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MARINE GEOLOGY OF THE NORTHWEST AUSTRALIAN CONTINENTAL SHELF

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SUMMARY

The broad continental shelf off tropical Western Australia is everywhere separated from the Indian Ocean basin by marginal plateaux, and except in the far southwest, near Barrow Island, its outer margin is not clearly defined. Elsewhere, there is no sharp increase in slope marking the edge of the shelf and, except for two areas near Scott Reef, gradients remain gentle until the outer margin of the Exmouth Plateau is reached at depths of about 2000 m. Near Scott Reef, there are two regions of steep slope commencing at about 600 m and descending to the Exmouth Plateau surface at a depth of 1500 to 2000 m.

The shelf is flat and almost featureless over very wide areas. Sand waves are widely distributed, but nowhere closely spaced. Morphological features produced by subaerial erosion processes are locally recognizable off the coast of the Kimberleys, and on the outer shelf some drowned littoral and sublittoral reefs and banks are preserved. A low ridge, which extends along the outer shelf for a distance of 300 km near the Rowley Shoals, marks an area of deposition of Recent sediment. Small scarps formed by coastal erosion at times of lowered sea level are present on the shelf, but are not so well developed as off eastern Australia. The most persistent occurs at a depth of about 120 m, and others are intermittently discernible down to depths of 380 m, and at several shallower levels between −60 and −105 m. Indirect evidence links the 120-m submerged strandline with the late Wisconsin glacial maximum immediately preceding the Holocene transgression some 17 000 years ago. The deepest strandlines are believed to date back to the Tertiary, and the shallower ones, which are poorly developed and difficult to correlate, mark short-lived still-stands during the Holocene transgression, and probably include strandlines formed during earlier transgressive and regressive cycles.

Few of the available seismic reflection profiles provide useful information on the near-surface sediments, particularly in the shallow waters of the continental shelf. Beds in the top 200 to 300 m of sediments on the shelf are flat-lying or exhibit gentle depositional dips. However, there is evidence of gentle folding, normal faulting, and slumping near the edge of the shelf. At least four of the reflectors in the upper 300 m of section probably represent unconformities. The lowest of these, which crops out on the sea floor near the Rowley Shoals, is identified with a Mio-Pliocene hiatus. There is no evidence of the age of the younger unconformities, but the uppermost one, which is overlain by as much as 70 m of sediment locally, probably represents the surface exposed during the last low sea-level stand of the Pleistocene.

The main source of data used in compilation of the facies map of the shelf sediments was the 353 sea-bed samples collected during the surveys. Shelly calcarenites and gravels consisting of relict organic material are widespread on the shelf, and fine-grained sediments are confined to local sediment traps in the inner shelf, and to the outer shelf margin. The proportion of non-carbonate terrigenous detritus in the surface sediments is nearly everywhere very low. Silica has been extensively replaced by carbonate, and much quartz sand may have been removed in this way. Cemented limestone pavement, either at the surface or buried under a thin veneer of unconsolidated sediment, is widespread; there is strong evidence that some at least of this lithification has taken place on the sea bed and is unrelated to periods of subaerial exposure. Some of the sediments near the outer edge of the shelf are relatively enriched in phosphorus, but P_2O_5 values nowhere exceed 3.6 percent.

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INTRODUCTION

This Bulletin presents the results of a geological reconnaissance of the northwest Australian continental shelf by the Bureau of Mineral Resources carried out during two 3-month cruises, one in late 1967 and the second in late 1968. In compilation of the results some use has also been made of the shallow seismic reflection profiles and echograms collected during a marine geophysical survey of the Northwest Shelf by Ray Geophysical Division of Mandrel Industries Inc. under contract to the BMR in 1968. The other main sources of data used are the published and unpublished soundings compiled by the RAN Hydrographic Office, and the sea-bed sediment notations on Australian and British Admiralty Charts. The brief description of the offshore structural framework and Phanerozoic sedimentation is almost entirely based on the subsidized petroleum exploration work of BOC of Australia Ltd and associated companies; it does not include results obtained after 1971.

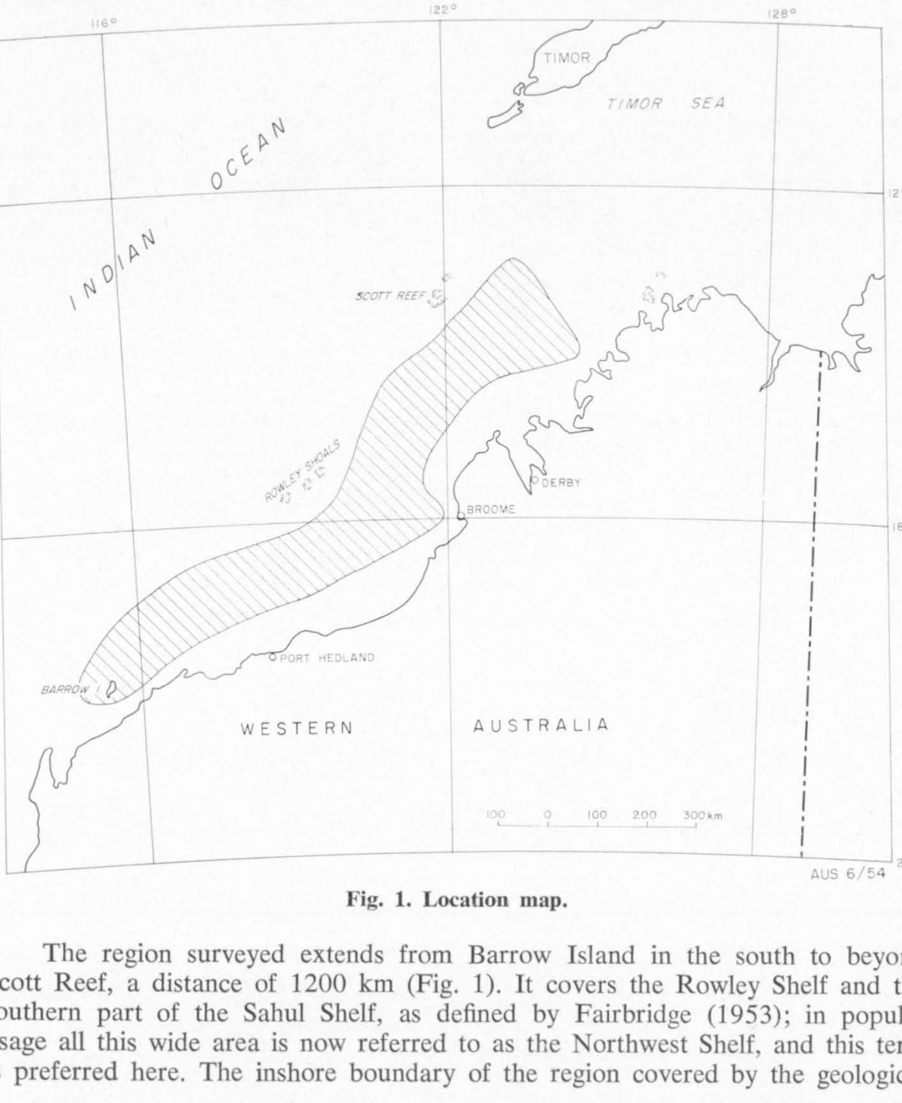

Fig. 1. Location map.

The region surveyed extends from Barrow Island in the south to beyond Scott Reef, a distance of 1200 km (Fig. 1). It covers the Rowley Shelf and the southern part of the Sahul Shelf, as defined by Fairbridge (1953); in popular usage all this wide area is now referred to as the Northwest Shelf, and this term is preferred here. The inshore boundary of the region covered by the geological reconnaissance approximates to the 40-m isobath, and the offshore boundary, which was governed to some extent by the limitations of the sampling equipment available, is at about 400 m. The adjoining geological provinces onshore are the northern part of the Carnarvon Basin, the Pilbara Block, the Canning Basin, and the Kimberley Block.

The first regional geological study of the continental shelf by the BMR took place in 1960-61 when, as a contribution to the International Indian Ocean Expeditions and in co-operation with the Scripps Institution of Oceanography of California, a survey of the sediments and morphology of Sahul Shelf and Timor Trough was carried out (van Andel & Veevers, 1967). Although the BMR took part in other marine geological investigations in the years following the Timor Sea work, it was not until the present study was undertaken in 1967 that the systematic regional survey of the shelf was resumed.

The basic objectives of the survey were to describe the sediments of the continental shelf and upper slope and to map their distribution, and to elucidate the late Cainozoic geological history of the continental margin from the study of surface morphology and shallow structures. The Northwest Shelf was chosen because of its position on the west side of the continent, and because the limited data available on ocean water chemistry and circulation patterns indicated that some potential for deposits of phosphate existed. Although sediments enriched with phosphorus were encountered locally, no material approaching economic grade was recovered.

Surveying Methods and Equipment

The vessel used for the 1967 survey was the steamship *Kos II* chartered from Tuna and Trawling Industries Pty Ltd, Brisbane. The *Kos II*, of about 250 tons displacement and 38 m overall, was built in England in 1929; designed as a whale chaser, the ship was of steel construction with a beam of 7.3 m and a draft of 3 m forward and 4.2 m aft. Propulsion was by a triple expansion steam engine driving a single screw giving a cruising speed of about 9 knots. Although steam has advantages over diesel in a survey vessel from the point of view of quietness, lack of vibration, and ability to run continuously at low revolutions, the engine and bunkers take up so much space that accommodation and working space available are much less than in a motor vessel of similar size. As might be expected in a vessel nearly 40 years old which has not been extensively refitted, mechanical breakdowns and failures of gear occurred. However, her low freeboard and firm underwater lines gave the *Kos II* a stability at sea remarkable in a vessel this size; this is a great advantage in a ship used as a platform for a marine geological survey and to some extent outweighed the shortcomings of the vessel in other respects. During the 1967 survey 6 days were lost as a result of mechanical breakdowns on board and 1½ days on account of injury to a member of the BMR party at sea. No time was lost due to bad weather.

The ship chartered for the 1968 survey was the motor vessel *Espirito Santo*, owned by the South Australian Fisherman's Co-Operative Ltd. The *Espirito Santo* was a single screw steel vessel of 42 m overall length and 10 m beam with a cruising speed of 10 knots. Built in the United States in 1945 as a conventional bait tuna boat, she was later converted for purse seine tuna fishing in Australian waters; her broad beam and covered bait tanks provided ample working space on deck and in many respects she was ideal for the purposes of this survey.

However, the vessel tended to roll heavily in moderate seas, and mechanical breakdowns resulted in some loss of time. During the three months of the charter, which lasted from mid-September until mid-December 1968, 8 days were lost through ship's mechanical trouble and 1 day through bad weather.

Sample station spacing of 10 nautical miles (18.5 km) on a square grid was aimed at, but this pattern suffered considerable distortion owing to the largely unpredictable currents. Most bottom samples were collected with a Shipek grab or with a small conical dredge with a lip diameter of 25 cm. The dredge had a narrow canvas bag and polythene liner some 30 cm long clamped over the open lower end to retain the sample. To get better recovery where the bottom consisted of hard-packed sand or cemented shell detritus, as was the case over wide areas of shelf, a doubled 1-m length of 20-mm chain was passed through the towing bridle and welded to the bridle and link to link. This helped the lip of the dredge to bite into the sediment surface and was more effective than a much heavier weight not rigidly attached to the dredge. The Shipek sampler is a spring-actuated device consisting of a cylindrical bucket tripped on contact with the sea bed by a weight resting above the bucket. It worked well on most types of sediment and the bucket closure was normally tight enough to prevent significant loss of fine sediment by washing out during recovery. Both the Shipek sampler and the small dredge were worked on a 4-mm wire from a diesel winch mounted on the stern of the vessel in the case of the *Espirito Santo,* and on the starboard side aft in the case of the *Kos II.*

Conventional rock dredges with mouth openings of 90 and 60 cm were used when heavier sampling equipment was needed. These were worked with 9-mm wire from a stern trawl winch on the *Espirito Santo* and from a winch mounted on the fore deck of the *Kos II.* An 800-lb gravity corer with a 3-m core barrel was carried, but the almost ubiquitous coarse-grained hard packed sediments on the shelf greatly restricted its use.

Seismic reflection profiles were obtained with a 1000-joule, 3-electrode Sparkarray sound source, a 30-element MP 7 hydrophone array, and an Ocean Sonics GDR-T recorder using a 24-cm wet paper. Traverses were run at a speed of 5 to 6 knots. Photographs of the sea bed were taken with an Edgerton Germenhausen and Grier Model 205 underwater camera and a Model 206 light source. The shutter opening and synchronized flash were triggered by a weight slung 3 m below the frame in which the camera and light source were mounted. This arrangement gave a field of view of about 4 m^2.

Position fixing was based almost entirely on celestial navigation, which was facilitated by the generally clear skies experienced during the surveys. It was usually possible to get reliable star fixes at dawn and dusk and repeated position lines from the sun during the day; these, combined with daylight moon and planet observations under favourable conditions, allowed the ships' tracks to be plotted with an accuracy acceptable in a reconnaissance survey of this sort.

Climate and Oceanography

The entire region lies within the tropics and comes under the influence of the southeast trade winds during the winter months and the northwest monsoon during the summer. Both systems blow for much shorter periods and with less constancy in the southern part of the area than they do in the north, and the influence of the summer northwesterlies in particular decreases rapidly south of the latitude of the Rowley Shoals, where they tend to be replaced by winds from the south and southwest. Close to the coast, diurnal land and sea breezes tend to mask the influence of seasonal winds; sea breezes regularly reach force 5 on the Beaufort Scale and extend 35 km or more out to sea; the nocturnal land breeze seldom exceeds force 4, and its influence is not felt more than 10 km from the coast.

TABLE 1. CLIMATIC AVERAGES, BROOME AND PORT HEDLAND

	Av. Daily Max. Temp. (°C)		Av. Daily Min. Temp. (°C)		Av. Daily Mean Temp. (°C)		Av. Rainfall (mm)	
	B.	P.H.	B.	P.H.	B.	P.H.	B.	P.H.
Jan	32.9	34.6	26.2	26.4	29.6	30.5	187	48
Feb	33.2	34.8	26.2	26.1	29.7	30.5	136	52
Mar	33.9	35.1	25.4	25.4	29.6	30.3	105	78
Apr	34.1	34.0	22.0	21.8	28.0	27.9	24	24
May	31.1	30.0	18.2	17.6	24.7	23.8	16	25
Jun	28.0	26.8	15.3	14.4	21.7	20.7	18	24
Jul	27.6	26.3	13.9	13.1	20.8	19.7	4	6
Aug	29.4	28.0	15.6	14.7	22.5	21.3	4	9
Sep	31.6	30.5	18.4	17.0	25.0	23.7	1	1
Oct	32.4	32.0	22.3	20.1	27.4	26.1	1	2
Nov	33.7	34.0	24.9	23.1	29.3	28.5	7	0
Dec	34.0	34.5	26.4	25.3	30.2	29.9	78	8
Year	31.8	31.7	21.2	20.4	26.5	26.1	581	277

Taken from *Climatic Averages Australia,* Bureau of Meteorology (1956).
Figures are based on readings taken over 30 years (rainfall) and 35 years (temperature) at Port Hedland, and over 30 years (rainfall and temperature) at Broome.

Rainfall and temperature statistics for Broome and Port Hedland are given in Table 1. Precipitation at Broome is about twice that at Port Hedland and the division between wet and dry seasons is more sharply defined. Comparison with rainfall figures from other Western Australian coastal stations show that these trends are continued both to the north and to the south of the region. West and south of Port Hedland the average annual rainfall decreases to 235 mm at Onslow and to 220 mm at Carnarvon, and northeast of Broome rainfall increases to 608 mm at Derby and 636 mm at Wyndham.

Information on surface water circulation patterns in the area is very incomplete. According to generalized surface current atlases of the southeastern Indian Ocean* the surface circulation off Western Australia is dominated by the West Australian Current, which originates in about latitude 30°S as a branch of the east-flowing Southern Ocean Current. The West Australian Current sets northwards to about latitude 20°S where it swings to the northwest under the influence of the southeast trades, and eventually joins the west-flowing South Equatorial Current far out in the Indian Ocean in about longitude 105°E. This picture is not fully confirmed by a study of the monthly resultant currents published by the US Hydrographic Office or by the conclusions of CSIRO workers (e.g. Wyrtki,

* See, for example, the *Australia Pilot,* V, *US Navy Hydrogr. Office spec. Publ.* 53, and Wyrtki (1961).

1962; Hamon, 1965; and Rochford, 1967), which indicate a much more variable circulation pattern. In any event, in the area of the present survey, the effect of tidal streams is dominant.

Hydrological and productivity observations have provided some evidence of upwelling off the northwest Australian coast (Rochford, 1962; Tranter, 1962; Wyrtki, 1962. See also the discussion in van Andel & Veevers, 1967). Surface water circulation would appear to favour upwelling along the margins of the Northwest Shelf, particularly during the southeast trades, but the data collected by the workers referred to above indicate that any upwelling present is minor. Rochford (1967) in a review of phosphate levels in surface waters of the Indian Ocean, stresses the very low phosphate content of surface waters throughout the year in the southeast Indian Ocean: regions of relative enrichment caused by upwelling or deep mixing in winter are small in area and do not occur east of about longitude 110°E.

The tidal range along the northwest Australian coast increases fairly regularly northwards from about 1.5 m at Carnarvon to 2.1 m at Port Hedland, and 8.5 m at Broome. The rate and direction of tidal streams are largely controlled by the local morphology of the coastline and sea bed, and their influence increases northwards with the tidal range. Tidal streams of up to 3 knots occur in the open water approaches to Roebuck Bay, and much higher rates of up to 10 knots have been recorded farther north in the approaches to King Sound. In the latitude of the Rowley Shoals, tidal influences are still strongly in evidence as far out as the edge of the continental shelf, where, during the strength of the tide in calm weather, surface rips and overfalls resembling heavy breakers are sometimes seen. These are probably related to the break in slope of the sea bed. In the southern part of the area tidal streams are usually much less strong. Rates of 2 to 3 knots occur near Cape Preston, between the Dampier Archipelago and Barrow Island, and spring tidal streams up to 3 knots have been recorded at the Madeleine No. 1 and Dampier No. 1 petroleum exploration wells drilled by BOC of Australia Ltd, 100 km offshore (Stroud, 1970). However, even in restricted waters maximum rates are generally less than 1 knot. Tides are semi-diurnal in character; the flood normally sets between south and east, and the ebb between north and west, but even well offshore, directions may be very irregular, particularly in shoal waters. Almost all the photographs taken of the sea bed provide evidence of bottom currents capable of moving sediment in all depths of water covered during this survey.

Summary of Onshore Geology and Coastal Morphology

The main elements of onshore geology consist of the Kimberley Block to the north, the Canning Basin, and the Pilbara Block to the south (Fig. 2). The western margin of the Kimberley Block is formed of Proterozoic rocks of the Kimberley Group. These consist of clean-washed quartz sandstones (King Leopold, Warton, and Pentecost Sandstones), basic volcanics (Carson Volcanics), and siltstones (Elgee Siltstone and facies of the Pentecost Sandstone) intruded by the Hart Dolerite. There is strong folding in the Yampi Peninsula, but elsewhere most of the rocks are undeformed.

Most of the area of continental shelf examined lies in the offshore Canning Basin, although the position of the margin of the Canning Basin against the flanking Precambrian blocks and the Carnarvon and Browse Basins becomes

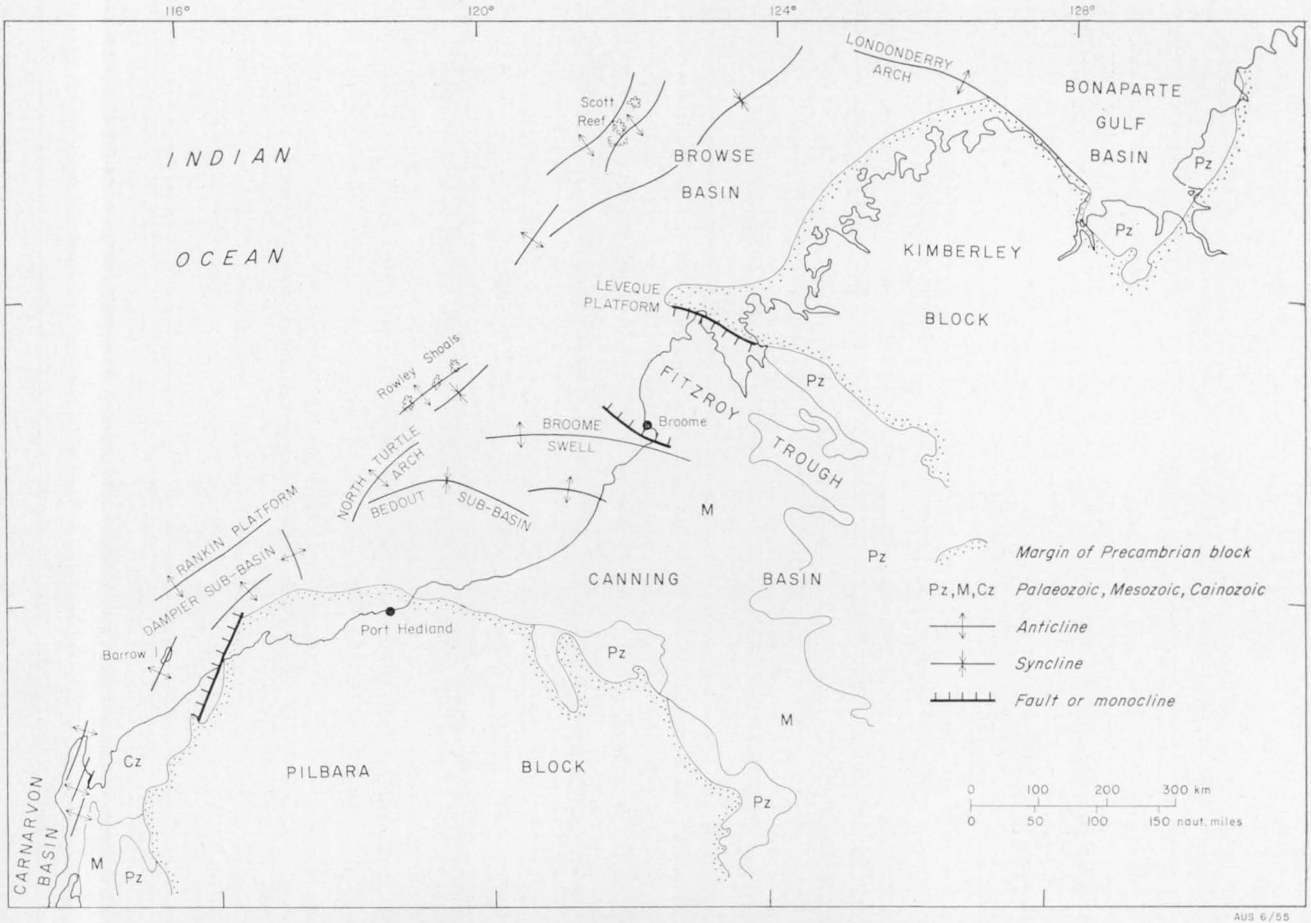

Fig. 2. Regional geology of northwest Australia and main structural elements in the Phanerozoic of the continental shelf.

increasingly obscure seawards. The geology of the Canning Basin has been described by Veevers & Wells (1961). Sedimentation in the basin probably began before the end of the Proterozoic and continued, with some important breaks, until the end of the Mesozoic. The basin is asymmetrical and contains about 6000 m of Palaeozoic sediments in the Fitzroy Trough, close to the northern margin, and much lesser thicknesses of Palaeozoic and Mesozoic combined in the central and southern areas. Since the Mesozoic, the Canning Basin has been land, except for the coastal fringe which has been intermittently submerged. Although the Cainozoic deposits are thin and superficial, they are, however, widespread and provide most of the terrigenous sediments now being laid down on the continental shelf flanking the basin. The Cainozoic deposits consist of stabilized dune sands, fluviatile deposits, ferruginous and siliceous duricrust, and coastal calcareous rocks.

The Pilbara Block comprises a large area of Archaean granites, gneisses, metasediments, and metavolcanics unconformably overlain by Lower Proterozoic clastic sediments, lavas, and pyroclastics. The inter-relationships of the Archaean rocks have been discussed by Ryan (1965), and the Proterozoic rocks have been described by Kreiwaldt (1964), and in the various Explanatory Notes to the 1:250 000 Geological Series. The Hamersley Iron Province to the south of the Pilbara Block, has been described by McLeod (1966), who provides a useful summary of the Precambrian geology of the region.

There is a marked contrast between the steep rocky coastline with deep inlets and numerous islands in the Kimberley terrain to the north and the almost uniformly low-lying and monotonous coastal topography of the Canning Basin to the south. Long stretches of the coast across the Canning Basin are backed by extensive tidal flats relieved only by low sand dunes. Locally, dissection of resistant coastal sediments produces low rocky cliffs, as at Cape Keraudren and the Dampier Peninsula, and elsewhere low red sandy cliffs are found where more or less indurated ancient erosion surfaces are being undercut along the shoreline. The coastal region of the northern part of the Pilbara Block also consists of a wide low-lying belt of poorly consolidated Quaternary sediments, but from Port Walcott westwards to Cape Preston (20°50′S, 116°12′E), where Precambrian bedrock crops out extensively along the shore, the topography is more varied. The islands of the Dampier Archipelago, with the exception of Legendre Island, which consists of coastal limestone, are formed mainly of Proterozoic volcanics and intrusives with a relief of up to 150 m.

Summary of Geology of the Continental Margin

Following the indications provided by the early magnetic and gravity surveys that sufficient thicknesses of sediment are present under the continental shelf to make the area prospective for petroleum, a succession of reconnaissance and detailed marine seismic surveys have been carried out with assistance under the Petroleum Search Subsidy Acts. Some 17 subsidized offshore petroleum exploration wells had been completed by the end of 1971 and major gas and condensate discoveries made in the Dampier Sub-basin and at Scott Reef. Despite the large body of information which has been built up, particularly in the Dampier Sub-basin, exploration is still at an early stage and stratigraphic control is lacking over very wide areas of shelf. Several papers presenting the regional geological results of this exploration have recently been published (Mollan, Craig, & Lofting, 1970;

Challinor, 1970; Halse & Hayes, 1971; Kaye, Edmond, & Challinor, 1972), and the brief description which follows is based on this work and on the combined gravity, magnetic, and seismic data collected during the BMR marine geophysical survey in 1968 (Whitworth, 1969).

Basement structure

The most striking feature of the regional structure is the change from northwesterly trends onshore to trends parallel with the continental margin on the shelf. The structural and topographic highs underlying Scott Reef, Rowley Shoals, and Rankin Bank are the dominant features of the outer shelf and upper continental slope. These features are not part of the same structural lineament; the strong positive Bouguer anomaly area underlying the Rankin Platform, for example, is now known to reflect a fractured Triassic horst which is possibly continuous with the Broome Swell, and according to Challinor (1970), the Rowley Shoals structure curves southwards to form the North Turtle Arch.

Interpretation of the morphology of the Precambrian basement surface is difficult because of the complexity of the structures and the lack of adequate stratigraphic control. Magnetic bodies are known to occur in the Phanerozoic, but their extent is unknown, and the upper part of the Precambrian may include thick non-magnetic sequences lacking density contrast with the overlying sediments. Thus indications of a magnetic basement high underlying Ashmore Reef, which lies to the north of the area under review in alignment with the Rowley Shoals and Scott Reef, were disproved by drilling. In this case the presence of 300 m of Upper Jurassic basic volcanics penetrated below 2400 m explains the magnetic results. Other magnetic basement highs to the north may likewise not reflect the structure of Precambrian basement.

Phanerozoic sedimentation and structure

The onshore area consists essentially of a simple Palaeozoic and Mesozoic basin bounded by stable Precambrian blocks, but the regional structure becomes increasingly more complex offshore as the fragmented continental margin is approached. In particular, the region northwest of the Pilbara Block is strongly faulted and broken up into blocks with greatly varying thicknesses of Palaeozoic and Mesozoic sections and significant lithological variations. Block-faulting has also occurred off the Kimberley Block margin to the north, but here a simple major sedimentary basin, the Browse Basin, has developed (Halse & Hayes, 1971). The Browse Basin, bounded on the south by the Leveque Platform, and separated from the Bonaparte Gulf Basin to the north by the Londonderry Arch, probably contains some 10 000 m of Phanerozoic sediments. Much of the faulting in the basin is pre-Mesozoic, but Mesozoic and Tertiary rejuvenation has occurred. An interesting feature indicated by the seismic work of BOC of Australia Ltd and associated companies is the reversal of older normal faults by compressive forces during the Cainozoic which resulted in the formation of some large structural traps. Halse & Hayes (1971) suggests that the main phase of this later movement reflects the Miocene Ramelauean Crogeny in Timor, where large-scale overthrusting from the north occurred.

There is no evidence of compressive structures in the Dampier Sub-basin to the south, however. This basin is known in greater detail than others because of its proved and potential hydrocarbon reserves. According to Kaye et al. (1972), it is essentially continuous with the Carnarvon Basin to the southwest and there is no significant depositional break between the Dampier and Barrow Island successions. The structure is dominated by a complex series of normal faults trending northeast which are downthrown on the southeast (landward) side. Horst blocks, such as the Rankin Trend, are formed where complementary normal faults downthrown to the northwest are present, and the structure is further complicated by subsidiary north-south normal faults downthrown to the west. Movement on the major faults is very large and may exceed 2000 m. Kaye et al. state that the faulting is mainly Triassic but that movement persisted into the Cretaceous. The Mesozoic depositional history is one of progressive burial of the fault blocks and the consequent formation of drape closures at different stratigraphic levels. In addition to the main source of sediments from the Pilbara Block to the southeast, a subsidiary source from the northwest during much of the Mesozoic is postulated. Sedimentation during the Tertiary began with deltaic progradation of the shelf westwards, but from the upper Eocene to Recent times, carbonate sediments have accumulated in an environment essentially similar to the present. The Tertiary section is up to 3000 m thick at the edge of the shelf.

Little is known of the offshore extension of the Fitzroy Trough which appears to retain its character as a northwesterly trending graben a considerable distance across the continental shelf. Some 7500 m of upper Palaeozoic sediments are believed to be present and the Mesozoic section thickens considerably offshore (Challinor, 1970). Most of the major structures offshore die out towards the end of the Mesozoic and regional northwesterly tilting of the continental shelf resulted in the accumulation of a wedge of Tertiary sediments some 3000 to 4000 m thick at the edge of the shelf. Periods of uplift and erosion also occurred in the Cainozoic, and the resulting unconformities become more marked shorewards and as the structural highs bounding the offshore sub-basins are approached.

MORPHOLOGY

Continuous echosounding records were kept during the BMR 1968 marine geophysical survey and these form the most complete source of bathymetric information available (Fig. 3). Soundings compiled by the RAN Hydrographic Office for the International Hydrographic Bureau's General Bathymetric Chart of the Oceans provide data on the deep water areas seaward of the shelf (Fig. 4), and unpublished results of detailed hydrographic surveys by the Navy on the shelf supplement the soundings on the published charts. Echosounding profiles obtained during the 1967 and 1968 BMR marine geological surveys are a useful additional source of data, but the positioning of these traverses is less accurate than that of the satellite-controlled geophysical survey grid.

The area cannot easily be split up into natural subdivisions for purposes of morphological description. In the extreme southwest the continental shelf is relatively narrow and a well defined break in slope at a depth of 120 m marks the beginning of the continental slope. Over the greater part of the area, however, the shelf is very wide, and there is no clear distinction between the shelf and the broad gently inclined marginal plateau, called the Scott Reef/Rowley Shoals Platform, which extends down to depths of 500 to 600 m. Seaward of this the Exmouth Plateau forms the outer continental margin between latitudes 12°S and 21°S (Figs 5, 6).

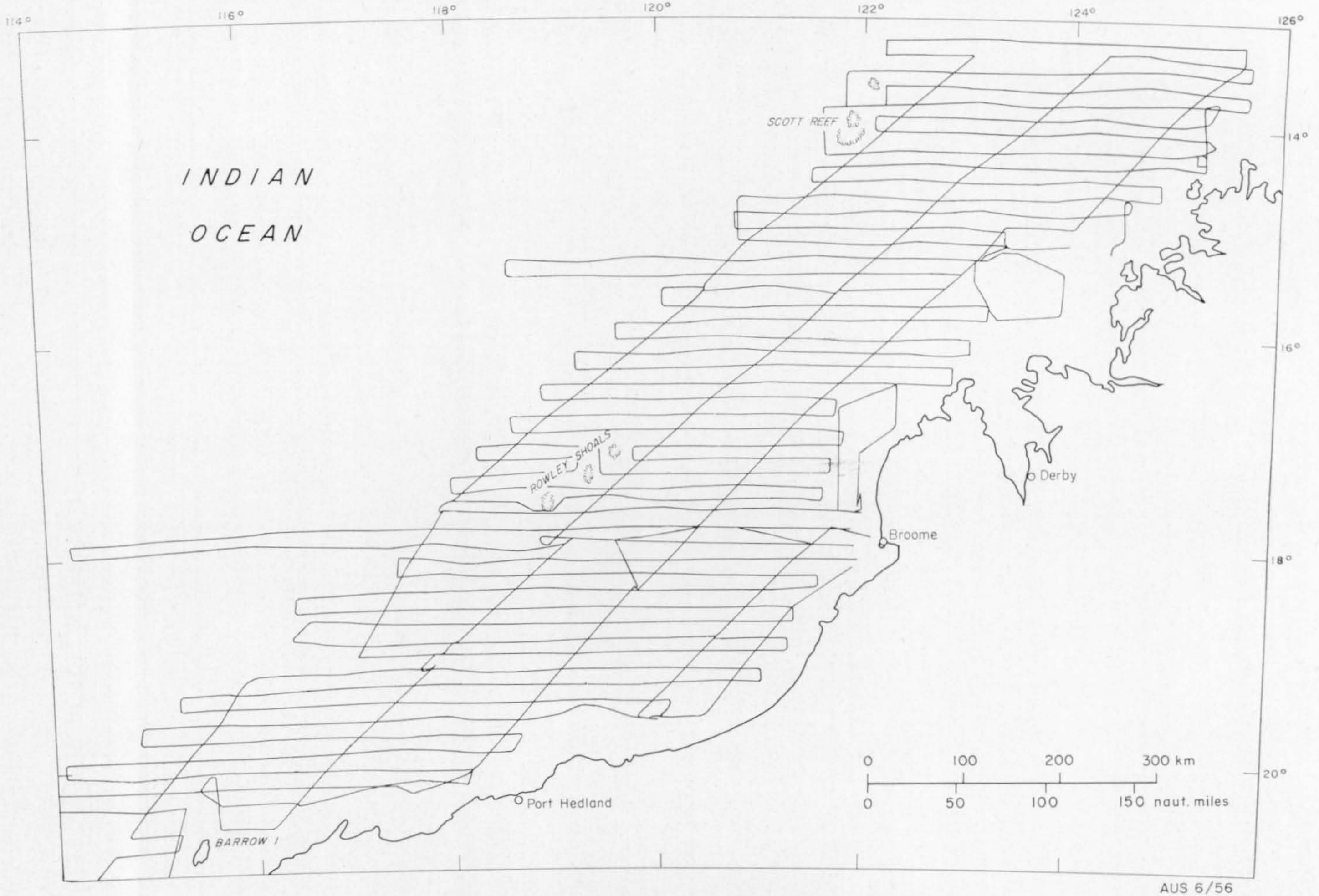

Fig. 3. Track chart, 1968 BMR marine geophysical survey.

Fig. 4. Lines of soundings from various sources shown on Oceanic Soundings Sheets 318, 319, and 350. (Hydrographic Office, RAN.)

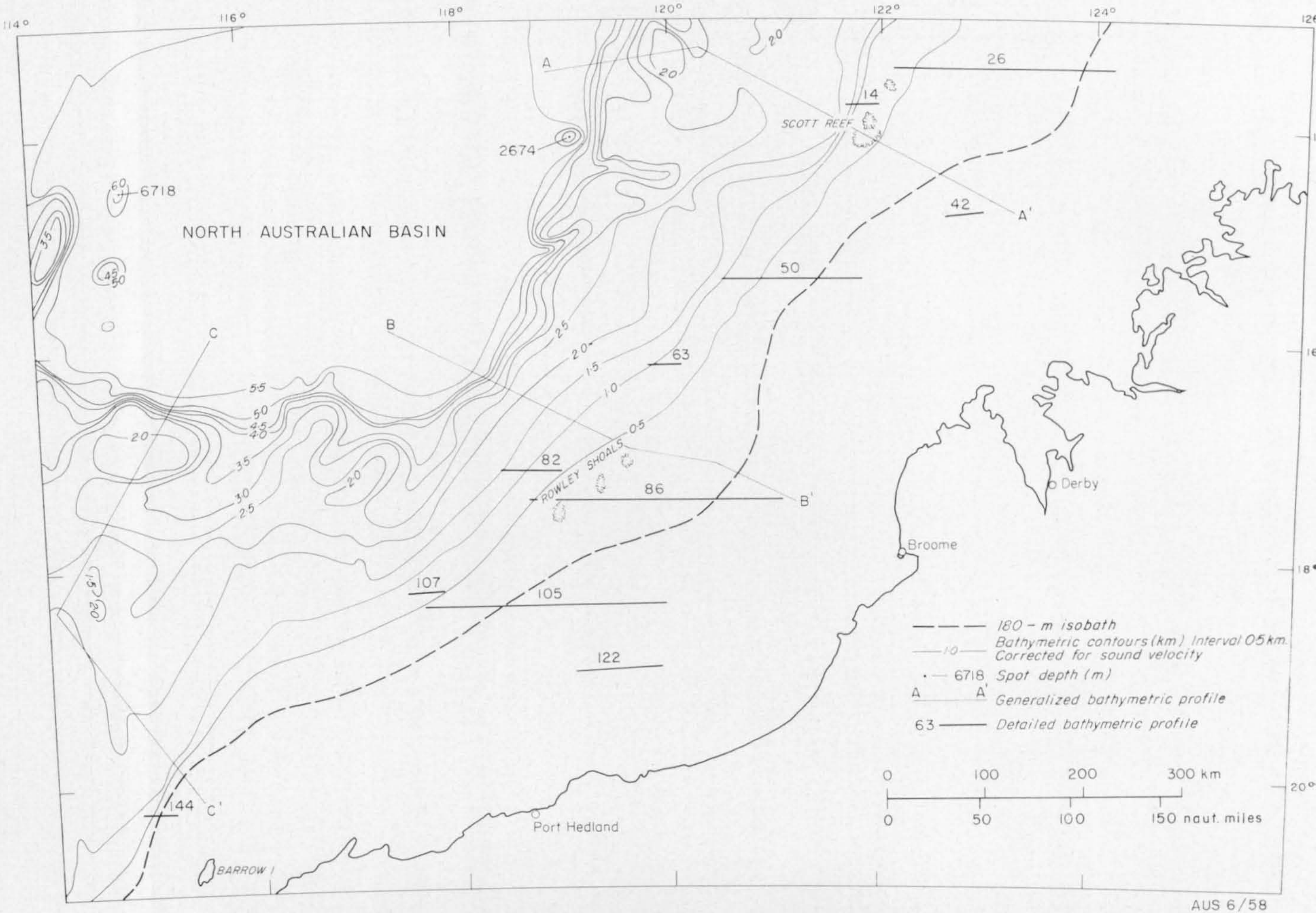

Fig. 5. Generalized morphology of the continental margin and North Australian Basin. Density of lines of soundings shown in Figure 4. The bathymetric profiles are reproduced in Figures 7, 10 and 12.

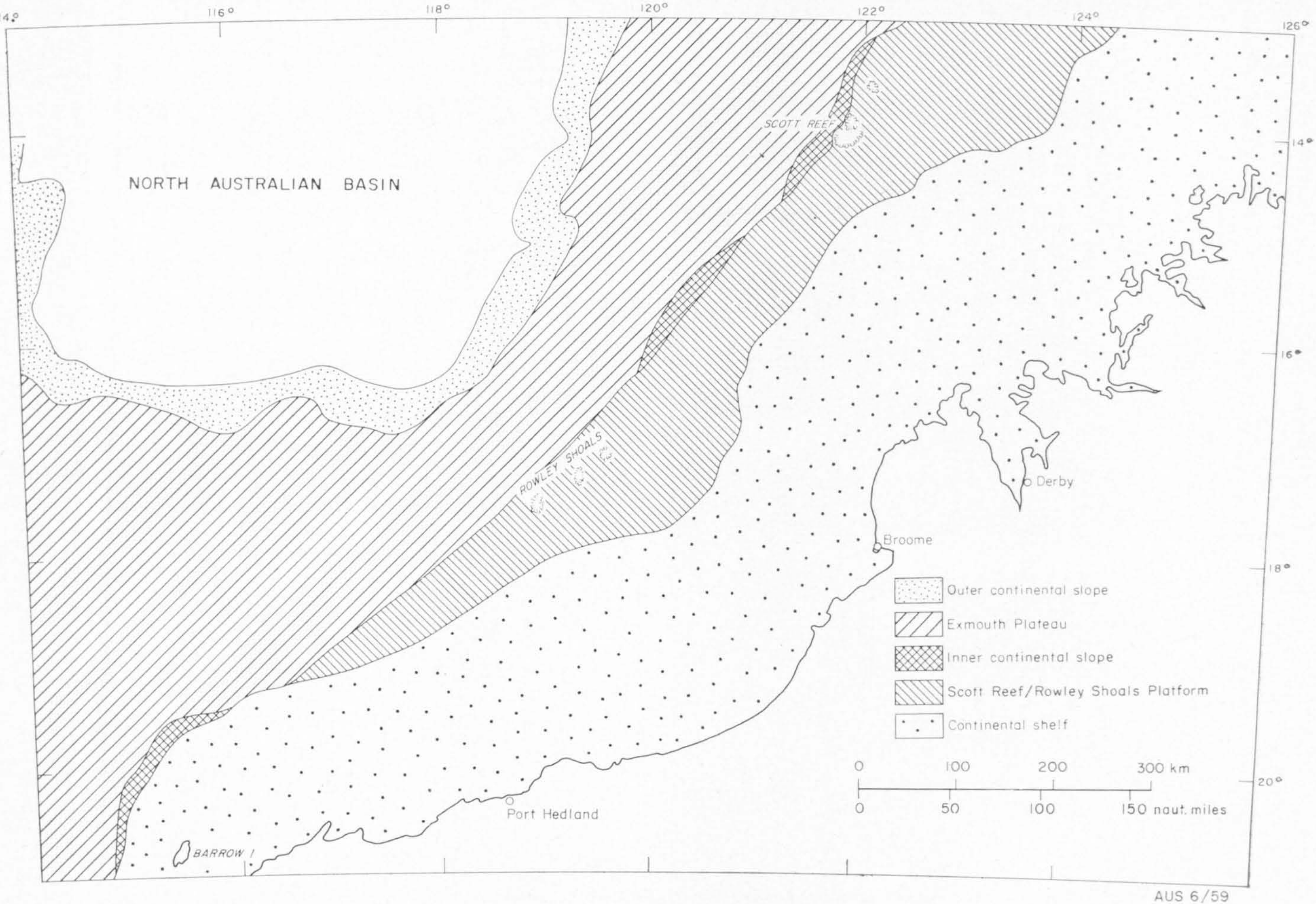

Fig. 6. Physiographic provinces.

For descriptive purposes the area is divided into three physiographic provinces (Fig. 6); the continental shelf proper, which extends from the shoreline down to the break in slope at depths of 120 to 180 m; the Scott Reef/Rowley Shoals Platform, a marginal plateau seaward of the shelf which extends down to depths of 500 to 600 m; and the outer continental margin, which includes the continental slope and the deeply submerged Exmouth Plateau.

Outer Continental Margin

The northwest Australian continental margin is bounded by the North Australian Basin. The floor of the basin, which has an area of about 160 000 km^2, is a true abyssal plain with as flat a surface as any found on the earth. Soundings along traverses several hundred kilometres in length vary by only a few metres from the mean depth of 5700 m. Two small depressions exceeding 6000 m are present close to its western margin and the greatest depth recorded in the basin (6718 m) occurs in the northern depression (Fig. 5). The density of soundings available is not high and extensive irregularities may be unrecorded.

Exmouth Plateau

On the eastern and southern flanks of the basin the sea floor rises towards the Australian continent. Nowhere can a straightforward division into continental rise, slope, and shelf be made as marginal plateaux are present along the whole of the northwest Australian continental margin. The term 'marginal plateau' was introduced by Heezen, Tharp, & Ewing (1959, p. 18) to describe shelf-like features at greater depths than continental shelves from which they are separated by incipient continental slopes. They probably result from faulting during fragmentation of continental margins, but the term has morphological implications only. The best documented example of a marginal plateau is the Blake Plateau off the southeastern United States which has been investigated by drilling (Joides, 1965) as well as by seismic and detailed morphological work (Ewing, Ewing, & Leyden, 1966; Uchupi, 1968). The Tertiary section under the Blake Plateau is much thinner than under the slope and shelf landwards, and shows no evidence of major faulting in the slope region. If the plateau is a downfaulted marginal block, the faulting must be pre-Tertiary. In Australian waters, marginal plateaux have been described in the Great Australian Bight by von der Borch (1967) and Connolly, Flavelle, & Dietz (1970), and the western Coral Sea by Gardner (1970); another example is the Naturaliste Ridge off Cape Leeuwin.

The form of the marginal plateaux off the Northwest Shelf is illustrated by the generalized bathymetric profiles shown in Figure 7. The Exmouth Plateau consists of two lobes, at about latitudes 14°S and 20°S, each extending some 400 km westwards into the Indian Ocean. They are joined by a gently sloping bench about 100 km wide in the Rowley Shoals region (Figs 5, 6). Although there is some justification for regarding the northern lobe as a separate plateau and restricting the term Exmouth Plateau to the feature to the south, in fact they are more or less continuous; Exmouth Plateau has previously been used to denote the whole of the northwest Australian marginal plateaux (Heezen & Tharp, 1966), and a similar usage is followed here.

The northern lobe forms an irregular plateau to the west of Scott Reef standing between 2000 m and 3000 m above the floor of the North Australian

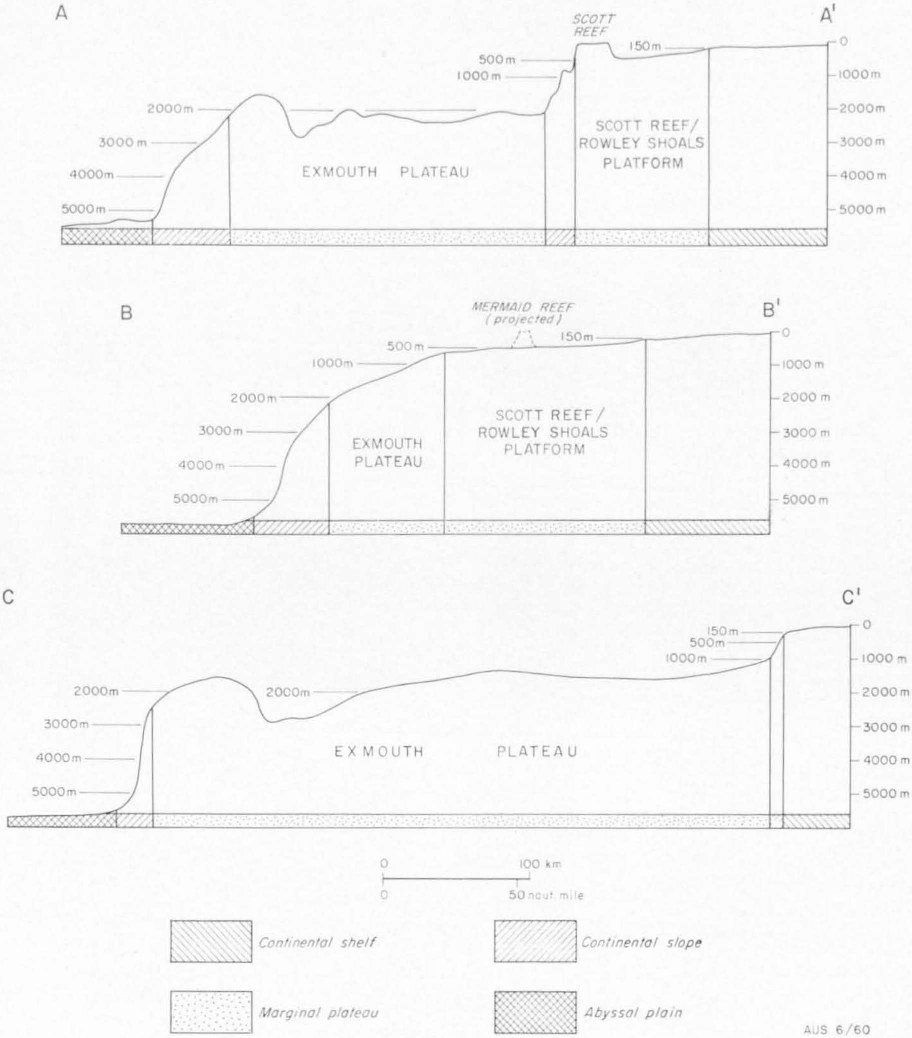

Fig. 7. Generalized bathymetric profiles showing the main morphological elements of the continental margin. Location of profiles shown in Figure 5.

Basin and a similar depth below sea level. It extends from about latitude 12°30′S to 14°30′S and has an area of some 40 000 km^2. The density of soundings over this plateau is low and only its gross morphology is known. Its average depth is around 2500 m, but there are a number of elevated areas standing several hundred metres above this level, and the outer margin of the plateau is deeply indented.

The southern lobe of the Exmouth Plateau is a larger and better known feature extending westwards into the Indian Ocean for a distance of some 450 km from Barrow Island. The main part of the plateau has a smooth surface rising gently westwards from a depth of about 1100 m in the region of the inner continental slope to about 800 m offshore. The seismic profiles show that this bathymetric rise reflects a gentle anticlinal structure in the underlying sediments

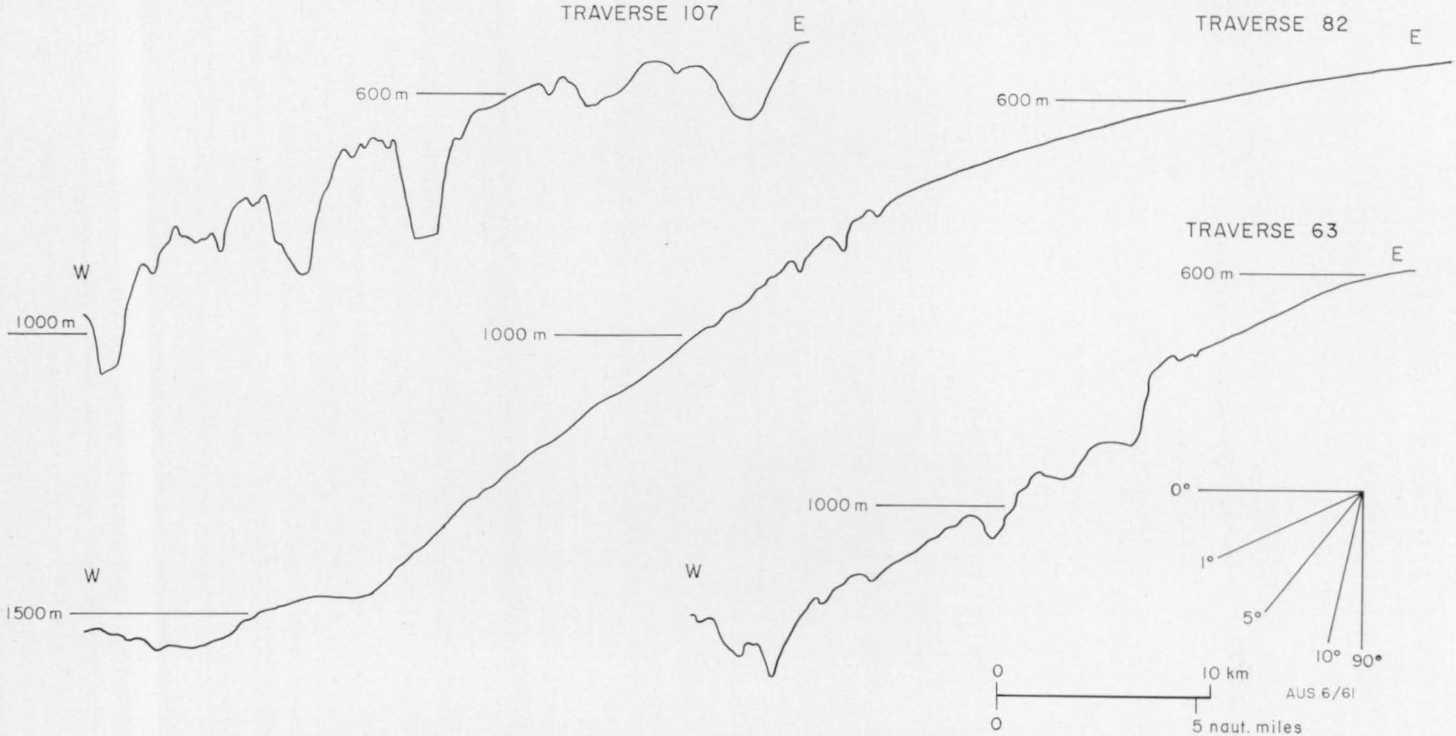

Fig. 8. Bathymetric profiles across the marginal zone between the Scott Reef/Rowley Shoals Platform and the Exmouth Plateau. Traverse 107 displays typical sections across submarine canyons; the irregularities in the other two profiles are probably caused by slumping. Locations of traverses shown in Figure 5.

(Whitworth, 1969). Bathymetric contours on the northern margin of the plateau (Fig. 5) suggest that a number of channels drain northwards into the North Australian Basin; however, the few seismic profiles available in this area show that the subsurface reflectors in general closely parallel the rugged sea-bed topography, and although there is some evidence of erosion, the precipitous-sided flat-floored form typical of submarine canyons is not developed. A number of gullies and small submarine canyons are, however, present in the vicinity of locality 18°15′S, 117°30′E, on the slope above the northeastern corner of the Exmouth Plateau (Fig. 8, Trav. 107). Their position directly up slope from the large valley in the plateau margin outlined by the generalized bathymetric contours (Fig. 5), suggests that they may be tributaries of a major submarine canyon draining into the North Australian Basin. No profiles across this feature are available and its form is not known.

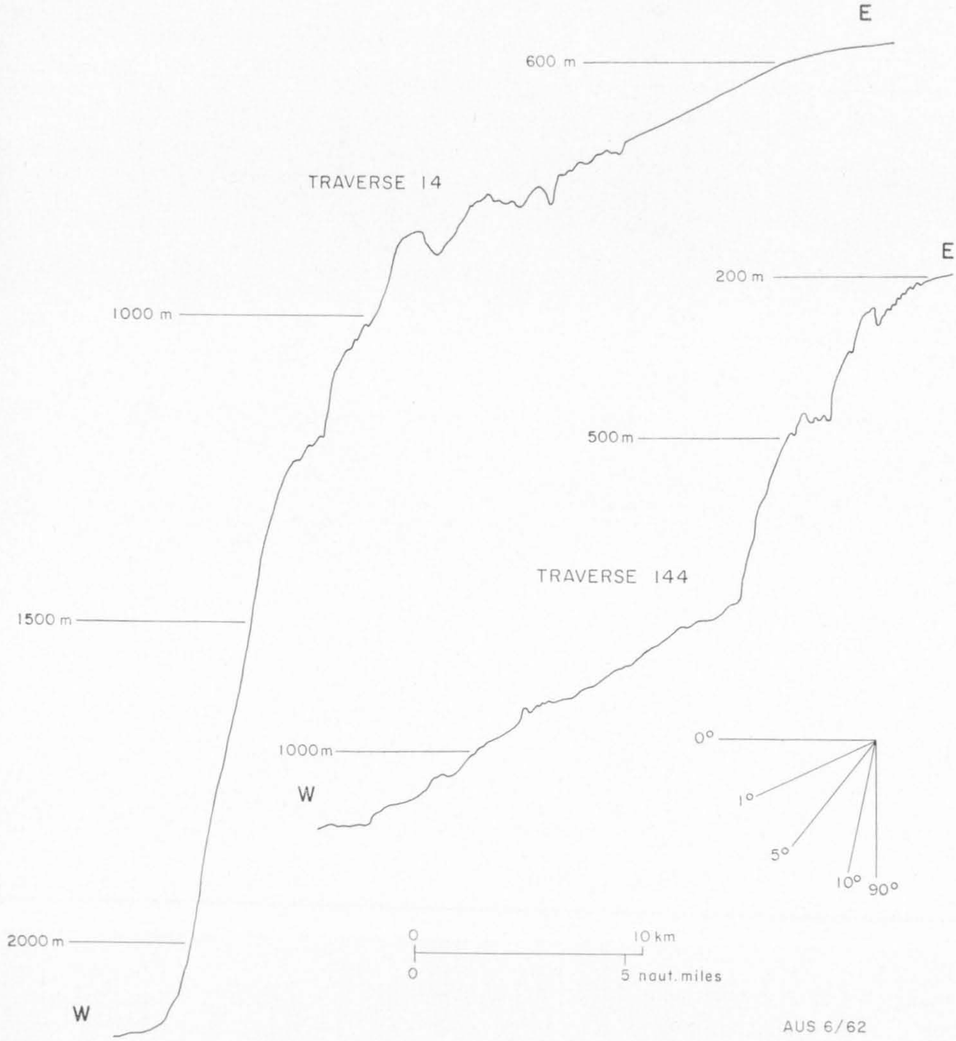

Fig. 9. Bathymetric profiles across the inner continental slope on the landward side of the Exmouth Plateau. Location of traverses shown in Figure 5.

Continental slope

The Exmouth Plateau is bounded seawards by an outer continental slope which drops down to the floor of the North Australian Basin. In three areas, inner continental slopes, each extending for a distance of about 180 km, are present on the landward side also (Fig. 6). Elsewhere gradients in the broad zone between the marginal plateaux and the shelf are gentle.

Only the generalized morphology of the outer slope is known as the BMR sounding and seismic traverses did not extend across this area. Gradients exceed 10° on parts of the slope, but average 3° to 6°, and the relief is about 3000 m

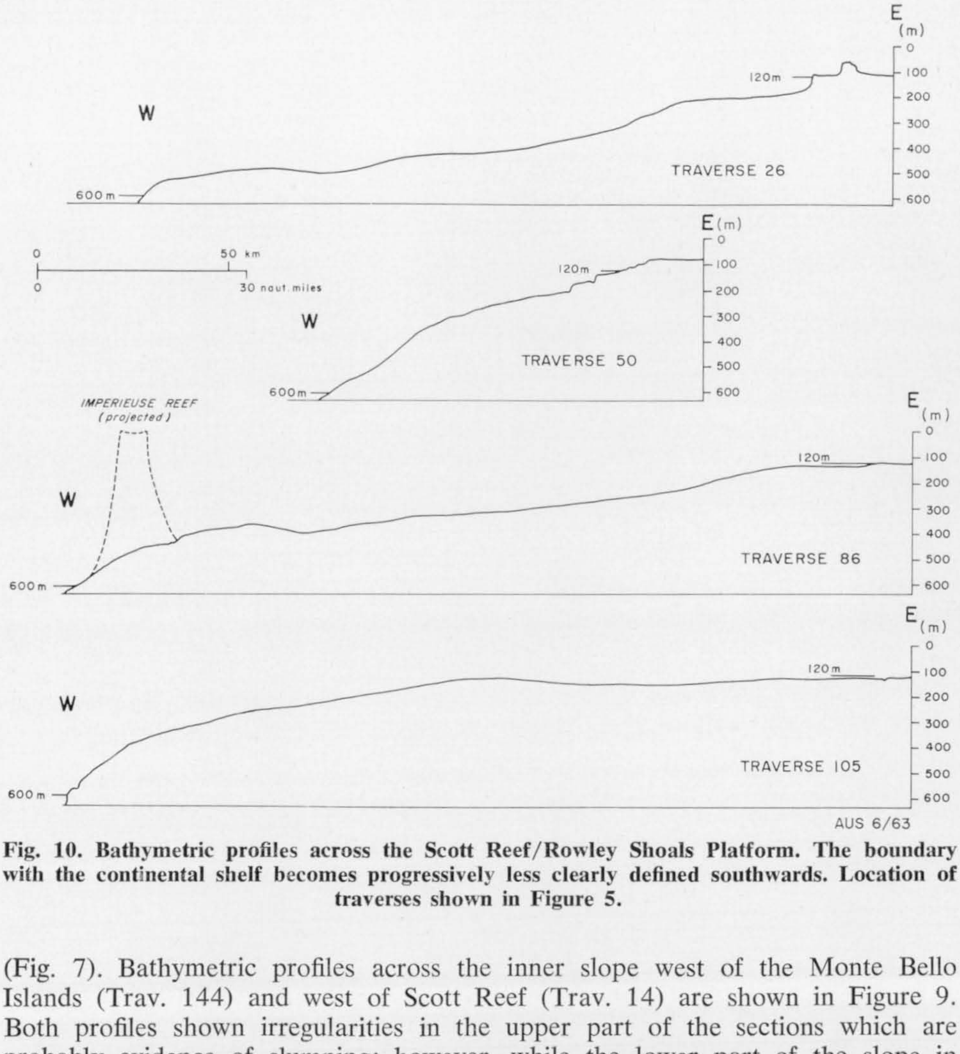

Fig. 10. Bathymetric profiles across the Scott Reef/Rowley Shoals Platform. The boundary with the continental shelf becomes progressively less clearly defined southwards. Location of traverses shown in Figure 5.

(Fig. 7). Bathymetric profiles across the inner slope west of the Monte Bello Islands (Trav. 144) and west of Scott Reef (Trav. 14) are shown in Figure 9. Both profiles shown irregularities in the upper part of the sections which are probably evidence of slumping; however, while the lower part of the slope in Traverse 144 is mantled by slumped sediments, this is not so in Traverse 14 near Scott Reef. It seems likely that in the northern area the broad shelf and the Scott Reef/Rowley Shoals Platform form an effective sediment trap, restricting the supply to the continental slope to the west.

Scott Reef/Rowley Shoals Platform

The Scott Reef/Rowley Shoals Platform does not fit easily into one of the commonly used morphological subdivisions of the continental margin. It is seaward of the break in slope marking the edge of the continental shelf and descends to depths of 500 to 600 m. Five atolls rise steeply from its outer margin, Scott and Seringapatam Reefs in the north, and Mermaid, Clerke, and Imperieuse Reefs (the Rowley Shoals) in the south. A submerged reef 50 km southwest of Imperieuse Reef rises abruptly 60 to 100 m above the surrounding sea floor to within 287 m of the surface; it is on line with, and maintains the spacing of, the three atolls comprising the Rowley Shoals. Other deeply drowned reefs may occur along the outer margin of the platform, but they would have to be small to have been missed by the east-west bathymetric profiles at 18 km intervals. Certainly nothing resembling a continuous barrier reef was ever present.

Both the inner and outer margins of the platform are in places very poorly defined. It can be regarded as an 'outer shelf', the description used by Fairbridge (1953), as the gently inclined top part of the continental slope, or as a marginal plateau. Jones (1971) and Veevers (in press) included it in the shelf edge zone, but I now prefer to describe it as a marginal plateau. In the far north (Fig. 10, Trav. 26) the boundary with the continental shelf is clearly marked, but it becomes progressively less sharply defined southwards. Near its southern end (Fig. 10, Trav. 105) it merges with the shelf, although a small notch at a depth of 120 m is still present. It is shallower than most marginal plateaux, but is by no means unique. It closely resembles, for example, the Arguello Plateau off southern California (Uchupi & Emery, 1963), a feature cited by Fairbridge (1966, p. 873) as representative of marginal plateaux. In Australian waters it is morphologically similar to the Marion Platform off the southern part of the Great Barrier Reef, and is at about the same depth.

Profiles across the Scott Reef/Rowley Shoals Platform are shown in Figure 7 (A-A′ and B-B′) and Figure 10. Its surface is normally smooth, except close to the marginal atolls, and the erosional channels developed on the slope between it and the deeper Exmouth Plateau near its southern end do not extend on to the platform itself. An erosional scarp with a maximum relief of 120 m extends for a distance of 110 km in a north-south direction east of the Rowley Shoals between the 300 and 400-m bathymetric contours. Two similar, but rather smaller, scarps are present on the platform east of Scott Reef.

A concave change in slope at depths of 240 to 260 m, commonly accompanied by a rather irregular surface, is a consistent feature of the profiles across the upper part of the platform east and south of the Rowley Shoals. This change of slope, which is believed to mark the outcrop of ancient surface of erosion, is intermittently detectable in the profiles north of latitude 17°S, but deepens and disappears in the region of latitude 14°20′S.

The five reefs aligned along the outer edge of the platform are true atolls. Scott and Seringapatam Reefs rise from a depth of about 450 m, and the three reefs comprising the Rowley Shoals from about 350 m. The submerged flanks of the atolls are extremely steep, and where close-in soundings have been made, as around the south and southwest edge of North (Scott) Reef, they are sometimes nearly vertical in the top 200 to 300 m. Scott Reef itself consists of two separate atolls (North Reef and South Reef) divided by a channel some 400 m deep. South

Reef provides a good anchorage in about 50 m of water, but entry to the central lagoons of the other atolls is by narrow overflow channels navigable by small boats at slack water only. Imperieuse Reef, the southernmost of the Rowley Shoals, appears to be totally enclosed. There is no record of the existence of a channel into the central lagoon of Seringapatam Reef either; however, this atoll has not been surveyed in detail, and an oblique air-photograph reproduced by Teichert & Fairbridge (1948) reveals a possible shallow channel breaching the outer barrier.

Closely spaced soundings have not been made around any of the reefs, but Clerke Reef in the Rowley Shoals is known to be flanked on its western side by a depression about 5 km across and 50 m deep. It is possible that moats encircle all the atolls; such features are common around reefs and are caused by differential compaction resulting from gravity loading. Current scour around the bases of the reef piles is a contributing cause.

Continental Shelf

The continental shelf varies in width from about 220 km south of the Rowley Shoals to less than 15 km off North West Cape in the southwest. Over most of the area it is 150 to 200 km wide. The shelf is largely an area of winnowing and sediment transport rather than deposition and over very wide areas the flat surface is interrupted by only minor irregularities which commonly consist of drowned littoral features. Sand waves are recognizable on the echosounder traces by their characteristic asymmetrical profile. The irregularity and very wide spacing of the sand waves indicate the paucity of sand-size sediment; they range from 4 to 10 m in height and are spaced from several hundred metres to 20 km or more apart. Smaller scale sand waves or megaripples, with a height of 1 to 2 m and a spacing of 200 to 300 m, are also found on the shelf and in the deeper waters of the Scott Reef/Rowley Shoals Platform. Normal current ripples have been observed in some underwater photographs also (Pl. 5, figs 1, 2).

The generalized regional morphological patterns on the shelf are shown in Figure 11. Consistently irregular surfaces occur to the north, particularly between latitudes 14°S and 16°S where the whole shelf seaward of the 40-m isobath is rough and uneven. Local relief is about 20 m (Fig. 12). Southwest of latitude 16°S the irregular topography continues into the central part of the shelf, but dominantly smooth surfaces occur near the outer edge of the shelf and also inshore. West of longitude 119°40′E the whole shelf consists mainly of smooth surfaces, except for local areas such as Rankin Bank. Sand waves are sparsely and irregularly developed in both rough and smooth areas, but are more noticeable on the echogram traces where the surface has little or no relief from other causes (Fig. 12, Trav. 122). Areas where they are particularly abundant are shown in Figure 11.

Direct evidence on the origin of the different types of topography is usually lacking, but two separate processes are obvious in both the rough and dominantly smooth areas. Much of the large region of irregular shelf surface off the Kimberley Block consists of flat-topped elevations separated by wide shallow channels. Sand waves and fossil littoral features are superimposed on this surface, but do not obscure the subaerial erosion pattern displayed (Fig. 12, Trav. 42). On the other hand, the rough topography near the edge of the shelf in the extreme north, and south of latitude 19°S, is basically of constructional rather than erosional origin;

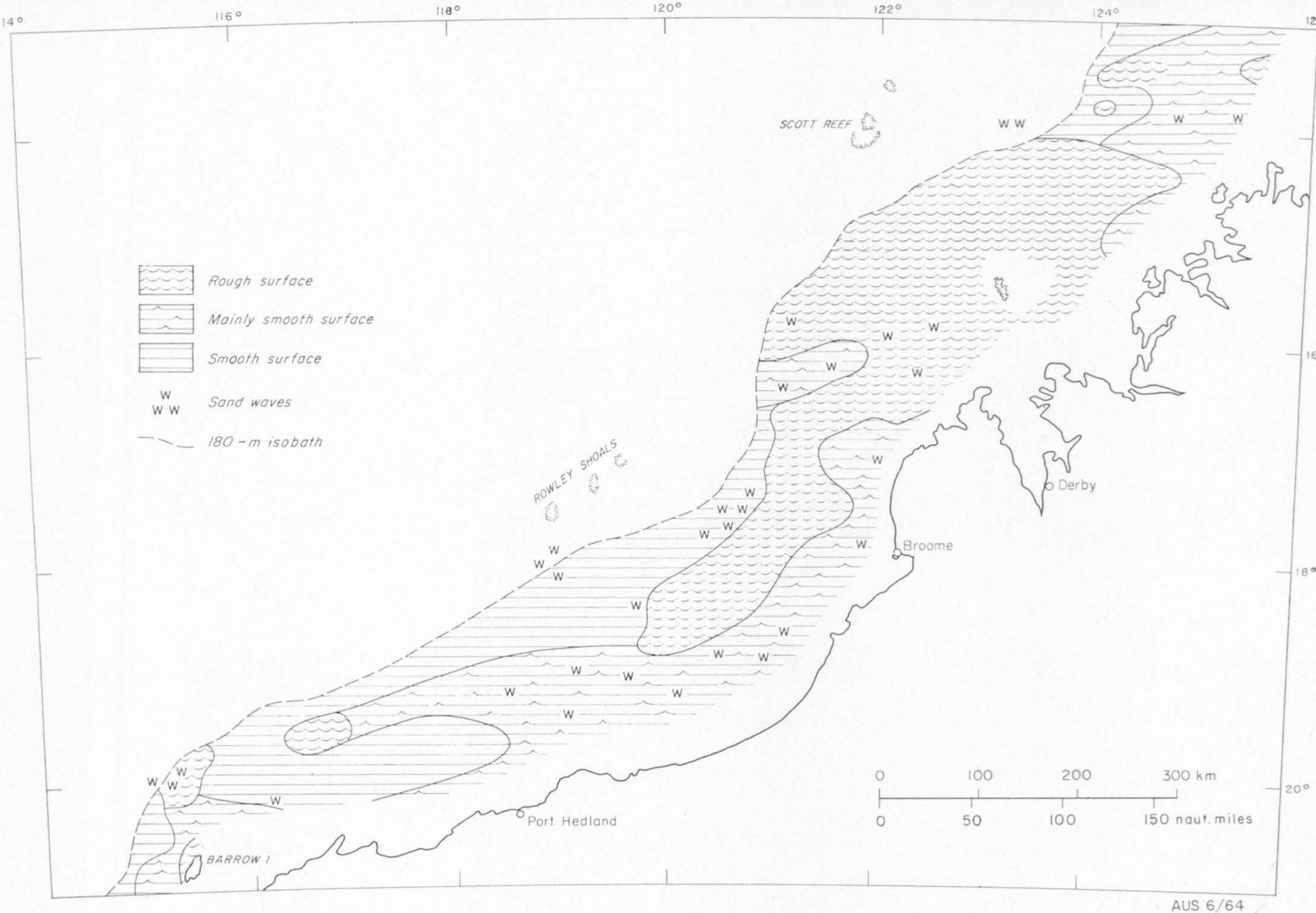

Fig. 11. Minor relief of the continental shelf.

submerged reefs, shell banks, and possibly drowned barrier islands and offshore bars related to the late Pleistocene low sea-level stillstand can be recognized.

The flat, monotonous surface of the outermost shelf and upper continental slope, which is locally present north of latitude 14°S and extensively developed south of latitude 16°S, marks the region of recent fine-grained sediment deposition. Smooth depositional areas are also present close inshore. Much of the extensive areas of flat shelf off the Canning Basin, however, are non-depositional and mark the submerged extension of the similar undissected plains of the onshore region. The dominating feature of the outer shelf in the Rowley Shoals area is a long low ridge which runs along the outer edge of the shelf parallel to the continental margin for a distance of some 300 km (Jones, 1971). A complementary trough is developed on the landward side of the ridge. The ridge is about 20 km wide, and in the vicinity of its maximum development near longitude 119°E, its crest stands about 45 m above the floor of the trough.

SHALLOW STRUCTURE AND LATE CAINOZOIC GEOLOGICAL HISTORY

Thirteen low energy seismic reflection traverses were run along lines approximately normal to the continental margin during the BMR 1968 marine geological survey. All except one of these are located in the southern half of the area (Fig. 13). Penetration averaged about 0.25 seconds (2-way time) and reached 0.6

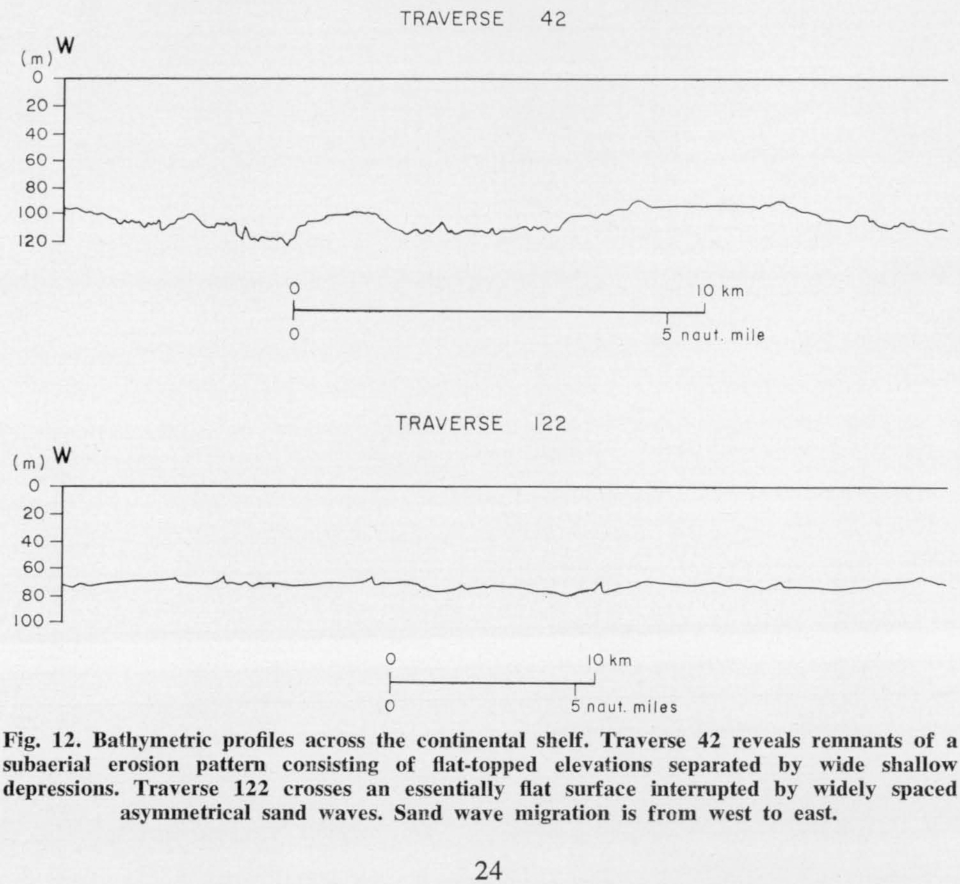

Fig. 12. Bathymetric profiles across the continental shelf. Traverse 42 reveals remnants of a subaerial erosion pattern consisting of flat-topped elevations separated by wide shallow depressions. Traverse 122 crosses an essentially flat surface interrupted by widely spaced asymmetrical sand waves. Sand wave migration is from west to east.

seconds under favourable conditions; resolution is of the order of 10 m. The 1968 marine geophysical survey carried out under contract for the BMR provides a complete coverage of seismic lines at about 16 km spacing, but these profiles are of only limited value in the shallow waters of the shelf. The high-energy sparker source (21 000 joules) produced a pulse about 50 milliseconds in length, reducing the resolution to around 50 m. This, combined with multiple reflections and distortion caused by the 200-m spacing between source and receiver, makes interpretation of records in waters shallower than about 120 m difficult or impossible. Veevers (in press) used the deeper parts of these profiles for his interpretation of the stratigraphy and structure of continental margin in this area; the present study relies mainly on the low-energy sparker records for the description of the upper part of the section and in the shallow water areas where the high-energy profiles are valueless. The low-energy seismic profiles are identified by Roman numerals.

Unconformities

Most profiles (Figs 14, 15) show one or more strong reflectors that are interpreted as erosion surfaces owing to their irregularities and discordant relationships to the underlying reflectors. Features displayed by these surfaces include scarps or sharp changes of slope (e.g. Trav. XI), which indicate subaerial or littoral erosion, and erosion channels of various sorts, which may be either subaerial or submarine erosional forms (Trav. III). Other strong reflectors within

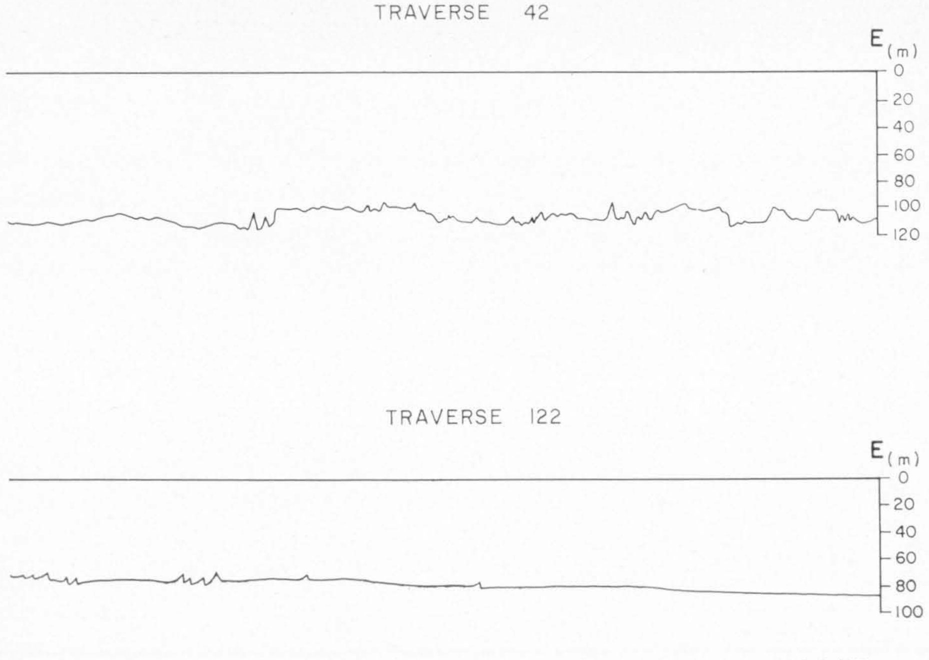

Fig. 12 (cont.).

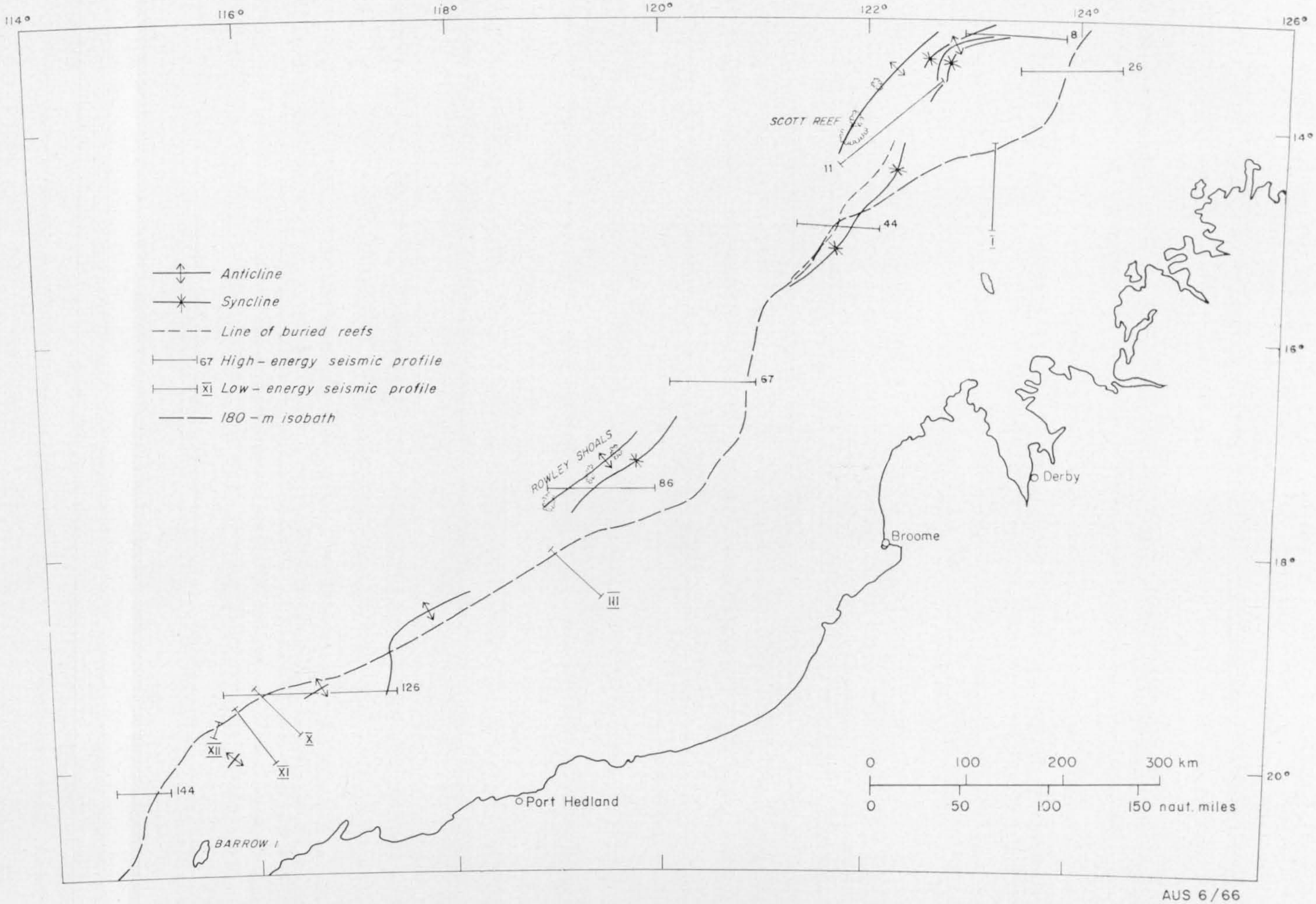

Fig. 13. Main structures in the superficial sediments. The seismic profiles plotted are illustrated in Figures 14 and 15.

apparently conformable sequences may mark indurated horizons developed during emergence, but proof of this is lacking where no dissection has occurred.

Correlation of these events between profiles is hazardous, and some subjective interpretations may even be involved in tracing reflectors within single profiles. However, at least four unconformities can be recognized in the top 200 to 300 m of section. The lowest of these (Surface 4) is equivalent to the shallowest unconformity (R1) mapped by Veevers (in press) in this area, and is believed to represent the important regional Miocene hiatus on the basis of correlation with the offshore petroleum exploration wells. Most of the wells provide little information on the uppermost part of the section in which boundaries are commonly inferred from wireline logs. Part of the middle and all the upper Miocene appear to be absent in the Ashmore Reef No. 1, Dampier No. 1, Legendre No. 1, and Madeleine No. 1 wells, but in Legendre No. 2 the first definite stratigraphic break occurs at a depth of 500 m during the lower Miocene and Oligocene. However, in this well no samples were recovered above 240 m below the sea bed and evidence of Pliocene/upper Oligocene sediments in the section down to a depth of 500 m is not conclusive. Surface 4 in Traverses X and XI is correlated with the period of erosion occupying much of the Miocene identified in the Dampier No. 1 and Legendre No. 1 wells. This correlation rests on the assumption that Surface 4 maintains its subhorizontal attitude landwards beyond where it is identifiable in the profiles; it certainly continues seaward subhorizontally, and comes close to cropping out beyond the edge of the shelf in 240 m of water (Trav. XI, 2200 hrs). The slight concave change in slope at this point is the expression of this Miocene surface still not completely obscured by later sedimentation; this feature is evident for a distance of 360 km along the continental slope between longitudes 116°E and 119°E. In the vicinity of the Rowley Shoals, Surface 4 crops out near the outer edge of the marginal plateau in 430 m of water (Fig. 14, Trav. 86); farther north again an ancient erosional scarp in this surface forms a well defined linear feature on the sea bed between the 300 and 400-m bathymetric contours for a distance of 130 km between latitudes 16°15′S and 17°10′S (Fig. 15, Trav. 67). Local induration of this surface is indicated by the powerful energy-scattering effect sometimes evident in the seismic profiles (Trav. 86).

It is likely that the platform in the Rowley Shoals area closely reflects the Miocene erosion surface and that little Pliocene and Quaternary sedimentation has taken place there except under the atolls themselves. It is tempting to postulate that the entire Scott Reef/Rowley Shoals Platform is underlain at shallow depth by the Miocene unconformity; this may be the case, but although most profiles across the platform reveal the presence of one or more near-surface unconformities, there is insufficient evidence to attempt correlation.

Only one well, Scott Reef No. 1, has been drilled on the Scott Reef/Rowley Shoals Platform. Sited within the lagoon of the southern atoll, it penetrated a thick sequence (2200 m) of Recent to lower Miocene reef limestones and calcarenites conformably overlying Oligocene and Eocene mainly fine-grained marine carbonates; the first unconformity recognized occurs at the base of the Tertiary, but time-restricted fossils are absent in the post-Oligocene section and stratigraphic breaks may be present. In fact Traverse 11, 18 km southeast of Scott Reef No. 1, reveals two unconformities in the top 400 m of section. Projected to the well, these would occur at 800 to 1200 m below sea bed, or deeper if downwarping caused by gravity loading has occurred, and would fall within the apparently conformable

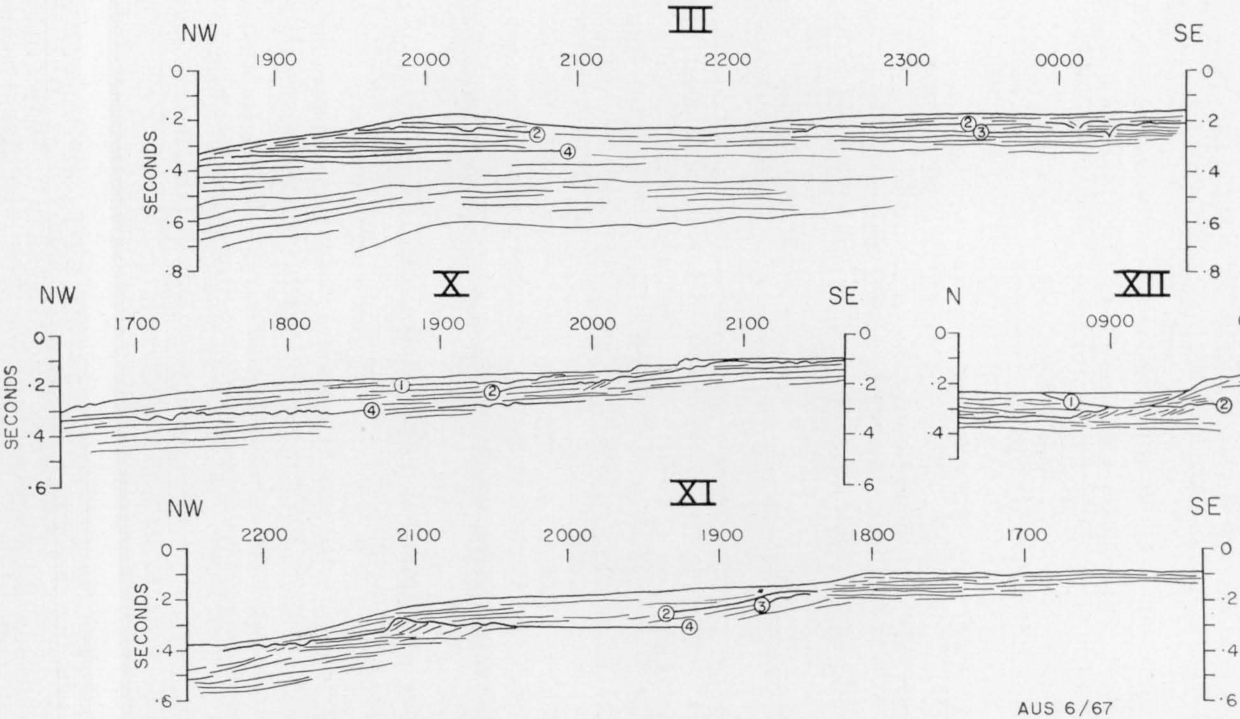

Fig. 14. Interpretations of seismic reflection profiles. Locations are shown in Figure 13. Numbered reflectors are referred to in the text. Horizontal scale is given by the time marks. Low-energy profiles (Roman numerals) were run at 5 knots; high-energy profiles (Arabic numerals) at 10 knots.

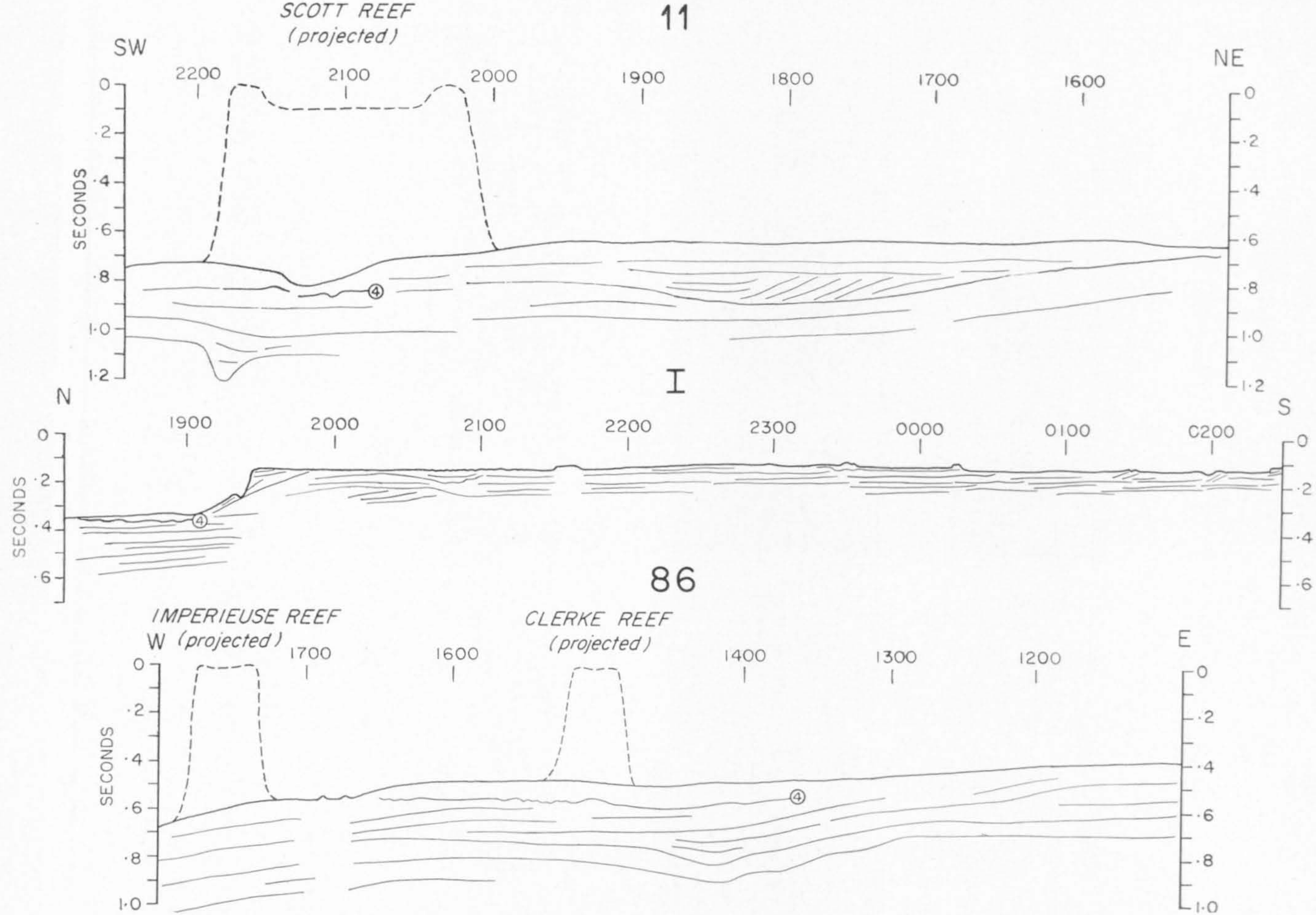
SCOTT REEF
(projected)
11
SW
NE
2200
2100
2000
1900
1800
1700
1600
SECONDS
I
N
S
1900
2000
2100
2200
2300
0000
0100
C200
SECONDS
86
IMPERIEUSE REEF
W (projected)
CLERKE REEF
(projected)
E
1700
1600
1400
1300
1200
SECONDS

Fig. 14.—(cont.)

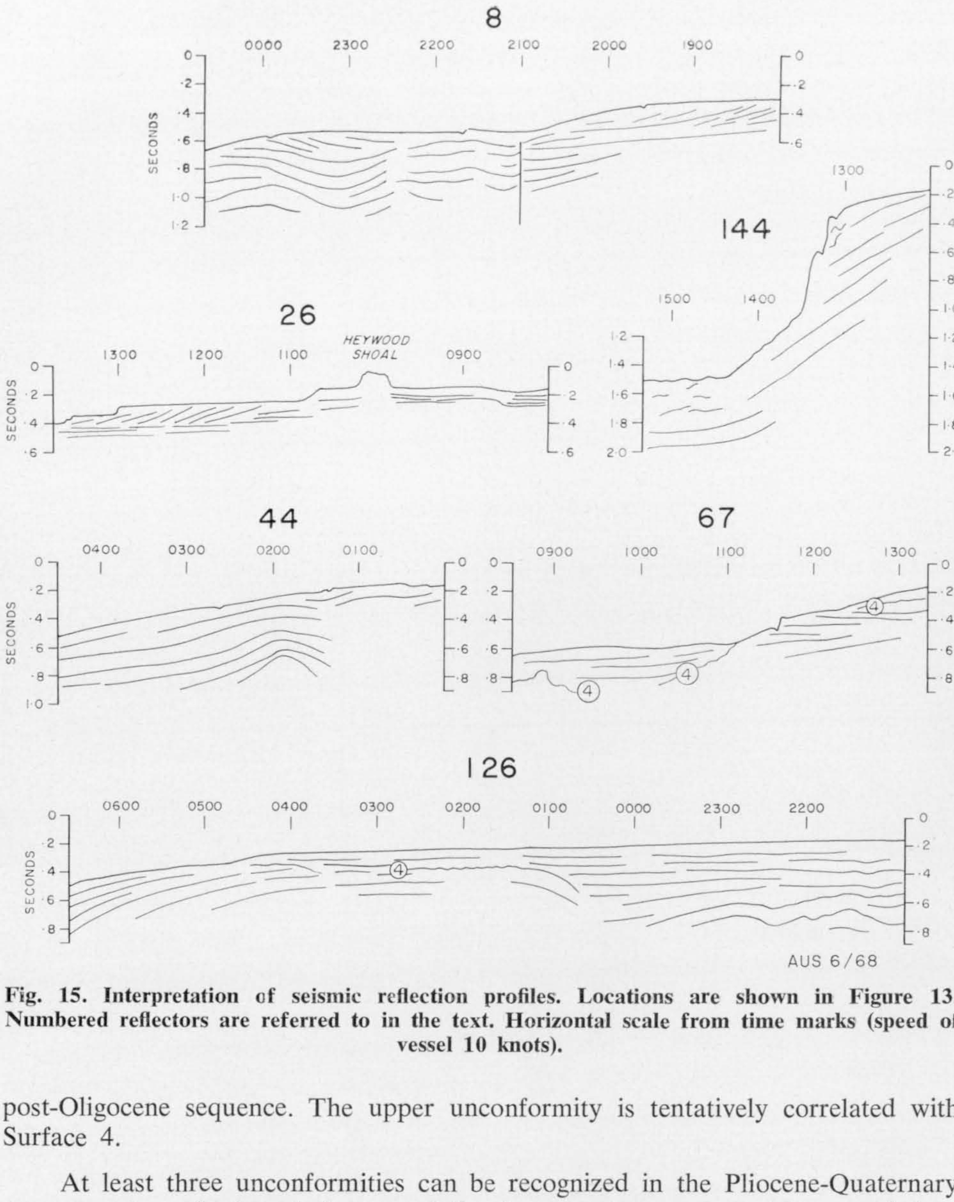

Fig. 15. Interpretation of seismic reflection profiles. Locations are shown in Figure 13. Numbered reflectors are referred to in the text. Horizontal scale from time marks (speed of vessel 10 knots).

post-Oligocene sequence. The upper unconformity is tentatively correlated with Surface 4.

At least three unconformities can be recognized in the Pliocene-Quaternary sequence above Surface 4, but correlation between traverses must be regarded as tentative and no evidence for dating the unconformities is available. Surface 1, well displayed in Traverse XII near Rankin Bank, probably represents the surface exposed during the last low sea-level stand of the Pleistocene. It is likely that this surface, and the underlying Surface 2, form the sea floor over the extensive areas where no Recent deposition has occurred or are buried by only a thin veneer of moving sand. Locally, 20 to 70 m of Holocene sedimentary fill has been deposited on Surface 1. Surfaces 2 and 3 occur below Surface 1 and above Surface 4. One or more other erosional surfaces are locally discernible in this interval also. Surface 2 is a strong irregular reflector of regional extent which is overlain by up to 100 m of sediments near the edge of the continental shelf. It is normally separated from the less prominent underlying Surface 3 by 35 m or less of section and the two surfaces probably merge locally.

Structure

The top few hundred metres of sediments on the continental shelf which, in general, comprises the Pliocene and Quaternary above Surface 4, is flat-lying or exhibits gentle depositional dips. Seaward of the edge of the shelf, the superficial sediments of the Scott Reef/Rowley Shoals Platform in some areas are gently folded, disrupted by normal faults, and exhibit supratenuous folds interpreted as draping over buried reefs. These structures chiefly affect the Miocene and older sequences underlying Surface 4, which lies at shallow depth under the platform; they may extend landwards under the thicker Pliocene and Quaternary section of the continental shelf, and indeed can be seen to do so in the southern part of the area, but it is likely that they are most pronounced in the less stable shelf edge zone. Gravitational slumping is common on the continental slope and is present in a few places at the edge of the shelf also.

Depositional structures

The gross exaggeration of vertical scale in the illustrated seismic sections, which averages 25 times for the low-energy profiles and 40 times for the high-energy profiles, emphasizes dips which would be undetected in outcrop without regional levelling. Depositional structures noted consist of huge seaward-dipping foreset beds in the region of the upper continental slope resulting from the regional progradation by sedimentation along the continental margin (Fig. 15, Trav. 126); smaller, but still large-scale, foreset bedding near the edge of the continental shelf indicating progradation of the shelf itself (Fig. 15, Trav. 26); depositional dips controlled by local irregularities of the surface on which the sediments were laid down (Fig. 14, Trav. 111); and supratenuous anticlines which are believed to result partly from depositional dip and partly from differential compaction in sediments deposited on ancient reefs (Fig. 15, Trav. 44). Very low-angle depositional dips are also found on the outer shelf, marginal plateaux, and upper continental slope where lenses of sediment whose axes mark zones of relatively rapid deposition are present.

Folds and faults

The superficial sediments underlying the Scott Reef/Rowley Shoals Platform are gently warped northeast of Scott Reef between latitudes 13°S and 14°S, and in the vicinity of the Rowley Shoals (Fig. 13; Fig. 15, Travs 8, 8b). In the southern part of the area, northeast of Rankin Bank, this folding extends under the shelf, dying out 200 to 300 m below the sea bed (Fig. 18, Trav. 126). Most of the seismic profiles provide poor-quality data in shallow water and it is possible that folding in the pre-Pliocene sequence under the shelf is more widespread than indicated in Figure 13. The broad structural high at the western end of Traverse 126 is on trend with the morphological rise forming Rankin Bank, under which the shallow seismic data are valueless, and it is likely that this anticline in the superficial sediments is the reflection of the deep-seated positive structural trend of the Rankin Platform. The gentle swell aligned with the Rowley Shoals group of atolls would also appear to reflect a deep-seated positive structure, but in contrast with the Rankin Platform, the gravity data here do not indicate the existence of a basement high.

The gentle warping of the sediments underlying the Scott Reef/Rowley Shoals Platform near the northern margin of area (Fig. 15, Trav. 8) might indicate an element of late Cainozoic compressive stress, although the presence of normal faults downthrown towards the North Australian Basin suggest that gravitational collapse in the prism of sedimentary rocks along the continental margin is the primary cause of the deformation.

Faults are not common in the near-surface sediments except on the relatively steep gradients of the continental slope where slumping is widespread. Small normal faults, usually devoid of surface expression, are in places apparent in the seismic profiles across the Scott Reef/Rowley Shoals Platform (Fig. 15, Trav. 8). Slumping along bedding planes inclined at angles as low as 1° has been noted on the slope west of Barrow Island (Fig. 15, Trav. 144). This profile shows the features which typify low-angle slumping in unconsolidated sediments: tensional depressions and oversteepening at the back wall of the slump (1300-1330 hrs); the slump plane approximately parallel to the bedding of the major units under the slope, which here dips at 1.0° to 1.5° (1330-1430 hrs); and the zone of convoluted, acoustically transparent, slumped sediment at the foot of the slope (1500 hrs).

Slumping on such gentle slopes is perhaps unusual; Lewis (1971) has recently described gravitational collapse structures on slopes inclined at 1° to 4° off the east coast of North Island, New Zealand, but major earthquakes are common there. Although the North West Cape area cannot be described as seismically active, it is worth noting that one of the severest earthquakes ever recorded in Western Australia, magnitude (MS) 7¾, had its epicentre at latitude 22°S, longitude 109°E, 600 km from the Barrow Island slope (Everingham, 1968). Thus earthquake shock could provide a triggering mechanism. In general, however, slumping can be expected to be mainly confined to specialized environments of rapid deposition in the near-shore zone (Moore, 1961); the conditions leading to instability, which is governed by the cohesion, grainsize, and porosity of the sediments, as well as by the gradient, are rarely encountered near the edge of the continental shelf. Certainly on the northwest continental margin there are thick piles of sediment showing no signs of slumping on slopes of up to 10°.

Submerged Strandlines

Wave-cut platforms and sea cliffs eroded at times of lowered sea level, unless they are of considerable size, may not appear on echosounder profiles produced by conventional wide-beam transducers. Thus Dill (1968) recorded smooth echosounder profiles of the Californian continental slope which submersible dives proved to be terraced, and Trail & Jones (1969) found that drowned reefs in the Arafura Sea, identified from the submarine *Yomiuri,* were sometimes poorly shown or absent on the echosounder profiles taken from a surface vessel.

However, study of some 80 echosounder profiles across the northwest shelf and slope, all taken with wide-beam transducers, has revealed submerged strandline features, some of which are traceable over long distances. The most widespread and persistent of these is a notch or scarp at a depth of about 120 m that can be traced with only minor breaks along the entire shelf from North West Cape to the Bonaparte Gulf. In addition to the step at 120 m, other features probably attributable to strandline erosion are intermittently discernible at lower levels down to —380 m and at several shallower levels between —60 and

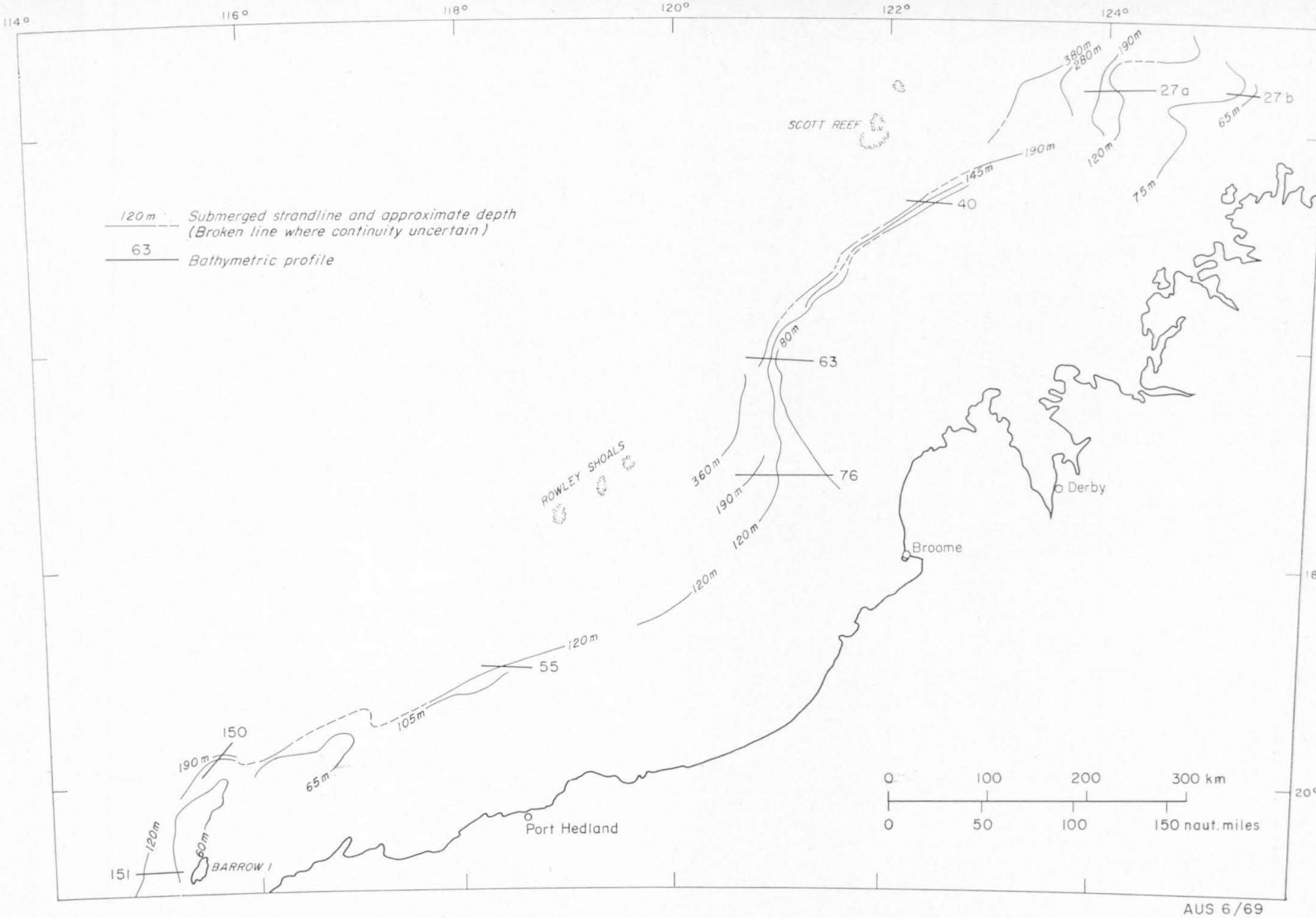

Fig. 16. Distribution of submerged strandlines. Illustrative bathymetric profiles are shown in Figure 17.

—105 m. The distribution of the submerged strandlines is shown in Figure 16, and tracings of representative echosounder profiles illustrating the form these features take are reproduced in Figure 17. The seismic profiles particularly Traverses 26 and 67 (Fig. 15), provide additional sections across the strandlines. In areas of high sea-bed relief the steps sometimes merge and correlation is further complicated by the erosion, sedimentation, and reef development that has taken

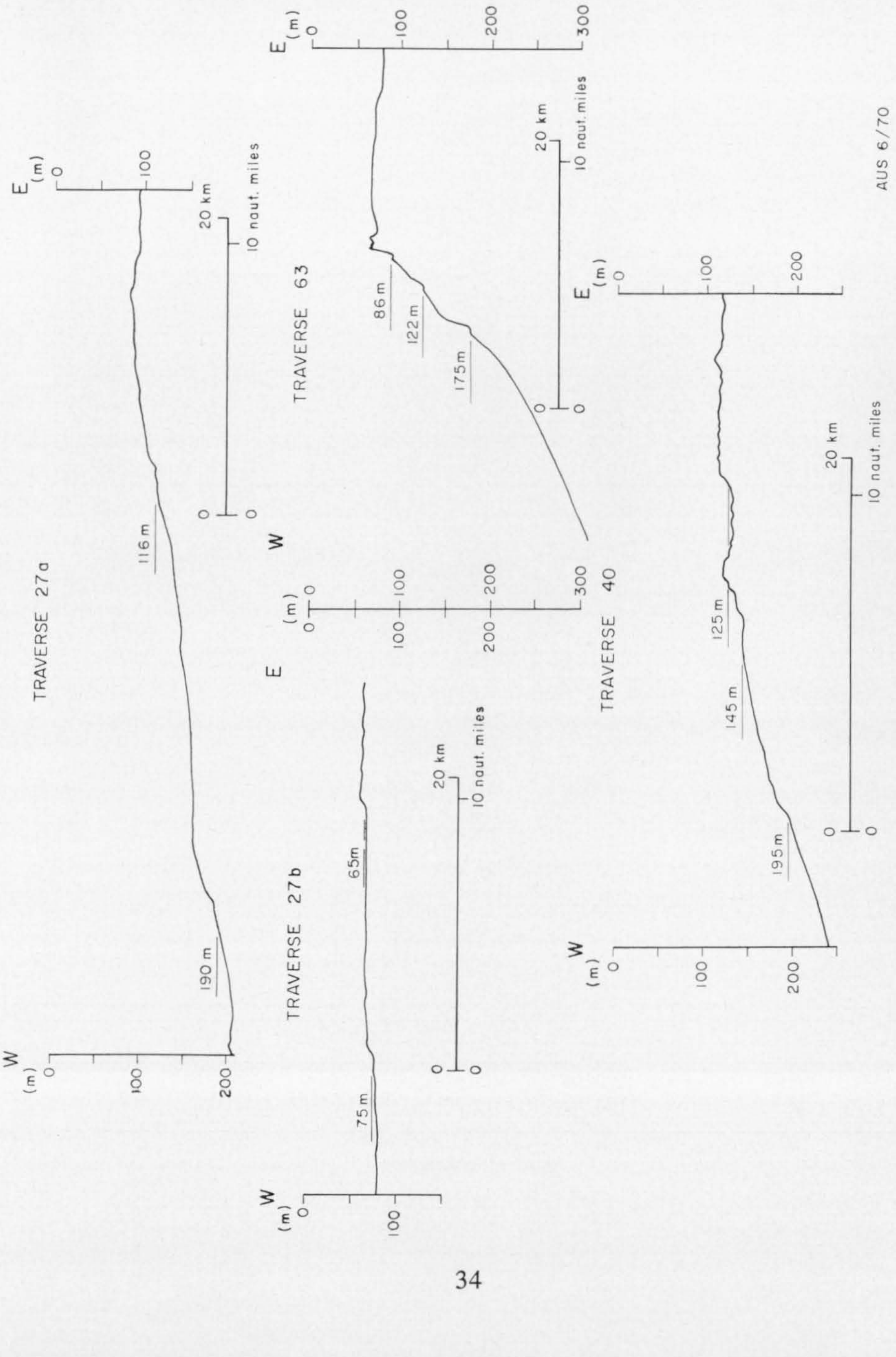

Fig. 17. Bathymetric profiles illustrating terracing of the continental shelf. Location of profiles shown in Figure 16.

place since the strandlines were formed, as well as by the often unfavourable orientation of the traverses themselves. The profiles readily lend themselves to subjective interpretation, particularly in the shallower parts of the records, but the terrace and step forms show sufficient continuity to be traceable over long distances and many gaps can reasonably be attributed to the poor resolution of the wide-beam echosounder transducers used.

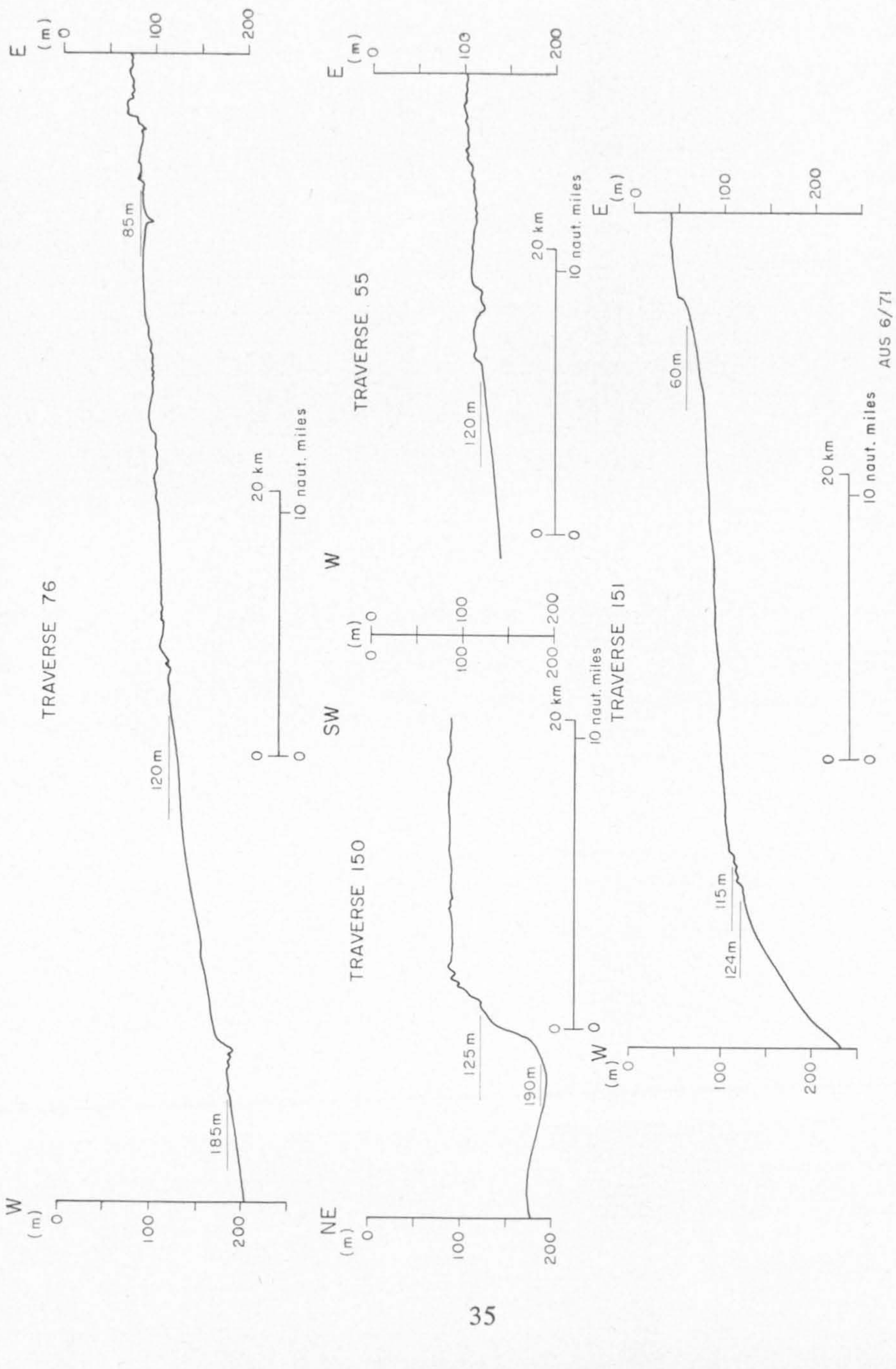

Fig. 17.—(cont.)

The step at —120 m is by far the most persistent and the best preserved; it can be correlated with the regional break in slope at depths of 102 to 143 m in the Timor Sea (van Andel & Veevers, 1967), with the step at about —125 m in the Arafura Sea (Jongsma, in press), and with the steps between —100 and —150 m off the Great Barrier Reef (Maxwell, 1968). These levels agree closely with the well documented world-wide eustatic sea-level stillstand at about —130 m which immediately preceded the Holocene transgression some 17 000 years ago (Curray, 1965). The good state of preservation of the step on the Northwest Shelf supports its youthful origin, while its constant level implies that there has been no structural warping since its formation. This conclusion is sharply at variance with that of Veevers (in press), who in this area traces a single shelf-edge notch varying in depth from 54 to 160 m, and a second notch seaward of this at depths of 136 to 238 m; he attributes each to a single low sea-level stand and postulates crustal instability to account for the differences in level.

There is no direct evidence on the age of these features. Dredging across the submerged strandlines was carried out, but no beach rock or reefal masses that would be likely to provide trustworthy radiocarbon dates were recovered. Three radiocarbon dates on relict shell material dredged from 159 m (corals and thick-shelled bivalves), 132 m (serpulids), and 113 m (corals and thick-shelled bivalves) all fell within the range 12 000 to 12 500 years[1]. There seems to be no doubt that during and after the Holocene transgression there has been widespread reworking of shallow-water shell banks and littoral material. Another radiocarbon date of 31 000 years[2] was obtained on oolitic limestone pavement dredged from 282 m, but this material must have formed in the marine environment and is unrelated to the ancient strandlines; its significance is discussed in the section on sediment lithology.

As mentioned above, there is some indirect evidence to link the step at —120 m with the eustatic low sea level accompanying the late Wisconin glacial maximum immediately preceding the Holocene transgression about 17 000 years ago. With regard to the notches at greater depths, similar features have been recorded elsewhere along the Australian continental margin, but their ages apparently vary widely. Samples have been collected under direct observation from a submersible, which must greatly reduce the possibility of contamination with derived material, from a submarine cliff at —200 m in the Arafura Sea and from a terrace at —175 m at the southern end of the Great Barrier Reef. The Arafura Sea sample was dated by the uranium series method at not less than 170 000 years (Jongsma, 1970), while radiocarbon and uranium series assays of the Great Barrier Reef material gave dates of 13 600 to 17 000 years (Veeh & Veevers, 1970). In each case the shallow-water origin of the samples is well established and that they were *in situ* is beyond question. Dill (1968) who recorded strandline features at about —200 m on both sides of the Pacific, off western North America and off Australia, suggests that the constancy of depth of the terraces indicates a youthful origin, implying that they were formed during the same low sea-level stillstand. The few radiometric dates available do not support this assumption, and indeed it would be surprising if ancient strandlines formed during the glacial maxima which preceded the late Wisconsin were not locally preserved.

1. Radiometric dating by V. Djohadze, Dep. Nuclear and Radiation Chemistry, Uni. New South Wales.

2. Radiometric dating by H. A. Polach, Dep. Geophysics and Geochemistry, Aust. Nat. Univ.

The lowest notches, at depths of 280 to almost 400 m, are believed to date back to the Tertiary; their present level is unrelated to Quaternary eustatic changes in sea level and must be partly due to subsidence of the continental margin during the late Cainozoic. The best developed of these features lies northeast of the Rowley Shoals at depths between 300 and 400 m and runs parallel to the edge of the shelf for a distance of 110 km. The seismic profiles (e.g. Fig. 15, Trav. 67) show clearly that it is incised into an erosion surface, identified as the Miocene Surface 4, which crops out on the Scott Reef/Rowley Shoals Platform in this area. The deep scarps east of Scott Reef in the far north are also clearly erosional in origin; there is a suggestion here too that they are cut into an ancient erosion surface which underlies the sediments forming the present-day shelf (Fig. 15, Trav. 26), but the evidence for this is less strong. Elsewhere these Tertiary wave-cut platforms and sea cliffs have been buried by later sediments but are clearly visible in some of the seismic profiles (Fig. 14, Trav. XI).

The submerged strandlines at depths of less than 120 m are impersistent, poorly developed, and at several different levels between —105 and —60 m. It seems likely that there were no lengthy stillstands during the Holocene transgression and that wave-cut platforms and cliffs only developed where elevated land formed of relatively resistant rocks was transgressed. Some may have developed during stillstands interrupting earlier Pleistocene transgressive and regressive cycles, and their poor state of preservation and variations in depth in this case can be attributed to modification by erosion and sedimentation and to subsidence or uplift since their formation.

Summary of Late Cainozoic Geological History

The oldest event that can be identified with any confidence in the shallow seismic records is an erosional surface separating the Miocene, or older sediments, from the Pliocene and Quaternary sequence. This unconformity crops out locally on the Scott Reef/Rowley Shoals Platform 300 to 400 m below sea level, and a well defined step in the surface marks the shore at a late stage in this erosional period. This ancient strandline is only intermittently discernible, but over most of the area it lies seaward of the present-day continental shelf near the inner edge of the Scott Reef/Rowley Shoals Platform. During this period the Scott Reef/Rowley Shoals Platform formed a narrow continental shelf with a broken line of atolls, after which it is named, along its outer margin. At least one reef in addition to those that have survived to Recent times was present, but nothing resembling a continuous barrier existed. The reefs probably first appeared during the Miocene, but there are also indications of the presence of a line of deeply buried lower Tertiary(?) reefs near the edge of the present-day continental shelf southeast of Scott Reef.

The Mio-Pliocene transgression was probably initiated by rapid subsidence which resulted in the preservation of the strandline features and the drowning of the reef south of Imperieuse Reef at a very early stage. The extremely low relief of the coastal plain presumably resulted in widespread and rapid inundation; there is no evidence of the easterly extent of this or of later transgressive cycles during the Pliocene and Quaternary, although late Cainozoic marine sediments locally extend inland for 30 km or more from the present-day coast. Likewise, except for the well preserved step at —120 m at the margin of the continental shelf, which is correlated with the Wisconsin glacio-eustatic low sea-level stillstand, there is no evidence for dating the regressions represented by several erosion surfaces in the shelf sediments. Two submerged strandlines, which were probably formed during a single glacial period, occur below the 120-m step, and several at shallower depths either exposed in the sea floor or buried under different thicknesses of sediment on the continental shelf.

The thickness of the Pliocene and Quaternary sequence probably does not exceed 200 m over most of the shelf and tends to be less seawards. The sequence is very thin or absent over much of the Scott Reef/Rowley Shoals Platform, except under the atolls themselves where it may exceed 1000 m. On the continental shelf several regressions related to Plio-Pleistocene glacio-eustatic low sea levels occurred; the thickness of the sedimentary units between the resulting unconformities is variable and is controlled partly by the relief of the depositional surface, the depressions receiving more sediment than the more elevated areas, partly by the development of constructional features, such as sand bars and bioherms, but mainly by regional variations in the rate of sedimentation.

The present-day shelf is mainly non-depositional, and wide areas are covered by coarse-grained relict sediments consisting of reworked littoral deposits and by a thin veneer of shelly and oolitic sands. Fine-grained terrigenous sediment is accumulating close inshore and there are extensive depositional areas near the outer edge of the shelf where silt-size and clay-size carbonates and *Globigerina* sands are being laid down. One of these areas lies to the south of the Rowley Shoals and forms a long low ridge along the outer edge of the shelf for a distance of about 300 km. The crest of the ridge coincides with the zone of maximum sedimentation, and is the site of deposition of somewhat pelagic sediments consisting of planktonic Foraminifera, fine-grained material winnowed from the middle and inner shelf, and minor amounts of terrestrial silt and clay (Jones, 1971). Normally such sediment would be deposited to seaward of the continental shelf and would contribute to the prograding of the continental slope, as it does off the narrow shelf west of Barrow Island. South of the Rowley Shoals, however, the great width of the shelf and the local regime of sediment transport and deposition has resulted in the deposition zone occurring on the shelf itself, where it forms a pronounced ridge or swell. Similar massive lenses of sediments marking loci of maximum sedimentation during the upward and outward building of the shelf are present in the Plio-Pleistocene succession; in the seismic profiles they can give a false impression of folding.

SEDIMENTS

Of the 364 stations occupied, surface sediment samples were recovered at 353. Failure to recover sea-bed samples was usually due to the nature of the bottom in areas of smooth limestone pavement devoid of loose sediment. Material recovered was hand-mixed; a small fraction (about 50 g) was sealed and stored as a reference sample and a second small sample was stained and preserved in alcohol for study of the Foraminifera (Appendix 1). About 1000 g was retained for later laboratory treatment. Station data and basic sediment characteristics are tabulated in Appendices 2 and 3.

Textures

The somewhat complex textural distribution pattern of the surface sediments on the Northwest Shelf broadly resembles those in the Timor and Arafura Seas, although the wide areas of fine-grained sediment in the Bonaparte Depression (van Andel & Veevers, 1967) and the central Arafura Shelf (Jongsma, in press) have no counterpart in this region. In general terms, medium, coarse, and very coarse-grained calcarenites and lag gravels, consisting mainly of relict organic material, in places with an important authigenic accretionary component, are spread over the shelf (Pl. 1, fig. 1), and regions of fine-grained sediments are restricted to near-shore depositional areas, local sediment traps on the central shelf, and the outer shelf margin. Two factors must be borne in mind in the interpretation of the textural distribution shown in Figures 18 and 19 and Plates 9 and 10. Firstly, the spacing of sample stations is very wide compared with the scale of the minor relief of the sea floor, and many of the samples themselves were recovered after prolonged dredging and therefore may be representative of sediments extending over a horizontal distance of 100 m or more. The samples also represent a mixture of the top 5 to 10 cm of sediment. Underwater photographs, taken at intervals of about 30 seconds, while the ship was drifting, show clearly how rapidly the lithology of the sediment may change (Pl. 1, fig. 2; Pl. 2, fig. 1), and considerable variation in the type of sediment may be detected within the field of view of a single photograph (Pl. 2, fig. 2). Thus a poorly sorted sample may consist of two or more different lithological types collected from separate pockets of sediment a few metres or tens of metres apart, or from superimposed laminae at a single position, while any sample may be representative of local rather than regional conditions.

The second factor concerns the influence of the biogenic component, which is everywhere strong and is dominant over wide areas; while a part of this component consists of detrital material in equilibrium with the present regime of sediment transport and deposition, an important fraction is either relict or living and therefore unrelated texturally to the depositional environment in which it occurs. Most of this fraction is coarser than 2 mm, and therefore is not reflected in the sand-silt-clay classification, but an important amount is present in the sand grade also. Selective removal of relict material and or organisms belonging to the existing ecological system from the sample before analysis would introduce unacceptable bias, and leaching of the entire carbonate component is impracticable as many of the sediments are almost devoid of non-carbonate detritus.

It follows that detailed textural analyses of material of this sort, and statistical treatment of the resulting measures of sediment size, must be of little or no value in the interpretation of environmental conditions, and therefore have not been undertaken. However, despite the limitations imposed by the wide sampling grid and by the inclusion of relict and living shells in the sediments analysed, the textural distribution map based on the relative proportions of the sand, silt, and clay end-members in the 10-compartment classification proposed by Shepard (1954) does present a picture that can be explained in terms of the regional morphology and sedimentation patterns on the shelf.

Figure 18 illustrates the dominance of sandy sediments on the shelf and beyond the break in slope to a depth of 200 to 300 m. There are two regions where fine-grained sediments are present in shallower water over wide areas where depositional conditions replace the otherwise ubiquitous erosional and transportational environments. The first is in the far northeastern corner of the region where silty sand and sand-silt-clay extend from inshore across the width of the shelf in the region of latitude 14°S. This belt, which coincides with a region of relatively low calcium carbonate content and a corresponding increase in terrigenous material, reflects the influence of the Fitzroy River and of the streams draining

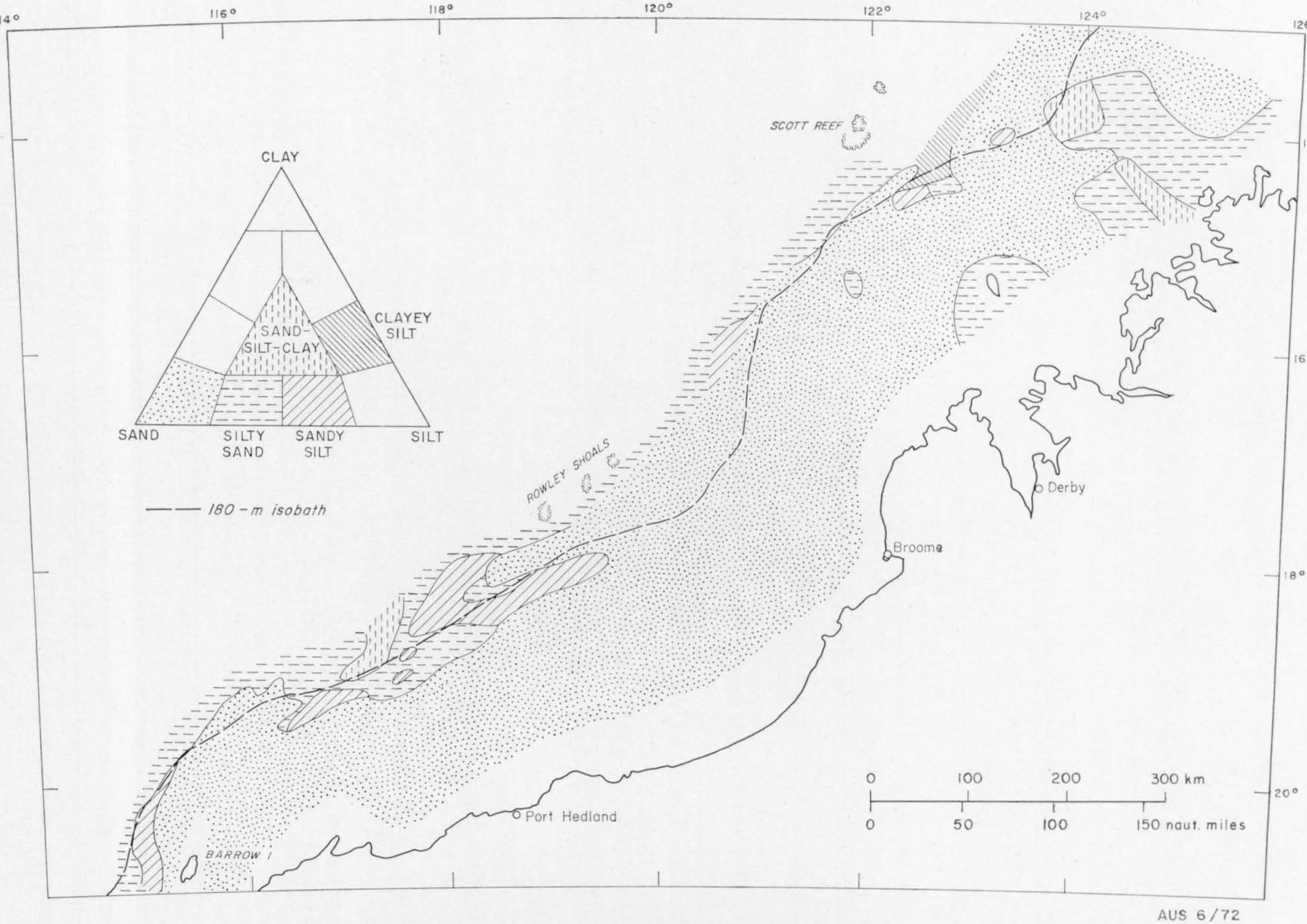

Fig. 18. Texture of surface sediments after removal of the gravel (+2 mm) fraction. The 3-component classification of Shepard (1954) is used.

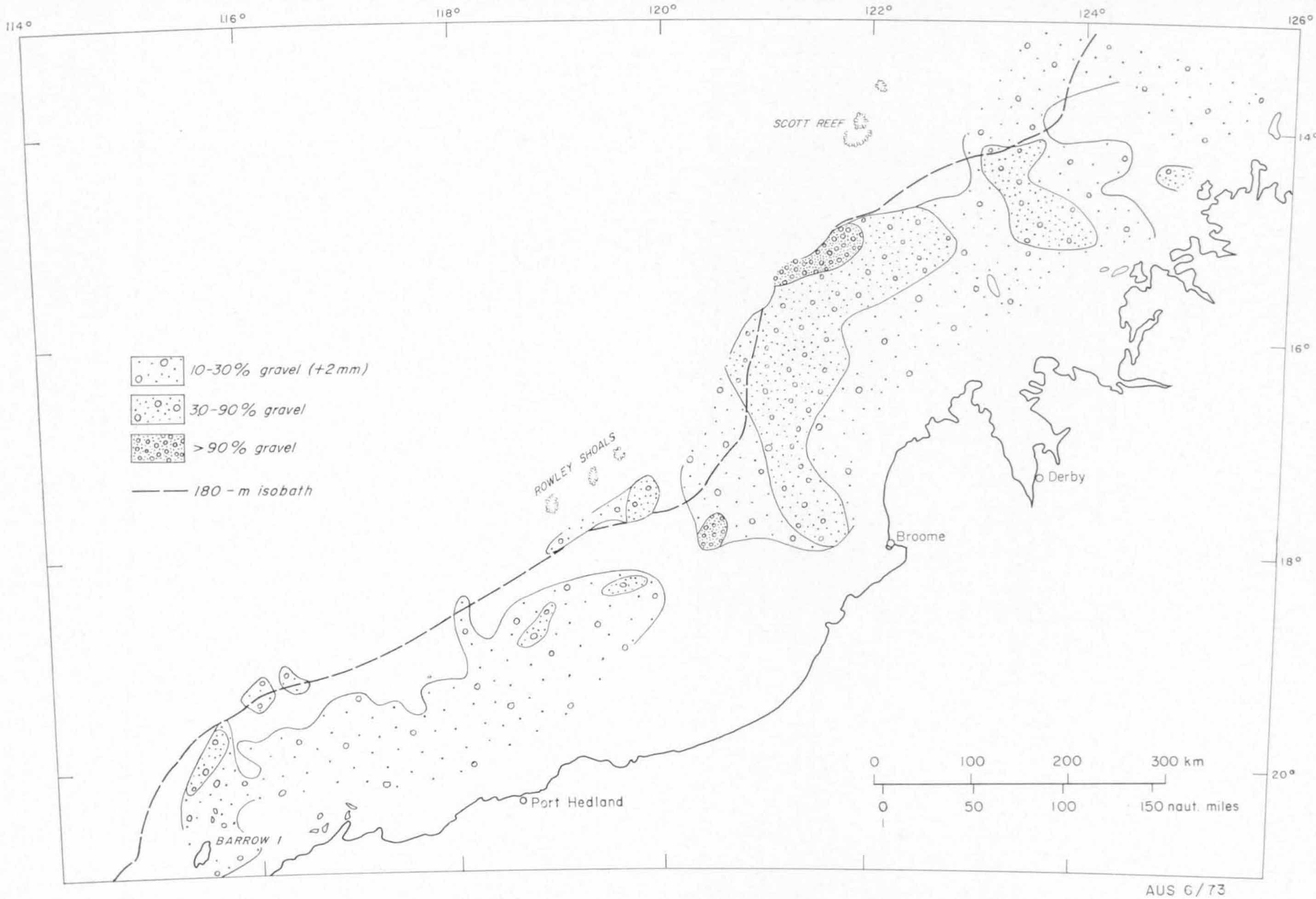

Fig. 19. Distribution of gravel in the surface sediments.

areas of high rainfall in the west Kimberley Basin. A similar tongue of fine-grained sediment appears off the Ord and Victoria Rivers in the Bonaparte Gulf to the northeast.

The second extensive region of fine-grained sediment occurs on the outer shelf south and southwest of the Rowley Shoals between longitudes 116°30′E and 119°30′E. It coincides with the long low ridge which follows the edge of the shelf in this region. Seismic profiles across the ridge (e.g. Fig. 14, Trav. 111) indicate that it is a constructional feature formed by a thickening of the sequence above a subhorizontal channelled erosion surface, the early Pleistocene(?) Surface 2, and therefore the axis of the feature marks a zone of relatively rapid sedimentation during the Quaternary. There is no obvious explanation for the existence of this depositional belt of fine-grained sediment on the present-day shelf, and for its persistence throughout much, if not all, of the Quaternary. Information on currents in the region is very incomplete, but British Admiralty and U.S. Navy Hydrographic Office publications indicate that sets to the south or southwest are dominant during the summer monsoon season, when the amount of sediment in suspension is likely to be greatest. If this is the case, deposition might be expected where the current is deflected and slowed by the change in direction of the shelf margin between longitudes 116°E and 120°E. A similar, although much smaller, embayment of fine sediment encroaches on to the shelf between longitudes 122°E and 123°E, and here too the edge of the shelf swings from a southerly to a westerly trend.

Another apparently anomalous feature of the textural distribution map is the lack of gradational decrease in grainsize passing from the shelf calcarenites seawards. A belt of sandy silt is often interposed between the silty sands of the upper continental slope and the coarse-grained sediments on the shelf. This can probably be partly explained by the marked difference in composition of the sand fraction of the deep water silty sands and that of the sand fraction of the shelf sediments. The former consists mainly of planktonic Foraminifera, whereas the latter is a heterogeneous mixture of organic detritus, pellets, and oolites. It would seem that the outer margin of the current-swept high-energy zone of the shelf and uppermost slope is quite sharply defined, and is commonly bounded by a belt where relatively rapid deposition of mainly silt-size carbonate and terrigenous detritus occurs. Farther seawards the slower rate of sedimentation brings about an increase in the relative proportion of sand-size planktonic Foraminifera resulting in the ubiquitous deep water silty sands.

Except for minor calcareous nodules and lithoclasts, the +2 mm fraction (gravel, or more properly calcirudite) is entirely of organic composition. The seaward limit of sediments containing over 10 percent of gravel generally approximates to the boundary of sand in the —2 mm fraction (Fig. 19). The presence of a gravel component in fine-grained sediments, as in near-shore areas in the northeast, reflects the influence of the local bottom fauna; on the other hand, the wide areas of middle and outer shelf west of longitude 121°E, where the sediments are devoid of a significant gravel component, represent high-energy zones with abundant moving sand blanketing the lag gravels and supporting a sparse macrofauna (compare Fig. 11, which indicates the sand wave distribution).

Composition, Lithology, Petrography

Pure carbonate and highly calcareous sediments occupy the whole of the middle and outer shelf and upper slope; at only four stations (just over 1% of all

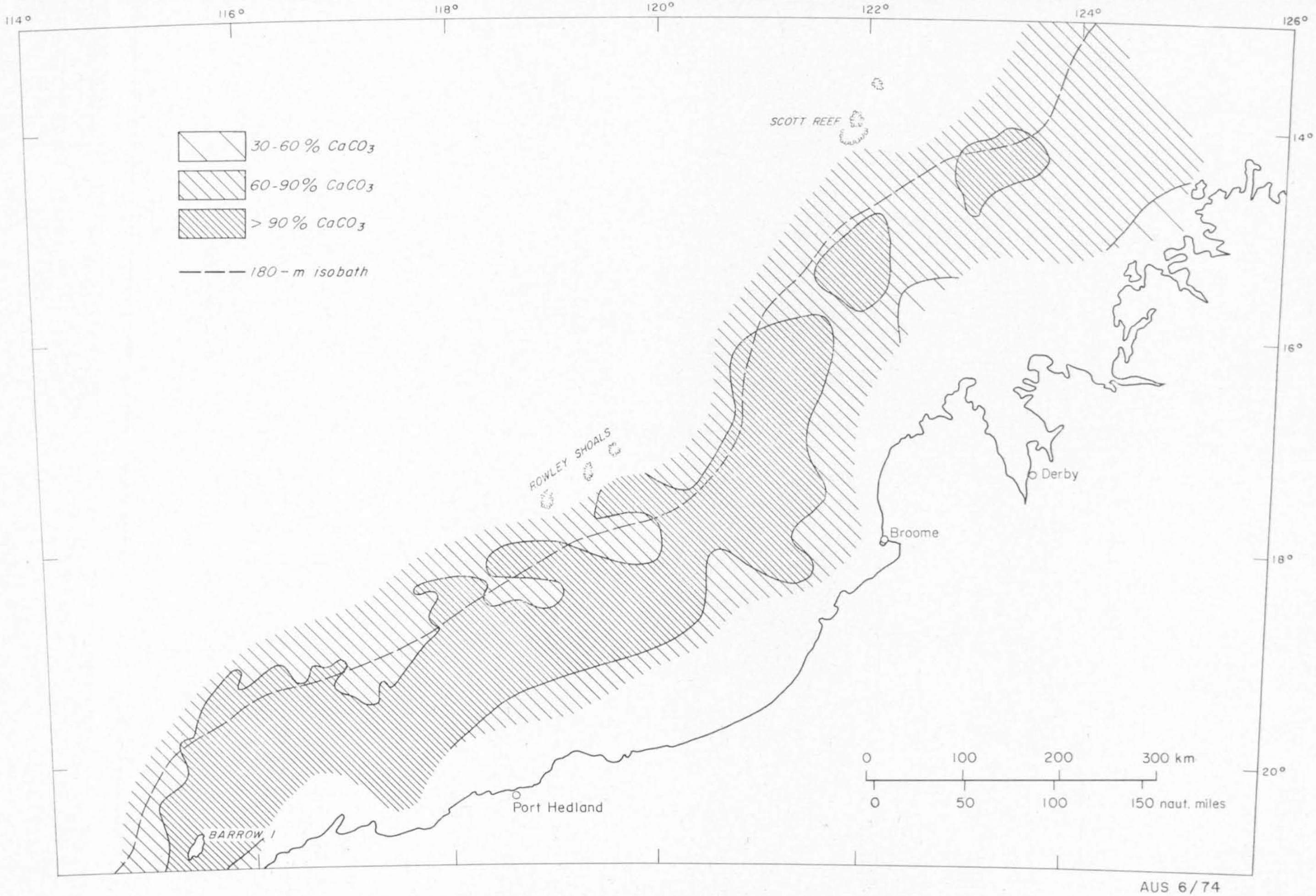

Fig. 20. Calcium carbonate content of the surface sediments.

samples) is the total carbonate content less than 60 percent, while at 190 stations (54% of the samples) the carbonate content exceeds 90 percent (Fig. 20). Most samples analysed by X-ray diffraction contained high magnesian calcite in addition to normal calcite and aragonite; electron probe analyses have shown this mineral to have the approximate formula $Ca_{0.84}\ Mg_{0.16}\ CO_3$. There is fairly good negative correlation between carbonate content and the proportion of silt and clay in the sediments. Thus the isopleth enclosing the stations with over 90 percent carbonate (Fig. 20) corresponds quite well with that bounding the sands in the textural diagram (Fig. 18). Clearly most of the sediment being shed by the land is fine-grained, and except in the far northeast, where the supply is relatively abundant, it is kept in suspension until it is seaward of the edge of the shelf. The positive correlation between silt-size and clay-size detritus and the non-carbonate component of the sediments is impaired where the coarse fraction contains a significant proportion of terrigenous or authigenic material in the form of pellets or lithoclasts, many of which were derived from ancient subaerial weathering profiles, glauconite pellets, and phosphatic grains.

Organic material

Skeletal debris makes up almost all of the material larger than 2 mm, most of the sand-size grains, and is often recognizable in the silt fraction. In the calcarenites and shelly calcarenites of the shelf, molluscs, benthic Foraminifera, bryozoans, echinoids, calcareous algae, and corals are all well represented. Large Foraminifera, among which members of the families Amphisteginidae and Miliolidae are particularly prominent, together with bivalve fragments, usually form most of the recognizable skeletal material (Pl. 3, fig. 1). Calcareous algae, benthic Foraminifera, bryozoans, and corals predominate in the area of shoals such as Rankin Bank and Heywood Shoal, whereas molluscs assume greater relative importance in regions of deposition of fine-grained sediment on the shelf; however, attempts to compile biofacies maps in more detail on the basis of the dominance of individual organisms or groups of organisms have proved unrewarding. An account of living Foraminifera identified in the samples is given in Appendix 1.

In contrast with the varied assemblages of fragmental skeletal debris in the high-energy shallow and intermediate depth waters, mainly unbroken tests of planktonic Foraminifera (Globigerinidae) form an important part of the sediment on the outer shelf and beyond, and commonly constitute virtually all of the sand-size fraction (Pl. 3, fig. 2). Even here, photographs of the sea bed provide evidence of bottom currents; this commonly takes the form of more or less distinct current lineation (Pl. 4, figs 1, 2), but ripple marks also occur (Pl. 5, fig. 1). The boundary between the Globigerinidae province and that of the heterogeneous skeletal debris lies almost entirely within the region of coarse-grained sediment on the outer shelf at depths between 80 and 120 m (Fig. 21). Large delicate glassy pteropod shells (*Cavolina* sp.) are sometimes abundant in the deep water silty sands rich in Globigerinidae.

Pellets and oolites

Brown micritic pellets are widespread and in places form the main constituent of the superficial sediments at all depths from the inner shelf to the outer limit of the area sampled in about 300 m of water. In thin section the pellets are usually structureless and heavily stained. They rarely exceed 2 mm in diameter and are

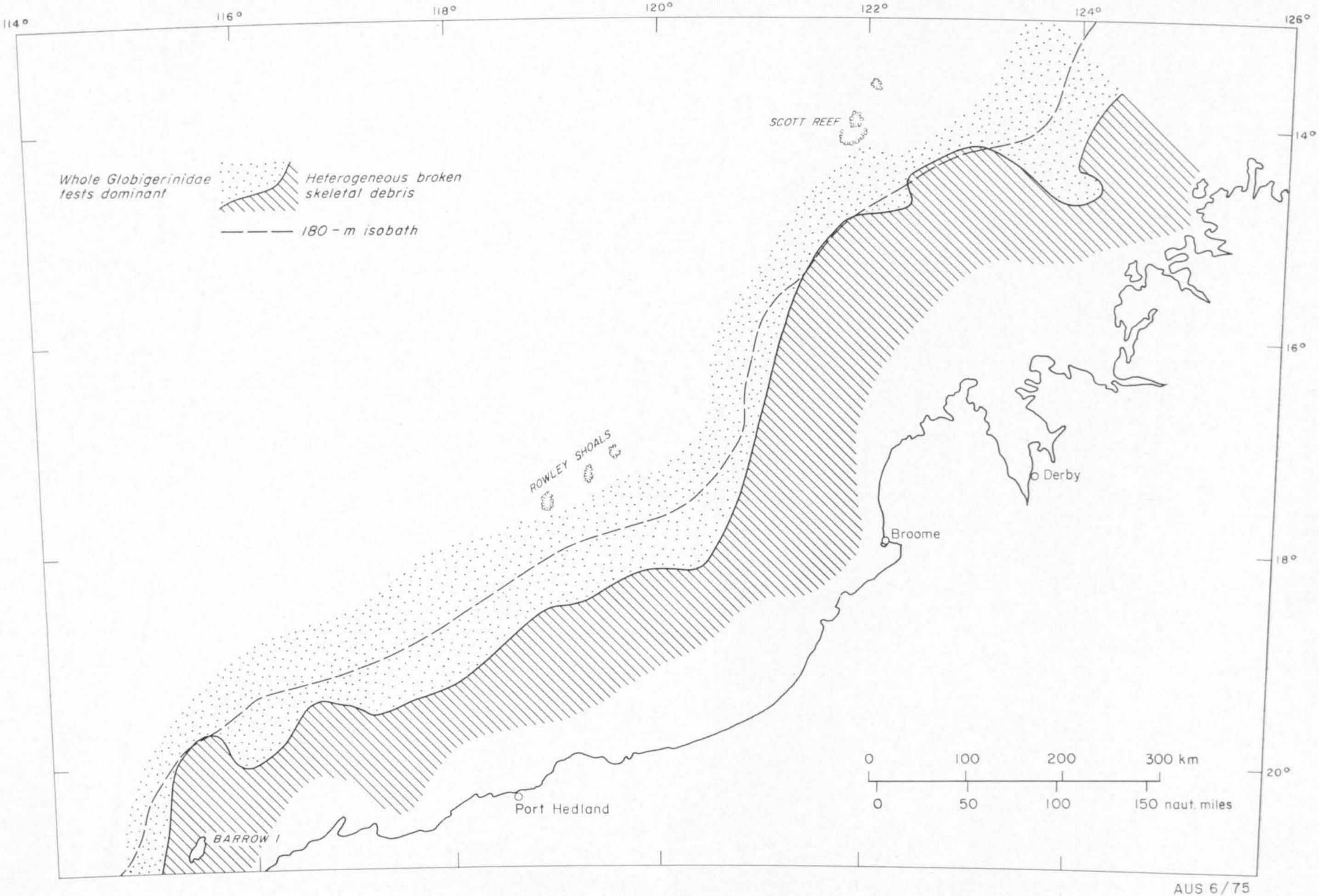

Fig. 21. Regional biofacies of the middle and outer continental shelf.

therefore much smaller than the brown pellets described by van Andel & Veevers (1967) in the Timor Sea, which range from 2 to 8 mm. The latter are restricted to the shallow waters of the middle and inner Sahul Shelf and are believed to have originated in soil profiles formed by subaerial weathering of the calcareous shelf sediments exposed during the last interglacial period.

The pellets of the northwest shelf can be divided on the basis of size and mode of origin into two well defined groups. One consists of small pellets, averaging about 0.1 mm in diameter, which are either of faecal origin or turbid micrite casts of small planktonic Foraminifera (Pl. 3, fig. 2). These are found on the outermost shelf and on the continental slope, and their distribution corresponds closely with that of sediments containing abundant Globigerinidae (Fig. 21). In thin section many of the Foraminifera shells are seen to be filled with turbid micrite, and fracturing or solution of the enveloping shells would release the casts to form the pellets. This is believed to be an important mode of formation of the pellets, but the abundance of burrowing organisms shown in the bottom photographs (Pl. 4, fig. 1; Pl. 5, fig. 1) indicates that faecal pellets must also be important.

The second group consists of much larger pellets, from 0.25 to 2.0 mm, that are most common in the high-energy environment of the middle and inner shelf (Fig. 22). They are associated with coarse skeletal detritus, lithoclasts, and oolites, and commonly occur where current ripple marks are well developed (Pl. 5, fig. 2). Some were formed in the same way as the first group, that is they are casts of shell chambers or faecal material, but most of them appear to be rounded lithoclasts of turbid microcrystalline carbonate with some non-carbonate clay material. Compound fragments, in which previously formed oolites and pellets are embedded, poorly rounded particles, and pellets showing faint indications of laminar structure occur as well as the more abundant subspherical structureless pellets. There seems little doubt that these bodies were formed either by the break-up and reworking of consolidated fine-grained argillaceous carbonate sediments, by concretionary processes within an unconsolidated calcareous mud, and to an unknown extent by the replacement of detrital quartz by carbonate (see p. 50). The presence of compound fragments indicates that more than one cycle of erosion, reworking, and sedimentation has occurred. It does not seem necessary to postulate a period of subaerial weathering to account for the lithification and staining of the fine-grained sediment; heavily stained micrite is abundant in the existing marine environment and abundant evidence of submarine lithification of carbonate is provided by the pavement limestones discussed below.

Oolites commonly occur in the superficial sediments with the large pellets, although sediments with abundant oolites are less widespread than those with abundant pellets. Occasional samples contain 50 to 75 percent oolites (Pl. 6, figs 1, 2). The diameter of the oolites ranges from 0.25 to 0.75 mm. Most of the oolites are cored by pellets of brown structureless micrite, although the nucleus may also consist of skeletal material or quartz grains. All gradations exist between structureless pellets, pellets with a thin oolitic envelope, and oolites consisting entirely of regularly arranged concentric aragonite fibres.

Examination in thin section revealed that the oolitic material has anomalous optical properties, showing low to moderate birefringence and uniaxial or slightly biaxial positive interference figures. The composition of the oolites was confirmed as calcium carbonate by electron probe, and only aragonite and calcite were

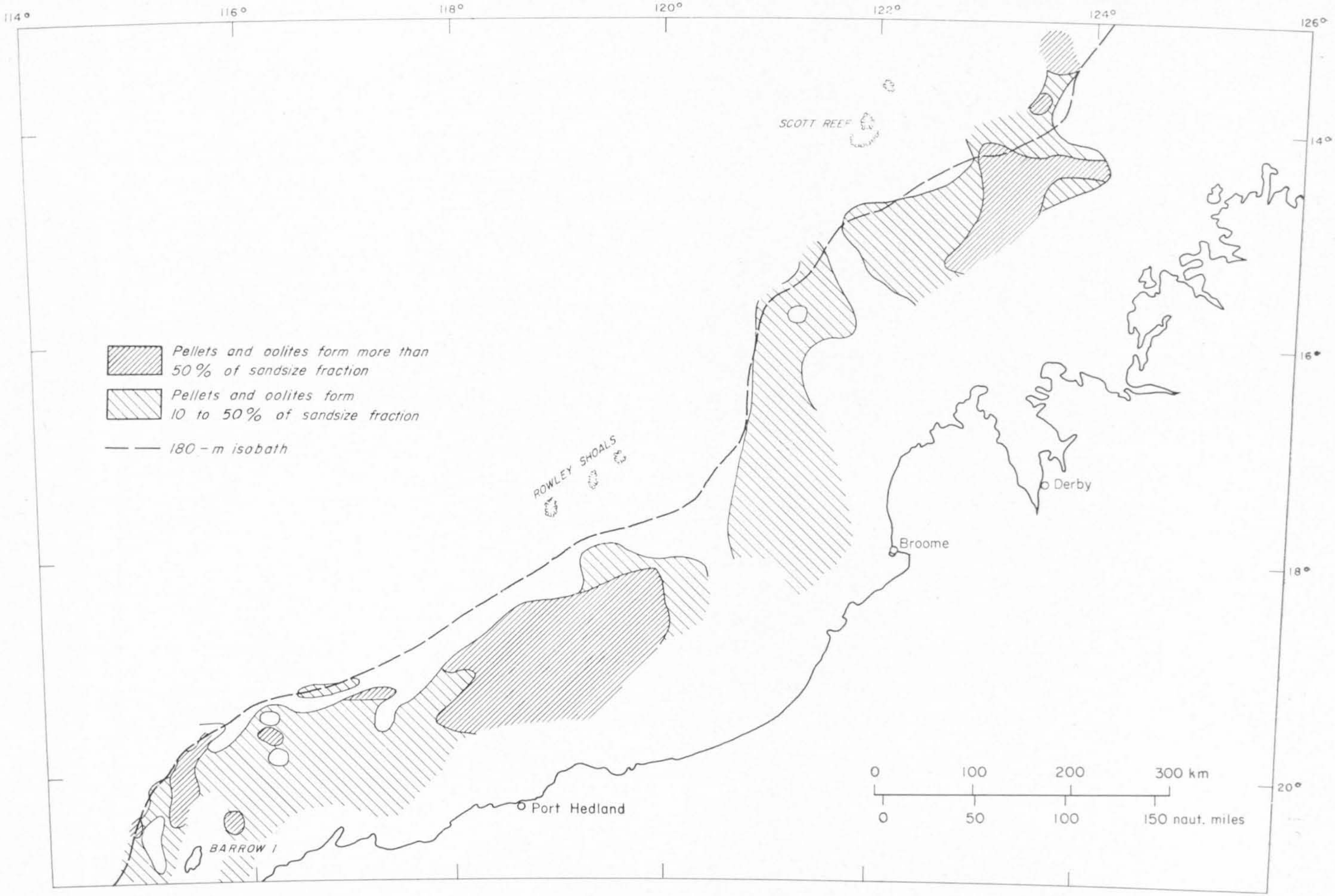

Fig. 22. Distribution of pelletal and oolitic sediments. Dominantly pelagic sediments with small faecal pellets and casts of Globigerinidae are excluded.

identified by X-ray diffraction; both these minerals, of course, have extreme birefringence and are optically negative. Under crossed nicols the oolites show a well defined extinction cross similar to that of spherulitic chalcedony and oolitic chamosite. The radial direction is invariably slow, implying that the *c* axes are orientated tangentially.

Scanning electron microscope photographs show that the aragonite envelope consists of a mat of rods, each about 0.5 microns long and 0.07 microns thick, whose long axes lie in the surface of the oolite shell, but which are randomly disposed when viewed from normal to the surface. The following explanation of the anomalous optical properties based on the aggregate indicatrix to be expected from a mat of crystals arranged in this way has been suggested by R. N. England of the Bureau of Mineral Resources[1].

'If we assume aragonite to be very nearly uniaxial, a submicroscopic aggregate with *c* axes all lying randomly within a horizontal plane will have a large number of indicatrices, all with circular section vertical but otherwise randomly disposed. Grain boundary effects aside, the aggregate will present a resultant indicatrix with a vertical axis equal in length to the *o* ray of each individual indicatrix (about 1.683) and horizontal circular section with radius equal to the average of the *e* and *o* rays of aragonite (1.683 and 1.530, of which there are equal numbers disposed randomly in the horizontal plane). Such an indicatrix is uniaxial positive with half the birefringence of aragonite and its axis normal to the plane containing the *c* axes of the aragonite crystals. Any departure from perfect confinement of the *c* axes to a plane reduces the maximum birefringence and a preferred orientation of *c* axes in any direction within the plane causes the indicatrix to become biaxial. All these effects are observed, but with the added complication that the 'plane' containing the *c* axes is bent into the roughly spherical surface of the oolite.'

Limestone pavement

At 16 stations cemented limestone was brought to the surface by dredging, and at many more stations, where repeated and prolonged dredging resulted in little or no recovery of sediment, the presence of limestone pavement is suspected. The stations where consolidated limestone was proved ranged from shallow water to 282 m depth. Most of the limestone samples consist of platy and nodular rock, brown to grey in colour, consisting of skeletal material rather poorly cemented in a micritic matrix. Pellets, oolites, and terrigenous detritus may be included. Others consist of hard brown oolitic and pelletal limestone, or of white chalky limestone in which only scattered small shell fragments and ghosts of pellets can be resolved under the microscope. Nearly all the samples are covered with encrusting organic material on exposed surfaces, which are usually irregular and cavernous. Chalky varieties are generally riddled with pholad borings which may be filled with unconsolidated muddy sediment.

Further information on the nature and extent of the limestone pavement has come to light as a result of oil exploration drilling and pipeline surveys. Severe anchoring problems caused by limestone pavement were encountered by BOC of Australia Ltd in locating the floating drilling platform *Glomar Tasman* over the Madeleine No. 1, Legendre No. 1, and Dampier No. 1 exploration wells on the

1. BMR Laboratory Rep. 28, 1970 (unpubl.).

shelf about 200 km northeast of Barrow Island (Stroud, 1970). Site investigation by divers at Madeleine No. 1, where the water was 67 m deep, revealed that a hard limestone surface underlay a veneer of sand only 15 to 40 cm thick. Sea-bed coring proved the limestone to be a crust 0.3 to 1.2 m thick resting on unconsolidated sand. A thin layer of sand resting on limestone was also encountered at Dampier No. 1, whereas at Legendre No. 1 flat limestone pavement with only intermittent sand cover formed the sea bed. At neither of the last two sites was the thickness of the limestone bed proved by drilling, but in each case it was sufficiently hard and massive to prevent the heavy mooring anchors from gaining a hold. Laboratory tests showed that the limestone at Madeleine No. 1 had a crushing strength of 400 to 2000 p.s.i., and at Legendre No. 1 1000 to 5000 p.s.i., but petrographic details are not available.

In addition to the well site foundation tests, investigations by divers of sea-floor conditions east of Barrow Island for pipeline installations again proved the existence of limestone pavement. In this region, where the depth of water is generally less than 20 m, a large number of shallow probes met rock under only a very thin veneer of sand.

The available evidence indicates that limestone pavement is widespread on the continental shelf, but in the absence of borehole data its distribution cannot be mapped. At only one station (Stat. 113, depth 282 m), was the pavement visible in an underwater photograph (Pl. 7, fig. 1), but it is likely that at many other stations only a thin cover of unconsolidated sediment is present, as at the Dampier No. 1 and Madeleine No. 1 wells.

The mode of formation of the limestone poses problems which have not been resolved. Most research on carbonate diagenesis at or near the surface stresses the importance of emergence and freshwater leaching, because there appears to be firm laboratory evidence that lithification is inhibited in sea water of ordinary salinity (e.g. see Berner, 1966). The shallow-water limestone pavements could have been lithified during the late Pleistocene marine regression when the continental shelf was exposed, but there is no evidence of a eustatic lowering of sea level to —282 m where the deepest limestone occurrence was recorded, nor is there any evidence of structural influences. This rock is an oolitic limestone consisting of brown micrite pellets, some of which are surrounded by aragonite envelopes radially or concentrically arranged, aragonitic and calcitic shell fragments, and rare quartz grains set in a matrix of turbid micrite. X-ray diffraction patterns reveal aragonite and calcite only. The possibility that it is derived from the pre-Quaternary succession exposed by erosion on the upper slope must be considered; unfortunately there are no useful seismic data in the area and the Foraminifera in the rocks are not age-diagnostic. However, the local topography as revealed by echosounder profiles and underwater photography is not suggestive of erosion and a radiocarbon age determination on the material gave a date of $30\,850 \pm 1200$ years[1]. Modern contamination of the sample dated is not suspected and very little recrystallization of aragonite to calcite has occurred. According to Polach, Chappell, & Lovering (1969), less than 3 percent recrystallization does not affect the radiocarbon date significantly. Unless this date is grossly erroneous, which appears unlikely, the limestone was formed during the interstadial period of high sea level preceding the end-Pleistocene glacial maximum; this would rule out emergence resulting from eustatic lowering of sea level, even if movement of the magnitude required was feasible.

The available evidence suggests, therefore, that the limestone pavement was formed in the marine environment, at least in the case of the deep water occurrences, and possibly on the continental shelf also. Despite the laboratory evidence to the contrary, lithification of carbonate sediments without emergence and without deep burial is probably common in the geological record. Bathurst (1966) and Zankl (1969) have reviewed the evidence and cite the rarity of compaction structures in lime muds, the presence of intraformational breccias, and the occurrence in ancient non-reefal sequences of corals believed to be restricted to growing on hard surfaces, in support of lithification of the sea bed. Among modern sediments Taft (1967) has recorded lithification of carbonate material under a thin veneer of grapestone sediment in the Bahamas, and contemporaneous cementation of shallow-water carbonate sediments in the Persian Gulf has been fully documented by Shinn (1969). Submarine lithification of Recent shelf carbonates has also been described by Mabesoone (1971) off tropical Brazil in water depths down to —140 m; Mabesoone also describes a single example of a lithified foraminiferal calcarenite from a depth of 370 m.

Terrigenous material and glauconite

Quartz makes up the bulk of the terrigenous component of the sediments, with variable amounts of clay minerals (mainly illite, montmorillonite, and glauconite), and traces of feldspar, muscovite, ferromagnesian, and accessory minerals. The heavy minerals are described separately below.

Provenance studies on marine sediments have been successfully carried out using variations in detrital quartz. Moore (1968), for example, indicated sediment dispersal patterns in Cardigan Bay, Wales, based on 16 varieties of quartz distinguished by type of extinction and nature of inclusions. Although the quartz in the Northwest Shelf sediments exhibits considerable variation in roundness and amount of solution, as well as in optical properties, no significant regional trends in the frequency of these characteristics are apparent. Replacement of quartz by carbonate is often evident in thin section and there is some evidence to suggest that the loss of silica in this way may be considerable. Early stages of this replacement are revealed by embayment of the quartz grain boundaries and by infiltration of carbonate along fractures (Pl. 7, fig. 2). The ghost outlines of the original grain are not preserved, and advanced stages of replacement are generally difficult to identify. Occasionally, however, isolated remnants of optically continuous quartz enclosed in turbid micrite pellets provide evidence of almost complete replacement of detrital grains (Pl. 8). Advanced replacement of this sort has only been observed in pelletal sediments, and there can be no doubt that at least some of the micrite pellets and aragonitic oolites result from the centripetal replacement of silica by carbonate. An interesting feature of these pelletal sediments is the occurrence of fresh quartz grains showing no evidence of solution or replacement by carbonate side by side with others that have undergone varying degrees of alteration up to almost complete replacement. Clearly these detrital grains have had different histories and whereas some have been recently shed from the continent, others have been exposed to solution and replacement on the continental shelf for a very long period of time. I know of no examples of similar rocks among ancient sediments.

1 Radiocarbon age determination by H. A. Polach, Dep. Geophysics and Geochemistry, Aust. Nat. Univ.; ref. ANU 749.

Glauconite is the only clay mineral recognizable in thin sections of the shelf sediments of which it is a widespread but minor constituent. It forms pellets, which can often be identified as casts of planktonic Foraminifera, and fills chambers in a wide variety of skeletal detritus. The glauconite ranges from bright green to yellowish green. There is some evidence from ancient sediments that the colour of glauconite, whether dark green, yellow-green, or greenish yellow, is related to the depth of water in the environment of formation (see the discussion in Teodorovich, 1961, p. 34). However, the data are conflicting. No correlation between water depth and colour of the mineral is evident on the Northwest Shelf.

Much of the glauconite is more or less degraded to a faintly birefringent greenish yellow clay which is commonly difficult or impossible to distinguish optically from impure phosphatic clay or ferruginous clay derived from the land. Presumably glauconitization is a two-way process, and there seems to be no way of telling whether this impure greenish material represents a stage in the formation of glauconite or a stage in the alteration of previously existing glauconite.

The glauconite content of the sediments ranges up to a few percent only. The mineral is irregularly distributed over all the area sampled, from the shallowest to the deepest stations, and is by no means confined to non-depositional regions. The distribution shows no recognizable trends; it is largely absent from the shelf and upper slope between longitudes 115°E and 116°E, north of the Monte Bello Islands, but is relatively abundant on the shelf to the west of Barrow Island. The highest concentrations tend to occur close to the edge of the shelf, but there is no positive correlation between the glauconitic and phosphatic sediments.

No exhaustive examination of other clay minerals present in the sediments was undertaken. X-ray diffraction analyses of 55 unorientated samples revealed clay patterns in 16 cases. Ten of these were again X-rayed after glycolation and two-stage heating. Montmorillonite, illite, and vermiculite were present in most cases, and montmorillonite appears to be the dominant clay material. Kaolinite is restricted to samples collected on the narrow shelf west and northwest of Barrow Island.

Heavy minerals

The proportion of terrigenous material in the sand-size fraction of the sediments is almost everywhere extremely low, and difficulty was often experienced in separating enough heavy minerals for determination of species distribution. The heavy mineral fraction never exceeds 0.1 percent of the total sediment. Grain counts were carried out on 65 samples (Table 2). In the translucent fraction zircon, epidote (including zoisite and clinozoisite), and amphiboles are dominant, with varying contributions from tourmaline and garnet. The 'others' group, which rarely exceeds 15 percent of the total translucent fraction, includes pyroxene, kyanite, staurolite, andalusite, apatite, sphene, monazite, and rutile. Only rare grains of rutile were noted, except at Stations 261 and 265 where 4 percent of the total heavy mineral fraction consists of this mineral.

Zircon, amphiboles, and particularly epidote and clinozoisite, are abundant over the whole Northwest Shelf. Garnet, pyroxene, and the various metamorphic and resistant accessory minerals included in the miscellaneous group, are somewhat sparsely and irregularly distributed, but again no regional trends in the abundance of individual species can be detected. Tourmaline, however, is virtually confined to the area east of longitude 120°30′E (Fig. 23), and although there is no evidence of increasing abundance of this mineral to the northeast, its distribution serves to separate the Fitzroy-Kimberley province in the north from the Canning-Pilbara province in the south.

Hornblende and epidote are relatively unstable and are placed low in order of persistence relative to zircon, garnet, tourmaline, apatite, and other species (Pettijohn, 1941). Neither mineral was recorded in some 45 Canning Basin sedimentary rocks examined by Johnson & Dallwitz (1961), although zircon, tourmaline, and other persistent accessory minerals were frequently noted. The abundance of amphiboles and epidotes in the shelf sediments throughout the area therefore suggests that the igneous and metamorphic rocks flanking the Canning Basin make an important contribution to the terrigenous component of the shelf sediments; similarly, the absence of tourmaline from the area west of longitude 120°30′E indicates that Canning Basin rocks do not contribute significantly to the shelf sediments of that region. In fact, there are no important streams draining the Canning Basin hinterland south of the Fitzroy River and only material derived by shoreline erosion of the coastal Cainozoic sediments reach the continental shelf. If these coastal rocks contain tourmaline, it would seem that sediment shed from them must have a near-shore northeasterly drift to contribute to the tourmaline-bearing sediments off the Dampier Peninsula and the Kimberley Block. The Fitzroy-Kimberley heavy mineral province, however, does not closely resemble the assemblages described by von der Borch (1965) from the Bonaparte Gulf on the northern flank of the Kimberley Block. The Ord River Province is dominated by amphiboles (about 60%), with epidote (about 15%), and approximately equal amounts of tourmaline and hypersthene (8% each). Zircon averages only 2 percent, compared with 14 percent in the Fitzroy-Kimberley province.

TABLE 2. HEAVY MINERAL CONTENT BASED ON COUNTS OF 100 GRAINS

Sample	Opaques*	Tourmaline+	Zircon+	Amphibole+	Epidote+	Garnet+	Others+
118	50	20	20	—	60	—	—
121	35	30	10	30	30	—	—
124	60	25	20	—	50	—	5
136	60	20	5	30	42	—	3
139	65	5	10	—	85	—	—
141	50	37	60	—	—	—	3
145	50	10	20	30	40	—	—
152	50	20	25	10	40	—	5
154	30	20	5	24	30	6	15
155	40	16	5	35	30	4	10
156	50	20	10	25	30	10	5
158	30	20	3	35	30	7	5
168	50	—	60	10	30	—	—
170	50	20	50	—	20	—	10
173	50	20	10	33	33	4	—
178	60	12	7	40	30	11	—
183	50	6	16	18	50	4	6
184	35	15	—	40	40	—	5
189	25	9	7	44	35	—	5
197	40	8	—	46	37	3	6
199	35	6	10	32	32	14	6
200	35	7	—	50	25	—	18

* % of total heavy fraction
+ % of translucent fraction

TABLE 2 (cont.)

Sample	Opaques*	Tourmaline+	Zircon+	Amphibole+	Epidote+	Garnet+	Others+
203	35	14	7	30	46	3	—
210	30	14	—	50	30	3	3
215	50	20	4	34	36	4	2
217	60	5	10	25	50	10	—
225	60	10	—	25	62	—	3
229	40	30	3	16	40	8	3
234	50	20	46	10	24	—	—
241	20	5	—	50	30	10	5
249	40	15	42	8	35	—	—
254	70	25	—	15	40	10	10
261	50	5	60	10	5	5	15
265	50	—	56	20	16	4	4
275	35	16	8	32	44	—	—
551	60	—	62	—	25	13	—
558	40	—	50	8	42	—	—
560	25	—	—	27	60	6	7
566	50	—	95	—	—	—	5
583	50	—	60	12	23	—	5
591	50	—	—	25	70	—	5
600	30	7	3	40	45	—	5
602	30	4	50	17	29	—	—
605	50	—	—	50	50	—	—
606	50	10	38	24	24	4	—
611	33	—	—	55	40	—	5
627	50	—	16	36	44	—	4
634	60	—	12	42	42	4	—
641	30	7	—	35	50	8	—
647	70	—	7	—	85	3	5
649	35	—	8	38	45	9	—
651	50	—	20	20	60	—	—
657	20	—	38	20	34	8	—
672	60	—	25	37	37	—	1
675	10	6	6	28	32	22	6
677	35	—	35	20	40	—	5
678	60	—	12	—	75	13	—
691	25	—	16	44	32	8	—
697	20	—	70	—	25	—	5
715	30	—	70	—	22	8	—
722	50	—	—	38	53	6	3
728	20	—	18	38	26	14	4
730	20	—	—	44	44	6	6
733	60	—	25	—	75	—	—
736	20	—	46	14	40	—	—

* % of total heavy fraction
\+ % of translucent fraction

Phosphate

The major deposits of marine phosphorites known in the world occur along the western margins of continents and are associated with eastern boundary currents, upwelling, and areas of high biological productivity. Although the available evidence suggests that any upwelling present along the northwest Australian continental margin is on a very moderate scale, the low rate of supply of terrigenous material and the tectonic stability of the region are favourable for the occurrence of phosphate, and these factors to a large extent influenced the selection of the Northwest Shelf as the area for study. However, no nodular phosphorites were

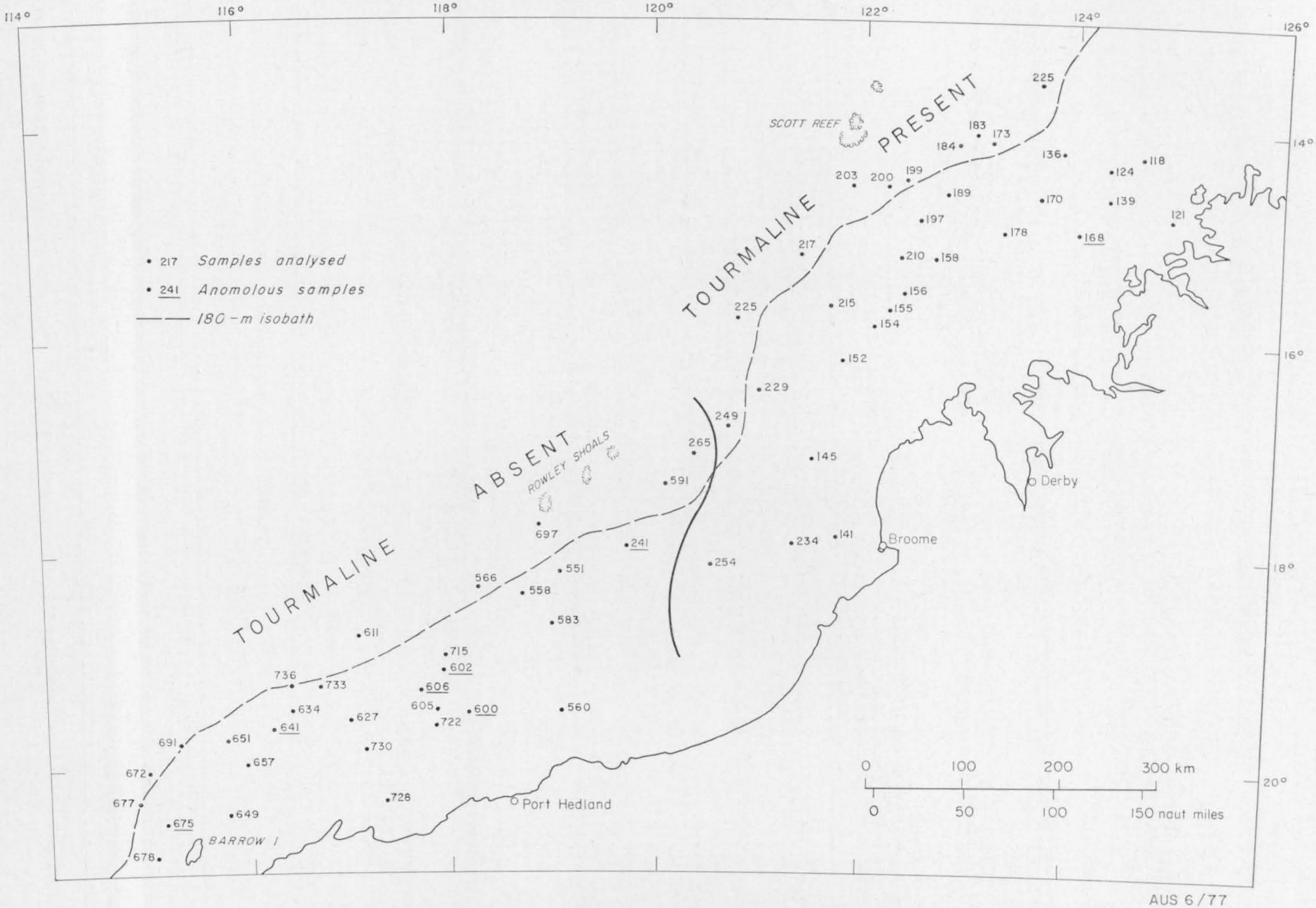

Fig. 23. Distribution of heavy minerals based on analyses of 65 samples.

Fig. 24. Phosphate content of surface sediments.

recovered in the areas sampled, and although relative enrichment with phosphorus occurs over wide areas, particularly close to the edge of the shelf, no material remotely approaching economic grade was found.

All samples were analysed for P_2O_5 (see Appendix 3) and the 0.2 and 1.0 percent isochems are plotted in Figure 24. Ten samples assayed more than 1 percent P_2O_5 (maximum value 3.6%) and nine of these occur in two areas just seaward of the edge of the shelf east of Scott Reef and southeast of the Rowley Shoals respectively. Duplicate analyses were done in most cases on the coarse (+2 mm) and fine fractions; higher values were usually, but not invariably, obtained on the coarser material. In thin section collophane is recognizable, but is often not easy to distinguish from yellow-brown degraded glauconite which it closely resembles. It is always intimately associated with biogenic detritus, and appears to fill cavities and not to replace shell fabric; this does not necessarily indicate that the collophane was formed by direct precipitation, because such cavities could well have originally contained lime mud.

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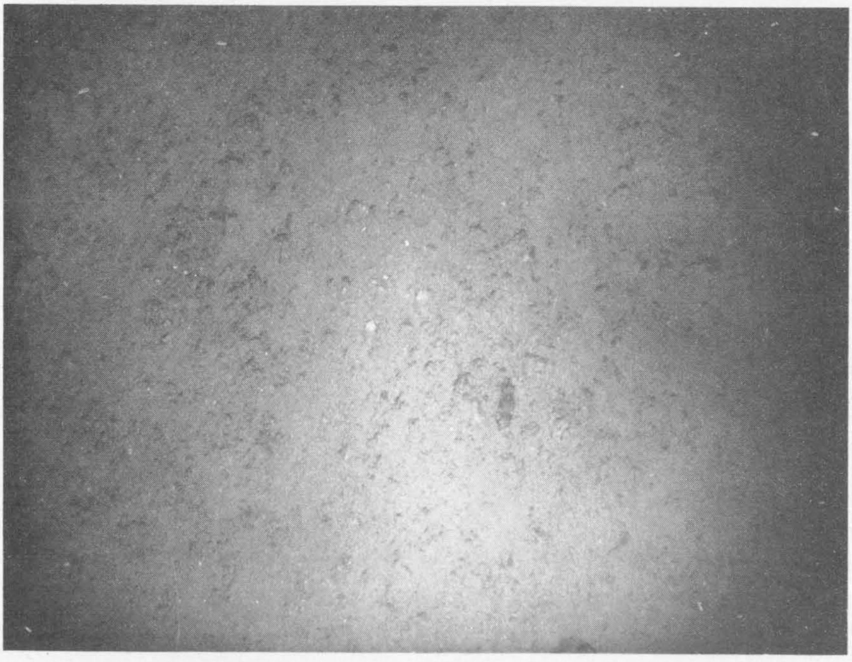
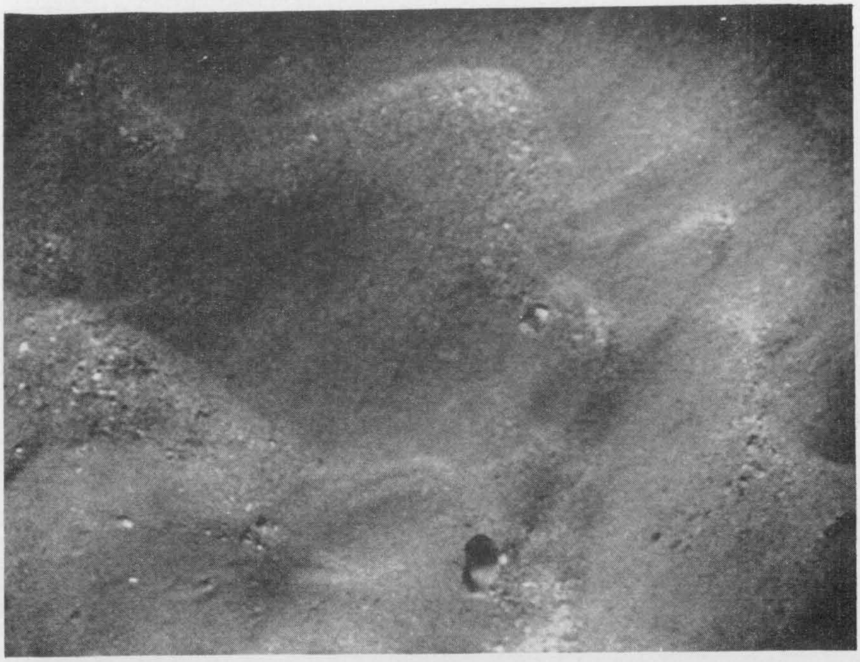
PLATE 1

Pl. 1, fig. 1. Station 232, depth 95 m. Flat sea floor consisting mainly of coarse relict broken shells. The fine fraction is brown oolite. No burrowing activity is visible. Field of view 4.5 m².



Pl. 1, fig. 2. Station 706, depth 88 m. Flat sea floor consisting of muddy sediment with some coarse relict broken shells and worm casts (?). Field of view 4 m².

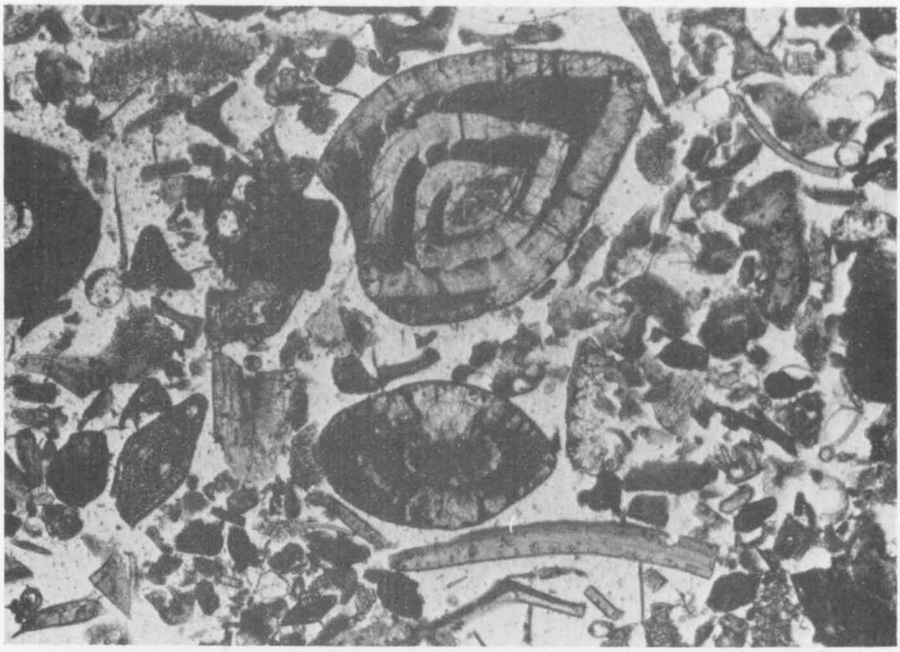
PLATE 2



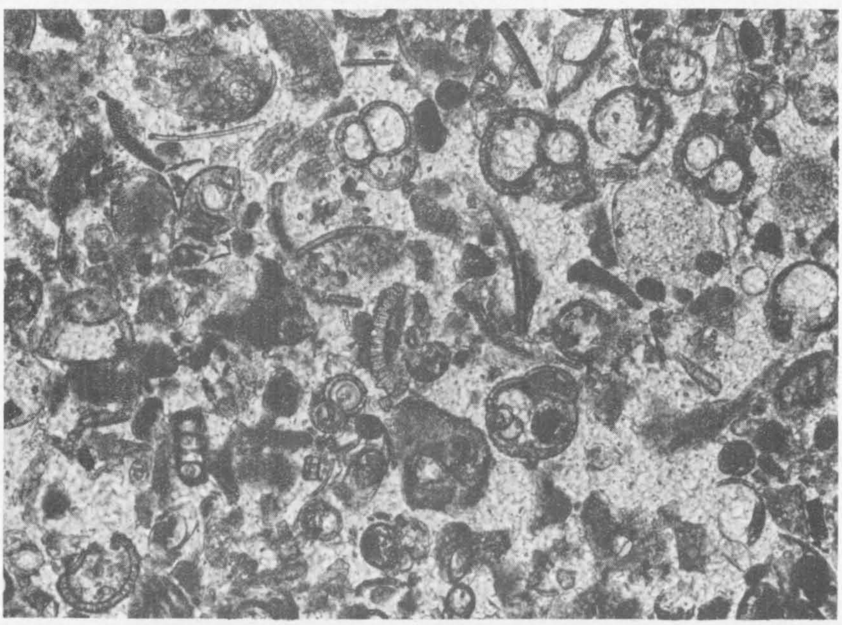
Pl. 2, fig. 1. Station 706, depth 88 m. Strongly ripple-marked shelly oolite. This photograph was taken a few metres distant from the area shown in Plate 1, figure 2. Field of view 0.3 m^2.

Pl. 2, fig. 2. Station 546, depth 289 m. Flat sea floor of muddy sediment overlain by a narrow train of ripple-marked sand. Current lineations on the mud (lower left) are inclined at an angle of 10° to the current direction indicated by the sand ripples. Field of view is 4 m^2.

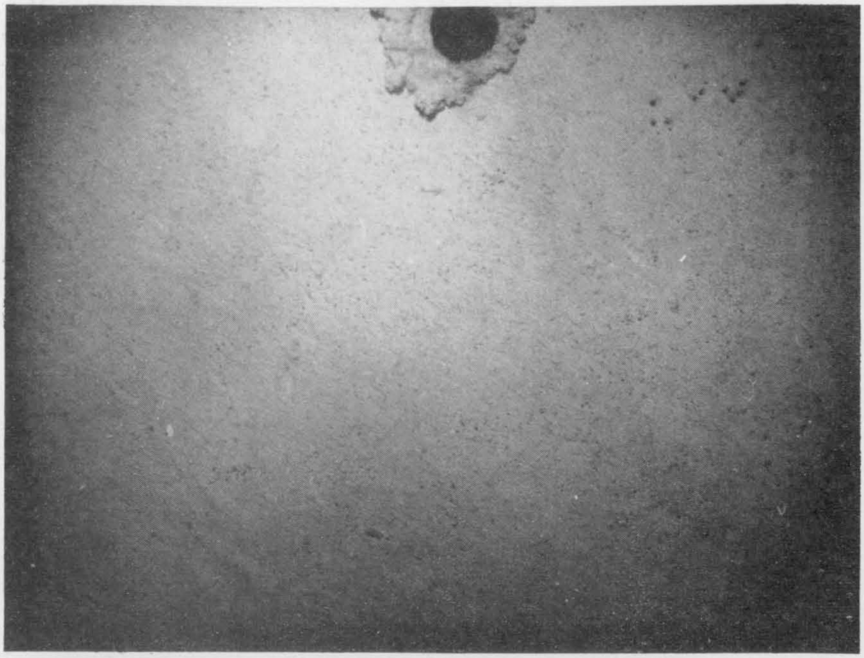
PLATE 3



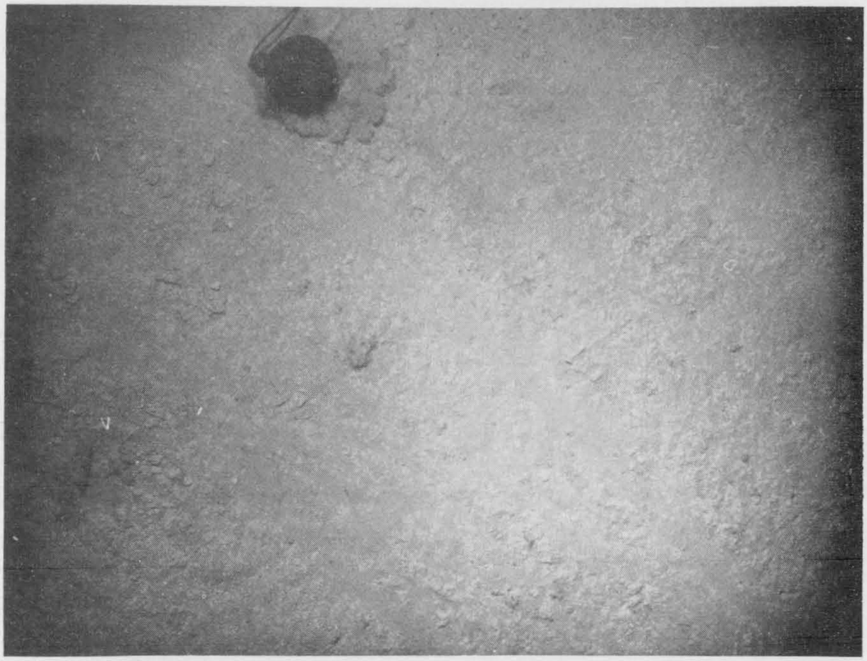
Pl. 3, fig. 1. Coarse-grained calcarenite. Chambers of benthic Foraminifera (Amphisteginidae and Elphidiidae) are filled with dark brown, almost opaque, micrite. No. 600. Ordinary light, x 40.



Pl. 3, fig. 2. Muddy foraminiferal calcarenite. Globigerinidae form most of the sand-size fraction, which includes pteropod fragments and small pellets of opaque micrite (faecal pellets and casts of Foraminifera chambers). Silt and clay-size slightly turbid micrite forms about 35 percent of the sediment; it is thinly dispersed in the mounting medium and also forms clots. No. 656. Ordinary light, x 50.



Pl. 4, fig. 1. Station 725, depth 124 m. Flat sea floor of foraminiferal sand closely pitted by burrowing organisms. A faint current lineation from lower right to upper left is visible. Field of view 3.5 m^2.

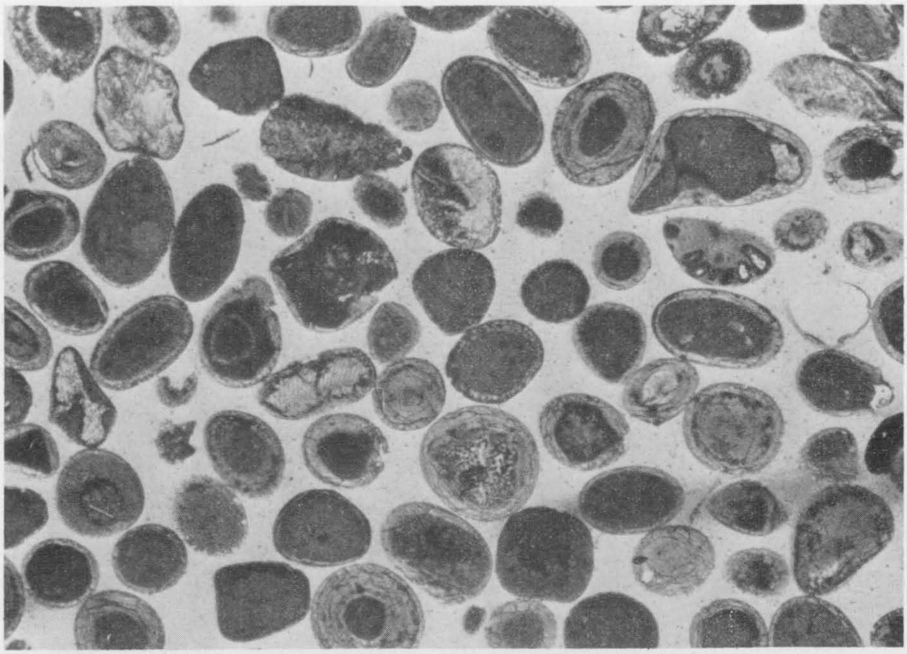


Pl. 4, fig. 2. Station 726, depth 227 m. Flat sea floor consisting of mud with a very thin discontinuous superficial veneer of foraminiferal sand. Current lineation from upper left to lower right is visible. Field of view 3.5 m^2.

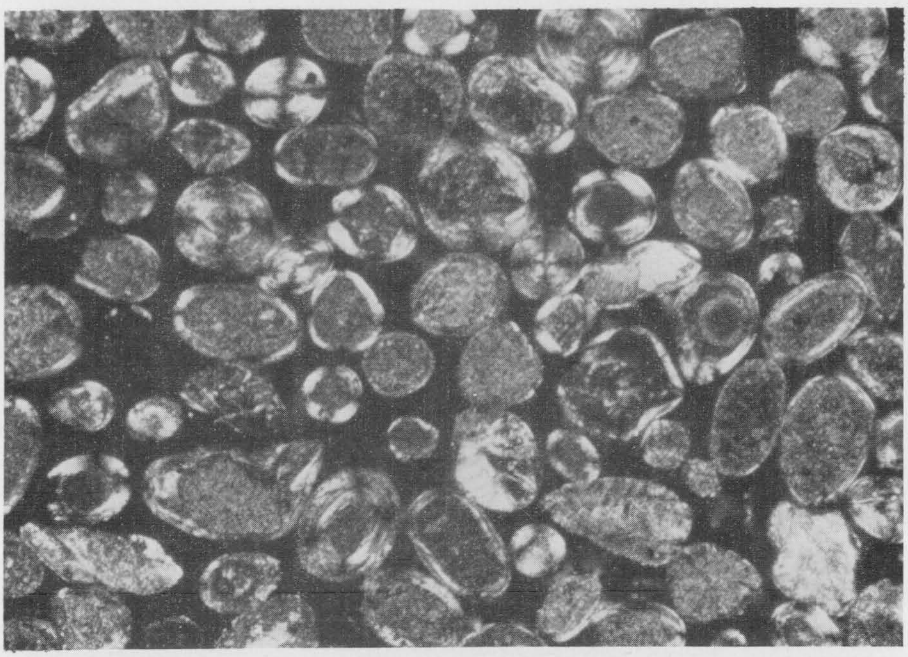
PLATE 5

Pl. 5, fig. 1. Station 702, depth 293 m. Ripple-marked foraminiferal very sandy mud. Current from lower right to upper left. Some pitting by burrowing organisms is visible. Field of view 3.5 m^2.

Pl. 5, fig. 2. Station 724, depth 82 m. Ripple-marked oolitic calcarenite. The small-scale linguoid ripples are densely pitted locally by burrowing organisms. Current from upper right to lower left. Field of view 3.5 m^2.



Pl. 6, fig. 1. Medium-grained pelletal oolite. Well sorted oolitic grains, with nuclei consisting of shell fragments or turbid micrite pellets, predominate. No. 670. Ordinary light, x 40.



Pl. 6, fig. 2. Same field of view as shown in Plate 6, figure 1, but with crossed nicols. The tangential orientation of the aragonitic oolitic envelopes results in extinction crosses.

PLATE 7

Pl. 7, fig. 1. Station 113, depth 282 m. Irregular pavement of oolitic limestone with a thin discontinuous veneer of loose sediment, and a few relict shells. Field of view 1.5 m^2.

Pl. 7, fig. 2. Quartz grain with thin oolitic envelope (long diameter 0.5 mm) showing an early stage in the replacement of silica by carbonate. No. 132. Ordinary light, x 200.

PLATE 8

Pl. 8. Medium to coarse-grained pelletal oolite. The quartz grain forming the nucleus of the oolite in the upper right quadrant shows extensive replacement by turbid micritic carbonate. No. 181. Ordinary light, x 100.

APPENDIX 1

RECENT FORAMINIFERA FROM THE NORTHWEST SHELF

by

A. D. Albani[1] and R. Geijskes

INTRODUCTION

A cut of all marine sediments collected by the Bureau of Mineral Resources on the Northwest Shelf was preserved for microfaunal studies. This account of the living Foraminifera is based on material collected in 1967 in the northern part of the area.

General accounts of Foraminifera of both the Indian Ocean and West Pacific have been published by various authors, but to our knowledge no published research has dealt in detail with the microfauna of the northwest Australian continental shelf.

The area sampled is situated on the middle and outer continental shelf and uppermost continental slope between latitudes 13°30'S and 18°30'S (Fig. A). Although morphological details are scarce, it is known that a number of gullies and a few deep channels run across it. In many places strong bottom currents have been detected, and well defined scattering layers were noted in a number of places seaward of the shelf edge.

Most of the area is covered by unconsolidated sediments of unknown thickness, ranging in composition from soft green silty clay to reasonably well sorted calcareous arenites. A remarkable feature was the relative scarcity of molluscs larger than 1 cm greatest dimension throughout the region.

A small grab or a dredge was used in obtaining bottom samples at each station. As a preservative 95 percent alcohol was used; this gave satisfactory results when added to the wet sample in the ratio of 1 volume of preservative to 2 volumes of sample. To stain the live Foraminifera 0.25 ml Rose of Bengal per litre was added to the alcohol. The samples were kept cooled during storage.

The material was prepared for microscopical examination by washing 8 cm^3 of wet material through a set of sieves with mesh openings of 0.422, 0.251, 0.152, and 0.076 mm (BSS Nos 36, 60, 100, 200). The four fractions thus obtained were examined while wet and all live Foraminifera picked.

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[1] University of New South Wales

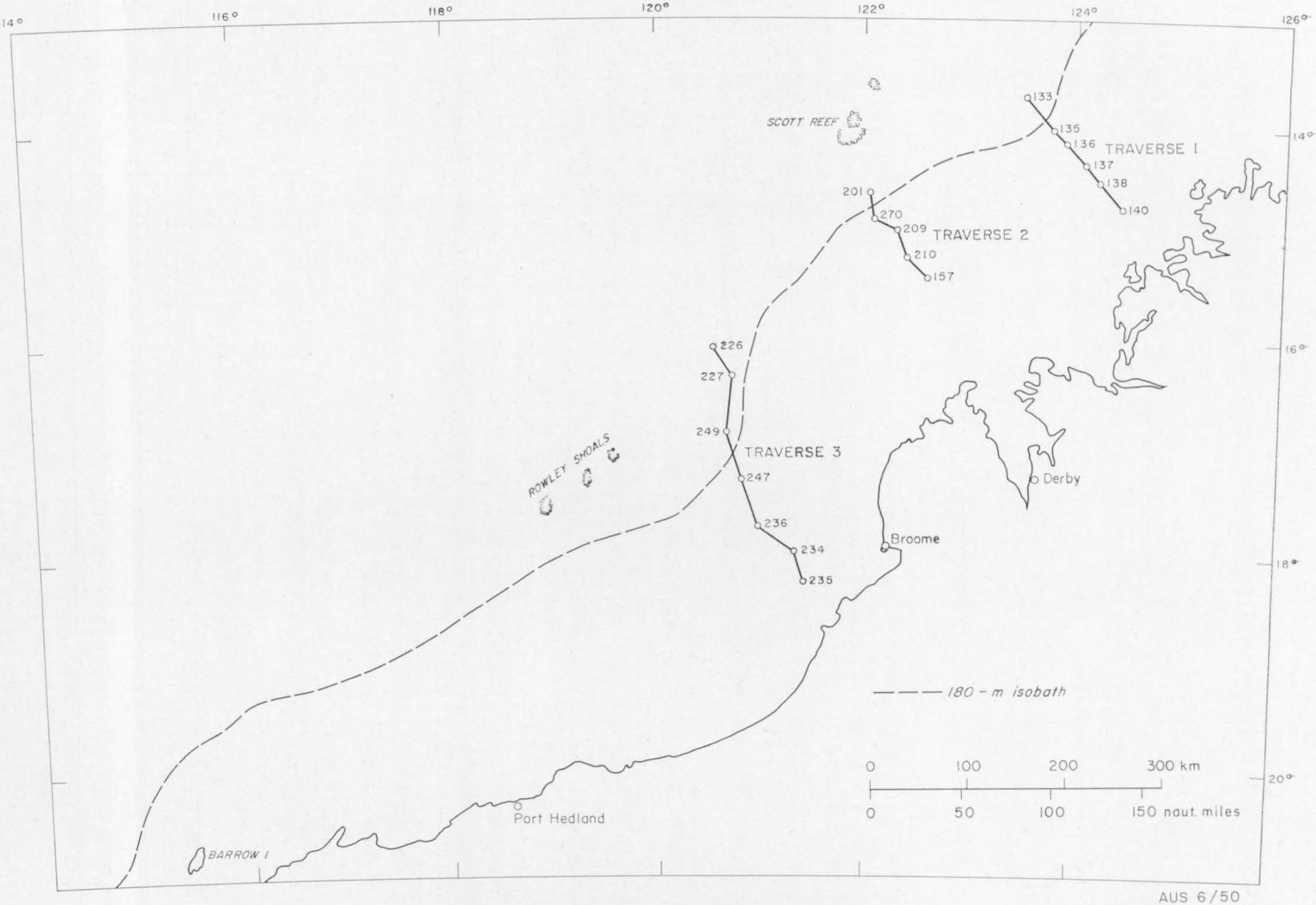

Fig. A. Location of traverses and sample stations.

DISTRIBUTION OF FORAMINIFERA

Samples from 18 stations situated along three traverses aligned approximately at right angles to the continental margin were examined. In all, 101 living species have been identified. The percentages in which they occur at each station are given in Table A, from which Figures B to D were compiled. Only significant genera have been used, and in a few instances single species are considered. Only a general picture can be obtained in this way, but the poor knowledge of the bottom topography and the hydrological conditions would in any case make a more detailed analysis difficult. The impossibility of repeating the sampling at regular time intervals prevented any studies of seasonal fluctuations.

However, some conclusions can be drawn from Figures B to D. Along all three traverses the arenaceous forms are most abundant in shallow and deep water, showing moderate numbers in between. The genera *Textularia* and *Reophax* are among the most common, the first in shallow waters (less than 150 m), the latter in deeper parts (over 250 m); the abundance of *Reophax* at Station 138 (90 m) may be due to local anomalous conditions.

An interesting situation appears to exist along Traverse 2 at the edge of the shelf (Station 209, 95 m), where the arenaceous forms are exceptionally abundant. This suggests a local absence or substantial decrease in bottom currents. A similar situation has been found at shallower depths along the continental shelf off eastern Australia (Albani, 1970).

The calcareous porcellaneous forms are, as elsewhere, typical of shallow water. *Quinqueloculina seminula* and *Q. pseudoreticulata* are among the dominant species.

The distribution of calcareous hyaline forms does not follow a simple pattern. It is interesting, however, to note how small differences in ecological parameters caused a marked shift in the distribution of many genera. The genus *Cibicides* is particularly abundant between 100 and 300 m, while *Hoeglundina* and *Lenticulina* are found at slightly greater depths (150-350 m). *Brizalina*, and especially *Siphonina reticulata*, seem to prefer deeper waters still, and are most abundant in depths exceeding 300 m. On the other hand *Rosalina bertheloti* is restricted to waters shallower than 150 m, and in all three traverses is most abundant at a depth of about 75 m.

More data are necessary to allow a full ecological interpretation to be made. In particular the lack of information on temperature ranges, salinity, and, most important, bottom currents prevents the drawing of definite conclusions. Nevertheless, the present preliminary survey has shown a constant and definite pattern in foraminiferal distribution, which, when related to information on sediment distribution and bottom topography, will certainly prove to be of great value for further studies.

TABLE A: DISTRIBUTION OF LIVING FORAMINIFERA

	TRAVERSE 1						TRAVERSE 2					TRAVERSE 3							
Station	133	135	136	137	138	140	201	270	209	210	157	226	227	249	247	236	234	235	
Total population	40	54	57	66	115	83	31	351	110	86	97	104	50	131	193	165	190	267	
Number/% of total population	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	
Suborder TEXTULARIINA																			
1 *Technitella legumen* Norman, 1878					1/0·9	5/6·0			5/4·6	3/3·5		8/1·8							1
2 *Ammodiscus incertus* (d'Orbigny, 1839)			1/1·8						3/2·7										2
3 *Reophax compressus* (Cushman & McCulloch, 1939)							2/6·5			1/1·2				2/1·5				6/2·3	3
4 *Reophax cylindricus* Brady, 1884	2/5·0																		4
5 *Reophax dentaliniformis* Brady, 1881					4/3·5							17/16·2	1/2·0	5/3·8					5
6 *Reophax horridus* Cushman, 1912												2/1·9							6
7 *Reophax scorpiurus* Montfort, 1808							5/16·0	10/2·9	1/0·9	2/2·3	7/7·3				8/4·2	7/4·3		9/3·4	7
8 *Reophax scorpiurus testacea* Wiesner, 1931		1/1·8	4/7·0	3/4·6	17/14·8	6/7·2	1/3·2	1/0·3	4/3·6		4/4·1	11/10·8		2/1·5	9/4·7	8/4·8	26/13·6	20/7·5	8
9 *Reophax spiculifer* Brady, 1879												1/0·9							9
10 *Haplophragmoides canariensis* (d'Orbigny, 1839)				2/3·0				9/2·6				3/2·9	1/2·0	2/1·5	2/1·0	9/5·5	1/0·5	4/1·5	10
11 *Textularia candeiana* d'Orbigny, 1839	2/5·0		1/1·8			1/1·2				1/1·2	2/2·0						7/3·7	6/2·3	11
12 *Textularia conica* d'Orbigny, 1839				2/3·0															12
13 *Textularia foliacea* Heron-Allen & Earland, 1915						7/8·4									2/1·0	2/1·2	12/6·3	23/8·5	13
14 *Textularia gramen* d'Orbigny, 1846	2/5·0										2/2·0	1/0·9		2/1·5	2/1·0			4/1·5	14
15 *Textularia pseudocarinata* Cushman, 1921		1/1·8		4/6·1	4/3·5	4/4·8						2/1·9		3/2·3	5/2·6	9/5·5			15
16 *Textularia ramosa* Lalicker & McCulloch, 1940		2/3·7	1/1·8		1/0·9			4/1·1					1/2·0	1/0·8	1/0·5				16
17 *Textularia siphonifera* Brady, 1881									5/4·6	1/1·2	2/2·0				4/2·1	3/1·8			17
18 *Textularia* sp.						5/6·0				1/1·2	2/2·0					1/0·6	2/1·0	3/1·1	18
19 *Trochammina inflata* (Montagu)										1/1·2									19
20 *Rotaliammina mayori* Cushman, 1924								26/7·4	17/15·4	10/11·6			1/2·0	2/1·5	6/3·1	6/3·7	31/16·5	15/5·6	20
21 *Tritaxis conica* (Parker & Jones, 1865)												1/0·9							21
22 *Gaudryina paupercula* Cushman, 1911													2/4·0						22
23 *Gaudryina quadrangularis* Bagg, 1908																	2/1·0		23
24 *Gaudryina transversaria* (Brady, 1884)				3/4·6	4/3·5			15/4·3	12/11·0	1/1·2	2/2·0				2/1·0	12/7·3	2/1·0	6/2·3	24
25 *Dorothia arenata* Cushman, 1936				1/1·5															25
26 *Clavulina pacifica* Cushman, 1924					2/1·8	5/6·0					3/3·1				1/0·5				26
27 *Cylindroclavulina bradyi* (Cushman, 1911)															1/0·5				27
Suborder MILIOLINA																			
28 *Spiroloculina communis* Cushman & Todd, 1944			1/1·8		3/2·6	4/4·8				1/1·2	1/1·0					5/3·0	2/1·0	8/3·0	28
29 *Spiroloculina disparilis* Terquem, 1878										5/5·7									29
30 *Quinqueloculina agglutinans* d'Orbigny, 1839																	2/1·0	19/7·2	30
31 *Quinqueloculina anguina arenata* Said, 1949				1/1·5		7/8·4												10/3·7	31
32 *Quinqueloculina lamarckiana* d'Orbigny, 1839		2/3·7		4/6·1	8/7·0	5/6·0		2/0·6		5/5·7	13/13·5				12/6·5	2/1·2	11/5·3	20/7·5	32
33 *Quinqueloculina pseudoreticulata* Parr, 1941				2/3·0	5/4·4	7/8·4		4/1·1	2/1·8	2/2·3	6/6·2				7/3·8	3/1·8	12/6·3	13/5·0	33
34 *Quinqueloculina seminula* (Linné, 1767)								3/0·9	1/0·9							5/3·0			34
35 *Flintina triquetra* (Brady, 1879)			1/1·8																35
36 *Pyrgo sarsii* (Schlumberger, 1881)		1/1·8											2/1·0						36
37 *Sigmoilopsis schlumbergeri* (Silvestri, 1904)		3/5·5		2/3·0											2/1·0				37
38 *Triloculina rupertiana* (Brady, 1879)						1/1·2												1/0·3	38
39 *Triloculina tricarinata* d'Orbigny, 1826			1/1·8													3/1·8			39

TABLE A (Cont.)

	TRAVERSE 1						TRAVERSE 2					TRAVERSE 3							
Station	133	135	136	137	138	140	201	270	209	210	157	226	227	249	247	236	234	235	
Total population	40	54	57	66	115	83	31	351	110	86	97	104	50	131	193	165	190	267	
Number/% of total population	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	
40 *Miliolinella subrotunda* (Montagu, 1803)								9/2·6											40
41 *Sorites marginalis* (Lamarck, 1816)																		1/0·3	41
Suborder ROTALIINA																			
42 *Amphicoryna scalaris* (Batsch, 1792)													2/4·0			1/0·6			42
43 *Dentalina communis* d'Orbigny, 1826							1/3·2	1/0·3						1/0·8					43
44 *Dentalina japonica* (Cushman, 1913)			1/1·8									1/0·9							44
45 *Dentalina millettii* Cushman, 1917							1/3·2												45
46 *Dentalina vertebralis* (Batsch, 1791)							1/3·2						2/4·0						46
47 *Lenticulina costata* (Fichtel & Moll, 1798)	1/2·5																		47
48 *Lenticulina echinata* (d'Orbigny, 1846)	1/2·5	3/5·5											1/2·0						48
49 *Lenticulina limbosa* (Reuss, 1863)	2/5·0			25/38·0	2/1·8		4/13·0	5/1·4	6/5·5		1/1·0	1/0·9	5/10·0	8/6·1	6/3·1				49
50 *Lenticulina orbicularis* (d'Orbigny, 1826)							1/3·2												50
51 *Lenticulina peregrina* (Schwager, 1866)												2/1·9							51
52 *Lenticulina subgibba* Parr, 1950												1/0·9							52
53 *Lenticulina vortex* (Fichtel & Moll, 1803)								9/2·6					1/2·0		2/1·0				53
54 *Lagena pliocenica–timmsana* Cushman & Gray, 1946					2/1·8				1/0·9										54
55 *Lagena sulcata* (Walker & Jacob, 1798)						1/1·2													55
56 *Pseudonodosaria torrida* (Cushman, 1923)												1/0·9							56
57 *Saracenaria italica* Defrance, 1824													1/2·0						57
58 *Guttulina problema* d'Orbigny, 1826		1/1·8														1/0·6		6/2·3	58
59 *Sigmoidella elegantissima* (Parker & Jones, 1865)		2/3·7		2/3·0				3/0·9	3/2·7	1/1·2					1/0·5	3/1·8	2/1·0	2/0·7	59
60 *Fissurina marginato perforata* (Sequenza, 1880)														1/0·8					60
61 *Fissurina orbignyana* Sequenza, 1862									1/0·9			3/2·9							61
62 *Brizalina earlandi* (Parr, 1950)			3/5·2								2/2·0								62
63 *Brizalina schwageriana* (Brady, 1881)	5/12·5	7/13·0	1/1·8	2/3·0	13/11·3		6/19·6	22/6·3	3/2·7	5/5·7	3/3·1	13/12·6		21/16·0	20/10·4	1/0·6		7/2·6	63
64 *Brizalina seminuda* (Cushman, 1911)	3/7·5				5/4·4	2/2·4	1/3·2			4/4·5	1/1·0	1/0·9							64
65 *Brizalina spathulata* (Williamson, 1858)								4/1·2	2/1·8										65
66 *Rectobolivina columellaris* (Brady, 1881)								22/6·3	4/3·6						22/11·5				66
67 *Rectobolivina raphana* (Parker & Jones, 1865)		3/5·5													10/5·5				67
68 *Bulimina marginata* d'Orbigny, 1826						1/1·2						1/0·9		1/0·8					68
69 *Reussella spinulosa* (Reuss, 1850)					2/1·8				1/0·9						7/3·8		1/0·5		69
70 *Uvigerina asperula* Czjzek, 1848									1/0·9										70
71 *Uvigerina peregrina* Cushman, 1923	1/2·5											1/0·9	1/2·0	3/2·3					71
72 *Uvigerina proboscidea* Schwager, 1866	1/2·5				4/3·5	4/4·8		2/0·6	2/1·8		8/8·3								72
73 *Siphouvigerina porrecta* (Brady)								12/3·4	4/3·6	4/4·5	3/3·1								73
74 *Trifarina bradyi* Cushman, 1923					2/1·8			2/0·6		1/1·2			1/2·0	2/1·5					74
75 *Discorbinella subbertheloti* (Cushman, 1924)	1/2·5	1/1·8												1/0·8		1/0·6			75
76 *Neoconorbina terquemi* (Rzehak, 1888)								8/2·3							2/1·0				76
77 *Rosalina bertheloti* d'Orbigny, 1839	1/2·5			1/1·5	6/5·2	7/8·4			4/3·6	12/14·0	7/7·3			2/1·5	5/2·6	10/6·0	5/3·0	30/11·2	77
78 *Cancris oblongus* (Williamson, 1858)		1/1·8	8/14·0	4/6·1	11/9·5	2/2·4			1/0·9	3/3·5	4/4·1					5/3·0			78
79 *Baggina philippinensis* (Cushman, 1921)																7/4·3	1/0·5	5/1·9	79
80 *Siphonina tubulosa* Cushman, 1924	1/2·5	1/1·8					5/16·0					24/23·5		1/0·8	2/1·0	1/0·6			80

TABLE A (Cont.)

	TRAVERSE 1						TRAVERSE 2					TRAVERSE 3							
Station	133	135	136	137	138	140	201	270	209	210	157	226	227	249	247	236	234	235	
Total population	40	54	57	66	115	83	31	351	110	86	97	104	50	131	193	165	190	267	
Number/% of total population	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	No/%	
81 *Carpenteria proteiformis* Goës, 1882								1/0·3								1/0·6			81
82 *Loxostomum amygdalaeformis* (Brady, 1881)			8/14·0	1/1·5	1/0·9					1/1·2					1/0·5				82
83 *Cassidulina pacifica* Cushman, 1925								6/1·7					4/8·0		1/0·5				83
84 *Chilostomella oolina* Schwager, 1878			11/19·4									2/1·9		6/4·6					84
85 *Nonion pacificum* (Cushman, 1924)												4/3·9							85
86 *Nonionella turgida* (Williamson, 1858)	2/5·0		2/3·5		1/0·9						2/2·0	2/1·9							86
87 *Anomalina coronata* Parker & Jones, 1857													3/6·0						87
88 *Anomalina nonionoides* Parr, 1932		1/1·8	2/3·5																88
89 *Anomalina polymorpha* Costa, 1856													3/6·0						89
90 *Hoeglundina elegans* (d'Orbigny, 1826)	4/10·0	11/20·5				2/2·4	2/6·5	12/3·4				1/0·9	15/30·0	34/26·0	4/2·1				90
91 *Spirillina vivipara* Ehrenberg, 1841								4/1·1							1/0·5		1/0·5	1/0·3	91
92 *Asterorotalia inflata* (Millett, 1904)					6/5·2	3/3·6					2/2·0								92
93 *Elphidium craticulatum* (Fichtel & Moll, 1798)					3/2·6	1/1·2										7/4·3	1/0·5		93
94 *Nummulites ammonoides* (Gronovius, 1781)													1/2·0					20/7·5	94
95 *Eponides berthelonianus* (d'Orbigny)	1/2·5	2/3·7	1/1·8		2/1·8	2/2·4					3/3·1		1/2·0				5/3·0		95
96 *Amphistegina lessonii* d'Orbigny, 1826				1/1·5													34/18·0	16/6·0	96
97 *Hyalinea balthica* (Schroeter, 1783)																1/0·6			97
98 *Cibicides margaritiferus* (Brady, 1881)		4/7·4	8/14·0	3/4·6			1/3·2		1/0·9										98
99 *Cibides praecinctus* (Karrer, 1868)								4/1·1	5/4·6	1/1·2			1/2·0	2/1·5					99
100 *Cibides refulgens* Montfort, 1808	10/25·0	7/13·0	2/3·5	2/3·0	6/5·2	1/1·2		119/33·9	19/17·4	17/20·0	11/11·5			8/6·1	44/23·0	49/29·7	28/14·8	8/3·0	100
101 *Planorbulinella larvata* (Parker & Jones, 1860)				1/1·5				2/0·6	2/1·8	3/3·5	6/6·3				1/0·5	2/1·2	2/1·0	4/1·5	101

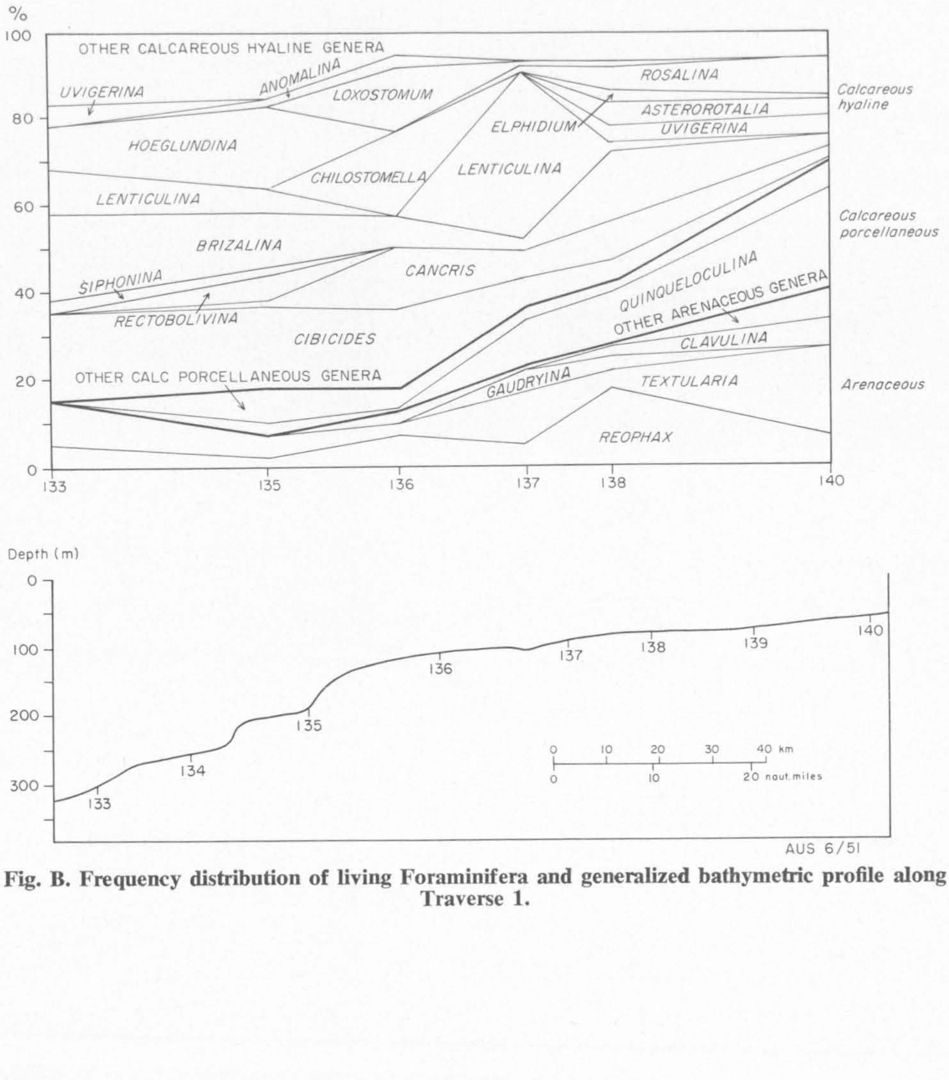

Fig. B. Frequency distribution of living Foraminifera and generalized bathymetric profile along Traverse 1.

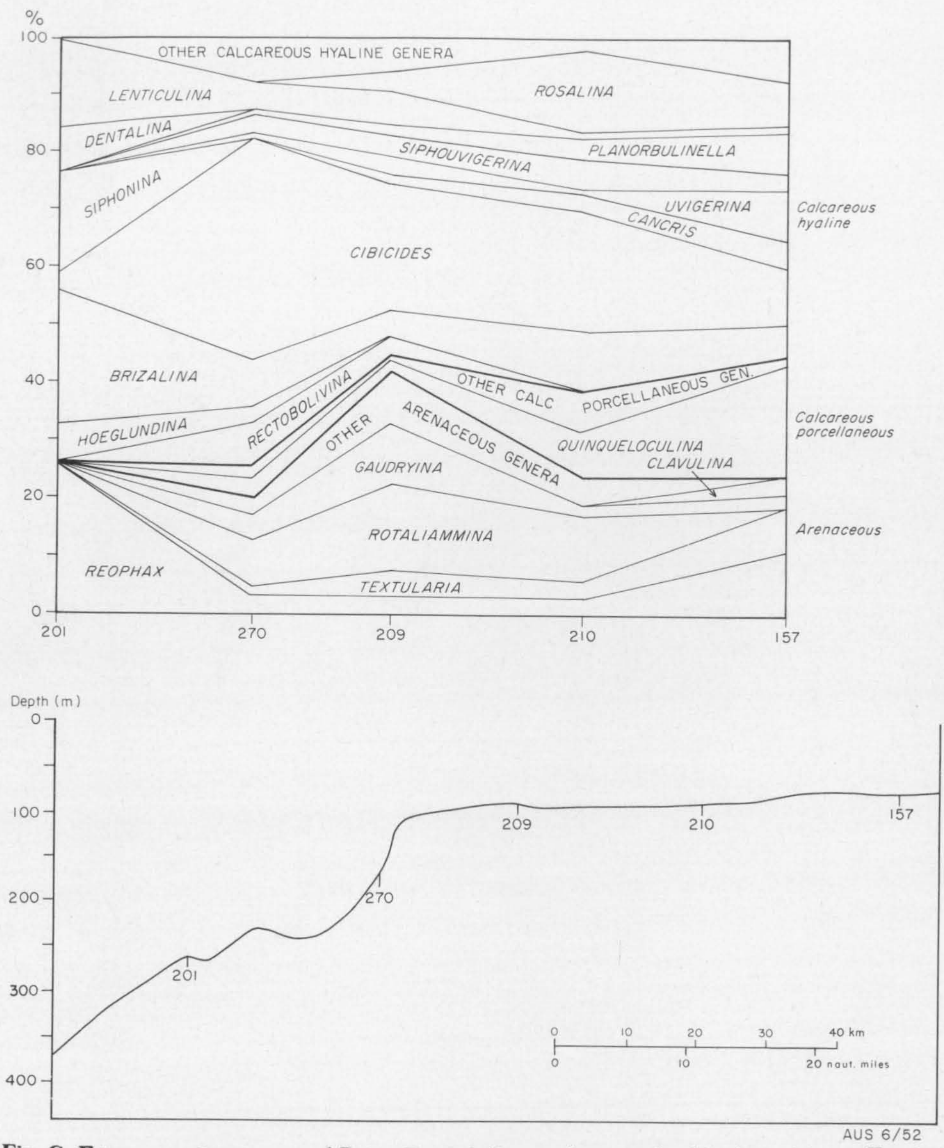

Fig. C. Frequency distribution of living Foraminifera and generalized bathymetric profile along Traverse 2.

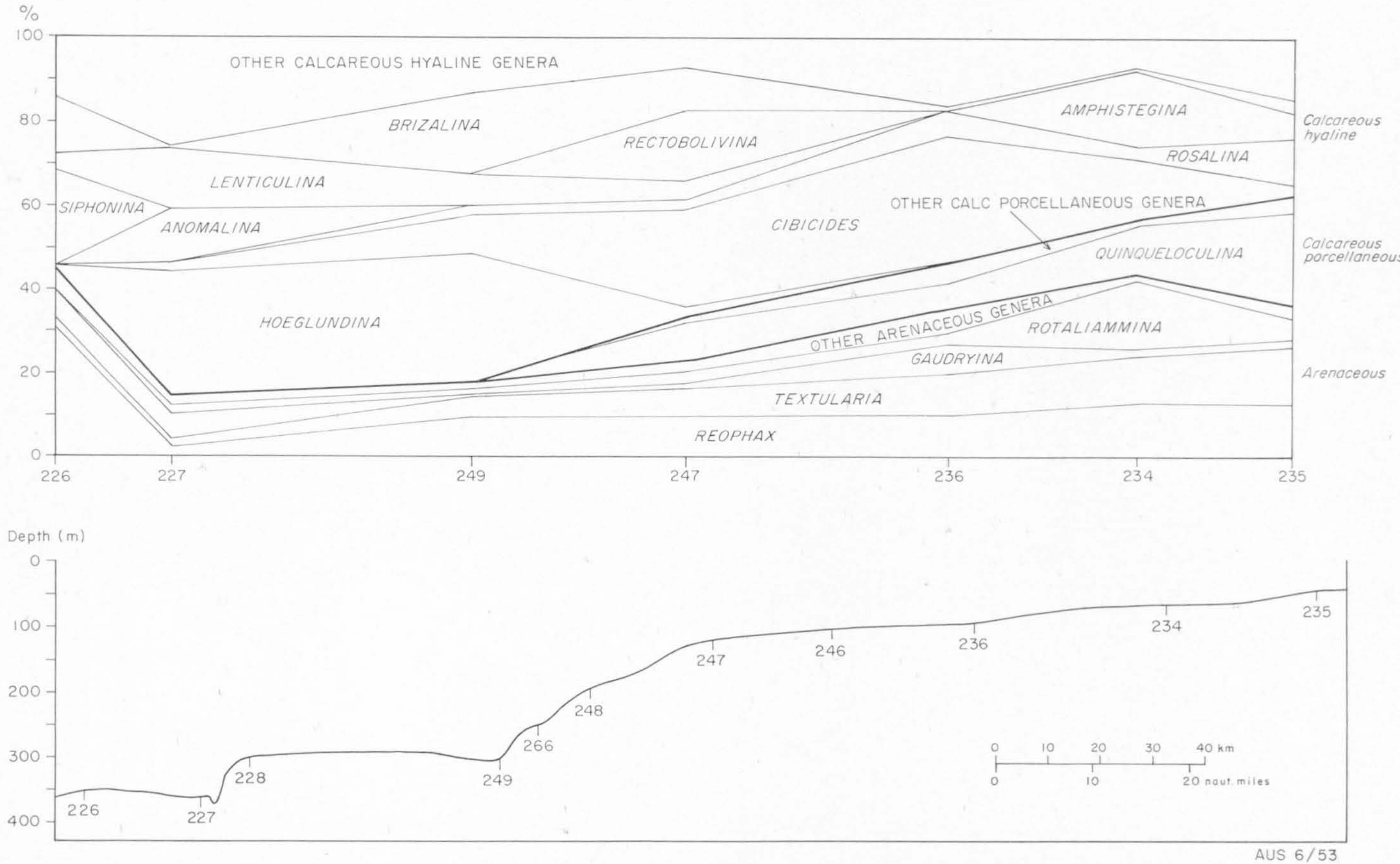

Fig. D. Frequency distribution of living Foraminifera and generalized bathymetric profile along Traverse 3.

SYSTEMATIC NOTES

The classification of Loeblich & Tappan (1964) has been adopted here; full references to all synonyms may be found in the bibliography.

Suborder TEXTULARIINA

Genus TECHNITELLA Norman, 1878.

TECHNITELLA LEGUMEN Norman, 1878

1878 *Technitella legumen* Norman, *Ann. Mag. nat. Hist., Ser.* 2(1), 279, pl. 16, figs 3, 4.
1884 *Technitella legumen* Norman; Brady, 246, pl. 25, figs 8-12.
1910 *Technitella legumen* Norman; Cushman, 48, fig 53.
1921 *Technitella legumen* Norman; Cushman, 50.
Very few and generally small specimens occur at five stations.

Genus AMMODISCUS Reuss, 1861

AMMODISCUS INCERTUS (d'Orbigny, 1839)

1839a *Operculina incerta* d'Orbigny, 49, pl. 6, figs 16, 17.
1884 *Ammodiscus incertus* (d'Orbigny); Brady, 330, pl. 38, figs 1-3.
1910 *Ammodiscus incertus* (d'Orbigny); Cushman, 73, figs 95, 96.
1921 *Ammodiscus incertus* (d'Orbigny); Cushman, 62, pl. 5, figs 1, 2.
Very few specimens, at a depth of 90-100 m.

Genus REOPHAX Montfort, 1808

REOPHAX COMPRESSUS (Cushman & McCulloch, 1939)

1939 *Ammofrondicularia compressa* Cushman & McCulloch, p. 68, pl. 4, figs 7-13.
The tests are very compressed and coarsely arenaceous.
The genus *Ammofrondicularia* has been placed among the synonyms of *Reophax* by Loeblich & Tappan (1964, p. C216).

REOPHAX CYLINDRICUS Brady, 1884

1884 *Reophax cylindrica* Brady, 299, pl. 32, figs 7-9.
1921 *Reophax cylindricus* Brady; Cushman, 70, pl. 13, fig. 1.
Only two individuals were found, at Station 133 (261 m).

REOPHAX DENTALINIFORMIS Brady, 1881

1881 *Reophax dentaliniformis* Brady, 49.
1910 *Reophax dentaliniformis* Brady; Cushman, 87, fig 121.
1921 *Reophax dentaliniformis* Brady; Cushman, 68, pl. 12, fig 4.
1960 *Reophax dentaliniformis* Brady; Barker, 62, pl. 30, figs 21, 22.
Only abundant at Station 226 (347 m); very rare to absent elsewhere.

REOPHAX HORRIDUS Cushman, 1912

1912 *Reophax horrida* Cushman, *Proc. U.S. nat. Mus.*, 42, 229, pl. 28, figs 3, 4.
1921 *Reophax horridus* Cushman; Cushman, 73, pl. 13, fig. 3; pl. 18, figs 3, 4.
The test is elongate, with several chambers. The arenaceous wall shows the typical abundance of sponge spicules. Present only at Station 226 (347 m).

REOPHAX SCORPIURUS Montfort, 1808

1808 *Reophax scorpiurus* Montfort, *Conch. Syst.*, 1, 330, 83rd genus.
1884 *Reophax scorpiurus* Montfort; Brady, 291, pl. 30, figs 12-17.
1910 *Reophax scorpiurus* Montfort; Cushman, 83, figs 114-16.
1921 *Reophax scorpiurus* Montfort; Cushman, 65, pl. 6, fig. 6.
This species occurs abundantly along Traverse 2, but only in the deepest section of Traverse 3, and is absent from Traverse 1.

REOPHAX SCORPIURUS TESTACEA Wiesner, 1931

1931 *Reophax scorpiurus* Montfort var. *testacea* Wiesner, 89, pl. 8, fig. 100.
1950 *Reophax scorpiurus* Montfort var. *testacea* Wiesner; Parr, 269, pl. 4, fig. 19.
Although generally associated with *R. scorpiurus,* this species has also been found along Traverse 1. Sometimes it is difficult to differentiate the two species because the foraminiferal tests, of which the wall of this variety is composed, may vary considerably in number.

REOPHAX SPICULIFER Brady, 1879

1879 *Reophax spiculifera* Brady, 54.
1884 *Reophax spiculifera* Brady; Brady, 295, pl. 31, figs 16, 17.
1910 *Reophax spiculifer* Brady; Cushman, 92, figs 132, 133.
One specimen only has been found, at Station 226 (347 m).

Genus HAPLOPHRAGMOIDES Cushman, 1910

HAPLOPHRAGMOIDES CANARIENSIS (d'Orbigny, 1839)

1839a *Nonionina canariensis* d'Orbigny, 128, pl. 2, figs 33, 34.
1884 *Haplophragmium canariensis* (d'Orbigny); Brady, 310, pl. 35, figs 1-5.
1910 *Haplophragmoides canariensis* (d'Orbigny); Cushman, 101, fig. 149.
1921 *Haplophragmoides canariensis* (d'Orbigny); Cushman, 79.
Very few specimens.

Genus TEXTULARIA Defrance, 1824

TEXTULARIA CANDEIANA d'Orbigny, 1839

1839a *Textularia candeiana* d'Orbigny, 143, pl. 1, figs 25-27.
1911 *Textularia candeiana* d'Orbigny; Cushman, 12, figs 14-17.
This species is normally found in the shallow section of each traverse.

TEXTULARIA CONICA d'Orbigny, 1839

1839a *Textularia conica* d'Orbigny, 143, pl. 1, figs 19, 20.
1921 *Textularia conica* d'Orbigny; Cushman, 123, pl. 25, fig. 2.
1960 *Textularia conica* d'Orbigny; Barker, 88, pl. 43, figs 13, 14.
Only two specimens have been found, at Station 137 (115 m).

TEXTULARIA FOLIACEA Heron-Allen & Earland, 1915

1915 *Textularia foliacea* Heron-Allen & Earland, 628, pl. 47, figs 17-20.
1921 *Textularia foliacea* Heron-Allen & Earland; Cushman, 117, pl. 19, fig. 7.
This species appears to be the most common along Traverse 3.

TEXTULARIA GRAMEN d'Orbigny, 1846

1846 *Textularia gramen* d'Orbigny, 248, pl. 15, figs. 4-6.
1911 *Textularia gramen* d'Orbigny; Cushman, 8, figs 6-8.
Very few specimens.

TEXTULARIA PSEUDOCARINATA Cushman, 1921

1884 *Textularia carinata* d'Orbigny; Brady, 360, pl. 42, figs 15, 16.
1911 *Textularia carinata* d'Orbigny; Cushman, 17, figs 26, 27.
1921 *Textularia pseudocarinata Cushman,* 121, pl. 22, fig. 5.
Abundant at a few stations.

TEXTULARIA RAMOSA Lalicker & McCulloch, 1940

1940 *Textularia ramosa* Lalicker & McCulloch, 138, pl. 15, fig. 20.
Very rare.

TEXTULARIA SIPHONIFERA Brady, 1881

1881 *Textularia siphonifera* Brady, 53.
1884 *Textularia siphonifera* Brady; Brady, 362, pl. 42, figs 25-29.
1911 *Textularia siphonifera* Brady; Cushman, 17, figs 28, 29.
1968 *Textularia siphonifera* Brady; Albani, 96.
A few specimens; all show the apertural projections typical of the species.

TEXTULARIA sp.

1960 *Textularia* sp. nov. Barker, 88, pl. 43, figs 15, 16, 18.
A few specimens occur in shallow waters. The tests are identical with the figure of *T. trochus* in Brady (1884, pl. 43, figs 15, 16, 18). Many more specimens are needed, however, before a precise diagnostic description of the average specimen can be made; therefore the views by Barker (1960) are here accepted and the specimens are referred to *T.* sp. nov.

Genus TROCHAMMINA Parker & Jones, 1859

TROCHAMMINA INFLATA (Montagu, 1808)

1808 *Nautilus inflatus* Montagu, *Test. Brit., Supp.,* 81, fig. 3.
1884 *Trochammina inflata* (Montagu); Brady, 338, pl. 41, fig. 4.
1910 *Trochammina inflata* (Montagu); Cushman, 121.
Only one specimen has been found alive, at Station 210 (88 m).

Genus ROTALIAMMINA Cushman, 1924

ROTALIAMMINA MAYORI Cushman, 1924

1924 *Rotaliammina mayori* Cushman, *Carnegie Inst. Wash. Publ.* 342, 11, pl. 1, figs 4, 5.
1955 *Rotaliammina mayori* Cushman; Loeblich & Tappan, 20, pl 3, fig. 4.
Several specimens occur along Traverses 2 and 3.

Genus TRITAXIS Schubert, 1920

TRITAXIS CONICA (Parker & Jones, 1865)

1865 *Valculina triangularis* d'Orbigny var. *conica;* Parker & Jones, *Phil. Trans.,* 155, 406. pl. 15, fig. 27.
1960 *Tritaxis conica* (Parker & Jones); Barker, 100, pl. 49, fig. 15.
Only one specimen, from Station 226 (347 m).

Genus GAUDRYINA d'Orbigny, 1839

GAUDRYINA PAUPERCULA Cushman, 1911

1911 *Gaudryina paupercula* Cushman, 66, fig. 106.
1921 *Gaudryina paupercula* Cushman; Cushman, 148, pl. 29, figs 4, 5.
Very rare and only at Station 227 (330 m).

GAUDRYINA QUADRANGULARIS Bagg, 1908

1908 *Gaudryina quadrangularis* Bagg, *Proc. U.S. nat. Mus.,* 34, 133, pl. 5, fig. 1.
1911 *Gaudryina quadrangularis* Bagg; Cushman, 64, fig. 103.
1921 *Gaudryina quadrangularis* Bagg; Cushman, 147, pl. 29, fig. 2.
Very rare.

GAUDRYINA TRANSVERSARIA (Brady, 1884)

1884 *Textularia transversaria* Brady, 359, pl. 113, figs 3-5.
1949 *Gaudryina (Siphogaudryina) transversaria* (Brady); Said, 8, pl. 1, fig. 12.
1960 *Gaudryina (Siphogaudryina) transversaria* (Brady); Barker, 232, pl. 113, figs 3-5.
This species was found to be abundant in the shallow section of each traverse.

Genus DOROTHIA Plummer, 1931

DOROTHIA ARENATA Cushman, 1936

1936 *Dorothia arenata* Cushman, *Cushman Lab., spec. Publ.* 6, 32, pl. 5, fig. 11.
1937a *Dorothia arenata* Cushman, 101, pl. 11, fig. 9.
Only one specimen, at Station 137 (115 m).

Genus CLAVULINA d'Orbigny, 1826

CLAVULINA PACIFICA Cushman, 1924

1884 *Clavulina angularis* (d'Orbigny); Brady, 396, pl. 48, figs 22-24.
1924 *Clavulina pacifica* Cushman, *Carnegie Inst. Wash. Publ.* 342, 22, pl. 6, figs 7-11.
1932 *Clavulina pacifica* Cushman; Cushman, 16, pl. 4, figs 4, 7, 9.
Very few specimens occur in shallow water along Traverse 1.

Genus CYLINDROCLAVULINA Bermudes & Key, 1952

CYLINDROCLAVULINA BRADYI (Cushman, 1911)

1884 *Clavulina cylindrica* Hantken; Brady, 396, pl. 48, figs 32-38.
1911 *Clavulina bradyi;* Cushman, 73, figs 118, 119.
1960 *Cylindroclavulina bradyi* (Cushman); Barker, 98, pl. 48, figs 32-38.
A single specimen, at Station 247 (128 m).

Suborder MILIOLINA

Genus SPIROLOCULINA d'Orbigny, 1826

SPIROLOCULINA COMMUNIS Cushman & Todd, 1944

1917 *Spiroloculina grateloupi* d'Orbigny; Cushman, 31, pl. 4, figs 4, 5.
1921 *Spiroloculina grateloupi* d'Orbigny; Cushman, 396, pl. 78, fig. 4; pl. 100, fig. 3.
1944 *Spiroloculina communis* Cushman & Todd, 62, pl. 8, figs 26-28.
1960 *Spiroloculina communis* Cushman & Todd; Barker, 20, pl. 9, figs 3, 4.
1965 *Spiroloculina communis* Cushman & Todd; Albani, 61, pl. 6, fig. 6.
This typical species occurs in shallow waters along all three traverses.

SPIROLOCULINA DISPARILIS Terquem, 1878

1878 *Spiroloculina disparilis* Terquem, *Mém. Soc. géol. France, Sér.* 3(1), 55, pl. 5, fig. 12.
1884 *Spiroloculina acutimargo* Brady; Brady, 154, pl. 10, fig. 12.
1944 *Spiroloculina disparilis* Terquem; Cushman & Todd, 35, pl. 5, figs 22-31.
Only a few specimens, at Station 210 (88 m).

Genus QUINQUELOCULINA d'Orbigny, 1826

QUINQUELOCULINA AGGLUTINANS d'Orbigny, 1839

1839a *Quinqueloculina agglutinans* d'Orbigny, 168, pl. 12, figs 11-13.
1921 *Quinqueloculina agglutinans* d'Orbigny; Cushman, 441, pl. 91, fig. 1.

This species seems to characterize very shallow waters; it has been found in great abundance only at Station 235 (57 m).

QUINQUELOCULINA ANGUINA ARENATA Said, 1949

1932 *Quinqueloculina anguina* (Terquem) var. *agglutinans* (Wiesner); Cushman, 18, pl. 5, fig. 1.
1949 *Quinqueloculina anguina* (Terquem) var. *arenata;* Said, 9, pl. 1, fig. 25.
1958 *Quinqueloculina anguina arenata* Said; Collins, 358.

Together with *Q. agglutinans,* this species, found only in waters less than 90 m deep, is characteristic of the shallow section of Traverses 1 and 3.

QUINQUELOCULINA LAMARCKIANA d'Orbigny, 1839

1839a *Quinqueloculina lamarckiana* d'Orbigny, 189, pl. 11, figs 14, 15.
1921 *Quinqueloculina lamarckiana* d'Orbigny; Cushman, 418, pl. 87, figs 2, 3.

Among the miliolids, *Q. lamarckiana* is by far the most abundant and with *Q. pseudoreticulata* it constitutes up to 80 percent of the porcellaneous species.

QUINQUELOCULINA PSEUDORETICULATA Parr, 1941

1884 *Miliolina reticulata* (d'Orbigny); Brady, 177, pl. 9, figs 2, 3.
1917 *Quinqueloculina reticulata* (d'Orbigny); Cushman, 55, pl. 16, figs 1-3.
1921 *Quinqueloculina reticulata* (d'Orbigny); Cushman, 434.
1941 *Quinqueloculina pseudoreticulata* Parr, 305.
1960 *Quinqueloculina pseudoreticulata* Parr; Barker, 18, pl. 9, figs 18-20.
1968 *Quinqueloculina pseudoreticulata* Parr; Albani, 98, pl. 7, figs 18-20.

Many large specimens, showing clearly the reticulated ornamentation, are present in all three traverses. The tests are identical with Brady's figures (1884) except for the tooth, which is simple. In a few cases the tooth may be considered slightly bifid; in this respect they resemble the specimens from the eastern coast of Australia (Albani, 1968).

QUINQUELOCULINA SEMINULA (Linné, 1767)

1767 *Serpula seminulum* Linné, *Syst. Nat.,* ed. 12, 1264, No. 791.
1917 *Quinqueloculina seminulum* (Linné); Cushman, 44, pl. 11, fig. 2.
1921 *Quinqueloculina seminulum* (Linné); Cushman, 416, pl. 88, fig. 4.

Only a few specimens.

Genus FLINTINA Cushman, 1921

FLINTINA TRIQUETRA (Brady, 1879)

1879 *Miliolina triquetra* Brady, 54.
1884 *Miliolina triquetra* Brady; Brady, 181, pl. 8, figs 8-10.
1921 *Flintina triquetra* (Brady); Cushman, 466, pl. 94, fig. 1.

Very rare.

Genus PYRGO Defrance, 1824

PYRGO SARSII (Schlumberger, 1881)

1881 *Biloculina sarsii* Schlumberger, *Mém. Soc. zool. France,* 4, 166, pl. 9, figs 55-59.
1917 *Biloculina sarsii* Schlumberger; Cushman, 76, pl. 30, fig. 2.
Biloculina sarsii Schlumberger; Cushman, 471, pl. 97, fig. 1.

Only a few specimens, in deep waters.

Genus SIGMOILOPSIS Finlay, 1947

SIGMOILOPSIS SCHLUMBERGERI (Silvestri, 1904)

1884 *Planispirina celata* (Costa); Brady, 197, pl. 8, figs 1-4.
1904 *Sigmoilina schlumbergeri* Silvestri, *Mem. Pont. Nuovi Lincei,* 22, p. 267.
1910 *Sigmoilina celata* (Costa); Cushman, 61, pl. 24, fig. 1.
1960 *Sigmoilopsis schlumbergeri* (Silvestri); Barker, 16, pl. 8, figs 1-4.

Very rare.

Genus TRILOCULINA d'Orbigny 1826

TRILOCULINA RUPERTIANA (Brady, 1879)

1879 *Miliolina rupertiana* Brady, 46.
1884 *Miliolina rupertiana* Brady; Brady 178, pl. 7, figs 7-12.
1921 *Triloculina rupertiana* (Brady); Cushman, 464, pl. 93, fig. 2.

Two specimens only, from very shallow water.

TRILOCULINA TRICARINATA d'Orbigny, 1826

1826 *Triloculina tricarinata* d'Orbigny, 299, 7.
1917 *Triloculina tricarinata* d'Orbigny; Cushman, 66, pl. 25, figs 1, 2.
1921 *Triloculina tricarinata* d'Orbigny; Cushman, 454.
One specimen only.

Genus MILIOLINELLA Wiesner, 1931

MILIOLINELLA SUBROTUNDA (Montagu, 1803)

1803 *Vermiculum subrotundum* Montagu, *Test Brit.*, 521.
1884 *Miliolina circularis* (Bornemann); Brady, 169, pl. 4, fig. 3.
1917 *Triloculina circularis* Bornemann; Cushman, 67, pl. 25, fig. 4; pl. 26, fig. 1.
1921 *Triloculina circularis* Bornemann; Cushman, 462, pl. 92, figs 1, 2.
1960 *Miliolinella subrotunda* (Montagu); Barker, 8, pl. 4, fig. 3.
A few specimens only, at Station 270 (119 m).

Genus SORITES Ehrenberg, 1840

SORITES MARGINALIS (Lamarck, 1816)

1816 *Orbulites marginalis* Lamarck, *Syst. Anim. sans Vert.*, 2, 196, No. 1.
1917 *Orbitolites marginalis* (Lamarck); Cushman, 92, pl. 38, figs 1, 2.
1921 *Orbitolites marginalis* (Lamarck); Cushman, 484.
Only one specimen, at Station 235 (57 m).

Suborder ROTALIINA

Genus AMPHICORYNA Schlumberger, 1881

AMPHICORYNA SCALARIS (Batsch, 1791)

1791 *Nautilus (Orthoceras) scalaris* Batsch, *Conchylien des Seesandes,* 4, pl. 2, figs a, c.
1960 *Amphicoryna scalaris* (Batsch); Barker, 134, pl. 63, figs 28-31.
1968 *Amphicoryna scalaris* (Batsch); Albani, 102, pl. 8, figs 2, 3.
Several specimens along Traverse 3. For a complete discussion of this species see Albani (1968).

Genus DENTALINA d'Orbigny, 1826

DENTALINA COMMUNIS d'Orbigny, 1826

(Pl. A, fig. 1)

1826 *Nodosaria (Dentalina) communis* d'Orbigny, 254, No. 35.
1840 *Dentalina communis* d'Orbigny, *Mém. Soc. géol. France,* 4, 13, pl. 1, fig. 4.
1913 *Nodosaria communis* d'Orbigny; Cushman, 54, pl. 28, figs 1, 2.
1960 *Dentalina communis* d'Orbigny; Barker, 130, pl. 62, figs 21, 22.
Very few specimens occur, in fairly deep waters along Traverse 2 and 3. Figured specimen: Station 249 (322 m).

DENTALINA JAPONICA (Cushman, 1913)

1913 *Nodosaria japonica* Cushman, 57, pl. 28, fig. 4.
The tests are elongate and consist of many cylindrical chambers. The sutures, composed of clear shell material, are visible although not depressed. Only one complete specimen has been found, at Station 136 (122 m).

DENTALINA MILLETTI Cushman, 1917

1902 *Nodosaria scalaris* var. *separans* (Brady); Millett, *J. Roy. microsc. Soc.,* 520, pl. 11, figs 11, 12.
1917 *Nodosaria millettii* Cushman, *Proc. U.S. nat. Mus.,* 51, 654.
1921 *Nodosaria millettii* Cushman; Cushman, 202, pl. 36, fig. 5.
One specimen only, at Station 201 (285 m).

DENTALINA VERTEBRALIS (Batsch, 1791)

1791 *Nautilus (Orthoceras) vertebralis* Batsch, 3, No. 6, pl. 2, fig. 6.
1884 *Nodosaria vertebralis* (Batsch); Brady, 514, pl. 64, figs 11-14.
1913 *Nodosaria vertebralis* (Batsch); Cushman, 60, pl. 32, fig. 1.
1921 *Nodosaria vertebralis* (Batsch); Cushman, 211, pl. 38, figs 2, 3; pl. 40, fig. 2.
1923 *Nodosaria vertebralis* var. *albatrossi* Cushman, 87, pl. 15, fig. 1.
1960 *Nodosaria albatrossi* Cushman; Barker, 134, pl. 64, figs 11-14.
1965 *Dentalina vertebralis* (Batsch); Hedley, Hurdle, & Burdett, 19, pl. 6.
The views of Hedley, Hurdle, & Burdett are followed here. The three specimens recovered show the typical longitudinal costae and the sutures are visible, although not depressed.

Genus LENTICULINA Lamarck, 1804

LENTICULINA COSTATA (Fichtel & Moll, 1798)

1798 *Nautilus costatus* Fichtel & Moll, 47, pl. 4, figs g-i.
1965 *Lenticulina costata* (Fichtel and Moll); Hedley, Hurdle, & Burdett, 14, pl. 4, figs 14a, b.
The test is large and compressed, with limbate sutures. The chambers are ornamented with independent sets of raised costae parallel to the periphery. One specimen only, at Station 133 (261 m).

LENTICULINA ECHINATA (d'Orbigny, 1846)
(Pl. A, fig. 2)

1846 *Robulina echinata* d'Orbigny, 100, pl. 4, figs 21, 22.
1913 *Cristellaria echinata* (d'Orbigny); Cushman, 73, pl. 34, fig. 5.
1960 *Lenticulina papillosoechinata* (Fornasini); Barker, 148, pl. 71, fig. 1.
The tests are biconvex and composed of few chambers. The sutures are limbate and, in the early part of the test, break up to form series of rounded and raised bosses of different sizes, the largest near the umbo. The last-formed sutures do not show such bosses and form a continuous raised ridge. Acicular spines are present along the periphery. A few specimens occur at Stations 133 (261 m), 135 (176 m), and 227 (330 m). Figured specimen: Station 135.

LENTICULINA LIMBOSA (Reuss, 1863)

1863 *Robulina limbosa* Reuss, *Sitz. Akad. Wiss. Wien,* 48(1), 55, pl. 6, fig.69.
1950 *Robulus limbosus* (Reuss); Cushman & McCulloch, 297, pl. 39, figs 1, 2.
The tests are close coiled and strongly biconvex. The chambers are uniform in shape with the umbilical area occupied by a large, but not raised, boss. The periphery is ornamented by a small rounded keel. This species is the most abundant of the genus and occurs along all three traverses.

LENTICULINA ORBICULARIS (d'Orbigny, 1826)

1826 *Robulina orbicularis* d'Orbigny, 288, pl. 15, figs 8, 9.
1913 *Cristellaria orbicularis* (d'Orbigny); Cushman, 67, pl. 36, figs 4, 5.
1921 *Cristellaria orbicularis* (d'Orbigny); Cushman, 224.
Only one specimen, from Station 201 (285 m), with characteristic keel well pronounced.

LENTICULINA PEREGRINA (Schwager, 1866)

1866 *Cristellaria peregrina* Schwager, *Novara Exped., geol. Theil,* 2, 245, pl. 7, fig. 89.
1884 *Cristellaria variabilis* Reuss; Brady, 541, pl. 68, figs 11-16.
1923 *Cristellaria peregrina* Schwager; Cushman, 113, pl. 30, figs 3, 4.
1960 *Lenticulina peregrina* (Schwager); Barker, 144, pl. 68, figs 11-16.
The tests are small, compressed, and formed by a few chambers; only three in the last-formed whorl. A very small keel marks the periphery and the aperture is slightly produced.

LENTICULINA SUBGIBBA Parr, 1950.

1950 *Lenticulina subgibba* Parr, 321, pl. 11, figs 1, 2.
1960 *Lenticulina subgibba* Parr; Hedley, Hurdle, & Burdett, 16, pl. 3, fig. 12; text fig. 2.
One specimen only, from Station 226 (347 m).

LENTICULINA VORTEX (Fichtel & Moll, 1803)

1803 *Nautilus vortex* Fichtel & Moll, *Test. Micr.,* 33, pl. 2, figs d-i.
1884 *Cristellaria vortex* (Fichtel & Moll); Brady, 548, pl. 69, figs 14-16.
1913 *Cristellaria vortex* (Fichtel & Moll); Cushman, 68, pl. 32, fig. 3.
1921 *Cristellaria vortex* (Fichtel & Moll); Cushman, 227.
This typical species is represented by a few specimens at Stations 270 (119 m), 227 (330 m), and 247 (128 m).

Genus LAGENA Walker & Jacob, 1798

LAGENA PLIOCENICA TIMMSANA Cushman & Gray, 1946

1946 *Lagena pliocenica* Cushman & Gray var. *timmsana;* Cushman & Gray, *Contr. Cushman Lab.,* 22, 68, pl. 12, figs 15-17.
1950 *Lagena pliocenica* Cushman & Gray var. *timmsana* Cushman & Gray; Cushman & McCulloch, 345, pl. 46, fig. 10.
The tests are globular with smooth walls. At the base a few plate-like raised costae are produced outwards. The neck is long and ornamented by a spiral costa.

LAGENA SULCATA (Walker & Jacob, 1798)

1798 *Serpula (Lagena) sulcata* Walker & Jacob, *in Adam's Essays, Kanmacher's ed.*, 634, pl. 14, fig. 5.
1884 *Lagena sulcata* (Walker & Jacob); Brady, 462, pl. 57, figs 22, 26, 33, 34.
1913 *Lagena sulcata* (Walker & Jacob); Cushman, 22, pl. 9, fig. 2.
1921 *Lagena sulcata* (Walker & Jacob); Cushman, 179.
Only one specimen, at Station 140 (64 m).

Genus PSEUDONODOSARIA Boomgaart, 1949

PSEUDONODOSARIA TORRIDA (Cushman, 1923)

1884 *Nodosaria (Glandulina) laevigata* d'Orbigny; Brady, 490, pl. 61, figs 20-22.
1913 *Nodosaria (Glandulina) laevigata* d'Orbigny; Cushman, 47, pl. 24, figs 1, 2.
1921 *Nodosaria (Glandulina) laevigata* d'Orbigny; Cushman, 185, pl. 33, fig. 1.
1923 *Nodosaria (Glandulina) laevigata* d'Orbigny var. *torrida* Cushman, 65, pl. 12, fig. 10.
1960 *Rectoglandulina torrida* (Cushman); Barker, 128, pl. 61, figs 20-22.
Only one specimen, at Station 226 (347 m).

Genus SARACENARIA Defrance, 1824

SARACENARIA ITALICA Defrance, 1824

1824 *Saracenaria italica* Defrance, *Dist. Sci. Nat.*, 32.
1960 *Cristellaria italica* (Defrance); Barker, 144, pl. 68, figs 17, 18, 20-23.
Only one specimen of this well known species has been found, at Station 227 (330 m).

Genus GUTTULINA d'Orbigny, 1839

GUTTULINA PROBLEMA d'Orbigny, 1826

1826 *Guttulina problema* d'Orbigny, 266, No. 14.
1884 *Polymorphina problema* (d'Orbigny); Brady, 568, pl. 72, fig. 20.
1930 *Guttulina problema* d'Orbigny; Cushman & Ozawa, 19, pl. 2, figs 1-6.
Very few specimens are present and there is no significant pattern of distribution.

Genus NUMMULITES Lamarck, 1801

NUMMULITES AMMONOIDES (Gronovius, 1781)

1781 *Nautilus ammonoides* Gronovius, *Zooph. Gron.*, 282, pl. 19, figs 5, 6.
1914 *Operculina ammonoides* (Gronovius); Cushman, 37, pl. 14, fig. 7.
1921 *Operculina ammonoides* (Gronovius); Cushman, 382.
1960 *Operculina ammonoides* (Gronovius); Barker, 230, pl. 112, figs 3-9, 11-13.
This species is unusually common at Station 235 (57 m). Except for a few records, it is a species of deep cold waters; this finding confirms the authors' views that more detailed and complete records of the hydrological parameters are essential.

Genus EPONIDES Montfort, 1808

EPONIDES BERTHELONIANUS (d'Orbigny)

1960 *Eponides berthelonianus* (d'Orbigny); Barker, 218, pl. 106, fig. 1.
Several specimens have been found, mainly along Traverse 1.

Genus AMPHISTEGINA d'Orbigny, 1826

AMPHISTEGINA LESSONII d'Orbigny, 1826

1826 *Amphistegina lessonii* d'Orbigny, 304, No. 3, pl. 17, figs 1-4.
1914 *Amphistegina lessoni* d'Orbigny; Cushman, 35.
1960 *Amphistegina lessoni* d'Orbigny; Barker, 230, pl. 111, figs 5, 6.
This species occurs abundantly in the shallow section of Traverse 3.

Genus HYALINEA Hofker, 1951

HYALINEA BALTHICA (Schroeter, 1783)

1783 *Nautilus balthicus* Schroeter, *Einleitung*, 1, 20, pl. 1, fig. 2.
1884 *Operculina ammonoides* Parker & Jones; Brady, 745, pl. 92, figs 1, 2.
1931 *Anomalina balthica* (Schroeter); Cushman, 108, pl. 19, fig. 3.
1960 *Hyalinea balthica* (Schroeter); Barker, 230, pl. 112, figs 1, 2.
One specimen only, at Station 236 (104 m).

Genus CIBICIDES Montfort, 1808

CIBICIDES MARGARITIFERUS (Brady, 1881)

1881 *Truncatulina margaritifera* Brady, 66.
1884 *Truncatulina margaritifera* Brady; Brady, 667, pl. 96, fig. 2.
1915 *Truncatulina margaritifera* Brady; Cushman, 40, pl. 17, fig. 1; text fig. 43.
1960 *Cibicides margaritiferus* (Brady); Barker, 198, pl. 96, fig. 2.
This species is quite abundant along Traverse 1.

CIBICIDES PRAECINCTUS (Karrer, 1868)

1868 *Rotalia praecincta* Karrer, *Sitz. Akad. Wiss. Wien.*, 58, 189, pl. 5, fig. 7.
1884 *Truncatulina praecincta* (Karrer); Brady, 667, pl. 95, figs 1-3.
1915 *Truncatulina praecincta* (Karrer); Cushman, 39, pl. 26, fig. 2.
1921 *Truncatulina praecincta* (Karrer); Cushman, 318.
1960 *Cibicides praecinctus* (Karrer); Barker, 196, pl. 95, figs 1-3.
Several specimens have been found along Traverse 2.

CIBICIDES REFULGENS Montfort, 1808

1808 *Cibicides refulgens* Montfort, 122.
1921 *Truncatulina refulgens* (Montfort); Cushman, 312, pl. 63, fig. 1.
1960 *Cibicides refulgens* Montfort; Barker, 190, pl. 92, fig. 7.
This species is the most abundant of the genus, reaching 30 percent of the living population at a few stations. The specimens are very often small and variable, and are present to a depth of 300 m, which seems to be the lower limit in the area studied.

Genus PLANORBULINELLA Cushman, 1927

PLANORBULINELLA LARVATA (Parker & Jones, 1860)

1860 *Planorbulina vulgaris* d'Orbigny var. *larvata;* Parker & Jones, *Ann. Mag. nat. Hist., Ser.* 3(5), 294.
1915 *Planorbulina larvata* Parker & Jones; Cushman, 27, pl. 8, fig. 2.
1921 *Planorbulina larvata* Parker & Jones; Cushman, 310.
1960 *Planorbulinella larvata* (Parker & Jones); Barker, 190, pl. 92, figs 5, 6.
Several specimens occur along Traverses 2 and 3.

Genus SIGMOIDELLA Cushman & Ozawa, 1928

SIGMOIDELLA ELEGANTISSIMA (Parker & Jones, 1865)

1865 *Polymorphina elegantissima* Parker & Jones, *Phil. Trans.*, 155, 438, pl. 10.
1913 *Polymorphina elegantissima* Parker & Jones; Cushman, 90, pl. 38, fig. 1.
1930 *Sigmoidella elegantissima* (Parker & Jones); Cushman & Ozawa, 140, pl. 39, fig. 1.
This species is abundant at several stations.

Genus FISSURINA Reuss, 1850

FISSURINA MARGINATO PERFORATA (Seguenza, 1880)

1880 *Lagena marginato perforata* Seguenza, *Atti Accad. Lincei, Ser.* 3(6), 332, pl. 17, fig. 34.
1923 *Lagena marginato perforata* Seguenza; Cushman, 37, pl. 7, fig. 4.
One specimen, at Station 249 (322 m).

FISSURINA ORBIGNYANA Seguenza, 1862

1862 *Fissurina orbignyana* Seguenza, *Foram. monotal. Mioc. Messina,* 66, pl. 2, figs 24, 26.
1884 *Lagena orbignyana* (Seguenza); Brady, 484, pl. 59, figs 1, 18, 24, 26.
1913 *Lagena orbignyana* (Seguenza); Cushman, 42, pl. 19, fig. 1.
Present at Stations 209 (95 m) and 226 (347 m).

Genus BRIZALINA Costa, 1856

BRIZALINA EARLANDI (Parr, 1950)

1950 *Bolivina earlandi* Parr, 339, pl. 12, fig. 16.
1960 *Bolivina earlandi* Parr; Barker, 106, pl. 52, figs 18, 19.
The tests are elongate and oval in transverse section. The chambers are distinct, with strongly curved sutures. The wall is smooth and translucent; the aperture consists of a narrow comma-shaped slit. This species is rare; very few specimens have been found, at Stations 136 (122 m) and 157 (75 m).

BRIZALINA SCHWAGERIANA (Brady, 1881)

1881 *Bolivina schwageriana* Brady, 28.
1884 *Bolivina schwageriana* Brady; Brady, 425, pl. 53, figs 24, 25.
1911 *Bolivina schwageriana* Brady; Cushman, 38, fig. 63.
1937 *Bolivina schwageriana* Brady; Cushman, 130, pl. 16, figs 22-24.
The test is very compressed and nearly as broad as long. The periphery is carinate and the few chambers are broader than high. The sutures are limbate with raised beads in the central portion of the test. This species is the most abundant of the genus in our material.

BRIZALINA SEMINUDA (Cushman, 1911)

1911 *Bolivina seminuda* Cushman, 34, fig. 55.
1950 *Bolivina seminuda* Cushman; Parr, 339, pl. 12, fig. 17.

Together with *B. schwageriana* this species forms up to 90 percent of the total population of the genus and is present in many stations in the three traverses.

BRIZALINA SPATHULATA (Williamson, 1858)

1858 *Textularia variabilis* var. *spathulata* Williamson, *Recent Brit. Foram.*, 76, pl. 6, figs 164, 165.
1884 *Bolivina dilatata* Reuss; Brady, 418, pl. 52, figs 20, 21.
1911 *Bolivina dilatata* Reuss; Cushman, 33, fig. 54.
1921 *Bolivina dilatata* Reuss; Cushman, 128, pl. 26, fig. 6.
1965 *Brizalina spathulata* (Williamson); Hedley, Hurdle, & Burdett, 21, pl. 6, fig. 23; text-fig. 6.

Very few specimens occur, at Stations 270 (119 m) and 209 (95 m).

Genus RECTOBOLIVINA Cushman, 1927

RECTOBOLIVINA COLUMELLARIS (Brady, 1881)

1881 *Sagrina columellaris* Brady, 64.
1913 *Siphogenerina columellaris* (Brady); Cushman, 104, pl. 47, figs 2, 3.
1921 *Siphogenerina columellaris* (Brady); Cushman, 276, pl. 56, fig. 1.
1960 *Rectobolivina columellaris* (Brady); Barker, 156, pl. 75, figs 15-17.

The test is elongate and cylindrical. The chambers of the uniserial portion are rounded but not inflated with distinct sutures. The aperture is large and terminal. This species is abundant only at Stations 270 (119 m) and 247 (128 m) and is present at Station 209 (95 m).

RECTOBOLIVINA RAPHANA (Parker & Jones, 1865)

1865 *Uvigerina (Sagrina) raphanus* Parker & Jones, *Phil. Trans.*, 155, 346, pl. 18, figs 16, 17.
1884 *Sagrina raphanus* Parker & Jones; Brady, 585, pl. 75, figs 21-24.
1913 *Siphogenerina raphanus* (Parker & Jones); Cushman, 108, pl. 46, figs 1-5.

Only a few specimens, at Stations 135 (176 m) and 247 (128 m).

Genus BULIMINA d'Orbigny, 1826

BULIMINA MARGINATA d'Orbigny, 1826

1826 *Bulimina marginata* d'Orbigny, No. 4, pl. 12, figs 10-12.
1884 *Bulimina marginata* d'Orbigny; Brady, 405, pl. 51, figs 3-5.
1911 *Bulimina marginata* d'Orbigny; Cushman, 83, fig. 136.
1921 *Bulimina marginata* d'Orbigny; Cushman, 159.

Very few specimens occur.

Genus REUSSELLA Galloway, 1933

REUSSELLA SPINULOSA (Reuss, 1850)

1850 *Verneuilina spinulosa* Reuss, *Denkschr. Akad. Wiss. Wien*, 1, 374, pl. 47, fig. 12.
1911 *Verneuilina spinulosa* Reuss; Cushman, 55, fig. 88.
1921 *Verneuilina spinulosa* Reuss; Cushman, 141, pl. 27, fig. 5.
1928 *Reussella spinulosa* (Reuss); Albani, 107, pl. 8, figs 12, 13.

The few specimens present are all of the type of Albani (1968).

Genus UVIGERINA d'Orbigny, 1826

UVIGERINA ASPERULA Czjzek, 1848

1848 *Uvigerina asperula* Czjzek, *Haidinger's Nat. Abh.*, 2, 146, pl. 13, figs 14, 15.
1884 *Uvigerina asperula* Czjzek; Brady, 578, pl. 75, figs 6-8.
1913 *Uvigerina asperula* Czjzek; Cushman, 101, pl. 43, fig. 1.
1921 *Uvigerina asperula* Czjzek; Cushman, 274, pl. 54, fig. 5.

One specimen, at Station 209 (95 m).

UVIGERINA PEREGRINA Cushman, 1923

1884 *Uvigerina pygmaea* d'Orbigny; Brady, 575, pl. 74, figs 11, 12.
1913 *Uvigerina pygmaea* d'Orbigny; Cushman, 96, pl. 42, fig. 1.
1923 *Uvigerina peregrina* Cushman, 166, pl. 42, figs 7-10.
1960 *Euuvigerina peregrina* (Cushman); Barker, 154, pl. 74, figs 11, 12.

Very few specimens occur at several stations.

UVIGERINA PROBOSCIDEA Schwager, 1866

1886 *Uvigerina proboscidea* Schwager, *Novara Exped., geol. Theil,* 2, 250, pl. 7, fig. 96.
1913 *Uvigerina proboscidea* Schwager; Cushman, 94, pl. 42, fig. 2.
1942 *Uvigerina proboscidea* Schwager; Cushman, 49, pl. 14, figs 1-4.

The tests are short and fusiform; the later chambers tend to become uniserial. The inflated chambers are ornamented with numerous short spines. The aperture is at the end of a short neck. Although not present in all the stations this species is the most abundant of the genus.

Genus SIPHOUVIGERINA Parr, 1950

SIPHOUVIGERINA PORRECTA (Brady, 1879)

(Pl. A, fig. 3)

1879 *Uvigerina porrecta* Brady, 60, pl. 8, figs 15, 16.
1884 *Uvigerina porrecta* Brady; Brady, 577, pl. 74, figs 21-23.
1913 *Uvigerina porrecta* Brady; Cushman, 99, pl. 44, fig. 2.
1968 *Siphouvigerina porrecta* (Brady); Albani, 108, pl. 8, fig. 11.

This species is quite abundant along Traverse 2, but is absent along the other two traverses. Figured specimen: Station 210 (88 m).

Genus TRIFARINA Cushman, 1923

TRIFARINA BRADYI Cushman, 1923

1884 *Rhabdogonium tricarinatum* (d'Orbigny); Brady, 525, pl. 67, figs 1-3.
1913 *Triplasia tricarinata* (d'Orbigny); Cushman, 62, pl. 39, fig. 2.
1921 *Triplasia tricarinata* (d'Orbigny); Cushman, 219.
1923 *Trifarina bradyi* Cushman, 99, pl. 22, figs 3-9.
1960 *Trifarina bradyi* Cushman; Barker, 140, pl. 67, figs 1-3.

Very few specimens occur sparsely in all three traverses.

Genus DISCORBINELLA Cushman & Martin, 1935

DISCORBINELLA SUBBERTHELOTI (Cushman, 1924)

1924 *Discorbis subbertheloti* Cushman, 33.
1960 *Discopulvinulina subbertheloti* (Cushman); Barker, 184, pl. 89, fig. 10.

Very few specimens.

Genus NEOCONORBINA Hofker, 1951

NEOCONORBINA TERQUEMI (Rzehak, 1888)

1876 *Rosalina orbicularis* Terquem, *Anim. sur la Plage de Dunkerque,* 75, pl. 9, fig. 4.
1884 *Discorbina orbicularis* (Terquem); Brady, 647, pl. 88, figs 4-8.
1915 *Discorbis orbicularis* (Terquem); Cushman, 16, pl. 11, fig. 1.
1921 *Discorbis orbicularis* (Terquem); Cushman, 305.
1960 *Neoconorbina terquemi* (Rzehak); Barker, 182, pl. 88, figs 4-8.

A few specimens occur at Stations 270 (119 m) and 247 (128 m).

Genus ROSALINA d'Orbigny, 1826

ROSALINA BERTHELOTI d'Orbigny, 1839

1839b *Rosalina bertheloti* d'Orbigny, 135, pl. 1, figs 28-30.
1884 *Discorbina bertheloti* (d'Orbigny); Brady, 650, pl. 89, figs 10-12.
1968 *Rosalina bertheloti* d'Orbigny; Albani, 109, pl. 8, figs 19, 20, 25, 26.

This species is abundant at many stations, particularly in the shallow section of each traverse.

Genus CANCRIS Montfort, 1808

CANCRIS OBLONGUS (Williamson, 1858)

1858 *Rotalina oblonga* Williamson, *Recent Brit. Foram.,* 51, pl. 4, figs 98-100.
1942 *Cancris oblongus* (Williamson); Cushman & Todd, 80, pl. 20, fig. 4.
1960 *Cancris oblongus* (Williamson); Barker, 218, pl. 106, fig. 4.

Several specimens, some reaching large dimensions for the species, occur along Traverse 1.

Genus BAGGINA Cushman, 1926

BAGGINA PHILIPPINENSIS (Cushman, 1921)

1921 *Pulvinulina philippinensis* Cushman, 331, pl. 58, fig. 2.
1960 *Baggina philippinensis* (Cushman); Barker, 218, pl. 106, fig. 7.

Very few specimens have been found, in the shallow section of Traverse 3.

Genus SIPHONINA Reuss, 1850

SIPHONINA TUBULOSA Cushman, 1924

(Pl. A, figs 4, 5)

1884 *Truncatulina reticulata* (Czjzek); Brady, 669, pl. 96, figs 5-7.
1915 *Siphonina reticulata* (Czjzek); Cushman, 43, pl. 16, fig. 4.
1924 *Siphonina tubulosa* Cushman, 40, pl. 13, figs 1, 2.
1960 *Siphonina tubulosa* Cushman; Barker, 198, pl. 96, figs 5-7.
Present in deep water, particularly below 350 m. Figured specimen: Station 201 (285 m).

Genus CARPENTERIA Gray, 1858

CARPENTARIA PROTEIFORMIS Goës, 1882

1882 *Carpenteria balaniformis* var. *proteiformis* Goës, *Konigl. Svensk Vet. Akad. Handl.,* 19, 94, pl. 6, figs 208-214; pl. 7, figs 215-219.
1884 *Carpenteria proteiformis* Goës; Brady, 679, pl. 97, figs 8-14.
1915 *Carpenteria proteiformis* Goës; Cushman, 49, pl. 20, fig. 2; pl. 21, fig. 2.
1921 *Carpenteria proteiformis* Goës; Cushman, 361, pl. 73, figs 2, 3.
Although considered by Cushman (1921) a characteristic species of the coral reef regions, it is very rare in the material studied.

Genus LOXOSTOMUM Ehrenberg, 1854

LOXOSTOMUM AMYGDALAEFORMIS (Brady, 1881)

(Pl. A, fig. 6)

1881 *Bolivina amygdalaeformis* Brady, 59.
1911 *Bolivina amygdalaeformis* Brady; Cushman, 42, fig. 69.
1937 *Loxostoma amygdalaeformis* (Brady); Cushman, 183, pl. 21, figs 21-23.
1960 *Loxostomum amygdalaeformis* (Brady); Barker, 110, pl. 53, figs 28, 29.
The test is fusiform and slightly compressed, with rounded periphery. The chambers are obscured by the ornamentation which consists of numerous anastomosing raised costae. The aperture is terminal and elliptical. This species is present at many stations, but is abundant at Station 136 (122 m) only. Figured specimen: Station 136.

Genus CASSIDULINA d'Orbigny, 1826

CASSIDULINA PACIFICA Cushman, 1925

1925 *Cassidulina pacifica* Cushman, *Contr. Cushman Lab.,* 1(3), 24.
1960 *Cassidulina pacifica* Cushman; Barker, 232, pl. 113, fig. 8.
Several specimens occur at Stations 270 (119 m) and 227 (330 m).

Genus CHILOSTOMELLA Reuss *in* Czjzek, 1849

CHILOSTOMELLA OOLINA Schwager, 1878

1878 *Chilostomella oolina* Schwager, *Boll. Uff. geol. ital. Roma,* 527, pl. 1, fig. 16.
1884 *Chilostomella ovoidea* Reuss; Brady, 436, pl. 55, figs 12-23.
1960 *Chilostomella oolina* Schwager; Barker, 112, pl. 55, figs 12-14, 17, 18.
This typical species is very abundant at Station 136 (122 m), where it is one of the three most common species.

Genus NONION Montfort, 1808

NONION PACIFICUM (Cushman, 1924)

1924 *Nonionina umbilicatula* (Montagu) var. *pacifica* Cushman, *Carnegie Inst. Wash. Publ.* 342, 48, pl. 16, fig. 3.
1939 *Nonion pacificum* (Cushman); Cushman, 25, pl. 6, fig. 25.
Four specimens only have been found, at Station 226 (347 m).

Genus NONIONELLA Cushman, 1926

NONIONELLA TURGIDA (Williamson, 1858)

1858 *Rotalina turgida* Williamson, *Recent Brit. Foram.,* 50, pl. 4, figs 95-97.
1884 *Nonionina turgida* (Williamson); Brady, 731, pl. 109, figs 17-19.
1914 *Nonionina turgida* (Williamson); Cushman, 29, pl. 15, fig. 3.
Several specimens occur sparsely in the material studied.

Genus ANOMALINA d'Orbigny, 1826

ANOMALINA CORONATA Parker & Jones, 1857

1857 *Anomalina coronata* Parker & Jones, *Ann. Mag. nat. Hist., Ser.* 2(19), 294, pl. 10, figs 15, 16.
1915 *Anomalina coronata* Parker & Jones; Cushman, 47, pl. 18, fig. 5.
1921 *Anomalina coronata* Parker & Jones; Cushman, 326, pl. 61, fig. 2.
Three specimens occur at Station 227 (330 m).

ANOMALINA NONIONOIDES Parr, 1932

1932 *Anomalina nonionoides* Parr, 2, 231, pl. 22, fig. 38.
1968 *Anomalina nonionoides* Parr; Albani, 117, pl. 10, fig. 11.
The few specimens found appear to be the most equatorial record of this species.

ANOMALINA POLYMORPHA Costa, 1856

1856 *Anomalina polymorpha* Costa, *Atti. Accad. Pont.*, 7, 252, pl. 21, figs 7, 9.
1915 *Anomalina polymorpha* Costa; Cushman, 47, pl. 19, figs 3, 4.
1921 *Anomalina polymorpha* Costa; Cushman, 324, pl. 61, fig. 3.
Three specimens occur at Station 227 (330 m).

Genus HOEGLUNDINA Brotzen, 1948
HOEGLUNDINA ELEGANS (d'Orbigny, 1826)
(Pl. A, fig. 7)

1826 *Rotalia elegans* d'Orbigny, 276, No. 54.
1884 *Pulvinulina elegans* (d'Orbigny); Brady, 699, pl. 105, figs 4-6.
1915 *Pulvinulina elegans* (d'Orbigny); Cushman, 63, pl. 26, fig. 3.
1960 *Höglundina elegans* (d'Orbigny); Barker, 216, pl. 105, figs 4-6.
The tests are generally large, biconvex and with rounded periphery. The many chambers show clearly the typical ornamentation which consists of an irregular pattern of lines, dots, and zones of opaque calcite against a background of clear shell material. The aperture is a slit on the umbilical end of the apertural face. This species is widely recorded from the tropical Pacific and is quite common in this material, especially in deep waters, where it reaches some 30 percent of the total population. Figured specimen: Station 135 (176 m).

Genus SPIRILLINA Ehrenberg, 1843
SPIRILLINA VIVIPARA Ehrenberg, 1841

1841 *Spirillina vivipara* Ehrenberg, *Abh. Akad. Wiss. Berlin,* 442, pl. 3, fig. 41.
1915 *Spirillina vivipara* Ehrenberg; Cushman, 3, pl. 1, figs 1, 2.
Very few specimens only.

Genus ASTEROROTALIA Hofker, 1950
ASTEROROTALIA INFLATA (Millet, 1904)

1904 *Rotalia schroeteriana* var. *inflata* Millet, *J. Roy. microsc. Soc.*, 504, pl. 10, fig. 5.
1965 *Asterorotalia inflata* (Millet); Albani, 63, pl. 6, figs 8-10.
This typical species occurs in fairly shallow water along Traverse 1.

Genus ELPHIDIUM Montfort, 1808
ELPHIDIUM CRATICULATUM (Fichtel & Moll, 1798)

1798 *Nautilus craticulatus* Fichtel & Moll, *Test. Micr.*, 51, pl. 5, figs h-k.
1939 *Elphidium craticulatum* (Fichtel & Moll); Cushman, 56, pl. 15, figs 14-17.
1968 *Elphidium craticulatum* (Fichtel & Moll); Albani, 111, pl. 9, figs 19, 20.
Present in shallow waters.

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PLATE A

Fig. 1. *Dentalina communis* d'Orbigny; side view, x 20.

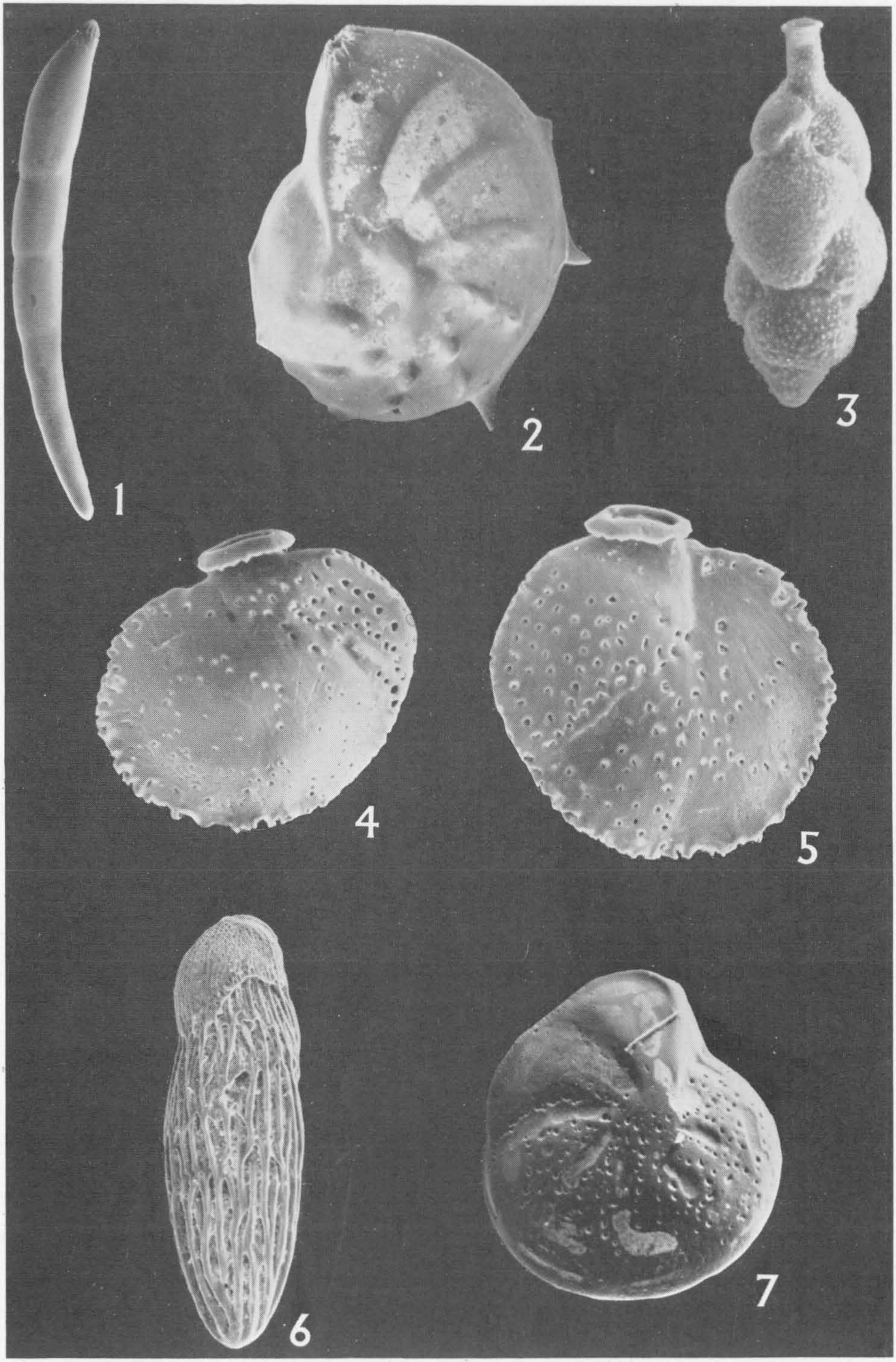
Fig. 2. *Lenticulina echinata* (d'Orbigny); side view, x 40.

Fig. 3. *Siphouvigerina porrecta* (Brady); side view, x 200.

Figs 4, 5. *Siphonina tubulosa* Cushman; opposite views, x 110.

Fig. 6. *Loxostomum amygdalaeformis* (Brady); side view, x 70.

Fig. 7. *Hoeglundina elegans* (d'Orbigny); ventral view, x 70.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APPENDIX 2

STATION DATA AND SAMPLE DESCRIPTIONS

NOTES

1. Times are all GMT + 8 hours.
2. Depths are in metres uncorrected for tidal and sound velocity variations.
3. An asterisk indicates that either a sea-bed photograph, or a photomicrograph of the sediment, is reproduced in the text.
4. In the sample descriptions, the terms *mud* and *muddy* are used to describe all material finer than sand size. Sediments with over 50% sand-size grains are called *calcarenites* and those with over 50% silt + clay are called *muds;* the amount of the subsidiary component is indicated by the following arbitrary values; *slightly muddy* (or sandy) 5-25%; *muddy* (or sandy) 26-33%; *very muddy* (or sandy) 33-50%. Precise textural data are given in Appendix 3. The term *shelly* refers to organic debris in the gravel (+2 mm) fraction, and *foraminiferal* distinguishes sediments rich in Globigerinidae; benthic Foraminifera are abundant in nearly all calcarenites. All sand-size subspherical carbonate grains, many of which have polished surfaces, are referred to as *oolitic,* although the regular internal structure of the oolites is often lacking (see text). *Slightly quartzose* and *slightly glauconitic* indicate that about 5% of the sample consists of optically identifiable quartz and glauconite; *quartzose* and *glauconitic* indicate that 10-40% consists of these minerals.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
113	22/10/67	0550	13°16′	123°37′	282	Grey and brown oolitic limestone. No unconsolidated sediment.*
114	22/10/67	1350	13°23′	123°46′	192	Grey oolitic limestone. No unconsolidated sediment.
115	22/10/67	1805	13°28′	124°03′	22	Coarse shell debris and living coral. Heywood Shoal.
116	22/10/67	2300	13°43′	124°14′	112	Grey-green shelly muddy calcarenite.
117	23/10/67	0300	13°59′	124°27′	82	Grey-green shelly very muddy calcarenite.
118	23/10/67	0700	14°14′	124°39′	68	Grey-green shelly very muddy calcarenite.
119	23/10/67	0926	14°25′	124°47′	51	Grey-green shelly very muddy calcarenite.
120	23/10/67	1150	14°38′	124°56′	44	Grey-green shelly very muddy quartzose calcarenite.
121	23/10/67	1348	14°49′	124°56′	44	Grey-green shelly very sandy quartzose calcareous mud.
122	23/10/67	1555	14°42′	124°43′	57	Grey-green shelly slightly sandy calcareous mud.
123	23/10/67	2000	14°33′	124°28′	60	Grey-green shelly very sandy calcareous mud.
124	23/10/67	2300	14°20′	124°20′	80	Grey-green shelly very sandy calcareous mud.
125	24/10/67	0300	14°08′	124°11′	99	Grey-green shelly very muddy calcarenite.
126	24/10/67	0630	13°59′	124°05′	97	Grey-green slightly sandy calcareous mud.
127	24/10/67	1300	13°54′	123°54′	18	Coarse shell debris and living coral. Echuca Shoal.
128	24/10/67	2000	13°42′	123°57′	144	Grey-green shelly very sandy calcareous mud.
129	24/10/67	2300	13°32′	123°51′	181	Grey-brown shelly foraminiferal calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
130	25/10/67	0300	13°21′	123°45′	196	Grey-brown shelly slightly glauconitic foraminiferal calcarenite.
131	25/10/67	0630	13°09′	123°39′	280	Grey-brown foraminiferal calcarenite.
132	26/10/67	2330	13°35′	123°24′	325	Light brown foraminiferal calcarenite.*
133	27/10/67	0300	13°45′	123°32′	261	Grey-green slightly muddy and glauconitic foraminiferal oolite.
134	27/10/67	0630	13°53′	123°39′	199	Grey-green very muddy foraminiferal calcarenite.
135	27/10/67	1005	14°02′	123°47′	176	Grey-green shelly sandy calcareous mud.
136	27/10/67	1502	14°10′	123°54′	122	Grey-green very muddy slightly quartzose calcarenite.
137	27/10/67	1915	14°21′	124°04′	115	Grey-green shelly slightly muddy and quartzose oolitic calcarenite.
138	27/10/67	2300	14°30′	124°12′	90	Grey-green shelly very sandy calcareous mud.
139	28/10/67	0230	14°38′	124°19′	71	Grey-green shelly very muddy calcarenite.
140	28/10/67	0500	14°43′	124°24′	64	Grey-green shelly very muddy calcarenite.
141	6/11/67	1130	17°51′	121°45′	53	Grey-green shelly slightly quartzose calcarenite.
142	6/11/67	1500	17°37′	121°40′	57	Light brown shelly calcarenite.
143	6/11/67	1800	17°25′	121°36′	55	Grey-brown shelly calcarenite.
144	6/11/67	2100	17°16′	121°33′	60	Grey-green shelly slightly muddy and glauconitic calcarenite.
145	7/11/67	0000	17°06′	121°30′	57	Grey-green shelly calcarenite.
146	7/11/67	0300	16°57′	121°27′	42	Grey-brown shelly calcarenite.
147	7/11/67	0600	16°48′	121°24′	40	Grey-brown shelly calcarenite.
148	7/11/67	0830	16°40′	121°23′	42	Grey-brown shelly slightly muddy calcarenite.
149	7/11/67	1145	16°32′	121°29′	51	Light brown shelly calcarenite.
150	7/11/67	1450	16°25′	121°35′	55	Light brown shelly calcarenite.
151	7/11/67	1745	16°18′	121°40′	69	Light brown shelly calcarenite.
152	7/11/67	2045	16°10′	121°48′	64	Brown shelly calcarenite.
153	7/11/67	2345	16°01′	121°57′	60	Grey-green shelly slightly muddy and quartzose calcarenite.
154	8/11/67	0245	15°51′	122°06′	53	Grey-green shelly slightly muddy quartzose calcarenite.
155	8/11/67	0545	15°42′	122°14′	53	Grey-green shelly slightly muddy quartzose calcarenite.
156	8/11/67	0845	15°33′	122°23′	80	Brown-green shelly very quartzose calcarenite.
157	8/11/67	1215	15°23′	122°32′	75	Brown-green shelly muddy quartzose calcarenite.
158	8/11/67	1545	15°13′	122°41′	91	Brown-green shelly slightly muddy and quartzose oolite.
159	8/11/67	2200	15°04′	122°50′	101	Brown-green shelly slightly muddy and quartzose oolitic calcarenite.
160	9/11/67	0115	14°54′	122°59′	101	Brown shelly slightly quartzose oolite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
161	9/11/67	0415	14°45′	123°08′	95	Brown shelly slightly muddy oolite.
162	9/11/67	1800	14°07′	123°33′	128	Grey-green shelly slightly muddy calcarenite.
163	9/11/67	2100	14°17′	123°40′	119	Grey-green shelly oolitic calcarenite.
164	10/11/67	0000	14°28′	123°48′	97	Grey-green shelly slightly muddy oolitic calcarenite.
165	10/11/67	0300	14°38′	123°57′	79	Grey-green shelly muddy calcarenite.
166	10/11/67	0600	14°48′	124°06′	58	Grey-green shelly very muddy calcarenite.
167	10/11/67	0900	14°57′	124°15′	55	Grey-green shelly very muddy calcarenite.
168	10/11/67	1340	14°58′	124°01′	53	Grey-green shelly slightly muddy calcarenite.
169	10/11/67	1700	14°48′	123°51′	69	Grey-green shelly calcarenite.
170	10/11/67	2030	14°37′	123°40′	80	Grey-brown shelly calcarenite.
171	11/11/67	0000	14°26′	123°30′	93	Grey-green shelly slightly muddy oolitic calcarenite.
172	11/11/67	0300	14°17′	123°21′	104	Grey-green shelly oolitic calcarenite.
173	11/11/67	0600	14°07′	123°12′	256	Grey shelly slightly sandy calcareous mud.
174	11/11/67	1145	14°13′	122°59′	159	Grey-brown shelly oolite.
175	11/11/67	1600	14°25′	123°05′	104	Grey-green shelly pelletal limestone. No unconsolidated sediment.
176	11/11/67	1833	14°34′	123°09′	115	Grey-green shelly oolite.
177	11/11/67	2130	14°46′	123°15′	106	Brown shelly slightly quartzose oolitic calcarenite.
178	12/11/67	0030	14°57′	123°20′	84	Brown shelly oolitic calcarenite.
179	12/11/67	0420	15°02′	123°05′	95	Grey-green shelly slightly muddy and glauconitic quartzose oolitic calcarenite.
180	12/11/67	0730	14°46′	123°04′	110	Brown-green shelly slightly quartzose oolite.
181	12/11/67	1130	14°29′	123°03′	124	Brown-green shelly oolite.*
182	12/11/67	1530	14°12′	123°02′	194	Brown shelly oolite.
183	12/11/67	2030	14°01′	123°02′	289	Grey-green shelly pelletal foraminiferal calcarenite.
184	13/11/67	0020	14°07′	122°52′	256	Light brown shelly foraminiferal calcarenite.
185	13/11/67	0330	14°21′	123°05′	130	Light brown foraminiferal calcarenite.
186	13/11/67	0715	14°35′	123°18′	113	Dark brown-green shelly oolite.
187	13/11/67	0920	14°41′	123°25′	110	Dark brown-green shelly oolite.
188	13/11/67	1225	14°42′	123°12′	106	Brown-green shelly oolite.
189	13/11/67	1710	14°36′	122°47′	176	Grey-green shelly very muddy slightly glauconitic foraminiferal calcarenite.
190	13/11/67	2030	14°26′	122°36′	229	Light grey-green slightly sandy calcareous mud.
191	13/11/67	2345	14°34′	122°25′	247	Light grey-green shelly slightly sandy calcareous mud.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
192	14/11/67	0300	14°44′	122°33′	106	Grey-green shelly slightly muddy oolitic calcarenite.
193	14/11/67	0615	14°52′	122°39′	102	Grey-green shelly slightly muddy calcarenite.
194	14/11/67	0940	15°03′	122°47′	102	Dark brown-green shelly slightly quartzose calcarenite.
195	14/11/67	1315	15°13′	122°39′	91	Grey-green shelly slightly muddy and quartzose oolitic calcarenite.
196	14/11/67	1600	15°02′	122°35′	88	Grey-green shelly slightly quartzose calcarenite.
197	14/11/67	2030	14°51′	122°31′	95	Grey-green shelly oolitic calcarenite.
198	14/11/67	2330	14°39′	122°26′	165	Grey-green very sandy calcareous mud.
199	15/11/67	0130	14°28′	122°22′	265	Grey-green foraminiferal calcarenite.
200	15/11/67	0430	14°32′	122°13′	263	Grey-green slightly muddy foraminiferal calcarenite.
201	15/11/67	0800	14°38′	122°01′	285	Grey-green very muddy foraminiferal quartzose calcarenite.
202	17/11/67	2000	14°23′	121°54′	366	Grey-green very sandy foraminiferal calcareous mud.
203	17/11/67	2400	14°32′	121°52′	292	Grey-green sandy foraminiferal calcareous mud.
204	18/11/67	0345	14°41′	121°51′	265	Grey-green very muddy slightly quartzose foraminiferal calcarenite.
205	18/11/67	0730	14°50′	121°49′	230	Light brown shelly foraminiferal calcarenite.
206	18/11/67	1100	14°59′	121°45′	132	Brown shelly slightly oolitic calcarenite.
207	18/11/67	1530	15°15′	121°42′	102	Brown and white shell gravel.
208	18/11/67	2000	15°06′	121°59′	84	Brown shelly calcarenite.
209	18/11/67	2335	14°57′	122°16′	95	Brown shelly calcarenite.
210	19/11/67	0440	15°12′	122°21′	88	Brown-green shelly slightly quartzose calcarenite.
211	19/11/67	0900	15°21′	122°03′	91	Light brown shelly calcarenite.
212	19/11/67	1220	15°29′	121°48′	44	Light brown shelly muddy calcarenite.
213	19/11/67	1545	15°42′	121°57′	69	Brown shelly calcarenite.
214	19/11/67	1900	15°53′	121°47′	58	Grey-green shelly slightly quartzose calcarenite.
215	19/11/67	2220	15°40′	121°40′	80	Grey-brown shelly slightly quartzose calcarenite.
216	20/11/67	0140	15°27′	121°31′	210	Grey-brown shelly oolitic calcarenite.
217	20/11/67	0520	15°12′	121°22′	329	Light grey-green very muddy foraminiferal calcarenite.
218	20/11/67	0900	15°24′	121°11′	285	Grey-green shelly muddy slightly quartzose and glauconitic foraminiferal calcarenite.
219	20/11/67	1345	15°40′	121°20′	106	Brown and white shell gravel with a little oolitic calcarenite.
220	20/11/67	1732	15°53′	121°28′	95	Grey-brown shelly slightly quartzose calcarenite.
221	20/11/67	2017	16°04′	121°34′	62	Shell gravel.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
222	20/11/67	2345	16°16′	121°24′	67	Light brown shelly foraminiferal calcarenite.
223	21/11/67	0240	16°07′	121°12′	77	Light brown shelly calcarenite.
224	21/11/67	0600	15°57′	120°58′	146	Light grey-brown shelly calcarenite.
225	21/11/67	0906	15°48′	120°46′	307	Light grey-brown shelly muddy foraminiferal calcarenite.
226	21/11/67	1250	16°01′	120°35′	347	Grey-green very sandy foraminiferal calcareous mud.
227	21/11/67	1900	16°16′	120°45′	330	Light grey-brown shelly foraminiferal slightly glauconitic calcarenite.
228	21/11/67	2005	16°18′	120°46′	283	No sample. Probably rocky sea floor.
229	21/11/67	2330	16°29′	120°59′	143	Grey-brown shelly slightly glauconitic foraminiferal calcarenite.
230	22/11/67	0240	16°46′	121°03′	110	Grey-brown shelly oolite.
231	22/11/67	0600	17°03′	121°07′	106	Light brown shelly oolitic calcarenite.
232	22/11/67	0900	17°20′	121°11′	95	Brown shelly oolitic calcarenite.*
233	22/11/67	1240	17°37′	121°15′	93	Light brown shelly oolitic calcarenite.
234	22/11/67	1615	17°55′	121°19′	79	Green-brown shelly slightly quartzose and glauconitic oolitic calcarenite.
235	22/11/67	1935	18°12′	121°24′	57	Light brown shelly slightly glauconitic calcarenite.
236	26/11/67	1850	17°41′	121°00′	104	Green-brown shelly slightly quartzose oolite.
237	26/11/67	2110	17°44′	120°47′	108	Light brown shelly oolite.
238	26/11/67	2345	17°49′	120°28′	119	No sample.
239	27/11/67	0320	17°52′	120°13′	146	Grey-green foraminiferal calcarenite.
240	27/11/67	0550	17°56′	119°57′	148	Grey-green foraminiferal calcarenite.
241	27/11/67	0815	18°00′	119°42′	141	Grey-green slightly muddy foraminiferal calcarenite.
242	27/11/67	1110	18°03′	119°28′	148	Grey-green very sandy foraminiferal calcareous mud.
243	27/11/67	1450	18°06′	119°15′	121	Grey-green very sandy foraminiferal calcareous mud.
244	27/11/67	1810	17°51′	119°11′	271	Green-brown slightly muddy and glauconitic foraminiferal calcarenite.
245	27/11/67	2140	17°48′	119°27′	235	No sample.
246	29/11/67	1345	17°27′	120°53′	117	Dark green-brown shelly oolitic calcarenite.
247	29/11/67	1705	17°13′	120°50′	128	Grey-brown shelly foraminiferal calcarenite.
248	29/11/67	2020	16°58′	120°47′	194	Light brown shelly foraminiferal calcarenite.
249	30/11/67	0110	16°49′	120°42′	322	Grey-brown shelly slightly muddy and glauconitic foraminiferal calcarenite.
250	30/11/67	0444	17°04′	120°35′	238	No sample. Probably rocky sea floor.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
251	30/11/67	0805	17°20′	120°28′	194	No sample. Probably rocky sea floor.
252	30/11/67	1130	17°34′	120°22′	188	Light brown shelly foraminiferal calcarenite.
253	30/11/67	1550	17°54′	120°28′	121	Light grey-brown shelly foraminiferal calcarenite.
254	30/11/67	1850	18°06′	120°31′	91	Grey-green slightly muddy foraminiferal calcarenite.
255	30/11/67	2210	18°11′	120°15′	102	Light grey-brown oolite.
256	1/12/67	0140	18°16′	119°59′	113	Light grey-brown shelly oolite.
257	1/12/67	0505	18°20′	119°43′	115	Grey-green shelly slightly muddy oolite.
258	1/12/67	0830	18°24′	119°28′	119	Light grey-green shelly slightly muddy oolite.
259	1/12/67	1320	17°41′	119°26′	256	Light brown shelly foraminiferal calcarenite.
260	1/12/67	1550	17°32′	119°30′	320	Light brown shelly slightly muddy foraminiferal calcarenite.
261	1/12/67	2008	17°42′	119°47′	247	Brown shelly slightly glauconitic foraminiferal calcarenite.
262	1/12/67	2345	17°25′	119°50′	296	Grey-brown shelly slightly glauconitic foraminiferal calcarenite.
263	2/12/67	0040	17°35′	120°08′	229	Light brown slightly glauconitic foraminiferal calcarenite.
264	2/12/67	0725	17°22′	120°14′	272	Dark green-brown shelly glauconitic foraminiferal calcarenite.
265	2/12/67	1045	17°05′	120°21′	344	Light brown shelly foraminiferal calcarenite.
266	2/12/67	1830	16°52′	120°46′	347	No sample. Possibly rocky sea floor.
267	3/12/67	0130	15°46′	121°18′	102	Light grey-brown slightly quartzose and glauconitic calcarenite.
268	3/12/67	0445	15°40′	121°03′	293	Light grey-brown shelly foraminiferal calcarenite.
269	3/12/67	1140	14°54′	121°36′	296	Green-brown glauconitic calcarenite. Insufficient recovered for analysis.
270	3/12/67	1500	14°52′	122°04′	119	Brown shelly oolite.
271	3/12/67	1800	14°44′	122°16′	198	Light grey-green sandy foraminiferal calcareous mud.
272	3/12/67	2300	14°26′	122°51′	112	Dark green-brown shelly oolite.
273	4/12/67	0118	14°12′	122°47′	272	Green-brown shelly glauconitic foraminiferal calcarenite.
274	4/12/67	0915	14°00′	123°24′	227	Grey-brown shelly slightly glauconitic calcarenite.
275	4/12/67	1300	13°32′	123°40′	190	Dark green-brown shelly slightly quartzose calcarenite.
546	3/10/68	1520	14°08′	123°12′	289	Grey-green shelly very sandy calcareous mud.*
547	6/10/68	0815	18°25′	119°50′	115	Light brown shelly oolite.
548	6/10/68	1000	18°32′	119°37′	112	Light brown shelly slightly muddy oolite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
549	6/10/68	1200	18°40′	119°23′	117	Light brown shelly oolite.
550	6/10/68	1340	18°27′	119°14′	124	Green-grey shelly slightly muddy foraminiferal oolitic calcarenite.
551	6/10/68	1540	18°13′	119°03′	135	Grey-brown very sandy foraminiferal calcareous mud.
552	6/10/68	1730	18°00′	118°56′	261	Grey-brown foraminiferal calcarenite.
553	7/10/68	0745	18°46′	119°17′	106	Grey-brown shelly oolite.
554	7/10/68	0940	18°33′	119°08′	128	Grey-green shelly oolitic calcarenite.
555	7/10/68	1145	18°25′	119°00′	150	Grey-green shelly foraminiferal calcarenite.
556	7/10/68	1330	18°09′	118°49′	216	Brown-grey shelly sandy calcareous mud.
557	7/10/68	1520	18°13′	118°37′	229	Brown-grey shelly slightly muddy foraminiferal calcarenite.
558	7/10/68	1715	18°25′	118°41′	133	Grey-green very sandy foraminiferal calcareous mud.
559	7/10/68	1910	18°39′	118°45′	137	Grey-green shelly slightly muddy oolitic calcarenite.
560	9/10/68	0535	19°30′	119°03′	38	Brown shelly oolitic calcarenite.
561	9/10/68	0720	19°17′	118°55′	69	Green-brown shelly oolitic calcarenite.
562	9/10/68	0910	19°04′	118°50′	84	Green-brown shelly oolitic calcarenite.
563	9/10/68	1100	18°53′	118°37′	88	Grey-green shelly slightly muddy oolitic calcarenite.
564	9/10/68	1240	18°40′	118°29′	132	Grey-green shelly oolitic calcarenite.
565	9/10/68	1440	18°32′	118°22′	132	Grey-green shelly very sandy slightly glauconitic foraminiferal calcareous mud.
566	9/10/68	1610	18°20′	118°15′	234	Grey-green shelly very muddy calcarenite.
567	9/10/68	1730	18°11′	118°09′	325	Grey-green very sandy foraminiferal calcareous mud.
568	9/10/68	1850	18°03′	118°05′	576	Grey sandy calcareous mud.
569	10/10/68	0700	18°10′	118°22′	296	Grey-green slightly muddy foraminiferal calcarenite.
570	10/10/68	1020	18°20′	118°29′	201	Grey shelly very muddy calcarenite.
571	10/10/68	1215	18°32′	118°36′	143	Grey shelly muddy oolitic calcarenite.
572	10/10/68	1340	18°41′	118°40′	137	Light grey shelly slightly muddy oolite.
573	10/10/68	1630	19°03′	118°29′	80	Light brown shelly oolite.
574	10/10/68	1810	18°54′	118°21′	119	Light grey shelly slightly muddy oolite.
575	10/10/68	2005	18°42′	118°12′	133	Light grey slightly muddy foraminiferal calcarenite.
576	11/10/68	0745	18°30′	118°03′	238	Light grey shelly slightly muddy calcarenite.
577	11/10/68	0940	18°19′	117°52′	399	Light grey sandy calcareous mud.
578	11/10/68	1145	18°26′	117°38′	448	Light grey very muddy foraminiferal calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
579	11/10/68	1340	18°37′	117°48′	261	Light grey shelly very sandy foraminiferal calcareous mud.
580	11/10/68	1530	18°48′	117°57′	152	Light grey shelly slightly muddy calcarenite.
581	11/10/68	1730	18°58′	118°07′	122	Light grey shelly slightly muddy oolitic calcarenite.
582	11/10/68	1900	19°07′	118°15′	88	Brown shelly slightly muddy oolitic calcarenite.
583	13/10/68	0623	18°42′	118°58′	128	Light grey shelly oolitic calcarenite.
584	13/10/68	0750	18°48′	118°47′	115	Very light grey shelly slightly muddy oolite.
585	13/10/68	1010	18°51′	119°05′	95	Brown shelly oolite.
586	13/10/68	1150	18°44′	119°17′	104	Grey-brown shelly oolite.
587	13/10/68	1340	18°43′	119°32′	104	Greenish grey shelly oolite.
588	13/10/68	1520	18°38′	119°43′	104	Brown-grey shelly oolite.
589	13/10/68	1700	18°32′	119°57′	102	Brown-grey shelly oolite.
590	13/10/68	1840	18°24′	120°10′	101	Brown-grey shelly slightly muddy oolite.
591	14/10/68	1100	17°22′	120°05′	300	Grey-brown shelly glauconitic foraminiferal calcarenite.
592	17/10/68	0555	18°37′	120°19′	86	Grey-brown shelly slightly muddy oolite.
593	17/10/68	0800	18°42′	120°06′	90	Brown-grey shelly slightly muddy oolite.
594	17/10/68	0955	18°49′	119°51′	82	Light brown shelly oolite.
595	17/10/68	1140	18°55′	119°37′	73	Light brown shelly slightly muddy oolite.
596	17/10/68	1325	18°59′	119°24′	77	Brown shelly oolite.
597	17/10/68	1510	19°04′	119°11′	82	Light brown shelly oolite.
598	17/10/68	1830	19°13′	118°46′	77	Light brown shelly calcarenite.
599	17/10/68	2115	19°21′	118°23′	73	Brown shelly oolitic calcarenite.
600	18/10/68	1000	19°30′	118°10′	60	Brown shelly calcarenite.*
601	18/10/68	1140	19°20′	118°03′	79	Brown shelly oolitic calcarenite.
602	18/10/68	1335	19°08′	117°54′	110	Brown-grey shelly slightly muddy calcarenite.
603	18/10/68	1520	18°54′	117°43′	146	Light grey very muddy foraminiferal calcarenite.
604	18/10/68	1845	18°44′	117°37′	274	Light grey very sandy foraminiferal calcareous mud.
605	19/10/68	0810	19°30′	117°51′	71	Brown shelly oolitic calcarenite.
606	19/10/68	1000	19°19′	117°42′	91	Grey-brown shelly oolitic calcarenite.
607	19/10/68	1145	19°05′	117°32′	137	Light grey sandy foraminiferal calcareous mud.
608	19/10/68	1340	18°54′	117°27′	183	Light grey shelly very muddy calcarenite.
609	19/10/68	1530	18°40′	117°22′	338	Light grey sandy calcareous mud.
610	19/10/68	1730	18°32′	117°27′	457	Light grey very muddy calcarenite.
611	20/10/68	0840	18°49′	117°05′	366	Light grey very muddy calcarenite.
612	20/10/68	1030	18°56′	117°10′	293	Light grey very muddy foraminiferal calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
613	20/10/68	1325	19°08′	117°12′	155	Green-grey shelly muddy foraminiferal calcarenite.
614	20/10/68	1515	19°17′	117°20′	119	Green-grey shelly muddy oolitic calcarenite.
615	20/10/68	1700	19°27′	117°27′	82	Brown-grey shelly slightly muddy oolitic foraminiferal calcarenite.
616	20/10/68	1820	19°33′	117°17′	86	Brown-grey shelly slightly muddy foraminiferal calcarenite.
617	21/10/68	0855	19°26′	117°14′	91	Brown-grey slightly muddy foraminiferal calcarenite.
618	21/10/68	1045	19°15′	117°07′	113	Light grey sandy foraminiferal calcareous mud
619	21/10/68	1225	19°04′	116°57′	219	Very light grey slightly sandy calcareous mud.
620	21/10/68	1430	18°51′	116°47′	366	Light grey very sandy foraminiferal calcareous mud.
621	21/10/68	1610	18°56′	116°39′	338	Green-grey very muddy foraminiferal calcarenite.
622	21/10/68	1810	19°06′	116°47′	247	Green-grey shelly very muddy foraminiferal calcarenite.
623	22/10/68	0725	19°11′	116°58′	133	Green-grey very sandy foraminiferal calcareous mud.
624	22/10/68	0845	19°17′	117°06′	119	Green-grey shelly slightly muddy foraminiferal calcarenite.
625	22/10/68	1040	19°17′	116°52′	119	Green-grey very sandy foraminiferal calcareous mud.
626	22/10/68	1135	19°26′	116°55′	82	Green-grey shelly slightly muddy oolite.
627	22/10/68	1330	19°35′	117°01′	73	Greenish grey-brown shelly slightly muddy oolitic calcarenite.
628	22/10/68	1500	19°33′	116°49′	26	Whitish brown encrusted coarse shell debris.
629	23/10/68	0700	19°07′	116°27′	274	Light grey-brown slightly muddy foraminiferal calcarenite.
630	23/10/68	0820	19°15′	116°30′	174	Light grey-brown shelly slightly muddy calcarenite.
631	23/10/68	0940	19°23′	116°36′	128	Light grey very sandy foraminiferal calcareous mud.
632	23/10/68	1110	19°30′	116°42′	60	Light grey-brown shelly slightly muddy oolite.
633	23/10/68	1250	19°37′	116°32′	66	Light brown oolitic calcarenite.
634	23/10/68	1400	19°30′	116°26′	117	Light green-grey very muddy oolitic foraminiferal calcarenite.
635	23/10/68	1530	19°21′	116°24′	146	Light green-grey slightly muddy foraminiferal calcarenite.
636	23/10/68	1700	19°14′	116°12′	283	Light grey very muddy foraminiferal calcarenite.
637	23/10/68	1830	19°00′	116°07′	357	Light grey very muddy foraminiferal calcarenite.
638	24/10/68	0715	19°12′	115°57′	274	Light grey foraminiferal calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
639	24/10/68	0842	19°21′	116°02′	168	Grey-brown shelly foraminiferal calcarenite.
640	24/10/68	0955	19°29′	116°09′	122	Green-grey shelly slightly muddy foraminiferal calcarenite.
641	24/10/68	1130	19°40′	116°14′	99	Green-brown shelly slightly muddy oolite.
642	24/10/68	1255	19°46′	116°22′	64	Greenish grey-brown shelly slightly muddy calcarenite.
643	24/10/68	1420	19°52′	116°11′	73	Light brown shelly slightly glauconitic calcarenite.
644	24/10/68	1535	19°44′	116°05′	101	Green-grey shelly slightly muddy calcarenite.
645	24/10/68	1650	19°38′	115°58′	132	Light brown foraminiferal calcarenite.
646	24/10/68	1820	19°25′	115°51′	256	Light brown slightly muddy foraminiferal calcarenite.
647	25/10/68	0900	21°06′	115°40′	15	Dark brown shelly slightly muddy quartzose calcarenite.
648	26/10/68	1800	20°47′	115°48′	18	Green-brown shelly slightly quartzose calcarenite.
649	26/10/68	2130	20°27′	115°48′	37	Green-brown shelly oolitic calcarenite.
650	27/10/68	0645	19°54′	115°48′	75	Green-grey shelly slightly muddy calcarenite.
651	27/10/68	0755	19°46′	115°48′	122	Green-grey very muddy foraminiferal calcarenite.
652	27/10/68	0910	19°39′	115°48′	146	Green-grey slightly muddy foraminiferal calcarenite.
653	27/10/68	0958	19°32′	115°49′	183	Light brown foraminiferal calcarenite.
654	27/10/68	1137	19°24′	115°52′	238	Light brown shelly foraminiferal calcarenite.
655	27/10/68	1255	19°16′	115°55′	293	Light brown shelly slightly muddy foraminiferal calcarenite.
656	27/10/68	1410	19°08′	115°53′	347	Light brown shelly very muddy foraminiferal calcarenite.*
657	28/10/68	0730	20°00′	116°00′	64	Green-brown shelly slightly muddy and quartzose calcarenite.
658	28/10/68	0845	19°51′	115°54′	82	Green-brown shelly slightly muddy oolitic calcarenite.
659	28/10/68	1056	19°35′	115°42′	183	Green-grey shelly slightly muddy calcarenite.
660	28/10/68	1200	19°29′	115°38′	320	Light grey-brown foraminiferal calcarenite.
661	28/10/68	1500	19°32′	115°29′	274	Light grey shelly muddy foraminiferal calcarenite.
662	28/10/68	1610	19°41′	115°32′	95	Green-grey shelly slightly muddy oolite.
663	28/10/68	1730	19°45′	115°36′	27	Algal and coralline limestone and coarse shell debris. Rankin Bank.
664	29/10/68	1035	19°50′	115°40′	68	Green-brown shelly oolitic calcarenite.
665	29/10/68	1155	19°57′	115°43′	77	Green-grey shelly slightly muddy oolitic calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
666	29/10/68	1325	20°06′	115°35′	73	Green-brown shelly oolite.
667	29/10/68	1440	19°58′	115°27′	82	Light brown shelly oolite.
668	29/10/68	1600	19°49′	115°22′	155	Green-grey shelly slightly muddy oolite.
669	30/10/68	0620	19°59′	115°20′	101	Light brown shelly oolite.
670	30/10/68	0710	20°03′	115°18′	82	Light brown shelly oolite.*
671	30/10/68	0815	19°53′	115°14′	247	Green-grey slightly sandy calcareous mud.
672	30/10/68	1115	20°03′	115°01′	219	Green-grey very muddy foraminiferal calcarenite.
673	30/10/68	1245	20°10′	115°08′	110	Green-brown slightly muddy oolitic calcarenite.
674	30/10/68	1440	20°24′	115°16′	55	Brown shelly oolite.
675	30/10/68	1625	20°32′	115°10′	55	Green-brown shelly oolite.
676	30/10/68	1745	20°23′	115°02′	91	Green-brown shelly slightly muddy and quartzose calcarenite.
677	30/10/68	1850	20°21′	114°54′	165	Green-grey very sandy calcareous mud.
678	4/11/68	1035	20°50′	115°05′	84	Light green-grey sandy calcareous mud.
679	4/11/68	1152	20°38′	114°55′	95	Light green-grey very sandy calcareous mud.
680	12/11/68	1034	20°30′	114°51′	119	Light green-grey shelly very muddy slightly glauconitic and oolitic calcarenite.
681	12/11/68	1330	20°46′	114°51′	104	Light green-grey very sandy foraminiferal calcareous mud.
682	12/11/68	1510	20°55′	115°01′	86	Light green-grey very sandy foraminiferal calcareous mud.
683	13/11/68	0800	20°31′	114°51′	124	Light green-grey very sandy foraminiferal calcareous mud.
684	13/11/68	1125	20°22′	115°02′	95	Light green-grey slightly muddy and quartzose foraminiferal calcarenite.
685	13/11/68	1500	20°18′	115°08′	86	Green-brown slightly muddy and quartzose foraminiferal calcarenite.
686	13/11/68	1655	20°07′	115°00′	192	Green-brown very muddy slightly quartzose foraminiferal calcarenite.
687	14/11/68	0850	19°58′	115°08′	219	Green-brown muddy foraminiferal calcarenite.
688	14/11/68	1015	20°02′	115°15′	95	Light brown shelly oolite.
689	14/11/68	1130	20°12′	115°19′	49	Brown shelly oolitic calcarenite.
690	14/11/68	1235	20°09′	115°26′	69	Brown shelly oolitic calcarenite.
691	14/11/68	1525	19°47′	115°20′	201	Greenish brown-grey slightly muddy oolite.
692	14/11/68	1837	19°43′	115°25′	201	Green-grey very muddy foraminiferal calcarenite.
693	14/11/68	1245	19°47′	116°30′	80	Light brown shelly oolitic calcarenite.
694	22/11/68	0952	18°18′	118°14′	238	Light grey muddy foraminiferal calcarenite.
695	22/11/68	1125	18°15′	118°26′	238	Light brown-grey shelly slightly muddy foraminiferal calcarenite.

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
696	22/11/68	1430	17°54′	118°41′	283	Light grey very muddy foraminiferal calcarenite.
697	22/11/68	1600	17°47′	118°50′	309	Light grey very sandy foraminiferal calcareous mud.
698	23/11/68	0810	19°05′	118°59′	82	Brown shelly oolitic calcarenite.
699	23/11/68	1143	18°34′	118°53′	135	Green-grey shelly slightly muddy oolitic calcarenite.
700	23/11/68	1550	18°04′	118°30′	274	Green-grey shelly slightly muddy foraminiferal calcarenite.
701	23/11/68	1725	18°04′	118°23′	333	Greenish brown-grey shelly slightly muddy and glauconitic foraminiferal calcarenite.
702	24/11/68	0745	18°20′	118°02′	293	Greenish brown-grey very sandy foraminiferal calcareous mud.*
703	24/11/68	0940	18°30′	118°11′	229	Light grey sandy foraminiferal calcareous mud.
704	24/11/68	1150	18°38′	118°20′	137	Light grey very sandy foraminiferal calcareous mud.
705	24/11/68	1354	18°52′	118°29′	122	Light green-grey shelly slightly muddy oolitic calcarenite.
706	24/11/68	1550	19°03′	118°37′	88	Brown shelly oolite.
707	25/11/68	0700	18°27′	117°49′	307	Green-grey very sandy foraminiferal calcareous mud.
708	25/11/68	1025	18°42′	118°02′	161	Green-grey shelly calcarenite.
709	25/11/68	1230	18°50′	118°18′	137	Green-grey shelly very muddy oolitic calcarenite.
710	25/11/68	1350	18°54′	118°12′	122	Green-grey shelly slightly muddy oolitic calcarenite.
711	25/11/68	1540	19°05′	118°23′	82	Green-grey shelly slightly muddy oolitic calcarenite.
712	25/11/68	1730	19°17′	118°33′	75	Green-brown shelly oolitic calcarenite.
713	26/11/68	0702	19°21′	118°13′	73	Brown shelly oolitic calcarenite.
714	26/11/68	0854	19°11′	118°05′	86	Brown shelly calcarenite.
715	26/11/68	1040	19°02′	117°56′	128	Light green-grey shelly slightly muddy oolite.
716	26/11/68	1230	18°50′	117°48′	152	Light green-grey shelly muddy foraminiferal calcarenite.
717	26/11/68	1430	18°39′	117°40′	265	Light green-grey slightly sandy foraminiferal calcareous mud.
718	26/11/68	1650	18°53′	117°34′	190	Light green-grey shelly very sandy foraminiferal calcareous mud.
719	27/11/68	0715	19°04′	117°39′	128	Light green-grey very sandy foraminiferal calcareous mud.
720	27/11/68	0830	19°13′	117°45′	91	Brown-grey shelly slightly muddy oolitic calcarenite.
721	27/11/68	1001	19°22′	117°53′	73	Brown shelly slightly muddy oolitic calcarenite.
722	27/11/68	1200	19°39′	117°50′	58	Green-brown shelly calcarenite.
723	27/11/68	1345	19°30′	117°39′	66	Brown shelly oolitic calcarenite.
724	28/11/68	0850	19°27′	117°30′	82	Green-grey shelly slightly muddy oolitic calcarenite.*

Station No.	Date	Time	Position S. Lat.	Position E. Long.	Depth (m)	Description and Remarks
725	28/11/68	1041	19°18′	117°24′	124	Light green-grey very muddy foraminiferal calcarenite.*
726	28/11/68	1335	18°58′	117°19′	227	Very light grey shelly slightly sandy foraminiferal calcareous mud.*
727	28/11/68	1530	18°46′	117°14′	311	Very light grey slightly sandy foraminiferal calcareous mud.
728	29/11/68	0700	20°21′	117°21′	22	Brown shelly calcarenite.
729	29/11/68	0914	20°07′	117°18′	42	Brown shelly oolitic calcarenite.
730	29/11/68	1125	19°52′	117°09′	62	Greyish brown-green shelly slightly quartzose calcarenite.
731	29/11/68	1358	19°31′	117°08′	82	Greyish brown-green shelly slightly muddy and glauconitic oolitic calcarenite.
732	29/11/68	1628	19°25′	116°47′	110	Greyish brown-green shelly slightly muddy oolitic calcarenite.
733	29/11/68	1752	19°16′	116°43′	137	Green-grey very sandy foraminiferal calcareous mud.
734	30/11/68	0705	19°06′	116°37′	282	Green-grey shelly very muddy foraminiferal calcarenite.
735	30/11/68	0920	19°06′	116°19′	293	Light green-grey shelly slightly muddy foraminiferal calcarenite.
736	30/11/68	1110	19°16′	116°25′	165	Light green-grey shelly slightly muddy foraminiferal calcarenite.
737	30/11/68	1330	19°13′	116°06′	271	Light green-grey shelly muddy foraminiferal calcarenite.
738	30/11/68	1500	19°22′	116°11′	146	Light green-grey shelly slightly muddy foraminiferal calcarenite.
739	30/11/68	1635	19°32′	116°19′	117	Light green-grey very sandy foraminiferal calcarenite.
740	30/11/68	1810	19°42′	116°28′	64	Light brown shelly calcarenite.
741	1/12/68	0732	19°50′	116°13′	68	Grey-green shelly slightly muddy calcarenite.
742	1/12/68	0905	19°38′	116°08′	110	Light grey shelly slightly muddy oolitic calcarenite.
743	1/12/68	1040	19°29′	116°01′	137	Light grey-brown shelly calcarenite.
744	1/12/68	1310	19°45′	115°58′	110	Grey-green shelly slightly muddy calcarenite.
745	1/12/68	1523	19°58′	116°07′	64	Brown shelly calcarenite.
746	2/12/68	0724	19°53′	115°35′	69	Brown shelly oolitic calcarenite.
747	2/12/68	0828	19°58′	115°39′	73	Grey-brown shelly oolitic calcarenite.
748	2/12/68	0947	20°07′	115°47′	64	Brown shelly calcarenite.

APPENDIX 3

SEDIMENT TEXTURES, CARBONATE AND PHOSPHATE CONTENT

Notes:

(1) Sample numbers are those of the stations where they were collected; BMR Registered Numbers of the samples are 67630113 to 67630275 and 68630546 to 68630748, the last three digits being the same as the station numbers.

(2) Calcium carbonate percentages are calculated on the assumption that all CO_2 is combined $CaCO_3$, and refer to the whole sample.

(3) Phosphorus pentoxide values less than 0.2 percent are not recorded. Analyses refer to the whole sample.

(4) Textural descriptions of the –2 mm fractions are based on the 10-compartment classification of Shepard (1954) and on the Wentworth scale.

(5) An asterisk indicates that insufficient material was available for full mechanical analysis, and the textural descriptions are based on visual estimation.

(6) n.d. = not determined.

Sample No.	Gravel (%)	Sand (% of –2 mm fraction)	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
113	—	—	—	—	97	0.2	Rock.
114	—	—	—	—	95	0.8	Rock.
115	100	—	—	—	98	—	Gravel.
116	20	69	21	10	87	—	Silty sand with gravel.
117	10	50	36	14	66	—	Silty sand with gravel.
118	9	65	22	13	67	—	Silty sand with gravel.
119	39	53	29	18	78	—	Silty sand with gravel.
120	3	66	20	14	49	—	Silty sand with gravel.
121	9	45	32	23	48	—	Sand-silt-clay with gravel.
122	2	15	45	40	47	—	Clayey silt with gravel.
123	9	42	37	21	62	—	Sand-silt-clay with gravel.
124	12	43	36	21	72	—	Sand-silt-clay with gravel.
125	21	63	27	10	72	—	Silty sand with gravel.
126	—	22	58	20	78	—	Sandy silt.
127	100	—	—	—	99	—	Gravel.
128	4	34	38	28	70	—	Sand-silt-clay with gravel.
129	26	100	—	—	72	2.8	Sand with gravel.
130	9	100	—	—	99	—	Sand with gravel.
131*	—	100	—	—	n.d.	n.d.	Sand.
132*	—	100	—	—	85	—	Sand.
133	—	83	13	4	66	2.6	Sand.
134	—	62	16	22	87	—	Clayey sand.
135	13	33	32	35	80	—	Sand-silt-clay with gravel.
136	—	52	33	15	70	—	Silty sand.
137	18	82	11	7	80	—	Sand with gravel.
138	9	49	43	8	70	—	Silty sand with gravel.
139	15	50	40	10	74	—	Silty sand with gravel.
140	18	52	37	11	72	—	Silty sand with gravel.
141	31	100	—	—	86	0.3	Sand with gravel.
142	63	100	—	—	90	0.2	Sand with gravel.
143	47	100	—	—	92	—	Sand with gravel.
144	27	95	3	2	85	—	Sand with gravel.
145	7	100	—	—	84	—	Sand with gravel.
146	6	100	—	—	89	—	Sand with gravel.
147	39	100	—	—	98	—	Sand with gravel.
148	60	77	14	9	90	—	Sand with gravel.
149	40	100	—	—	95	—	Sand with gravel.
150	64	100	—	—	93	—	Sand with gravel.
151	68	100	—	—	92	—	Sand with gravel.

Sample No.	Gravel (%)	Sand	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
		(% of –2 mm fraction)					
152	35	100	—	—	86	—	Sand with gravel.
153	28	80	13	7	75	—	Sand with gravel.
154	27	92	5	3	76	—	Sand with gravel.
155	21	86	9	5	60	—	Sand with gravel.
156	17	100	—	—	42	0.2	Sand with gravel.
157	26	73	20	7	61	0.3	Silty sand with gravel.
158	50	87	8	5	75	—	Sand with gravel.
159	21	85	12	3	68	—	Sand with gravel.
160	14	100	—	—	85	—	Sand with gravel.
161	24	92	6	2	88	—	Sand with gravel.
162	56	90	7	3	93	—	Sand with gravel.
163	25	100	—	—	92	—	Sand with gravel.
164	9	86	10	4	89	—	Sand with gravel.
165	22	72	24	4	81	—	Sand with gravel.
166	20	54	31	15	76	—	Silty sand with gravel.
167	15	52	34	14	64	—	Silty sand with gravel.
168	34	89	10	1	88	—	Sand with gravel.
169	66	100	—	—	89	—	Sand with gravel.
170	40	100	—	—	88	—	Sand with gravel.
171	18	93	4	3	98	—	Sand with gravel.
172	40	100	—	—	88	—	Sand with gravel.
173	19	23	67	10	64	0.4	Sandy silt with gravel.
174	47	100	—	—	90	0.2	Sand with gravel.
175	—	—	—	—	95	—	Rock.
176	24	100	—	—	93	—	Sand with gravel.
177	26	100	—	—	83	0.2	Sand with gravel.
178	38	100	—	—	82	—	Sand with gravel.
179	21	88	10	2	64	—	Sand with gravel.
180	59	100	—	—	86	—	Sand with gravel.
181	27	100	—	—	95	—	Sand with gravel.
182	40	100	—	—	95	0.2	Sand with gravel.
183	22	100	—	—	87	0.3	Sand with gravel.
184	18	100	—	—	85	0.4	Sand with gravel.
185*	—	100	—	—	93	—	Sand.
186	46	100	—	—	81	—	Sand with gravel.
187	32	100	—	—	81	—	Sand with gravel.
188	23	100	—	—	89	—	Sand with gravel.
189	3	59	30	11	67	—	Silty sand with gravel.
190	—	18	43	39	83	—	Clayey silt.
191	4	8	56	36	84	—	Clayey silt with gravel.
192	12	86	11	3	92	—	Sand with gravel.
193	16	91	7	2	79	—	Sand with gravel.
194	88	100	—	—	87	—	Sand with gravel.
195	46	82	12	6	80	—	Sand with gravel.
196	85	100	—	—	81	—	Sand with gravel.
197	41	100	—	—	89	—	Sand with gravel.
198	—	34	55	11	64	—	Sandy silt.
199*	1	100	—	—	n.d.	n.d.	Sand with gravel.
200	—	87	7	6	72	—	Sand.
201	—	50	36	14	63	—	Silty sand.
202*	—	40	40	20	67	—	Silty sand.
203*	—	30	40	30	78	—	Sand-silt-clay.
204	—	64	26	10	67	—	Silty sand.
205	5	100	—	—	88	—	Sand with gravel.
206*	80	100	—	—	85	0.3	Sand with gravel.
207	100	—	—	—	95	—	Gravel.
208	32	100	—	—	95	—	Sand with gravel.
209*	80	100	—	—	84	—	Sand with gravel.
210	29	100	—	—	82	—	Sand with gravel.

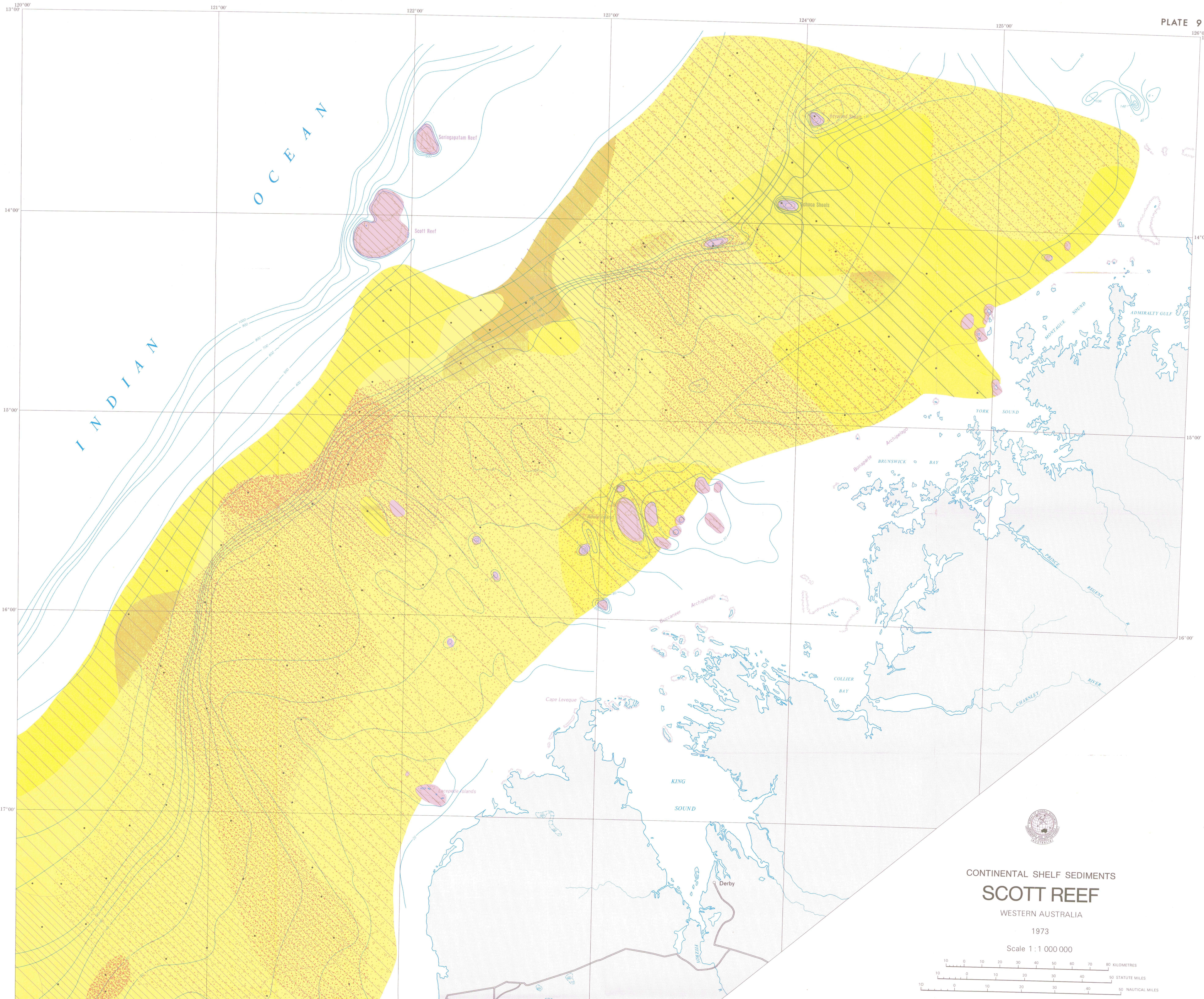
Sample No.	Gravel (%)	Sand (% of –2 mm fraction)	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
211	43	100	—	—	96	—	Sand with gravel.
212	51	69	25	6	90	—	Silty sand with gravel.
213	75	100	—	—	93	—	Sand with gravel.
214	7	100	—	—	76	—	Sand with gravel.
215	36	100	—	—	85	—	Sand with gravel.
216	22	100	—	—	90	—	Sand with gravel.
217	—	50	36	14	77	—	Silty sand.
218*	80	70	25	5	78	0.3	Silty sand with gravel.
219	98	100	—	—	86	—	Sand with gravel.
220	64	100	—	—	92	—	Sand with gravel.
221	100	—	—	—	99	—	Gravel.
222	41	100	—	—	93	—	Sand with gravel.
223	34	100	—	—	92	—	Sand with gravel.
224	59	100	—	—	91	—	Sand with gravel.
225	13	72	26	2	87	—	Silty sand with gravel.
226	—	35	45	20	77	—	Sandy silt.
227	35	100	—	—	98	—	Sand with gravel.
229	24	100	—	—	93	0.5	Sand with gravel.
230	30	100	—	—	92	0.4	Sand with gravel.
231	44	100	—	—	96	—	Sand with gravel.
232	84	100	—	—	92	0.2	Sand with gravel.
233	39	100	—	—	97	—	Sand with gravel.
234	29	100	—	—	89	—	Sand with gravel.
235	9	100	—	—	93	—	Sand with gravel.
236	12	100	—	—	93	—	Sand with gravel.
237	20	100	—	—	95	—	Sand with gravel.
239	—	100	—	—	92	—	Sand.
240	—	100	—	—	85	—	Sand.
241	—	83	10	7	84	—	Sand.
242	—	42	52	6	89	—	Sandy silt.
243	—	48	45	7	90	—	Silty sand.
244*	—	80	15	5	85	0.9	Sand.
246	28	100	—	—	97	0.3	Sand with gravel.
247*	80	100	—	—	95	0.4	Sand with gravel.
248	28	100	—	—	97	0.2	Sand with gravel.
249	13	79	12	9	89	—	Sand with gravel.
252	27	100	—	—	96	—	Sand with gravel.
253*	70	100	—	—	90	0.7	Sand with gravel.
254	—	86	12	2	80	—	Sand.
255*	—	100	—	—	n.d.	n.d.	Sand.
256	1	100	—	—	98	0.2	Sand with gravel.
257	32	91	7	2	95	—	Sand with gravel.
258	32	80	10	10	96	—	Sand with gravel.
259	20	100	—	—	92	0.9	Sand with gravel.
260	5	95	2	3	93	—	Sand with gravel.
261	41	100	—	—	80	3.0	Sand with gravel.
262	92	100	—	—	92	—	Sand with gravel.
263	—	100	—	—	93	—	Sand.
264	22	100	—	—	79	3.6	Sand with gravel.
265	7	100	—	—	80	—	Sand with gravel.
267	—	100	—	—	80	—	Sand.
268	8	100	—	—	89	—	Sand with gravel.
271	—	26	57	17	87	0.2	Sandy silt.
272	8	100	—	—	92	—	Sand with gravel.
273	9	100	—	—	92	—	Sand with gravel.
274	24	100	—	—	91	0.2	Sand with gravel.
270	42	100	—	—	94	—	Sand with gravel.
275	23	100	—	—	87	1.5	Sand with gravel.

Sample No.	Gravel (%)	Sand	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
		(% of –2 mm fraction)					
546	14	11	47	42	82	0.2	Clayey silt with gravel.
547	13	96	3	1	92	0.2	Sand with gravel.
548	17	94	4	2	94	0.2	Sand with gravel.
549	10	97	2	1	92	0.3	Sand with gravel.
550	11	90	9	1	94	0.2	Sand with gravel.
551	—	47	48	5	92	—	Sandy silt.
552	27	100	—	—	94	—	Sand with gravel.
553	14	100	—	—	98	—	Sand with gravel.
554	14	100	—	—	94	0.4	Sand with gravel.
555	12	100	—	—	87	0.2	Sand with gravel.
556	6	33	53	14	91	0.3	Sandy silt with gravel.
557	7	75	16	9	92	0.2	Sand with gravel.
558	—	43	48	9	78	—	Sandy silt.
559	24	78	18	4	86	0.4	Sand with gravel.
560	16	100	—	—	86	—	Sand with gravel.
561	16	100	—	—	93	—	Sand with gravel.
562	18	100	—	—	93	—	Sand with gravel.
563	41	88	10	2	91	0.2	Sand with gravel.
564	18	100	—	—	88	0.9	Sand with gravel.
565	9	48	51	1	89	—	Sandy silt with gravel.
566	8	59	35	6	92	—	Silty sand with gravel.
567	—	39	48	13	71	—	Sandy silt.
568	—	29	48	23	85	—	Sandy silt.
569	—	89	9	2	93	—	Sand.
570	18	64	29	7	86	0.4	Silty sand with gravel.
571	36	75	21	4	91	0.3	Sand with gravel.
572	11	94	5	1	94	—	Sand with gravel.
573	3	100	—	—	99	0.2	Sand with gravel.
574	13	92	7	1	99	—	Sand with gravel.
575*	—	90	8	2	95	—	Sand.
576	15	88	9	3	99	0.2	Sand with gravel.
577	—	27	56	17	95	—	Sandy silt.
578	—	50	35	15	93	—	Silty sand.
579	3	40	47	13	96	—	Sandy silt with gravel.
580	14	76	21	3	95	0.2	Sand with gravel.
581	19	78	19	3	90	0.2	Sand with gravel.
582	31	94	6	0	98	—	Sand with gravel.
583	16	97	2	1	93	—	Sand with gravel.
584	43	88	11	1	96	—	Sand with gravel.
585	17	100	—	—	94	—	Sand with gravel.
586	12	100	—	—	93	0.4	Sand with gravel.
587	12	100	—	—	94	0.2	Sand with gravel.
588	11	100	—	—	95	—	Sand with gravel.
589	19	100	—	—	96	—	Sand with gravel.
590	8	88	9	3	92	—	Sand with gravel.
591	8	100	—	—	77	3.3	Sand with gravel.
592	20	88	8	4	92	0.2	Sand with gravel.
593	5	95	1	4	94	—	Sand with gravel.
594	9	100	—	—	93	—	Sand with gravel.
595	13	95	2	3	95	—	Sand with gravel.
596	11	100	—	—	95	—	Sand with gravel.
597	19	100	—	—	94	0.2	Sand with gravel.
598	13	100	—	—	93	—	Sand with gravel.
599	7	100	—	—	92	—	Sand with gravel.
600	33	100	—	—	92	—	Sand with gravel.
601	26	100	—	—	92	—	Sand with gravel.
602	7	92	6	2	92	0.2	Sand with gravel.
603	—	56	36	8	91	—	Silty sand.
604	—	45	42	13	90	—	Silty sand.

Sample No.	Gravel (%)	Sand	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
		(% of –2 mm fraction)					
605	11	100	—	—	96	—	Sand with gravel.
606	19	100	—	—	95	—	Sand with gravel.
607	—	31	57	12	94	—	Sandy silt.
608	10	63	27	10	94	0.2	Silty sand with gravel.
609	—	33	41	26	83	0.2	Sand-silt-clay.
610*	—	60	30	10	n.d.	n.d.	Silty sand.
611	—	64	33	3	87	—	Silty sand.
612*	—	50	40	10	n.d.	n.d.	Silty sand.
613	7	73	21	6	90	0.2	Silty sand with gravel.
614	3	70	24	6	92	—	Silty sand with gravel.
615	11	94	4	2	94	0.2	Sand with gravel.
616	17	79	10	11	92	—	Sand with gravel.
617	—	93	5	2	90	—	Sand.
618	—	32	57	11	88	—	Sandy silt.
619	—	23	42	35	94	—	Sand-silt-clay.
620	—	46	35	19	88	—	Silty sand.
621	—	53	34	13	82	—	Silty sand.
622	24	64	31	5	84	0.2	Silty sand with gravel.
623	—	49	41	10	88	—	Silty sand.
624	9	75	23	2	87	—	Sand with gravel.
625	—	46	46	8	87	—	Silty sand.
626	18	86	12	2	92	—	Sand with gravel.
627	16	94	5	1	92	—	Sand with gravel.
628	100	—	—	—	89	—	Gravel.
629*	—	85	10	5	88	0.3	Sand.
630	13	84	10	6	89	0.3	Sand with gravel.
631	—	41	50	9	92	—	Sandy silt.
632	24	94	3	3	94	—	Sand with gravel.
633	—	100	—	—	88	—	Sand.
634	—	63	32	5	90	—	Silty sand.
635	—	79	12	9	92	0.3	Sand.
636	—	50	40	10	91	—	Silty sand.
637	—	66	18	16	78	—	Silty sand.
638	—	100	—	—	90	—	Sand.
639	17	100	—	—	94	0.3	Sand with gravel.
640	5	87	10	3	88	0.3	Sand with gravel.
641	19	82	14	4	86	—	Sand with gravel.
642	16	91	7	2	88	—	Sand with gravel.
643	31	100	—	—	93	—	Sand with gravel.
644	5	77	22	1	88	—	Sand with gravel.
645	—	100	—	—	95	0.5	Sand.
646	—	92	7	1	93	0.2	Sand.
647	3	94	4	2	81	—	Sand with gravel.
648	19	100	—	—	93	—	Sand with gravel.
649	8	100	—	—	98	—	Sand with gravel.
650	6	88	11	1	92	—	Sand with gravel.
651	—	66	30	4	90	—	Silty sand.
652	—	91	7	2	96	0.5	Sand.
653	—	100	—	—	94	0.5	Sand.
654	29	100	—	—	90	0.3	Sand with gravel.
655	8	83	14	3	88	0.2	Sand with gravel.
656	4	64	26	10	91	—	Silty sand with gravel.
657	5	94	4	2	88	—	Sand with gravel.
658	25	87	11	2	94	—	Sand with gravel.
659	12	92	6	2	94	0.4	Sand with gravel.
660	—	100	—	—	96	0.2	Sand.
661	3	57	34	9	92	—	Silty sand with gravel.
662	31	83	14	3	92	—	Sand with gravel.
663	100	—	—	—	n.d.	n.d.	Gravel.

Sample No.	Gravel (%)	Sand (% of –2 mm fraction)	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
664	41	100	—	—	93	0.2	Sand with gravel.
665	22	88	10	2	86	—	Sand with gravel.
666	30	100	—	—	93	—	Sand with gravel.
667	58	100	—	—	95	—	Sand with gravel.
668	3	92	6	2	92	—	Sand with gravel.
669	9	100	—	—	82	—	Sand with gravel.
670	5	100	—	—	89	—	Sand with gravel.
671	—	20	65	15	83	—	Sandy silt.
672	—	50	44	6	85	—	Silty sand.
673	—	82	16	2	87	—	Sand.
674	14	100	—	—	97	—	Sand with gravel.
675	5	100	—	—	94	—	Sand with gravel.
676	3	81	17	2	82	—	Sand with gravel.
677	—	41	52	7	81	—	Sandy silt.
678	—	27	65	8	77	—	Sandy silt.
679	—	36	59	5	82	—	Sandy silt.
680	6	60	36	4	83	—	Silty sand with gravel.
681	—	42	55	3	84	0.2	Sandy silt.
682	—	47	46	7	82	—	Silty sand.
683	—	40	54	6	85	—	Sandy silt.
684	—	87	11	2	84	—	Sand.
685	—	82	17	1	93	—	Sand.
686	—	51	41	8	83	—	Silty sand.
687	—	74	21	5	87	—	Silty sand.
688	10	100	—	—	98	—	Sand with gravel.
689	34	100	—	—	95	—	Sand with gravel.
690	28	100	—	—	96	—	Sand with gravel.
691	—	85	13	2	93	—	Sand.
692	—	64	31	5	86	—	Silty sand.
693	48	100	—	—	92	—	Sand with gravel.
694	—	67	29	4	88	—	Silty sand.
695	9	90	7	3	93	0.3	Sand with gravel.
696	—	62	31	7	86	0.2	Silty sand.
697	—	49	44	7	87	0.2	Silty sand.
698	11	100	—	—	91	0.2	Sand with gravel.
699	32	84	4	2	89	0.9	Sand with gravel.
700	3	95	4	1	94	1.1	Sand with gravel.
701	6	94	5	1	96	0.3	Sand with gravel.
702*	—	35	50	15	n.d.	n.d.	Sandy silt.
703	—	33	50	17	94	—	Sandy silt.
704	—	34	60	6	91	—	Sandy silt.
705	9	89	10	1	94	—	Sand with gravel.
706	14	100	—	—	96	—	Sand with gravel.
707	—	38	48	14	90	—	Sandy silt.
708	23	96	3	1	95	0.3	Sand with gravel.
709	11	59	30	11	94	—	Silty sand with gravel.
710	17	78	17	5	94	—	Sand with gravel.
711	6	94	3	3	95	0.2	Sand with gravel.
712	21	100	—	—	94	—	Sand with gravel.
713	16	100	—	—	91	—	Sand with gravel.
714	8	100	—	—	88	—	Sand with gravel.
715	8	88	9	3	94	—	Sand with gravel.
716	7	71	23	6	89	0.2	Silty sand with gravel.
717	—	15	66	19	89	0.2	Clayey silt.
718	3	37	50	13	89	0.2	Sandy silt with gravel.
719	—	48	46	6	93	—	Silty sand.
720	8	91	8	1	98	—	Sand with gravel.
721	11	95	2	3	97	—	Sand with gravel.
722	14	100	—	—	92	—	Sand with gravel.

Sample No.	Gravel (%)	Sand (% of −2 mm fraction)	Silt	Clay	$CaCO_3$ (%)	P_2O_5 (%)	Textural Classification
723	7	100	—	—	97	—	Sand with gravel.
724	7	92	6	2	96	—	Sand with gravel.
725	—	50	42	8	89	—	Silty sand.
726	7	18	53	29	93	0.2	Clayey silt with gravel.
727	—	22	57	21	84	0.2	Sand-silt-clay.
728	3	100	—	—	91	—	Sand with gravel.
729	21	100	—	—	94	—	Sand with gravel.
730	4	96	3	1	89	—	Sand with gravel.
731	14	93	6	1	95	—	Sand with gravel.
732	16	87	11	2	95	—	Sand with gravel.
733	—	44	48	8	92	—	Sandy silt.
734	9	58	32	10	91	0.2	Silty sand with gravel.
735	12	78	16	6	95	0.2	Sand with gravel.
736	11	75	20	5	94	0.3	Sand with gravel.
737	12	68	27	5	94	0.2	Silty sand with gravel.
738	13	81	14	5	93	0.5	Sand with gravel.
739	—	49	45	6	88	—	Silty sand.
740	11	100	—	—	98	—	Sand with gravel.
741	23	91	8	1	94	—	Sand with gravel.
742	4	78	19	3	91	—	Sand with gravel.
743	13	100	—	—	98	0.3	Sand with gravel.
744	11	77	21	2	93	—	Sand with gravel.
745	25	100	—	—	96	—	Sand with gravel.
746	49	100	—	—	91	—	Sand with gravel.
747	24	100	—	—	95	—	Sand with gravel.
748	13	100	—	—	93	—	Sand with gravel.



CONTINENTAL SHELF SEDIMENTS

SCOTT REEF

WESTERN AUSTRALIA

1973

Scale 1 : 1 000 000

10 0 10 20 30 40 50 60 70 80 KILOMETRES

10 0 10 20 30 40 50 STATUTE MILES

10 0 10 20 30 40 50 NAUTICAL MILES

Lambert Conformal Conic Projection

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Geological reliability: The distribution of sediments is based on analyses of sea bed samples from stations whose positions are marked. Extrapolation between stations, and outside the area sampled, has been guided by bathymetry and by sediment notations on British Admiralty and Australian charts

Bathymetric reliability: Bathymetric contours have been compiled from water depth data collected during Bureau of Mineral Resources marine geophysical survey in 1968, chiefly E–W traverses at 10 nautical miles spacing, and from published and unpublished R.A.N. Hydrographic Service charts

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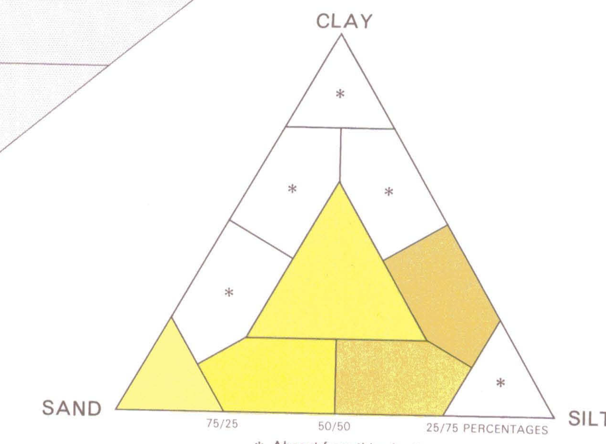

SEDIMENT CLASSIFICATION

Note: The triangular diagram classifies the sediments according to the proportion of sand,-silt-and clay-sized particles they contain. The Wentworth scale is used. The corners of the inner triangle represent 60/20/20 percentages

- Sand
- Silty sand
- Sandy silt
- Clayey silt
- Sand, silt, clay
- > 90 % gravel
- 30–90 % gravel
- 10–30 % gravel
- > 90 % carbonate
- 60–90 % carbonate
- 30–60 % carbonate
- Biohermal limestone

- Sea bed sample station
- 60 Bathymetric contour in metres. Contour intervals 20m (0–200m) and 100m (200–1000m). Contours below 1000m not shown. Some contours have been omitted in areas of steep submarine topography
- 5 Spot depth in metres
- Swamp
- Coral reef
- Highway
- Road

INDEX TO ADJOINING MAPS

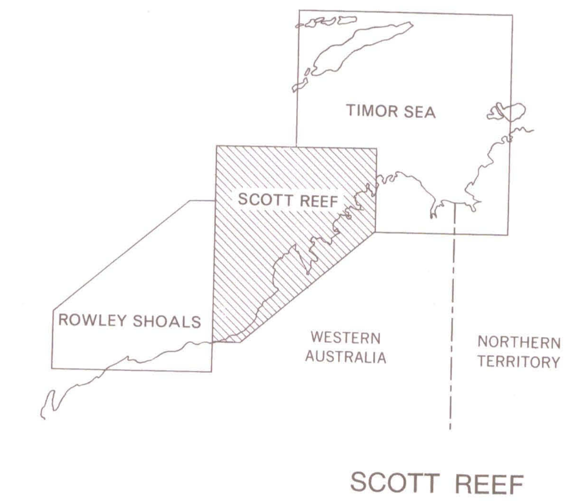

PLATE 10

CONTINENTAL SHELF SEDIMENTS

ROWLEY SHOALS

WESTERN AUSTRALIA

1973

Scale 1 : 1 000 000

Lambert Conformal Conic Projection

Published by the Bureau of Mineral Resources, Geology and Geophysics
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Geology 1971 by H. A. Jones, F. Walraven, R. Geijskes
Compiled 1971 by H. A. Jones
Cartography by Geological Branch, BMR
Drawn 1972 by S. Daric
Printed by Mercury–Walch Pty Ltd., Hobart, Australia

Bibliographic reference: H. A. Jones 1973. Marine Geology of the Northwest Australian Continental Shelf. Bureau of Mineral Resources, Geology and Geophysics. Australian Bulletin 136

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.

Geological reliability: The distribution of sediments is based on analyses of sea bed samples from stations whose positions are marked. Extrapolation between stations, and outside the area sampled, has been guided by bathymetry and by sediment notations on British Admiralty and Australian charts

Bathymetric reliability: Bathymetric contours have been compiled from water depth data collected during Bureau of Mineral Resources marine geophysical survey in 1968, chiefly E–W traverses at 10 nautical miles spacing, and from published and unpublished R.A.N. Hydrographic Service charts

NOT TO BE USED FOR NAVIGATION

SEDIMENT CLASSIFICATION

* Absent from this sheet

Note: The triangular diagram classifies the sediments according to the proportion of sand,-silt-and clay-sized particles they contain. The Wentworth scale is used. The corners of the inner triangle represent 60/20/20 percentages