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The Sediments, Structure, and Morphology of the Northwest Australian Continental Shelf between Rowley Shoals and Monte Bello Islands

Survey 139

by

H.A. Jones

THE SEDIMENTS, STRUCTURE, AND MORPHOLOGY OF THE N.W. AUSTRALIAN CONTINENTAL SHELF BETWEEN ROWLEY SHOALS AND MONTE BELLO ISLANDS

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Contents

Contents
(ii)

TABLES

PLATE

FIGURES

THE SEDIMENTS, STRUCTURE, AND MORPHOLOGY OF THE N.W. AUSTRALIAN CONTINENTAL SHELF BETWEEN ROWLEY SHOALS AND MONTE BELLO ISLANDS.

SUMMARY

This report gives the preliminary results of a survey of the superficial sediments of the continental shelf and upper continental slope off northwestern Australia approximately between the 115°E and 120°E meridians. Two hundred and one bottom sample stations were occupied and about 800 kilometres of continuous seismic profiling was carried out. In the structural interpretation, limited use has also been made of the shallow seismic reflection profiles made during the marine geophysical survey done under contract to the B.M.R. in 1968.

Several unconformities can be recognized in the top few hundred metres of section and one of these can be correlated with reasonable confidence with the regional late-Miocene hiatus. The outcrop or sub-outcrop of this surface is believed to be responsible for the persistent change in slope noted in the area at a water depth of 240 metres and it is also postulated that this surface controls the gently shelving terrace on the continental slope in depths of about 400 metres of water which supports the Rowley Shoals.

A long low ridge, which follows the edge of the continental shelf for a distance of about 300 kilometres, is shown by the seismic profiles to be a constructional feature built up on a flat surface by increased sedimentation in the axial zone. Other features buried in the late Cainozoic section resembling gentle anticlinal structures are also believed to be constructional plano-convex lenses of sediment unrelated to warping.

Calcareous sediments completely dominate the continental shelf which over most of its area is a region of winnowing and sediment transport rather than deposition. Coarse-grained skeletal material and pelletal and oolitic calcarenites cover most of the middle and inner shelf. Fine-grained carbonate sediments with abundant planktonic foraminifera tests occur in the depositional belts of the outer shelf and the continental slope. The sediments are uniformly low in phosphorus. Analyses for P_2O_5 show few values in excess of 1 percent and the maximum recorded was 3.3 percent. Sediments with higher than average phosphate content generally occur in the region of the edge of the shelf.

INTRODUCTION

The geological reconnaissance of the northwest Australian continental shelf started in 1967 (Jones, 1968) was continued in late 1968 when an area extending from the Rowley Shoals south-westwards to the Monte Bello Islands was covered (Fig.1). Sampling of the bottom sediments on a grid pattern was carried out and shallow seismic reflection profiles were obtained. The broad objectives of the survey were to describe and map the superficial sediments, the morphology, and the shallow structure of the middle and outer shelf and the uppermost continental slope. The area was chosen from the limited information available, for its phosphate potential.

The ship chartered for the survey was the motor vessel Espirito Santo, owned by South Australia Fisherman's Co-operative Limited. The Espirito Santo is a single screw steel vessel of 41 metres overall length and 10 metres beam with a cruising speed of 10 knots (Fig.2). 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-over 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, eight days were lost through ship's mechanical trouble and one day through bad weather.

Surveying methods and equipment.

Most bottom samples were collected with a small conical dredge with a lip diameter of 25 cm. A canvas bag, with a polythene bag as an inner liner, was clamped over the open lower end of the dredge to retain the sample. To get better recovery of sediment where the bottom consisted of hard packed sand or cemented shell detritus, a doubled 1-metre 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 found to be more effective than a much heavier weight not rigidly attached to the dredge. The small dredge was worked on 4-mm wire from a fast running, 3 h.p. diesel winch mounted on the stern of the ship.

Where hard sea bottom was suspected, conventional rock dredges with mouth openings of 60 cm and 90 cm were used. These were towed on 9-mm steel wire using the ship's 10-ton trawl winch and the large A-frame on the stern of the vessel (Fig,2). These dredges were constructed from mild steel plate top and bottom, with mesh sides, and removable steel containers at the ends to recover the fine fraction.

Grabs of other designs, where closure is effected on touching bottom, were also used but were found to be less reliable with the varying bottom sediment types and strong currents encountered.

The regular 10-mile spacing of sample stations which was aimed at suffered considerable distortion owing to the largely unpredictable tidal current pattern. Position fixing relied almost entirely in celestial navigation and was assisted by the generally clear sky conditions during the survey. It was usually possible to get a reliable star fixes at dawn and dusk and repeated position lines from the sun during the day, combined with daylight moon and planet observations when possible, allowed the ship's track to be plotted with an accuracy acceptable in a reconnaissance survey of this sort.

Water depth profiles were obtained with the ship's Marconi "Fishgraph 24 Kc/sec echo-sounder. This instrument had a straight line dry paper recorder with a 2-range scale to a maximum depth of 550 metres. Seismic reflection profiles were obtained with a 1000-joule, 3-electrode Sparkarray sound source, a 7-element MP 7 hydrophone, and an Ocean Sonics GDR-T recorder using 19-inch wet paper. Traverses were run at a speed of 5 to 6 knots.

Photographs of the seabed were obtained with an Edgerton Germehansen 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 metres below the frame in which the camera and light source were mounted. This arrangement gave a field of view of about four square metres.

Figure 1. Location map.

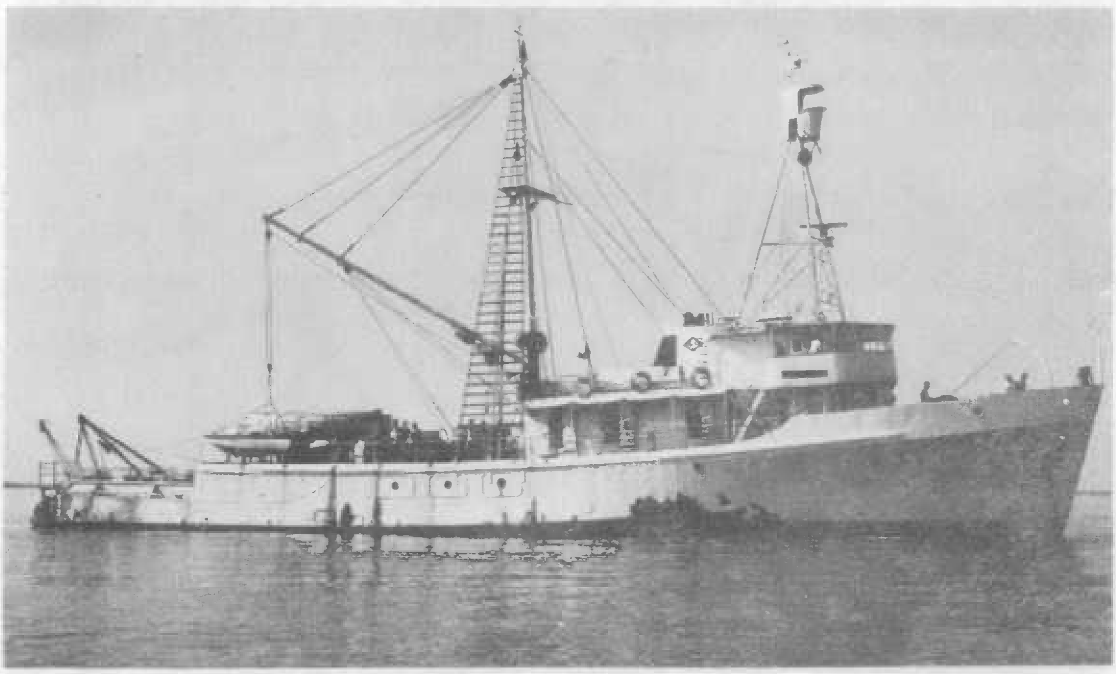

Figure 2. M.V. Espirito Santo. The two frames for handling over the side equipment can be seen on the stern. The Bureau's portable laboratory is obscured behind the lifeboat.

Climate and oceanography

This region lies near the southern limit of influence of the southeast trade wind and of the northwest monsoon, but although both blow for short periods and with less constancy than they do in lower latitudes to the north, they still dominate the climate for part of the year. The southeast trades, in particular, blow with great constancy from May to July, and for a longer period in the northern part of the area. About August, southerly and southwesterly winds tend to replace the easterlies and are well established in September. The transitional period before the onset of the northwest or west monsoon, which usually commences in December, is marked by normally light and variable winds with occasional squalls; during this period diurnal land and sea breezes dominate circulation near the coast. The northeast monsoon is less constant in duration and often shorter than the southeast trades; it usually dominates the weather between December and March and it is during this period most precipitation occurs.

Rainfall and temperature averages for Port Hedland are given in Table 1. Comparison with rainfall figures from other Western Australia coastal stations show that there is a steady increase in precipitation from Port Hedland northeastward; at Broome the rainfall is about twice that at Port Hedland and the division into wet and dry seasons is more sharply defined. West and south of Port Hedland this trend is continued; the average yearly rainfall at Onslow is 235 mm and at Carnarvon 220 mm, and it is spread more evenly through the year in this region.

Table 1. CLIMATIC AVERAGES - PORT HEDLAND.

	Average daily -			Average
	Max. Temp.	Min. Temp.	Mean Temp.	Rainfall.
January	34.6	26.4	30.5	48
February	34.8	26.1	30.5	52
March	35.1	25.4	30.3	78
April	34.0	21.8	27.9	24
May	30.0	17.6	23.8	25
June	26.8	14.4	20.7	24
July	26.3	13.1	19.7	6
August	28.0	14.7	21.3	9
September	30.5	17.0	23.7	1
October	32.0	20.1	26.1	2
November	34.0	23.1	28.5	0
December	£ 34.5	25.3	29.9	8
Year	31.7	20.4	26.1	277

Units: degrees centigrade and millimetres. Taken from Climatic Averages Australia, Bureau of Meteorology, 1956. Figures are based on averages for 30 years (rainfall) and 35 years (temperature).

Information on surface water circulation patterns in the area is very incomplete. According to generalized surface current atlases of the south-eastern Indian Ocean (see, for example, the Australia Pilot Vol. V, US Navy Hydrographic Office Special Publication 53, and Wyrtki, 1961), the surface circulation off Western Australia is dominated by the West Australian Current, which originates in about 30°S. latitude as a branch of the east-flowing Southern Ocean Current. The West Australian Current sets northwards to about 20°S latitude where it swings north-westwards, being maintained by the south-east trades, and eventually joins the west-flowing South Equatorial Current far out in the Indian Ocean in about 105°E longitude. This picture is not fully confirmed by a study of the monthly resultant currents published by the U.S. Hydrographic Office or by the conclusions of C.S.I.R.O. workers, for example Wyrtki (1962), Hamon (1965), 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 north-west Australian coast (Rochford, 1962; Tranter, 1962; Wyrtki, 1962. See also the discussion in Van Andel and Veevers, 1967). Surface water circulation would appear to favour upwelling along the margins of the north-west shelf, particularly during the south-east 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 110°E longitude.

The tidal range along the northwest Australian coast increases fiarly regularly northwards from about 5 feet at Carnarvon to 7 feet at Onslow, 19 feet at Port Hedland, and 28 feet at Broome. The rate and direction of tidal streams are largely controlled by local coastline and sea bed morphology 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, where Broome is situated to the north of the area described here, and much higher rates of up to 10 knots have been recorded north again 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 of 3 to 4 knots with a range of 3 metres have been recorded at the drilling site of an oil well 110 kilometres offshore. (Madeleine No.1, 19°39'S 116°21E, Burmah Oil Company of Australia Ltd). However, even in restricted waters maximum rates are more often 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.

Geology of bordering land and coastal morphology

Almost all the area of continental shelf examined lies in the offshore Canning Basin, although the position of the margin of the Canning Basin against the Archaean rocks of the Pilbara Block to the south and its relation to the Onslow sub-basin to the southwest are not clear.

The geology of the Canning Basin has been described by Veevers & Wells (1961). Sedimentation in the basin was probably initiated before the end of the Proterozoic, and continued, with some important breaks, until the end of the Mesozoic. The basin is asymmetrical in form with about 6000 metres of Palaeozoic sediments in the Fitzroy Trough, close to the northern margin of the basin, and with much lesser thicknesses of Palaeozoic and Mesozoic combined in the central and southern areas. Since the Mesozoic the Canning Basin has been land, apart from intermittent submergence of the coastal fringe, and the Cainozoic deposits are thin and superficial; they are, however, widespread and provide almost all the sediment now being contributed by the basin to the continental shelf. They 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 has been described by Kriewaldt (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.

The coastal topography of the Canning Basin is almost uniformly low-lying and monotonous. Long stretches of coastline are backed by extensive tidal flats relieved only by low sand dunes. Locally, dissection of resistant coastal limestones produces low rocky cliffs, as at Cape Keraudren, and elsewhere low red sandy cliffs are found where more or less indurated ancient erosion surfaces are being undercut at the present shoreline.

The coastal region of the northern part of the Pilbara Block is also formed 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) Precambrian bedrock crops out extensively along the shore which therefore has some relief. Thus the islands of the Dampier Archipelago, with the exception of Legendre Island which consists of coastal limestone, are dominantly formed of Proterozoic volcanics and intrusives with a relief of up to 150 metres.

REGIONAL GEOLOGY AND STRUCTURE

Petroleum exploration activity on the northwest continental shelf has provided reconnaissance geophysical data over all the area described in this report, and detailed seismic surveys have been carried out over some structures; stratigraphical control from drilling is, however, still very limited. In addition to work by Oil Companies, the Bureau of Mineral Resources in 1968 engaged a contractor to carry out a marine geophysical survey over a wide area of continental margin including the area under review. During this survey about 24,000 kilometres of combined gravity magnetic and seismic reflexion traverses were completed (Whitworth, 1969). Some seismic refraction work was also done to provide velocity information.

Basement structures

Interpretation of the morphology of the Precambrian basement surface is made difficult by the complexity of the structures and the scarcity of 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 sedimentary pile.

A reconnaissance aeromagnetic survey by Woodside (Lakes Entrance) Oil Company provided magnetic basement form lines in the Ashmore Reef area, between Scott Reef and King Sound, and between Rowley Shoals and Broome (Woodside, 1964). Several aeromagnetic surveys have also been carried out in the Timor Sea - Joseph Bonaparte Gulf region since 1958 (Associated Australian Oilfields, 1963; Arco & Australian Aquitaine Petroleum, 1965; Quilty, 1966). An aeromagnetic survey of the inner part of the shelf off the Canning Basin was carried out by Adastra Hunting Geophysics for WAPET (1966a) and aeromagnetic surveys of the northern part of the Carnarvon Basin have also been done by the B.M.R. (Spence, 1961) and by Adastra Hunting Geophysics for WAPET (1968).

Figure 3 shows some of the important features of the basement structure which these surveys have brought to light. The magnetic basement high underlying the discontinuous topographic ridge marked by Ashmore Reef, Scott Reef, and Rowley Shoals is the dominant feature of the shelf-edge region. The complementary trough on the landward side of the ridge, named the Cartier Furrow by Veevers (1967), can be traced far to the northeast along the southern margin of the Timor Trough. Some 6000 to 9000 metres of sedimentary section is indicated in the trough and 2000 to 5000 metres above magnetic basement in the outer ridge. However, seismic surveys by B.O.C. of Australia Limited of the Ashmore Reef anticlinal structure provided strong evidence of a thick sedimentary sequence in a region where the magnetic data indicated a depth of only 2800 metres to basement. Ashmore Reef No.1 Well confirmed the seismic results; it was still in Upper Triassic clastic and carbonate sediments at total depth 3900 metres, so Precambrian basement must lie at a greater, probably much greater depth than this. An explanation of the magnetic interpretation is provided by the 300-metre sequence of Upper Jurassic basic volcanics penetrated below 2400 metres. It is, of course, possible that a Precambrian basement ridge underlies Ashmore Reef and the other topographic and structural highs near the edge of the shelf to the south but in view of the results of the Ashmore Reef well, the evidence that it does is not strong. Certainly the magnetic and gravity data over the Barrow Island anticlinal structure, which is in approximate alignment with these shelf-edge features, do not indicate that a basement high is present there, and the gravity and magnetic results of the 1968 B.M.R. survey do not provide any evidence of a basement ridge under Scott Reef and Rowley Shoals (Whitworth, 1969).

Closer to the continent, the other basement features shown in Figure 3 are more or less aligned with onshore structural trends, that is normal to the edge of the shelf and to the problematical basement ridge and trough feature along the edge of the shelf. The seaward margin of both the Kimberley Block and the Pilbara Block are bounded by fault complexes which are not shown on Figure 3. Some 6000 metres of post-Palaeozoic sediments are believed to be present in the Browse basin off the Kimberley Block and a similar thickness of Phanerozoic sediments probably occurs close to the faulted margin of the Pilbara Block which plunges steeply seawards.

The offshore extent of the east-west structures in the central coastal Canning Basin and their relationship with the Cartier Furrow to the west are not known. These structures were indicated by the aeromagnetic survey done by Adastra Hunting Geophysics for WAPET in 1966 which did not extend far offshore. It would appear that the Samphire depression, south of the Cape Bossut arch and its flanking troughs, does not extend out under the continental shelf; the Cape Bossut arch itself is probably of limited extent, as Whitworth (1969) indicates a depth to magnetic basement of 7300 metres approximately on the line of the arch some 60 miles offshore. Farther north there are indications that the graben faults bounding the Fitzroy Trough extend offshore and that thick Precambrian basement lies at great depth under the shelf off Dampier Land.

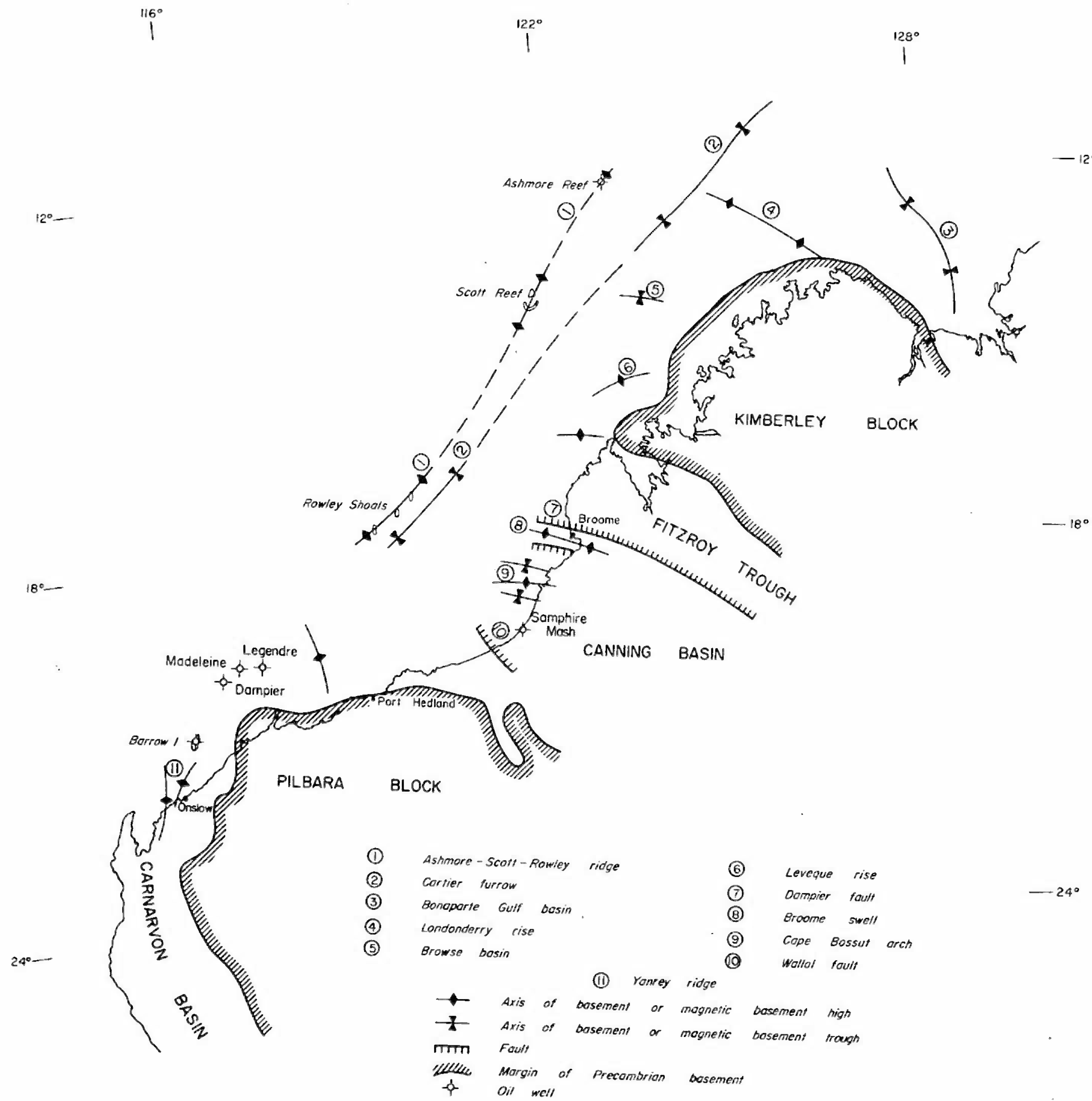

Fig. 3. BASEMENT STRUCTURES, NORTHWEST AUSTRALIAN CONTINENTAL SHELF

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Phanerozoic sedimentation and structure

Following the indications provided by the early magnetometer and gravimeter surveys that sufficient thicknesses of sediments 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. In compiling this summary, reference has been made to eight surveys for B.O.C. of Australia Limited (1965, 1966, 1967a and b, 1968, 1969 a and b, 1970) and one for WAPET (1966b). Four subsidized offshore oil wells (Ashmore Reef, Dampier, Legendre and Madeleine*), together with Barrow Island and Samphire Marsh, provide some stratigraphic control. Much additional work has, of course, been carried out in the Timor Sea - Bonaparte Gulf region to the north, in the offshore Carnarvon - Onslow basin to the south, and in adjoining onshore areas. The following brief account summarizes some of the more important results of this Oil Company work, together with those of the 1968 geophysical reconnaissance by the B.M.R.

In the southern part of the area a compound sedimentary basin exists, which, from the results of the Legendre and Dampier wells, clearly seems to be connected with the Carnarvon Basin to the southwest, rather than to the Canning Basin to the northeast. This relation suggests that during the Mesozoic and much of the Cainozoic a northward extension of the Pilbara Block basement high in the Port Hedland - Port Walcott area may have formed a ridge separating the two depositional basins. The Mesozoic and Tertiary sequences penetrated in the wells (Table 2) are broadly similar to those of the onshore Carnarvon Basin and Barrow Island No.1. The Cainozoic section in Dampier No.1, totalling 1460 metres, is the thickest recorded in the region. In addition to the unconformities in the Mio-Pliocene and Oligocene noted in Table 2, major depositional hiatuses probably also occur in the Upper Eocene and in the Paleocene at Dampier and in the Paleocene at Legendre. In all three wells the Tertiary is a marine, dominantly carbonate, shallow or intermediate depth sequence.

General lithological similarity between the three wells continues throughout the Upper and part of the Lower Cretaceous (the equivalent of the Toolonga Calcilutite and the Winning Group of the Carnarvon Basin - Barrow Island stratigraphy). This sequence consists of marine

* The results from Madeleine No.1 are not yet available.

Table 2 : GENERALIZED LITHOLOGY AND TENTATIVE CORRELATIONS, BARROW ISLAND, LEGENDRE, AND DAMPIER WELLS

	Barrow No.1. Thickness (m) and lithology	Legendre No.1. Thickness (m) and lithology	Dampier No.1 Thickness (m) and lithology
Quaternary to Pliocene		(Water depth 61 m) 201 Calcarenite with subordinate quartz sand and calcilutite	(Water depth 87 m) 189 Calcarenite with subordinate quartz sand and calcilutite.
		- - - - - - - - - UNCONFORMITY	- - - - - - - - -
M to L Miocene	8 (Trealla Lst.)	105 Calcilutite	702 Calcarenite, calcilutite, quartz sand, dolomite.
	- - - - - - - - - - - - -	UNCONFORMITY - - - - -	- - - - - - - - - - - - -
Eocene to Paleocene	247 Calarenite (Giralia Calcarenite and Carbadia Group)	643 Calcarenite and calcilutute underlain by calcareous and sandy siltstone.	569 Silty, calcareous and glauconitic sandstones with subordinate calcilutite and claystone.
	- - - - - - - - - - - - -	UNCONFORMITY - - - - -	- - - - - - - - - - - -
Upper Cretaceous	27 Calcilutite (Tooloonga Calcilutite). --- UNCONFORMITY - - - 626 Shale, glauconitic sandstone at base. (Winning Group)	883 Calcareous claystone, shale, and subordinate marl and calcilutite.	1088 Shale dominant, with three minor calcareous intervals.
Lower Cretaceous	745 Glauconitic and calcareous sandstone, siltstone dominant in lower part. ('Barrow Group')	455 Quartzose sandstones with subordinate siltstones claystones and carbonates. Possible unconformity near base.	267 Shale with subordinate argillaceous sandy siltstone ---?UNCONFORMITY?----
Upper Jurassic	329 Siltstone and shale with minor sandstone ('Massive Siltstone Unit')	192 Shale and siltstone.	1241 Very fine-grained silty sandstone overlying shale sequence. Marine throughout.
Middle Jurassic		933 Sandstone underlain by siltstone. Non-marine sandstone at base.	
	T.D. 2980 m.	T.D. 3472 m.	T.D. 4142 m.

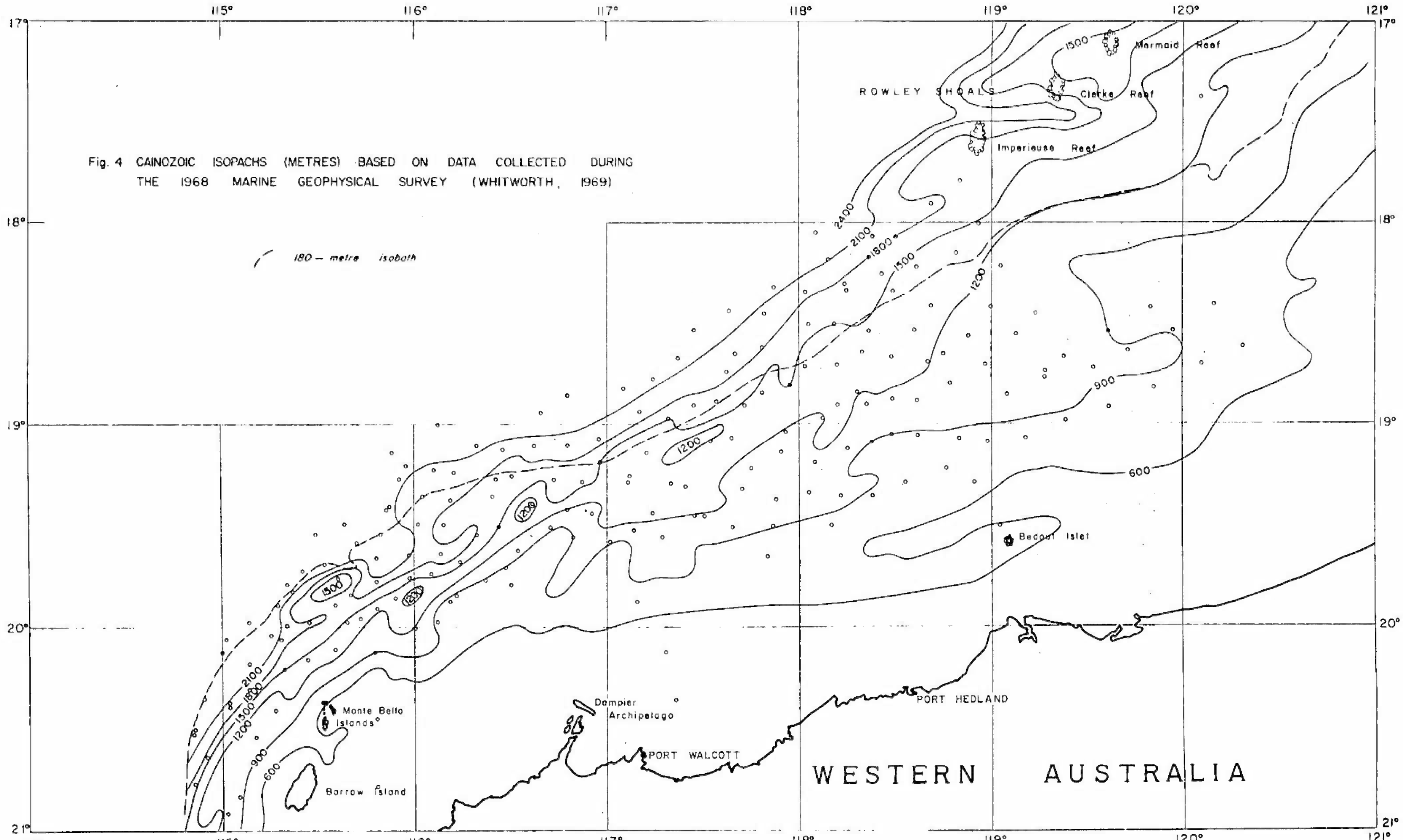

Fig. 4 CAINOZOIC ISOPACHS (METRES) BASED ON DATA COLLECTED DURING THE 1968 MARINE GEOPHYSICAL SURVEY (WHITWORTH, 1969)

To accompany Record 1970/27

F50/A/11

argillaceous sediments. The underlying Lower Neocomian to Upper Jurassic sectio, however, shows significant differences between the mainly sandy sediments at Barrow No.1 and the mainly fine-grained sediments at Dampier. Hydrocarbons are present in this interval in all three wells. The much higher proportion of permeable coarse-grained clastics at Barrow No.1 and Legendre No.1 as compared with Dampier in this important interval, and dip-metre evidence, suggest that the source area lay to the southeast.

The underlying Middle Jurassic section penetrated in Legendre No.1 passes down through shallow water marine clastic sediments to deltaic and possibly fluviatile deposits including coal. The top of the non-marine sequence may be marked by a disconformity. Seismic data indicate that there is at least another 2000 metres of section above high velocity basement at Legendre and Dampier.

No offshore wells have been drilled in the wide area of shelf between the Dampier Archipelago in the southeast and Ashmore Reef in the northeast. However, seismic coverage is complete on a reconnaissance basis and structural leads have been detailed in selected areas. The regional picture of post-Mesozoic sedimentation presented by the seismic reflexion interpretation of the B.M.R. 1968 marine geophysical survey (Whitworth, 1969) is one of outbuilding of the shelf resulting in a wedge-shaped sedimentary mass thickening seawards. The contours drawn on a horizon believed to be at, or close to, the unconformity at the base of the Tertiary indicate an en echelon series of ridges and troughs running sub-parallel to the coastline and to the edge of the shelf (Whitworth, 1969). Figure 4 shows the Cainozoic isopachs based on these data assuming a uniform velocity in the sediments of 3 km/sec. Particularly prominent are a deep trough in the Upper Cretaceous surface cutting through the southern part of the Rowley Shoals and a series of elongated highs close to the edge of the shelf between 19°S and 20°S. Correlation of these trends with gravity and magnetic data is poor. Flexuring of the sedimentary pile close to the edge of the shelf, and collapse faulting, must have played a dominant role in the formation of these structures, but local differences in rates of accumulation of sediment, and differential compaction, have also played a part. The shallow seismic profiling carried out during the survey described in this report revealed the influence of differential sedimentation during the later Cainozoic on present-day shelf morphology and this process is likely to have continued throughout the earlier Cainozoic and the Mesozoic.

Considerable structural complexity in the pre-Tertiary section in the offshore Canning Basin is inferred from the seismic results. At the southern end, the Cretaceous and Tertiary dip steeply seaward from the faulted margin of the Pilbara Block and it is likely that large-scale collapse of the sedimentary pile at the shelf edge has occurred (B.O.C., 1970). Although the principal fault trends are east-west, important north-south cross faults, possibly associated with a structural high separating the Canning and Onslow Offshore basins, also occur in this area. Sub-basins with at least 8500 metres of sedimentary section are believed to be present in structurally depressed zones.

Detailed seismic surveys have been carried out on the shelf east of the Rowley Shoals in the area forming the offshore extension of the Fitzroy Trough and the Broome Swell. The area is of particular significance to petroleum exploration because of the great thickness of section, and the possible occurrence of fault traps, Devonian reefs, and Palaeozoic salt diapirs. The results of this work (B.O.C., 1970) confirm the northwesterly thickening of the Cainozoic section indicated in Figure 4, and also suggest that irregularities of the end-Cretaceous unconformity surface reflect deep seated evaporite movements. The Mesozoic and Palaeozoic sections are much disturbed by faulting, particularly close to the bounding faults of the Fitzroy graben structure. The lowest horizon (unidentified) described in the oil company's interpretation of the seismic results has a hummocky surface suggestive of salt flowage while steep dips and high velocities in the overlying formation indicate the possibility of reef structures.

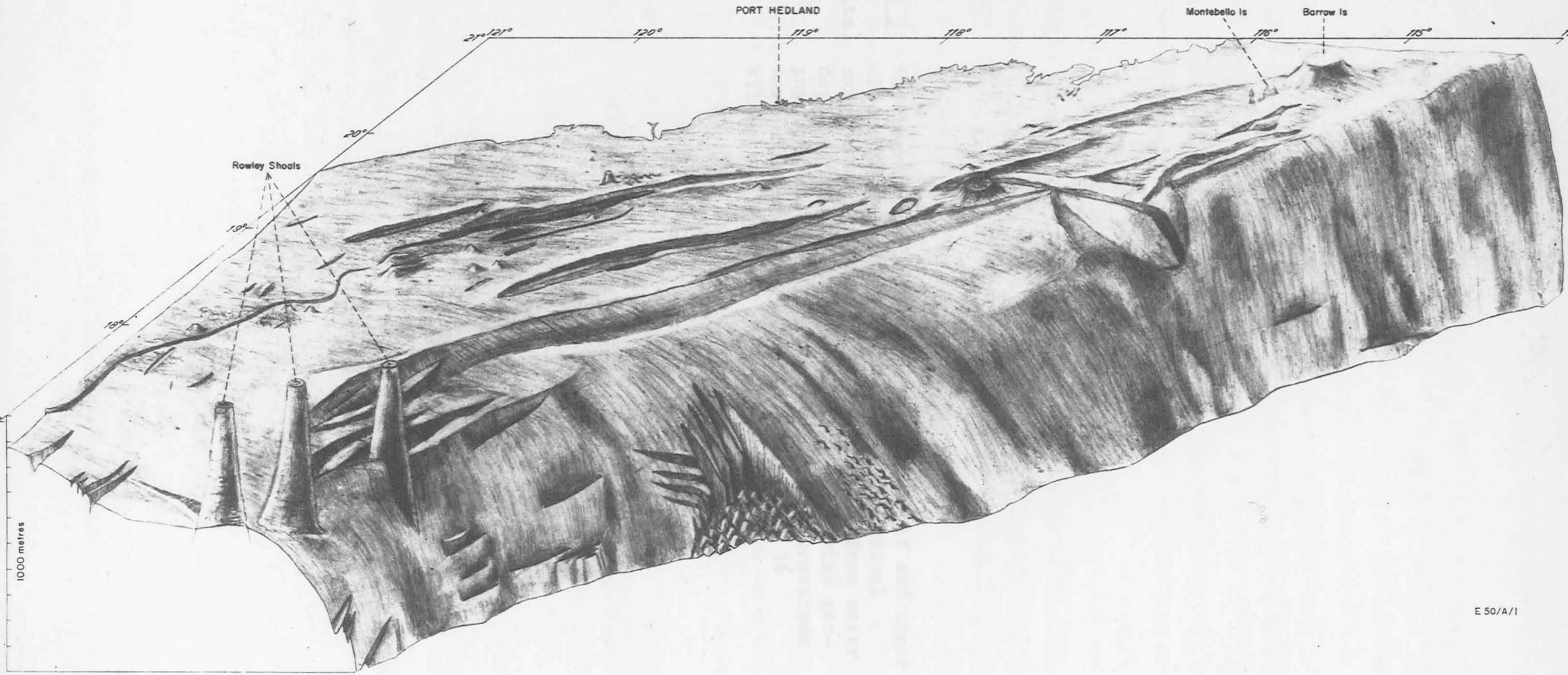
PORT HEDLAND
Montebello Is
Barrow Is
Rowley Shoals
21°
121°
120°
119°
118°
117°
116°
115°
114°
20°
19°
18°
17°
1000 metres

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Figure 5: Physiographic block diagram of the shelf and upper slope. View is from the northwest; vertical
(Opposite) exaggeration is about X 200. Compiled from water depth data collected during the 1968 marine geophysical survey in the area. Sounding traverses were aligned east-west and spaced about 16 kilometres apart.

MORPHOLOGY

In addition to the soundings shown on the published charts of the region, and data from unpublished detailed hydrographic surveys by the R.A.N., some 40 echosounding profiles were obtained across the middle and outer shelf during the present survey. Water depth data were also collected during the 1968 marine geophysical survey; because of the density of soundings and accuracy of positioning achieved, this material forms the main source of the bathymetric information shown in Plate 1 and Figure 5.

The area cannot be easily split up into natural subdivisions for morphological description. In the extreme southwest the continental shelf is relatively narrow and a well defined break in slope at about 120 metres water depth marks the commencement of the continental slope. Over the greater part of the area, however, the shelf is broad, flat, and largely featureless; it merges with the continental slope over a broad zone and no clear distinction between shelf and slope can be drawn. In the far northeast, a broad, gently sloping platform on the upper continental slope at a depth of about 400 metres separates the shallow shelf to the east from the true continental slope to the west.

For descriptive purposes the region is divided into three areas; the shallow shelf (0-120 metres); the edge of shelf zone (120-300 metres); and the Rowley Shoals terrace and continental slope.

Shallow shelf.

The shallow shelf is taken to extend from the shoreline out to 120 metres water depth; it varies in width from 180 kilometres southeast of the Rowley Shoals to 120 kilometres off the Dampier Archipelago. It includes all the continental shelf from the Monte Bello Islands westward, but over the greater part of the area it covers the middle and inner portions of the shelf only. The shallow shelf is largely an area of winnowing and sediment transport rather than deposition and the flat surface is interpreted by minor irregularities caused by banks of coarse organic detritus, mounds and depressions probably consisting of drowned reef structures and more or less cemented littoral deposits, and sand waves. Sand waves, sometimes recognizable by their characteristic asymmetric profile, are irregularly, and generally very widely spaced, indicating the paucity of contributing sand-size sediment; they have a height of 5 to 10 metres and are spaced from several hundred metres to 20 kilometres or more apart. Smaller scale sand waves or megaripples, with a height of 1 to 2 metres and spaced 100 metres or so apart also occur, but are more common in deeper water at or beyond the edge of the shelf. Normal current ripples appear in the bottom photographs where there is an adequate supply of loose sediment (Figs. 21 and 24).

On many continental shelves evidence of the low sea level stands which occurred during the Quaternary is preserved in the form of terrace - and - step forms and submerged strandline features. Several steps above 120 metres water depth are present, for example, on the eastern Australian shelf off the Sydney basin, and it is likely that when more narrow-beam echosounding information is available these features will be identified and correlated over wide areas. There is only limited evidence of these forms on the middle and inner shelf of this part of the northwest Australian shelf, although the wide-beam echosounding equipment used would be unable to resolve narrow and steep features and they may be more abundant than present evidence suggests.

A well marked and relatively persistent step at a depth of about 100 metres runs from the northeastern margin of the area southwestwards parallel to the edge of the shelf. Although on the physiographic diagram (Fig. 5) it appears to fade out at around 118^{o}E, it can still be detected on the echosounding profiles intermittently as far south as the shelf off Barrow Island. Although referred to as a step, the maximum slope is usually much less than 5^{o} and the height over much of its length is about 10 metres.

Much less persistent steps are intermittently discernible on the echosounding profiles about 20 metres above and 20 metres below the main step, that is in water depths of 80 and 120 metres.

Small, irregular, plateau-like features rising up to 25 metres above the surrounding surface are common on the middle and inner shelf. Only the larger of these appear on the bathymetric chart and physiographic diagram. The largest feature of this sort runs along the outer edge of the shelf for a distance of 120 kilometres in the southwestern part of the area between latitudes 19°50'S and 20°50'S; it is about 25 kilometres wide and stands 10 to 25 metres above the flat surface on the landward side over most of its length. Rankin Bank, which is situated at the northern end of the feature, rises to within 18 metres of the surface and stands 45 metres above the shelf inshore; it is capped by living coral.

It is likely that all these elevated areas are biohermal structures, although in most cases they represent relict accumulations of organic material dating from periods of lowered sealevel , which have not been buried by later sedimentation.

Edge of shelf zone

The edge of shelf zone is taken to include the area banded by the 120-metre and 300-metre isobaths. Over most of the region it covers the outer part of the continental shelf and the wide transitional zone between the shelf and continental slope; in the extreme southwest it is confined to the uppermost continental slope, and in the northeast it includes part of the depressed platform which supports the Rowley Shoals.

The dominating morphological feature of the outer continental shelf in the eastern part of the region is a long, low ridge or swell, with a complementary trough on the landward side running along the edge of the shelf between longitudes 120°E and 117°E. At its maximum development, about longitude 119°E, the crest of the rise stands about 45 metres above the floor of the trough. The feature can be traced over a distance of about 300 kilometres and its width, between the axes of the trough and the rise, is about 15 kilometres south of Imperieuse Reef decreasing rather rapidly northwards and slowly southwards. Water depths over the crest of the rise are fairly constant at about 125 metres over most of its length, shallowing gently to 110 metres as the rise disappears in the region of 117°E. The floor of the trough shallows gradually from a depth of 170 metres south of Clerke Reef to 115 metres at 117°E.

The rise, whose origin is discussed in detail in the section on Quaternary sedimentation, is a depositional area characterised by very smooth bottom topography. The floor of the trough on its landward side, however, is slightly irregular indicating a non-depositional environment similar to that occurring over much of the middle and inner shelf. In the far northeast of the area, and southwest of 117°E, on either side of the rise, the transition from the inshore non-depositional environment, marked by a bottom surface showing small irregularities, to the offshore depositional area, masked by a smooth bottom, occurs at a depth of about 120 metres. Extensive depositional belts occur, however, in waters shallower than this, and localized areas of bottom showing some minor relief are found in deeper water.

In general, the 120- to 300- metre zone shows the very smooth bottom topography characteristic of depositional areas. There is a gradual increase in slope seawards, and except in the far southwest, no abrupt change in slope occurs to mark the edge of the continental shelf. Slopes are extremely gentle, and east of the longitude of the Monte Bello Islands the maximum slope down to 300 metres is of the order of 1°, or 20 metres to the kilometre. This compares with a slope of around 1 metre to the kilometre usual on the continental shelf, and slopes of 5° to 8° found on the normal continental slope north and west of the Monte Bello Islands.

While it is true that apart from restricted areas of sand waves and ripple marks, indicating sediment transport (Fig. 26), and localized erosional gullying, the 120- to 300- metre belt is a depositional zone, there is a narrow but laterally persistent strip at a depth of about 240 metres where an irregular bottom surface occurs. This strip extends over much of the eastern part of the region, between 116°E and 120°E, and it is marked by a gentle but consistent concave change in slope (Fig. 6). It is believed to mark the outcrop of an ancient erosion surface referred to in the section on shallow structure below. There is no obvious explanation why sedimentation has been restricted along this strip, but it is likely that it coincides with the outer limit of shelf-derived sediment deposition and that for some reason tidal current influences are concentrated in this region of the upper continental slope. Certainly there are surface indications of unusually strong currents, in the form of rips and overfalls resembling breakers in shoal waters, over wide areas of the continental margin in this area.

Rowley Shoals terrace and the continental slope.

Fewer data are available on the continental slope below 300 metres depth, and nearly all the continuous sounding profiles run in one direction (east-west). It is significant that the region of greatest relief on the physiographic diagram occurs between 18° and 19°S where information from one of the rare cross traverses is available. It seems likely that the generally smooth, steep slope in the southern part of the region is in reality more broken up by slumping than the physiographic diagram suggests.

The enormous exaggeration of vertical scale in the diagram grossly distorts the three atolls forming the Rowley Shoals; slopes on the flanks of these structures are nevertheless steep (20°) and probably approximate to the angle of rest of the coarse organic detritus derived from the reefs. They rise from an irregular hummocky floor at a depth of about 400 metres; Clerke Reef is known to be flanked by a depression on its western side some 5 kilometres across and 50 metres deep and it is probable that depressions encircle all three reefs. Such depressions are common around reefs; they are caused by differential compaction and downwarping of the underlying sediments, caused by loading, although current scour at the base of the structure is probably a contributing cause.

SHALLOW STRUCTURE AND CAINOZOIC SEDIMENTATION.

Twelve low-power sparker traverses were made in the area along lines approximately normal to the edge of the shelf (Fig. 7). Penetration averaged about 0.25 seconds (2-way time) and reached 0.6 seconds under favourable conditions. Resolution was of the order of 5 metres. The 1968 marine geophysical survey carried out for the B.M.R. by contract provides a much denser coverage of seismic lines; traverses were spaced about 16 kilometres apart. However, the records are of only limited value in the shallow waters of the shelf. The high energy (21,000 joules) sparker source produced a pulse about 50 milliseconds in length reducing the resolution to around 75 metres. This, combined with multiple reflexions, and the distorting effect of the 600-foot spacing between the sound source and the hydrophone array, makes interpretation of records in waters shallower than about 200 metres difficult or impossible. A sharper pulse may perhaps be producible on play-back of the tapes, and experimentation in recording techniques is being undertaken with this end in view.

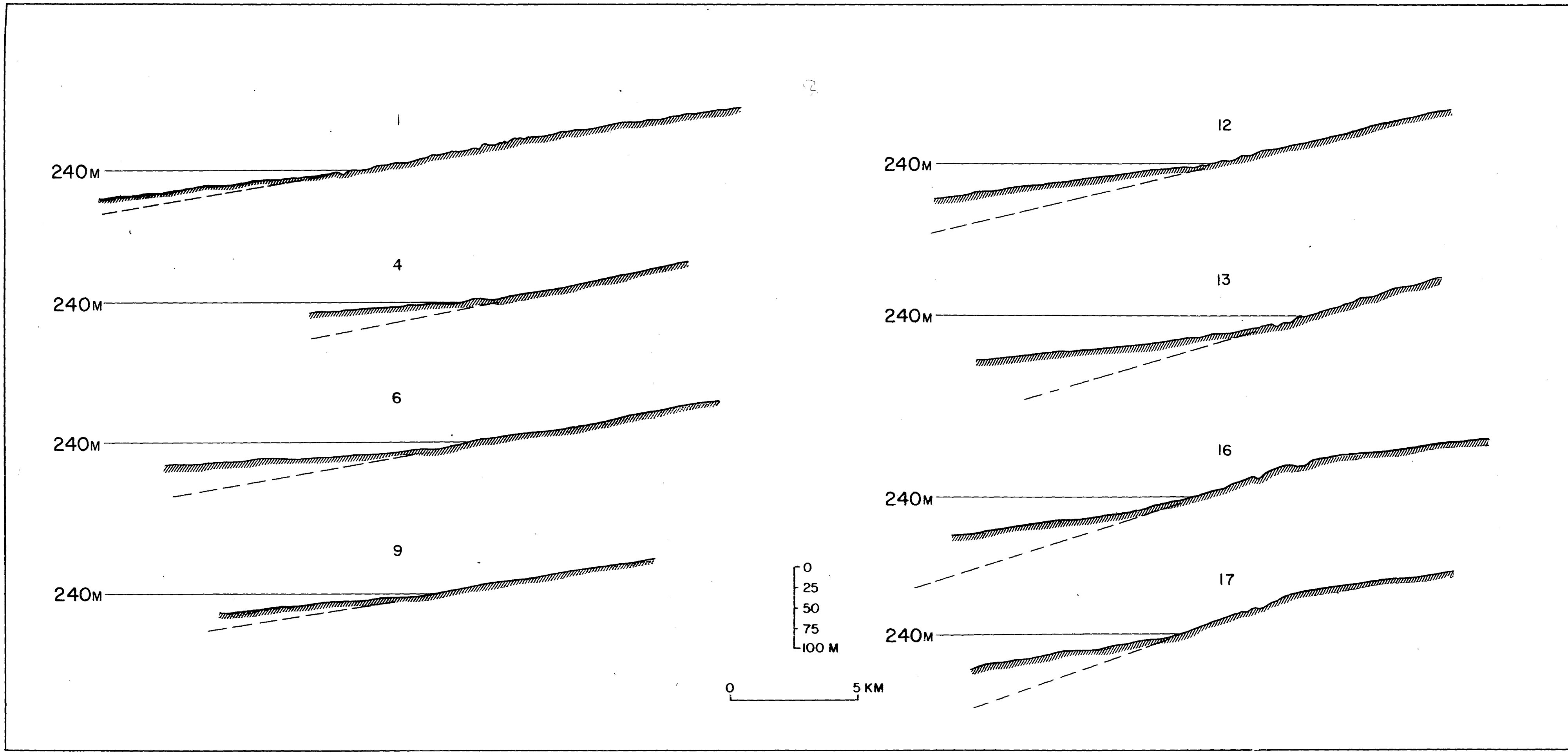


Fig. 6 Tracings of Echosounder profiles illustrating the change in slope at about 240 metres depth. Location of profiles shown in Figure 7. The broken line indicates the angle of inclination of the bottom immediately above the change in slope.

F50/A/12

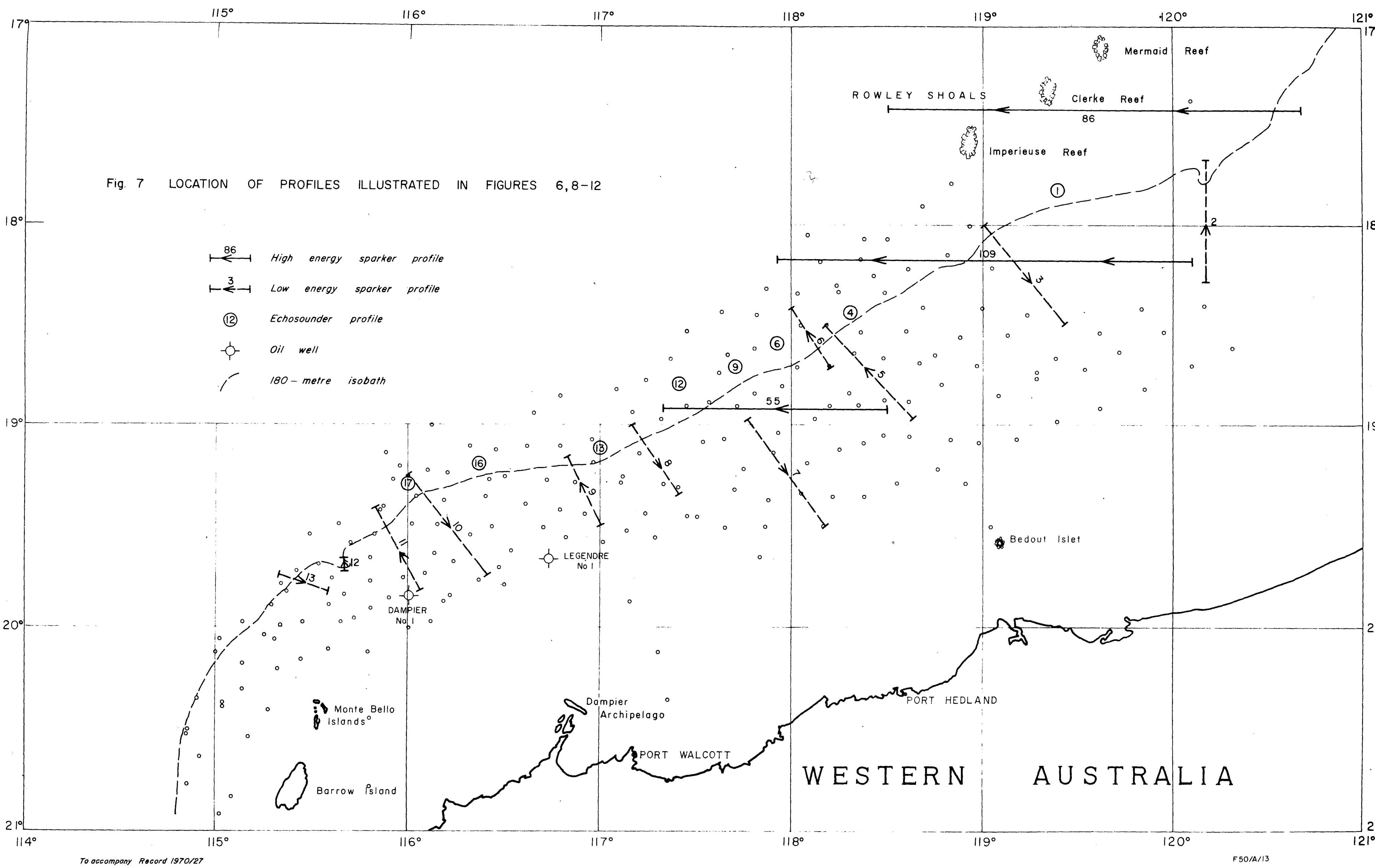


Fig. 7 LOCATION OF PROFILES ILLUSTRATED IN FIGURES 6, 8-12
86 High energy sparker profile
3 Low energy sparker profile
12 Echosounder profile
Oil well
180 - metre isobath
Mermaid Reef
ROWLEY SHOALS
Clerke Reef
Imperieuse Reef
Bedout Islet
LEGENDRE No 1
DAMPIER No 1
Monte Bello Islands
Barrow Island
Dampier Archipelago
PORT WALCOTT
PORT HEDLAND
WESTERN AUSTRALIA
114°
115°
116°
117°
118°
119°
120°
121°
17°
18°
19°
20°
21°
To accompany Record 1970/27
F50/A/13

Some of the low-energy sparker records are illustrated in Figures 8 - 10, and diagrammatic interpretations of selected high energy shallow seismic profiles in Figure 11. The following interpretations are mainly based on the high-resolution sparker profiles and the traverse numbers quoted refer to these unless stated otherwise. Water depths are calculated on a velocity of sound in water of 1500 metres, and thicknesses of sediment on an assumed average velocity of 2000 metres/second.

Unconformities.

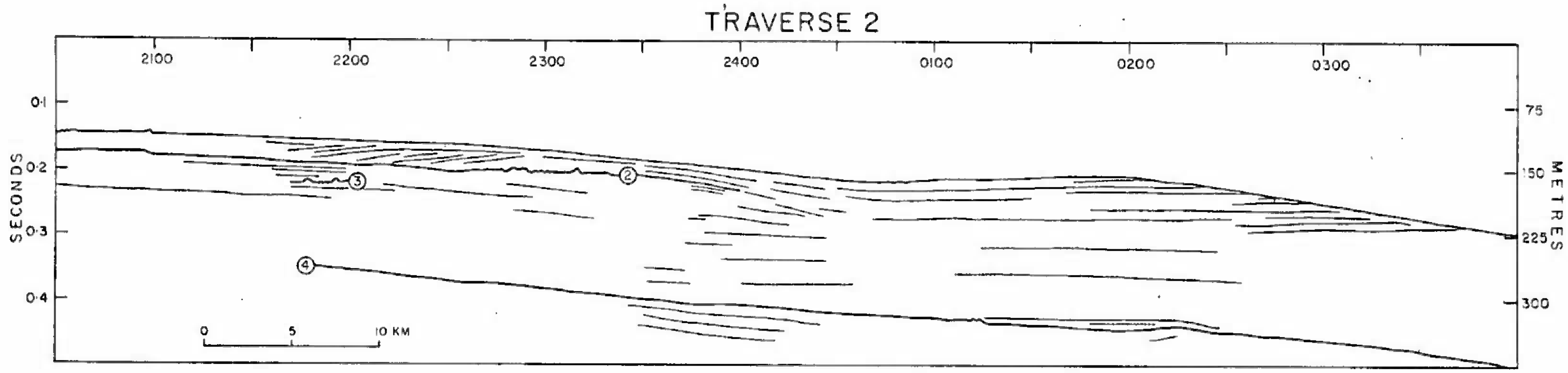
Several profiles show one or more strong reflectors which, from their irregularities and discordant relationships to the underlying reflectors, are taken to be erosion surfaces (See Figs. 8 - 11). Features displayed by these surfaces include notches or sharp changes in slope, which mark ancient shore lines or shelf edge breaks in slope, and erosion channels of various sorts. Other strong and more or less irregular reflectors occurring within apparently conformable sequences are of very limited lateral extent (Fig.10); they probably represent areas of short-lived reef growth overwhelmed by sedimentation. Although the hiatuses involved in these instances, if present at all, are only minor, such features do point to changes in the patterns of sedimentation which are probably of more than local significance.

Correlation of these events between profiles is hazardous, and some subjective interpretation may even be involved in tracing reflectors within single profiles. However, six events can be recognized and two of these (Surfaces 2 and 4) are believed to be of regional extent. Stratigraphical control is limited to Dampier No.1 and Legendre No.1 Wells. Traverse 10 approaches to within 20 miles of Legendre No.1 and Traverse 11 to within 4 miles of Dampier No.1. These wells provide little information on the uppermost part of the section. In each well the first hiatus in the succession occurs at a depth of about 200 metres below the sea bed and separates the Quaternary - Pliocene above from the Middle to Lower Miocene below. Both Traverse 10 and 11 (Fig.10) reveal an unconformity (Surface 4) at about this depth and this surface can therefore be related with reasonable confidence to the period of erosion occupying the Upper Miocene and lowermost Pliocene. This unconformity is of regional extent;

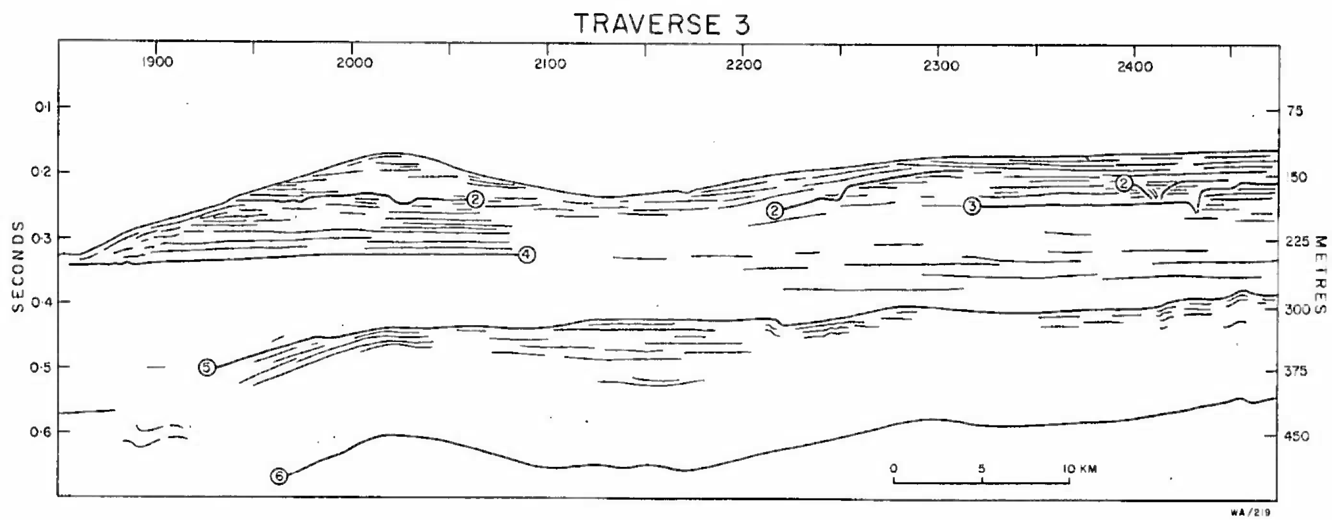
Figure 8: (Opposite)

Traverse 2: Surfaces 2, 3, and 4 are present. An unusual feature of the uppermost part of the section at 2200 hours is the landward-dipping foreset beds. The crest of the edge-of-shelf depositional rise is at 0200 hours.

Traverse 3: Surfaces 2 - 6 are present. Erosional gulleying of surface 2 occurs at 2015 hours. Notches probably related to previous shore lines, occur on Surface 2 at 2230 hours and Surface 3 at 0020 hours. This traverse shows the maximum development of the edge of shelf rise at 2015 hours. The absence of reflectors above and below Surface 6, except at the inshore end of the traverse, makes interpretation of this event difficult.

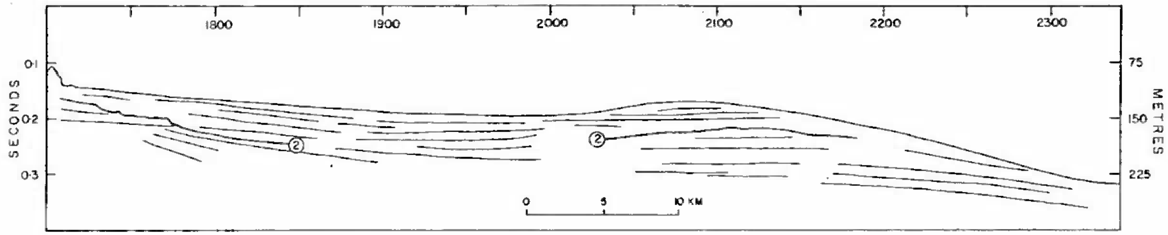


TRAVERSE 2
2100
2200
2300
2400
0100
0200
0300
0·1
0·2
0·3
0·4
SECONDS
75
150
225
300
METRES
0
5
10 KM

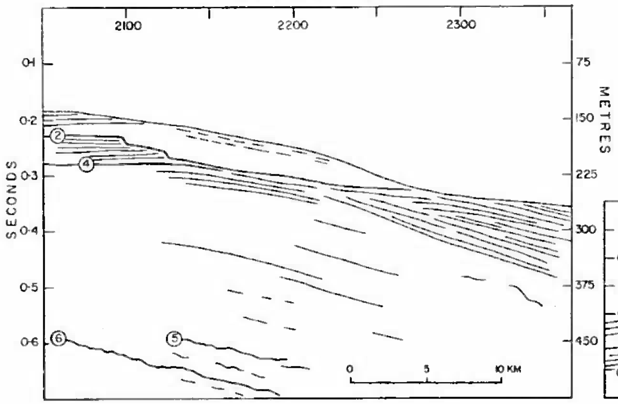


TRAVERSE 3
1900
2000
2100
2200
2300
2400
0·1
0·2
0·3
0·4
0·5
0·6
SECONDS
75
150
225
300
375
450
METRES
0
5
10 KM
WA/219

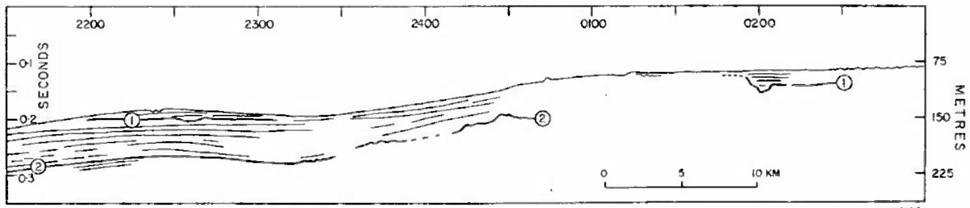
TRAVERSE 5



TRAVERSE 6



TRAVERSE 7



WA/220

Figure 9: (Opposite)

Traverse 5: Only Surface 2 can be identified. The notch on this surface at 1745 hours may be related to an ancient shore line. The crest of the edge of shelf is at 2045 hours.

Traverse 6: Surfaces 2, 4, 5, and 6 are present. Two well defined steps on Surface 2 at 2100 and 2110 hours are erosional in origin and probably related to an ancient shore line.

Traverse 7: Surfaces 1 and 2 are present. The crest of the edge-of-shelf rise at 2220 hours is marked by erosional gulleying which is repeated on the underlying Surface 1.

Figure 10: (Opposite)

Traverse 8: Surfaces 1 - 5 are present. A deep channel in Surface 1 at 2100 hours is infilled by Recent sediment. The notch in Surface 2 at 2330 hours may be related to an ancient erosion surface. The deep reflector identified as Surface 5 appears to be part of a folded sequence.

Traverse 9: Surface 2 is present. Thickening of the sedimentary sequence under the edge-of-shelf rise and seawards is well shown.

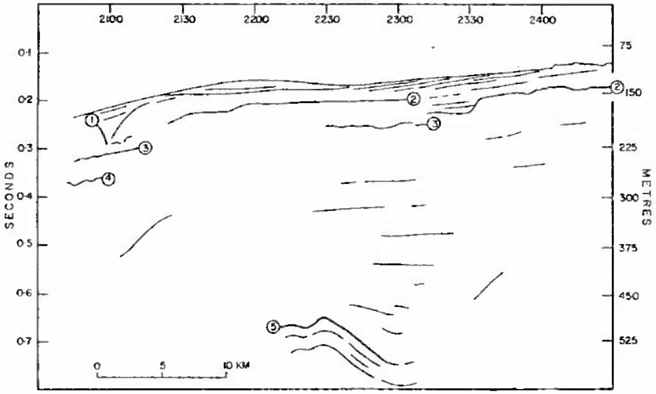
Traverse 10: Surfaces 1, 2 and 4 are present. The notches in Surface 2, 1930 and 2015 hours, are probably strand line features. The confused reflexions under Surface 4, 1715 to 1800 hours, are possibly formed by biohermal structures.

Traverse 11: Surfaces 2 - 4 are present. The prominent knoll and cliff feature on Surface 4 is related to an ancient shore line.

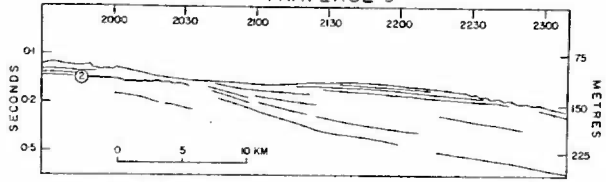
Traverse 12: Surface 1 forms the present-day sea floor at each end of the traverse and is buried by about 50 metres of fill at 0900 hours.

Traverse 13: Surfaces 2 - 4 are present. Seaward-dipping huge scale foreset bedding illustrates the outward and upward building of the shelf. The reflectors identified as Surfaces 2 and 3 at 1930 hours are probably biohermal structures.

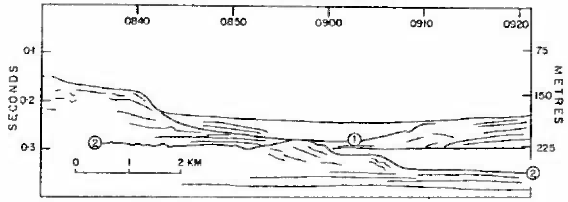
TRAVERSE 8



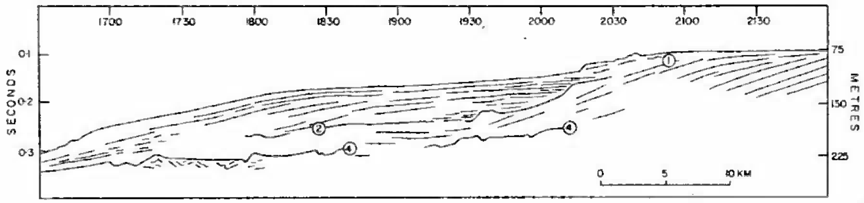
TRAVERSE 9



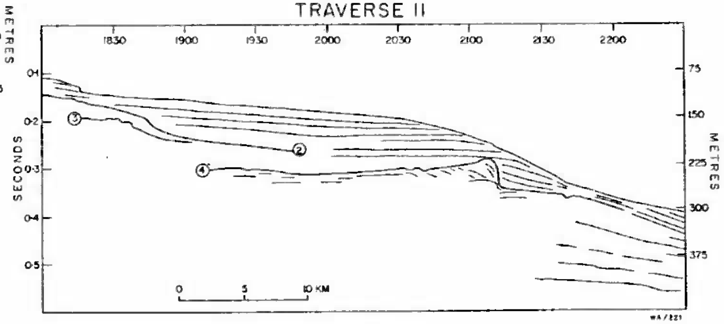
TRAVERSE 12



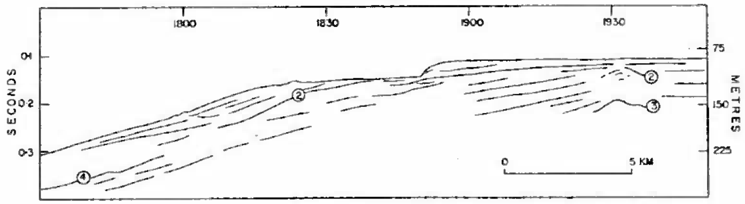
TRAVERSE 10



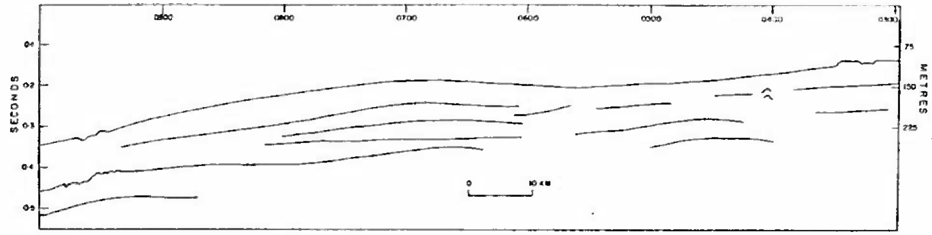
TRAVERSE 11



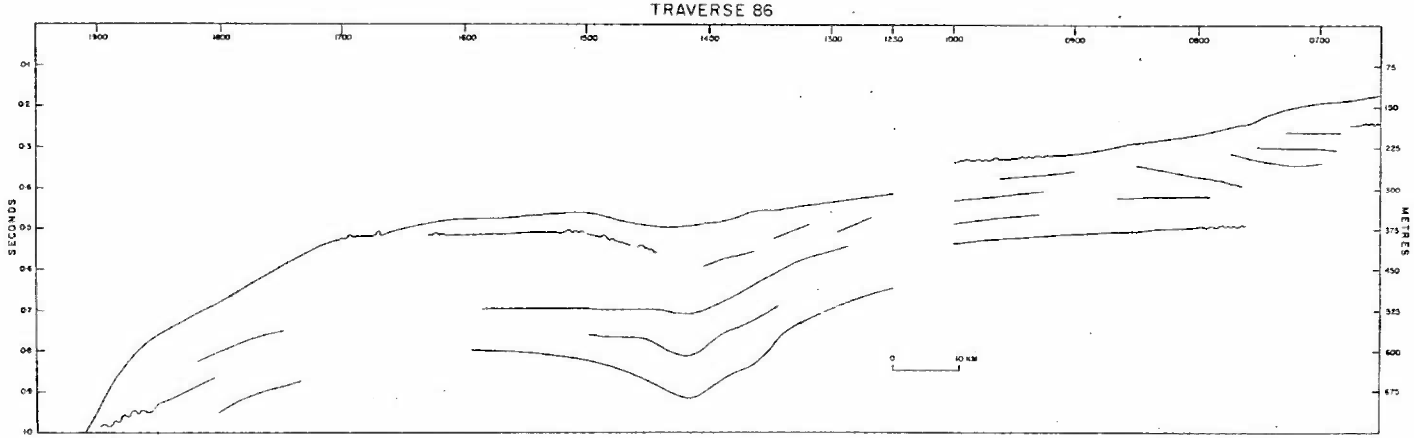
TRAVERSE 13



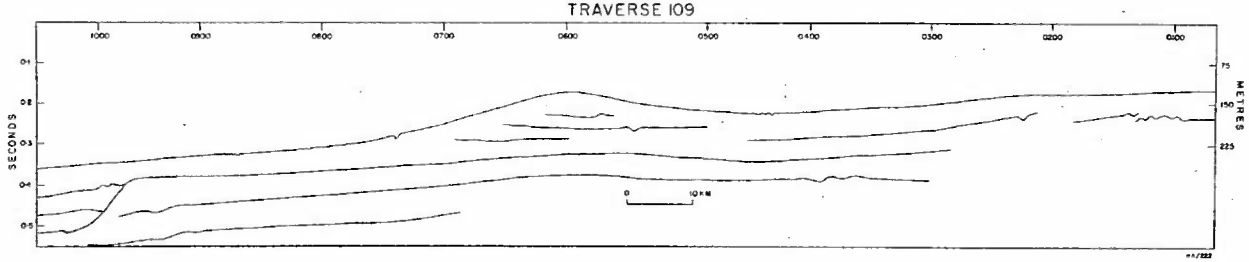
TRAVERSE 55



TRAVERSE 86



TRAVERSE 109



<u>Figure 11</u>: (Opposite) High energy sparker profiles 55, 86, and 109. Only the gross structural features appearing before the arrival of the first multiple are shown. Traverse 55 shows the crest of the present-day edge-of-shelf rise at 0700 hours, and an earlier buried feature of similar origin at 0430 hours. A buried biohermal structure appears at 0400 hours. Traverse 86 crosses the down-warped terrace supporting the Rowley Shoals. The ancient erosion surface controlling this terrace crops out at 1700 hours. Slumping is evident in the section underlying the steep slope at 1900 hours. Traverse 109 shows a major buried erosional scarp at 1000 hours. The crest of the present-day edge-of-shelf rise is at 0600 hours.

it occurs in the Ashmore Reef Well, has been recognized over quite a wide area on the Sahul Shelf by Veevers (in press), and is related to the powerful Middle Miocene orogeny of Timor and New Guinea. There is good evidence in Traverses 10 and 11 that Surface 4 maintains a sub-horizontal attitude seawards and comes close to cropping out below the present-day break in slope at the edge of the shelf in 240 metres of water (2145 hours, Traverse 11). The relatively abrupt buried feature on this surface at 2115 hours (Traverse 11) appears to be partly continental and partly formed by erosion; a short distance seawards the surface disappears into a conformable sequence and the feature referred to must mark the shoreline during this major regression. The slight concave change in slope of the sea bottom at 240 metres evident in Traverse 11 is the expression of his Miocene surface still not completely obscured by later sedimentation. Traverses 3 and 6, and high-energy Traverse 109, also provide evidence of an erosion surface, assumed to be Surface 4, coming close to cropping out at 240 metres depth and being responsible for the change in slope of the sea bed. This concave changes in slope at 220 to 260 metres depth is present for a distance of 360 kilometres along the continental slope between the 116°E and 119°E meridians (Figs. 5 and 6) and it is concluded that it is the expression of the sub-outcrop of the Miocene surface. This feature disappears of 116°E while northeast of 119° evidence provided by high-emergy Traverse 86 (Fig.11), supported to some extent by Traverse 2 (Fig. 8), indicates that it has been downwarped to a depth of about 400 metres. In this region it controls the gently shelving platform on the upper continental slope on which the three atolls comprising the Rowley Shoals stand. It seems probable that these reefs started to grow early in the Pliocene following the transgression of the sea over Surface 4.

At least three surfaces of erosion can be recognized inthe Pliocene - Quaternary sequence above Surface 4, but correlation between traverses must be regarded as tentative and no evidence for dating them is available. Surface 1, well displayed in Traverse 2 near Rankin Bank, probably represents the surface exposed during the last major low sea-level stand of the Pleistocene. It is likely that this surface and the underlying Surface 2, controls the present day sea floor over wide areas of the middle shelf where little or no Recent deposition has occurred. Elsewhere (Traverses 8 and 12) 20 to 70 metres of Recent sedimentary fill has been deposited upon Surface 1.

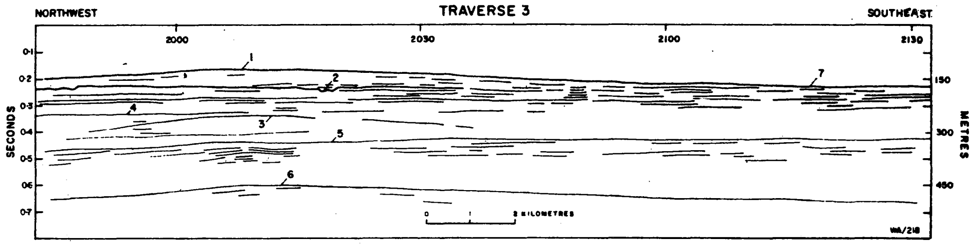


Figure 12. Detail of Traverse 3. Direct tracing of record. 1 indicates the crest of the edge-of-shelf rise in a water depth of 125 metres. The underlying erosion surface (2) loses its identity shortly after 2030 hrs, but must come close to cropping out at 7. 7 also marks the axis of the trough on the landward side of the shelf-edge rise. 3 is the first multiple of the bottom echo. 4,5 and 6 are surfaces 4,5, and 6 referred to in the text. Surface 4 becomes a strong and irregular reflector to the northwest (seawards) of the profile illustrated, and eventually crops out on the continental slope in 240 metres water depth.

Surfaces 2 and 3 occur below Surface 1 and above the Mio-Pliocene Surface 4. One or possibly two other planes of erosion may occur in this interval also (Traverses 8, Fig 10). Surface 2 is a strong irregular reflector of regional extent which is overlain by up to 100 metres of sediment; it is normally separated from the less persistent and less prominent underlying Surface 3 by 35 metres or less of section and the two surfaces probably merge locally.

Two surfaces, 5 and 6, can be discerned in the Tertiary sequence underlying the Mio-Pliocene Surface 4 in Traverses 3 and 6 (Figs. 8 & 9). In both traverses Surface 6 occurs at a depth of about 500 metres below Surface 4, but while in Traverse 3 Surface 5 appears about half way between Surfaces 4 and 6, in Traverse 6 it is much lower in the section. One of these reflectors may represent the Oligocene hiatus known from Barrow No.1, Legendre No.1, and Dampier No.1, but no positive identification is possible. The deep reflector interpreted as Surface 5 in Traverse 8 (Fig.10) gives an impression of warping of the underlying strata. It is possible either that an unconformity is present in the overlying section, which is lacking in strong reflexions, or that the dipping strata infill on erosional feature in a deeper, undetected surface. The gross exaggeration of vertical scale must be borne in mind in the interpretation of these profiles.

Sedimentation

The few hundred metres of Cainozoic sediments penetrated in the widely spaced and stratigraphically poorly controlled sparker profiles appear to be quite undeformed. They exhibit only extremely gentle depositional dips, which usually take the form of seaward dipping fore-set beds on the outer shelf indicating normal upward and outward building of the continental shelf and slope. They also show subsurface features which can be explained in terms of the present day regime of sediment erosion, transport, and deposition. Of particular interest are themprresence in the section of lens-shaped masses of sediment with a flat lower surface and a convex upper surface (high-energy Traverse 55, Figure 11). They present the appearance of gentle anticlinal structures. These bodies are elongated parallel to the continental margin, are of the order of 20 kilometres in width, and the convex upper surfaces have a relief of about 50 metres. A feature of this sort is found close to the outer edge of the present-day shelf. It takes the form of a long low swell running close to the margin of the continental shelf for a distance of 300 kilometres to the 117°E meridian. A sparker profile across this swell shows that it is formed of a body of sediments lying in an essential flat, slightly channelled surface of erosion (Traverse 3, Fig. 12).

Ridges running roughly parallel to coastlines are quite common features of continental shelves and are usually interpreted as drowned barrier islands or offshore bars. Barrier islands are found along many low-lying coasts, and according to Shepard (1960) they are particularly characteristic of slowly subsiding shelves. Drowned barriers are well developed, for example, off the Gulf Coast and central Atlantic coast of the United States, but in general they are much smaller and less regular than the vast, low-amplitude swell described here, and the two features are clearly formed by different processes.

The sparker profiles show quite clearly that the swell is a constructional feature formed by a thickening of the sediments towards the crest, and that structural warping has not occurred. The superficial sediments recovered from the area of the swell are invariably fine-grained and contain a high proportion of planktonic foraminifera, in contrast with the sediments on the landward side of the swell which commonly consist of medium-to coarse-grained relict material indicative of non-deposition. The line of the crest of the swell thus marks the zone of active sedimentation since the submergence of Surface 2; it is the site of deposition of planktonic organisms from the waters of the shelf, fine-grained material winnowed from the middle and inner shelf sediments, and minor amounts of terrestrial silts and clays. Normally such fine-grained material would be deposited seaward of the continental shelf and would contribute to the prograding of the upper continental slope. Examples of such lens-shaped sedimentary bodies are provided by airgun profiles on the continental slope off the Otway Basin illustrated by von der Borch <u>et alia</u> (1970). On the northwest shelf, however, the local regime of sediment transport and deposition, and the great width of the shelf in this area, has resulted in the depositional zone occurring on the shelf itself. The size of the feature indicates continuance of the same depositional conditions for a period during which some 50 metres of sediment have accumulated along the axis of the rise.

The seismic profiles, particularly high-energy traverse 55 (Fig.11) provide evidence that similar features have developed at earlier periods during the Cainozoic. It is likely that these earlier constructional features were in approximately the same position relative to the coastline and the edge of the shelf at the time as is the present-day feature to the existing continental margin.

SEDIMENTS OF THE SHELF

Two hundred and one bottom sample stations were occupied in the area of this study; at 5 stations insufficient sample was recovered for analysis because of the nature of the bottom or because of equipment failure. The location of the samples is shown in Figure 13 and station data are given in Appendix I together with a summary of the chemical and physical properties of the sediments.

Carbonate (CO_2) and P_2O_5 analyses were done on the +2 mm and -2 mm fractions of all samples, except where they obviously consisted entirely of unaltered biogenic material. Mineralogical and textural determinations were made by thin action petrography and by examination of the unconsolidated material under a binocular microscope. No full mechanical analyses have been carried out, and although some work on these lines is planned, it is felt that over much of the shelf the influence of the biogenic component, which may be partly relict, partly transported, and partly in place of growth, is so over-riding as to make conclusions drawn from statistical treatment of such data meaningless.

Textures

In general terms medium-, coarse-, and very coarse-grained sediments cover the inner and middle part of the shelf and extend out to about the 120-metre isobath (Fig. 14). They consist of lag gravels composed dominantly of shallow water organic fragments, and sand-size biogenic material in which there is often an important authigenic accretionary component. This extensive area is a high-energy zone in which winnowing and transportation are dominant and active deposition is restricted to local pockets.

Recognizable terrigenous material coarser than silt grade is not an important constituent of the sediments, although no sampling was carried out close in shore where some coarse land-derived detritus might be expected. Some of the pelletal material, which forms a significant fraction of the sediments over wide areas (Fig. 15), may, however, be lithic carbonate of terrigenous origin.

Figure 14 shows two areas where coarse-grained sediments extend into deeper water on the upper continental slope. One stretches from about 118°E northeastwards towards the Rowley Shoals and probably forms an unbroken belt to beyond 120°E, although data are lacking between 119° and 120°E. This zone corresponds in a general way with the 240-metre change in slope which, from morphological and structural evidence, is believed to mark the outcrop or sub-outcrop of an early Pliocene erosion surface. As previously noted, the absence of fine-grained Quaternary sediments here can only be explained by current scour resulting from the regional water mass circulation which is poorly understood. In the same area, coarse reef detritus must form aprons on and around the steep rises capped by the Rowley Shoals, although no samples are available to confirm this.

The second area where coarse-grained sediments extend into deeper water beyond the continental shelf lies northeast of the Monte Bello Islands between 115°30' and 116°30'E. The southwestern end of this belt links up with the drowned barrier reef at the edge of the shelf which culminates in Rankin Bank. Here locally derived coarse organic detritus must make an important contribution to the sediments. Farther to the northeast the sparker profiles show again that an ancient erosion surface approaches close to the surface indicating decreased sedimentation owing to a local increase in environmental energy.

The region floored by dominantly fine-grained sediments outlined in Figure 14 is that in which sedimentation is now active and upward and outward building of the continental margin is taking place. The extensive belt of fine-grained sediments on the landward side of the 180-metre isobath coincides over most of its length with the topographic rise on the outer edge of the continental shelf; the seismic profiles have shown this to be a constructional feature formed by sedimentation during the late Cainozoic and the sediments dredged from it are found to include abundant planktonic foraminifera together with carbonate and terrigenous silts and clays winnowed from the middle and inner shelf.

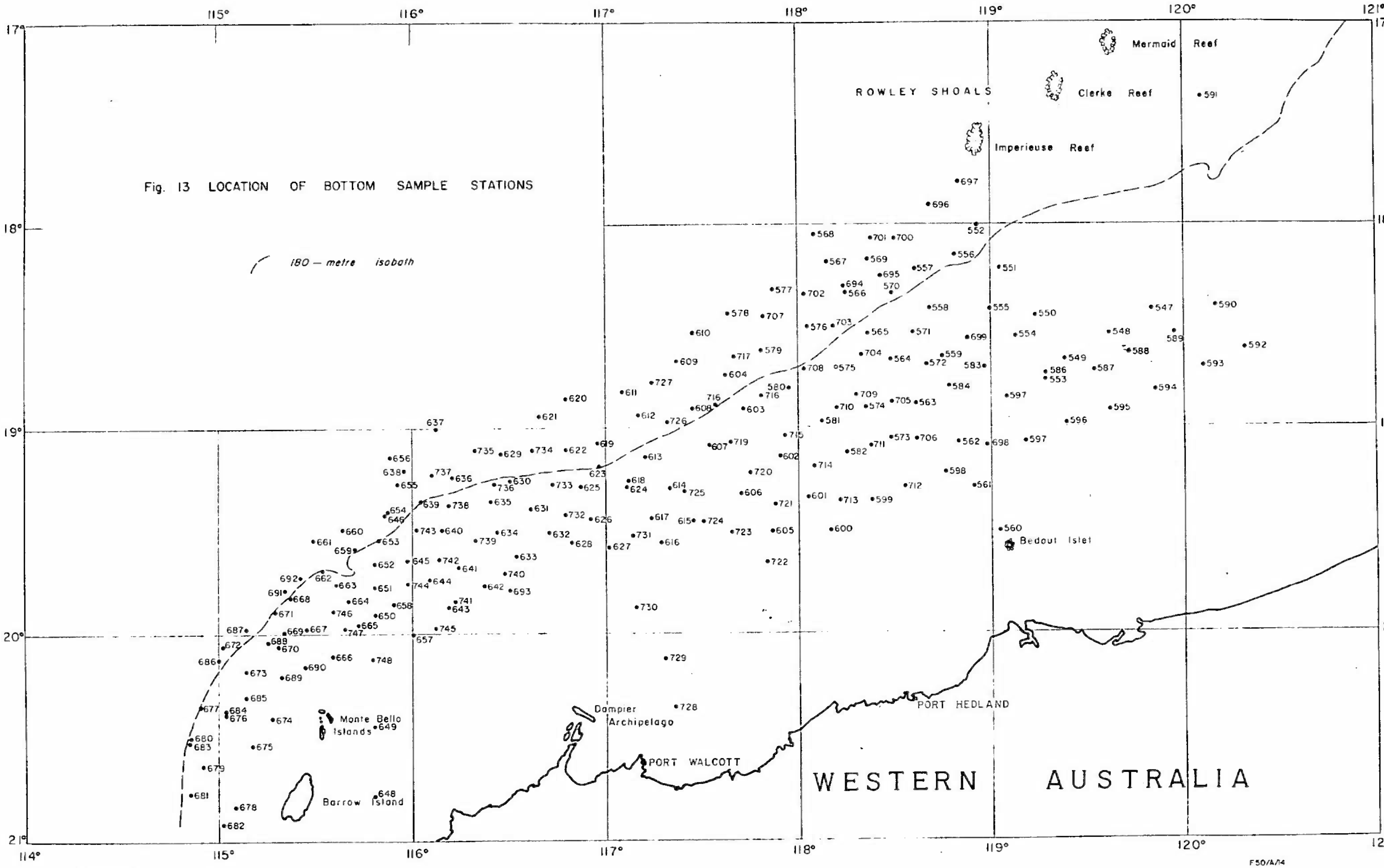


Fig. 13 LOCATION OF BOTTOM SAMPLE STATIONS

To accompany Record 1970/27

F50/A/14

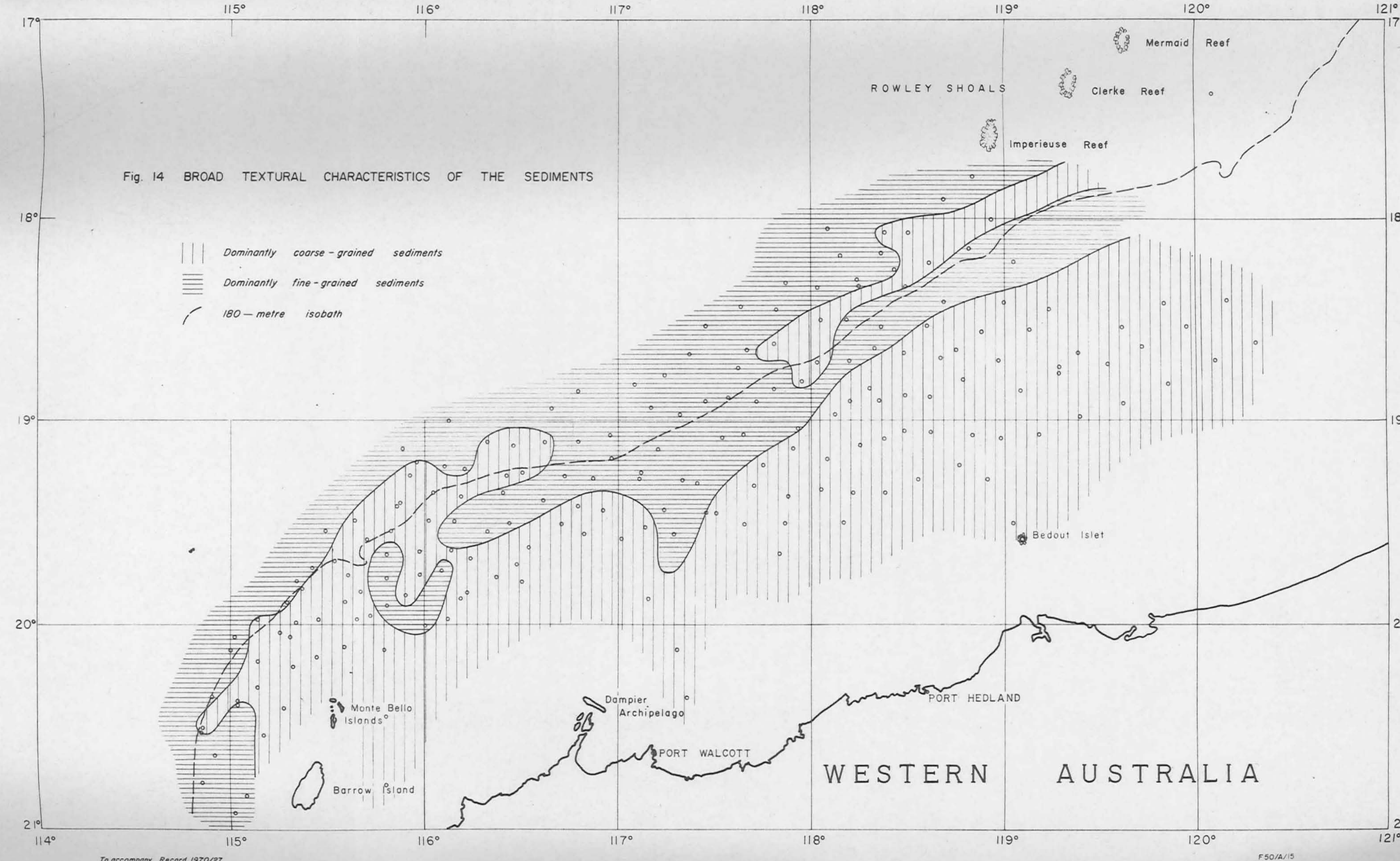


Fig. 14 BROAD TEXTURAL CHARACTERISTICS OF THE SEDIMENTS
Dominantly coarse-grained sediments
Dominantly fine-grained sediments
180 — metre isobath
ROWLEY SHOALS
Mermaid Reef
Clerke Reef
Imperieuse Reef
Bedout Islet
Monte Bello Islands
Barrow Island
Dampier Archipelago
PORT WALCOTT
PORT HEDLAND
WESTERN AUSTRALIA
114°
115°
116°
117°
118°
119°
120°
121°
17°
18°
19°
20°
21°
To accompany Record 1970/27
F50/A/15

Pellets and Oolites

Structureless micro-crystalline carbonate pellets, usually heavily stained, are widespread and often form the dominant constituent of the superficial sediments from the inner shelf to the limit of the sampled area in about 300 metres of water. Van Andel and Veevers (1967) record similar, but usually much larger material in the shelf sediments of the Timor Sea; they believe that these pellets represent reworked nodular concretionary limestone (kunkur) formed on the shelf during subaerial exposure at the time of the last major low sealevel stand. The difficulty here is to distinguish authigenic pellets, which may be casts of chambers of foraminifera pteropods or molluscs, faecal pellets, or locally derived micritic concretions, from pellets derived from the land or reworked products of subaerial weathering on the drowned land surface.

The pellets on this area of the northwest shelf can be divided on the basis of size and mode of origin into two quite well defined groups. One consists of small pellets averaging about 0.1 mm diameter which are either faecal pellets or turbid micrite casts of planktonic foraminifera. These are found on the outermost shelf and on the continental slope and their distribution closely parallels that of sediments containing abundant Globigerina-type foraminifera (Figures 15 and 17). Thin sections show many instances of Globigerina-type foraminifera shells filled with turbid micrite (Fig. 28) 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 (for example Figure 26), indicates that faecal pellets must also be important.

The second group consists of much larger pellets, 0.25 mm to 0.5mm or more, which are confined to the high energy environment of the middle and inner shelf (Fig.16) They are associated with coarse skeletal detritus, lithoclasts, and oolites (Fig. 31). A proportion of them were formed in the same way as the first group, that is they are casts of shell chambers or faecal pellets; most, however, 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 sub-spherical, structureless pellets . There seems little doubt that these bodies were formed from the break-up and reworking of an original poorly consolidated fine-grained argillaceous carbonate sediment. 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 and non-carbonate clay is abundant in the existing marine environment, although only recovered on the shelf where it is trapped in shell chambers, and pockets of this sediment must accumulate locally and be subject to periodic reworking.

Oolites often occur in the superficial sediments with the large pellets, although sediments with abundant oolites are more restricted than those with abundant pellets (Figs. 16 and 18). Occasional samples contain 50 to 75 percent oolites (Fig. 29). Most oolites are cored by pellets of dark structureless microcrystalline carbonate and range from 0.25 to 0.75 mm in diameter. All gradations exist between ordinary pellets, pellets with a thin aragonite oolitic envelope, and oolites consisting entirely of regularly arranged concentric aragonite fibres. Skeletal material or grains of quartz also commonly form the nucleus of the oolites. Examination in thin section revealed that the oolitic material has anomalous optical properties, showing low to moderate birefringence, and a biaxial positive interference figure with a small 2V. The X-ray diffraction patterns indicate that only aragonite and calcite are present in the oolites and the absence of silicates was confirmed by spectrograph and by electron probe. Electron microscope photographs show that the aragonite envelope consists of a tangentially oriented mat of rods about 0.5 microns in length and 700 Å thick. (See Appendix II by R.N. England). England has put forward a satisfactory explanation of the anomalous optical properties based on the aggregate indicatrix to be expected from a mat of aragonite rods orientated in the way observed.

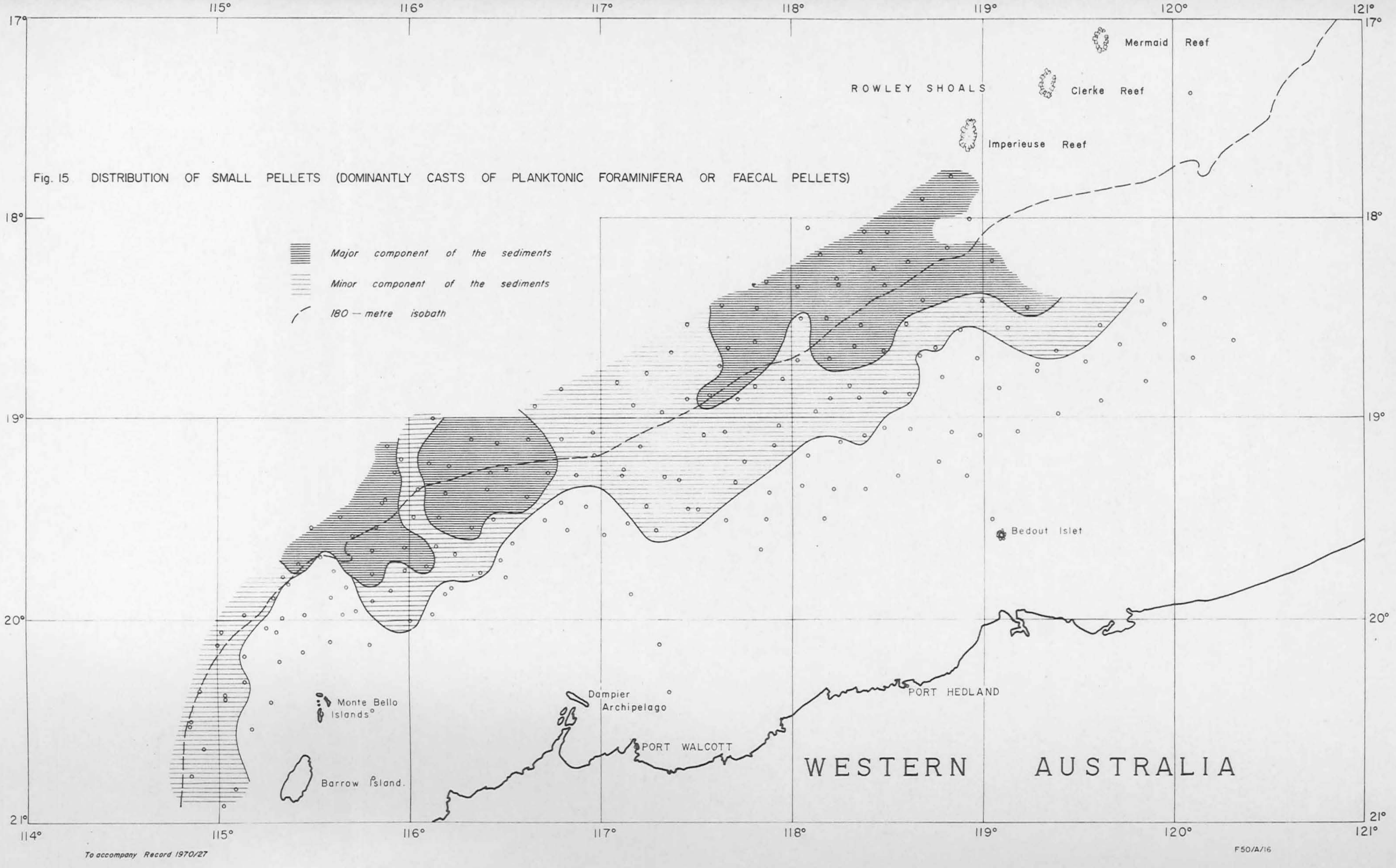


Fig. 15 DISTRIBUTION OF SMALL PELLETS (DOMINANTLY CASTS OF PLANKTONIC FORAMINIFERA OR FAECAL PELLETS)
Major component of the sediments
Minor component of the sediments
180 — metre isobath
ROWLEY SHOALS
Mermaid Reef
Clerke Reef
Imperieuse Reef
Bedout Islet
Monte Bello Islands
Barrow Island.
Dampier Archipelago
PORT WALCOTT
PORT HEDLAND
WESTERN AUSTRALIA
114°
115°
116°
117°
118°
119°
120°
121°
17°
18°
19°
20°
21°
To accompany Record 1970/27
F50/A/16

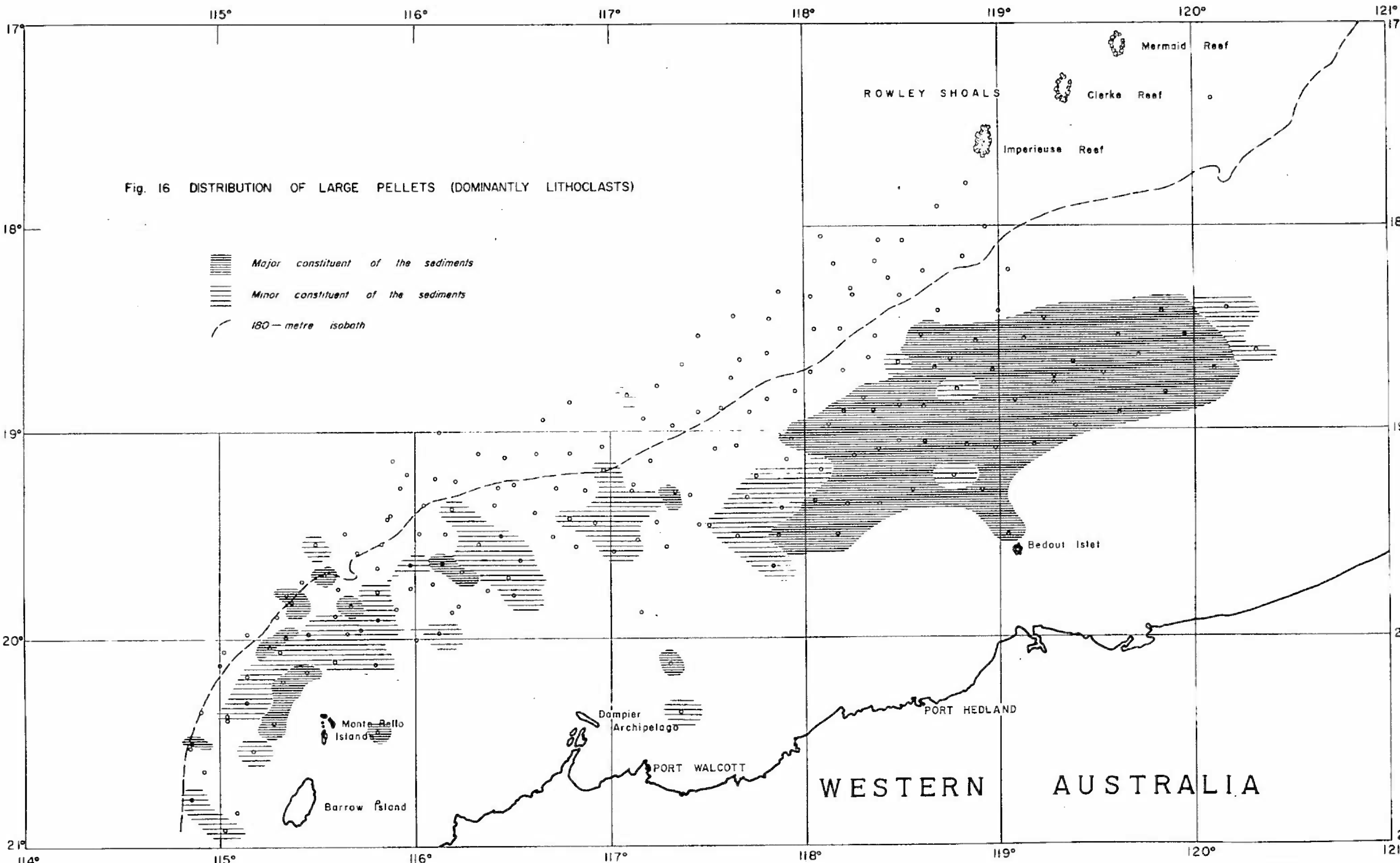
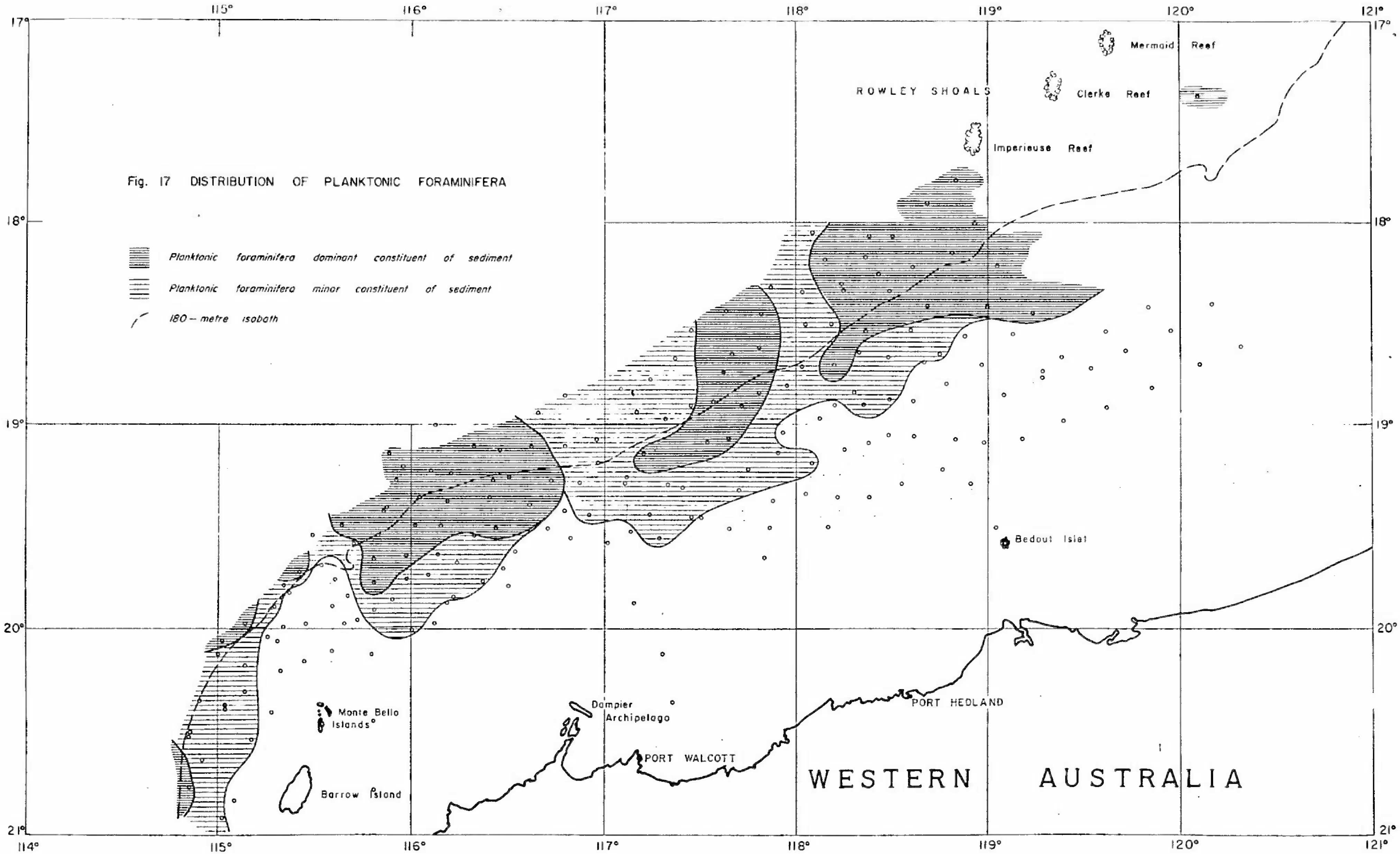


Fig. 16 DISTRIBUTION OF LARGE PELLETS (DOMINANTLY LITHOCLASTS)

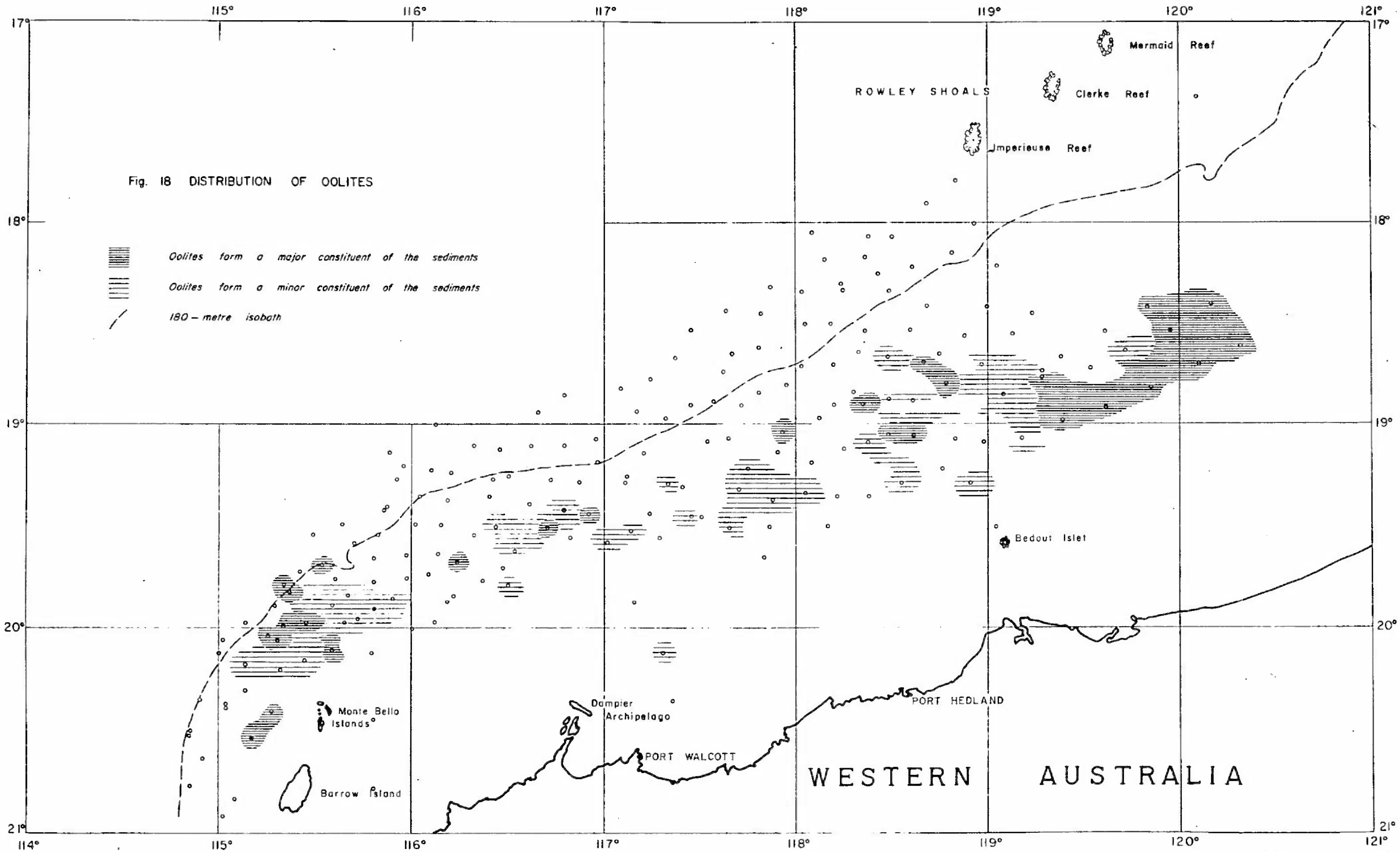
To accompany Record 1970/27

F50/A/17



To accompany Record 1970/27

F 50/A/18



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Carbonate and terrigenous detritus

Figure 19 shows the distribution of sediments with over 90 percent carbonate, 75 to 90 percent and under 75 percent. The values were calculated from the analyses assuming that all the CO_2 is combined as $CaCO_3$, and except where indicated otherwise in the figure, relate to the -2mm size fraction. Where coarser material is present, it often consists of pure carbonate shell skeletal debris, and thus the whole sediment carbonate values are rather higher than those shown. However, in a number of stations scattered irregularly over the middle and inner shelf the coarse fraction is relatively low in carbonate (Fig. 19). This occurs where large pellets and lithoclasts with a significant non-carbonate component occur in the sediment. It is often difficult to distinguish in thin section dark fine-grained material consisting of almost pure carbonate from that containing a large proportion of silt and clay-sized authigenic and terrigenous clay.

There is quite a good positive correlation between areas of fine-grained sediment deposition and areas of relatively low carbonate content (Figures 14 and 19). This emphasizes once again the non-depositional conditions obtaining over the greater part of the shelf and shows that the small amount of fine-grained terrigenous detritus being shed by the land is kept in suspension until it approaches the outer edge of the shelf. The correlation is to some extent obscured where the authigenic non-carbonate component (glauconite or phosphatic material) assumes importance in non-depositional areas.

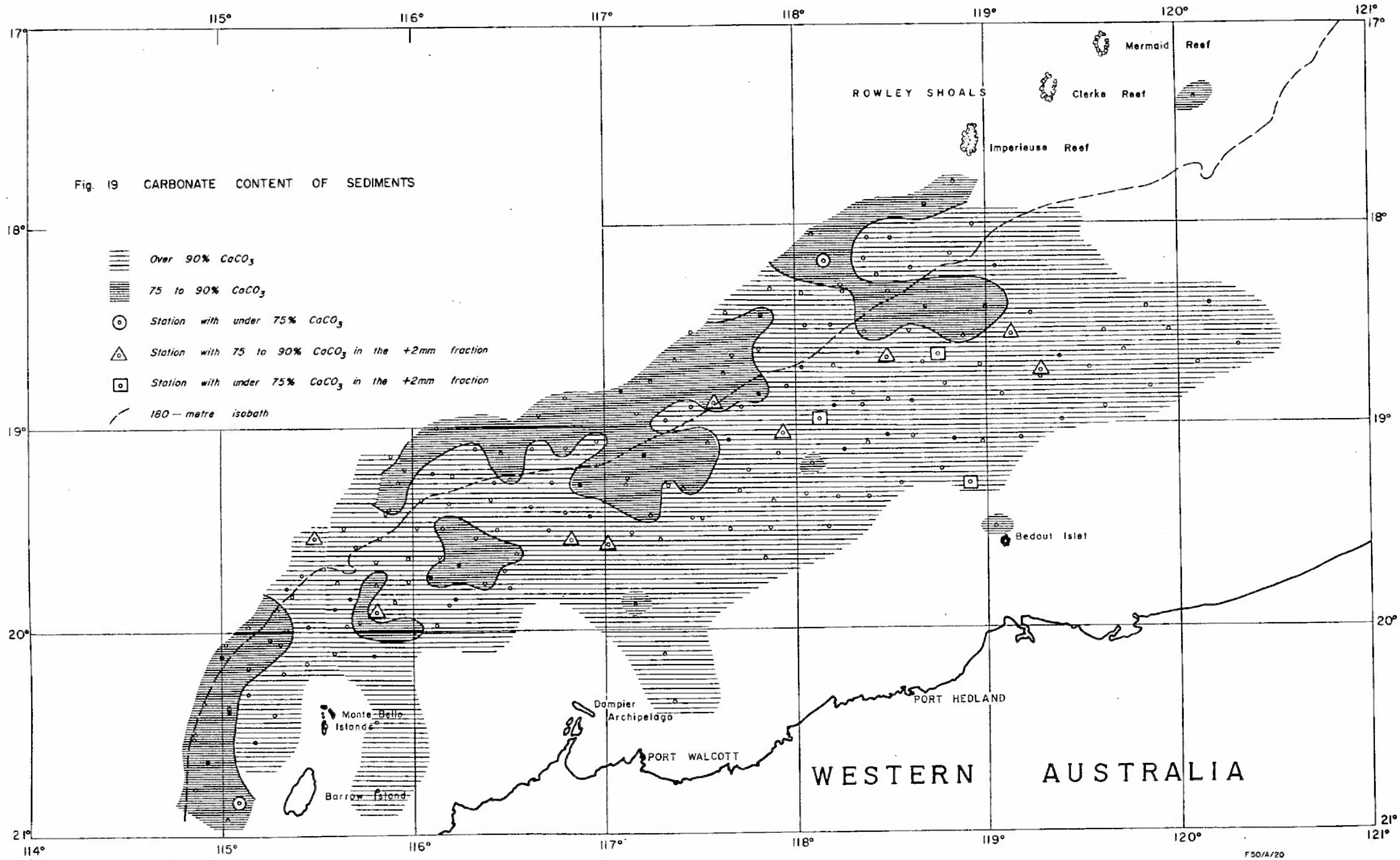
Apart from lithoclasts, terrigenous detritus large enough to be resolved under the microscope is rarely present in more than accessory proportions, although very few samples indeed have none at all. Very fine sand-size quartz is normally present in quantities ranging from a few parts per thousand up to 1 or 2 percent. Distribution is somewhat irregular with the highest concentrations occurring, as might be expected, on the narrow shelf near the Monte Bello Islands. Rare grains of feldspar and iron ore, and very rare ferromagnesian minerals, were also noted.

Glauconite and phosphate.

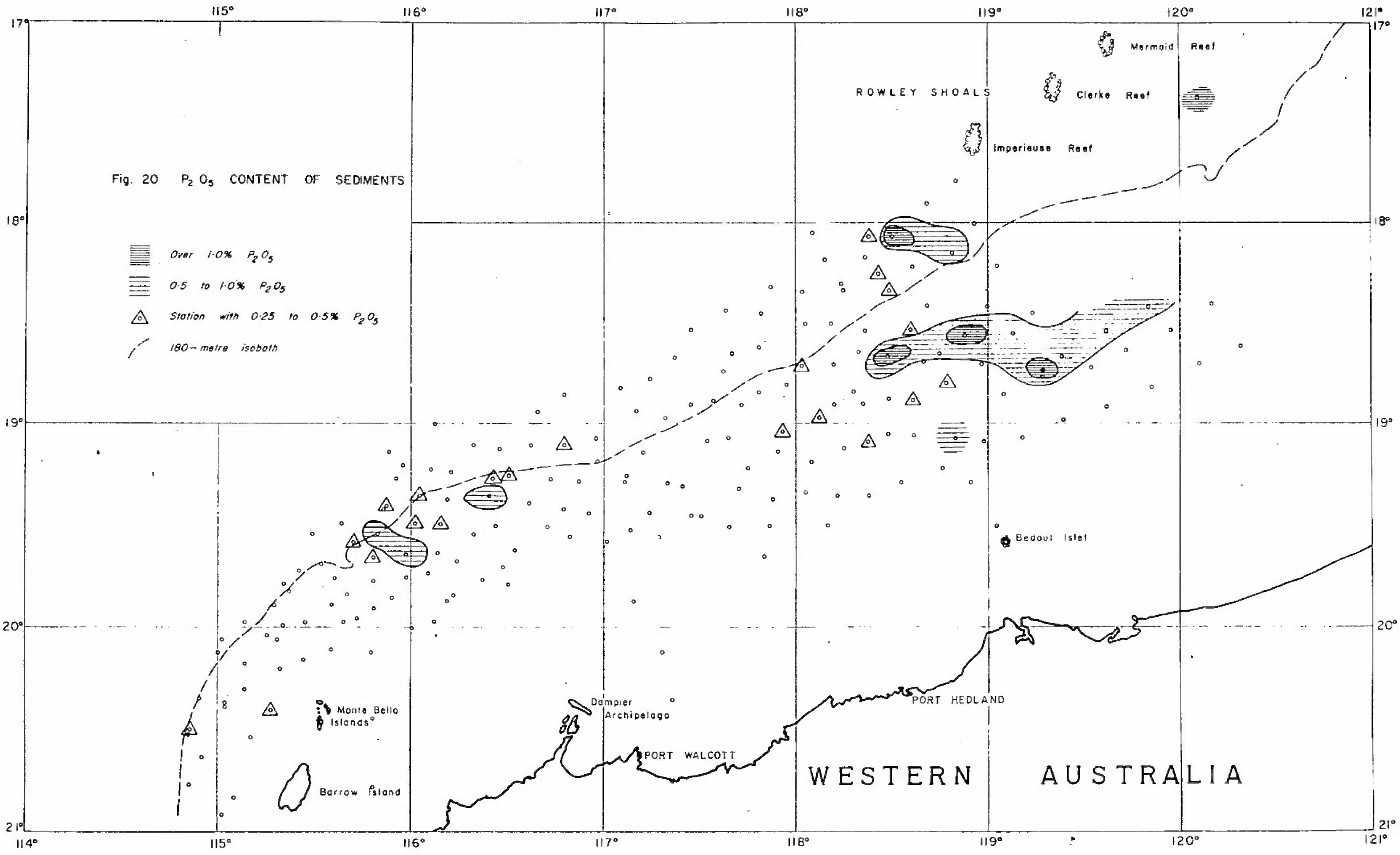
Glauconite is a widespread but minor constituent of the sediments; it forms pellets, which can often be identified as casts of planktonic foraminifera, and fills chambers in a wide variety of skeletal detritus. Much of the glauconite is more or less degraded to a faintly birefringent limonitic clay which is commonly difficult or impossible to distinguish 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 recognizalbe trends; it is largely absent from the shelf and upper slope between 115°E and 116°E, north of the Monte Bello Islands, but is relatively abundant on the shelf to the west of Barrow Island. Highest concentrations tend to occur close to the edge of the shelf, but there is no positive correlation between the glauconitic and phosphatic sediments.

The phosphate content of the sediments is uniformily low, the highest P_2O_5 value recorded being 3.3% from station 591 southeast of Mermaid Reef. The map of the distribution of the slightly phosphatic sediments (Fig. 20) shows that they occur in the zones of medium - and coarse-grained sediments near the outer edge of the shelf (compare Fig.14). In thin section the phosphatic material appears as a finely divided aggregate of isotropic collophane, faintly birefringent crystalline phosphate, and more or less ferruginous, carbonaceous, glauconitic, and carbonate matter. These impure phosphatic aggregates occur as discrete pellets, casts or infillings of Globigerina - type foraminifera, or chamber infillings of benthic foraminifera and miscellaneous skeletal detritus.



To accompany Record 1970/27



To accompany Record 1970/27

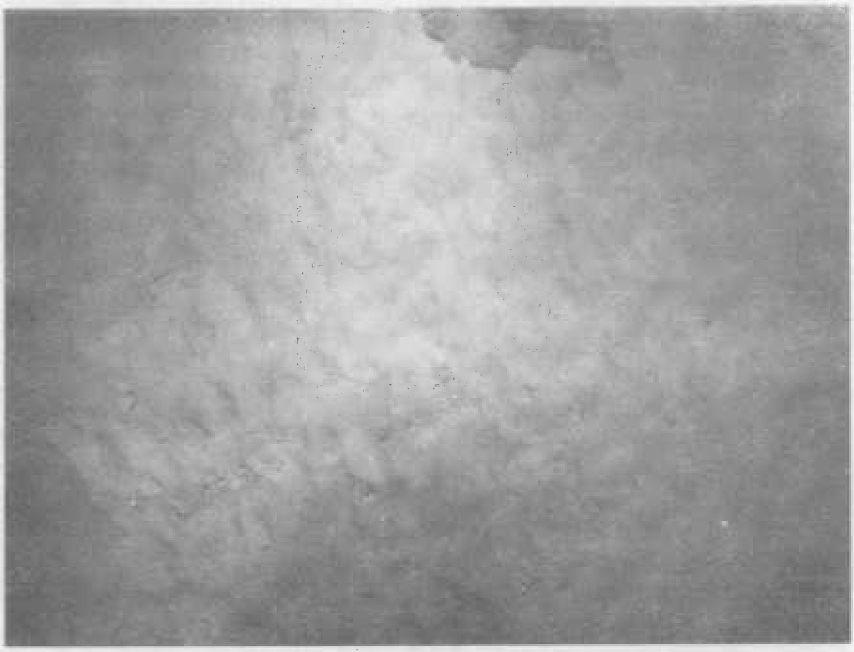


Figure 21. Station 724, 82 metres. Small scale linguoid ripples, current from upper right. Pits of burrowing organisms present. Field of view 4 sq. metres.

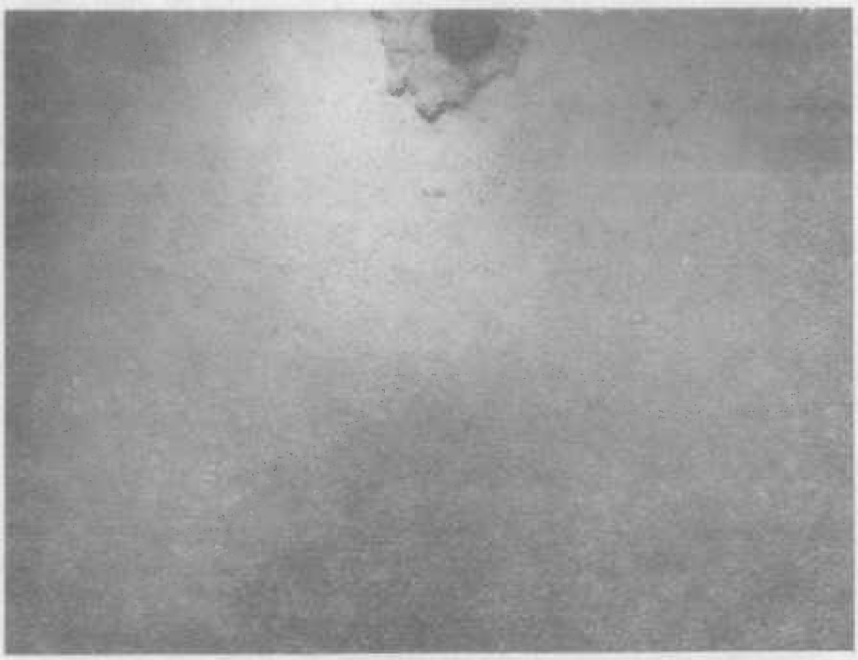


Figure 22. Station 725, 124 metres. Flat floor, densely pitted. Current lineation, from lower right, is discernible. Field of view 4 sq. metres.

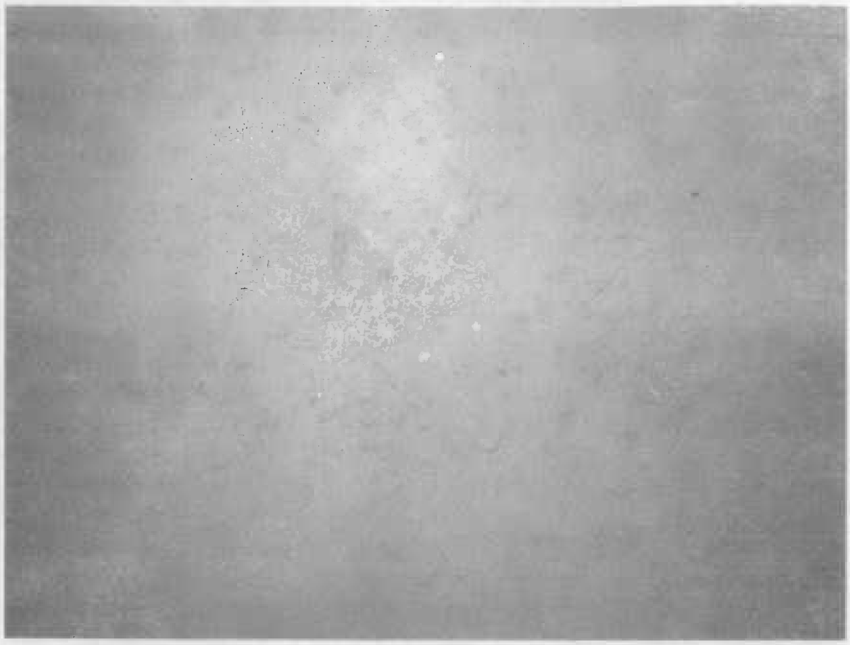


Figure 23. Station 706, 88 metres. Flat floor consisting of fine-grained carbonate sediment with abundant coarse shell detritus and nodular carbonate exposed. A faint current lineation, bottom to top, is present. The object near the centre of the field of view is probably a holothurian. Field of view 4 sq. metres.

Figure 24. Station 706, 88 metres. Photograph taken a few tens of metres from Figure 23. Ripple marked oolitic, pelletal and shelly calcarenite. Field of view $\frac{1}{4}$ sq. metre.

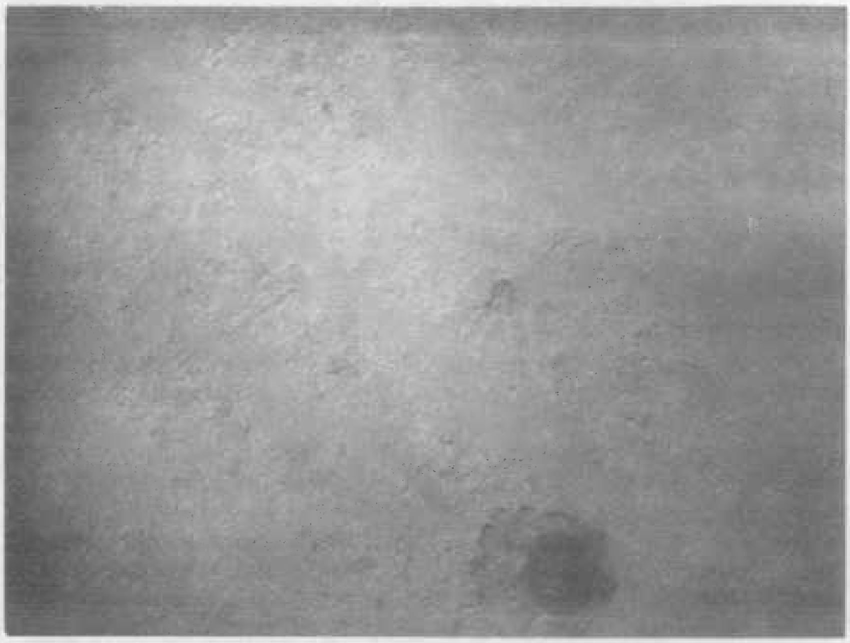


Figure 25. Station 726, 227 metres. Flat floor showing well marked current lineation. Current from lower right. Sediment is dominantly a lime mud with coarse shell detritus and bored carbonate nodules. Field of view 4sq. metres.

Figure 26. Station 702, 293 metres. Ripple marked floor, current from lower right. Numerous small pits formed by burrowing organisms are present. Field of view 4 sq. metres.

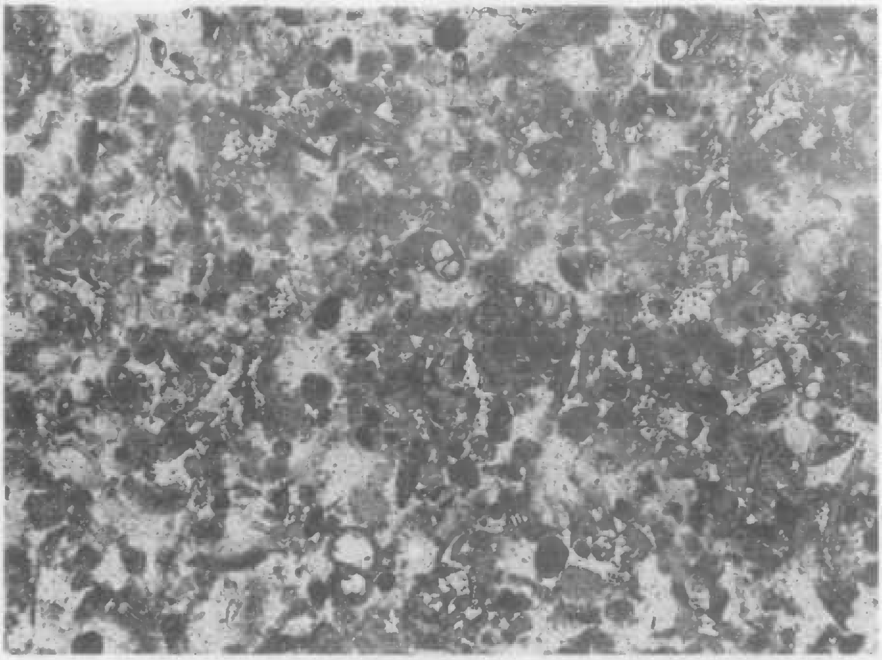


Figure 27. Station 567. Fine-grained, foraminiferal, silty calcarenite. Small Globigerina-type foraminifera and similar sized faecal and cast pellets dominate the sand-size fraction. Sub-sandsize terrigenous material is quite abundant. Ordinary light, X40.

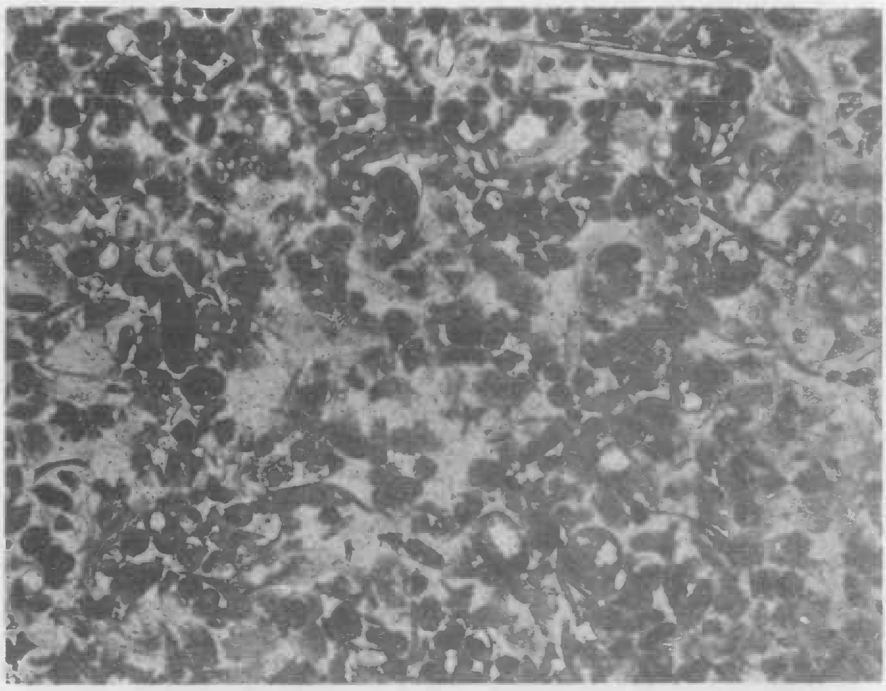


Figure 28. Station 575. Fine-grained pelletal foraminiferal calcarenite. Similar to Figure , but clean-washed. The sample consists almost exclusively of small Globigerina-type foraminifera and similar-sized pellets consisting of turbid micrite and subordinate glauconite. Ordinary light, X40.

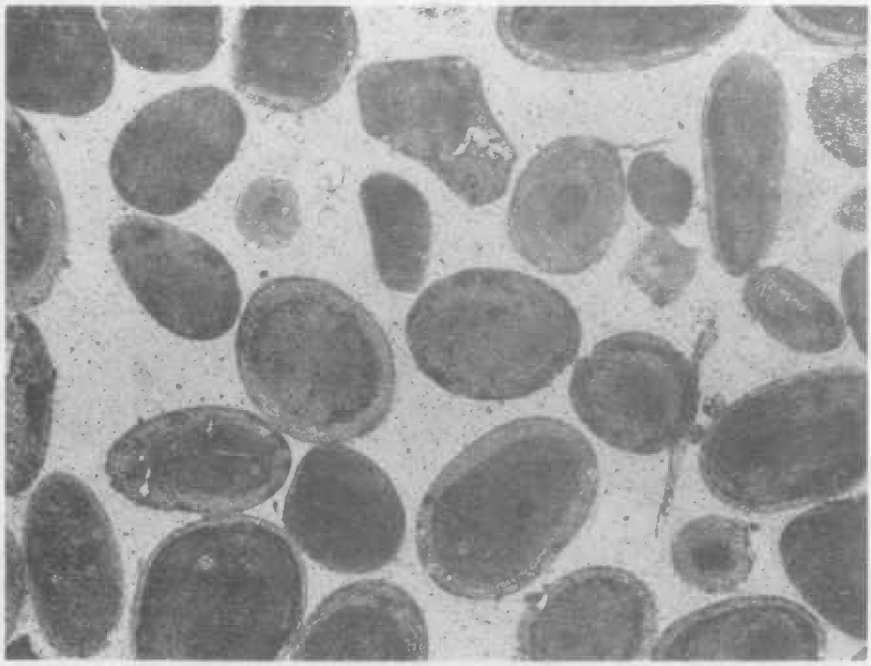


Figure 29. Station 670. Oolite. The variation in thickness of the concentrically arranged aragonitic oolitic envelopes is shown. Ordinary light, X50.

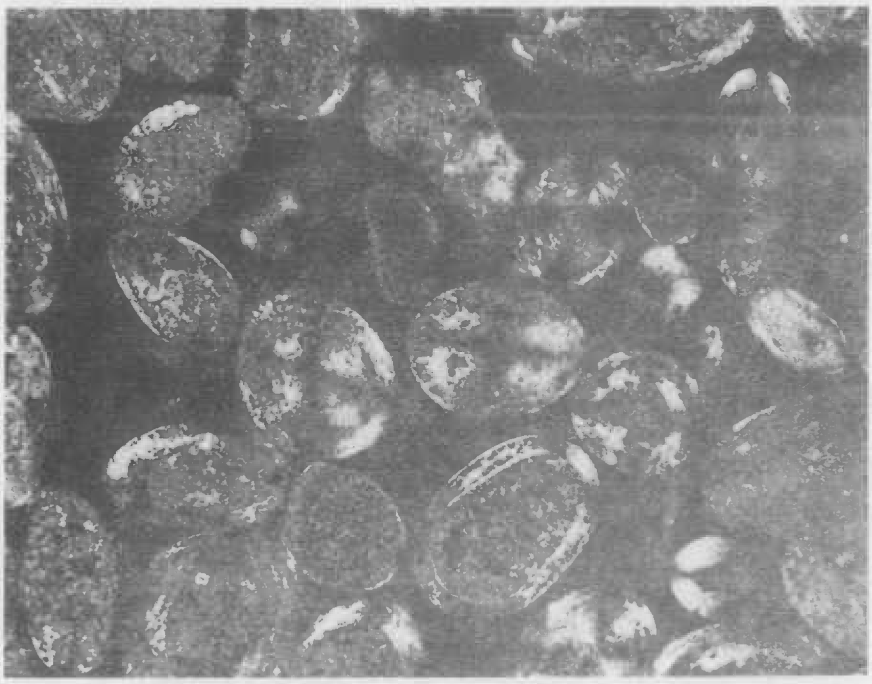


Figure 30. Station 670. Same field of view as Figure 29, crossed nicols. The extinction crosses of the aragonite oolites are shown. In sections of normal thickness this material shows mainly 1st Order interference colours.

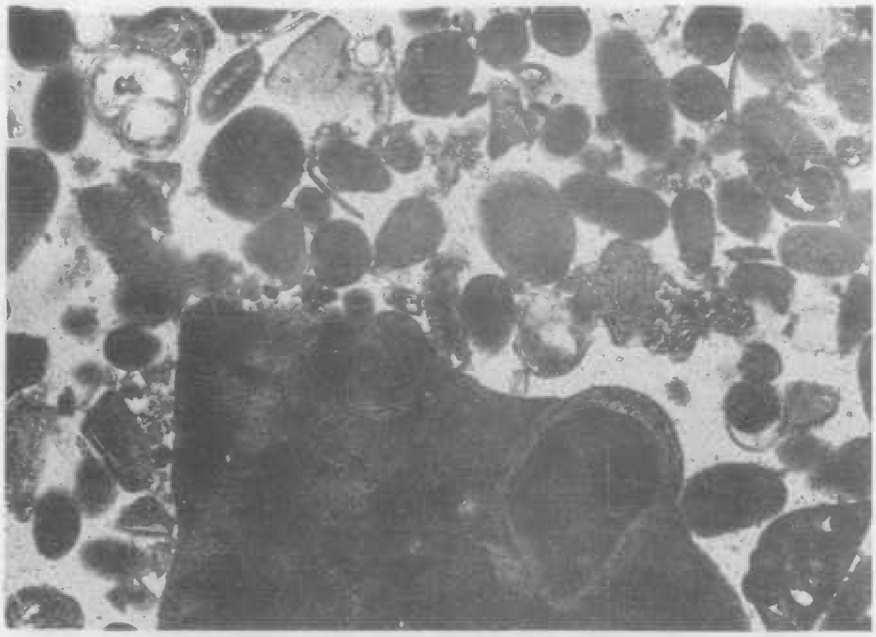


Figure 31. Station 572. Shelly oolitic and pelletal calcarenite. A large lithoclast consisting of oolites and pellets embedded in a dark matrix of fine-grained carbonate and ferruginous clay occupies much of the field of view. Ordinary light, X60.

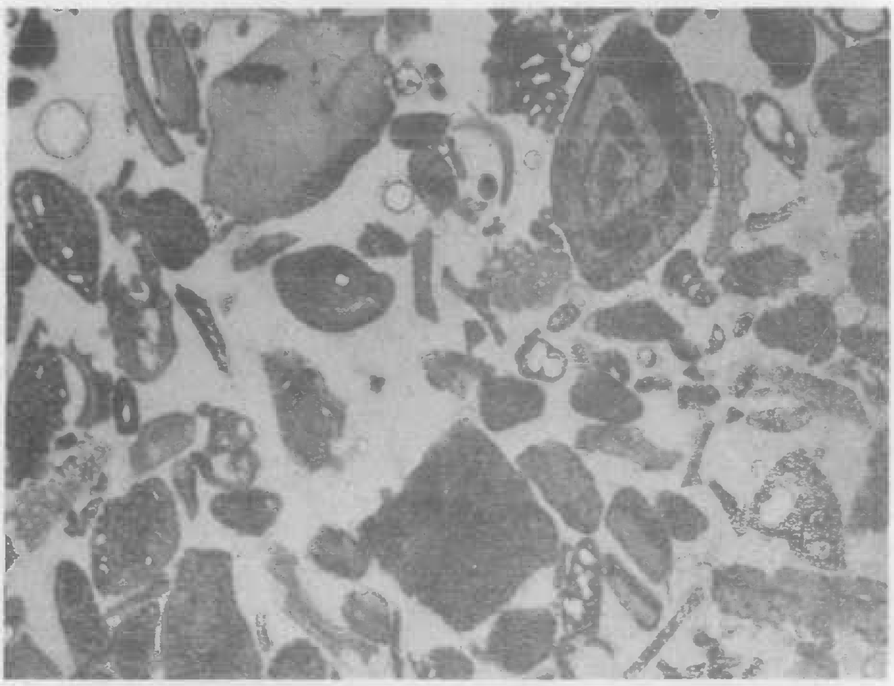


Figure 32. Station 748. Shelly calcarenite. Thick-walled benthic foraminifera are dominant amongst the skeletal material: dark material filling shells and forming scattered pellets is stained carbonate and degraded glauconite. Ordinary light, X40.

ACKNOWLEDGEMENT

The physiographic diagram (Fig. 5) was constructed by Mr. J.F. Marshall of the Bureau of Mineral Resources.

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APPENDIX 1

Notes Times are all GMT + 8 hours. Depths are in metres uncorrected for tidal variations. Sample descriptions are based on macroscopic and binocular microscope examination and on thin section petrography. Textural terms are not derived from complete mechanical analyses. Where no analytical data is given for the + 2 mm fraction this implies either that not enough coarse material was available for analysis or that it consists entirely of unaltered skeletal debris. The term *Globigerina* is taken to include all globular planktonic foraminifera.

Station No (E68-)	Date & Time (1968)	Lat S	Long E	Depth m	Carbonate % + 2mm	Carbonate % - 2mm	P_2O_5 % + 2mm	P_2O_5 % - 2mm	Sample description
547	6/10 0815	18°25'	119°50'	115	95.6	91.7	0.46	0.15	Light brown, medium to coarse, pelletal, shelly oolite.
548	6/10 1000	18°32'	119°37'	112	95.2	94.0	0.61	0.20	Light brown, medium-grained, oolitic, pelletal, shelly calcarenite
549	6/10 1200	18°40'	119°23'	117	95.0	92.0	0.52	0.30	Light brown, medium-grained, oolitic, pelletal, shelly calcarenite
550	6/10 1340	18°27'	119°14'	124	-	94.0	-	0.23	Green-grey, fine-grained, pelletal, *Globigerina* calcarenite
551	6/10 1540	18°13'	119°03'	135	-	92.2	-	0.18	Grey-brown, fine-grained, well sorted, pelletal, *Globigerina* calcarenite
552	6/10 1730	18°00'	118°56'	261	-	94.4	-	0.18	Grey-brown, medium-grained, *Globigerina* calcarenite

553	7/10 0745	18°46'	119°17'	106	-	97.6	-	0.14	Grey-brown, medium to coarse, pelletal, shelly oolite
554	7/10 0940	18°33'	119°08'	128	86.5	94.4	0.79	0.30	Grey-green, medium to coarse, poorly sorted, shelly, pelletal calcarenite
555	7/10 1145	18°25'	119°00'	150	-	86.5	-	0.20	Grey-green, medium-grained, poorly sorted, shelly, <u>Globigerina</u>, calcarenite.
556	7/10 1330	18°09'	118°49'	216	91.7	91.0	0.55	0.25	Brown-grey, fine-grained, silty, pelletal calcarenite
557	7/10 1520	18°13'	118°37'	229	-	92.0	-	0.21	Brown-grey, medium-grained, silty, pelletal, <u>Globigerina</u> calcarenite
558	7/10 1715	18°25'	118°41'	133	-	78.0	-	0.19	Grey-green, fine-grained, pelletal, <u>Globigerina</u> calcarenite
559	7/10 1910	18°39'	118°45'	137	47.2	95.4	0.95	0.29	Grey-green, medium to coarse, poorly sorted, shelly, pelletal calcarenite
560	9/10 0535	19°30'	119°03'	38	-	86.3	-	0.13	Brown, coarse-grained, pelletal, shelly calcarenite
561	9/10 0720	19°17'	118°55'	69	60.0	97.3	0.12	0.12	Green-brown, coarse-grained, oolitic, pelletal, shelly calcarenite
562	9/10 0910	19°04'	118°50'	84	90.9	92.4	0.85	0.18	Green-brown, coarse-grained, pelletal, shelly calcarenite.
563	9/10 1100	18°53'	118°37'	88	82.2	95.4	0.44	0.14	Grey-green coarse-grained, muddy, oolitic, pelletal, shelly calcarenite
564	9/10 1240	18°40'	118°29'	132	83.4	90.0	2.37	0.25	Grey-green, coarse-grained, muddy, oolitic, pelletal, <u>Globigerina</u> calcarenite

565	9/10 1440	18°32'	118°22'	132	-	88.6	-	0.19	Grey-green, fine-grained, muddy, *Globigerina*, pelletal calcarenite
566	9/10 1610	18°20'	118°15'	234	-	91.7	-	0.19	Grey-green, fine-grained, muddy, *Globigerina*, pelletal, shelly calcarenite.
567	9/10 1730	18°11'	118°09'	325	-	71.3	-	0.15	Grey-green, fine-grained, muddy, *Globigerina*, pelletal calcarenite
568	9/10 1850	18°03'	118°05'	576	-	85.1	-	0.16	Grey lime mud. Sand-size fraction subordinate, consisting of *Globigerina* tests
569	10/10 0700	18°10'	118°22'	296	-	93.1	-	0.19	Grey-green, fine-grained, muddy, *Globigerina* calcarenite
570	10/10 1020	18°20'	118°29'	201	-	85.6	-	0.37	Grey, coarse-grained, muddy, shelly, pelletal calcarenite
571	10/10 1215	18°32'	118°36'	143	-	91.0	-	0.26	Grey, coarse-grained, muddy, shelly, pelletal calcarenite
572	10/10 1340	18°41'	118°40'	137	-	94.2	-	0.18	Light grey, fine to medium, pelletal oolite
573	10/10 1630	19°03'	118°29'	80	-	100.0	-	0.23	Light brown, medium to coarse, shelly, pelletal oolite
574	10/10	18°54'	118°21'	119	-	98.8	-	0.14	Light grey, fine to medium, pelletal oolite
575	10/10 2005	18°42'	118°12'	133	-	94.6	-	0.15	Light grey, fine-grained, muddy, pelletal, *Globigerina* calcarenite
576	11/10 0745	18°30'	118°03'	238	-	99.2	-	0.24	Light grey, coarse-grained, muddy, shelly calcarenite

577	11/10 0940	18°19'	117°52'	399	-	94.6	-	0.16	Light grey, fine-grained, very muddy, pelletal calcarenite
578	11/10 1145	18°26'	117°38'	448	-	93.3	-	0.17	Light grey, medium-grained, very muddy, pelletal, *Globigerina* calcarenite
579	11/10 1340	18°37'	117°48'	261	-	96.2	-	0.18	Light grey, medium-grained, very muddy, pelletal, *Globigerina* calcarenite
580	11/10 1530	18°48'	117°57'	152	-	95.2	-	0.22	Light grey, coarse-grained, muddy, shelly calcarenite
581	11/10 1730	18°58'	118°07'	122	62.2	94.0	0.44	0.16	Light grey, coarse-grained, muddy, oolitic, pelletal, shelly, calcarenite
582	11/10 1900	19°07'	118°15'	88	-	97.6	-	0.16	Brown, coarse-grained, clean washed, pelletal, shelly calcarenite
583	13/10 0623	18°42'	118°58'	128	-	92.7	-	0.15	Light grey, medium to coarse, oolitic, pelletal, shelly calcarenite
584	13/10 0750	18°48'	118°47'	115	90.5	98.0	0.42	0.08	Very light grey, medium-grained, shelly, pelletal oolite
585	13/10 1010	18°51'	119°05'	95	93.3	94.2	0.20	0.13	Brown, medium-grained, clean washed, oolitic, pelletal, shelly calcarenite
586	13/10 1150	18°44'	119°17'	104	89.5	93.5	1.93	0.25	Grey-brown, medium-grained, oolitic, pelletal, shelly calcarenite
587	13/10 1340	18°43'	119°32'	104	-	94.0	-	0.21	Greenish grey, medium-grained, clean washed, oolitic, pelletal, shelly calcarenite
588	13/10 1520	18°38'	119°43'	104	-	94.6	-	0.18	Brown-grey, coarse-grained, clean washed, oolitic,pelletal, shelly calcarenite

589	13/10 1700	18°32'	119°57'	102	-	95.6	-	0.13	Brown-grey, coarse-grained, clean washed, pelletal, shelly oolite
590	13/10 1840	18°24'	120°10'	101	92.5	92.4	0.14	0.13	Brown-grey, coarse-grained, pelletal, shelly oolite
591	14/10 1100	17°22'	120°05'	300	-	77.0	-	3.30	Grey-brown, medium-grained, glauconitic, _Globigerina_ calcar-enite
592	17/10 0555	18°37'	120°19'	86	93.7	92.2	0.15	0.20	Grey-brown, coarse-grained, muddy, pelletal, shelly oolite
593	17/10 0800	18°42'	120°06'	90	-	94.0	-	0.12	Brown-grey, medium to coarse, pelletal, shelly oolite
594	17/10 0955	18°49'	119°51'	82	-	93.1	-	0.11	Light brown, coarse-grained, clean washed, pelletal, shelly oolite
595	17/10 1140	18°55'	119°37'	73	-	94.6	-	0.12	Light brown, coarse-grained, clean washed, pelletal, shelly oolite
596	17/10 1325	18°59'	119°24'	77	-	95.2	-	0.12	Brown, coarse-grained, clean washed, pelletal, shelly oolite
597	17/10 1510	19°04'	119°11'	82	93.5	94.0	0.20	0.20	Light brown, medium to coarse, oolitic, pelletal, shelly calcarenite
598	17/10 1830	19°13'	118°46'	77	-	92.9	-	0.14	Light brown, coarse-grained, shelly calcarenite
599	17/10 2115	19°21'	118°23'	73	-	92.2	-	0.18	Brown, medium to coarse, clean washed, pelletal, shelly calcarenite

600	18/10 1000	19°30'	118°10'	60	92.9	91.5	0.12	0.14	Brown, coarse-grained, pelletal, shelly calcarenite
601	18/10 1140	19°20'	118°03'	79	93.1	92.2	0.14	0.16	Brown, coarse-grained, oolitic, pelletal, shelly calcarenite
602	18/10 1335	19°08'	117°54'	110	-	91.7	-	0.21	Brown-grey, fine to medium, muddy, shelly, Globigerina calcarenite
603	18/10 1520	18°54'	117°43'	146	-	90.9	-	0.17	Light grey, fine-grained, very muddy, Globigerina calcarenite
604	18/10 1845	18°44'	117°37'	274	-	89.5	-	0.19	Light grey, fine-grained, very muddy Globigerina calcarenite
605	19/10 0810	19°30'	117°51'	71	93.7	96.3	0.12	0.15	Brown, medium to coarse, clean washed, pelletal, shelly calcarenite
606	19/10 1000	19°19'	117°42'	91	96.5	94.4	0.14	0.15	Grey-brown, medium to coarse, oolitic, pelletal, shelly calcarenite
607	19/10 1145	19°05'	117°32'	137	-	88.1	-	0.16	Light grey, fine-grained, very muddy, Globigerina calcarenite
608	19/10 1340	18°54'	117°27'	183	98.3	93.7	0.13	0.25	Light grey, medium-grained, very muddy, shelly calcarenite
609	19/10 1530	18°40'	117°22'	338	-	82.6	-	0.20	Light grey, fine-grained, very muddy, shelly calcarenite
610	19/10 1730	18°32'	117°27'	457	-	-	-	-	Light grey, medium-grained, very muddy, shelly calcarenite
611	20/10 0840	18°49'	117°05'	366	-	87.4	-	0.17	Light grey, fine-grained, very muddy, shelly calcarenite

612	20/10 1030	18°56'	117°10'	293	-	-	-	-	Light grey, fine-grained, very muddy, *Globigerina* calcarenite
613	20/10 1325	19°08'	117°12'	155	-	89.5	-	0.20	Green grey, fine-grained, very muddy, shelly, pelletal, *Globigerina* calcarenite
614	20/10 1515	19°17'	117°20'	119	-	92.0	-	0.15	Green-grey, medium-grained, very muddy, oolitic, pelletal, shelly calcarenite
615	20/10 1700	19°27'	117°27'	82	-	94.0	-	0.20	Brown-grey, medium-grained, very muddy, oolitic, shelly, *Globigerina* calcarenite
616	20/10 1820	19°33'	117°17'	86	98.3	90.9	0.16	0.17	Brown-grey, fine-grained, very muddy, pelletal, *Globigerina* calcarenite
617	21/10 0855	19°26'	117°14'	91	-	89.7	-	0.16	Brown-grey, fine-grained, very muddy, shelly, *Globigerina* calcarenite
618	21/10 1045	19°15'	117°07'	113	-	87.8	-	0.16	Light grey, slightly sandy, lime mud. Sand-size fraction includes *Globigerina* and shell fragments
619	21/10 1225	19°04'	116°57'	219	-	94.2	-	0.17	Very light grey, silty, lime mud. Few *Globigerina*
620	21/10 1430	18°51'	116°47'	366	-	87.8	-	0.19	Light grey, slightly sandy, lime mud. Sand-size fraction is dominantly *Globigerina*
621	21/10 1610	18°56'	116°39'	338	-	81.5	-	0.19	Green-grey, sandy, lime mud. Sand-size fraction is dominantly *Globigerina*
622	21/10 1810	19°06'	116°47'	247	90.5	84.0	0.46	0.21	Green-grey, sandy, lime mud. Sand-size fraction is dominantly *Globigerina*
623	22/10 0725	19°11'	116°58'	133	-	88.1	-	0.17	Green-grey, sandy, lime mud. Sand-size fraction is dominantly *Globigerina*

624	22/10 0845	19°17'	117°06'	119	-	87.4	-	0.16	Green-grey, medium-grained, very muddy, shelly, Globigerina calcarenite
625	22/10 1040	19°17'	116°52'	119	-	86.5	-	0.15	Green-grey, medium-grained, very muddy, shelly, Globigerina calcarenite
626	22/10 1135	19°26'	116°55'	82	-	91.7	-	0.13	Green-grey, coarse-grained, shelly, pelletal oolite
627	22/10 1330	19°35'	117°01'	73	75.2	92.4	0.14	0.17	Green-brown-grey, medium-grained, oolitic, pelletal, shelly calcarenite
628	22/10 1500	19°33'	116°49'	26	88.7	-	0.13	-	Whitish brown, pebbly, stained and encrusted, skeletal detritus
629	23/10 0700	19°07'	116°27'	274	-	87.8	-	0.27	Light grey-brown, medium-grained, muddy, shelly, Globigerina calcarenite
630	23/10 0820	19°15'	116°30'	174	-	89.3	-	0.28	Light grey-brown, medium to coarse, muddy, shelly calcarenite
631	23/10 0940	19°23'	116°36'	128	-	92.0	-	0.16	Light grey, very fine-grained, pelletal, Globigerina calcarenite
632	23/10 1110	19°30'	116°42'	60	-	94.2	-	0.12	Light grey-brown, coarse-grained, shelly oolite
633	23/10 1400	19°37'	116°32'	66	-	87.6	-	0.13	Light brown, medium-grained, clean washed, oolitic, pelletal, shelly calcarenite
634	23/10 1400	19°30'	116°26'	117	-	90.2	-	0.15	Light green-grey, very fine-grained, oolitic, pelletal, Globigerina calcarenite
635	23/10 1530	19°21'	116°24'	146	-	92.0	0.53	0.30	Light green-grey, fine-grained, pelletal, Globigerina calcarenite
636	23/10 1700	19°14'	116°12'	283	-	90.9	0.11	0.17	Light grey, very fine-grained, silty, pelletal, Globigerina calcarenite

637	23/10 1830	19°00'	116°07'	357	-	78.1	-	0.17	Light grey, very fine-grained, silty, pelletal, *Globigerina* calcarenite
638	24/10 0715	19°12'	115°57'	274	-	90.0	-	0.19	Light grey, medium grained, pelletal, *Globigerina* calcarenite
639	24/10 0842	19°21'	116°02'	168	96.5	93.7	0.28	0.29	Grey-brown, medium-grained, pelletal, shelly, *Globigerina* calcarenite
640	24/10 0955	19°29'	116°09'	122	-	88.1	-	0.28	Green-grey, fine-grained, pelletal, *Globigerina* calcarenite
641	24/10 1130	19°40'	116°14'	99	97.5	85.1	0.11	0.16	Green-brown, coarse-grained, muddy, pelletal, shelly oolite
642	24/10 1255	19°46'	116°22'	64	-	87.8	-	0.14	Green-brown-grey, fine to medium, muddy, shelly calcarenite
643	24/10 1420	19°52'	116°11'	73	100.0	91.0	0.08	0.15	Light brown, coarse-grained, shelly calcarenite
644	24/10 1535	19°44'	116°05'	101	-	87.8	-	0.18	Green-grey, fine-grained, muddy, shelly calcarenite
645	24/10 1650	19°38'	115°58'	132	-	95.4	0.17	0.52	Light brown, medium-grained, pelletal, *Globigerina* calcarenite
646	24/10 1820	19°25'	115°51'	256	-	93.3	-	0.24	Light brown, medium-grained, pelletal, *Globigerina* calcarenite
647	25/10	21°06'	115°40'	15	-	81.3	0.09	0.13	Dark brown, medium to coarse, shelly, quartzose calcarenite
648	26/10 1800	20°47'	115°48'	18	-	92.9	-	0.13	Green-brown, coarse-grained, shelly slightly quartzose calcarenite
649	26/10 2130	20°27'	115°48'	37	-	97.5	-	0.13	Green-brown, medium-grained, shelly, pelletal calcarenite

650	27/10 0645	19°54'	115°48'	75	88.1	92.4	0.17	0.19	Green-grey, fine-grained, silty, shelly calcarenite
651	27/10 0755	19°46'	115°48'	122	-	90.0	-	0.18	Green-grey, fine-grained, muddy, pelletal, *Globigerina* calcarenite
652	27/10 0910	19°39'	115°48'	146	-	95.6	-	0.46	Green-grey, fine-grained, muddy, pelletal, *Globigerina* calcarenite
653	27/10 0958	19°32'	115°49'	183	95.2	94.2	0.61	0.43	Light brown, medium-grained, slightly muddy, shelly, pelletal, *Globigerina* calcarenite
654	27/10 1137	19°24'	115°52'	238	95.4	90.0	0.19	0.28	Light brown, medium-grained, slightly muddy, shelly, pelletal, *Globigerina* calcarenite
655	27/10 1255	19°16'	115°55'	293	-	87.8	-	0.21	Light brown, medium-grained, slightly muddy, shelly, pelletal, *Globigerina* calcarenite
656	27/10 1410	19°08'	115°53'	347	-	90.5	-	0.17	Light brown, fine-grained, very muddy pelletal, *Globigerina* calcarenite
657	28/10 0730	20°00'	116°00'	64	-	88.1	-	0.13	Green-brown, fine-grained, shelly calcarenite
658	28/10 0845	19°51'	115°54'	82	-	93.7	-	0.16	Green-brown, coarse-grained, muddy, oolitic, shelly calcarenite
659	28/10 1056	19°35'	115°42'	183	-	94.4	-	0.44	Green-grey, medium-grained, slightly muddy, shelly, pelletal calcarenite
660	28/10 1200	19°29'	115°38'	320	-	95.7	-	0.21	Light grey-brown, medium to coarse, *Globigerina* calcarenite
661	28/10 1500	19°32'	115°29'	274	88.6	92.2	0.24	0.17	Light grey, fine-grained, very silty, pelletal, *Globigerina* calcarenite
662	28/10 1610	19°41'	115°32'	95	-	91.5	-	0.15	Green-grey, coarse-grained, very muddy, pelletal oolite

663	28/10 1730	19°45'	115°36'	27	-	-	-	-	Blocky reef rock, corals, bryozoans, serpulids etc
664	29/10 1035	19°50'	115°40'	68	92.4	94.6	0.25	0.12	Green-brown, very coarse-grained, slightly muddy, shelly, oolitic, pelletal calcarenite
665	29/10 1155	19°57'	115°43'	77	-	85.6	-	0.15	Green-grey, coarse-grained, very muddy, oolitic, pelletal calcarenite
666	29/10 1325	20°06'	115°35'	73	-	93.1	-	0.13	Green-brown, coarse-grained, shelly oolite
667	29/10 1440	19°58'	115°27'	82	94.0	95.7	0.14	0.11	Light brown, very coarse-grained, shelly oolite
668	29/10 1600	19°49'	115°22'	155	-	92.4	-	0.14	Green-grey, medium-grained, shelly, pelletal oolite
669	30/10 0620	19°59'	115°20'	101	-	82.2	-	0.11	Light brown, medium-grained, clean washed, pelletal oolite
670	30/10 0710	20°03'	115°18'	82	97.5	83.7	0.10	0.10	Light brown, medium-grained, clean washed, oolite
671	30/10 0815	19°53'	115°14'	247	-	82.9	-	0.14	Green-grey, very fine-grained, muddy, calcarenite
672	30/10 1115	20°03'	115°01'	219	-	84.9	-	0.13	Green-grey, fine-grained, muddy, *Globigerina* calcarenite
673	30/10 1245	20°10'	115°08'	110	-	86.5	-	0.12	Green-brown, fine to medium, shelly, oolitic, pelletal calcarenite
674	30/10 1440	20°24'	115°16'	55	98.0	97.3	0.27	0.12	Brown, coarse-grained, shelly, pelletal oolite
675	30/10 1625	20°32'	115°10'	55	-	94.2	-	0.12	Green-brown, medium-grained, shelly, pelletal oolite

676	30/10 1745	20°23'	115°02'	91	-	82.2	-	0.12	Green-brown, fine-grained, shelly calcarenite
677	30/10 1850	20°21'	114°54'	165	-	81.3	-	0.13	Green-grey, very fine-grained, muddy, shelly calcarenite
678	4/11 1035	20°50'	115°05'	84	-	77.4	0.20	0.13	Light green-grey, very fine-grained, muddy, shelly calcarenite
679	4/11 1152	20°38'	114°55'	95	-	82.0	-	0.13	Light green-grey, very fine-grained, muddy, shelly calcarenite

680	12/11 1034	20°30'	114°51'	119	97.5	82.6	0.36	0.17	Light green-grey, medium-grained, muddy, oolitic, pelletal calcarenite
681	12/11 1330	20°46'	114°51'	104	-	83.6	-	0.23	Light green-grey, very fine-grained, muddy, shelly, pelletal, Globigerina calcarenite
682	12/11 1510	20°55'	115°01'	86	-	81.7	-	0.12	Light green-grey, very fine-grained, muddy, shelly, pelletal, Globigerina calcarenite
683	13/11 0800	20°31'	114°51'	124	-	84.6	-	0.13	Light green-grey, very fine-grained, muddy, shelly, pelletal, Globigerina calcarenite
684	13/11 1125	20°22'	115°02'	95	-	84.0	-	0.12	Light green-grey, fine to medium, shelly, pelletal, Globigerina calcarenite
685	13/11 1500	20°18'	115°08'	86	-	93.1	-	0.13	Green-brown, fine to medium, muddy, shelly, pelletal, Globigerina calcarenite
686	13/11 1655	20°07'	115°00'	192	-	83.1	-	0.14	Green-brown, fine to medium, muddy, shelly, pelletal, Globigerina calcarenite
687	14/11 0850	19°58'	115°08'	219	-	87.2	-	0.13	Green-brown, fine to medium, muddy, shelly, pelletal, Globigerina calcarenite
688	14/11 1015	20°02'	115°15'	95	96.5	98.0	0.19	0.11	Light brown, medium to coarse, clean washed, pelletal, shelly oolite
689	14/11 1130	20°12'	115°19'	49	96.5	94.9	0.13	0.10	Brown, very coarse-grained, shelly, pelletal calcarenite
690	14/11 1235	20°09'	115°26'	69	-	95.6	-	0.14	Brown, very coarse-grained, shelly, pelletal calcarenite

691	14/11 1525	19°47'	115°20'	201	-	92.0	-	0.17	Green-brown-grey, fine-grained, muddy, pelletal oolite
692	14/11 1837	19°43'	115°25'	201	-	85.8	-	0.15	Green-grey, very fine-grained, muddy, pelletal, *Globigerina* calcarenite
693	14/11 1245	19°47'	116°30'	80	99.2	92.4	0.12	0.09	Light brown, very coarse-grained, oolitic, pelletal, shelly calcarenite
694	22/11 0952	18°18'	118°14'	238	-	87.8	-	0.16	Light grey, very fine-grained, *Globigerina* calcarenite
695	22/11 1125	18°15'	118°26'	238	-	92.7	-	0.25	Light brown-grey, fine-grained, shelly, *Globigerina* calcarenite
696	22/11 1430	17°54'	118°41'	283	-	85.9	-	0.21	Light grey, fine-grained, shelly, *Globigerina* calcarenite
697	22/11 1600	17°47'	118°50'	309	-	87.4	-	0.22	Light grey, fine-grained, shelly, *Globigerina* calcarenite
698	23/11 0810	19°05'	118°59'	82	-	90.5	-	0.22	Brown, medium to coarse, clean washed, shelly, pelletal calcarenite
699	23/11 1143	18°34'	118°53'	135	94.7	87.0	2.7	0.42	Green-grey, medium to coarse, muddy, shelly, pelletal calcarenite
700	23/11 1550	18°04'	118°30'	274	-	93.5	-	1.1	Green-grey, fine to medium, pelletal, *Globigerina* calcarenite
701	23/11 1725	18°04'	118°23'	333	-	96.2	-	0.29	Green-brown-grey, fine to medium, pelletal, glauconitic, *Globigerina* calcarenite

702	24/11 0745	18°20'	118°02'	293	-	-	-	-	Green-brown-grey, fine to medium, pelletal, Globigerina calcarenite
703	24/11 0940	18°30'	118°11'	229	93.3	93.5	0.14	0.19	Light grey, very fine-grained, muddy, pelletal, Globigerina calcarenite
704	24/11 1150	18°38'	118°20'	137	-	90.5	-	0.16	Light grey, very fine-grained, muddy, pelletal, Globigerina calcarenite
705	24/11 1354	18°52'	118°29'	122	-	94.0	-	0.16	Light green-grey, medium to coarse, muddy, oolitic, pelletal, shelly calcarenite
706	24/11 1550	19°03'	118°37'	88	93.7	95.6	0.20	0.19	Brown, coarse grained, shelly, pelletal oolite
707	25/11 0700	18°27'	117°49'	307	-	89.5	-	0.18	Green-grey, very fine-grained, muddy, pelletal, Globigerina calcarenite
708	25/11 1025	18°42'	118°02'	161	-	94.6	-	0.25	Green-grey, very coarse-grained, silty, shelly calcarenite
709	25/11 1230	18°50'	118°18'	137	-	94.2	-	0.16	Green-grey, medium-grained, silty, shelly, pelletal calcarenite
710	25/11 1350	18°54'	118°12'	122	-	94.4	-	0.17	Green-grey, medium-grained, silty, shelly, pelletal calcarenite
711	25/11 1540	19°05'	118°23'	82	92.7	94.6	0.35	0.19	Green-grey, medium-grained, silty, shelly, pelletal calcarenite
712	25/11 1730	19°17'	118°33'	75	94.4	94.0	0.13	0.17	Green-brown, medium to coarse, shelly, oolitic, pelletal calcarenite

713	26/11 0702	19°21'	118°13'	73	94.4	91.3	0.12	0.17	Brown, medium to coarse, pelletal, shelly calcarenite
714	26/11 0854	19°11'	118°05'	86	-	88.1	-	0.19	Brown, medium to coarse, pelletal, shelly calcarenite
715	26/11 1040	19°02'	117°56'	128	86.5	93.7	0.27	0.14	Light green-grey, fine-grained, silty, pelletal oolite
716	26/11 1230	18°50'	117°48'	152	-	89.0	-	0.21	Light green-grey, fine-grained, muddy, *Globigerina* calcarenite
717	26/11 1430	18°39'	117°40'	265	-	88.6	-	0.20	Light green-grey, fine-grained, muddy, *Globigerina* calcarenite
718	26/11 1650	18°53'	117°34'	190	83.6	89.3	0.10	0.23	Light green-grey, fine-grained, muddy, *Globigerina* calcarenite
719	27/11 0715	19°04'	117°39'	128	-	92.7	-	0.16	Light green-grey, fine-grained, muddy, *Globigerina* calcarenite
720	27/11 0830	19°13'	117°45'	91	-	97.5	-	0.14	Brown-green, medium-grained, shelly, oolitic, pelletal calcarenite
721	27/11 1001	19°22'	117°53'	73	-	97.3	-	0.17	Brown, medium to coarse, shelly, oolitic, pelletal calcarenite
722	27/11 1200	19°39'	117°50'	58	-	92.4	-	0.15	Green-brown, medium-grained, shelly calcarenite
723	27/11 1345	19°30'	117°39'	66	-	96.7	-	0.17	Brown, medium to coarse, shelly, oolitic, pelletal calcarenite

724	28/11 0850	19°27'	117°30'	82	-	95.6	-	0.18	Green-grey, fine to medium, pelletal, shelly calcarenite
725	28/11 1041	19°18'	117°24'	124	-	88.6	-	0.15	Light green-grey, fine-grained, silty, Globigerina calcarenite
726	28/11 1335	18°58'	117°19'	227	-	92.7	-	0.20	Very light grey, silty and shelly lime mud, Globigerina present in sandsize fraction
727	28/11 1530	18°46'	117°14'	311	V-	84.4	-	0.20	Very light grey, silty and shelly lime mud, Globigerina present in sandsize fraction
728	29/11 0700	20°21'	117°21'	22	-	91.0	-	0.12	Brown, medium to coarse, clean washed, shelly calcarenite
729	29/11 0914	20°07'	117°18'	42	-	93.7	-	0.12	Brown, coarse-grained, clean washed, shelly, oolitic, pelletal calcarenite
730	29/11 1125	19°52'	117°09'	62	-	88.7	-	0.17	Grey-brown-green, medium-grained, quartzose, shelly calcarenite
731	29/11 1358	19°31'	117°08'	82	95.7	95.0	0.18	0.14	Grey-brown-green, medium to coarse, silty, oolitic, pelletal, shelly calcarenite
732	29/11 1628	19°25'	116°47'	110	-	95.4	-	0.13	Grey-brown-green, medium to coarse, silty, oolitic, pelletal, shelly calcarenite
733	29/11 1752	19°16'	116°43'	137	-	92.2	-	0.16	Green-grey, fine-grained, muddy, pelletal, Globigerina calcarenite
734	30/11 0705	19°06'	116°37'	282	-	90.9	-	0.21	Green-grey, fine-grained, muddy, pelletal, Globigerina calcarenite

735	30/11 0920	19°06'	116°19'	293	-	95.2	-	0.21	Light green-grey, fine to medium, muddy, pelletal, Globigerina calcarenite
736	30/11 1110	19°16'	116°25'	165	-	94.4	-	0.27	Light green-grey, fine to medium, muddy, pelletal, Globigerina calcarenite
737	30/11 1330	19°13'	116°06'	271	94.2	93.5	0.13	0.21	Light green-grey, fine to medium, muddy, pelletal, Globigerina calcarenite
738	30/11 1500	19°22'	116°11'	146	-	93.3	-	0.52	Light green-grey, fine to medium, muddy, pelletal, Globigerina calcarenite
739	30/11 1635	19°32'	116°19'	117	-	87.6	-	0.16	Light green-grey, fine-grained, muddy, pelletal, shelly calcarenite
740	30/11 1810	19°42'	116°28'	64	-	97.5	-	0.12	Light brown, medium to coarse, clean washed, shelly calcarenite
741	1/12 0732	19°50'	116°13'	68	95.0	94.2	0.14	0.14	Grey-green, fine to coarse, silty, shelly calcarenite
742	1/12 0905	19°38'	116°08'	110	-	91.0	-	0.16	Light grey, fine to medium, silty, oolitic, pelletal, shelly calcarenite
743	1/12 1040	19°29'	116°01'	137	-	98.0	-	0.30	Light grey-brown, medium to coarse, shelly calcarenite
744	1/12 1310	19°45'	115°58'	110	-	93.1	-	0.18	Grey-green, fine to medium, silty pelletal, shelly calcarenite
745	1/12 1523	19°58'	116°07'	64	96.2	95.6	0.14	0.16	Brown, very coarse-grained, clean washed, shelly calcarenite

2/12 0724	19°53'	115°35'	69	96.5	91.0	0.13	0.14	Brown, coarse-grained, clean washed, oolitic, pelletal, shelly calcarenite
2/12 0828	19°58'	115°39'	73	91.2	94.6	0.10	0.11	Grey-brown, coarse-grained, oolitic, pelletal, shelly calcarenite
2/12 0947	20°07'	115°47'	64	-	92.7	-	0.15	Brown, coarse-grained, clean washed, pelletal, shelly calcarenite

APPENDIX II

Laboratory Report No. 28 29th May, 1970

STRUCTURE OF CALCAREOUS OOLITES FROM THE N.W. CONTINENTAL SHELF

by

R.N. England

Oolites from the N.W. Shelf have curious optical properties in thin section. The optics reflect the submicroscopic structure which is described with the aid of a scanning electron microscope. The oolites are made up mainly of concentric shells of matted needles of aragonite whose c - direction (the direction of elongation) lies roughly within the surface of the shell.

Calcareous oolites collected from Latitude 20°03'S, Longitude 115°18'E at a depth of 82 m are described. They have centres of broken shell material or sparry calcite covered by a selvage of accreted calcium carbonate of variable thickness. The accreted material was identified by electron probe as calcium carbonate and the bulk of the sample was identified as calcite and aragonite by X-ray diffraction.

Section through the accreted material have an aggregate polarization with a maximum birefringence of about 0.03 which is usually observed to decrease towards the core. Glancing sections through the outer parts of oolites show low first order colours and a uniaxial or slightly biaxial positive interference figure. In orthoscopic light the accreted material has an extinction cross similar to that shown by chalcodonic spherulites. The radial direction is invariably slow, implying a preferred orientation of c axes normal to it.

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 prefered 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.

Subsequent examination with a scanning electron microscope showed the accreted material to be made up of concentric spherical shells of matted aragonite rods whose long axes (almost certainly the c axes) are roughly parallel to the surface of the shell. Each rod is about 0.5μ long by about 700Å wide. Scanning electron micrographs show that the long axes of the needles lie roughly in the surface of the oolite shell but appear randomly disposed when viewed normally to the oolite surface.

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