CONTRIBUTIONS

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373. RECENT FORAMINIFERA FROM THE WESTERN CONTINENTAL SHELF OF WESTERN AUSTRALIA

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ABSTRACT

The western part of the Western Australian continental shelf is inhabited by a rich foraminiferal fauna which exhibits familiar trends, including:

(1) planktonic foraminifera dominate the fauna of the outer shelf and upper continental slope samples;
(2) arenaceous benthonic foraminifera are most abundant in the mid-shelf area;
(3) calcareous benthonic foraminifera show a steady decrease in abundance toward the shelf edge;
(4) the number of species and genera slightly increases offshore;
(5) the highest total population density is reached on the outer edge of the shelf.

The environment is a fairly stable one. The uniformity of the substratum, the lack of active sedimentation, the typically oceanic salinities, the lack of significant fresh-water run-off, and the small annual variation in water temperatures suggest that these are not major factors in controlling the general distributions of the foraminifera. A latitudinal temperature cline, from a maximum of 26°C (minimum 23°C) in the north to a maximum of 21°C (minimum 17°C) in the south, is probably the most influential environmental factor.

The general distribution of Recent Foraminifera may be divided alongshore into tropical-subtropical and temperate faunal regions and offshore into three depth biofacies, recognised by the presence of certain guide species and the absence of others.

INTRODUCTION

The continental shelf of Western Australia covers some 400,000 square miles, varies in width from 24 miles near latitude 22° south to more than 250 miles near latitude 16° south, and is primarily under the influence of the open-sea waters of the south-east Indian Ocean. This report, the first of its kind from the Indian Ocean, is based upon the foraminifera found in sediment samples taken from the western part, between latitudes 18° and 34° south. Of the environmental factors, water temperatures appear to play the major role in the overall distribution of foraminiferal species, but in certain restricted areas other factors are equally important.

PREVIOUS WORK

Work on the ecology of Foraminifera in the Indian Ocean region has lagged well behind that in the Pacific and Atlantic. Parr (in Fairbridge, 1950) listed 98 species occurring in several recent beach sand samples collected between Naval Base and Trigg Island near latitude 32° south and in one sample from Geraldton Harbour at latitude 29° south. Chapman and Parr (1935) identified 112 species of foraminifera from soundings made by the trawler "Bonthorpe" in the Great Australian Bight. Logan (1959) has listed the fauna of Shark Bay, a marine embayment on the central west coast, and McTavish (in Ives, 1961) identified the foraminifera from Cockburn Sound on the south-west coast. Hassell (1962) and McKenzie (1962) have studied estuarine faunas on the south coast.

Ekman (1953) recognises two zoogeographic provinces (Hedgpeth, 1957) on the west coast of Australia. The northern Damperian province contains a tropical and probably partly subtropical fauna and is contrasted with the southern, temperate, Flindersian province. Ekman states that the southern limit of the warm water found on the west coast may be situated at about 29° south. Carrigy and Fairbridge (1954) note that the shelf is characterised by uniformity of fauna along thousands of miles of coastline, though an almost imperceptible change in fauna occurs north of the Abrolhos Islands (about latitude 29° south) where there is a gradual transition from temperate to subtropical faunas. The foraminiferal evidence also suggests that the change is a gradual one in a transition zone extending from latitude 25° south to latitude 30° south.

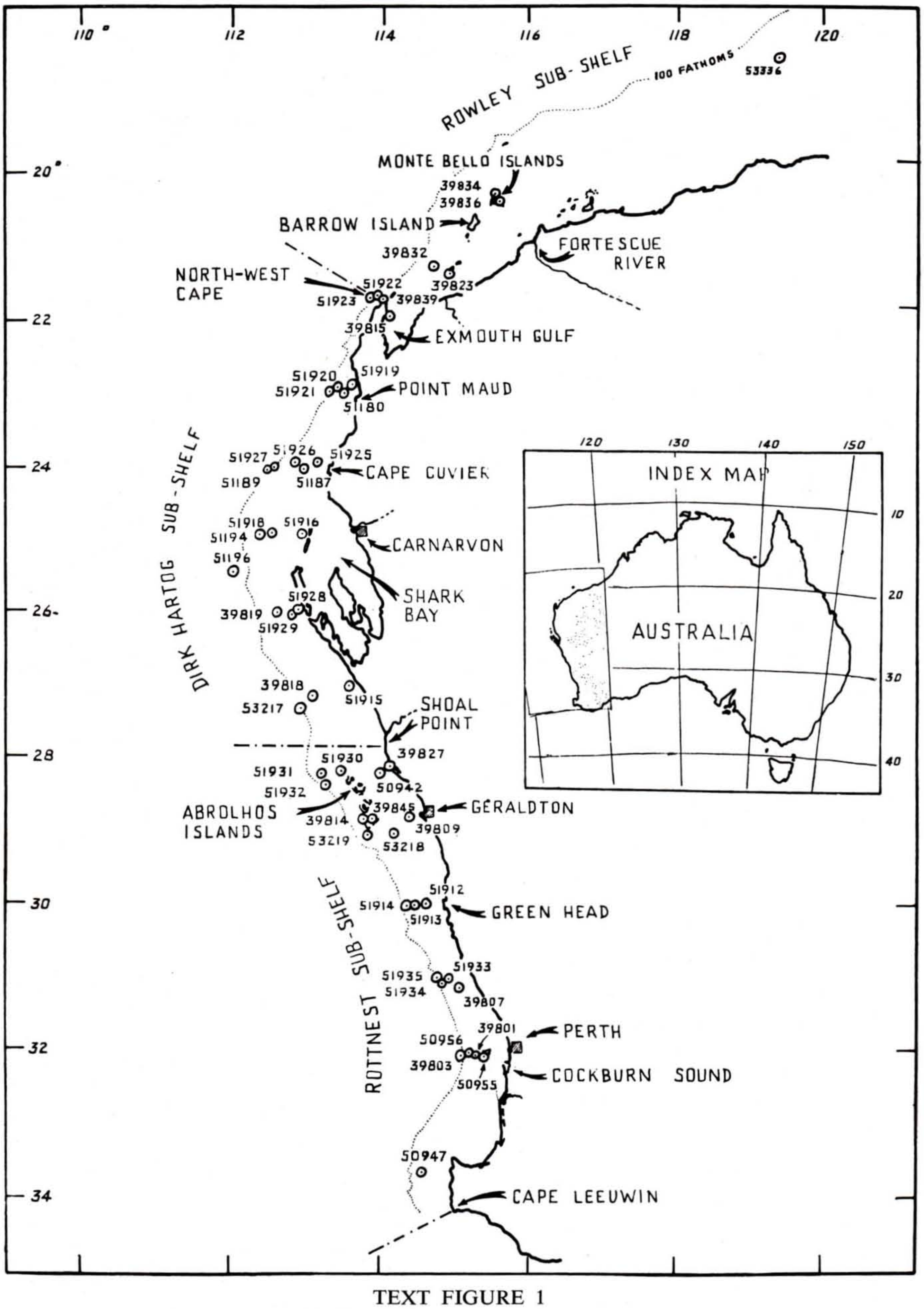
METHODS OF STUDY

Fifty samples were collected, using Petersen and Van Veen grabs, between latitudes 20° and 34° south in depths varying from 0 to 165 fathoms. Station locations are shown in text fig. 1. Full details of station data and sediment types are on file in the Geology Department of the University of Western Australia.

A unit (wet) volume of sediment (Phleger, 1960, pp. 36-37; Kornicker, 1959) was wet sieved on a 112-mesh Tyler screen, dried, and the foraminiferal tests then concentrated by carbon tetrachloride flotation. The residue was re-examined and remaining foraminifera were separated by hand picking.

Each concentrated faunal sample was spread at random onto a corrugated ceramic picking tray, and between 300 and 400 specimens were counted by traversing one or more grooves. The total population was then estimated from the ratio of the number of grooves traversed to the total number of grooves on the tray. If a low total population count was obtained several unit wet volumes were examined. Faunal slides were made for each station and a set of species reference slides built up for the whole shelf region (material stored in the Department of Geology, University of Western Australia).

The rather low sample density, the unknown



TEXT FIGURE 1
Station locations and bathymetry

error due to quartering (Phleger, 1960, p. 34) and the probable sample variation over small distances on the substratum (Shifflett, 1961) impose strict limitations on the interpretation of data. Detailed analysis of distributions of the foraminifera was not possible, but the generalisations given here are illuminative and provide a framework for future localised and detailed studies.

ENVIRONMENT

Physiography and Geology

Carrigy and Fairbridge (1954) have made the only detailed analysis of the physiography and geology of the continental shelf of Western Australia; the following discussion is based on their work.

The most western part of the Western Australian continental shelf consists of the Rottnest, Dirk Hartog and Rowley sub-shelves. This area occupies some 80,000 square miles and varies in width from 24 miles at North-West Cape to a maximum of 110 miles off Shark Bay. The shelf break occurs at 110, 160, 180, 90 and 100 fathoms off Barrow Island, North-West Cape, Shark Bay, Shoal Point and Perth respectively.

Shelf morphology shows very distinct terracing, with a transverse division into an inner and outer shelf, the latter having a steeper gradient. Superimposed on these are several intermediate terraces.

The shelf is characterised by slow, uniform sedimentation of calcareous and residual deposits which is consistent with an arid hinterland of low relief; the intermittent rivers transport large amounts of sediment only during the short winter flood period. Also, protective sandstone reefs along the coastline prevent extensive marine erosion.

The sediments on the shelf are clastic, calcareous and organogenic, being derived from skeletal debris of foraminifera, molluscs, bryozoans, and corals. There is very little terrigenous material on the Dirk Hartog and Rottnest sub-shelves. Benthonic organisms have thoroughly reworked most of the sediments, as shown by the severely fragmented bryozoans and sponges which are characteristic off Shark Bay and in the vicinity of the Abrolhos Islands. Oceanwards the shelf deposits grade progressively into gelatinous red-brown muds. Landwards they interfinger with aeolianites, quartz sand, and local estuarine silts, clays and grits. In assessing the importance of the substratum to the foraminiferal distribution, evidence given by Thorson (1957) has been used.

Hydrology

Rochford (1961, 1962, 1963, 1964) and Wyrtki (1962) described the hydrology and circulation of the water masses of the south-eastern Indian Ocean. There is, however, a lack of published systematic data concerning the hydrology of waters overlying the continental shelf. R. W. George (Western Australian Museum), B. W. Logan (University of Western Australia), officers of the Commonwealth Scientific and Industrial Research Organisation, and, more recently, the author obtained data on shelf water temperatures and salinities during the periods 1953, 1956-1957, and 1962-1964. Some of the data are good, some rather scattered.

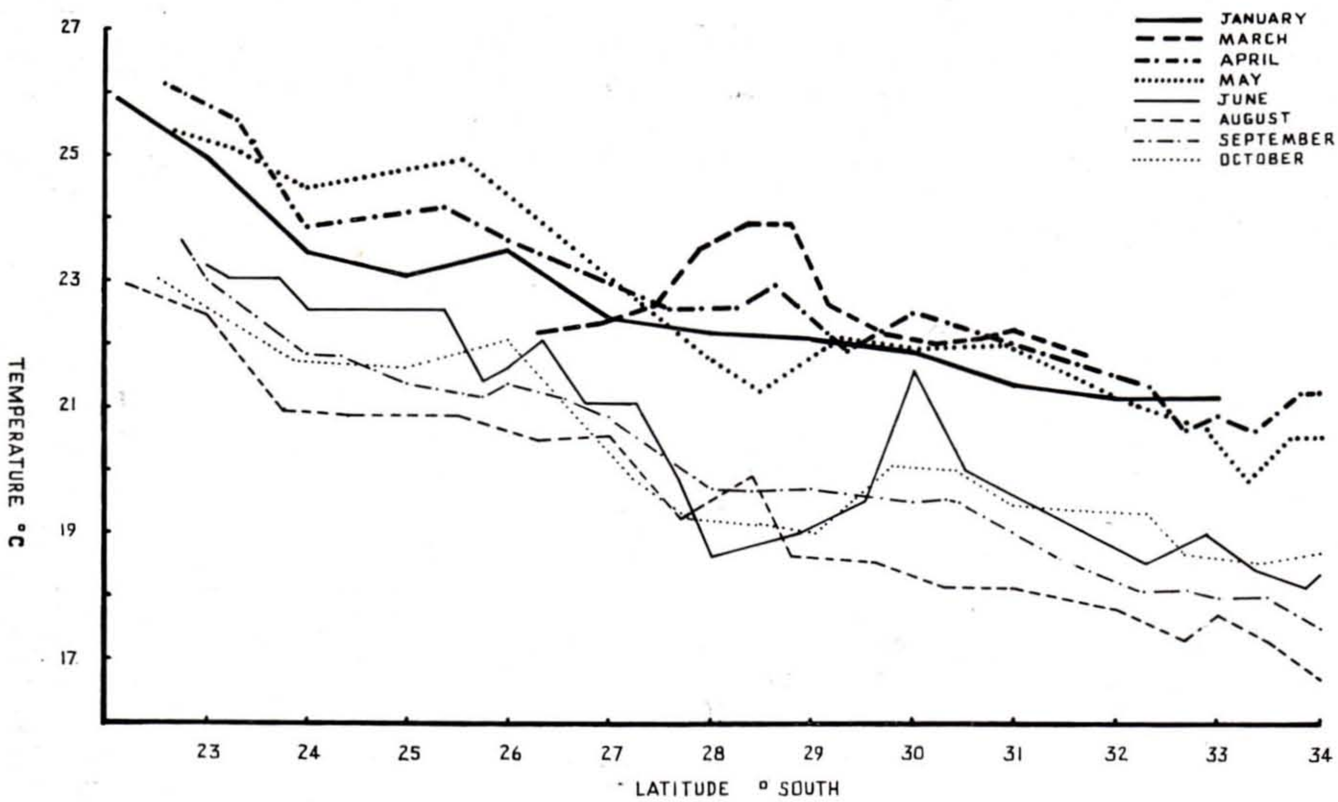
Temperature

Surface water temperatures vary from a winter minimum of 17°C in the south to an autumn maximum of 26°C at North-West Cape (text fig. 2). The difference between the average surface and bottom temperatures for the first 100 fathoms is 4°C in summer and 1°C in winter.

At the end of autumn (May to June) water temperatures drop sharply (2°C) over the whole shelf (text fig. 3). There is a further slight drop in temperature (approximately ½°C) during the winter (June through August). Minimum surface-water temperatures are recorded at the end of the winter throughout the entire length of coast, ranging from 17°C in the south to 23°C in the north. There is a slight (½°C) rise in temperature from late winter to early spring (August to September). From then on the temperature rises steadily over the Rottnest sub-shelf to an average maximum of 22°C. North of the Abrolhos Islands, however, there is first the suggestion of a slight decrease in water temperature from early to mid-spring (September to late October). Maximum temperatures are attained throughout the region in autumn (March, April, and May), being 21°C in the south and 26°C in the north.

The cyclone/anticyclone wind systems undergo a north-south seasonal migration, influencing the lower latitudes during the winter months and bringing rain by strong onshore winds to the southwest of Western Australia. Throughout summer the wind systems shift to the south, allowing dry easterly air to dominate the southern half of the state. It is probable that the cold Southern Ocean Current (*The Times* Atlas of the World, 1958) moves north and south with the seasonal migration of the winds. Text fig. 3 shows a lowering of temperatures over the Rottnest sub-shelf before that which takes place over the more northerly Dirk Hartog sub-shelf. This may be due to the fact that at the end of autumn (between May and June, as the wind systems are moving to the north) the cold current is deflected north by the Naturaliste submarine ridge at Cape Leeuwin, causing the sharp drop in temperatures, an effect which reaches its maximum in late winter (August).

The slight decrease in spring water temperatures north of the Abrolhos Islands could be due to the effect of the southeast winds blowing the surface water offshore and allowing cooler water from offshore and/or from the south into this region. Signifi-



TEXT FIGURE 2
Variation of surface water temperature with latitude

cantly these winds have their onset in early spring (September). Meteorological records for Carnarvon (latitude 24°51′ south) establish that winds with mainly a southeasterly component strengthen from 11 to 14 m.p.h. in early spring to 16 to 20 m.p.h. in mid spring (October).

In January the anticyclone wind systems move to their maximum distance south; they move so with the Southern Ocean Current, so that it is no longer deflected by the Naturaliste submarine ridge; this allows the temperatures to rise steadily over the shelf as the warmer northern waters infiltrate into more southerly latitudes.

Salinity

The slight (3° to 4°C) annual average temperature variation of the surface waters is comparable with the constant salinity. The reader is reminded of the fact that the hinterland is poorly endowed with permanent rivers. There is so little fresh-water run-off from the coast that the salinity of the water overlying the shelf remains within the range 34 to 37 p.p.t. throughout the year.

R. W. George (personal communication) has found that at stations 26 to 50 miles west of Rottnest Island at latitude 32° south the average salinity is 36.2 p.p.t. with an annual and depth variation of less than ± 0.5 p.p.t. Rochford (1964) has recorded salinities of 34.6-35.8 p.p.t. at depths up to 250 fathoms for water in the south-east region of the Indian Ocean.

There is a uniformity of hydrologic conditions for both nearshore and offshore waters. The whole area of shelf is covered by oceanic water except in:

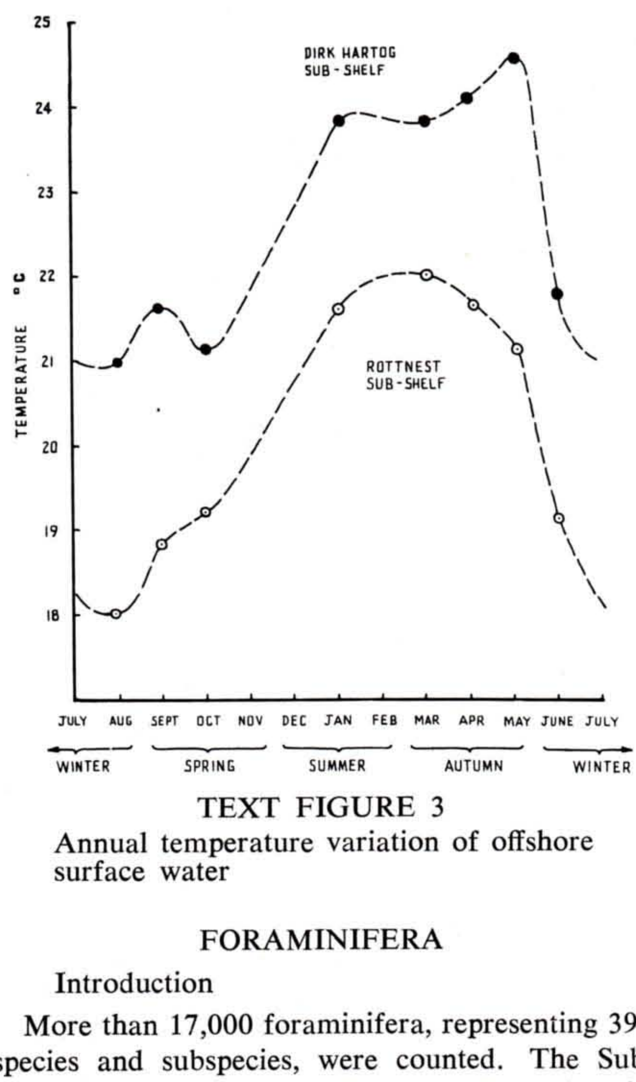
(1) the barred estuaries on the south-west coast where faunas must be adapted to environments with restricted circulation and continued fresh-water influence (Hassell, 1962; McKenzie, 1962),
(2) Cockburn Sound which receives a small influx of fresh water and fine sediment during the winter flooding of the Swan River (Ives, 1961),
(3) the major marine embayments at Shark Bay where high evaporation, low fresh water supply, bathymetry, and the dynamics of the regime itself establish and maintain horizontal salinity gradients ranging from 34 p.p.t. in the open bay areas to 65 p.p.t. in the bay heads (Logan, 1959, and
(4) Exmouth Gulf which also has a high evaporation rate with little or no fresh water supply from the mainland.

Tides and Currents

Tides of Western Australia (Hodgkin and Di Lollo, 1958) are predominantly of the daily type, but they have superimposed on them significant changes in sea level caused by atmospheric pressure and prevailing winds. Mean spring ranges decrease from 6 feet at Point Maud to 2 feet at Bunbury. North of North-West Cape the tides are semi-daily. A mean spring range of 13.5 has been recorded at the mouth of the Fortescue River.

Probably most near-surface currents follow the winds, and because these have an easterly component for most of the year the surface water over the inner shelf tends to be blown offshore.

Logan (1959) described tidal currents up to 3 knots confined to a few restricted channels in Shark Bay and states that in such areas only robust attached foraminifera having lenticular tests are suitably adapted. Aerial photographs also reveal that Shark Bay and Exmouth Gulf have numerous tidal channels scoured through sediments in water less than 3 fathoms. Currents and tides, however, probably exert little influence on the distribution of benthonic foraminifera in the majority of the area being studied.



TEXT FIGURE 3
Annual temperature variation of offshore surface water

FORAMINIFERA

Introduction

More than 17,000 foraminifera, representing 397 species and subspecies, were counted. The Suborder Textulariina is represented by 51 species, the Suborder Miliolina by 116 species, and the Suborder Rotaliina by 230 species (including 21 planktonic species). 114 species have been recorded for the first time from Western Australia, including 18 possible new species or subspecies.

The total sample of foraminifera of each station has been counted and the results summarised in table 1. The composition of the fauna is described in the following pages. It must be emphasised again that extensive additional sampling could alter some of the conclusions reached.

Total Population

Table 1 and text fig. 4a show that the total population density per wet cc. of sediment increases with depth. This is largely due to a marked increase in the numbers of planktonic species from less than 1000 per wet cc. in depths less than 130 fathoms to more than 4300 per wet cc. on the outer shelf. The Rottnest sub-shelf shows a gradual increase in population density from an average minimum of 200 per wet cc. to an average maximum of 800 per wet cc. towards the shelf edge at 110 fathoms, and then a marked increase to 1,800 per wet cc. on the upper continental slope. The Rowley sub-shelf nearshore population is slightly more dense than that of the Rottnest sub-shelf, but a lack of samples prevents a generalisation for depths greater than 60 fathoms.

Table 2 shows the distribution of "common" species, *i.e.* species with an average percentage of occurrence of more than 2%. There are 23 of these common species, 3 of which are planktonic. The only species whose average percentage of occurrence exceeded 5% of the total population are *Cibicides refulgens, Globorotalia menardii,* and *Globigerina bulloides.* The low percentages of occurrence are due, in part, to the large spread of species found in any one sample, the number ranging from 24 to 102, with an overall average of 67 per sample.

The greatest number of species (average 82 per sample) was found on the Rowley sub-shelf (text fig. 5). The Dirk Hartog sub-shelf has the lowest average number of species (58). The general trend for the entire shelf is an increase in the number of species with an increase in depth, peak abundances occurring at 50 and 130 fathoms before markedly decreasing toward the shelf edge. The genera show similar trends.

Species which are less than 2%, but widespread, are *Rheophax scorpiurus, Textularia foliacea, T. candeiana, T. dupla, T. sagittula* var. *fistulosa, Quinqueloculina bradyana, Q. costata, Q. laevigata, Q. vulgaris, Q. kerimbatica* var. *phillipensis, Q.* sp. A, *Triloculina circularis, T. tricarinata, T. trigonula, Miliolinella australis, Reussella spinulosa, Discorbis dimidiatus, D. globularis* var. *anglica, D. mira, Pulleniatina obliquiloculata, Globigerina conglomerata, Elphidium craticulatum, E. advenum, Operculina complanata, Planorbulina acervalis,* and *Anomalina colligera.*

Planktonic Fauna

There is a general offshore increase in the percentage of planktonic specimens, so that on the outer shelf and upper continental slope, planktonic species make up more than 90% of the total population (text fig. 4b and Table 1).

The occurrence of planktonic species is rare in depths less than 10 fathoms. This is probably due

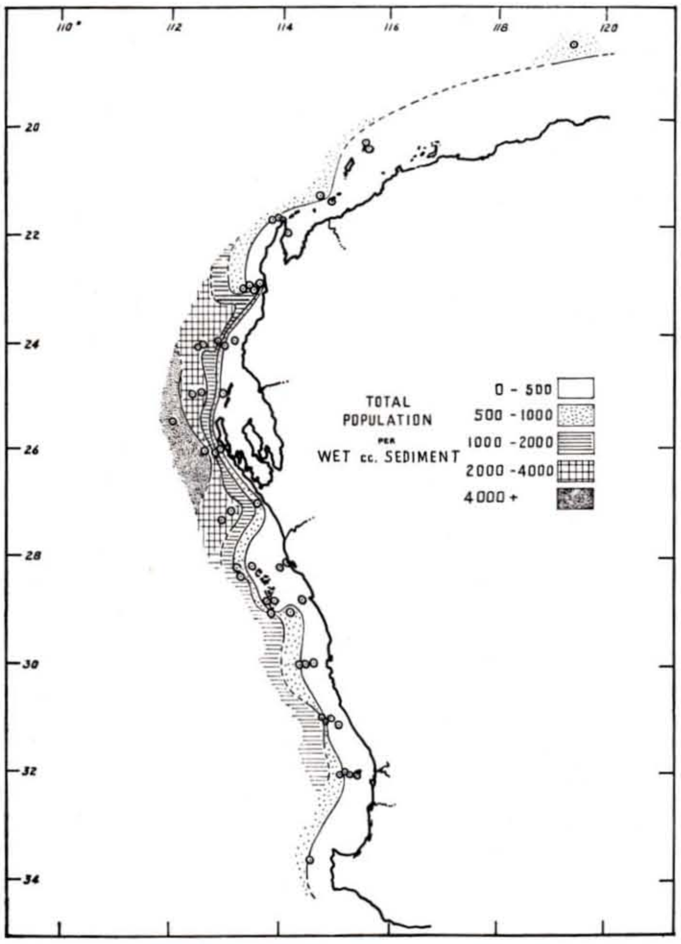
TABLE 1

Data on the foraminiferal populations

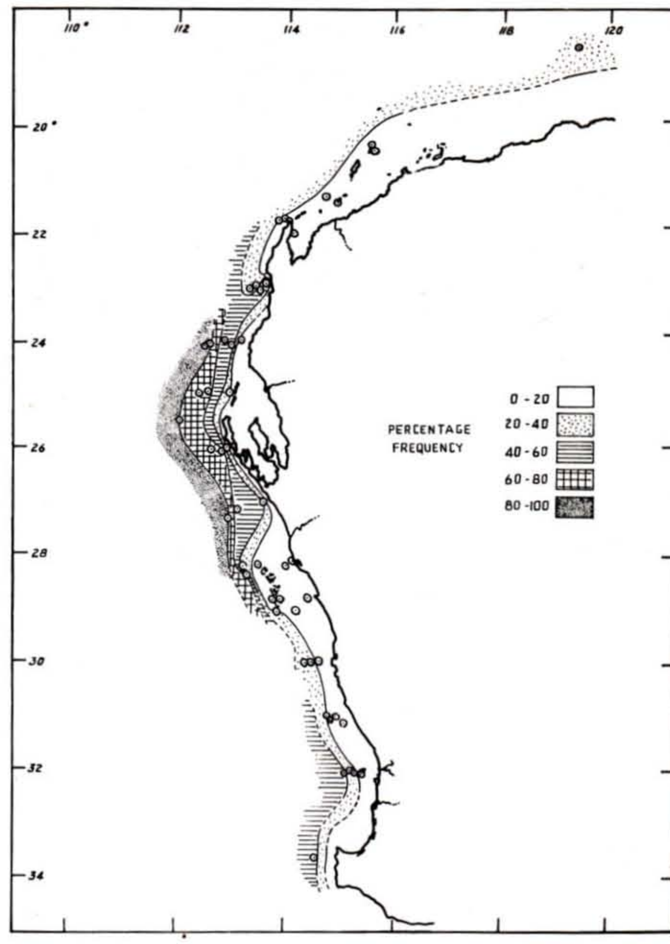
Sub Shelf	Station	Depth	Number Counted	Benthonic			Plank-tonic	Population per wet cc.			No. Species	No. Genera
				% Are-naceous	% Cal-careous	Total %		Ben-thonic	Plank-tonic	Total		
Rowley	53336	58	345	12.5	53.5	66.0	34.0	424	219	643	79	42
	39836	0	223	1.8	97.8	99.6	0.4	38	0	38	43	23
	39834	8	413	15.9	83.9	99.8	0.2	1136	3	1139	100	49
	39823	6	351	17.9	82.1	100.0	0.0	91	0	91	55	27
	39832	36	364	19.4	68.4	87.8	12.2	689	95	784	102	51
	39815	9	372	33.6	65.9	99.5	0.5	398	3	401	70	36
Dirk Hartog	31839	0	364	0.6	99.4	100.0	0.0	1255	0	1255	57	24
	51922	28	344	22.6	76.5	99.1	0.9	490	4	494	75	40
	51923	61	313	18.7	65.5	84.2	15.8	295	56	351	94	49
	51919	35	350	13.6	43.2	56.8	43.2	309	234	543	70	37
	51180	50	338	9.9	38.5	48.4	51.6	734	781	1515	72	37
	51920	60	285	13.2	51.1	64.3	35.7	221	123	344	78	37
	51921	100	343	9.1	52.1	61.2	38.8	489	309	798	75	37
	51925	31	321	16.2	66.4	82.6	17.4	170	36	206	66	33
	51187	48	394	15.8	39.7	55.5	44.5	245	197	442	73	32
	51926	60	413	6.5	35.1	41.6	58.4	1038	1454	2492	67	37
	51927	100	460	3.1	12.0	15.1	84.9	323	1818	2141	53	30
	51189	165	458	2.6	3.6	6.2	93.8	192	2878	3080	24	18
	51916	38	289	6.2	62.5	68.7	31.3	178	81	259	74	37
	51918	61	361	5.9	26.6	32.5	67.5	1011	2101	3112	73	43
	51194	71	400	6.8	23.1	29.9	70.1	804	1886	2690	68	37
	51196	156	415	3.8	16.9	20.7	79.3	1155	4426	5581	52	29
	51928	42	349	13.6	36.9	50.5	49.5	79	77	156	63	31
	51929	61	437	10.1	24.5	34.6	65.4	573	1085	1658	77	37
	39819	65	368	9.7	23.8	32.7	67.3	1348	2776	4124	44	25
	51915	47	333	13.2	41.8	55.0	45.0	537	439	976	65	34
	39818	68	351	13.9	28.6	42.5	57.5	1106	1496	2602	65	39
	53217	100	372	0.8	4.9	5.7	94.3	20	339	359	31	23
Rottnest	39827	0	323	0.9	98.5	99.4	0.6	553	3	556	41	20
	50942	19	307	26.9	68.8	95.7	4.3	284	12	296	62	26
	51930	30	282	14.8	79.9	94.7	5.3	92	5	97	64	32
	51931	60	354	13.5	49.7	63.2	36.8	463	269	732	76	39
	51932	106	404	6.3	23.4	29.7	70.3	517	1224	1741	65	35
	39809	19	303	7.6	89.8	97.4	2.6	220	6	226	59	28
	53218	29	387	12.7	79.8	92.5	7.5	802	65	867	81	39
	39814	3	190	1.1	98.9	100.0	0.0	33	0	33	23	15
	39845	6	269	2.2	97.4	99.6	0.4	171	0	171	70	33
	53219	55	366	11.9	63.5	75.4	24.6	857	279	1136	90	45
	51912	32	105	23.6	68.9	92.5	7.5	17	1	18	32	19
	51913	64	340	7.6	45.2	52.8	47.2	222	200	422	63	32
	51914	101	313	8.3	58.0	66.3	33.7	322	164	486	77	40
	39807	22	344	6.4	86.6	93.0	7.0	358	27	385	69	43
	51933	28	307	8.9	88.8	97.7	2.3	96	2	98	73	38
	51934	67	377	11.5	76.8	88.3	11.7	248	34	282	89	36
	51935	120	399	6.3	69.1	75.4	24.6	1348	441	1789	82	37
	50955	16	106	8.3	90.8	99.1	0.9	18	0	18	52	27
	39801	57	272	14.4	64.9	79.3	20.7	112	29	141	84	43
	50956	60	360	9.5	70.3	79.8	20.2	380	96	476	96	43
	39803	108	335	13.4	41.4	54.8	45.2	210	175	385	76	38
	50947	82	344	12.2	44.9	57.1	42.9	237	178	415	65	33

to the fragmentation of tests by winter storms or their offshore transportation by currents induced by summer winds which have mainly an easterly component.

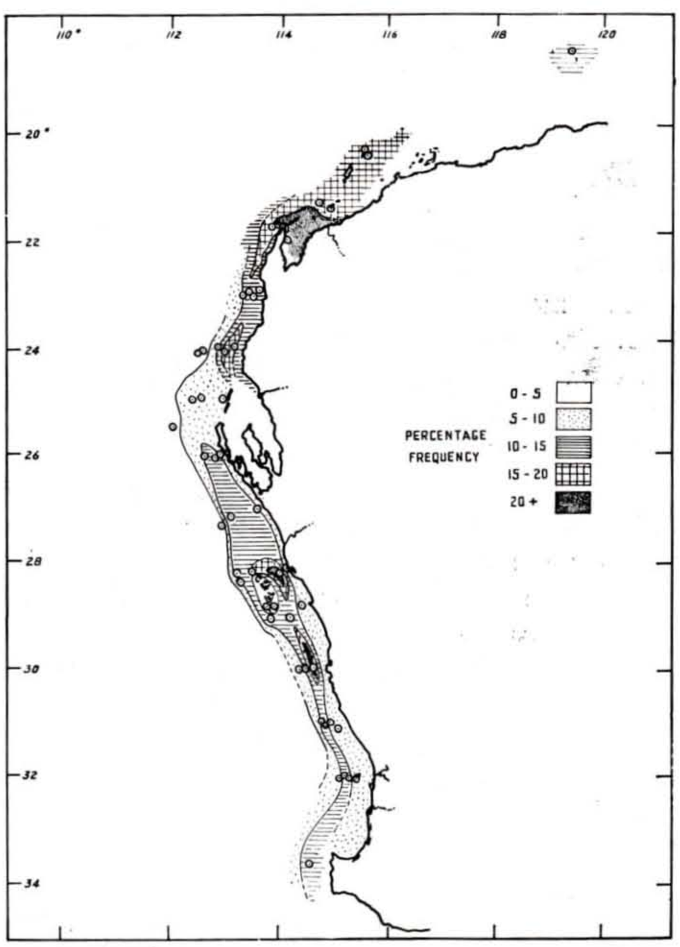
Frequencies of 20% are not exceeded on the Rottnest sub-shelf or the southern part of the Rowley sub-shelf until the shelf edge is reached. The Dirk Hartog sub-shelf, however, exhibits a steady increase in the percentage of planktonics from trace percentages near-shore to more than 80% on the outer shelf. No explanation for this increase is offered here, but it is worth noting that this sub-shelf is more exposed to the effects of the Indian Ocean than areas in which offshore shoals (Rowley sub-shelf), peninsulas (Exmouth Gulf and Shark Bay), headlands (southern Rottnest sub-



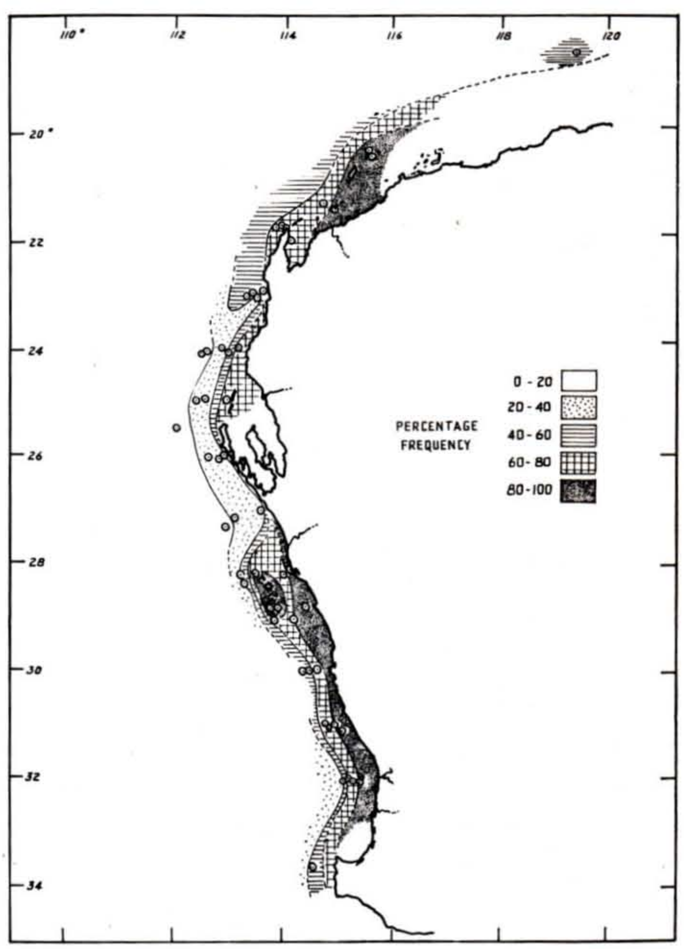
TEXT FIGURE 4a
Total population density of foraminifera



TEXT FIGURE 4b
Distribution of planktonic foraminifera



TEXT FIGURE 4c
Distribution of arenaceous benthonic foraminifera



TEXT FIGURE 4d
Distribution of calcareous benthonic foraminifera

TABLE 2
Summary of the common species

Percentage frequency of occurrence in the total population			
2.1 - 3.0%	3.1 - 4.0%	4.1 - 5.0%	> 5%
Quinqueloculina sp. F	*Textularia agglutinans*	*Quinqueloculina* sp. C	*Cibicides refulgens*
Sigmoilina australis	*Spirolina arietina*	*Alveolinella boscii*	*Globorotalia menardii*
Peneroplis planatus	*Marginopora vertebralis*	*Globigerinoides rubra*	*Globigerina bulloides*
Dendritina antillarum	*"Rotalia" beccarii*	*"Rotalia" ozawaii*	
Spirolina hamelini	*Calcarina calcar*		
Reussella armata	*Amphistegina lessonii*		
Epistomaroides polystomelloides	*Cibicides pseudoungerianus*		
Elphidium crispum			
E. simplex			
Cibicides lobatulus			

shelf), or island complexes (Rottnest sub-shelf to the east of the Abrolhos Islands) obstruct the transportation of planktonic tests (Smith, 1955).

The most abundant planktonic species are: *Globigerina bulloides, Globorotalia menardii, Globigerinoides rubra,* and *Pulleniatina obliquiloculata.*

Globigerina bulloides is by far the most abundant species, having an average percentage of occurrence of 22% of the total population and up to 62% of the planktonic fauna.

These four species each show a relatively constant average percentage of occurrence in the planktonic population along offshore traverses. This may be related to a comparatively stable shelf, a low rate of sedimentation, and a lack of significant fresh water run-off. The lack of active near-shore sedimentation prevents dilution of the shallow-water fauna (Shepard *et al.* 1960).

Other planktonic species recorded are: *Hastigerina aequilateralis,* which is apparently restricted to low latitudes because it was not found in samples south of latitude 30°; *Globigerinoides sacculifer,* found only as a trace species south of the Abrolhos Islands, and may be regarded as a subtropical species; *Globigerina* cf. *G. conglomerata,* which has its most northerly occurrence at Dirk Hartog Island; and *Tretomphalus bulloides,* most common in samples from northern warmer waters.

Benthonic Fauna on the Continental Shelf

Arenaceous Benthonic Fauna

Arenaceous foraminifera are found throughout the area. They are most abundant on the Rowley sub-shelf and never make up less than 16% of the total population in samples from depths greater than 6 fathoms. Generally they reach maximum percentages in the mid-shelf area (text fig. 4c). They favour depths from 10 to 40 fathoms and reach peak abundances of more than 30% at about 25 fathoms.

The north-south trend of abundance in the mid-shelf area is broken off the northern entrances to Shark Bay where the arenaceous species never exceed 7%. The Abrolhos Islands support only a sparse arenaceous fauna. Areas of particular concentration are:

(1) between the Abrolhos Islands and Shoal Point
(2) in Exmouth Gulf
(3) offshore from Green Head.

They are most abundant in the shallow, warm, protected waters of Exmouth Gulf, where on brown, silty, medium grained quartz sands and calcarenites there is a population peak of 34%.

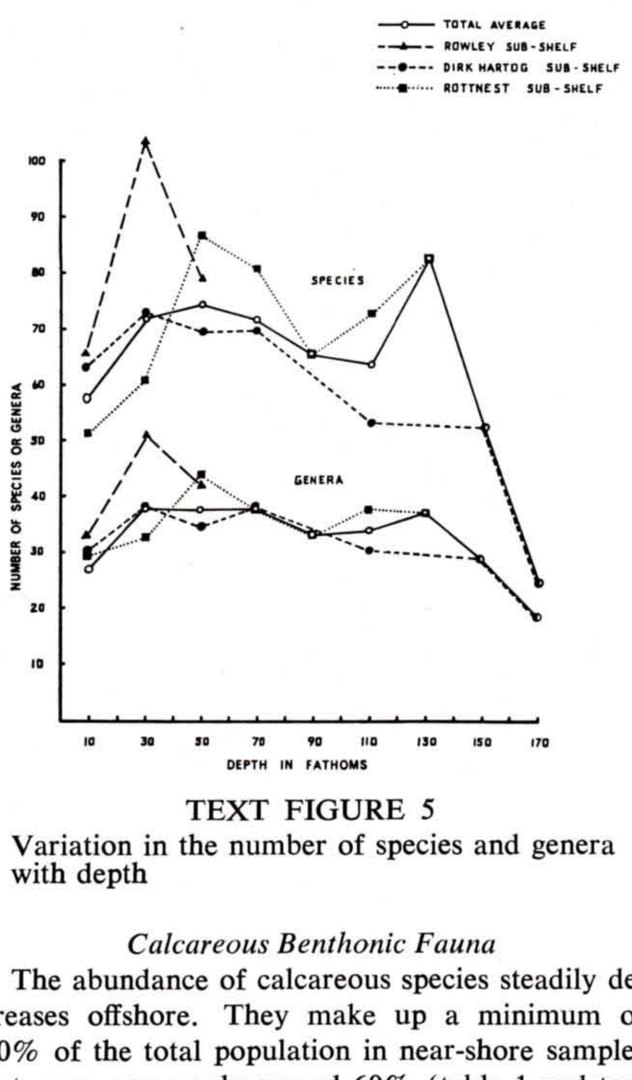
The distribution may be a reflection of bottom sediment type, because they are restricted to medium-grained quartz sands and calcarenites, away from gravelly or rocky nearshore sediments (Carrigy and Fairbridge, 1954).

The most abundant of the arenaceous species are: *Textularia agglutinans, T. foliacea, T. dupla, T. candeiana, Reophax scorpiurus, Gaudryina triangularis, G. triangularis* var. *angulata,* and *Sigmoilina australis.*

Textularia agglutinans is the most abundant and widespread arenaceous species, making up 4-5% of the benthonic population. It has been recorded from the Rowley, Dirk Hartog, and Rottnest sub-shelves, Exmouth Gulf, Shark Bay, the Abrolhos Islands, and Cockburn Sound. The species has also been recorded from the southern inlets, and the Recherche sub-shelf on the southern coast of Western Australia. It is present at all depths to 100 fathoms, but reaches a maximum level of 17% of the benthonic population at 20-40 fathoms.

Textularia foliacea is the next most abundant, with an average percentage frequency less than 2%. It is least abundant on the Rottnest sub-shelf. Like *T. agglutinans* it constitutes from 9 to 10% of the benthonic fauna in the warmer, protected waters of Exmouth Gulf.

Textularia dupla and *T. candeiana* are prevalent on the Rowley sub-shelf. *Reophax scorpiurus* was found at most latitudes in the study area and makes up 7% of the benthonic fauna off Cape Cuvier. *Gaudryina triangularis* and *G. triangularis* var. *angulata* are more numerous in the south.



TEXT FIGURE 5

Variation in the number of species and genera with depth

Calcareous Benthonic Fauna

The abundance of calcareous species steadily decreases offshore. They make up a minimum of 40% of the total population in near-shore samples but more commonly exceed 60% (table 1 and text fig. 4d). Maximum abundances of 98% are found in the lagoons of the Monte Bello and Abrolhos Islands and off Shoal Point.

The most abundant of the calcareous species are: *Quinqueloculina vulgaris, Miliolinella australis, Peneroplis planatus, Marginopora vertebralis, Reussella spinulosa, Elphidium advenum, E. crispum, Amphistegina lessonii, Cibicides refulgens,* and *Anomalina colligera.*

Miliolinella australis occurs at all latitudes within the study area and at all depths to 120 fathoms. Logan (1959) reported its occurrence off the entrance to South Passage at Shark Bay and Parr found several specimens in shore sands from Point Lonsdale, Victoria. All specimens were very similar to those figured by Parr (1932a, pl. 1, fig. 13). The species increases in abundance to the south where it makes up 3-5% of the benthonic population at stations 51914, 39807, 50955, 39801, and 50956.

Peneroplis planatus and *Marginopora vertebralis* also occur at all latitudes in the study area and are most abundant in water less than 10 fathoms, but the latter species does not occur in any samples from water deeper than 30 fathoms and is most abundant on the Rowley sub-shelf and in samples from the protected waters of the Abrolhos Island lagoons (where it makes up 15% of the benthonic fauna). Although *M. vertebralis* has been frequently recorded along the western coastline it is rare along the southern coast of Western Australia (McKenzie, 1962).

Reussella spinulosa is found at all latitudes in the study area and at all depths to 120 fathoms. *Elphidium advenum* and *E. crispum* are widely distributed in the near-shore waters, both being found in abundance at all depths to 60 fathoms and 40 fathoms respectively. *Amphistegina lessonii* makes up to 10% of the benthonic population at depths between 10 and 40 fathoms. It has not been recorded from the south coast.

Cibicides refulgens is a common species with an average percentage of occurrence of 12% in the benthonic population. It is found over the entire length of the shelf and is most abundant between 10 and 120 fathoms. It is absent from depths less than 10 fathoms, and its abundance decreases beyond 120 fathoms. *C. lobatulus* and *C. pseudoungerianus* show similar distributions but are less abundant.

Anomalina colligera has a similar distribution to *Cibicides refulgens.* The peak abundance occurs in samples from 30-70 fathoms. It was absent from samples less than 30 fathoms.

As shown in table 3, those species important as guides for latitudinal variations are: *Quinqueloculina* sp. F, *Dendritina antillarum, Spirolina arietina, Alveolinella boscii,* and *Epistomaroides polystomelloides.*

Benthonic Fauna in Marginal Shelf Areas

Introduction

The preceding discussion has been directed towards the benthonic foraminifera of the western shelf in general. Several areas within this region, however, deserve special mention. Exmouth Gulf, Shark Bay, and Cockburn Sound are all west coast marine embayments formed by the inundation of dune landscapes by Recent marine transgression. Also included are some of the numerous tidal inlets on the southern coast.

Environment

Exmouth Gulf is a sublittoral marine embayment located at the extreme south of the Rowley subshelf at latitude 22° south and longitude 114° east. Available information on tides is scanty and unreliable, but Chapman (1938) reports mean spring ranges of 6 feet at Maud Landing and 13.5 feet at the mouth of the Fortescue River. Run-off is low and evaporation high. Summer temperatures of 26°C and winter minima of 24°C have been recorded at North-West Cape; these are probably reasonably indicative of minimum water temperatures inside the gulf. There is a steady increase in depth to 10 fathoms at the mouth of the gulf.

Shark Bay is an embayment on the central west coast at latitude 25° south. It is physiographically classified as a marine, sublittoral lagoon formed by the inundation of an aeolian dune landscape. In this embayment, surface water temperatures rarely, if ever, exceed 25°C, and at any time of the year the maximum gradient from the bay heads to Cape Cuvier is only 3°C. The temperature probably does not have an important influence on the zonation of the benthos (Logan, 1959). The bathymetry is similar to that of Exmouth Gulf, in that there is a gradual increase in depth away from the bay heads. The depth varies from 0 to 10 fathoms over the majority of the bay and increases to approximately 20 fathoms near the barrier island chain at the bay mouths. Bathymetry primarily controls the distribution of isohalines, which are arranged along a horizontal gradient from 36 p.p.t. at the mouths to 65 p.p.t. in the bay heads.

Cockburn Sound is located at the southern end of the Rottnest sub-shelf at approximately latitude 32° south. It is a marine sublittoral lagoon subjected to a small influx of fresh water and fine sediment during the winter flooding of the Swan River. Normal marine salinities are maintained throughout most of the year and surface water temperatures vary from a winter minimum of 20°C to a summer maximum of 23°C. The sound may be subdivided into a marginal shelf surrounding a central basin 11 fathoms deep (Ives, 1961).

On the south coast Hassell (1962) and McKenzie (1962) have studied the faunas in the tidal inlets (Nornalup, Walpole, Broke, Irwin, Wilson, Beaufort, Wellstead, Gordon, and St. Mary Inlets; and Oyster Harbour). As with the west-coast marginal embayments, water depth rarely exceeds 10 fathoms. There is sufficient fresh-water run-off from the hinterland to cause a winter flushing of most of the estuaries which do not have continual access to the sea. Thus both brackish and oceanic foraminiferal faunas are recognised.

Foraminifera

With the exception of Exmouth Gulf, each marginal embayment has a temperate assemblage of foraminifera. Species of *Elphidium* and *Peneroplis planatus* are common to all areas. *Marginopora vertebralis* occurs frequently in the west coast embayments but was found in only trace percentage from Oyster Harbour and was not recorded by Hassell (1962) from the tidal inlets on the south coast.

Species apparently restricted to Exmouth Gulf and not so far found in other areas are *Elphidium macellum* var. *aculeata, Triloculina durrandi, Quinqueloculina striata,* and *Rhabdammina irregularis.* The following species are abundant in Exmouth Gulf, with other occurrences on the Rowley sub-shelf and in Shark Bay: *Elphidium simplex, Quinqueloculina agglutinans, Q. bidentata, Q. kerimbatica* var. *phillipensis,* and *Bolivinella elegans.* The more abundant of the remaining 61 recorded species are *Planispirinella exigua, Triloculina tricarinata, Reophax scorpiurus, Textularia agglutinans, T. conica, T. dupla, T. foliacea, T. orbica, T. pseudogramen, Elphidium craticulatum, Glabratella patelliformis, Spiroloculina depressa, Hauerina fragilissima, Nonionella japonica,* and *Lamarckiana atlantica.*

Shark Bay is split by shallow bars into three foraminiferal biofacies correlated with salinity, which is the most important single limiting factor in the distribution of the benthonic fauna (Logan, 1959):

(1) oceanic bay biofacies in the lower bays with salinities from 36 to 39 p.p.t. The two most common species are *Amphistegina lessonii* and *Cibicides refulgens.* Other species restricted to this facies are *Buliminella madagascariensis* var. *spicata, Cibicides lobatulus, Elphidium craticulatum, Massilina secans, Reussella spinulosa,* and *Textularia dupla.*

(2) metahaline bay biofacies in the middle bays with salinities from 39 to 56 p.p.t. This zone is distinguished by *Discorbis dimidiatus, Textularia agglutinans* and *Quinqueloculina anguina* var. *arenata.*

(3) hypersaline lagoon biofacies in the bay heads with salinities from 56 to 65 p.p.t. The very common and characteristic species are *Peneroplis planatus, Spirolina hamelini* and *Triloculina circularis* var. *cribostoma.*

Other common euryhaline species occurring in all biofacies are *Quinqueloculina laevigata, Q. neostriatula, Q. vulgaris,* and *Triloculina circularis.* The major biotic units are subdivided into a number of subfacies controlled by depth, organic matter, and other biotic factors. In general, the Shark Bay assemblage of foraminifera is more related to the temperature assemblages on the west and south coasts of Australia than to the tropical-subtropical assemblage on the northwest and north coasts.

Cockburn Sound has a temperate assemblage of foraminifera. The most common species in this area are *Textularia agglutinans, T. pseudogramen, Vertebralina striata, Spiroloculina antillarum, Triloculina trigonula, Marginopora vertebralis, Elphidium craticulatum, E. crispum,* and *Discorbis dimidiatus* var. *acervulinoides*. *Textularia agglutinans* and *T. pseudogramen* are most abundant in the central basin, while *Vertebralina striata, Marginopora vertebralis,* and *Discorbis dimidiatus* var. *acervulinoides* are more abundant in the shallows. The latter species shows a preference for the sandy substrata which are covered with dense beds of the sea grasses *Posodonia* and *Cymodocea*.

Benthonic Fauna in Lagoons on the Shelf

There are numerous coral reefs bordering the western coast of Australia (Carrigy and Fairbridge, 1954). Two such groups of coral islands are the Monte Bello Islands at latitude 20°30′ south and Houtman's Abrolhos Islands at latitude 28°30′ south.

No hydrological data are available for the waters of the Monte Bello area. Surface water temperatures should rarely exceed a summer maximum of 26°C and a winter minimum of 23°. Vaughan (1940) classifies this area as subtropical.

The Abrolhos Islands have a fauna similar to that found on the Rowley sub-shelf. It is an oasis of tropical-subtropical foraminiferal species located within the temperate Rottnest sub-shelf region and is anomalous, probably, for oceanographical reasons, because the sample stations were in less than six fathoms and protected by bordering coral reefs and islands.

The following species are found in abundance in the warm, shallow, protected waters of both island groups: *Peneroplis planatus, Marginopora vertebralis, Dendritina antillarum, Spirolina arietina,* and *Calcarina calcar*.

Species so far recorded from only the Monte Bello Islands are *Spiroloculina elegans, Sigmoilina australis, Hauerina orientalis, Webbinella* sp. A, and *Operculinella venosa*. The following are common Monte Bello species which also occur elsewhere on the shelf: *Textularia dupla, T. foliacea, T. semialata, Quinqueloculina* sp. C, *Q.* sp. F, *Triloculina bertheliniana, T. tricarinata, T. trigonula, Planorbulina acervalis, Amphistegina lessonii, Operculina complanata, Elphidium advenum,* and *Miliolinella australis*. *Spirolina arietina, Peneroplis planatus, P. pertusus, Dendritina antillarum,* and *Marginopora vertebralis* have the highest percentage occurrences in the beach sample, but this is undoubtedly due to sorting. *Textularia dupla* and *T. semialata* are more abundant in the lagoon at Monte Bello than anywhere else on the shelf.

Abundant Abrolhos Island species, with other main occurrences at stations north of the islands, are *Bolivina rhomboidalis, Quinqueloculina parkeri, Bolivina abbrevata, Discorbis dimidiatus* var. *vesicularis, Epistomaroides polystomelloides, Vertebralina striata, Triloculina bassensis, T. circularis, T. oblonga, Elphidium crispum, Homotrema rubra,* and *Spiroloculina antillarum*.

Trace Species

The majority of all the species studied had frequencies of less than 1% and were recorded as "trace" species, of which those having restricted latitudinal distribution (see Table 3) are *Hauerina ornatissima, H. bradyi, Operculina complanata, Planispirinella exigua, Quinqueloculina kerimbatica* var. A, *Q. parkeri, Marsipella* sp. A, *Elphidium* sp. B, *Spirillina obconica, Patellina corrugata, Annulopatellina annularis,* and *Amphistegina radiata* var. *papillosa*.

The following are trace species having a wide distribution: *Textularia conica, T. orbica, T. pseudogramen, T. sagittula, Gaudryina triangularis, G. triangularis* var. *angulata, Quinqueloculina seminula, Discorbis globularis, D. praegeri, Glabratella patelliformis, Eponides repandus, Cibicides subhaidingerii, Planorbulinella larvata, Acervulina inhaerens, Cymbaloporetta bradyi,* and *Anomalina glabrata*.

Species Not Identified Positively

Most of the species which could not be identified have been illustrated. A few remarks have been appended to the species whose occurrences suggest that they have environmental significance.

Marsipella sp. A cf. *M. dextrospiralis* Chapman and Parr - Not illustrated due to inadequate preservation. This species is rare, only three specimens being found at latitude 31° south. Each specimen had an agglutinated test consisting of spicules arranged with a dextral twist. They closely resemble *M. dextrospiralis*, but positive identification could not be made because both ends of all tests were missing.

Textularia sp. A - Plate 19, fig. 21.

Siphotextularia sp. A - Plate 19, fig. 14.

Siphotextularia sp. B - Plate 19, fig. 15.

Gaudryina sp. A - Plate 18, fig. 12.

Spiroloculina sp. A - Plate 19, fig. 16. One specimen was found at station 39832 and another at station 51923. Both specimens resemble that illustrated by Barker (1960, pl. 10, figs. 1 and 2) but have more concave lateral surfaces.

Quinqueloculina kerimbatica var. A - Several specimens found on the Rowley sub-shelf.

Quinqueloculina sp. A - Plate 19, fig. 4.

Quinqueloculina sp. C - Plate 19, fig. 5. Nineteen specimens were recovered from the beach sand sample taken from the Monte Bello Islands. This species is large, robust, with very prominent regular striae running longitudinally on the test. The species is regarded as being part of the tropical-subtropical fauna.

Quinqueloculina sp. D - Plate 19, fig. 6.

Quinqueloculina sp. E - Plate 19, fig. 7.

Quinqueloculina sp. F - Plate 19, fig. 8. This species shows a preference for subtropical

TABLE 3
Summary of the distributions of the foraminifera

	Depth Biofacies (Distinguished by the presence of the species listed, and the absence of shallower guide species.)		
	Outer Shelf 40-120 fathoms	Inner Shelf 10-40 fathoms	Near Shore 1-10 fathoms
Guide Species Common to Both Faunal Regions	*Anomalina colligera* *Cibicides refulgens* *Textularia agglutinans* *Quinqueloculina vulgaris* *Miliolinella australis* *Reussella spinulosa* *Cibicides lobatulus* *C. pseudoungerianus*	*Amphistegina lessonii* *Elphidium advenum* *E. crispum*	*Marginopora vertebralis* *Peneroplis planatus*
Guide Species of Tropical-Subtropical Faunal Region	*Globigerinoides sacculifer*	*Elphidium simplex* *Amphistegina radiata* var. *papillosa* *Operculina complanata* (t) *Planispirinella exigua* (t)	*Alveolinella boscii* *Quinqueloculina* sp. F *Q. parkeri* (t)* *Sigmoilina australis* *Spirolina arietina* *Calcarina calcar* *Dendritina antillarum* *Hauerina ornatissima* (t) *H. orientalis* (t)
Guide Species of Temperate Faunal Region	*Spirillina obconica* (t) *Patellina corrugata* (t)	*Reussella armata* *Elphidium* sp. B (t) *Annulopatellina annularis* (t)	*Epistomaroides polystomelloides*

*t = trace species

waters, thirteen specimens being found in samples from the Rowley sub-shelf and none being found south of latitude 21°30′.

Triloculina sp. A cf. *T. flavescens* d'Orbigny - Plate 19, fig. 20.

Miliolinella sp. B - Plate 18, fig. 24.

Miliola sp. A - Plate 18, fig. 23. Test calcareous, imperforate, porcellaneous, with cribate aperture. Six specimens found on the Rowley sub-shelf.

Hauerina aff. *H. diversa* Cushman - Not illustrated due to fragmentation of all tests. This species was found only in samples from the Rowley sub-shelf and hence may indicate the tropical-subtropical faunal region.

Dentalina sp. A cf. *D. translucens* Parr - Plate 18, fig. 6.

Lenticulina sp. A aff. *L. iota* (Cushman) - Plate 18, fig. 18. Several specimens found south of Cape Cuvier.

Lenticulina sp. B - Plate 18, fig. 19.

Lenticulina sp. C - Plate 18, fig. 20.

Lenticulina (*Robulus*) sp. B - Plate 18, fig. 21.

Lenticulina (*Astacolus*) sp. A cf. *L.* (*Astacolus*) *crepidulus* (Fichtel and Moll) - Plate 18, fig. 22.

Webbinella sp. A - One specimen found in the beach sand sample from the Monte Bello Islands. Not illustrated due to fragmented test.

Rectobolivina sp. A cf. *R. digitata* Parr - Plate 19, fig. 9.

Chrysalidinella sp. A - Plate 18, fig. 7.

Reussella sp. A - Plate 19, fig. 10.

Discorbis sp. A cf. *D.* sp. nov. Barker 1960 - Illustrated by Barker (1960), pl. 87, fig. 2.

Discorbis sp. B cf. *D.* sp. nov. Barker 1960 - Illustrated by Barker (1960), pl. 87, fig. 4.

Rosalina sp. A cf. *R. globularis* Galloway and Wissler - Plate 19, figs. 11, 12.

Rosalina sp. B - Plate 19, fig. 13.

Heronallenia sp. A. aff. *H. wilsoni* Heron-Allen and Earland - Plate 18, figs. 15, 16.

Elphidium sp. A cf. *E. milletti* Heron-Allen and Earland - Plate 18, figs. 8, 9.

Elphidium sp. B - Plate 18, fig. 10. This species occurs at fourteen stations between latitudes 29° south and 34° south. It is distinguished from other species of *Elphidium* by the laterally compressed test.

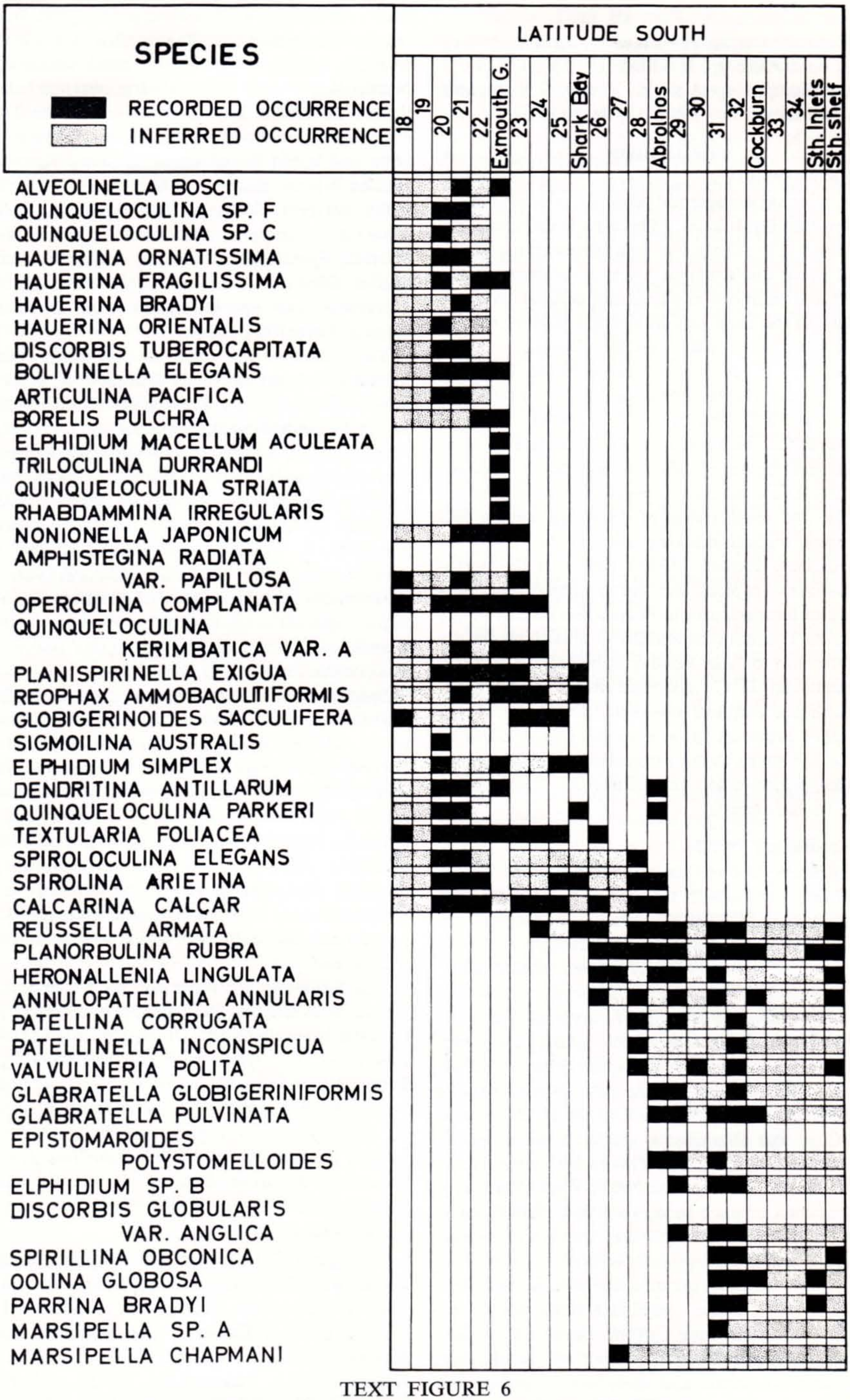
Polystomellina sp. A cf. *P. australis* Cushman - Plate 19, fig. 3. Seven specimens have been recorded from five stations south of latitude 28°. The species is regarded as being a component of the temperate faunal region.

Heterostegina sp. A - Plate 18, fig. 17.

Planulina sp. B - Plate 19, figs. 1, 2.

Caribeanella sp. A - Plate 18, figs. 2, 3.

Cassidulina sp. A - Plate 18, figs. 4, 5.



TEXT FIGURE 6
Foraminiferal species whose distribution varies with latitude

Anomalina sp. A - Plate 18, fig. 1.
Stomatorbina sp. A - Plate 19, fig. 17.
Stomatorbina sp. B - Plate 19, figs. 18, 19.
Geminospira sp. A aff. *G. simaensis* Makiyama and Nakagawa - Plate 18, figs. 13, 14.

DISCUSSION

Environment

The western continental shelf is inhabited by a rich foraminiferal fauna. The high species number per station is probably due to a favourable and relatively stable environment. Active sedimentation is limited and salinities are typically oceanic over the majority of the shelf and little influenced by runoff. Data on currents is poor and inconclusive.

Vaughan (1940) sets the temperature limits of tropical biogeographic zones as 25°C+, subtropical as 15°C to 30°C, and those of temperate zones as 10°C to 25°C. Hedgpeth (1957) illustrates a tropical faunal region off the north-west of Western Australia and a warm temperate faunal region off the west and south coasts of Australia, with a biogeographic transition taking place in the vicinity of Cape Cuvier. Ekman (1953) describes the northern fauna as tropical and partly subtropical. Surface-water temperatures indicate a temperature cline from a 23°C minimum and 26°C maximum on the southern part of the Rowley sub-shelf to a 17°C minimum and 21°C maximum in the southern extremes of the Rottnest sub-shelf. On this evidence the author proposes to refer to the region north of latitude 25° south as the tropical-subtropical region, and that region south of latitude 30° as the temperate faunal region.

Latitudinal Trends

Text fig. 6 shows foraminiferal species whose distribution varies with latitude. Of the total species recorded 31 clearly show a preference for tropical-subtropical waters. *Alveolinella boscii, Quinqueloculina* sp. F, *Hauerina ornatissima, Hauerina fragilissima, Hauerina bradyi, Hauerina orientalis, Hauerina* sp. aff. *H. diversa, Discorbis tuberocapitata, Bolivinella elegans, Articulina pacifica, Borelis pulchra, Elphidium macellum* var. *aculeata, Quinqueloculina striata* and *Rhabdammina irregularis* were not recorded south of the North-West Cape and characterise the subtropical region. *Quinqueloculina* sp. C and *Triloculina durrandi* are most abundant north of the North-West Cape, only one specimen of each being recorded further south (from the Abrolhos Islands and Shark Bay respectively). *Nonionella japonica, Operculina complanata, Quinqueloculina kerimbatica* var. A, and *Amphistegina radiata* var. *papillosa* were not found further south than Cape Cuvier, except for the last species, which occurs very rarely off Shark Bay. *Planispirinella exigua* and *Reophax ammobaculitiformis* appear to be restricted to Shark Bay and latitudes north. *Quinqueloculina parkeri* and *Dendritina antillarum* may also be regarded as tropical-subtropical species, both being found south of the North-West Cape only in the warmer shallow waters of Shark Bay and the Abrolhos Islands. *Elphidium simplex* is restricted to the near shore zone and is not found south of Shark Bay. Other species which showed a definite preference for more northerly latitudes are *Textularia foliacea, Sigmoilina australis, Calcarina calcar, Spirolina arietina, Spiroloculina elegans,* and the planktonic species *Globigerinoides sacculifer*. As a group the aforementioned species indicate the tropical-subtropical faunal region.

The following are other species more abundant in samples from northern latitudes: *Spiroloculina antillarum, S. costata, S. depressa, S. milletti, S.* sp. A, *Quinqueloculina agglutinans, Q. anguina* var. *arrenata, Q. bidentata, Q. crassatina, Q. kerimbatica* var. *phillipensis, Q. neostriatula, Q. polygona, Q. pseudoreticulata, Q. striata, Massilina crenata, Miliola* sp. A, *Articulina alticostata, Peneroplis pertusus, P. planatus, Spirolina hamelini, Neocorbina terquemi, "Rotalia" gaimardi* var. *compressiuscula, Elphidium craticulatum, E. hispidulum, Operculinella venosa, Amphistegina quoyii, Planorbulina acervalia, Cymbalopora poeyi, Cymbaloporetta bradyi,* and *Anomalina colligera*.

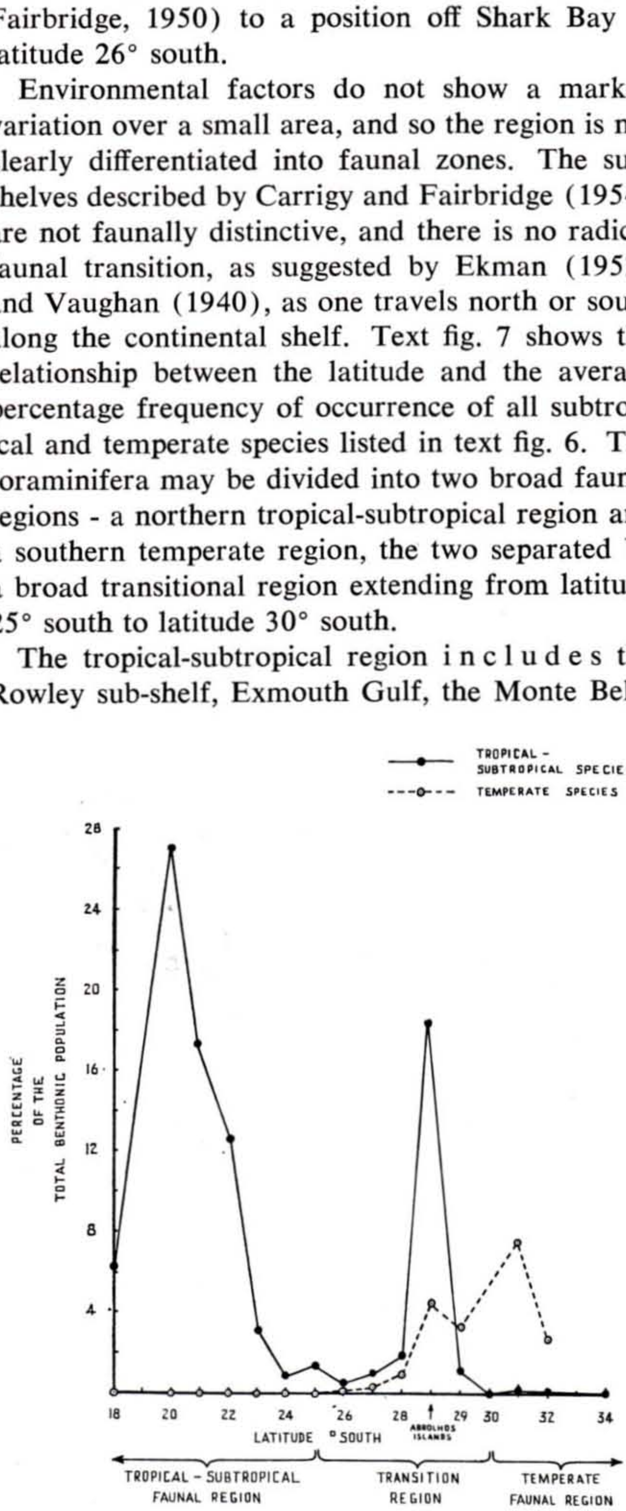
Species which together indicate the temperate faunal region are *Marsipella chapmani, Marsipella* sp. A, *Oolina globosa, Parrina bradyi, Spirillina obconica, Discorbis globularis* var. *anglica, Elphidium* sp. B, *Epistomaroides polystomelloides, Glabratella pulvinata, Glabratella globigeriniformis, Patellinella inconspicus, Valvulineria polita, Patellina corrugata, Annulopatellina annularis, Heronallenia lingulata, Planorbulina rubra,* and *Reussella armata. Epistomaroides polystomelloides* and *Reussella armata* are the only two which are common and widespread.

The following are other species which are more abundant in samples from southern latitudes: *Spiroloculina inaequilateralis, Quinqueloculina bradyana, Ptychomiliola separans, Pyrgo subglobulus, Triloculina circularis, Miliolinella circularis, Lenticulina* sp. A aff. *L. iota, Fissurina contusa, F. lacunata, F. orbignyana, Discorbis isabelleanus, Rosalina bradyi, Glabratella opercularis, Spirillina denticulogranulata, Polystomellina* sp. A cf. *P. australis, Dyocibicides biseralis, Sigmavirgulina tortuosa,* and *Cassidulina subglobosa*.

The general latitudinal distribution of species agrees with data presented by Chapman and Parr (1935), Chapman, Parr, and Collins (1934), Davies (1963), Graham and Militante (1959), Hassell (1962), Ives (1961), Logan (1959), McKenzie (1962), Parr (1932a, 1932b, and in Fairbridge, 1950), and Phleger (1960). *Planorbulina* *rubra*, a typical temperate species, was reported by Parr (1932b) as having its most northerly occurrence at Geraldton; however, its distribution is now extended to latitude 26° south, where one specimen was collected in 42 fathoms at station 51928. It still lacks the characteristic rose-pink colour of the specimens found from more southern latitudes. *Poroeponides cribrorepandus* has been found at latitudes 28° south and 32° south, thus extending the Shark Bay southern limit as reported by Logan (1959). *Annulopatellina annularis* clearly shows a preference for cooler waters, but its northern limit is extended from Geraldton Harbour (Parr, in Fairbridge, 1950) to a position off Shark Bay at latitude 26° south.

Environmental factors do not show a marked variation over a small area, and so the region is not clearly differentiated into faunal zones. The sub-shelves described by Carrigy and Fairbridge (1954) are not faunally distinctive, and there is no radical faunal transition, as suggested by Ekman (1953) and Vaughan (1940), as one travels north or south along the continental shelf. Text fig. 7 shows the relationship between the latitude and the average percentage frequency of occurrence of all subtropical and temperate species listed in text fig. 6. The foraminifera may be divided into two broad faunal regions - a northern tropical-subtropical region and a southern temperate region, the two separated by a broad transitional region extending from latitude 25° south to latitude 30° south.

The tropical-subtropical region includes the Rowley sub-shelf, Exmouth Gulf, the Monte Bello



TEXT FIGURE 7
Distribution of tropical-subtropical and temperate species in the total benthonic population

Islands, the Dirk Hartog sub-shelf north of Cape Cuvier, and the Abrolhos Islands. The northern fauna is typically Indo-Pacific, as shown by the fact that more than 30% of all species found at either the Abrolhos or Monte Bello Islands are also to be found elsewhere; for example, in recent sediments from the subtropical Puerto-Galero area in the Philippine Islands (Graham and Militante, 1959). The majority of the sub-tropical Indo-Pacific species are restricted north of the North-West Cape, but many are distributed as far south as latitude 29°.

The transitional faunal region occupies the southern half of the Dirk Hartog sub-shelf, the northern part of the Rottnest sub-shelf, Shark Bay, and Cockburn Sound. It is the region with the lowest number of genera and species, the densest total population, the smallest benthonic population and the highest near-shore planktonic population. The small variety of species and dense population in this region may exist because of a spring convergence between the northward-flowing cool West Australian current and the warm current flowing southward from the low latitudes over the submarine platform extending westward from this most western tip of Australia.

The temperate faunal region includes the southern part of the Rottnest sub-shelf and the Recherche sub-shelf and contains many species common to the shallow nearshore waters of Victoria and South Australia.

Offshore Zonation

The offshore zonation of the foraminifera is more distinct than the latitudinal zonation.

The beach fauna is well sorted by water turbulence and dominated by species of the genera *Quinqueloculina*, *"Rotalia," Cibicides, Elphidium,* and *Amphistegina*. All specimens exhibit the effects of abrasion. The smaller and more delicate tests have been transported elsewhere or destroyed by winter wave action. There was a complete lack of planktonic specimens in depths less than 10 fathoms, except for a very eroded single specimen of *Pulleniatina obliquiloculata* and *Globigerinoides rubra* in each of samples 39815 and 39827. The composition of beach sample 39827 taken south of Shoal Point illustrates well the sorting effect of nearshore water turbulence:

"Rotalia" beccarii	46%
"Rotalia" gaimardi var. *compressiuscula*	2%
Elphidium crispum	5%
Calcarina calcar	4%
Discorbis dimidiatus	6%
Cibicides refulgens	3%

Marginopora vertebralis and *Peneroplis planatus* are common near-shore shallow-water species on the Rottnest and Dirk Hartog sub-shelves, but were only rarely found in the southern inlets. *Peneroplis planatus* is common in depths less than 40 fathoms on the Recherche sub-shelf (Chapman and Parr, 1935). *Spirolina arietina, Calcarina calcar,* and *Epistomaroides polystomelloides* do not occur in waters having a summer maximum surface temperature of more than 22°C, and their distributions may be limited by this isotherm. *"Rotalia" beccarii* occurs rarely at all depths, but reaches a peak abundance of 12% on the Abrolhos rise. *Alveolinella boscii, Quinqueloculina parkeri, Quinqueloculina* sp. F, *Sigmoilina australis,* and *Dendritina antillarum* were absent from depths greater than 10 fathoms.

Amphistegina lessonii makes up to 11% of the total benthonic population in depths from 30-40 fathoms and 6% in depths from 10-30 fathoms. This species occurs less frequently in shallow nearshore waters, and deeper than 40 fathoms its abundance decreases markedly. These findings are in agreement with those of Parker (1954). *Elphidium advenum* and *Elphidium crispum* were found at all depths, but were most abundant from 10-40 fathoms. *Elphidium simplex* made up 4% of the benthonic population at depths of 10 fathoms. It was absent from less than 8 fathoms, with rare occurrences up to 40 fathoms. *Reussella armata, Elphidium* sp. B, and *Planispirinella exigua* are most abundant in depths of 10-40 fathoms. *Discorbis dimidiatus* is a cosmopolitan species, but shows a preference for water less than 50 fathoms. *Hauerina ornatissima* and *Hauerina orientalis* are more common in the shallower waters, while *Hauerina fragilissima* was found at depths up to 70 fathoms, and a single specimen of *Hauerina bradyi* was recorded at station 39832 in 36 fathoms. *Annulopatellina annularis* is characteristic of the temperate faunal region and prefers water of 10-40 fathoms. *Spirillina obconica* and *Patellina corrugata* range from 10-110 fathoms and were most frequent in depths beyond 50 fathoms.

Anomalina colligera is absent from depths less than 28 fathoms, makes up 7% of the total benthonic population in the 40-50 fathom zone, and contributes 1-2% of the benthonic fauna in samples from deeper waters. *Cibicides refulgens* is one of the most widespread and abundant species on the shelf, decreasing offshore from approximately 14% in the inner shelf area to 7% in the deeper regions of the outer shelf, and is conspicuous by its absence in the near-shore zone. *Textularia agglutinans* is another cosmopolitan species that shows similar trends in offshore distribution. *Miliolinella australis, Reussella spinulosa,* and *Quinqueloculina vulgaris* decrease in abundance offshore; none were found beyond 130 fathoms. *Quinqueloculina laevigata* has a similar distribution to *Q. vulgaris,* but is not as abundant. *Cibicides pseudoungerianus* is a characteristic species in the outer shelf fauna and steadily increases in abundance offshore to about 130 fathoms, then shows a marked decrease. *Cibicides lobatulus* is most abundant in water deeper than 30 fathoms. *Bulimina aculeata, Amphicoryana separans, Amphicoryana scalaris,* and *Amphicoryana scarlaris* var. *compacta* are deep water outer shelf species typical of samples from 50-120 fathoms.

Such planktonic species as *Globigerina bulloides, Globorotalia menardii, Globigerinoides rubra,* and *Pulleniatina obliquiloculata* constitute a reasonably constant percentage of the planktonic population recorded from all depths and make up more than 80% of the total population beyond 120 fathoms. *Globigerinoides sacculifer* occurs only in samples deeper than 47 fathoms in the Rowley and Dirk Hartog sub-shelves.

The offshore distribution of species permits a subdivision of the shelf into three depth biofacies distinguished by the fact that some species have a markedly higher frequency of occurrence within a specific depth range even though they may be present at other depths.

The nearshore biofacies extends to 10 fathoms and is characterised by the presence of *Marginopora vertebralis* and *Peneroplis planatus.*

The inner shelf biofacies extends from 10-40 fathoms and is characterised by the presence of *Amphistegina lessonii, Elphidium advenum,* and *Elphidium crispum,* and by the absence of *Marginopora vertebralis* and *Peneroplis planatus.*

The guide species to the outer shelf biofacies (from 40-120 fathoms) are *Anomalina colligera, Cibicides refulgens, Textularia agglutinans, Quinqueloculina vulgaris, Miliolinella australis, Reussella spinulosa;* all guide species from shallower biofacies are absent here. *Cibicides lobatulus* and *Cibicides pseudoungerianus* are also common, but their distribution continues to deeper waters. *Bulimina aculeata, Amphicoryna separans, Amphicoryna scalaris,* and *Amphicoryna scalaris* var. *compacta* are typical of this biofacies but are not common.

The alongshore and offshore distributions of the more common species are summarised in table 5.

Residual Faunas

Samples 51916, 51928, and 51930 may have come from residual faunal belts located between continental shelf terraces (Carrigy and Fairbridge, 1954) cut during the Holocene marine transgression. In each of these samples the markedly eroded foraminifera represent either residual or reworked species.

CONCLUSIONS

The foraminiferal fauna of the western part of the Western Australian continental shelf exhibits most of the trends that are typical of other continental shelves. There were severe limitations to the interpretation of evidence, but the following broad generalisations are proposed until modified by more detailed sampling:

(1) the western continental shelf is inhabited by a rich foraminiferal fauna with its highest total population density towards the outer edge of the shelf.

(2) the high species number per station is probably due to a favourable and relatively stable marine environment.

(3) the whole shelf is characterised by slow uniform sedimentation of calcareous and residual deposits; active sedimentation is confined to a few marginal estuarine areas.

(4) surface-water temperatures display only a small annual variation.

(5) salinities are typically oceanic over the majority of the shelf and little influenced by run-off.

(6) the number of species and genera slightly increases offshore.

(7) arenaceous benthonic foraminifera are most abundant in the midshelf area and favour depths of 10-40 fathoms.

(8) calcareous benthonic foraminifera show a steady decrease in abundance offshore.

(9) planktonic foraminifera increase in abundance offshore and dominate the fauna of the outer shelf and upper continental slope samples.

(10) tropical-subtropical and temperate faunal regions may be distinguished; they overlap in a transition zone extending from latitude 25° south to latitude 30° south.

(11) the fauna of the Abrolhos Islands, at latitude 29° south, is an oasis of tropical-subtropical species located within the temperate faunal region.

(12) the Rowley sub-shelf fauna is tropical-subtropical Indo-Pacific.

(13) three depth biofacies are recognised by the occurrence of certain guide species and the absence of other guide species.

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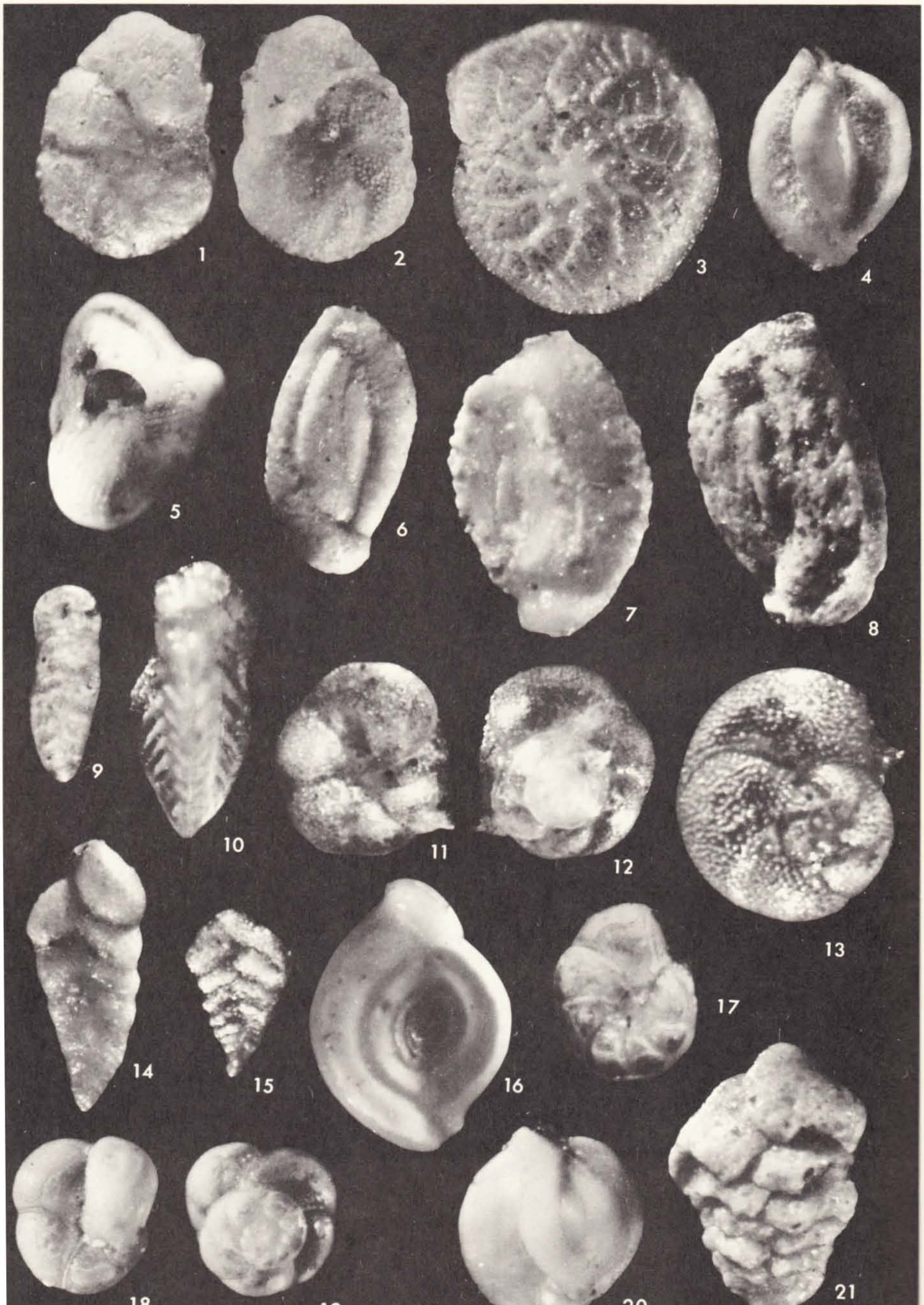
Betjeman: Recent Western Australian Foraminifera



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EXPLANATION OF PLATE 19

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374. SEASONAL OCCURRENCE OF *ELPHIDIUM EXCAVATUM* (TERQUEM) IN LLANDANWG LAGOON (NORTH WALES, U.K.)

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ABSTRACT

The seasonal variation in abundance of **Elphidium excavatum** (Terquem) = **Polystomella excavata** Terquem 1875 is described. Previous published data on seasonal variation of foraminifera are reviewed.

INTRODUCTION

Interest has been shown in the seasonal occurrence of foraminifera by a number of authors, lists of which can be noted in Phleger (1960) and Boltovskoy (1964). The purposes of this paper are to examine a species not hitherto examined in detail from this aspect, to describe any seasonal abundance variations, and to relate these to previously published observations.

Area description:—Llandanwg lagoon is located on the west coast of North Wales (Great Britain), approximately 12 Kms. due south of Port Madoc estuary, the lagoon being on latitude 52°49′N, and longitude 4°8′W.

The lagoon has the following physical characteristics:

(a) a tidal range of approximately 10-20 ft. (3-7 metres).
(b) annual surface temperature range of 1.0°C-17.0°C (approx. 32°F-63°F).
(c) annual salinity range of 3.0‰-30.0‰.
(d) a bottom composed of very fine to fine sand (Wentworth scale).
(e) bottom sediment composed of 70-80% quartz, 20-30% lithoclasts, and 1-5% bioclasts.

Material:—Samples were collected at regular monthly intervals during the period February 1965 to January 1966 from the same lagoon station. The samples were obtained by means of a bottom sediment scrape, the sediment placed in a 100ml. glass jar, covered with sea water to prevent further oxidation, and 10 ml. of neutralized formaldehyde added for preservation. Standardized 10 ml. cuts of sediment were washed, stained with Rose Bengal, rewashed to remove excess stain, and allowed to dry naturally prior to examination.

OBSERVATIONS

General

The following species obtained from the lagoon samples are listed in order of their frequency (100% means that it occurs in each of the monthly samples), the living forms being indicated with an asterisk (*):

100% occurrence
Ammonia beccarii (Linne)

75% - 100% occurrence
*Elphidium excavatum** (Terquem)

30% - 75% occurrence
Bulimina gibba Fornasini
Cibicides lobatulus (Walker and Jacob)
Elphidium crispum (Linne)
Elphidium discoidale (d'Orbigny)
Elphidium magellanicum Heron-Allen and Earland
Elphidium selseyense Heron-Allen and Earland
Miliolinella oblonga (Montagu)
Miliolinella subrotunda (Montagu)
*Nonion depressulum** (Walker and Jacob)
Quinqueloculina seminula (Linne)

1% - 30% occurrence
Astrononion gallowayi Loeblich and Tappan
Cibicides refulgens de Montford
Cyclogyra involvens (Reuss)
Discorbis bradyi Cushman
Discorbis williamsoni Chapman and Parr
Elphidium bartletti Cushman
Elphidium crispum (Linne) var.
Elphidium macellum (Fitchel and Moll)
Lagena laevis (Montagu)
Lagena sulcata (Walker and Jacob)
Lagena sulcata (Walker and Jacob) var. *interrupta* Williamson
Miliammina fusca Heron-Allen and Earland
Oolina hexagona (Williamson)
Patellina corrugata Williamson
Planorbulina mediterranensis d'Orbigny
Quinqueloculina lata Terquem
Reophax arctica Brady
*Saccammina sphaerica** Brady
Triloculina angulata Karrer
Trochammina inflata (Montagu)

Of the three living species indicated above, only *Elphidium excavatum* (Terquem) occurred with sufficient frequency and abundance to have validity in a study of this type. Examination of the number of individuals per sample (text fig. 1A) shows a major peak occurring in total numbers (living plus dead forms) from April to June and secondary

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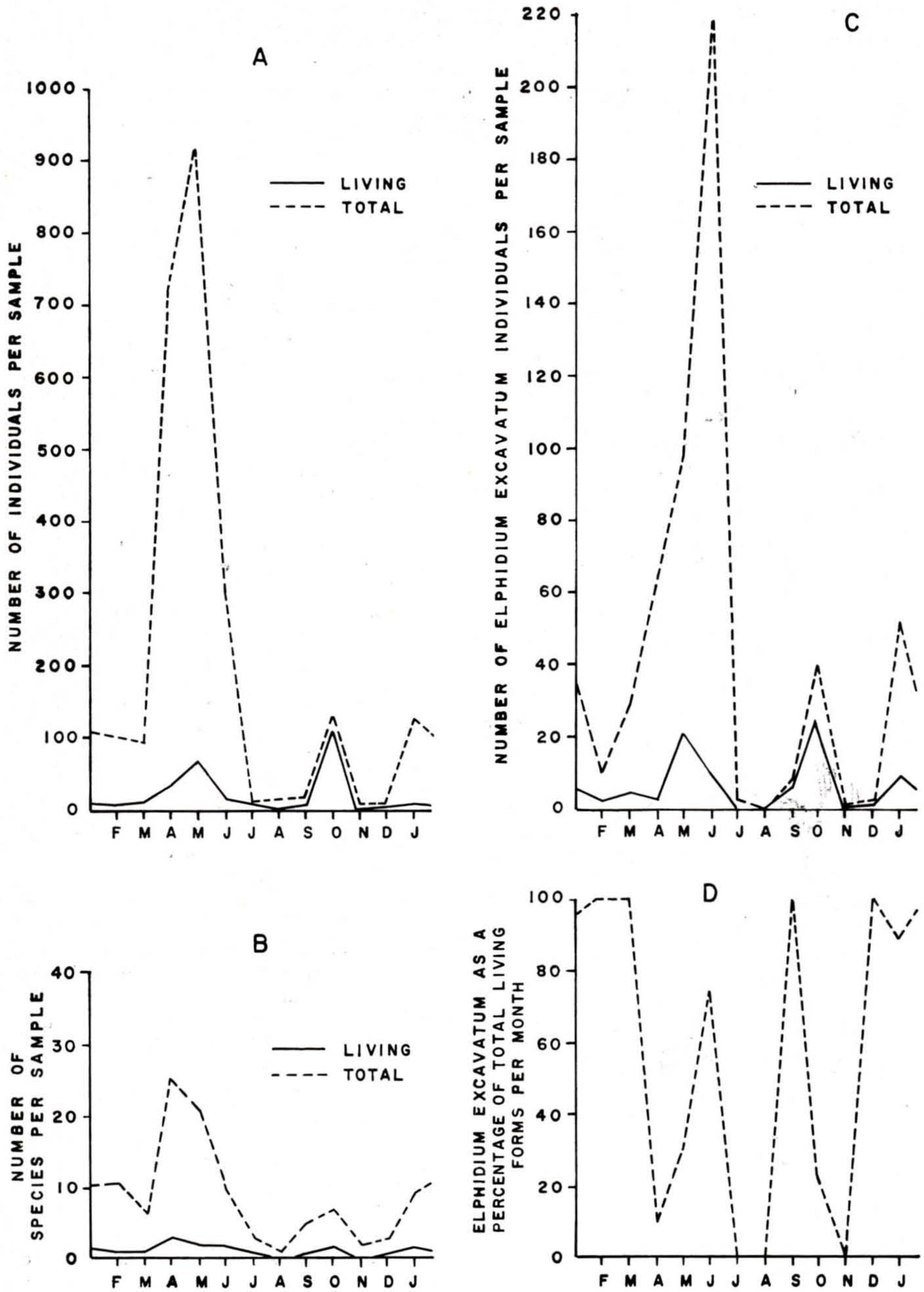

TEXT FIGURE 1

1A. Number of individuals per sample
1B. Number of species per sample
1C. Number of *Elphidium excavatum* individuals per sample
1D. *Elphidium excavatum* as a percentage of total living forms per month

peaks in October and January. The number of living individuals per sample (text fig. 1A) shows a similar pattern of peaks, the October peak accounting for almost the entire faunal recovery. With the increase in number of individuals, both total and living, there is a corresponding increase in the number of species obtained (text fig. 1B), both total and living.

Elphidium excavatum (Terquem)

This species when plotted as a percentage of the total living population (text fig. 1D) in each sample was noted to be the exclusive living form in four samples (February, March, September, and December) and the dominant form (above 50% of total living population) in a further two samples (January and June). Actual numbers of this species plotted for both living and total representatives (text fig. 1C) indicate three major peaks, occurring in May/June, October, and January. As a result of examination of this dimorphic species, the following seasonal pattern is hypothesized:

(a) In January, a minor phase of reproductive activity takes place, resulting in a dominance of large-test microspheric forms in the samples. This phase is associated with the adverse environmental conditions that prevail in this area at this time of year (low temperatures, low salinities, and high runoff from adjacent areas, with correspondingly high sedimentation rate) and is believed to represent a sexual phase.

(b) After this initial activity not all the "juvenile" forms survive, owing to the severe environmental conditions mentioned above, with the result that a slight drop in abundance of living forms occurs; this decline continues with the beginning of April.

(c) Towards the end of April, with an amelioration of environmental conditions (warmer temperatures, higher salinities, and less runoff from adjacent areas, with a correspondingly lower sedimentation rate) a distinct reproductive "burst" commences which reaches its acme in May. This reproductive activity, associated with the more hospitable conditions and dominance of small-sized megalospheric tests, is believed to represent an asexual phase of the reproductive cycle.

(d) After the May zenith a gradual decline in the living population is noted, no living forms being retrieved in July or August, these two months tentatively suggested as representing a dormant/semi-dormant period prior to further reproduction.

(e) At the end of August and in September another reproductive phase commences, culminating in an October peak, this phase believed to be asexual.

(f) After October the living population count undergoes a sharp decrease in numbers, no living forms being found in November. This is believed to be associated with the onset of adverse winter conditions.

(g) There is a very slight increase in living population numbers after November, this possibly representing the initial portion of the January reproductive phase.

In summary, *Elphidium excavatum* (Terquem) in this lagoon exhibits seasonal variation in abundance of living forms, this variation being related to, and/or controlled by, the environmental conditions that exist in the lagoon at various times of the year. The species exhibits two major phases of reproduction, believed to be asexual, one occurring in the spring (April-June) and the other in the autumn (September-October). A minor phase of reproduction, believed to be sexual, occurs in the winter (January).

DISCUSSION

Boltovskoy (1964) stated "at present very little is known about the seasonal occurrence of Foraminifera." To date this knowledge has not been expanded to any significant degree. The fact is evident from analysis of work published on this subject that a certain degree of confusion exists as to whether or not foraminiferal species exhibit seasonal variations in abundance, this problem being complicated by the fact that observations on a given species occasionally give anomalous results, as noted below. It would appear that some forms simply exhibit this seasonal variation while others do not, this probably being related to some critical environmental factor in a given habitat at any one time.

It has been stated that the following forms are unrelated to any seasonal activity:

> *Streblus beccarii tepida* (Cushman), Bradshaw (1957); *Streblus beccarii* (Linne), *Ammotium salsum* (Cushman and Brönnimann), Phleger and Lankford (1957); *Rotalia beccarii* (Linne), *Buliminella elegantissima* (d'Orbigny), and *Cyclogyra involvens* (Reuss), Boltovskoy (1964).

By contrast, the following forms are believed to be seasonally influenced:

> *Elphidium crispum* (Linne), Myers (1942, 1943); *Quinqueloculina poeyana* d'Orbigny, Phleger and Lankford (1957); *Ammotium salsum* (Cushman and Brönnimann), *Elphidium galvestonense* Kornfeld, *Protelphidium tisburyense* (Butcher), Parker and Athearn (1959); *Elphidium macellum* (Fichtel and Moll), *Quinqueloculina seminula* (Linne), Boltovskoy (1964); *Ammonia beccarii batava* (Hofker), *Elphidium excavatum* (Terquem), *Reophax moniliformis* Siddall, *Quinqueloculina dimidiata* Terquem, Murray (1968).

Foraminiferal assemblages studied *in toto* appear to exhibit seasonal variation in their abundances. Walton (1955) recorded an August maximum and a secondary peak in June for a fauna from Todos Santos Bay, Baja California. Reiter (1959) examined a fauna from Santa Monica Bay, California and recorded September, October and November as having the largest living populations, with a decrease in the winter months. Parker and Athearn (1959) worked on a fauna from Poponesset Bay, Massachusetts, and recorded the largest standing crops in June and the lowest in December. Bé (1960) noted seasonal changes in planktonic abundances, the largest crops being recorded in March and October, the smallest populations in December. In contradiction to the general seasonal activity indicated, Phleger and Lankford (1957) recorded no uniform relationship between size of living population and season of collection at the lower bay stations in their work on Aransas, Mesquite, and San Antonio Bays along the central Texas coast. This study also noted that in upper San Antonio Bay the average populations for November and January were almost twice as large as those for other seasons in this area, the explanation for this being unknown.

It is evident from the above review that when dealing with foraminiferal populations as a whole, generalisations concerning seasonal abundances are acceptable, but when a particular species is examined confusion may arise, as with the anomalous results concerning *Ammotium salsum* (Cushman and Brönnimann). In one study this species is stated to be unrelated to any seasonal activity (Phleger and Lankford 1957), in another, to be related to the seasons (Parker and Athearn 1959). Thus it may be somewhat fallaceous to attempt any correlation between the seasonal activities of different species, or even of the same species from different areas. Instead each species should be examined in its own localized area, and no attempt be made to relate these variations in different areas until further knowledge of these relationships is obtained.

CONCLUSIONS

In Llandanwg lagoon, *Elphidium excavatum* (Terquem) appears to indicate seasonal activity and corresponding variations in abundance. Three phases of reproduction are believed to take place in a twelve-month period.

A review of published data on seasonal variation in foraminifera indicates some anomalous results, indicating that more research on this subject is required.

ACKNOWLEDGEMENTS

The author is indebted to Dr. J. R. Haynes for critically reading the original draft of this paper, Dr. Z. M. Arnold for editorial advice, and Mrs. R. D. Payne for technical assistance.

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375. TWO NEW SPECIES OF FORAMINIFERA FROM THE LOWER MANCOS SHALE (UPPER CRETACEOUS) OF THE SAN JUAN BASIN, NEW MEXICO

GEORGE M. LAMB

In studying the stratigraphy of the lower portion of the Mancos Shale, in the San Juan Basin of New Mexico, the possibility of zoning the lower Mancos by foraminifers was investigated. Two hitherto undescribed species of Foraminifera were observed. Dane (1948) suggested that the Mancos on the northeast side of the San Juan Basin could be divided into five members: the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Shale, and an unnamed upper member which ranges up into beds of Pierre age. These names were unfortunately taken from the formational names of the eastern Colorado Plains and the Western Interior in general. The advisability of using these as members is dubious, but the fact remains that these divisions can actually be seen and mapped over much of the San Juan Basin (Lamb, 1968).

The two new species of Foraminifera were originally found in samples from a stratigraphic section measured in Red Wash, about one-quarter mile north of Highway 504, in Secs. 11 and 12, T. 30 N., Range 20 W., San Juan Co., New Mexico. The new species of the genus *Haplophragmium* were found in the lower portion of the Greenhorn Limestone as exposed near the bottom of Red Wash, and the new species of the genus *Ammomarginulina* came from beds some 200 feet higher in the section, which seem to be equivalent to the Blue Hill Member of the Carlile. The species of *Ammomarginulina* occurs through a stratigraphic interval of slightly over 100 feet. The holotype and several paratypes of each species are in the collection of the University of Colorado Museum.

SYSTEMATIC DESCRIPTIONS

Family LITUOLIDAE de Blainville, 1825
Genus **Ammomarginulina** Wiesner, 1931
Ammomarginulina carlilensis Lamb n. sp.

Text figures 1, 2, 3

Diagnosis.—Test large, compressed; early portion closely coiled and partially involute, comprising about two-thirds of the test; nine or ten chambers in the last whorl; two or three chambers in the straight portion; chambers, especially earlier ones, visible only in transmitted light; sutures almost straight; wall rough, but finely arenaceous, with much cement; last chamber much larger than the preceding and definitely rectangular.

Length of holotype, 1.79 mm., diameter of coiled portion, 0.50 mm.; diameter of coil in figured paratype, 0.34 mm.; a majority of the specimens have a coiled portion ranging from 0.30 mm. to 0.40 mm. in diameter.

Occurrence.—Throughout the San Juan Basin in beds seemingly equivalent to the upper portion of the Blue Hill Shale Member of the Carlile. The greatest stratigraphic range seems to be at Red Wash, where this form is found up through the beds of the Juana Lopez Member of the Mancos. The Juana Lopez is equivalent, at least in part, to the Turner Sandy Member of the Carlile. Other foraminifers associated with *Ammomarginulina carlilensis* in this zone are: *Trochammina wickendeni* Loeblich, *Gaudryina spiritensis* Stelck and Wall, and *Haplophragmoides howardense* Stelck and Wall.

Remarks.—Differs from *A. loricata* Loeblich and Tappan in that the ultimate coil is completely evolute; the chambers are more rectangular, giving a less lobate outline; and the chambers in the straight portion are relatively of larger size.

Holotype: UCM 26237; figured paratype, UCM 26279.

Genus **Haplophragmium** Reuss, 1860
Haplophragmium arenatum Lamb n. sp.

Text figures 4, 5, 6

Diagnosis.—Test large, coarsely arenaceous; early portion in an irregular coil, later portion straight; entire straight portion seemingly not preserved on any individual; aperture apparently round and terminal; most specimens appear to be distorted as well as being irregularly coiled.

Length of holotype, 0.82 mm., diameter of coiled portion, 0.62 mm., length of figured paratype, 0.64 mm., diameter of coiled portion, 0.57 mm. Length of other specimens ranges between 0.76 mm. and 1.08 mm., and the diameter of the coiled portion is 0.50 mm. to 0.75 mm.

Occurrence.—This form is found in the lowermost Greenhorn beds on the west side of the San Juan Basin, associated with specimens of *Bigenerina hastata* Cushman, *Heterohelix globulosa* (Ehrenberg), *Guembelitria harrisi* Tappan, *Globigerinelloides bentonensis* (Morrow), and *Hedbergella delrioensis* (Carsey). The author has also seen this form in beds of Greenhorn age in western Colorado.

Holotype: UCM 26246; figured paratype, UCM 26241.

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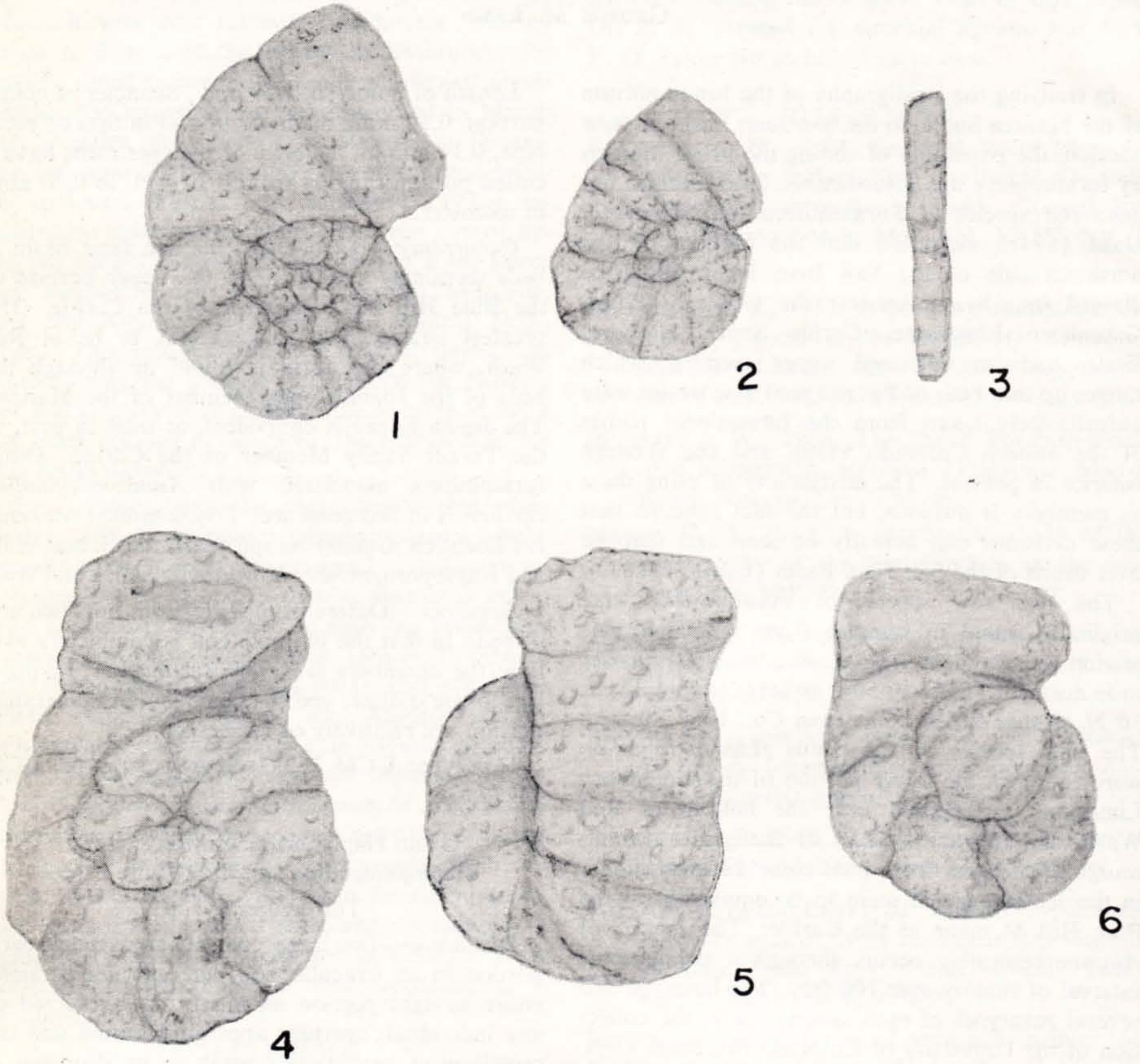

TEXT FIGURES 1 - 6

All figures ×75

1-3. *Ammomarginulina carlilensis* Lamb n. sp. 1, side view of holotype; 2, side view of paratype; 3, edge view of paratype.

4-6. *Haplophragmium arenatum* Lamb n. sp. 4, 5, opposite views of holotype; 6, side view of paratype.

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376. A NOTE ON THE TAXONOMIC STATUS OF THE GENUS *AFROBOLIVINA* REYMENT 1959

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ABSTRACT

The genus **Afrobolivina** Reyment (1959) is studied in detail and emended. The inward growths of the wall, which Reyment regarded as the vertical septa, are not sufficiently diagnostic to support the recognition of a new genus.

INTRODUCTION

During the study of ditch cuttings retrieved from Afowo 1 well in southwestern Nigeria, numerous specimens assigned by Reyment to the new genus *Afrobolivina* were obtained.

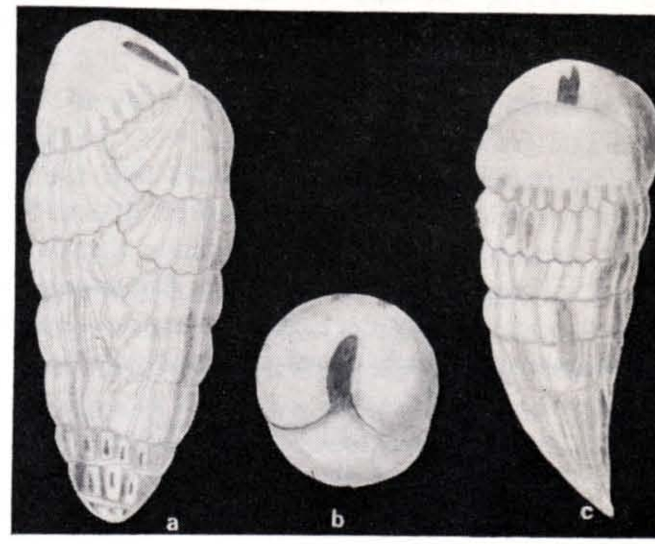
Reyment (1959) erected this genus, with *A. afra* as the type species, on the basis of the so-called "vertical septa." These features he found to be restricted to the basal portion of the chamber and connected with the external riblets. He also recorded 8-10 of these projections per chamber. The writer has examined many specimens and found that all of them possess these internal growths, but they are better developed in some than in others.

The geographical distribution of *A. afra* along the coast of Africa was described by Cartelain *et al.* (1962). The species has been recorded from the upper Cretaceous rocks in Angola, Gabon, Nigeria, Cameroon, Cote d'Ivoire and Senegal in association with species of *Bulimina, Globotruncana, Siphogenerinoides, Rugoglobigerina, Pseudotextularia, Hedbergella* and *Heterohelix*. In western Nigeria, Reyment recorded it in the Araromi borehole (between 518 metres and 449 metres) and the Gbekebo borehole (between 1100 and 960 metres). In the former, it was recorded as occurring with both a Palaeocene and a Maestrichtian foraminiferan fauna and was questionably assigned to the "upper Maestrichtian to lowermost Palaeocene."

In southwestern Nigeria, *A. afra* occurs in abundance in, but is restricted to, the upper Maestrichtian rocks. In the section studied by the writer, the species is abundant and restricted to the Maestrichtian. Its presence in the Palaeocene may therefore be due to reworking.

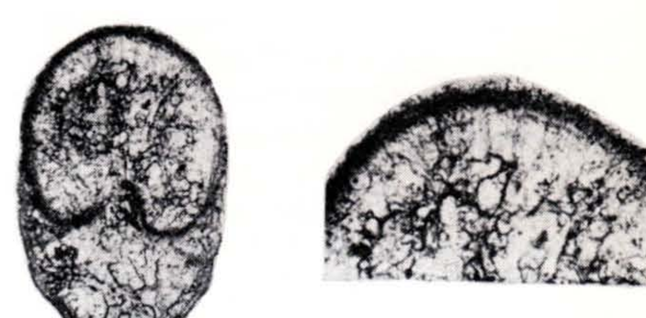
DISCUSSION

Bolivina afra (Reyment), first described from the Araromi shale of the Abeokuta Formation (upper Maestrichtian) in western Nigeria, was placed in the genus *Afrobolivina*. Reyment has since erected a few new species. Among them is *A. bantu*, which he differentiated mainly on variations in external morphological features, including convexity, test size and ornamentation. Most authors have to date followed Reyment in removing such forms from the genus *Bolivina*.



TEXT FIGURE 1
a. Megalospheric individual. Length, 1.5 mm.; maximum breadth, 0.52 mm.; maximum thickness, 0.5 mm. b. Apertural view. c. Microspheric individual. Length, 1.48 mm; maximum breadth, 0.51 mm.; maximum thickness, 0.49 mm.

The writer had the opportunity of studying numerous specimens, most of which were sectioned so that internal features could be observed. The tooth-plate structure and the form of the aperture are bolivinoid. Some specimens have a small tooth at the aperture (text fig. 1c). The internal outgrowths referred to by Reyment as vertical septa are also regarded by him as outgrowths of the toothplate. According to his sketches (fig. 8, illustrations 3 and 4) the "septa" in the lower chambers extend nearly to the centre of the test. None of



TEXT FIGURE 2
Section of entire test on left. Size, 0.54 mm. × 0.5 mm. To the right is a magnified view of the top margin of the same specimen.

the transverse sections made by the writer showed the development of the "septa" to this degree. Text fig. 2 depicts the average development in the sections studied. However, in the proximal areas of some specimens, where the chambers are relatively small, these outgrowths tend to approach the centre of the test. Whilst the writer does not wish to doubt Reyment's illustrations, photographs of the transverse sections would have been more convincing.

CONCLUSION

It is believed, firstly, that the development of internal outgrowths is characteristic of the large endemic upper Cretaceous bolivinids that are apparently restricted to the west coast of Africa. Secondly, these outgrowths are not equally well developed in all forms; they are buttresses that strengthen the tests, presumably developed in response to the environment in which the organisms lived.

ACKNOWLEDGEMENTS

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TYPES

Hypotype.—No. 21, sample no. 128; restricted to the upper Maestrichtian Araromi shale.

Repository.—The hypotypes are kept in the department of Geology, University of Ife, Nigeria.

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377. A RE-EVALUATION OF EASTERN MEDITERRANEAN FORAMINIFERA USING FACTOR-VECTOR ANALYSIS

KENNETH HOOPER

Parker (1958) described foraminiferal depth-assemblages of the Eastern Mediterranean Sea. Her method of analysis was the usual one of comparing lists of species present in each sample. An alternative method, which has the advantage of being more consistent, is provided by the mathematical method of factor-vector analysis. The Fortran program known as COVAP, described by Manson and Imbrie (1964), performs factor-vector analysis in the Q-mode using an IBM 7090 or 7094 computer. This report describes the results of COVAP analysis when applied to Parker's data on Eastern Mediterranean Foraminifera and includes a comparison between the COVAP results and Parker's results.

PARKER'S DEPTH-ASSEMBLAGES

Parker concluded that five depth-assemblages, based on benthonic foraminiferal faunas, are present in the eastern Mediterranean Sea. Her depth-assemblages are defined below:

Depth-assemblage 1 has a lower limit of 51 m. It is characterized by temperatures ranging from 11 to 21°C at 25 m. and a salinity of 39‰.

Depth-assemblage 2 extends from 51 m. to 143-205 m. Temperatures are 12 to 20°C at 50 m., and 13 to 16°C at 200 m. Salinities range from 38 to 39‰.

The third depth-assemblage ranges from 143-205 m. to 500-700 m. It has temperatures of 13 to 16°C at 200 to 300 m., 14 to 15°C at 400 m., and 14°C at 500 m. Salinities are 38 to 39‰.

Depth-assemblage 4 ranges in depth from 500-700 m. to 1000-1300 m. It is characterized by temperatures of 13 to 14°C and a salinity of 39‰.

Depth-assemblage 5 ranges in depth from 1000-1300 m. to 3974 m., and deeper. Temperatures are in the order of 13 to 14°C and salinities are 38 to 39‰.

Parker also concluded that six samples were displaced and two samples represented areas of non-deposition.

COVAP DEPTH-ASSEMBLAGES

The reordered oblique projection matrix for five rotated factors of COVAP is given in table 1; sample depths in metres, and comments about assignment of samples to assemblages are included.

The left hand column, the station-name column, contains the station numbers of Parker. The index column contains sequential numbers of the stations as automatically assigned to the stations by computer. The next five columns contain the coefficients of proportional similarity—a measure of faunal similarity in which end-member samples are represented by unity. Values higher than approximately 0.690 are regarded by the writer as indicating similar faunas.

Assemblage No. 1

The samples 4687 to 4652 have high coefficients of faunal similarity when compared to the end-member sample. These samples comprise the main constituents of benthonic foraminiferal assemblage 1; they range in depth of occurrence from 201 m. to 799 m. These depths are here regarded as the limits of the zone. Sample 4671 has a moderate coefficient of faunal similarity with respect to the first end-member sample (4687), and therefore to this assemblage; it has very low similarity to the four other end-member samples. Its depth of 1061 m. might indicate displacement downslope, or it might indicate that the lower limit of the depth zone should be assumed to occur at around 1061 m. rather than 799 m. Parker (*op. cit.*, p. 232) notes that specimens from this sample are poorly preserved and contain glauconite. She suggests that the sample comes from an area of non-deposition. On the other hand, the poor preservation of foraminifers might be the result of displacement by transportation downslope.

Sample 4703, with a moderate coefficient of similarity to end-member 4687 and with a depth of 552 m., is probably correctly placed in COVAP assemblage 1.

Sample 4649A has a moderate coefficient (0.606) when compared to COVAP assemblage 1, but with its coefficient of 0.564 relative to end-member sample 4662A it almost as well fits assemblage 3. Its depth of occurrence, 106 m., is perhaps more appropriate to COVAP assemblage 3 (see below). Its retention in COVAP assemblage 1 would necessitate raising the upper limit of this assemblage to 106 m.

Sample BS 9 has only a moderate coefficient (0.601) with respect to COVAP assemblage 1, but its coefficients with respect to the four other end-member samples are extremely low. It is, therefore, retained in this assemblage.

Sample BS 29 has only a moderate coefficient (0.594) with respect to COVAP assemblage 1. It seems that it might almost as well fit in COVAP

TABLE 1

RQ ANALYSIS OF E MED BEN FORAMS PARKER BY HOOPER TRY QQ MODE M7-5 TRIAL SERIES
REORDERED OBLIQUE PROJECTION MATRIX

NAME	INDEX	4687 24	4681 49	4662A 2	4705 42	4650 35	Depth (m)	COMMENTS
4687	24	1.000	0.000	0.000	0.000	0.000	631	
4686	33	0.988	0.059	—0.011	—0.035	0.021	799	
4685	25	0.973	—0.005	—0.049	—0.126	0.116	647	
4718	21	0.972	—0.053	—0.008	—0.093	0.087	541	Assemblage No. 1
4657	20	0.907	—0.006	0.063	—0.060	0.244	384	201 - 799 m.
4723	23	0.847	—0.063	0.270	—0.135	0.250	567	
4656	29	0.838	—0.006	—0.035	—0.008	0.322	680	
4657B	16	0.823	—0.081	0.168	—0.186	0.274	256	1 Displaced? Or lower limit of depth assemblage 1.
BS20	15	0.804	—0.094	0.164	—0.184	0.406	210	
BS21A	14	0.795	—0.092	0.162	—0.221	0.420	205	2 Coeff. 6, could almost as well fit in Assemblage 3.
4660	27	0.761	—0.082	—0.093	—0.213	0.513	665	
4648	18	0.751	—0.071	0.155	—0.139	0.392	338	
4647	19	0.720	—0.031	0.217	—0.007	0.323	366	3 On coeff. could almost as well fit in Assemblage 2, or be displaced.
4652	13	0.689	—0.027	0.624	—0.133	—0.010	201	
4671	37	0.672	—0.020	0.053	0.203	0.214	1061[1]	
4703	55	0.631	—0.062	0.003	—0.111	0.583	552	4 On coeff. could almost as well fit in Assemblage 5, or be displaced, or lower limit of depth zone 1.
4649A	8	0.606	—0.051	0.564	—0.193	0.075	106[2]	
BS9	31	0.601	0.246	0.107	0.347	0.178	731	
BS29	17	0.594	—0.045	0.308	—0.182	0.501	287	
4689	46	0.584	0.569	—0.084	0.367	0.042	2442[3]	
4694	22	0.521	0.030	0.352	0.093	0.217	567	
4675	57	0.515	—0.058	0.316	0.141	0.499	1064[4]	
4681	49	0.000	1.000	0.000	0.000	0.000	2852	
4683	45	—0.004	0.999	—0.006	0.063	0.022	2358	
4698	47	0.083	0.987	—0.009	0.050	0.007	2738	Assemblage No. 2
4710	50	0.095	0.973	0.007	—0.013	0.019	3241	
4708	52	—0.004	0.927	0.014	—0.013	0.010	3499	1862 - 3499 m.
4678	44	—0.027	0.882	—0.021	0.365	0.159	1862	
4701	48	—0.011	0.661	0.139	—0.019	0.018	2760	
4662A	2	0.000	0.000	1.000	0.000	0.000	51	
4657A	7	0.191	—0.030	0.995	—0.091	0.145	104	Assemblage No. 3
4658	5	0.058	—0.032	0.994	—0.106	0.189	82	
BS61	54	0.075	0.029	0.975	0.042	—0.041	462[1]	25 - 179 m.
4668	10	0.035	—0.002	0.953	0.056	0.017	117	
4667	6	0.040	—0.031	0.932	—0.089	0.214	86	
4721A	12	0.258	—0.024	0.891	—0.106	0.128	179	1 Displaced.
4666	3	—0.030	—0.037	0.886	—0.111	0.293	71	2 Displaced.
4654A	9	0.089	0.051	0.878	0.051	—0.184	115	
4654B	11	0.100	0.002	0.872	0.046	—0.116	143	3 Coeff. low. Low faunal similarity to this assemblage or any other. Possibly derived from underlying rocks — a fossil assemblage?
4661	4	0.022	0.017	0.811	0.039	—0.167	75	
BS32	1	0.035	0.019	0.795	0.019	—0.055	Bay	
4665	60	0.143	—0.054	0.666	—0.153	0.476	1587[2]	
4711	51	0.031	0.017	0.287	—0.010	—0.013	3309[3]	
4705	42	0.000	0.000	0.000	1.000	0.000	1788	
4688	40	0.011	0.185	0.043	0.992	—0.014	1312	
4716	41	0.051	0.092	0.070	0.981	0.036	1378	Assemblage No. 4
4673	43	—0.013	0.141	0.024	0.977	0.087	1844	
4693	38	0.188	0.428	0.212	0.816	—0.017	1073	996 - 1844 m.
4670	36	0.441	0.082	0.184	0.614	0.276	996	
4650	35	0.000	0.000	0.000	0.000	1.000	859	
4659	56	0.209	—0.062	—0.020	—0.116	0.867	850	Assemblage No. 5
4655	58	0.234	0.106	0.273	—0.057	0.841	1102	
4714	28	0.088	0.001	0.157	0.036	0.787	665	658 - 1102, 1331 m.
4702	34	—0.080	—0.030	0.111	0.320	0.773	799	
4664	26	0.501	—0.087	0.030	—0.113	0.726	658	1 On coeff. second preference, assemblage 4.
4649	39	—0.033	0.225	0.010	0.410	0.673	1265[1]	
4654	32	0.312	0.128	—0.023	0.122	0.639	746	2 Low coeff.
4691	59	0.162	—0.066	0.225	—0.156	0.589	1331	
4713	30	0.150	—0.008	0.295	0.263	0.408	684[2]	3 Low coeff. No similarity to any assemblage. Fossil?
4676	53	—0.057	—0.028	0.074	—0.019	0.254	3974[3]	

TABLE 2

Sediment samples that are displaced, faunally invalid, non-depositional in origin, or of uncertain status

PARKER*		COVAP	
Sample number		Sample number	
BS 61	Specimens badly preserved Glauconite Non-depositional area	BS 61	High coefficient Depth below zone range Displaced *en masse* from assemblage 3
4675	Displaced	4675	Coefficient could fit assemblage 5, or sediment might be displaced downslope from assemblage 1
4665	Displaced	4665	Displaced downslope from assemblage 3
4691 4655 4659 4703	Displaced Displaced Displaced Displaced		
4711	Small amount of material Shallow species in deep water Displaced	4711	Small amount of material Not statistically valid Low coefficient. Fossil? Displaced?
		4676	Small amount of material? Not statistically valid? Low coefficient. Fossil? Displaced?
		4689	On coefficient might fit in assemblage 2, or be displaced downslope from assemblage 1
		4671	Displaced, or to be taken as lower limit of assemblage 1
		4649A	On coefficient could fit assemblage 1 or 3

* Summarized from Parker (1958)

assemblage 5; however, its depth (287 m.) is inappropriate to that assemblage, which has a depth range of 658 m. to 1331 m. Sample 4689 has a moderate coefficient (0.584) with respect to COVAP assemblage 1, and could almost equally well be correlated with COVAP assemblage 2 (coefficient, 0.569). Alternatively, it might belong to COVAP assemblage 1 but be displaced, because the depth of occurrence (2442 m.) is far beyond the lower limit of this assemblage. However, it is well within the range of COVAP assemblage 2, and, therefore, is assigned to this assemblage. Sample 4694, also, is regarded as belonging to COVAP assemblage 1.

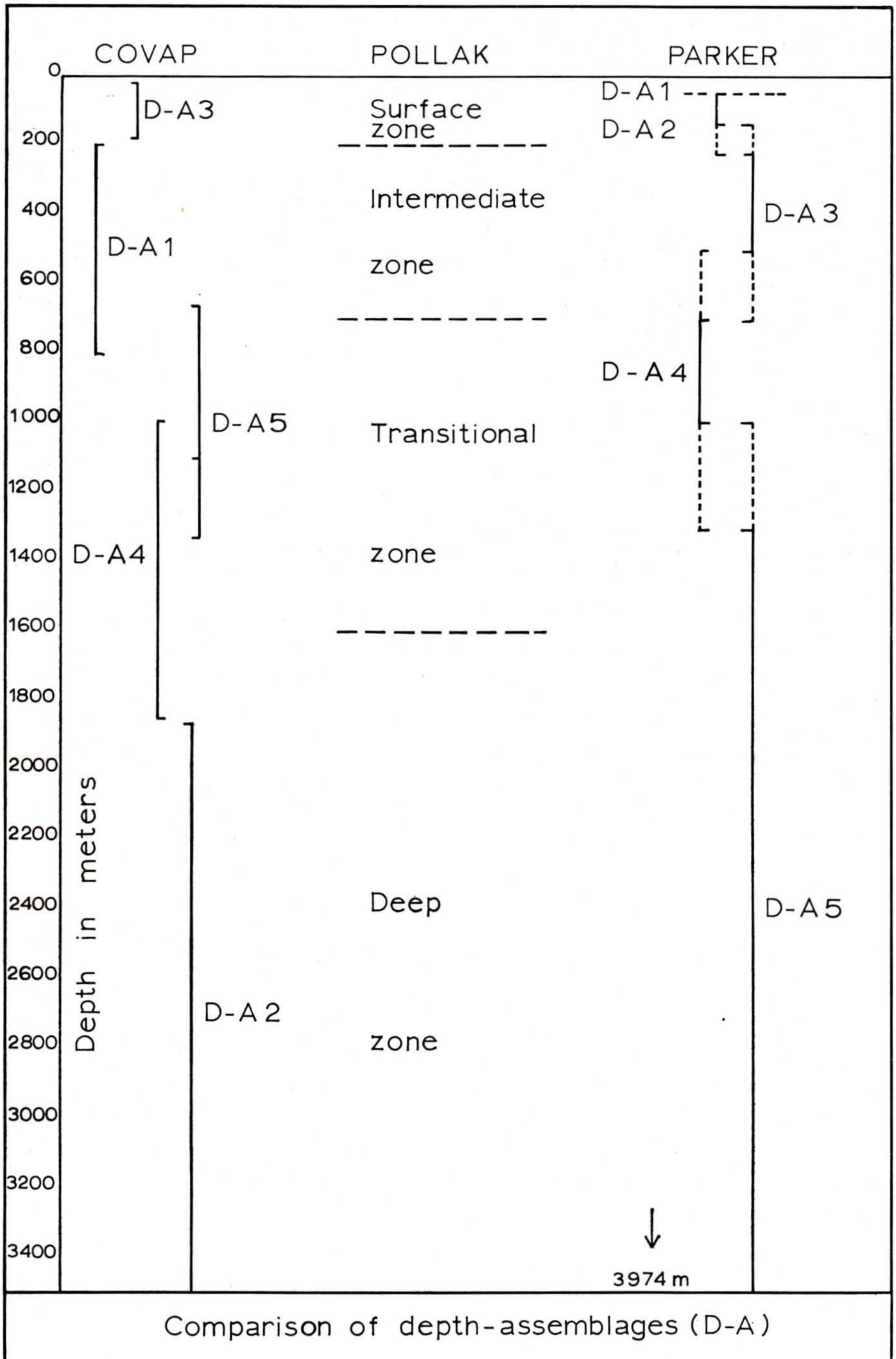
Sample 4675, judged by its coefficients of faunal similarity relative to various end-members, fits COVAP assemblage 5 almost as well as COVAP assemblage 1; moreover, the depth of occurrence (1064 m.) is consistent with COVAP assemblage 5. The possibility of downslope displacement cannot be ruled out, and it might even be argued that the lower limit of COVAP assemblage 1 should be extended to include sample 4675 at 1064 m.; sample 4671, taken from a depth of 1061 m. (see above), might be a supporting argument for drawing the limit here.

Assemblage No. 2

Samples 4681 to 4678 have high coefficients of faunal similarity with respect to end-member 2 (sample 4681), and sample 4701 has a moderate coefficient. The samples range from 1862 m. to 3499 m.

Assemblage No. 3

Samples 4662A to BS 32 have a high coefficient compared to end-member 3 (sample 4662A). They range in depth from approximately 25 m. (Bay) to 179 m., except for sample BS 61, which has an anomalous depth of occurrence (462 m.). Coupled with this anomalous depth is its coefficient of faunal similarity of 0.975. It therefore seems most likely that the sediment with its contained dead fauna has been displaced downslope. Sample 4665 has a moderate coefficient with respect to COVAP assemblage 3 and also an anomalous depth of occurrence (1587 m.). The sediment with its contained fauna is probably displaced.



TEXT FIGURE 1

Sample 4711 (3309 m.) has a very low coefficient of faunal similarity with respect to all five assemblages. The possibilities are: (1), the sample represents a fossil fauna of different age or ecology than those faunas at present existing in the region, (2), too few species or specimens were counted to render the sample statistically valid, and (3), the sediment (from which sample 4711 was taken) has been displaced downslope, in which case it may, or may not, have undergone considerable admixture, exchange of material, or loss of faunal constituents. Parker noted that the amount of material available for study was small.

Assemblage No. 4

Samples 4705 to 4693 have high coefficients, and sample 4670 has a moderate one. They comprise COVAP assemblage 4, ranging in depth from 996 m. to 1844 m.

Assemblage No. 5

Samples 4659 to 4664 have high coefficients with respect to end-member 5 (sample 4650) and, with sample 4650, constitute the main members of COVAP assemblage 5, ranging in depths from 658 m. to 1102 m. Moderate coefficients for samples 4649 to 4691 extend the depth range of the assemblage to 1331 m. Sample 4713 has a moderately low coefficient (0.408), but its depth of occurrence (684 m.) is appropriate for this assemblage. Sample 4676, at 3974 m., which has a very low coefficient (0.254), seems not to be correlated with any of the five assemblages. The considerations given for sample 4711 (above) also are applicable to sample 4676.

CONCLUSION

Sediment samples that are displaced, faunally invalid, from areas of non-deposition, or uncertain in status are shown in Table 2.

COVAP analysis of Parker's data suggests the presence of five depth-assemblages, but the limits of the depth zones differ slightly from those of Parker (see text fig. 1). Furthermore, COVAP analysis suggests that eight samples may be displaced, only three of which are the same as Parker's, and two may be statistically invalid on account of paucity of material (Table 2).

In general, the zonation of depth-assemblages suggested by the mathematical model tends to agree more closely with the layering of water masses postulated for the region by Pollak (1951), than does Parker's interpretation (text fig. 1). The main differences are that COVAP suggests two depth-assemblages (Nos. 2 and 4) against Parker's No. 5, and one depth-assemblage (COVAP No. 3) against Parker's Nos. 1 and 2.

ACKNOWLEDGMENT

Thanks are due Dr. Frances L. Parker for critically reading the manuscript.

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378. *GLOBIGERINA* MARLS AND THEIR PLANKTONIC FORAMINIFERA FROM THE EOCENE OF NANGGULAN, CENTRAL JAVA[1]

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ABSTRACT

Prior to the present report the Eocene Nanggulan group was subdivided by Oppenoorth and Gerth (1929) into the **Axinea**, **Jogjakartae** and **Discocyclina** layers. These sediments were formed in non-marine and near-shore environmental conditions. Above these layers, **Globigerina** marls are observed which prove to contain typical Eocene planktonic foraminifera, hence an additional layer of completely different facies occur in the Eocene Nanggulan group. Seventeen planktonic foraminiferal species from six samples are recorded in this paper, of which one species, **Hantkenina nanggulanensis** nov. sp., is here described as new.

INTRODUCTION

The present paper discusses *Globigerina* marls which occur in close proximity with the Eocene sediments of Nanggulan, central Java. This study is based on field and laboratory investigations. Samples of marls, all surface collections, were gathered by the author in the dry season of 1965; it appears that some of the marls contain typical Eocene planktonic foraminiferal fossils. Actually the presence of these fossils has been known to the author since 1959, from samples collected by Dr. W. Rothpletz in 1943. However, the number of specimens obtained from the washed samples, which were mainly collected from the Watupuru river, was small and moreover not well preserved. From the recently collected marl samples, a total of eight from six localities were studied; three localities are here considered Eocene in age, the rest younger. Previously all these localities are indicated as *Globigerina* marls, Miocene in age in the geological map of Rothpletz (1943).

In this report the distribution of the marls will be described in relation to geographic factors and geologic formations. The layers are correlated with well known occurrences and the age assignment is mainly based on planktonic foraminifera, which constitute the main element of the fauna. The fauna will be described in the systematics section, and all the identified species are figured. A distribution chart of species in the samples is also given.

Further, this paper proposes that besides the existing subdivisions of the Eocene of Nanggulan which were established by Oppenoorth and Gerth (1929), viz. *Axinea, Jogjakartae* and *Discocyclina* layers, a new unit, the *Globigerina* marl, should be added.

I am grateful to the retired irrigation worker of Nanggulan, Pak Martokrijono, who provided us with rooms in his house during our stay in the field. Jatim Karsoprajitno and Pardi Jososudarmo, both from the Geological Survey, assisted me in the field and also in the laboratory with the preparation of the samples. Drawings in this report were done by Tugiman, illustrator of the Geological Survey.

DISTRIBUTION OF MARLS IN NANGGULAN

The Eocene marls mainly occur as isolated outcrops and stratigraphically lie between *Discocyclina* layers in the lower part and volcanic andesite breccias and agglomerates above. They occur in three localities (text fig. 1) and will be described in relation to their geographic position and geologic formation.

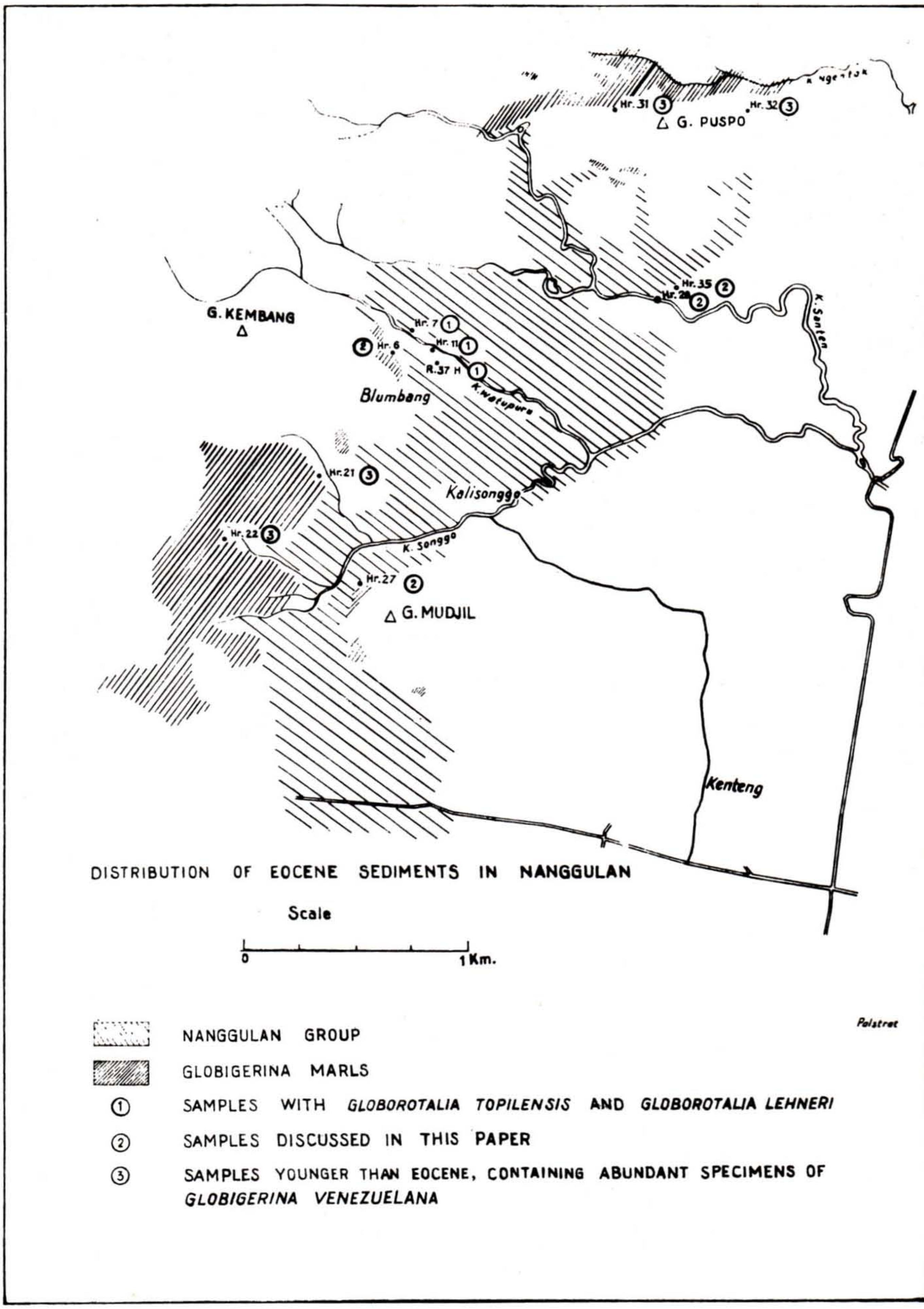
Occurrence at Tempel village

The samples were taken from the wall of a footpath cut northwest of the top of Mudjil Hill at the village Tempel. The general topography of the sample locality is that of the conical Mudjil Hill. The outcrop is an elongated one trending more or less in the same direction as the contour line. The marl is very calcareous, much weathered, and white to somewhat light-brownish with soil impurities. Although the marl is weathered, good fossil specimens can be obtained from it. The lower contact is with the sandy clay of the *Discocyclina* layers, the upper with the volcanic andesite breccias and agglomerates of which Mudjil Hill is constructed. The length of the outcrop is estimated to be 150 meters, its width ± 15 meters. Rothpletz (1943) indicated on his geologic map two other isolated occurrences farther south. Although samples from the latter have not been taken and studied, the three localities must belong to the same bed, because they have the same lithology; they are located at about the same elevation and on the geologic map form a discontinuous line surrounding Mudjil Hill.

Occurrence at Kali Santen

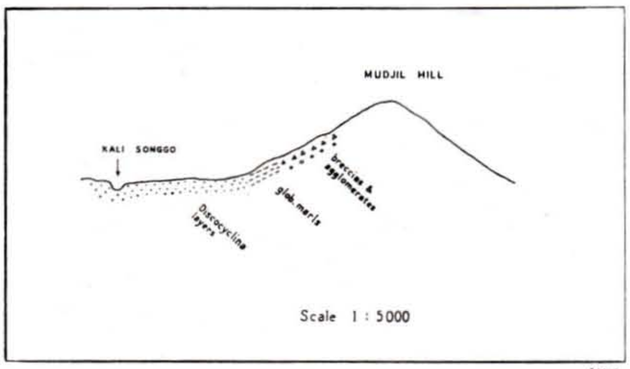
The marls were here revealed by the excavation for an irrigation channel. The location of the sample is near the intersection of the irrigation

1 Publication of this paper authorized by the Director of The Geological Survey.



TEXT FIGURE 1
Distribution of Eocene sediments in Nanggulan

channel with the Kali Santen, and on the northern side of the latter. The marl is grey and has a rather high clay content compared with the marls of Tempel and Blumbang village. Fossils from Kali Santen are the most beautifully preserved. The position of the marl is near outcrops belonging to the *Axinea* layers. The extent of the marl has not been traced, but it is an isolated one and could not be very extensive.



TEXT FIGURE 2

Occurrence near Blumbang village

The *Globigerina* marls in this area crop out at a small tributary of the Watupuru river, not far from the village Blumbang, on the general slope down from the village to the river. The outcrop, elongated in a north-south direction, is 250 meters long and 60 wide. The nature of the rock is the same as those found at Tempel village. Good fossil specimens were also obtained here. Contact with other formations is not very distinct, but not far down the slope outcrops belonging to the *Discocyclina* layers are observed. The southernmost tip of the marl is closely connected with outcrops belonging to the Jogjakartae layers, which crop out at the Watupuru river. If the strike be extended to the southwest, it will cut the southernmost tip of the marl outcrop. Farther uphill occur volcanics, consisting of andesite breccias and agglomerates.

From the upper course of the Watupuru river, some samples have been analysed which on the geologic map belong to the *Discocyclina* layers; they contain a mixture of faunas derived from the *Globigerina* marls and the *Discocyclina* layers. This faunal mixing is also indicated by the different type of preservation and different sediments in which the fossils are embedded. The rocks from which the samples were taken should be considered debris.

From the above-mentioned marl occurrences it is evident that the Eocene *Globigerina* marls discussed here do not always lie above the *Discocyclina* layers; their position may be above either the *Discocyclina* and *Jogjakartae* layers or the *Axinea* layers, which means that the marls transgressively overlie Nanggulan group, as it was formerly known.

Occurrence in Kebon Agung

The *Globigerina* marls are not restricted to the above-mentioned localities; the presence of such rocks of Eocene age containing *Hantkenina* sp. has been reported (Hartono, 1960) from core samples from Kebon Agung, not far from the Eocene Nanggulan exposures. The core samples are also composed of marly rocks having abundant planktonic foraminifera. From the distribution chart of species (text fig. 4) it can be seen that four species occurring at Kebon Agung also occur in the marls from Nanggulan, which means that they must belong to the same bed. At the time the relationship to the outcropping Eocene Nanggulan group was not clear, because such Eocene marls were not then known. The present discovery of *Globigerina* marls in close connection with known beds clarifies the relationship. The distribution of the Eocene *Globigerina* marls must, therefore, also be extended to the east under the alluvial Progo Plain.

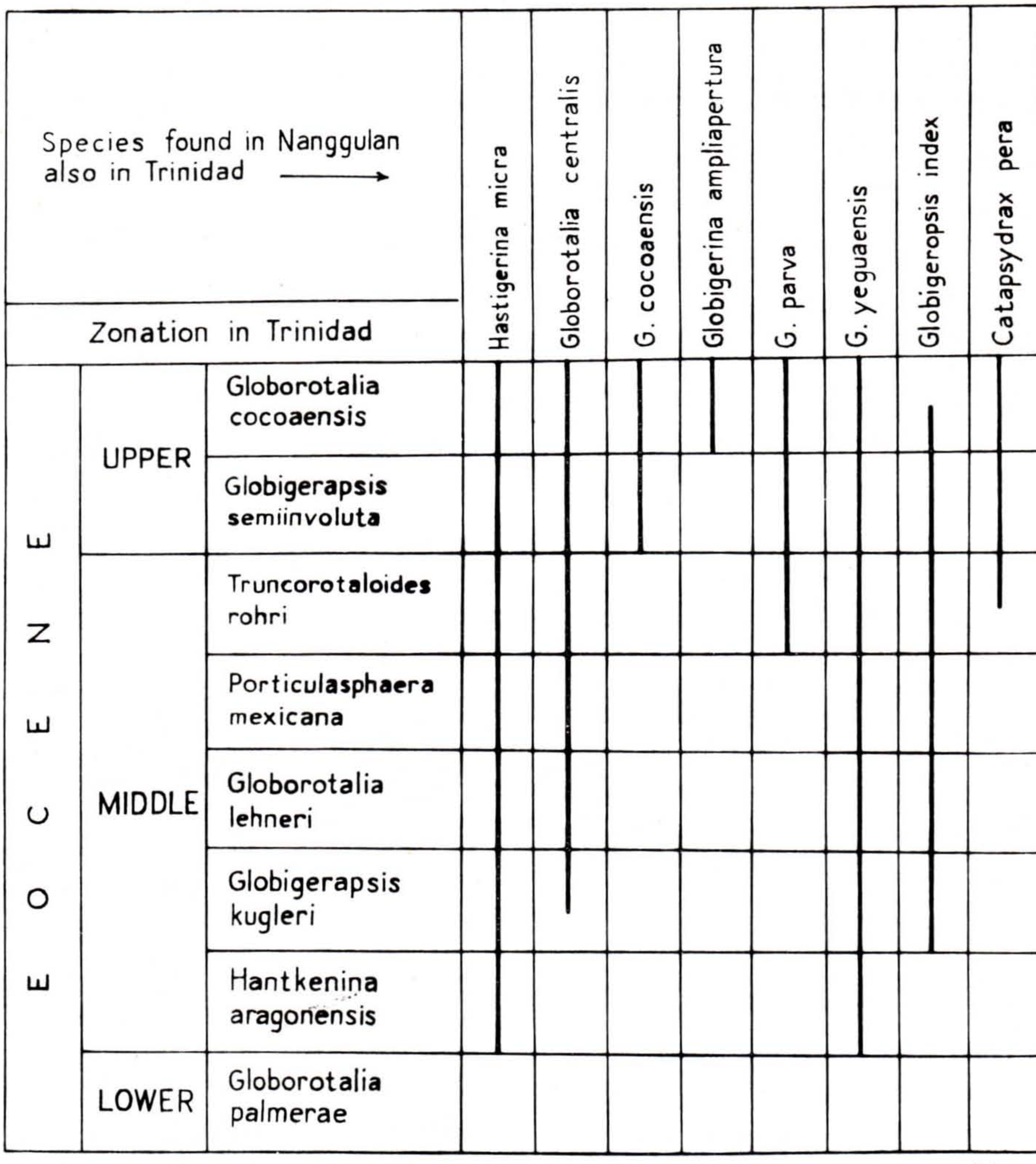
FACIES CHANGE

Judging from the character of the sediments of the *Axinea, Jogjakartae* and *Discocyclina* layers, a fully developed *Globigerina* fauna cannot be expected in these layers. Sedimentation took place in a terrestrial to marginal lagoonal to nearshore environment, as shown by coal beds in the *Axinea* layers and abundant molluscs in almost the whole sequence. From the type of sediments and its fossil content it seems obvious that a facies change has taken place from bottom to top.

The coal layers and abundant molluscs of the *Axinea* beds indicate a terrestrial to marginal lagoonal environment. Moreover, euxinic conditions during their deposition also prevailed, as is shown by sulphur crystals or their derivatives on the surface of black clays. The *Axinea* layers are also characterized by a paucity or absence of calcium carbonate.

The *Jogjakartae* and *Discocyclina* layers show clearly an increase in the marine influence, for instance the appearance of abundant larger foraminifera and, rarely, smaller and planktonic foraminifera. That conditions were apparently not fully marine but still dominated by shore factors, however, is shown by the occurrence of littoral fossils in abundance. The calcium carbonate content of the beds is not very high, but it shows a marked increase upward.

The *Globigerina* marls developed under entirely marine conditions without influence of shore factors. This is reflected by the type of sediment, viz., marl, as well as by the fossils occurring in them, which consist almost exclusively of planktonic foraminifera. Because of predominance of this planktonic element, the marls are interpreted as deposits from relatively deep water or from the same con-



TEXT FIGURE 3

ditions as those in which *Globigerina* oozes are currently being deposited in Recent seas. Compared with the underlying layers, the *Globigerina* marls are far more calcareous.

ADDITIONAL EOCENE LAYER

The previously known Eocene sediments of Nanggulan were called the "Nanggulan group" (Marks, 1957). It was subdivided by Oppenoorth and Gerth (1929) into three layers, viz., the *Axinea, Jogjakartae* and *Discocyclina* layers. Marks called these subdivisions formations. The term "layer" is still used in this report, although they actually represent biostratigraphic units, because the subdivisions are based on biologic factors and fossil names are applied; hence they are fossil zones.

It has already been indicated that *Globigerina* marls occur on top of the *Discocyclina* layers and were originally considered Miocene in age (Rothpletz, 1943). However, the planktonic foraminiferal content of part of the samples proves that they are Eocene in age. Therefore an additional layer, viz., *Globigerina* marls, should be supplemented to the existing subdivisions. This additional layer is a new biostratigraphic unit, or a fossil zone, and a formation in Marks' terms. This new unit com-

TABLE 1

Age	Group	Oppenoorth & Gerth (1929)	This Report	Fauna
Upper Eocene	Nanggulan		*Globigerina* marl	Discussed in this report
		Discocyclina layer	*Discocyclina* fm.	*Globorotalia topilensis*
		Jogjakartae layer	*Jogjakartae* fm.	*G. lehneri* *G. centralis*
		Axinea layer	*Axinea* fm.	*Hastigerina micra*, etc.

prises the *Globigerina* marls of Tempel, Blumbang, Kali Santen and the unexposed marls under the alluvial Progo deposit (Table 1).

Zonation by means of planktonic foraminifera is at present not possible here.

AGE AND CORRELATION

All the samples discussed in this paper are considered as one unit, because the species are more or less evenly distributed in them, as can be seen from the distribution chart (text fig. 4). One exception is that *Globorotalia cocoaensis* occurs only in the samples from Kebon Agung; this raises the possibility of the presence of another fossil zone.

The fauna is compared with three reported occurrences: first, the Eocene planktonic fauna of Trinidad, described by Bolli (1957); second, the Eocene fauna of Saipan (Todd, 1957); and, third, the Eocene fauna of Guam (Todd, 1966). Comparison with other faunas has not been attempted, due to the limited literature available.

Eight species recorded in this paper, excluding species of *Hantkenina,* also occur in the Eocene Navet and San Fernando formations of Trinidad. By computing the range of these species with their range in Trinidad, the Nanggulan planktonic fauna can be correlated with the *Globorotalia cocoaensis* zone. The time span is narrowed by the overlapping range of *Globigerina ampliapertura* and *Globigerapsis index*. From this it may safely be concluded that the age of the *Globigerina* marls is Upper Eocene.

The following species occur also in the Eocene of Guam: *Hantkenina alabamensis, Globigerina conglomerata, G. yeguaensis, Globorotalia centralis* and *Globigerapsis index* (Todd, 1966, p. 3, table 1). Three of these are reported to occur also in the Oligocene of Guam. These three species may well range to the Oligocene, but the age assignment is based more upon the restricted Eocene species. Moreover, the presence of Eocene species in Oligocene strata can also be attributed to redeposition from older beds, as was the case with *Hantkenina inflata,* found only as a single specimen in the Oligocene of Guam.

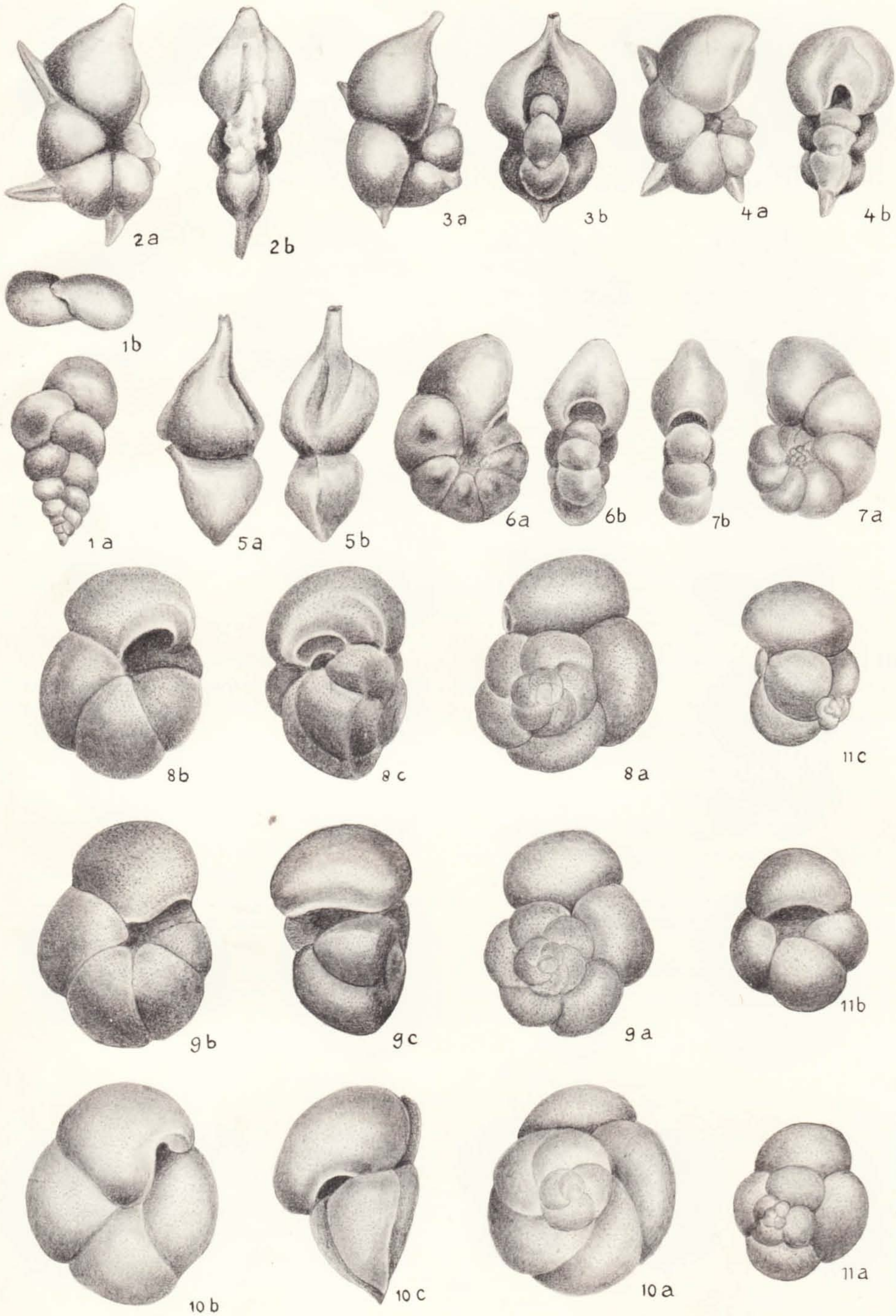
According to Todd (1957) the Eocene fauna of Saipan appears to show a closer affinity to those of equivalent age to the east (America and Europe) than to the west and south (Asia and Indonesia). However, this affinity may well be more apparent than real and merely reflect a better acquaintance with American and European faunas. I believe that the Saipan Eocene fauna should have strong affinities with the Asian and Indonesian fauna, as does the Guam fauna, not only because it is geographically closer, but also because it is still located within the Indo-Pacific faunal province. Five planktonic species occurring in Saipan also occur in Nanggulan. The Eocene *Globigerina* marls of Nanggulan are likely to be correlatable with the Densinyama formation of Saipan.

Because of similarities with other planktonic Eocene species and of the known ranges of these species, the age of the *Globigerina* marls can, therefore, best be interpreted as Upper Eocene.

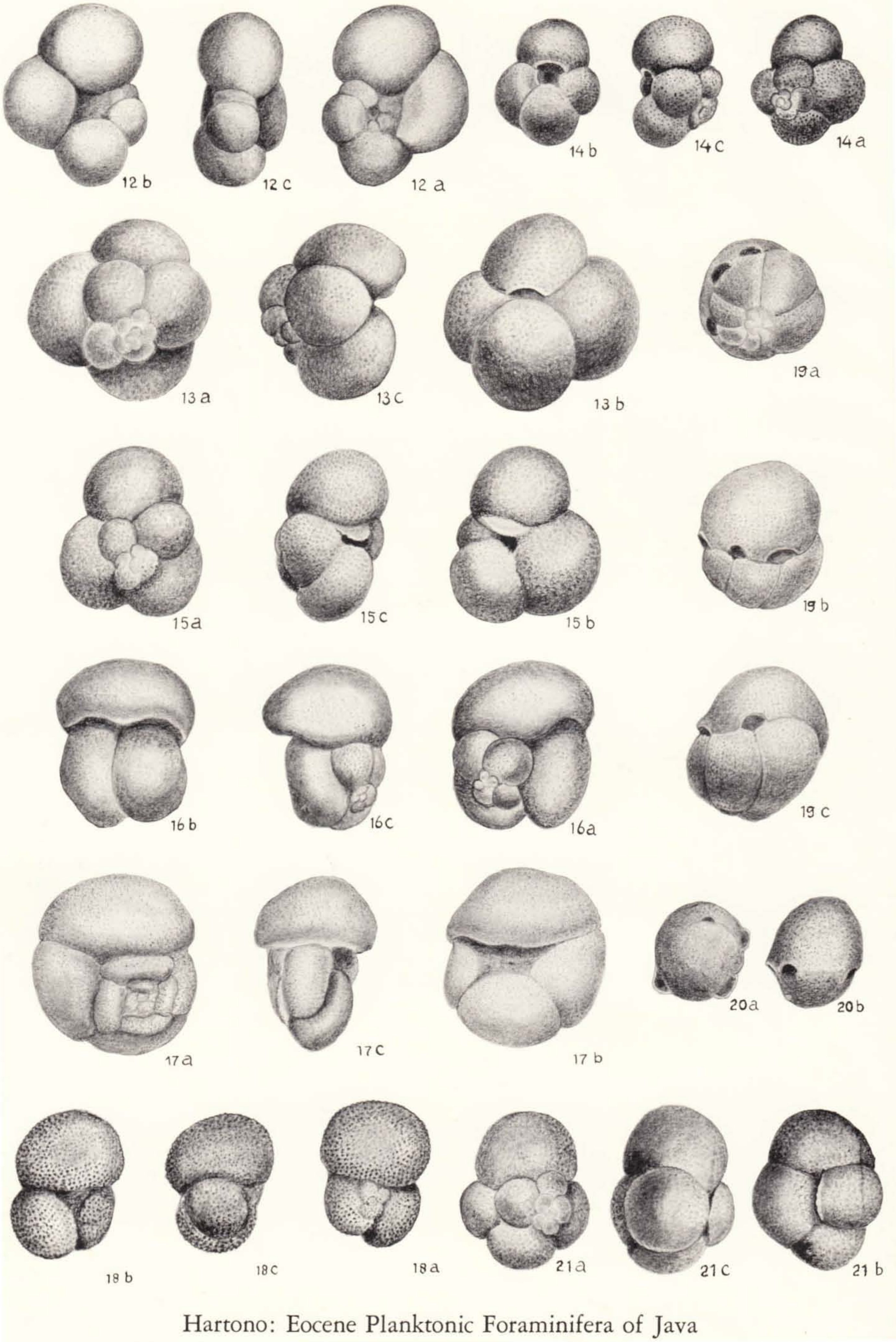
EXPLANATION OF PLATE 20

(Unless otherwise noted, *a,* side view; *b,* peripheral view)

Figs.		Page
1.	*Chiloguembelina martini* (Pijpers), ×100. Hr 6. *a,* front view; *b,* top view.	157
2.	*Hantkenina alabamensis* Cushman, ×55. Hr a7A.	157
3, 4.	*Hantkenina nanggulanensis* n. sp., ×55. 3, Hr 6. 4, Holotype, Kebon Agung.	158
5.	*Hantkenina*? sp., ×55. Hr 6.	158
6, 7.	*Hastigerina micra* (Cole). 6, Hr 35, ×110. 7, Kebon Agung, ×130.	158
8, 9.	*Globorotalia centralis* Cushman and Bermudez, ×60. 8, Kebon Agung. 9, Hr 6. *a, a,* dorsal views; *b, b,* ventral views; *c, c,* peripheral views.	158
10.	*Globorotalia cocoaensis* Cushman, ×60. Kebon Agung. *a,* dorsal view; *b,* ventral view; *c,* peripheral view.	158
11.	*Globigerina ampliapertura* Bolli, ×50. Hr 27A. *a,* dorsal view; *b,* ventral view; *c,* peripheral view.	158



Hartono: Eocene Planktonic Foraminifera of Java



Hartono: Eocene Planktonic Foraminifera of Java

Family and Species	Hr. 35	Hr. 28A	Hr. 27A	Hr. 6	Hr. 6A	Kebon Agung
Family HETEROHELICIDAE						
Chiloguembelina martini				x		
Family HANTKENINIDAE						
Hantkenina alabamensis		x	x	x	x	x
H. nanggulanensis n. sp.	x		x	x	x	x
H. sp.			x	x	x	
Hastigerina micra	x	x		x	x	x
Family GLOBOROTALIIDAE						
Globorotalia centralis	x	x	x	x	x	x
G. cocoaensis						x
Family ORBULINIDAE						
Globigerina ampliapertura	x		x	x	x	
G. compressa			x	x	x	
G. conglomerata		x	x	x	x	
G. aff. *linaperta*				x		
G. parva			x	x	x	
G. quadritriloculinoides				x		
G. yeguaensis	x	x	x	x	x	
G. sp.		x				
Globigerapsis index			x	x	x	
Catapsydrax pera				x	x	

TEXT FIGURE 4
Distribution of species in the samples

SYSTEMATIC DESCRIPTIONS

(The systematic arrangement of genera in this report follows the classification of Bolli, Loeblich and Tappan, 1957).

Family HETEROHELICIDAE Cushman, 1927
Genus **Chiloguembelina** Loeblich and Tappan, 1956
Chiloguembelina martini (Pijpers), 1933

Plate 20, figure 1

Textularia martini PIJPERS, 1933, Geog. Geol. Med., Utrecht, Netherlands, No. 6, p. 57, figs. 6-10 (*Vide* Ellis and Messina, Catalogue of Foraminifera).

Chiloguembelina martini (Pijpers), BECKMANN, 1957, U. S. Natl. Mus. Bull. 215, p. 89, pl. 21, fig. 14.

This species is found only in sample Hr 6; 12 fossils were picked.

Family HANTKENINIDAE Cushman, 1927
Subfamily HANTKENININAE Cushman, 1927
Genus **Hantkenina** Cushman, 1924
Hantkenina alabamensis Cushman, 1924

Plate 20, figure 2

Hantkenina alabamensis Cushman, BECKMANN, 1953, Eclogae Geol. Helv., v. 46, p. 395, pl. 26, fig. 6; BOLLI, LOEBLICH and TAPPAN, 1957, U. S. Natl. Mus. Bull. 215, p. 26, pl. 2, fig. 8a, b.

The distribution of this species in Nanggulan is widespread; it occurs in all samples except sample Hr 35.

EXPLANATION OF PLATE 21

(Unless otherwise noted, *a*, dorsal view; *b*, ventral view; *c*, peripheral view)

FIGS.		PAGE
12.	*Globorotalia compressa* (Plummer) ×50. Hr 27A. *a, b*, side views; *c*, peripheral view.	158
13.	*Globigerina conglomerata* Schwager, ×50. Hr 27A.	159
14.	*Globigerina parva* Bolli, ×55. Hr 35.	159
15.	*Globigerina yeguaensis* Weinzierl and Applin, ×55. Hr 35.	159
16.	*Globigerina quadritriloculinoides* Chalilov, ×55. Hr 37.	159
17.	*Globigerina* sp., ×88. Hr 28A.	159
18.	*Globigerina* aff. *linaperta* Finlay, ×46. Hr 6.	159
19, 20.	*Globigerapsis index* (Finlay), Hr 6. 19, ×60. *a*, dorsal view with a clear spiral; *b, c*, views showing supplementary apertures. 20, ×55. *a*, dorsal view with indistinct spiral; *b*, peripheral view.	159
21.	*Catapsydrax pera* (Todd), ×60. Hr 6A.	159

Hantkenina nanggulanensis n. sp.

Plate 20, figures 3, 4

Hantkenina bermudezi Thalmann, Todd, 1957, U. S. Geol. Survey Prof. Paper 280-H, p. 304, pl. 70, fig. 13.

Test planispiral, bilaterally symmetrical; especially in the later chambers the periphery is lobate. Chambers inflated, five or six in the last coil, each provided with a short spine located anteriorly. Sutures distinct, depressed and straight. Wall smooth, calcareous and finely perforate. Aperture relatively large, more or less triangular in shape, with blunt angles, its base at the base of the last-formed chamber at the apertural face. The aperture is provided with a lateral liplike projection. Largest diameter of the holotype, 0.47 mm.

Holotype (catalog number P.D. 5104) deposited in the Paleontological collection of the Geological Survey of Indonesia, Bandung. Paratypes at U. S. National Museum, Washington.

This species is more inflated than specimens of *Hantkenina alabamensis* Cushman, which are also present in the marl samples. It differs from *H. bermudezi* Thalmann (which is also inflated) in lacking supplementary apertures. This species differs from *H. inflata* Howe [figured by Todd (1966, pl. 8, fig. 8) from the Oligocene of Guam with supplementary apertures] in its lack of supplementary apertures. This species resembles Mohler's figure in Van Bemmelen (1949, The Geology of Indonesia, Vol. IA, p. 90, text fig. 26, *Hantkenina* sp. 2). The present species is probably conspecific with this species.

The known geographical distribution of this species is Nanggulan, Southeast Kalimantan, and Saipan.

?Hantkenina sp.

Plate 20, figure 5

Specimens referred to ?*Hantkenina* sp. are present in the samples from Tempel and Blumbang. They consist of two chambers only, the earlier chambers absent. Apertures are obscure. They are referred to this genus because of the presence of a spine protruding from each chamber at the periphery and also because of the general outline of the chambers.

Subfamily HASTIGERININAE Bolli, Loeblich and Tappan, 1957

Genus **Hastigerina** Thomson, 1876

Hastigerina micra (Cole), 1927

Plate 20, figures 6, 7

Nonion micrus Cole, 1927, Bull. American Paleontology, v. 14, No. 51, p. 22, pl. 5, fig. 12 (*Vide* Ellis and Messina, Catalogue of Foraminifera).

Nonion micrum Cole, Todd, 1957, U. S. Geol. Survey Prof. Paper 280-H, p. 267 (table), pl. 65, fig. 26.

Hastigerina micra (Cole), Bolli, 1957, U. S. Natl. Mus. Bull. 215, p. 161, pl. 35, figs. 1a-2b.

This seems to be a very common and widespread Eocene species; in Nanggulan it occurs in the *Globigerina* marls as well as in the *Discocyclina* layers.

Family GLOBOROTALIIDAE Cushman, 1927

Genus **Globorotalia** Cushman, 1927

Globorotalia centralis Cushman and Bermudez, 1937

Plate 20, figures 8, 9

Globorotalia centralis Cushman and Bermudez, 1937, Contr. Cushman Lab. Foram. Res., v. 13, pt. 1, p. 26, pl. 2, figs. 62-65 (*Vide* Ellis and Messina, Catalogue of Foraminifera). Todd, 1957, U. S. Geol. Survey Prof. Paper 280-H, p. 268 (table 1), pl. 71, figs. 1, 3. Bolli, 1957, U. S. Natl. Mus. Bull. 215, p. 169, pl. 39, figs. 1a-4. Todd, 1966, U. S. Geol. Survey Prof. Paper, 403-I, p. 33, pl. 3, fig. 1

This species is the most common in the samples; it occurs also in the *Discocyclina* layers.

Globorotalia cocoaensis Cushman, 1928

Plate 20, figure 10

Globorotalia cocoaensis Cushman, 1928, Contr. Cushman Lab. Foram. Res., v. 4, pt. 3, no. 64, p. 75, pl. 10, fig. 3 (*Vide* Ellis and Messina, Catalogue of Foraminifera). Bolli, 1957, U. S. Natl. Mus. Bull. 215, p. 169, pl. 39, figs. 5a-7b.

This species occurs only in the samples from Kebon Agung. Its restricted occurrence might make it important for future zonation.

Globorotalia compressa Plummer, 1926

Plate 21, figure 12

Globigerina compressa Plummer, 1926, Texas Univ. Bull., No. 2644, p. 135, pl. 18, fig. 11 (*Vide* Ellis and Messina, Catalogue of Foraminifera).

Globanomalina simplex Haque, 1956, Mem. Geol. Survey Pakistan, Pal. Pakistanica, v. 1, p. 149, pl. 30, fig. 2.

The aperture of our specimens is not clear. The general outline of the specimens agrees well with that of the species figured by Plummer (1926) and Haque (1956).

Family ORBULINIDAE Schultze, 1854

Subfamily GLOBIGERININAE Carpenter, 1862

Genus **Globigerina** d'Orbigny, 1826

Globigerina ampliapertura Bolli, 1957

Plate 20, figure 11

Globigerina ampliapertura Bolli, 1957, U. S. Natl.

Mus. Bull. 215, p. 108, pl. 22, figs. 4a-7b; p. 36, fig. 8a-c. TODD, 1966, U. S. Geol. Survey Prof. Paper, 403-I, p. 33, pl. 8, fig. 7.

Some specimens having a somewhat high spire are also grouped with this species.

Globigerina conglomerata Schwager, 1866

Plate 21, figure 13

Globigerina conglomerata Schwager, BECKMANN, 1953, Eclogae Geol. Helv., v. 46, No. 2, p. 391, pl. 25, figs. 6-9. TODD, 1966, U. S. Geol. Survey Prof. Paper, 403-I, p. 33, pl. 2, fig. 5, pl. 8, fig. 5, pl. 14, fig. 1.

Globigerina parva Bolli, 1957

Plate 21, figure 14

Globigerina parva BOLLI, 1957, U. S. Natl. Mus. Bull. 215, p. 108, pl. 22, fig. 14a-c; p. 164, pl. 36, fig. 7a-c.

Globigerina quadritriloculinoides Chalilov, 1956

Plate 21, figure 16

Globigerina quadritriloculinoides CHALILOV, 1956, Akad. Nauk, Azerb., S.S.R., Inst. Geol., Baku, Trudy, v. 17, p. 237, pl. 1, fig. 5 (*Vide* Ellis and Messina, Catalogue of Foraminifera).

The apertures of the present specimens are not clear, because they are covered with secondary calcite material; their position is apparently umbilical. This species is almost similar to *Globigerina boweri* Bolli; it differs in the apertural features, which in our specimens, although not clear, are not arched. Both have a quadrangular test.

Globigerina yeguaensis Weinzierl and Applin, 1929

Plate 21, figure 15

Globigerina yeguaensis WEINZIERL and APPLIN, 1929, Journal Paleontology, v. 3, p. 408, pl. 43, fig. 1. BOLLI, 1957, U. S. Natl. Mus. Bull. 215, p. 163, pl. 35, figs. 14a-15c. TODD, 1966, U. S. Geol. Survey Prof. Paper 403-I, p. 33, pl. 2, fig. 6, pl. 8, fig. 9.

Globigerina aff. **linaperta** Finlay, 1939

Plate 21, figure 18

Globigerina linaperta FINLAY, 1939, Trans. Proc. Roy. Soc. New Zealand, v. 69, pt. 1, p. 125, pl. 13, figs. 54-57.

Only two specimens of this species were found. It is a *Globigerina* of the *triloba* type, but with an indistinct aperture; moreover, supplementary apertures cannot be observed. This species is probably closely related to *Globigerina linaperta* Finlay.

Globigerina sp.

Plate 21, figure 17

Test with flattened dorsal side, umbilical side convex, low, except for the last chamber. Chambers subangular, the last four increase rapidly in height, constituting the main size of the test. Sutures depressed, on spiral side oblique, on umbilical side radial. Umbilicus open and filled with secondary deposit. Aperture not clear.

Subfamily ORBULININAE Schultze, 1854

Genus **Globigerapsis** Bolli, Loeblich and Tappan, 1957

Globigerapsis index (Finlay), 1939

Plate 21, figures 19, 20

Globigerinoides index FINLAY, 1939, Trans. Roy. Soc. New Zealand, v. 69, p. 125, pl. 14, fig. 85-88.

Globigerinoides semiinvolutus KEIJZER, 1945, Geogr. Geol. Med., Utrecht Univ., ser. 2, No. 6, p. 206, pl. 4, fig. 58.

Globigerapsis index (Finlay), BOLLI, 1957, U. S. Natl. Mus. Bull. 215, p. 165, pl. 36, figs. 14a-18b.

Subfamily CATAPSYDRACINAE Bolli, Loeblich and Tappan, 1957

Genus **Catapsydrax** Bolli, Loeblich and Tappan, 1957

Catapsydrax pera (Todd), 1957

Plate 21, figure 21

Globigerina pera TODD, 1957, U. S. Geol. Survey Prof. Paper 280-H, p. 301, pl. 70, figs. 10-11.

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CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
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RECENT LITERATURE ON THE FORAMINIFERA

Below are given some of the more recent works on the Foraminifera that have come to hand.

ANDERSON, JOHN B. Ecology of Foraminifera from Mississippi Sound and surrounding waters.—Jour. Alabama Acad. Sci., v. 39, No. 4, Oct. 1968, p. 261-269, pls. 1, 2 (maps), text figs. 1-5 (graphs).—Six biofacies corresponding with ranges in salinity and fluctuations of salinity.

ANGLADA, ROGER, and MAGNÉ, JEAN. *Taxyella*, a new genus of foraminifer from the Miocene of southeast France.—Micropaleontology, v. 15, No. 3, July 1969, p. 367-372, pls. 1, 2.—A brackish-water genus similar to *Helenina*.

ARNAUD-VANNEAU, ANNIE. Étude statistique et morphologique des Orbitolines du synclinal d'Autrans (Vercors septentrional).—Géologie Alpine, Lab. Géol. Fac. Sci. Grenoble, tome 44, 1968, p. 27-48, text figs. 1-12 (columnar sections, drawings, graphs, diagrams).

ASANO, KIYOSHI, INGLE, JAMES C., and TAKAYANAGI, YOKICHI. Neogene planktonic foraminiferal sequence in northeastern Japan.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 14-25, text figs. 1-5 (map, depth range diagram, paleobathymetric curves, range chart, graphs).—Coiling directions of *Globigerina pachyderma* and percentages of certain species are used to interpret paleotemperatures and age of beds.

BANDY, ORVILLE L. Cycles in Neogene paleoceanography and eustatic changes.—Palaeogeography, Palaeoclimatology, Palaeoecology, v. 5, 1968, p. 63-75, text figs. 1-4 (diagrams, graph).—Possibility of correlation in the later Neogene by means of expansions of polar planktonic faunas accompanied by lowered sea level is discussed.

Relationships of Neogene planktonic Foraminifera to paleoceanography and correlation.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 46-57, text figs. 1-5 (diagrams).—Five groups of planktonics, defined by their species populations and coiling directions, correspond to 5 major water masses (from less than 2°C to more than 18°C summer surface temperatures). Marine faunas in temperate areas reflect invasions of cold or warm faunas as cyclic fluctuations and these cycles may be used in worldwide correlation.

BANERJI, RANJIT K. Late Cretaceous foraminiferal biostratigraphy of Pondicherry area, South India, *in* Cretaceous-Tertiary formations of South India.—Geol. Soc. India Mem. No. 2, 1968, p. 30-49, text figs. 1-4 (correl. charts, range chart, evolution diagram).—Three zones and 2 subzones, from Santonian to early Maestrichtian, are recognized.

Statistical study of foraminiferal fauna from the lower Ariyalur stage (Late Cretaceous) of Vridhachalam area, South India, *in* Cretaceous-Tertiary formations of South India.—Geol. Soc. India Mem. No. 2, 1968, p. 50-65, pl. 1, text figs. 1-15 (graphs), tables 1-4.—Interpretations of depositional conditions based on Recent analogues of the Cretaceous species.

BANG, INGER. Planktonic Foraminifera and biostratigraphy of the type Danian.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 58-65, pls. 1-4, text figs. 1-4 (maps, columnar sections, range chart).—Study based on submarine boreholes in Storebaelt. Four zones recognized. One new species of *Globigerina* and a new subspecies of *Globoconusa* described.

BARBIERI, FRANCESCO. Planktonic Foraminifera in western Emily Pliocene (North Italy).—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 66-80, pl. 1, text figs. 1-3 (map, diagram, correl. diagram).—Seven species and their ranges between Tabianian and Calabrian.

BAYLISS, DERYK D. The distribution of *Hyalinea balthica* and *Globorotalia truncatulinoides* in the type Calabrian.—Lethaia, v. 2, No. 2, April 15, 1969, p. 133-143, text figs. 1-5 (map, columnar sections, stereoscan photos), table 1.—*G. truncatulinoides* appears later than *Hyalinea*, thus doubt is cast on these species as markers for the base of the Pleistocene.

BÉ, ALLAN W. H. Microstructural evidence of the close affinity of *Globigerinella* Cushman to *Hastigerina* Thomson.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 89-91, pls. 1-4.—Triradiate spines occur on both genera, thus the placing of the two genera

under *Hastigerina* is warranted on morphologic grounds. But *Hastigerina* is cytologically different in possessing a frothy, gelatinous capsule of bubbles that completely surrounds the shell.

Planktonic Foraminifera, *in* Distribution of selected groups of marine invertebrates in waters south of 35° S latitude.—Antarctic Map Folio Series, Am. Geogr. Soc., Folio 11, 1969, p. 9-12, pls. 1, 2, text figs. 1, 2 (distrib. map, graph), tables 1, 2.—Plotted on maps are absolute and relative abundances for *Globigerina bulloides, G. pachyderma, G. quinqueloba, Globigerinita glutinata, Globorotalia inflata,* and *G. truncatulinoides,* and coiling percentages for *G. pachyderma.* Areas studied are in the Western Hemisphere.

BECKMANN, JEAN-PIERRE, EL-HEINY, IHAB, KERDANY, MUSTAFA, T., SAID, RUSHDI, and VIOTTI, CARLO. Standard planktonic zones in Egypt.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 92-103, text fig. 1 (map), table 1.—From Lower Cretaceous to Miocene. Occurrence indicated in regions of unstable shelf, stable shelf, and Gulf of Suez.

BERGGREN, W. A. Biostratigraphy and planktonic foraminiferal zonation of the Tertiary system of the Sirte Basin of Libya, North Africa.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 104-120, text figs. 1-4 (map, zonation chart, range charts).—Application of the West Indian zonation to Libya.

Paleogene biostratigraphy and planktonic Foraminifera of northern Europe.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 121-160, pls. 1-8, text figs. 1-7 (maps, check lists, diagrams), tables 1-3.—Attempt at correlation between northern European biostratigraphy and zonation of low latitude regions. Includes illustrations and brief discussions of about 30 species.

Rates of evolution in some Cenozoic planktonic Foraminifera.—Micropaleontology, v. 15, No. 3, July 1969, p. 351-365, text figs. 1-13 (age charts, diagram, graphs, evolution diagram), tables 1-8.—With radiometric dates for the Cenozoic time scale and graphs showing when species originated and became extinct, it is possible to estimate the span of a species and its rate of evolution, and the evolutionary radiation and extinction of a genus or morphologic group. Undisturbed deep-sea core sections make it possible to plot against time the evolution from one species into another in the Pleistocene, such as that of *Globorotalia tosaensis* into *G. truncatulinoides.*

BERTHOIS, L., CROSNIER, A., and LE CALVEZ, Y. Contribution a l'étude sédimentologique du plateau continental dans la Baie de Biafra.—Cahiers O. R. S. T. O. M., ser. Oceanographie, v. 6, No. 3-4, 1968, p. 55-86, text figs. 1-8 (maps, graphs, drawings), tables 1-11.—Quantitative analysis of Foraminifera and summary of their ecology.

BHALLA, S. N., and KHAN, V. G. Foraminifera from the Kateru Inter-Trappean beds (Lower Eocene), India.—Jour. Paleontology, v. 43, No. 4, July 1969, p. 1019-1028, pl. 125, text figs. 1, 2 (map, columnar section).—Eight species, indicating a shallow, warm, near-shore, brackish environment.

BIGNOT, G., and LE CALVEZ, Y. Contribution à l'étude des Foraminifères planctoniques de l'Éocène du Bassin de Paris.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 161-166, pls. 1, 2, range chart.—Illustrations of 9 species having restricted ranges in Cuisian, Lutetian, and Bartonian,

BILELO, MARIA M. Fusulinidae of the Winchell Formation (Pennsylvanian), North-central Texas.—Jour. Paleontology, v. 43, No. 3, May 1969, p. 688-704, pls. 85-87, text figs. 1, 2 (map, columnar sections), table 1.—Six species, 3 new.

BIZON, J.-J., and G., and HORSTMANN, G. Les Foraminifères planctoniques du Miocène de l'Île de Zanthe (Grèce Occidentale).—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 190-198, pl. 1, text figs. 1, 2 (range charts).—Illustrations of 10 species.

BIZON, GERMAINE, and MIRKOU, RHÉA. Les Foraminifères planctoniques du Pliocène de l'Île de Zanthe (Grèce Occidentale).—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 179-189, pl. 1, text figs. 1-4 (map, range charts).—Illustrations of 15 species.

BLOW, WALTER H. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy.—Internat. Conf. on Planktonic Microfossils, 1st, Geneva, 1967, Proc. [Leiden, E. J. Brill and Co.], v. 1, 1969, p. 199-422, pls. 1-54, text figs. 1-43 (range charts, correl. charts, stratigraphic sections, check lists, diagrams).—Zones P.13 to P.20 and N.1 to N.23 are discussed in detail and ranges of many planktonic species shown. Comparisons are made with other zonations and numerous stratigraphic sections are placed

within the planktonic zonation. Six new species and 13 new subspecies are described.

BRÖNNIMANN, PAUL, and KOEHN-ZANINETTI, LOUISETTE. *Involutina hungarica* Sido et *Involutina farinacciae*, n. sp., deux Involutines post-triasiques, et remarque sur *Trocholina minima* Henson.—Paläont. Zeitschr., Stuttgart, Band 43, Heft 1/2, April 1969, p. 72-80, pls. 7-9, text figs. 1, 2 (drawings).

CEBULSKI, DONALD E. Foraminiferal populations and faunas in Barrier-Reef tract and lagoon, British Honduras.—Am. Assoc. Petr. Geol., Mem. 11, Feb. 1969, p. 311-328, pls. 1-3, text figs. 1-12 (maps, occurrence charts, graphs). —Quantitative records and illustrations of 28 species (living and total) from main reef, marginal reef, reef channel, and lagoon. Study based on 89 sediment samples.

CIFELLI, RICHARD. Radiation of Cenozoic planktonic Foraminifera.—Systematic Zoology, v. 18, No. 2, June 1969, p. 154-168, text figs. 1-8 diagrams, range chart).—Interesting summary paper. Two major radiations from globigerine stocks followed severe reductions in diversity; one followed the reduction at the close of the Cretaceous, the other followed the reduction during the Mid-Tertiary. Distributional patterns were repeated, the Neogene radiation was essentially a repetition of the Paleogene one, with only the pulleniatine form not previously known. By analogy with distribution of morphotypic groups in the present oceans, times of reduction are interpreted as times of uniformly cool oceans lacking thermal barriers. However, the Pleistocene cooling did not result in reduction in diversity but only in shifted boundaries of species and in the appearance of the conical globorotalid.

CONIL, RAPHAEL, and PAPROTH, EVA. Mit Foraminiferen gegliederte Profile aus dem nordwestdeutschen Kohlenkalk und Kulm, mit einem paläontologischen Anhang, by RAPHAEL CONIL and MAURICE LYS.—Decheniana, Bonn, Band 119, Heft 1/2, Jan. 1968, p. 51-94, pls. 1-6, text figs. 1-3 (columnar sections, diagram, map), tables 1-4.—A few Carboniferous Foraminifera reported and illustrated in thin section, *Propermodiscus liebusi* new.

DHILLON, D. S. Three new species of Foraminifera from Malaysia.—Jour. Paleontology, v. 43, No. 3, May 1969, p. 767-770, text fig. 1 (outline drawings).—Three arenaceous species from Recent sediments in the Labuk Estuary, Sabah.

DUQUE CARO, HERMANN. Observaciones generales a la bioestratigrafia y geologia regional en los departamentos de Bolivar y Cordoba.—Univ. Industrial Santander, Bol. Geol., No. 24, May 1968, p. 71-87, text figs. 1-3 (geol. map, correl. charts).—Eight planktonic foraminiferal assemblages between Late Cretaceous and Miocene.

DVORAK, J., and CONIL, R. Foraminifères du Dinantien de Moravie.—Bull. Soc. Belge Geol., tome 77, fasc. 1, 1968 (Jan. 31, 1969), p. 75-88, pls. 1-3.—Eight species.

EMILIANI, CESARE. A new paleontology.—Micropaleontology, v. 15, No. 3, July 1969, p. 265-300, pls. 1-22, text figs. 1-7 (graphs, micrographs), tables 1-3.—Examples of groups of phenotypes of the eight planktonic species commonly found in various levels in 3 Pleistocene deep-sea cores from the Equatorial and North Atlantic, representing about 175,000 years. An idealized concept to replace the traditional holotype.

FOURY, GENEVIÈVE. Le Crétacé Inférieur des Alpilles. Contribution a l'étude stratigraphique et micropaléontologique.—Geobios, Lyon, No. 1, 1968, p. 119-163, pls. 18-20, text figs. 1-12 (map, columnar sections, graphs, diagrams). —Six new species in the Lituolacea, 2 in new genera: *Alpillina* n. gen. (generotype *A. antiqua* n. sp.) and *Eygalierina* n. gen. (generotype *E. turbinata* n. sp.).

FUCHS, WERNER. Eine bemerkenswerte, tieferes Apt belegende Foraminiferenfauna aus den konglomeratreichen Oberen Rossfeldschichten von Grabenwald (Salzburg).—Verhandl. Geol. Bundes., Heft 1-2, 1968, p. 87-97, pls. 1-4, text fig. 1 (map).—Illustrations of about 50 species.

FUNNELL, B. M., FRIEND, J. K., and RAMSAY, A. T. S. Upper Maestrichtian planktonic Foraminifera from Galicia Bank, west of Spain.—Palaeontology, v. 12, pt. 1, April 1969, p. 19-41, pls. 1-5, text figs. 1-22 (drawings).—Twenty-one species.

GHEORGIAN, M., IVA, MARIANA, and GHEORGHIAN, MIHAELA. *Cribrononion dollfusi* (Cushman) dans le Miocène de Transylvanie (French résumé of Rumanian text).—Studi si Cercetari Geol. Geofiz. Geograf., ser. Geol., tom. 13, No. 2, 1968, p. 481-490, pls. 1-3, text fig. 1.—A new subspecies, *pseudoelphidiformis*, described.

GUDINA, V. I. Morskoi Pleistothen Sibirskikh Ravnin. Foraminifery Eniseiskogo Severa.—Akad. Nauk SSSR, Sibirskoe Otdel., Trudy Instit. Geol. i Geofiz., vyp. 63, 1969, p. 1-80, pls. 1-16, text figs. 1-18 (map, drawings, graphs), tables 1, 2.—Forty-five species, 9 new.

GUDINA, V. I., SAIDOVA, KH. M., and TROITHKAJA, T. S. K Ekologii i Sistematike Islandiellid (Foraminifera).—Doklady Akad. Nauk SSSR, tom. 182, No. 1, 1968, p. 225-227, text fig. 1 (drawings).—*Cassandra* Gudina and Saidova,

gen. n. (type species *Cassidulina inflata* Gudina 1966).

GUTIERREZ DOMECH, M. R. Una localidad cotipo de la formacion Consuelo en la provincia de La Habana, Cuba.—Instit. Nac. Recursos Hidraulicos, Publ. Espec. No. 7, 1969, p. 31-52, pls. 1-4.—Nine species, 8 subspecies, and 3 indeterminate forms from the Eocene Consuelo Formation.

HANSEN, HANS JORGEN. On the biostratigraphical age of the lower Selandian of Denmark.—Bull. Geol. Soc. Denmark, v. 18, pts. 3, 4, 1968, p. 277-284, figs. 1-6 (electroscan micrographs).—Belongs in the *Globorotalia angulata* biozone.

X-ray diffractometer investigations of a radiate and a granulate Foraminifera.—Bull. Geol. Soc. Denmark, v. 18, pts. 3-4, 1968, p. 345-348, text figs. 1-3 (photomicrographs, graphs).—*Polymorphina* sp. and *Melonis scaphum* are used.

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(England) and relationship between their distribution and sedimentation.—Revue de Micropaléontologie, v. 11, No. 4, March 1969, p. 222-232, text figs. 1-7 (maps).—A total of 104 species is found. About a third of them, those having abundances over 2%, are listed and their areal distributions plotted. Study based on 67 shore samples.

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Tertiary formations of South India.—Geol. Soc. India Mem. No. 2, 1968, p. 18-29, pls. 1-4, tables 1, 2.—Fourteen species and subspecies, none new, in two zones: Campanian and lower Maestrichtian.

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Eocene planktonic Foraminifera from the Garo Hills, Assam, India.—Micropaleontology, v. 15, No. 3, July 1969, p. 325-350, pls. 1-3, text figs. 1, 2 (drawings), tables 1, 2.—Thirty-one species and subspecies, none new, from 2 upper Eocene samples and 3 middle Eocene ones, correlated with the planktonic zonation.

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