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MID-TERTIARY SMALLER FORAMINIFERA FROM A BORE AT HEYWOOD, VICTORIA, AUSTRALIA

A Thesis

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BIOGRAPHICAL SKETCH

The author was born on November 22, 1937, at Bacchus Marsh, Victoria, Australia. He attended Box Hill and Melbourne High Schools, and completed his secondary education in 1954. He entered the University of Melbourne on a Commonwealth Government Scholarship in March, 1955, and received the B.Sc. degree in February, 1958.

From March, 1958 until August, 1961, he was employed as a geologist in the Underground Water Section of the Geological Survey Branch of the Victorian Department of Mines.

He entered Cornell University in September, 1961 as a teaching graduate assistant in the Department of Geology, a position that was held for the next three years. He was the recipient of two grants from the William F. E. Gurley Foundation for Paleontology of Cornell to study the foraminiferal collections at the U. S. National Museum, Washington, D. C., and a Summer Scholarship from Cornell that enabled him to take a course in Marine Ecology at the Marine Biological Laboratory, Woods Hole, Massachusetts during the summer of 1963.

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ABSTRACT

Mid-Tertiary foraminiferal faunas comprising 123 benthonic and 20 planktonic species from 12 cores which range in depth from 191 to 1355 feet in a bore at Heywood, Victoria, Australia, are analyzed. All of the planktonic species and certain of the benthonic species are discussed and figured.

The strata encountered represent a typical marine transgression. The stratigraphically older sediments were deposited in a comparatively shallow-water (20 - 60 m.) environment, whereas the younger sediments accumulated in a deeper-water (up to 95 m.) situation. The benthonic Foraminifera reflect these environmental changes. Abundant planktonic faunas throughout the sequence, however, indicate that connection with the ocean was maintained throughout the depositional cycle.

The sequence is correlated with the Janjukian - Bairnsdalean Stages of the Australian Tertiary, and a broad correlation by means of planktonic Foraminifera is made with the *Globigerina ampliapertura* - *Globorotalia fohsi barisanensis* Zones of the Caribbean region. Such correlation is difficult as the Heywood planktonic fauna is dominated by cool-water species and only a few of the warm-water Caribbean species are present.

The Oligocene - Miocene sequence at Lakes Entrance in eastern Victoria contains a warm-water planktonic foraminiferal fauna in contrast to the cool-water faunas of the western Victorian sequence, found in the

ABSTRACT (continued)

Heywood bore. An oceanic circulation at that time, similar to that existing today off the southern Australian coast, is postulated as the cause of the faunal differentiation between the two areas.

INTRODUCTION

As the foraminiferal faunas from the marine part of the mid-Tertiary sequence of southwestern Victoria have not been described adequately, certain faunas obtained from 12 cores in a well, known as Bore 10, drilled in the Township of Heywood, Normanby County, by the Victorian Department of Mines in early 1961 are analyzed.

Heywood is located approximately 17 miles north of Portland (Fig. 1), and is in the depositional basin known as the Portland Sunklands, a sub-basin of the more extensive Otway Basin as defined by the Bureau of Mineral Resources, Geology and Geophysics (Commonwealth of Australia, 1960, p. 32, pl. 1). The Portland Sunklands are separated from the Gambier Sunklands to the west by the Dartmoor Ridge, a geotectonic swelling originating in the basement rocks and active at different times during the Tertiary (Boutakoff, 1952). McQueen (1961) stated that the Portland Sunklands extend eastward to Cape Otway (Fig. 1). However, deep-seated structures such as the Mount Eccles Fault (Boutakoff and Sprigg, 1953) or other pre-Tertiary basement faults inferred from geophysical evidence (McQueen, 1961) may restrict the eastward extent of the Portland Sunklands, and thereby form more, as yet unnamed, depositional subbasins within the Victorian part of the Otway Basin.

Tertiary deposition in the Otway Basin began in the Paleocene or Eocene with a thick sequence of largely nonmarine carbonaceous siltstones and quartz sands, ranging in thickness from 450 to more than 5000 feet (McQueen, 1961, p. 11). This was followed in Oligocene and Miocene times

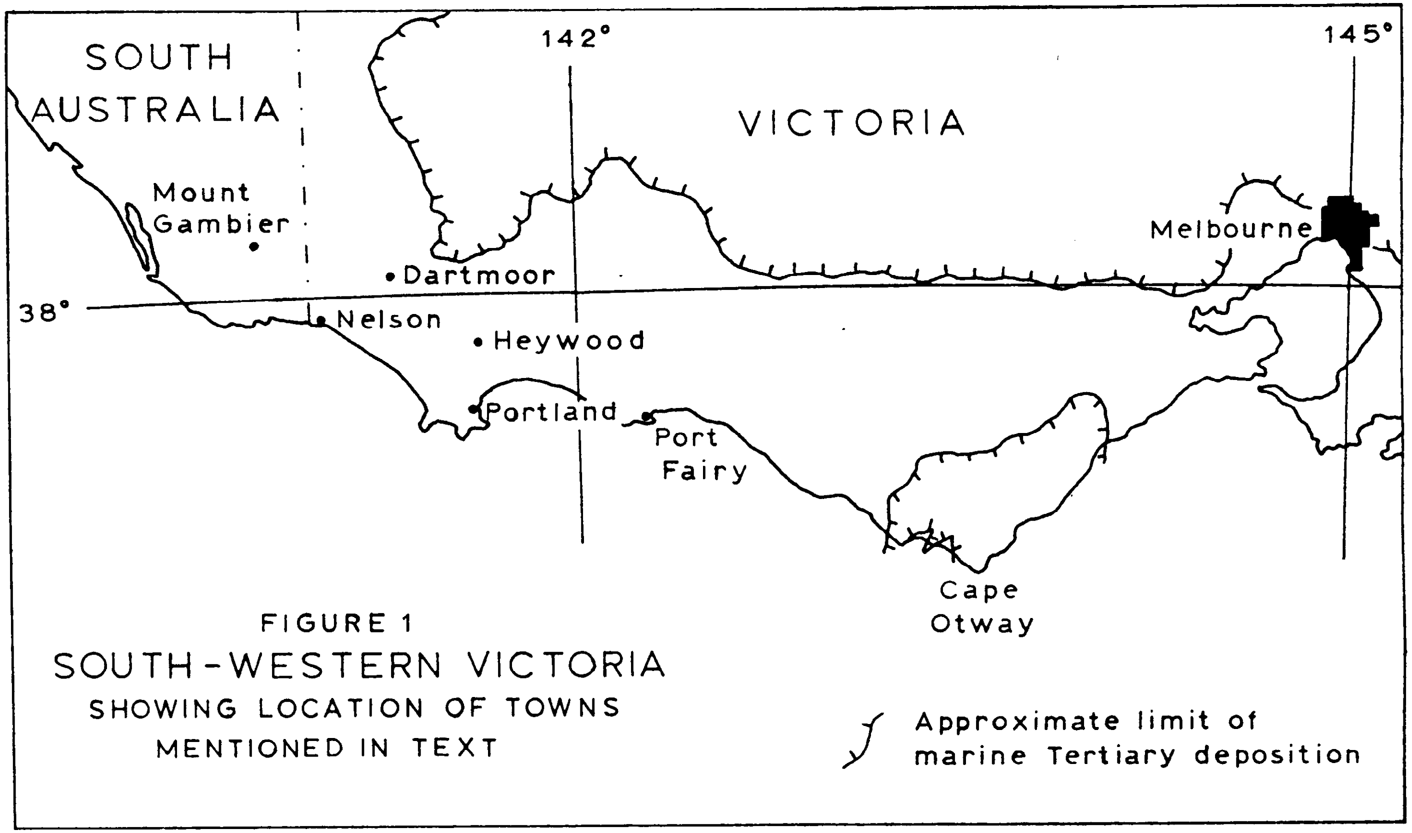

FIGURE 1
SOUTH-WESTERN VICTORIA
SHOWING LOCATION OF TOWNS
MENTIONED IN TEXT

by a marine transgression during which from 1180 to over 2800 feet of limestones and marls were deposited.

Although a number of wells have penetrated this thick Tertiary sequence in southwestern Victoria, little has been published on the paleontology of the subsurface rocks. Chapman (1925) listed a fauna of Foraminifera, worms, polyzoans, pelecypods, and gastropods comprising 25 species from cores between 110 and 970 feet in a well drilled at Port Fairy (Fig. 1) and assigned a "Janjukian or Miocene age" to this section. Crespin (1954) published lithologic descriptions and foraminiferal faunal lists of samples from depths between 108 and 7299 feet in a well drilled at Nelson, near the South Australian - Victorian border (Fig. 1). She recognized Janjukian fossils in the upper part of the section, but the section below 976 feet was assigned to the lower and middle Eocene. Baker and Cookson (1955) revised Crespin's conclusion and correlated the sediments below approximately 4500 feet with the Upper Cretaceous on the basis of the contained microflora. Douglas (1961) made some broad correlations of Lower Tertiary and Mesozoic subsurface rocks from a number of wells in the Western District of Victoria, using dinoflagellates (Deflandreidae), but his samples did not include any from the upper carbonate part of the sequence.

STRATIGRAPHY

A lithologic and stratigraphic summary of the Heywood No. 10 Bore, compiled from information in the files of the Victorian Department of Mines (unpublished reports of R. C. Glenie and the writer), is given in Table 1. The twofold subdivision of the Gambier limestone was proposed by Glenie and Reed (1961, p. 42) from the subsurface section observed in Bore No. 3 drilled at Portland by the Victorian Department of Mines. The other stratigraphic units shown were defined by Boutakoff and Sprigg (1953) with the exception of the Belfast mudstone. This unit was named by geologists of the Frome-Broken Hill Company Pty. Ltd. and was applied to Cretaceous marine sediments first found in Mines Department Belfast No. 4 Bore at Port Fairy (McQueen, 1961, p. 11). Ludbrook (1957) used a somewhat different stratigraphic nomenclature for the South Australian part of the Otway Basin, but so far her units have not been distinguished in Victoria.

The sequence penetrated in Heywood No. 10 Bore is similar to that encountered in the Portland No. 3 Bore (Glenie and Reed, 1961). The most significant difference is that the Heywood No. 10 Bore finished in Cretaceous marine sediments assigned to the Belfast mudstone, whereas this formation was not recognized in the Portland Bore. The Tertiary sequences of the two bores are comparable except for some differences in thicknesses and the absence of the Whaler's Bluff formation in the Heywood No. 10 Bore.

The youngest stratigraphic unit is the Gambier limestone from which the foraminiferal faunas of eight cores (Table 2) were studied. This formation is highly fossiliferous and grades from a pure limestone (97

Table 1.- Stratigraphic and lithologic summary of Heywood No. 10 Bore

	Group	Formation	Member	Lithology	Depth (feet)	Thickness (feet)
				Soil and superficial clay	0 - 12	12
Miocene	Glenelg	Gambier limestone	Portland limestone	Pure limestone and marly limestone	12 - 519	507
Oligo-cene			Heywood marl	Marl and marlstone, with pure and marly limestone near base	519 - 1288	769
		Nelson		Sandy limestone and sandy dolomitic limestone, in part glauconitic; dolomitic and ferruginous siltstones	1288 - 1373	85
- - ? - - -						
Eocene	Knight	Dartmoor		Quartz sand, silty quartz sand, carbonaceous siltstone, basalt (1423 - 1454), minor coal, dolomitic siltstone and sandstone.	1373 - 4238	2865
		Bahgallah?		Carbonaceous siltstone, in part sideritic, dolomitic sandstone and siltstone, quartz sand, minor coal and dolomite	4238 - 5282	1044
- - ? - - -						
Cret-aceous		Belfast mudstone		Carbonaceous siltstone and claystone	5282 - 5390	108

per cent soluble carbonate) in its upper part to a marl (40 per cent soluble carbonate) toward the base. It conformably overlies the Nelson formation.

The faunas of two cores (Table 2) from the Nelson formation were examined. The variable lithology of this unit (Table 2) reflects a transitional depositional sequence between the nonmarine Dartmoor formation below and the entirely marine Gambier limestone above. Although an unconformity may be present between the Dartmoor and Nelson formations, there is not sufficient evidence for a positive statement.

The faunas from the Nelson formation, unlike the well-developed ones found in the Gambier limestone, are poorly preserved and have few species. Moreover, it was difficult to separate the specimens in the Nelson formation from the matrix.

Six cores were examined from the nonmarine Dartmoor formation. As these cores were unfossiliferous, this formation is not discussed.

Table 2.- Details of core samples from Heywood Bore No. 10

Core	Depth (feet)	Formation or Member		Lithology	Fauna
AA	191 - 211	Gambier limestone	Portland limestone	Pale grey marly limestone	Abundant bryozoa, ostracoda and foraminifera; Occasional brachiopods, gastropods and pelecypods
AB	403 - 423				
AC	603 - 623		Heywood marl	Pale grey limey marlstone	Abundant bryozoa, ostracoda, foraminifera, echinoid spines and test fragments, <u>Ditrupa</u> (polychaete) tubes Occasional gastropods and pelecypods
AD	734 - 754			Grey marlstone	
AE	855 - 875				
AF	976 - 986				
AG	1095 - 1105				
AH	1211 - 1228				
AI	1315 - 1335	Nelson formation		1. Sandy dolomitic limestone	Occasional bryozoa; rare foraminifera and echinoid fragments. Limonite, glauconite and clay molds of above. Echinoid? fecal pellets.
				2. Brown micaceous siltstone	Pyritized worm? trails; rare foraminifera. Internal moulds
AJ	1335 - 1355			1. Calcareous sandstone	Fossils rare. Limonite moulds and staining
				2. Grey-brown siltstone	Rare foraminifera and a small pelecypod; in part pyritized
AK	1468 - 1489	Dartmoor formation		Black micaceous carbonaceous siltstone	
AM	1712 - 1722			Brownish-black micaceous siltstone	

Table 2.- (continued)

Core	Depth (feet)	Formation or Member	Lithology	Fauna
AN	1835 - 1855	Dartmoor formation	Brownish-grey micaceous siltstone	Unfossiliferous. Pyrite absent; occasional carbonized plant material
AO	1955 - 1975		Dark-brown micaceous carbonaceous siltstone	
AQ	2095 - 2116		Grey micaceous siltstone	
AT	2370 - 2390		Dark-brown micaceous siltstone	

CORRELATION

Correlations have been made with the local stages and faunal units defined by Carter (1958a, b; 1958/59; 1963), and with the planktonic foraminiferal zones of the Caribbean region (see Fig. 2). This latter zonation was established by Bolli (1957), based on earlier work by Cushman and Stainforth (1945) and Stainforth (1948), for the Cipero Formation of Trinidad. The validity of this zonation has been shown by its recognition elsewhere (e.g. Mediterranean region - Blow, 1957; Venezuela - Blow, 1959; Saipan - Todd, 1957; Japan - Saito, 1960; Asano, 1962; Philippines - Bandy, 1963). Stainforth (1960) summarized the occurrences of pelagic Foraminifera on both sides of the Atlantic and from this data proposed a correlation between the Caribbean planktonic zones and the European stages. An attempt has been made to correlate the sequence encountered in the Heywood No. 10 Bore with the European stages via the intermediate step of the Caribbean, using Stainforth's conclusions.

Because continuous core samples were not available throughout the entire section, it was impossible to fix accurately the boundaries between foraminiferal zones, which are indicated on the correlation chart (Fig. 2) as lying somewhere between adjacent cores.

Correlation with Subdivisions of the Victorian Tertiary

A subdivision of the Victorian Tertiary from Eocene to Miocene into a sequence of 11 faunal units, each with a diagnostic foraminiferal association of planktonic and benthonic forms was proposed by Carter (1958a). This subdivision gave a paleontological basis for delimiting and correlating most of the well-established Victorian Tertiary Stage Classification originated by Hall and Pritchard (1902) and expanded by later workers (see: Singleton, 1951, for the historical development of this classification). Carter elaborated his subdivision in two subsequent papers (1958b; 1958/59), and later condensed the 11 faunal units into a sequence of 10 foraminiferal zones (1963). As these zones are based on the faunal units, and because some of the Heywood samples have yielded the diagnostic fossils of a particular zone without the zone fossil being present, the subdivision into faunal units rather than into formal zones is followed here.

The foraminiferal associations characterizing the faunal units and their correlation with the local Stage names, as given by Carter (1963, table 4), with youngest at top, are summarized below. The last appearance of a particular species is indicated by "(l)" after the name, the first appearance by "(f)".

Stage	Faunal Unit	Foraminifera
Bairnsdalean	11	Orbulina universa (f), O. bilobata, Cibicides victoriensis
Balcombian	10	Globigerinoides transitorius (f), G. glomerosus, Orbulina suturalis
Batesfordian	9	Globigerinoides trilobus with large apertures (f), Lepidocyclina howchini, Cycloclypeus victoriensis, Austrotrillina howchini
	8	Globigerinoides ruber (f), Astrononion centroplax

Stage	Faunal Unit	Foraminifera
	7	Globigerinoides trilobus (f), G. bisphericus (f), Sherbornina cuneimarginata, Planorbulinella plana (f), P. inaequilateralis
Longfordian		
	6	Globoquadrina dehiscens (f), Globigerina ciperoensis (f), Gypsina howchini (f), Operculina victoriensis (f), Sherbornina cuneimarginata (f), Hofkerina semiornata (f)
	5	Astrononion centroplax (f), Amphistegina lessonii (f), Victoriella conoidea (l)
Janjukian		
	4	Globigerina ouachitaensis - G. bulloides group (f), Sherbornina atkinsoni (f), Gumbelina rugosa (l)
	3	Victoriella conoidea (f), Globigerina linaperta (l), Vaginulinopsis acanthonucleus
Aldingan		
	2	Globigerinoides index (l), Globigerinella micra
	1	Globigerinoides index, Hantkenina alabamensis (l)

In the Heywood samples, faunal units 5, 6, 7, 8, and 11 are definitely recognized. Faunal unit 11 however, is the only one which has the complete association defined by Carter (1963, table 4). Faunal units 4, 9, and 10 are assumed to be present on less reliable evidence.

Globigerina ciperoensis, whose initial appearance marks faunal unit 6, is found in core AG with Astrononion centroplax. The latter species, however, is not found in core AH, and so faunal unit 5, characterized by the first appearance of Astrononion centroplax, must occur between cores AG and AH.

The base of faunal unit 7 is placed between cores AD and AE as Globigerinoides trilobus and G. bisphericus are first found in core AD. G. ruber is found in core AB but probably makes its first appearance earlier. Faunal unit 8, therefore, is placed between cores AB and AC. The association of Orbulina bilobata and O. universa in core AA indicates faunal unit 11. The extent of this faunal unit above core AA is not known. Faunal units 9 and 10 are placed on the chart (Fig. 2), without any of the diagnostic fossils being recognized, between cores AA and AC, below faunal unit 11 and above faunal unit 8.

Only three of the benthonic Foraminifera used to define the faunal units have been found in Heywood No. 10 Bore. The range of Astrononion centroplax in the bore, from cores AD to AG, is somewhat shorter than that recorded by Carter (1963), who found this species in faunal unit 8, which occurs above core AC in the Heywood Bore. Operculina victoriensis (= Camerina complanata) is found only in the Portland limestone. Carter (1963) recorded its first appearance earlier in faunal unit 6. The increased clay content of the sediments in the Heywood Marl indicate turbid waters and a muddy substrate during deposition, possibly an unfavourable environment for this form, which would explain its absence below core AB. The occurrence only in core AA of Cibicides victoriensis agrees with its first appearance in faunal unit 11 as defined by Carter (1963).

The absence of Victoriella conoidea (Rutten) [= V. plecte (Chapman) - see: Glaessner and Wade, 1959] in the Heywood Bore is unexpected, since Crespin (1954) has reported this typically Janjukian form from a number of bores in the surrounding area at Dartmoor, Mt. Gambier, Nelson, and Portland.

Correlation with Caribbean planktonic zones

By means of planktonic Foraminifera, Bolli (1957) established 13 zones within the Oligocene and Miocene of Trinidad, B.W.I. This zonation has been recognized elsewhere, and is accepted, at least in its broad aspects, as valid over much of the world. The sequence of the eight lower zones, beginning with the youngest, is as follows:

Globorotalia fohsi barisanensis Zone

Globigerinatella insueta Zone [subdivided by Blow (1959) into an upper *Globigerinatella insueta*/ *Globigerinoides bisphericus* Subzone and a lower *Globigerinatella insueta*/ *Globigerinoides trilobus* Subzone]

Catapsydrax stainforthi Zone

Catapsydrax dissimilis Zone

Globorotalia kugleri Zone

Globigerina ciperoensis ciperoensis Zone

Globorotalia opima opima Zone

Globigerina ampliapertura Zone

In the Heywood Bore, core AA is correlated with the upper part of the *Globigerinatella insueta* Zone of Bolli (1957) [= *Globigerinatella insueta*/ *Globigerinoides bisphericus* Subzone of Blow (1959)], or with the base of the *Globorotalia fohsi barisanensis* Zone, as indicated by the association of *Orbulina universa* and *Globorotalia menardii* "*praemenardii*" with the three variations ("subspecies") of *Globigerinoides glomerosus*. With less certainty, the Gambier limestone below core AA and the Nelson formation have been correlated with the six lower zones of the Caribbean sequence (Fig. 2). Although the characteristic fossils were not found, the *Globigerina ampliapertura* Zone is thought to extend from the Nelson formation into the base of the Heywood marl on the opinion of Jenkins (1960, p. 369), who correlated the basal part of the sequence in the Lakes Entrance Oil Shaft, which contains a similar fauna to that of the lower part of the Heywood sequence, with this Zone.

Jenkins (1960, p. 369) pointed out that some differences in the Tertiary planktonic assemblages of Lakes Entrance in eastern Victoria and those of the Caribbean region do exist,". . . due probably to a latitude and depth difference . . ." between the two areas. The same is true of the Heywood assemblages and those of the Caribbean. The absence or scarcity of some of the Caribbean zone fossils, particularly in the lower depths of the bore, however, indicates that alternative zonal indices which have a wider distribution should be selected for the geographically different, southern Australian region. "*Globorotalia*" *extans* of Jenkins (1960) may be important in this regard. Its stratigraphic range in the bore corresponds roughly with that given by Jenkins (1960), but insufficient knowledge at present concerning its exact stratigraphic and geographic distribution would make the establishment of a zone based on this form somewhat tenuous.

Jenkins (1960, p. 370) discussed the stratigraphic range of *Globoquadrina dehiscens* in Australia and New Zealand as compared with that in the Caribbean region. In the Heywood Bore, this species was found abundantly in Cores AA and AB but only rarely in core AE and not at all in cores AC and AD. The stratigraphic occurrence of *G. dehiscens* in the bore is thus earlier than in the Caribbean but later than recorded by Jenkins (1960) in the Lakes Entrance Oil Shaft. Ecologic factors are thought to be responsible for its scarcity below core AB in the Heywood bore (see: section on "Influence of oceanic circulation on planktonic fauna").

The range of *Globigerinoides bisphericus* in Heywood No. 10 Bore is more comparable to that recorded by Carter (1958a, b; 1958/59; 1963) than to the short time range ascribed to this form by Bolli (1957), Blow (1959), and Jenkins (1960). Jenkins (1960, p. 353) questioned this discrepancy, suggesting that Carter's earlier identifications of this species were erroneous. The present work, however, supports Carter's original extended range. It may be that *G. bisphericus* originated in the southern Australian region and later spread to other areas in a similar manner to that described for *Globoquadrina dehiscens* by Jenkins (1960, p. 370). Further work is needed to establish this postulate.

Correlation with European Stages

Although the Caribbean planktonic zones have been recognized in Europe, their exact correlation within the European stages is still in doubt. The existing confusion is well exemplified in papers by Drooger (1956), Hornibrook (1958), Glaessner (1959), Stainforth (1960), and Eames, *et al.*, (1962), in each of which a different interpretation of correlation of the planktonic zones with the European stages was proposed.

The succession in the Heywood Bore nevertheless has been correlated tentatively with the European stages by accepting the stratigraphic ranges of Caribbean planktonic species as interpreted by Stainforth (1960, distribution chart, p. 221). The base of the Aquitanian, regarded as defining the Oligocene - Miocene boundary, is placed between cores AD and AE. This interpretation may be modified, however, as the pelagic Foraminifera of the European Tertiary are more thoroughly studied, and further data are accumulated in other parts of the world.

Correlation with the Murray Basin in South Australia

The northern continuation of the Otway Basin in Victoria and South Australia is known as the Murray Basin. Ludbrook (1961, tables 10 and 11), working with both outcrop and subsurface samples, published the ranges of stratigraphically important benthonic and planktonic Foraminifera in the South Australian portion of the Murray Basin in terms of the stratigraphic units previously established for this area (ludbrook, 1957).

The association of Orbulina universa, "Biorbulina" bilobata, "Candorbulina" universa, "Porticulasphaera" glomerosa glomerosa, and "P." glomerosa curva in the lower part of Ludbrook's Pata limestone correlates this part of the sequence with the upper part of the Globigerinatella insueta Zone or base of the Globorotalia fohsi barisanensis Zone (Bolli, 1957) of the Caribbean, and with core AA of the Heywood Bore. The presence of Cibicides victoriensis in core AA and in the Pata limestone strengthens the correlation.

The lower part of the Heywood marl and the Nelson formation appear to correlate with at least the upper part of Ludbrook's Ettrick formation, but some discrepancies make this and further correlations uncertain. According to Ludbrook (1961, tables 10 and 11), Astrononion centroplax, Globigerina linaperta, and Gumbelina rugosa occur together in the lower part of the Ettrick formation. This is not in agreement with the ranges of these species given by Carter (1963, table 4) in defining his Faunal Units (see section on "Correlation with subdivisions of the Victorian Tertiary"). Ludbrook (1961, table 11) showed Globigerinoides ruber making its appearance earlier than either Globigerina ciperoensis or Globigerinoides trilobus in the Murray Basin, contrary to the records from the Caribbean (Bolli, 1957, p. 99), from Lakes Entrance (Jenkins, 1960, p. 347), and from the Aire district in western Victoria (Carter, 1958b, p. 29), as well as from other areas throughout the world. Finally, the occurrences of Globigerina bulloides in and below the Pata limestone (Ludbrook, 1961, table 11) probably refer to another species, as G. bulloides does not appear until much later (Blow, 1959, p. 175).

Unfortunately, no descriptions and only a few illustrations of the Foraminifera were published by Ludbrook (1961), so that the identifications cannot be checked. Misinterpretation of the stratigraphic position of certain of her samples, which included both outcrop and subsurface samples from over a wide area, may have also contributed to the discrepancies mentioned.

Correlation with Indo-Pacific Letter Classification

The Indo-Pacific "Letter Classification" was originally set up by van der Vlerk and Umbgrove (1927) on the basis of larger Foraminifera. To attempt to correlate this classification with the Caribbean planktonic zones, it is necessary to use samples containing larger Foraminifera and planktonic Foraminifera in association - the former to give the age in terms of the "Letter Classification", and the latter to enable correlation with the Caribbean zonation to be made. Three instances involving this approach have been published. All are concerned with the correlation of the Globigerinatella insueta/ Globigerinoides bisphericus Subzone (Blow, 1959), or more specifically, the initial appearance of Orbulina suturalis, near the top of this subzone.

LeRoy (1958, p. 506) recorded the first appearance of Candorbulina universa (= Orbulina suturalis) near the top of the Telisa formation in Central Sumatra and regarded this point as marking the division between Tertiary e and Tertiary f. However, Glaessner (1959) in his correlation chart (table 1), included most of the Telisa in Tertiary f, thus placing the first appearance of O. suturalis at some time during Tertiary f, rather than at the beginning, as suggested by LeRoy.

Todd, _et al_. (1954) recognized the _Globigerinatella insueta_/ _Globigerinoides bisphericus_ Subzone in the Fina-Sisu formation on Saipan, and correlated it with beds containing an assemblage of Tertiary _e_ larger Foraminifera. Glaessner (1959, p. 58) discussed this occurrence and suggested a possible alternative interpretation of the field evidence. He correlated the _Globigerinatella insueta_/ _Globigerinoides bispharicus_ Subzone with Tertiary _f_. The findings of Cole, _et al_. (1960) on Yap, in the light of this reinterpretation, added support to Glaessner's conclusion, as under the original interpretation of Todd, _et al_. (1954) the question of conflicting age determinations on Yap using larger and smaller Foraminifera could not be resolved.

It thus appears, from the available evidence, that the _Globigerinatella insueta_/ _Globigerinoides bispharicus_ Subzone of the Caribbean correlates with at least part of the Tertiary _f_ Stage of the Indo-Pacific region. Correlation of other planktonic zones with the "Letter Classification" in the Indo-Pacific will be an important test of this conclusion.

PALEOECOLOGY

Environment of deposition of Glenelg Group sediments

The Nelson formation represents the initiation of true marine sedimentation in the Tertiary section encountered in Heywood No. 10 Bore. The general lithologic aspect (coarse calcareous sandstones; carbonaceous siltstones) indicates fluctuating marginal conditions in a near-shore environment. An unfavourable bottom environment is suggested by the paucity of the fauna with its accompanying pyritization, but the appearance of a few pelagic Foraminifera (Table 3) in the upper parts of the formation demonstrates that access to the open sea had been established by this time.

Uniform, normal marine deposition of the Gambier limestone in an open-sea environment is indicated by relatively uniform lithology and abundant pelagic Foraminifera throughout this formation (Table 3).

Most of the Heywood Marl is characterized by an abundance of simple arenaceous forms, miliolids, and coarsely perforate genera such as *Cibicides* (Table 3), an association which suggests an inner continental shelf environment (depth between 20 and 60 m.). Abundant remains of echinoids, most of which are shelf dwellers (Hyman, 1955, p. 569), also supports this hypothesis. The fauna from core AH is deficient in these inner shelf indicators, and this part of the Heywood marl was probably deposited in deeper water than the overlying part.

Table 3.- Percentages of various foraminiferal groups within core samples from the Heywood Bore

Core	Arenaceous	Miliolids	Polymorphinids	Other benthonics	Pelagics	Total number of specimens counted
AA	2	-	-	38	60	1867
AB	4	-	10	37	49	2170
AC	12	14.5	-	25.5	48	1174
AD	13	16	0.5	21.5	49	1926
AE	27	17.5	2	28	25.5	1115
AF	11	8	1.5	33	46.5	1761
AG	11.5	18	8	15.5	47	2076
AH	1	-	2.5	43.5	53	1426
AI(1)	-	7	-	40	53	15
AI(2)	100	-	-	-	-	3
AJ(2)	92	-	-	8	-	37

Deeper water is suggested for the Portland limestone by the absence of miliolids and echinoid fragments, and the rare occurrence of arenaceous Foraminifera (Table 3). The environment, however, was still probably on the shelf, as shown by the presence of *Camerina complanata* in this member. Cole (1959, table 1) stated that *Operculina bartschi* (= *Camerina complanata*; see Cole, 1961, pp. 120-122) occurs commonly in the Recent Philippine and adjacent seas between depths of 19 and 52 fathoms (35 - 95 m.), corresponding to a position on the outer continental shelf. Reduction in the amount of detritus entering the environment, correlated possibly with a more distant shoreline, is expressed in the increased proportion of soluble carbonate in the Portland limestone.

Polymorphinids have an irregular distribution throughout the Gambier limestone. The ecological implications of this are not apparent.

The overall picture is one of a typical marine transgression, beginning in Nelson time, with the sea progressively deepening, and the shoreline shifting away from the area during the time of deposition of the Gambier limestone.

Influence of oceanic circulation on planktonic fauna

As mentioned above, Jenkins (1960) noted differences in the Tertiary planktonic faunas of the Caribbean region and of the Lakes Entrance Oil Shaft in eastern Victoria. Differences have also been recognized in the Tertiary planktonic assemblages of eastern Victoria, as exemplified in the Lakes Entrance Oil Shaft, and those of western Victoria and south-eastern South Australia, as recorded by Ludbrook (1961) and in the present study.

Planktonic Foraminifera typical of the present tropical and subtropical oceans are found in the eastern Victorian sequence, whereas these warm-water elements are absent or rare in western Victoria and southeastern South Australia. Important points of difference are as follows: (1) the presence of a number of species of Globorotalia s.s. in the eastern Victorian Tertiaries contrasted with the complete absence of this genus in South Australia (Ludbrook, 1961, table 11) and its extreme scarcity in the Heywood section; (2) the dominance of Globigerina species throughout most of the section in the western area, with other genera (except Orbulina) forming only a relatively small proportion of the total planktonic population; and (3) the rarity or absence of Globoquadrina dehiscens (and absence of other species of this genus) from the western area in the lower part of its range as recorded by Jenkins (1960, text fig. 2) in the Lakes Entrance Oil Shaft in eastern Victoria.

An Oligocene - Miocene oceanic circulation, similar to that existing today in the southern Australian region, may have been responsible for the faunal differences noted above. Figure 3, based on data from Wyrtki (1960, fig. 13) and von Arx (1962, fig. 6-20), shows the present generalized current pattern in this region.

The warm East Australian Current moves southward (Fig. 3) along the eastern coast of Australia before turning eastward and northeastward away from the continent. The most southerly point reached by the current before turning depends largely on the time of year (Wyrtki, 1960, fig. 15). During summer, its influence may extend as far south as latitude 42°S (Newell, 1961), thus affecting part of the eastern Victorian coast. Recent planktonic Foraminifera obtained within the area influenced by the current include forms found only in tropical and subtropical waters (Brady, 1884;

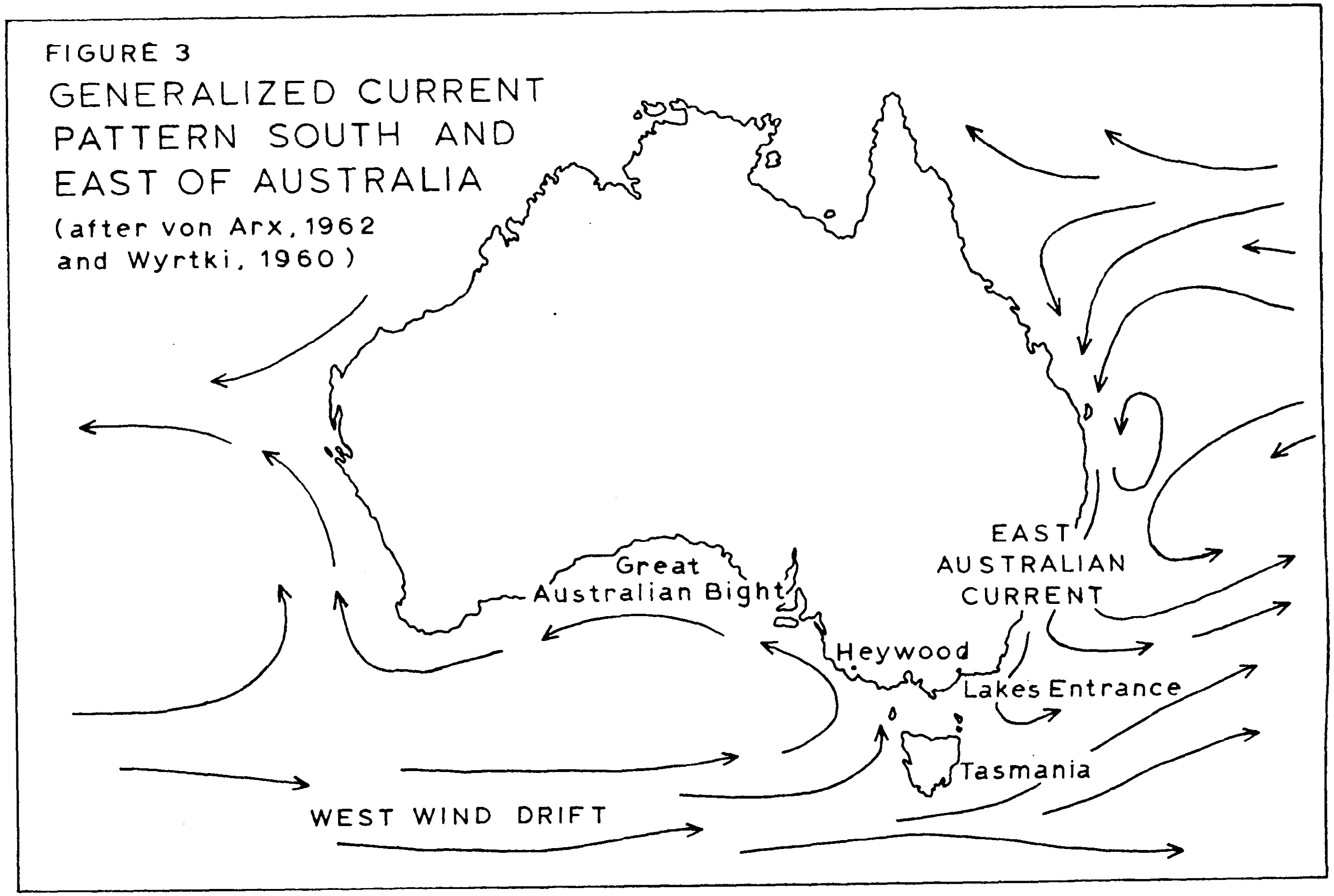

FIGURE 3
GENERALIZED CURRENT PATTERN SOUTH AND EAST OF AUSTRALIA
(after von Arx, 1962 and Wyrtki, 1960)

Whitelegge, 1889; Jensen, 1904; Goddard, 1907; Goddard and Jensen, 1907; Chapman, 1941).

The western Victorian coast is influenced by a branch of the West Wind Drift (Fig. 3) deflected northward along the west coast of Tasmania and continuing westward through the Great Australian Bight. This current is made up of cool waters (Rochford, 1962, fig. 17 and table 1), although in summer, subtropical water from the southern Indian Ocean moves eastward with the West Wind Drift and the temperature is slightly raised. Little data are available on the planktonic Foraminifera occurring within the area influenced by this current off the southern coast of Australia. No tropical or subtropical forms have been recorded in published lists of planktonic Foraminifera from this area (Brady, 1884; Chapman, 1907b; McKenzie, 1962). Further work is needed to confirm this, especially in the light of the statement by Newell (1961, p. 9) that strandings of subtropical and tropical fauna are regular occurrences along the west coast of Tasmania during the summer.

On the available evidence, however, it seems reasonable to conclude that tropical and subtropical forms, carried by the warm East Australian Current, will be found in a zone along the eastern Australian coast, extending an unknown distance westward along the eastern part of the Victorian coast. The western shores of the State, however, influenced by the West Wind Drift, will harbor a cooler-water fauna. Similar faunal separation into warm- and cool-water assemblages by water masses of different temperature has been observed in the Recent planktonic Foraminifera of the western North Atlantic (Bé, 1959; Cifelli, 1962), the western South Atlantic (Boltovskoy, 1962), and the seas surrounding Japan (Asano, 1957).

In Oligocene - Miocene times, it is postulated that a differentiation of the planktonic fauna took place in a similar way in southeastern Australia through the influence of a current pattern not unlike that existing today. During the time of maximum transgression, represented in the Heywood Bore by the Portland limestone, it is possible that the influence of the warm East Australian Current extended farther westward than at present. This allowed occasional warm-water forms to enter the area normally affected by the West Wind Drift waters in detached eddies, a mechanism postulated for the entry of warm-water faunas into the shelf regions of the western North Atlantic by Cifelli (1962, p. 212). By this means, a few planktonic Foraminifera restricted to warm waters, such as Globorotalia menardii, may have occasionally entered the Portland Sunklands and become associated in the bottom sediments with the typical indigenous cooler-water forms.

Globoquadrina dehiscens by its faunal association was seemingly a warm-water form but probably had a greater tolerance for lower temperature than Globorotalia menardii. Globoquadrina dehiscens could thus still exist and be able to penetrate westward into the cooler-water area during the time of maximum transgression of the Portland sea, whereas Globorotalia menardii was restricted by temperature requirements to areas in which the temperature could be no lower than that of the present East Australian Current in its most southerly extension. The rarity of Globoquadrina dehiscens in the Heywood marl is the result of the influence of the East Australian Current not extending as far west in the earlier stages of the transgression, so that this species rarely reached the Heywood area.

Orbulina universa is regarded by some authors (e.g. Bé, 1959) as a warm-water species. Stone (1956), working with samples from the western Atlantic, concluded that this species was abundant at temperatures of 54°F (12.2°C.) and above. The present-day temperature of the northern edge of the West Wind Drift in the area south of Australia is about 15.5°C. (Rochford, 1962, table 1) and becomes higher as the coastline is approached. Therefore, O. universa could survive, at least, in the northern fringes of this current. Under such conditions, the abundance of Orbulina in core AA from the Heywood Bore would not be unexpected.

At some point off the coast of eastern Victoria, there is an area where the East Australian Current and the West Wind Drift come into contact. Chapman (1941, p. 149) drew attention to the presence of small calcite crystals in the bottom sediments of eastern Bass Strait in this vicinity. He attributed the formation of these crystals to "supersaturated" warmer waters being cooled by admixture with cooler waters, thus causing the excess calcium carbonate to be precipitated as a shower of small crystals. Although his explanation was incorrect as an increase, rather than a decrease, in temperature, or an increase in salinity (among other factors) causes the precipitation of calcium carbonate from sea water (Cloud, 1962, p. 102), the conclusion that accumulation of small calcite crystals on the sea floor occurs in the vicinity of the meeting of the two currents was correct. Chapman (1941, p. 149) also noted that the same type of calcite crystals were obtained in the washings of the "...fossiliferous marls of Lower Miocene age..." in eastern Victoria. This supports the idea that the Oligocene - Miocene current pattern was similar to that existing today, since no calcite crystals have been observed in washings of sediments from western Victoria.

SYSTEMATIC DESCRIPTIONS

This section is divided into three parts. The first part lists by families, according to the classification of Glaessner (1945), those benthonic species which have been recorded previously from Australia or the Indo-Pacific region and for which adequate descriptions are available. To avoid needless listings of synonymies, a single reference is given for each species and its occurrence in the Heywood Bore is indicated by the core designation after the reference. Benthonic species on which taxonomic or ecologic observations have been made are grouped by families and discussed in the second part. The third part consists of a systematic treatment of the planktonic forms. Although most of these forms are abundant in all cores, a qualitative assessment of their relative frequencies in terms of the total planktonic population is included in the discussion of these species.

Relative frequencies and occurrences of the benthonic species are summarized in Table 4. The relative frequencies of specimens in a sample of standard size were assigned on the following basis:

abundant (A)	26 or more specimens
common (C)	11 - 25 specimens
frequent (F)	7 - 10 specimens
scarce (S)	3 - 6 specimens
rare (R)	1 - 2 specimens

Ranges of the planktonic species in the Heywood Bore are shown on the correlation chart (Fig. 2).

Table 4.- Distribution of benthonic Foraminifera in Heywood Bore (see introduction to "Systematic Descriptions" for explanation of letters indicating frequencies).

Species / Cores	AA	AB	AC	AD	AE	AF	AG	AH	AI(1)	AI(2)	AJ(2)
Alabamina tenuimarginata		S									
Ammodiscus parri				F							
Ammosphaeroidina sphaeroidiniformis			C		R						
Anomalina macraglabra	A	C	S	C	S	C	C	A	R		
Anomalinoides procolligera		S		S		A	S	S			
Astrononion australis			S	F			R				
Astrononion centroplax				R	R	F	F				
Astrononion obesus		F									
Biloculinella globula			C	C	S	C	R				
Bolivina robusta	R										
Bolivina sublobata			R	R		F	R				
Bolivina victoriana	A	R	R	S							
Buliminella spicata			R	S	R	S	R				
Camerina complanata	S	A									
Cancris intermedius	C		R	R							
Carpenteria rotaliformis		C		R	A	C					
Cassidulina laevigata		F									
Cassidulina subglobosa		A				C		A	R		
Cibicides brevoralis		A		R	R	C					
Cibicides lobatulus	C	A	C	C	F	A	C	A			
Cibicides mediocris	S	C		F	S	C					
Cibicides pseudoungerianus	A	A	A		A	A	F	A	S		
Cibicides subhaidingerii	F										
Cibicides victoriensis	A										
Clavulinoides victoriensis					A	A					
Cornuspira crassisepta				R		R					
Cornuspira foliacea			S	S	S	R	R				
Cornuspira involvens					S		C				
Cyclammina incisa	R			R		R				R	C
Cyclammina longicompressa										R	C

Table 4.- (continued)

Species / Cores	AA	AB	AC	AD	AE	AF	AG	AH	AI(1)	AI(2)	AJ(2)
Cyclammina paupera					R						F
Cyclammina rotundata	R			R	R					R	
Dentalina communis	R	R									
Dentalina consobrina	S					R					
Dentalina obliquestriata				R		R					
Discorbinella biconcava		R									
Discorbis balcombensis	R		S	C			R				
Ehrenbergina osbornei		F									
Elphidium crespinae								R			
Elphidium parri	F	R									
Eponides repandus		A	R	C	C	F	A	S			
Fissurina bifida		R		R	R	R	S				
Fissurina circularis	C	C	S	S	R	C	R	F			
Fissurina lacunata					R	A	S	C			
Fissurina lagenoides				R							
Fissurina pacifica	C	R	R	R		R					
Frondicularia inaequalis	R			R							
Gaudryina (Gaudryina) collinsi			R	C		R					
Gaudryina (Pseudogaudryina) crespinae	R	S	F	A	C	A	A	R			
Gaudryina (Gaudryina) heywoodensis			R	A	A	A					
Glandulina laevigata	R			R	S	S	F	S			
Globulina gibba		S			S		A	S			
Guttulina irregularis		F		R		R	A	S			
Guttulina pacifica		S			S						
Guttulina problema				S			A	S			
Guttulina silvestrii		S									
Guttulina spicaeformis		S					S	R			
Guttulina yabei		C		R		R	C	R			
Gyroidinoides allani					C						
Gyroidinoides zelandicus		C					R	C			
Heronallenia lingulata			R	R		R		S			
Heronallenia parri				R		R	R	F			

Table 4.- (continued)

Species \ Cores	AA	AB	AC	AD	AE	AF	AG	AH	AI(1)	AI(2)	AJ(2)
Hopkinsina mioindex		S									
Lagena acuticosta	S	S				F		C			
Lagena favosopunctata	F	S		F	R	S	R	C			
Lagena semistriata				S		R		R			
Lagena striata	R						S	R			
Lagena sulcata	S			R		R					
Lagenonodosaria scalaris	A	A				S					
Lenticulina crepidula		F					C				
Marginulina tenuis	S										
Miliolinella oblonga				S							
Mississippina concentrica		R	S	R	R	R	S	C			
Nodosaria hispida	S			R							
Nodosaria insecta		R		F	S	S	R	R	R		
Nodosaria obliqua					R	F	F	R			
Nodosaria pyrula	R										
Nodosaria raphanistrum	R	R		R	S						
Nodosaria vertebralis	R	F		R		R					
Nonion victoriensis	C										
Pseudoclavulina bradyana				F							
Pseudoclavulina rudis					A	S	A				
Pullenia bulloides	F				R		F	R			
Pullenia quinqueloba						F	S	C			
Pyrgo bulloides			S			R	R				
Pyrgo inornata			R	S	S		F				
Pyrgo sarsi			C	C	C	F	A				
Pyrgo subsphaerica				R							
Pyrulina cylindroides							C				
Pyrulina fusiformis				R	S	R	C	S			
Quinqueloculina cuvieriana			F	F	S	S					
Quinqueloculina lamarckiana				C	F						
Quinqueloculina polygona				R		S					
Quinqueloculina vulgaris			A	A	A	C	A		R?		

Table 4.- (continued)

Species	Cores AA	AB	AC	AD	AE	AF	AG	AH	AI(1)	AI(2)	AJ(2)
Reussella simplex				R		R		R			
Robulus alatolimbatus	S	C	S	S	C	R		S			
Robulus cultratus				S	S	R					
Robulus gyroscalprus		R			S			R			
Robulus inornatus	R	C		F	S	F	F	F			
Rotalia scabricula						F	S				
Rosalina bertheloti	A	R	S	C		C	R				
Sigmoidella elegantissima		A			R	S					
Sigmoidella kagaensis		C									
Sigmoilina victoriensis					F	R					
Sigmoilopsis compressa			R	S	R						
Sigmoilopsis chapmani			F	R							
Sigmomorphina chapmani						R	A	F			
Sigmomorphina subregularis		C									
Siphonina australis	C	R	R	S		F					
Sphaeroidina bulloides	C	A		S	F	C	F	A	R?		
Spirillina vivipara			S	R	R		R				
Spiroloculina disparilis				S		R					
Spiroloculina tenuiseptata					C	S	A				
Textularia barnetti			F								
Textularia fistulosa	S	F	A	A	S	A	A				
Textularia porrecta	C	A	S	R							
Textularia sagittula	C	A	F	R	S	S	F				
Trifarina bradyi		R				R	F	F			
Triloculina brochita			S	A	C	C	C				
Triloculina collinsi					S		R				
Triloculina trigonula			C	S	F	C	C				
Uvigerina nitidula		R									
Uvigerina proboscidea				S				A			

Hypotypes and all figured specimens will be deposited in the Collections of the Museum of the Geological Survey of Victoria, Melbourne, Australia.

a. Benthonic species previously recorded from the Indo-Pacific and Australian regions

Family AMMODISCIDAE

Ammodiscus parri Crespin (Crespin, 1950, p. 71, 72, pl. 10, fig. 2) - AD.

Family LITUOLIDAE

Cyclammina incisa (Stache) (Crespin, 1950, p. 72, pl. 10, fig. 3) - AA, AD, AF, AI(2), AJ(2).

C. longicompressa Chapman and Crespin (Chapman and Crespin, 1930, p. 97, pl. 5, figs. 3, 4) - AI(2), AJ(2).

C. paupera Chapman (Crespin, 1950, p. 72, pl. 10, fig. 4) - AE, AJ(2).

C. rotundata Chapman and Crespin (Crespin, 1950, p. 72, pl. 10, figs. 5a, b) - AA, AD, AE, AI(2).

Family TEXTULARIIDAE

Textularia porrecta (Brady) (Heron-Allen and Earland, 1924, p. 137) - AA-AD. Pl. 1, fig. 7.

T. sagittula Defrance (Heron-Allen and Earland, 1924, p. 136) - AA-AG. Pl. 1, fig. 8.

Family TROCHAMMINIDAE

Ammosphaeroidina sphaeroidiniformis (Brady) (Haplophragmium sphaeroidiniforme Brady, in Chapman, 1907a, pp. 24, 25, pl. 3, figs.

50,51) - AC, AE.

Family VERNEUILINIDAE

Gaudryina (Gaudryina) collinsi Cushman (Cushman, 1936, pp. 8, 9, pl. 2, figs. 2a, b) - AC, AD, AF.

G. (Pseudogaudryina) crespinae Cushman (Cushman, 1936, p. 14, pl. 2, figs. 15a, b) - AA-AH. Pl. 1, figs. 4, 11.

Family MILIOLIDAE

Quinqueloculina cuvieriana d'Orbigny (Miliolina cuvieriana d'Orbigny, in Chapman, 1907a, p. 19, pl. 2, fig. 33) - AC-AF.

Q. lamarckiana d'Orbigny (Q. aff. lamarckiana d'Orbigny, in LeRoy, 1941, p. 71, pl. 5, figs. 5, 6) - AD, AE.

Q. polygona d'Orbigny (Miliolina polygona d'Orbigny, in Chapman, 1907a, p. 18, pl. 2, fig. 29) - AD, AF.

Q. vulgaris d'Orbigny (Miliolina vulgaris d'Orbigny, in Chapman, 1907a, pp. 18, 19, pl. 2, fig. 32) - AC-AG, ?AI(1).

Triloculina collinsi Carter (Carter, 1963, pp. 59, 60, pl. 1, figs. 5, 6) - AE, AG.

Pyrgo sarsi (Schlumberger) (Carter, 1963, p. 61, pl. 1, figs. 10, 11) - AC-AG.

P. subsphaerica (d'Orbigny) (P. subspherica (d'Orbigny), in LeRoy, 1941, p. 22, pl. 1, figs. 33, 34) - AD.

Miliolinella oblonga (Montagu) (Miliolina oblonga Montagu, in Chapman, 1907a, p. 17, pl. 2, fig. 25) - AD.

Biloculinella globula (Bornemann) (Biloculina globulus Bornemann, in Chapman, 1907a, pp. 15, 16, pl. 1, figs. 17, 18) - AC-AG.

Spiroloculina disparilis Terquem (Cushman and Todd, 1944, pp. 35, 36, pl. 5, figs. 29-31) - AD, AF.

Sigmoilina victoriensis Cushman (Cushman, 1946b, p. 103) - AE, AF.

Sigmoilopsis chapmani (Cushman) (Sigmoilina chapmani Cushman, in Cushman, 1946a, p. 31, pl. 5, figs. 7-9) - AC, AD. Pl. 1, fig. 5.

Family OPHTHALMIDIIDAE

Cornuspira crassisepta Brady (Chapman, 1907a, p. 22, pl. 2, fig. 45) - AD, AF.

C. foliacea (Philippi) (Chapman, 1907a, p. 24, pl. 3, fig. 48) - AC-AG.

C. involvens (Reuss) (Chapman, 1907a, pp. 22, 23, pl. 2, fig. 46) - AE, AG.

Family LAGENIDAE

Nodosaria hispida d'Orbigny (Chapman and Parr, 1926, p. 379, pl. 18, fig. 25) - AA, AD.

N. insecta Schwager (LeRoy, 1944, p. 80, pl. 1, fig. 18) - AB, AD-AI(1).

N. obliqua (Linné) (Heron-Allen and Earland, 1924, p. 155) - AE-AH.

N. pyrula d'Orbigny (Heron-Allen and Earland, 1924, p. 153) - AA.

N. raphanistrum (Linné) (Chapman and Parr, 1926, pp. 380,381, pl. 18, fig. 29) - AA, AB, AD, AE.

N. vertebralis (Batsch) (Chapman and Parr, 1926, p. 380. pl. 18, fig. 28) - AA, AB, AD, AF.

Dentalina communis (d'Orbigny) (Nodosaria (Dentalina) communis (d'Orbigny), in Chapman and Parr, 1926, p. 381, pl. 18, fig. 31) - AA, AB.

D. consobrina d'Orbigny (Nodosaria (Dentalina) consobrina (d'Orbigny), in Chapman and Parr, 1926, p. 381, pl. 18, fig. 33) - AA, AF.

D. obliquestriata Reuss (Todd, 1957, p. 267 (tab.), p. 270 (tab.), pl. 65, figs. 17, 18) - AD, AF.

Lagena acuticosta Reuss (LeRoy, 1944, p. 22, pl. 1, fig. 11) - AA, AB, AF, AH.

L. favosopunctata Brady (Chapman and Parr, 1926, p. 376, pl. 17, fig. 10) - AA, AB, AD-AH.

L. semistriata (Williamson) (Chapman and Parr, 1926, p. 374, pl. 17, fig. 19) - AD, AF, AH.

L. striata (d'Orbigny) (Chapman and Parr, 1926, pp. 374, 375, pl. 17, fig. 5) - AA, AG, AH.

L. sulcata (Walker and Jacob) (Chapman and Parr, 1926, p. 375, pl. 17, fig. 6) - AA, AD, AF.

Fissurina bifida (Heron-Allen and Earland) (Lagena orbignyana var. bifida nov., in Heron-Allen and Earland, 1924, p. 152, pl. 9, figs. 46-50) - AB, AD-AG.

F. circularis Todd (Cushman, Todd and Post, 1954, p. 351, pl. 87, fig. 27) - AA-AH.

F. lacunata (Burrows and Holland) (Lagena lacunata Burrows and Holland, in Chapman and Parr, 1926, p. 378, pl. 17, fig. 18) - AE-AH.

F. lagenoides (Williamson) (Parr, 1947, p. 128, pl. 6, fig. 15) - AD.

F. pacifica Parr (Parr, 1950, p. 314, pl. 9, figs. 10a, b) - AA-AD, AF.

Marginulina tenuis Bornemann (Cristellaria tenuis (Bornemann), in Brady, 1884, pl. 66, figs. 21-23) - AA.

Lenticulina crepidula (Fichtel and Moll) (Cristellaria crepidula (Fichtel and Moll), in Chapman and Parr, 1926, pp. 387, 388, pl. 20, fig. 57) - AB, AG.

Robulus alatolimbatus (Gümbel) (Todd, 1957, p. 266 (tab.), pl. 64, figs. 24a, b) - AA-AF, AH.

R. cultratus Montfort (Cristellaria cultrata (Montfort), in Chapman and Parr, 1926, p. 390, pl. 21, fig. 68) - AD-AF.

R. gyroscalprus (Stache) (Hornibrook, 1961, p. 36, pl. 5, fig. 67) - AB, AE, AH.

R. inornatus (d'Orbigny) (R. aff. inornatus (d'Orbigny), in LeRoy, 1941, p. 25, pl. 3, figs. 62, 63) - AA, AB, AD-AH.

Frondicularia inaequalis Costa (Chapman and Parr, 1926, p. 385, pl. 20, fig. 50) - AA, AD.

Family POLYMORPHINIDAE

Guttulina irregularis (d'Orbigny) (Cushman and Ozawa, 1930, pp. 25-27, pl. 3, figs. 4, 5; pl. 7, figs. 1, 2) - AB, AD, AF-AH.

G. pacifica (Cushman and Ozawa) (G. (Sigmoidea) pacifica (Cushman and Ozawa), in Cushman and Ozawa, 1930, p. 50, pl. 37, figs. 3-5) - AB, AF.

G. silvestrii Cushman and Ozawa (G. (Sigmoidea) silvestrii Cushman and Ozawa, in Cushman and Ozawa, 1930, p. 51, pl. 37, figs. 6, 7) - AB.

G. yabei Cushman and Ozawa (Cushman and Ozawa, 1930, pp. 30, 31, pl. 4, figs. 6, 7) - AB, AD, AF-AH.

Pyrulina cylindroides (Roemer) (Cushman and Ozawa, 1930, pp. 56, 57, pl. 14, figs. 1-5) - AG.

P. fusiformis (Roemer) (Cushman and Ozawa, 1930, pp. 54-56, pl. 13, figs. 3-8) - AD-AH.

Globulina gibba (d'Orbigny) (Cushman and Ozawa, 1930, pp. 60-64, pl. 16, figs. 1-4) - AB, AE, AG, AH.

Sigmomorphina chapmani (Heron-Allen and Earland) (Polymorphina chapmani Heron-Allen and Earland, in Heron-Allen and Earland, 1924, p. 163, pl. 10, figs. 60-63) - AF-AH. Pl. 2, fig. 3.

S. subregularis Howchin and Parr (Howchin and Parr, 1938, p. 308, pl. 18, figs. 2, 11) - AB.

Sigmoidella elegantissima (Parker and Jones) (Cushman and Ozawa, 1930, pp. 140,141, pl. 39, figs. 1a-c) - AB, AE, AF. Pl. 2, fig. 6.

Glandulina laevigata (d'Orbigny) (Cushman and Ozawa, 1930, p. 143, pl. 40, figs. 1a, b) - AA, AD-AH.

Family BULIMINIDAE

Buliminella spicata (Cushman and Parker) (Buliminella madagascariensis (d'Orbigny) var. spicata Cushman and Parker, in Cushman, 1942, p. 8, pl. 3, figs. 5, 6) - AC-AG.

Reussella simplex (Cushman) (Cushman, 1945, p. 40, pl. 7, figs. 5a, b) - AD, AF, AH.

Uvigerina nitidula Schwager (Todd, 1957, p. 273 (tab.), pl. 73, figs. 6a, b) - AB.

Hopkinsina mioindex Finlay (Finlay, 1947, p. 282, pl. 5, figs. 80-82) - AB.

Trifarina bradyi Cushman (Chapman and Parr, 1926, p. 386, pl. 20, fig. 52) - AB, AF-AH.

Bolivina robusta Brady (Cushman, 1937b, pp. 131-133, pl. 17, figs. 1-4) - AA.

B. sublobata Cushman (Cushman, 1936, p. 52, pl. 7, figs. 16a, b) - AC, AD, AF, AG.

Family CASSIDULINIDAE

Cassidulina laevigata d'Orbigny (Heron-Allen and Earland, 1924, p. 145) - AB.

C. subglobosa Brady (Heron-Allen and Earland, 1924, p. 146) - AB, AF, AH, AI(1).

Ehrenbergina osbornei Finlay (Finlay, 1939, p. 322, pl. 28, figs. 120, 123, 124) - AB.

Family CHILOSTOMELLIDAE

Pullenia quinqueloba (Reuss) (Carter, 1958b, pp. 32, 33, pl. 2, figs. 8, 9) - AF-AH.

Sphaeroidina bulloides d'Orbigny (Cushman and Todd, 1949, pp. 13-15, pl. 3, figs. 8-11) - AA, AB, AD-AH, ?AI(1).

Family SPIRILLINIDAE

Spirillina vivipara Ehrenberg (Carter, 1958b, pp. 39, 40, pl. 4, figs. 32, 33) - AC-AE, AG.

Family DISCORBIDAE

Discorbis balcombensis Chapman, Parr and Collins (Chapman, Parr and Collins, 1934, pp. 562, 563, pl. 8, figs. 10a-c) - AA, AC, AD, AG.

Discorbinella biconcava (Parker and Jones) (Carter, 1963, pp. 86, 87, pl. 5, fig. 97-100) - AB.

Heronallenia lingulata (Burrows and Holland) (Carter, 1958b, pp. 42, 43, pl. 5, figs. 40-42) - AC, AD, AF, AH.

H. parri Carter (Carter, 1958b, pp. 43, 44, pl. 5, figs. 43-45) - AD, AF-AH.

Gyroidinoides zelandicus (Finlay) (Hornibrook, 1961, p. 113, pl. 16, figs. 339, 344) - AB, AG, AH.

Alabamina tenuimarginata (Chapman, Parr and Collins) (Carter, 1963, p. 114, pl. 11, figs. 220-222) - AB.

Siphonina australis Cushman (Carter, 1963, p. 93, pl. 7, figs. 127-129) - AA-AD, AF.

Cibicides brevoralis Carter (Carter, 1958b, pp. 47-49, pl. 6, figs. 54-56) - AB, AD-AF.

C. subhaidingerii Parr (Carter, 1963, p. 95, pl. 8, figs. 145-147) - AA.

Anomalina macraglabra Finlay (Carter, 1963, pp. 99, 100, pl. 8, figs. 151-153) - AA-AI(1).

Anomalinoides procolligera Carter (Carter, 1958b, pp. 59, 50, pl. 6, figs. 60-63) - AB, AD, AF-AH.

Family NONIONIDAE

Nonion victoriensis Cushman (Carter, 1963, pp. 109, 110, pl. 10, figs. 201, 202) - AA.

Astrononion australis Cushman and Edwards (Carter, 1963, p. 111, pl. 11, fig. 207) - AC, AD, AG.

A. centroplax Carter (Carter, 1958b, pp. 61-63, pl. 9, figs. 95-97) - AD-AG.

A. obesus Carter (Carter, 1963, p. 112, pl. 10, figs. 205-206) - AB.

Elphidium crespinae Cushman (Carter, 1963, p. 121, pl. 12, figs. 240, 241) - AH.

E. parri Cushman (Carter, 1963, p. 122, pl. 13, figs. 250, 251) - AA, AB.

Family ROTALIIDAE

Rotalia scabricula (Chapman) (Carter, 1963, p. 119, pl. 12, figs. 234-239; pl. 16, figs. 285-287) - AF, AG.

b. Observations on other benthonic species

Family TEXTULARIIDAE

Genus TEXTULARIA Defrance, 1824

Textularia barnetti Bermudez

1949. Textularia barnetti Bermudez, Cushman Lab. Foram. Res., Sp. Pub. 25, p. 58, pl. 2, figs. 1, 2.

Chapman (1907, p. 26, pl. 3, fig. 55) recorded this form from the Balcombian of the Port Phillip area under the name T. abbreviata d'Orbigny. The Heywood specimens, Chapman's figured specimen, and the type of T. barnetti, however, have a rounded cross-section, and fewer and higher chambers than T. abbreviata, in which the test has an angular margin and consists of more chambers.

Occurrence: AC

Textularia fistulosa (Brady)

1884. Textularia sagittula Defrance var. fistulosa Brady, Rep. Challenger Exped., Zool., pt. 22, v. 9, p. 362, pl. 42, figs. 19 - 22.

This form has been separated from T. sagittula Defrance, which also occurs in the Heywood material, as a distinct species. There are no intergrading forms between the two. The "tubulated projections" of Brady (1884, p. 362), accompanied nearly always by ridgelike tubercles along each chamber transverse to the direction of growth, and often a coarser texture, distinguish T. fistulosa from T. sagittula, which has a smooth unornamented text (Pl. 1, fig. 8). The number and arrangement of the "tubulated projections" exhibit the same variability described by Brady (1884).

Occurrence: AA - AG

Family VERNEUILINIDAE

Genus GAUDRYINA d'Orbigny, 1839, emend. Bowen, 1955

Subgenus GAUDRYINA d'Orbigny, 1839

Gaudryina (Gaudryina) heywoodensis Reed, nom. nov. Pl. 1, figs. 1, 13.

1936. Dorothia parri Cushman, Cushman Lab. Foram. Res., Sp. Pub. 6, pp. 29, 30, pl. 4, figs. 19a, b. (non Gaudryina (Pseudogaudryina) parri Cushman, 1936, Cushman Lab. Foram. Res., Sp. Pub. 6, p. 15, pl. 2, figs. 11a, b).

Description: "Test large, broadly oval in front view, circular in end view, earliest stage with four or five chambers, then triserial, adult biserial; chambers comparatively few, two pairs making up the larger part of the adult test, distinct, inflated, high as bread, somewhat overlapping; sutures fairly distinct, slightly depressed, horizontal or slightly oblique in adult; wall coarsely arenaceous, surface somewhat roughened; aperture elongate, low. Length 1.60 mm.; diameter 1.10 mm.."

Holotype: From the Miocene of Campbell's Point, Lake Connewarre near Geelong, Victoria, Australia (Cushman Coll. No. 19173).

Remarks: Bowen (1955) gave adequate reasons for placing the genus Dorothia Plummer, 1931 in synonymy with that of Gaudryina d'Orbigny, 1839. The original distinction was based on the presence of a "...youthful trochoid spire composed of more than three chambers in the first whorl..." (Plummer, 1931, p. 130) in Dorothia, which later became triserial and then biserial, as in Gaudryina. Bowen's conclusion is supported by the present study of G. heywoodensis, in which the number of chambers in the initial whorl seems to vary from four to three. The determination of this number is difficult, in that a section ground not quite at right angles to the axis of growth will appear to show more than three chambers in the whorl. Misinterpretation of such sections may have led to errors in the past.

It is thus proposed to name the present form Gaudryina (Gaudryina) heywoodensis Reed, since the trivial name parri is preoccupied by G. (Pseudogaudryina) parri Cushman, 1936.

Occurrence: AC - AF

Genus PSEUDOCLAVULINA Cushman, 1936

Pseudoclavulina bradyana (Cushman) Pl. 1, fig. 10.

1936. Listerella bradyana Cushman, Cushman Lab. Foram. Res., Sp. Pub. 6, p. 40, pl. 6, fig. 11.

This species has been placed in the genus Pseudoclavulina as examination of a number of sections revealed no more than three chambers in the initial wherl, thus excluding this form from the genus Schenckiella Thalmann, 1942 (= Listerella Cushman, 1933, preoccupied name). In his type description of Listerella bradyana, Cushman did not mention the initial chambers, nor are they shown in his type figure. In all other respects, the Heywood forms are identical with the type description.

Occurrence: AD

Pseudoclavulina rudis (Costa) Pl. 1, figs. 3,6,12,14.

1855. Glandulina rudis Costa, R. Accad. Sci. Napoli, Mem., v. 2 (1855-57), p. 142, pl. 1, figs. 12, 13.

1937. Liebusella rudis (Costa), Cushman, Cushman Lab. Foram. Res., Sp. Pub. 8, pp. 168, 169, pl. 20, figs. 17 - 21.

Cushman placed this species in the genus Liebusella. Costa's original figures, however, do not show the labyrinthic chamber interior which is supposedly characteristic of this genus, and Cushman did not mention this feature in his description of the species (1937a, p. 168), not is it well shown in his illustrations (1937a, pl. 20, figs. 20, 21).

In a generic description subsequent to the original, Cushman (1937a, p. 163) stated "...the interior of the chambers often becomes distinctly labyrinthic..." If this is not a constant feature, therefore, it is unreasonable to regard it as a generic criterion. Similarly, the aperture is recorded as "...often becoming complex or irregularly radiate in the adult..."; once again, an unacceptable generic criterion because of its inconstancy. A taxonomic restudy of this and related genera, similar to Bowen's (1955) study of Gaudryina and its synonyms, is needed to show the exact nature of these structural differences among the arenaceous Foraminifera, and whether they have any value as generic or specific criteria.

Although a number of basal sections were made, no specimen was found to have more than three chambers in the initial whorl, which thus excludes this form from the genus Schenkiella Thalmann, 1942, and the aperture is always simple, sometimes with a short neck, but never with a tooth, thus excluding it from the genus Martinottiella Cushman, 1933. The present form is, therefore, placed in the genus Pseudoclavulina Cushman, 1936.

Occurrence: AE - AG

Genus CLAVULINOIDES Cushman, 1936

Clavulinoides victoriensis (Cushman) Pl. 1, figs. 2, 9.

1936. Clavulinoides szaboi (Hantken) var. victoriensis Cushman, Cushman Lab. Foram. Res., Sp. Pub. 6, p. 22, pl. 3, figs. 19, 22.

This species shows variability in a number of features. In some specimens, the aperture is a simple terminal opening at the end of the last chamber, and in others, it is located at the end of a short cylindrical neck. In a few specimens, the sides are somewhat concave, whereas most have flat or slightly convex sides. The surface texture is also variable, but mostly coarse and rough.

Occurrence: AE, AF

Family MILIOLIDAE

Genus TRILOCULINA d'Orbigny, 1826

Triloculina brochita Carter

1963. Triloculina brochita Carter, Geol. Surv. Victoria, Mem. 22, p. 59, pl. 1, figs. 3, 4.

This species shows much variation in amount of inflation of the chambers and of embracing of earlier chambers by the later ones.

Occurrence: AC - AG

Triloculina trigonula (Lamarck)

1804. Miliolites trigonula Lamarck, Paris Mus. National Hist. Nat., Ann., v. 5, p. 351; v. 9 (1807), pl. 17, figs. 4a-c.

1826. Triloculina trigonula (Lamarck), d'Orbigny, Ann. Sci. Nat., Paris, sér. 1, v. 7, p. 299, pl. 16, figs. 5-9.

Typical specimens occur throughout most of the Haywood marl. However, two specimens from core AE were identical with the typical form in all respects, except for a platelike tooth in the aperture, which distinguishes the genus Triloculinella Riccio, 1950. Because of the otherwise close similarity with typical Triloculina and the association of the two forms together in the same sample, some doubt is cast on the tooth as a constant morphological feature in Triloculina.

Occurrence: AC - AG

Genus PYRGO Defrance, 1824

Pyrgo bulloides (d'Orbigny)

1826. Biloculina bulloides d'Orbigny, Ann. Sci. Nat., Paris, sér. 1, v. 7, p. 297, pl. 16, figs. 1-4.

The few specimens from cores AC, AF, and AG vary in the degree to which the last chamber envelopes the penultimate chamber. In some specimens the last chamber folds around most of the penultimate, so that in side view it has a distinct C-shape.

Occurrence: AC, AF, AG

Pyrgo inornata (d'Orbigny)

1846. Biloculina inornata d'Orbigny, Foraminifères fossiles du bassin tertiaire de Vienne (Autriche), p. 266, pl. 16, figs. 7-9.

There is some variation in the degree to which the last chamber embraces the penultimate, and in the position of the bifid tooth, which lies normally within the aperture, but in some specimens, projects beyond the apertural margin.

Occurrence: AC, AD, AE, AG

Genus SIGMOILOPSIS Finlay, 1947

Sigmoilopsis compressa Hornibrook

1958. Sigmoilopsis compressa Hornibrook, New Zealand Jour. Geol. Geophys., v. 1, no. 4, pp. 657, 671, figs. 5, 6, 11.

Specimens with a test composed of coarser sand grains than in the type species, but otherwise similar, are referred to this species. The size of the arenaceous material is considered to be an environmentally imposed, rather than a genetic, feature.

Occurrence: AC - AE

Genus SPIROLOCULINA d'Orbigny, 1826

Spiroloculina tenuiseptata Brady

1884. Spiroloculina tenuiseptata Brady, Rep. Challenger Exped., Zool., pt. 22, v. 9, p. 153, pl. 10, figs. 5, 6.

Carter (1958b, p. 30, pl. 2, figs. 1, 2) described and figured a similar form from near Birregurra, Victoria, as S. canaliculata d'Orbigny. His identification was based on a comparison with a topotype from Baden in the Vienna Basin. However, Cushman and Todd (1944, pp. 47, 48) recorded a specimen from Birregurra as S. tenuiseptata, pointing out that this species closely resembles S. canaliculata, but differs in having the inner part of each chamber depressed and the outer part strongly raised, while S. canaliculata has both inner and outer margins raised. S. tenuiseptata is also apparently restricted to the Indo-Pacific region, whereas the other species has been recorded only from Europe and northern Africa.

Family LAGENIDAE

Genus LAGENONODOSARIA Silvestri, 1900

Lagenonodosaria scalaris (Batsch)

1791. Nautilus (Orthoceras) scalaris Batsch, Testaceorum arenulae marinae tabulae sex....(Sechs Kupfertafeln mit Conchylien des Seesandes), Jena, pp. 1, 4, pl. 2, figs. 4a, b.

Stainforth (1952, p. 14) restricted the name Nodosaria to species with radiate apertures, and used the genus Lagenonodosaria for forms having a simple aperture at the end of a long thin tube ornamented by multiple rings or collars, and consisting of a small number of evenly-arranged, globose, and usually striate or hispid chambers. The specimens of L. scalaris have from one to three, rarely four, chambers with variable longitudinal ornament as described by Heron-Allen and Earland (1924, p. 153) for forms from the "Filter Quarry", Moorabool River, Victoria.

Occurrence: AA, AB, AF

Family POLYMORPHINIDAE

Genus GUTTULINA d'Orbigny, 1839

Guttulina problema (d'Orbigny)

1826. Polymorphina (Guttulina) problema d'Orbigny, Ann. Sci. Nat., Paris, sér. 1, v. 7, p. 266, No. 14.

Some specimens, ornamented with faint longitudinal costae, would be classified as G. regina by Brady, Parker, and Jones (1870), who stated (p. 241) that this latter species "may be regarded morphologically as P. problema with an ornamentation of longitudinal ribs." Here the ornamentation is regarded as an ecologic, rather than a specific, character, on the basis of observations on living Foraminifera by Heron-Allen (1915,

p. 262).

Occurrence: AD, AG, AH

Guttulina spicaeformis (Roemer)

1838. Polymorphina (Guttulinen) spicaeformis Roemer, Neues Jahrb. Min. Geogn. Geol. Petref.-Kunde, p. 386, pl. 3, fig. 31a, b.

Some forms with faint longitudinal costae are included also under this species for the same reasons given above under G. problema, in which a similar situation arises.

Occurrence: AB, AG, AH

Genus SIGMOIDELLA Cushman and Ozawa, 1928

Sigmoidella kagaensis Cushman and Ozawa Pl. 2, fig. 1.

1928. Sigmoidella kagaensis Cushman and Ozawa, Cushman Lab. Foram. Res., Contr., v. 4, p. 19, pl. 2, fig. 14.

Typical forms similar to that illustrated in Cushman and Ozawa (1930, pl. 39, fig. 5), as well as forms transitional between this species and S. elegantissima, were found in core AB. It is possible that only one species is represented. Transverse sections across the two species show that S. kagaensis (Pl. 2, fig. 1) has a much larger initial chamber than S. elegantissima (Pl. 2, fig. 6), and it may be that the forms typical of S. kagaensis are actually a different stage in the life cycle of S. elegantissima. However, no specimens of S. kagaensis were found associated with S. elegantissima in cores AE and AF. Further work is needed to resolve the question.

Occurrence: AB

Family BULIMINIDAE

Genus UVIGERINA d'Orbigny, 1826

Uvigerina proboscidea Schwager

1866. Uvigerina proboscidea Schwager, Novara Exped. 1857-1859, Geol. Theil, v. 2, pt. 2, p. 250, pl. 7, fig. 96.

Besides the typical form, there are also specimens which, except for the lack of an acicular basal spine, are similar to the variety vadescens of Cushman (1933).

Occurrence: AD, AH

Genus BOLIVINA d'Orbigny, 1839

Bolivina victoriana Cushman

1936. Bolivina victoriana Cushman, Cushman Lab. Foram. Res., Sp. Pub. 6, p. 52, pl. 7, figs. 16a, b.

There is considerable variation in the specimens examined. Some have the typical Loxostomum development whereas others are typical Bolivina. Hofker (1951, p. 47) and Bhatia (1956) showed that Loxostomum has no generic standing but is merely a developmental end-stage in Bolivina, and thus, no distinction is made between these variants in the samples studied. Some forms show faint longitudinal costae in the initial part of the test, but apart from this ornamentation, these cannot be distinguiqhed from the typical form. It is probable that the specimens recorded and figured as Loxostoma heatyanum (Chapman) by Cushman (1937b, p. 180, pl. 21, figs. 6-8) belong to this species. Chapman's original Bolivina hentyana has since been shown to be an echinoid spine (Jenkins, 1958).

Occurrence: AA - AD

Family CHILOSTOMELLIDAE

Genus PULLENIA Parker and Jones, 1862

Pullenia bulloides (d'Orbigny)

1846. Nonionina bulloides d'Orbigny, Foraminifères fossiles du bassin tertiaire de Vienne (Autriche), p. 107, pl. 5, figs. 9, 10.

The specimens from the Heywood Bore and the type specimen of P. bulloides have four to four and a half chambers in the last whorl, compared with six chambers in the type specimen of P. miocenica Kleinpell. A specimen from the Miocene of eastern Victoria, intermediate between the two but referred to P. miocenica by Carter (1963, p. 71, pl. 2, figs. 45, 46), has five to five and a half chambers in the last whorl. In other respects, all are identical, and consequently must either belong to the same species, or be closely related.

Occurrence: AA, AE - AH

Family DISCORBIDAE

Genus ROSALINA d'Orbigny, 1826

Rosalina bertheloti d'Orbigny

1839. Rosalina bertheloti d'Orbigny, Foraminifères des Iles Canaries, in Barker-Webb and Berthelot, Hist. Nat. des Iles Canaries, v. 2, pt. 2, Zool., p. 135, pl. 1, figs. 28-30.

This species is probably the same as that from the Aire coast near Cape Otway referred to R. scopos (Finlay) by Carter (1958b, pp. 41, 42, pl. 4, figs. 34-36).

Occurrence: AA - AD, AF, AG

Genus GYROIDINOIDES Brotzen, 1942

Gyroidinoides allani (Finlay)

1939. Gyroidina allani Finlay, Roy. Soc. New Zealand, Trans. Proc., v. 69, pt. 3, p. 323, pl. 28, figs. 134-136.

The specimens found are somewhat smaller (0.83 mm) than the type species (1.3 mm) but are otherwise typical. G. zelandicus (Finlay), also found in the Heywood section, is smaller than G. allani, and has eight to nine chambers in the last whorl, compared with ten to eleven in G. allani.

Occurrence: AE

Genus EPONIDES Montfort, 1808

Eponides repandus (Fichtel and Moll)

1798. Nautilus repandus Fichtel and Moll, Testacea microscopica aliaque minuta ex generibus Argonauta et Nautilus ad naturam delineata et descripta, Vienna, (1803 reprint), p. 35, pl. 3, figs. a-d.

1958. Eponides repandus (Fichtel and Moll), Carter, Geol. Surv. Victoria, Bull. 55, pp. 45, 46, pl. 6, figs. 51-53.

This form shows great variability in the number of chambers in the last whorl, in the degree of convexity of both sides, in the development of accessory openings in the face of the last chamber, and in the limbacity of the dorsal sutures. Resig (1962) described the great variability in growth stages of E. repandus from the Californian Pleistocene, and her conclusions are supported by this study.

Forms comparable to those named E. lornensis by Finlay (1939, pp. 521, 522) occur together with those more typical of E. repandus, but all gradations between the two forms are present. They are thus grouped here under the same name.

Occurrence: AB - AH

Genus MISSISSIPPINA Howe, 1930

Mississippina concentrica (Parker and Jones)

1864. Pulvinulina concentrica Parker and Jones, in Brady, Linn. Soc. London, Trans., v. 24, pt. 3, p. 470, pl. 48, figs. 14a, b.

1958. Stomatorbina concentrica (Parker and Jones), Carter, Geol. Surv. Victoria, Bull. 55, pp. 40, 41, pl. 4, figs. 37-39; pl. 7, fig. 75.

The present status of the genera Mississippina and Stomatorbina was discussed by Hornibrook (1961, pp. 114-115), and his conclusion that Stomatorbina is a synonym of Mississippina has been followed.

Occurrence: AB - AH

Genus CANCRIS Montfort, 1808

Cancris intermedius Cushman and Todd

1942. Cancris intermedius Cushman and Todd, Cushman Lab. Foram. Res., Contr., v. 18, p. 88, pl. 22, figs. 11, 12.

As Carter (1963, p. 85) observed, this species occurs with forms named C. ovatus by Cushman and Todd (1942, p. 89), as well as with transitional specimens. All are regarded as a single species.

Occurrence: AA, AC, AD

Genus CIBICIDES Montfort, 1808

Cibicides lobatulus (Walker and Jacob)

1798. Nautilus lobatulus Walker and Jacob, in Kanmacher, F., Adams' Essays on the microscope. Ed. 2, p. 642, pl. 14, fig. 36.

The highly variable nature of the tests of this species has been discussed by a number of authors (Bhatia, 1956; Carter, 1951; Drooger, 1953; Dupeuble, 1962). Studies of the living animal by Nyholm (1961a, b) have revealed a complex life cycle, which not only confirms the conclusions of others regarding test variability, but also suggests that the variation may be even more extreme than previously thought.

Nyholm (1961a) concluded that the supposed genera Cibicidella, Dyocibicides, and Stichocibicides were all based on individual variation within the plastic species, Cibicides lobatulus. Although Vagocibicides was not mentioned by Nyholm, it also appears to be based on a variant of Cibicides lobatulus and, therefore, is another synonym of Cibicides. All these aberrant forms which were found in the Heywood samples with typical Cibicides lobatulus, have an initial Cibicides-like test before adopting their various erratic growth patterns.

Occurrence: AA - AH

Cibicides pseudoungerianus (Cushman)

1922. Truncatulina pseudoungeriana Cushman, U.S. Geol. Sur., Prof. Paper 129-E, p. 97, pl. 20, fig. 9.

Specimens from the Heywood Bore have been compared with the holotype and paratypes in the Cushman Collection in the National Museum, Washington, D.C., and are considered identical. This species is variable in the degree of convexity of both sides, and in the amount of clear shell material which obscures the early whorls of the test. It is probable that the form referred to C. perforatus by Carter (1958b, p. 46, pl. 6, figs. 57-59) belongs to this species also.

Occurrence: AA - AC, AE - AI(1)

Cibicides mediocris Finlay

1940. Cibicides mediocris Finlay, Roy. Soc. New Zealand, Trans. Proc., v. 69, pt. 1, p. 464, pl. 67, figs. 198, 199.

This species appears to be fairly constant in its characters, varying only in the amount of inflation of the last-formed chambers.

Occurrence: AA, AB, AD - AF

Cibicides victoriensis Chapman, Parr, and Collins Pl. 5, figs. 13-15.

1934. Cibicides victoriensis Chapman, Parr, and Collins, Linn. Soc. London, Jour., Zool., v. 38, p. 571, pl. 9, figs. 16a-c.

The spiral surface of the test of this distinctive species, whose initial appearance indicates Faunal Unit 11 (Carter, 1963, p. 43) or the Bairnsdalean Stage of the Victorian Tertiary, is covered by a variable amount of secondary shell material. In some specimens, this obscures the sutures of all chambers save those of the last-formed whorl, while other specimens have only a small accumulation on the earliest one or two whorls.

Occurrence: AA

Family PLANORBULINIDAE

Genus CARPENTERIA Gray, 1858

Carpenteria rotaliformis Chapman and Crespin Pl. 2, figs. 4,7,8,11.

1930. Carpenteria rotaliformis Chapman and Crespin, Roy. Soc. Victoria, Proc., n.s., v. 43, pp. 98, 99, pl. 5, figs. 7, 8.

A good description of the development and mode of growth of this species, in agreement with observations made on the Heywood specimens, was published by Glaessner and Wade (1959, p. 200).

Occurrence: AB, AD - AF

Family CAMERINIDAE

Genus CAMERINA Bruguière, 1792

Camerina complanata (Defrance) Pl. 2, figs. 2,5,9,10,12.

1882. Lenticulites complanata Defrance, Dict. Sci. Nat., v. 25, p. 453.

1938. Operculina victoriensis Chapman and Parr, Roy. Soc. Victoria, Proc., n.s., v. 50, pp. 284-287, pl. 16, figs. 3-8, text fig. 1.

The internal structure of specimens from the Heywood Bore (Pl. 2, figs. 5, 10, 12) is the same as that of Recent and fossil specimens identified as C. complanata by Cole (1959, pl. 29, fig. 16; pl. 31, figs. 2-4; 1961, pl. 15, fig. 1; pl. 16, figs. 1-9), and it compares well with the structure of "Operculina victoriensis" as shown in the type figures of Chapman and Parr (1938, pl. 16, figs. 4, 5, 8).

The Heywood specimens of Camerina complanata exhibit the same variations in ornament as that described for "Operculina victoriensis" by Chapman and Parr (1938, pp. 284-287) and Carter (1963, pp. 128, 129). Topotype specimens of Camerina complanata from Dax, France, in the Cushman Collection at the U.S. National Museum, Washington, D.C., show a similar variation in ornament. The test may be entirely smooth, or may be beaded, and have raised, often beaded, limbate sutures (Pl. 2, figs. 2, 9). Intermediate combinations of beading and sutural ornament occur. The test ornament is unrelated to internal characters such as proloculus size, or number of chambers per whorl, and is apparently an ecologically controlled feature. An ecologic, rather than a genetic control was suggested previously for the variable ornament in "Operculina" floridensis (Cole, 1958, p. 193) and in Camerina complanata (Cole, 1961, p. 122).

Occurrence: AA, AB

c. Planktonic species

Family GLOBIGERINIDAE

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina angustiumbilicata (Bolli) Pl. 3, figs. 1-6; pl. 4, fig . 2.

1957. Globigerina ciperoensis angustiumbilicata Bolli, U.S. Nat. Mus., Bull. 215, p. 109, pl. 22, figs. 12a-c, 13a-c.

The final chamber in this species is subject to variation in shape and size, ranging from the normal spherical chamber down to what may be regarded as a large apertural lip on the penultimate chamber. No taxonomic significance is attached to the aberrant final chamber. Takayanagi and Saito (1962, p. 74) have given good reasons why they do not consider this feature to be the basis for specific distinction in this or in other planktonic species in which it also occurs.

Occurrence: Common in cores AF - AH, rarer in AA, AC, AE.

Globigerina ciperoensis Bolli Pl. 4, figs. 6-8

1954. Globigerina ciperoensis Bolli, Cushman Found. Foram. Res., Contr., v. 5, pt. 1, pp. 1, 2, textfigs. 3, 3a, 4, 4a-b, 5, 5a-b, 6.

1957. Globigerina ciperoensis ciperoensis Bolli, U.S. Nat. Mus., Bull. 215, p. 109, pl. 22, figs. 10a-b.

G. ciperoensis "angulisuturalis" has not been recognized in the Heywood material, although it occurs with the typical form in the Lakes Entrance samples (Jenkins, 1960, p. 350) and in samples from the Caribbean region (Bermudez, 1960, p. 1166).

Occurrence: Scarce in cores AF and AG.

<u>Globigerina euapertura Jenkins</u> Pl. 3, figs. 7,14,15.

1960. <u>Globigerina</u> <u>euapertura</u> Jenkins, Micropaleont., v. 6, p. 351, pl. 1, figs. 8a-c.

This species extends higher in the Heywood Bore than in the Lakes Entrance Oil Shaft, from where it was originally described. As pointed out by Jenkins (1960, p. 351), the height of the aperture varies within any population of <u>G</u>. <u>euapertura</u>, and this is confirmed by the Heywood specimens.

Occurrence: Frequent in cores AG and AH, scarcer in AF; rare in AI(1)?

<u>Globigerina falconensis Blow</u> Pl. 3, figs. 8-10.

1959. <u>Globigerina</u> <u>falconensis</u> Blow, Bull. Amer. Paleont., v. 39, no. 178, p. 177, pl. 9, figs. 40a-c, 41.

Specimens from the Heywood Bore have been compared with the holotype and paratypes in the U.S. National Museum Collection at Washington, D.C., and are considered identical.

Occurrence: Frequent in cores AA and AB.

<u>Globigerina glutinata Egger</u> Pl. 3, figs. 16,23,24.

1893. <u>Globigerina</u> <u>glutinata</u> Egger, K. bayer. Akad. Wiss., math.-physik. Cl., Abh., v. 18, pt. 2 (1893), p. 371, pl. 13, figs. 19-21.

1962. <u>Globigerina</u> <u>glutinata</u> Egger, Takayanagi and Saito, Sci. Rep. Tohoku Univ., ser. 2 (geol.), Sp. Vol. 5, pp. 86-88, pl. 27, figs. 13a-c, 17a-c.

An accessory apetture occurs in some specimens, especially in core AD. A good discussion of the significance of this feature was published by Takayanagi and Saito (1962, p. 87), who regard it as of no taxonomic importance.

<u>*Globigerina praebulloides* Blow</u> Pl. 3, figs. 25-27.

1959. *Globigerina praebulloides* Blow, Bull. Amer. Paleont., v. 39, no. 178, pp. 180, 181, pl. 8, figs. 47a-c; pl. 9, fig. 48.

Specimens from the Heywood cores have been compared with the holotype and paratypes in the U.S. National Museum Collection in Washington, D.C., with which there is good agreement.

Some specimens, particularly in cores AF - AH, but also in the other cores from the upper part of the Gambier limestone, possess a bulla covering the umbilicus. It is usually in the form of a flattened plate but occasionally may be inflated. Jenkins (1960, p. 356) recorded similar forms from the Lakes Entrance Oil Shaft as *Catapsydrax* cf. *stainforthi* Bolli, Loeblich and Tappan. Here, however, the opinion of Hofker (1959; 1961) that the bulla possesses no taxonomic value but is merely a feature developed during reproduction, is followed in placing these bullate forms in the genus *Globigerina*. On removal of the bulla, no difference can be seen from normal *G. praebulloides*.

Occurrence: Abundant in cores AA - AH, rare in AI(1).

<u>*Globigerina triloculãris* d'Orbigny</u> Pl. 3, figs. 17-19.

1826. *Globigerina trilocularis* d'Orbigny, Ann. Sci. Nat., Paris, sér. 1, v. 7, p. 277, no. 2 (nom. nud.).

1832. *Globigerina trilocularis* d'Orbigny, Deshayes, Encyclopédie Méthodique; Histoire naturelle des vers, v. 2, pt. 2, p. 170.

1897. *Globigerina trilocularis* d'Orbigny, Fornasini, Rend. R. Accad. Sci. Ist. Bologna, n.s., v. 2 (1897-1898), fasc. 1, pl. 1, figs. 6, 7, 7a; p . 12, textfig.

1962. *Globigerina trilocularis* d'Orbigny, Takayanagi and Saito, Sci. Rep. Tohoku Univ., ser. 2 (Geol.), Sp. Vol. 5, p. 91, pl. 25, figs. 5a-c.

Jenkins (1960, p. 352) recorded from the bottom part of the Lakes Entrance Oil Shaft "...a variety of Globigerina praebulloides Blow, which tends to have only three chambers in the final whorl...". His description of this indicates that it is probably the same as the present species, which possesses a low arched to slitlike aperture and a relatively smooth test.

Occurrence: Common in cores AF - AG, rare in AE.

Globigerina woodi Jenkins Pl. 3, figs. 11-13.

1960. Globigerina woodi Jenkins, Micropaleont., v. 6, p. 352, pl. 2, figs. 2a-c.

This species is distinguished from the related forms, G. falconensis, G. praebulloides, and G. triloculris, by its coarsely pitted surface. The position and size of the aperture varies within the species as described by Jenkins (1960, p. 352).

Occurrence: Common to abundant in cores AA - AF.

Genus GLOBIGERINOIDES Cushman, 1927

Globigerinoides bisphericus Todd Pl. 5, figs. 1,2.

1954. Globigerinoides bispherica Todd, in Todd, Cloud, Low and Schmidt, Amer. Jour. Sci., v. 252, no. 11, p. 681, pl. 1, figs. 1a-c, 4.

The longer stratigraphic range of this species in the Heywood Bore and as recorded by Carter (1958a, b; 1959; 1963) from other Victorian occurrences compared with the shorter range ascribed to it in the Caribbean region (Bolli, 1957; Blow, 1959) and in eastern Victoria (Jenkins, 1960) has been discussed under the section on "Correlation with Caribbean planktonic zones." In the Caribbean region, Bermudez (1960,

p. 1241) recorded a longer stratigraphic range than given by Bolli for this species. Moreover, Bermudez regarded G. bispharicus as synonymous with G. sicanus de Stefani.

Occurrence: Scarce in cores AB and AD.

Globigerinoides glomerosus Blow Pl. 5, figs. 5,6,8,9.

1956. Globigerinoides glomerosa Blow, Micropaleont., v. 2, p. 64, textfig. 1, nos. 9-19; textfig. 2, nos. 1-4.

Blow (1956) recognized three subspecies of this form, each with a supposedly slightly different stratigraphic range, making up a bioseries linking G. bispharicus Todd with Orbulina suturalis Bronnimann. However, as Bermudez (1960, p. 1229) pointed out, it is difficult in practice to separate the three forms. Because they are found together in the same sample, they cannot by definition be subspecies (Mayr, Linsley and Usinger, 1953, p. 37; Boltovskoy, 1958, p. 199), but are best regarded as variations or forms.

Occurrence: Frequent in core AA (all three "subspecies" recognized).

Globigerinoides ruber (d'Orbigny) Pl. 4, figs. 14-16.

1839. Globigerina rubra d'Orbigny, Foraminifères, in de la Sagra, Histoire physique et naturelle de l'Ile de Cuba, p. 82, pl. 4, figs. 12-14.

Occurrence: Frequent in core AB.

Globigerinoides trilobus (Reuss) Pl. 4, figs. 17-21.

1850. Globigerina triloba Reuss, K. Akad. Wiss. Wien, Math.-Nat. Cl., Denkschr., v. 1, p. 374, pl. 47, figs. 11a-e.

Bolli (1957, p. 112) described the relationships between members of the G. trilobus group. Because they may occur together in the same sample, however, the members of the group are not subspecies, but are to be regarded rather as variations or forms. G. trilobus "trilobus" and G. trilobus "immaturus" were the only forms found in the Heywood samples.

Occurrence: Common in cores AA - AD.

Genus ORBULINA d'Orbigny, 1839

Orbulina bilobata (d'Orbigny) Pl. 5, fig. 3.

1846. Globigerina bilobata d'Orbigny, Foraminifères fossiles du bassin tertiaire de Vienne (Autriche), p. 164, pl. 9, figs. 11-14.

1956. Biorbulina bilobata (d'Orbigny), Blow, Micropaleont., v. 2, p. 69, textfig. 2, no. 16.

The taxonomic status of this species is at present unsettled. It always occurs in association with O. universa, and some authors (e.g. Jenkins, 1960, p. 356; Belford, 1962, p. 8), therefore, regard it simply as a growth form of this latter species. Other authors (e.g. Blow, 1956, p. 69; Bermudez, 1960, p. 1255) have given it generic status, having no direct relation with Orbulina. The former view seems more reasonable at present, but because of the doubt concerning the life history of O. universa, O. bilobata has been retained as a separate species until further evidence is forthcoming.

Occurrence: Scarce in core AA.

Orbulina suturalis Brönnimann Pl. 5, fig. 7.

1951. Orbulina suturalis Brönnimann, (part), Cushman Found. Foram. Res., Contr., v. 2, p. 135, textfig. 2, nos. 1,2,5-8,10; textfig. 3, nos. 3-8,11,13-16,18,20-22; textfig. 4, nos. 2-4, 7-12, 15,16,19-22.

1956. Orbulina suturalis Brönnimann, Blow, Micropaleont., v. 2, p. 66, textfig. 2, nos. 5-7.

Some specimens are difficult to distinguish from Globigerinoides glomerosus "circularis", and it may be preferable to regard the latter as a synonym of O. suturalis, as has been done by Chang and Yen (1958, p. 51) who do not accept Blow's emendation of Brönnimann's original diagnosis.

Occurrence: Abundant in core AA.

Orbulina universa d'Orbigny Pl. 5, fig. 4.

1839. Orbulina universa d'Orbigny, Foraminifères, in de la Sagra, Histoire physique, politique et naturelle de l'Ile de Cuba, p. 2, pl. 1, fig. 1.

Hofker (1956b; 1959) suggested that this form may include several species, in that it probably represents a reproductive stage of several species of Globigerina. This is supported to some extent by the fact that different wall structures can be found in specimens from the same Recent populations (Hofker, 1956b, p. 236) and from the same fossil populations (Belford, 1962, p. 7), and would account for the wide distribution of O. universa in the present seas (Parker, 1960, p. 80).

A factor that may impede the solution of the problem of the identity of O. universa in the future is that the initial globigerine portion of the test is apparently resorbed during the course of the reproductive process as the animal slowly sinks from the surface down to a depth of around 300 m., so that only the final spherical chamber remains (LeCalvez, 1936, p. 128). Without the initial chambers of the test it may be difficult to establish the true nature of this form from anything but living material. No evidence has yet been found for dimorphism associated with alternation of sexual and asexual reproduction in O. universa. This may be because there is no such alternation, the form itself representing one type of reproduction with the other type occurring in the globigerine stage.

Until this question is resolved, we can do nothing but retain O. universa in its presently held state as a form-species, rather than as an established genetic species.

Occurrence: Abundant in core AA.

Genus TURBOROTALIA Cushman and Bermudez, 1949

Hofker (1956a, p. 371) pointed out that a number of forms similar to "Globorotalia" centralis, the subgenotype of Turborotalia, "do not show the characters of Globorotalia, but those of Globigerina, with a nearly closed umbilicus and a sutural aperture," and are "actually globigerines in which the test has become more or less compressed and the umbilicus more or less closed." Although it may ultimately prove to be a synonym of Globigerina, the genus Turborotalia is retained for these forms.

The suprageneric position of Turborotalia is unsettled. Bermudez (1960, p. 1315) placed Turborotalia with Globoquadrina in the family Globorotaliidae. He considered Turborotalia to be more closely related to Globoquadrina than to Globigerina, the only difference being that Turborotalia lacks the typically globoquadrine tooth or valvular plate at the base of the septal face of each chamber. Although he classified Globoquadrina as a globorotaliid, Bermudez (1960, p. 1307) stated that Globoquadrina and Globigerina probably intergrade, a statement seemingly contradictory to his classification. Parker (1962, p. 235) classified the two genera as globorotaliids on the basis of similarity in wall structure, but she noted that whereas most species of Turborotalia have a globorotaliid type of wall structure, some species may have a globigerinid wall structure, thus revealing a flaw in the basis of her classification. Bolli, Loeblich and Tappan (1957, p. 20) placed Globoquadrina in the family Globigerinidae, but retained Turborotalia as a subgenus of Globorotalia in the family Globorotaliidae. The two genera however, are obviously too closely related to be placed in separate families. In this article, both are placed in the family Globigerinidae, following Hofker's (1956a) conclusions regarding the relationship of Turborotalia with Globigerina.

Turborotalia extans (Jenkins) Pl. 3, figs. 20-22.

1960. Globorotalia extans Jenkins, Micropaleont., v. 6, p. 360, pl. 4, figs. 4a-c, 5a-c.

Only the megalospheric form with four chambers (see Jenkins, 1960, p. 360) in the final whorl was found in the Haywood material.

Occurrence: Scarce in cores AG and AH.

Turborotalia increbescens (Bandy) Pl. 4, figs. 11-13.

1949. Globigerina increbescens Bandy, Bull. Amer. Paleont., v. 32, no. 131, p. 120, pl. 23, figs. 3a-c.

The specimens obtained agree well with the type description and figures.

Occurrence: Scarce to frequent in cores AG and AH, rare in AF.

?Turborotalia opima (Bolli) Pl. 4, figs. 3-5.

1957. Globorotalia opima opima Bolli, U.S. Nat. Mus., Bull. 215, p. 117, 118, pl. 28, figs. 1a-c, 2.

A single specimen from core AG having five chambers in the last whorl, but with a somewhat reduced or aborted final chamber, has been referred to this species. If the final chamber is not considered, it compares reasonably well with Bolli's illustration of the holotype. However, because of its aborted form and the lack of additional specimens, its identification is in doubt, and for this reason it is not shown on the correlation chart. Bermudez (1960, p. 1322) considered this species a synonym of T. increbescens (Bandy).

Occurrence: One specimen in core AG.

Genus GLOBOQUADRINA Finlay, 1947

Globoquadrina dehiscens (Chapman, Parr and Collins) Pl. 5, figs. 10-12.

1934. Globorotalia dehiscens Chapman, Parr and Collins, Linn. Soc. London, Jour., Zool., v. 38, p. 569, pl. 11, figs. 36a-c.

The probable reason for the extreme scarcity of this species below core AB in the Heywood marl has been already discussed in the section on "Influence of oceanic circulation on planktonic fauna."

Occurrence: Abundant in core AB, frequent in AA, rare (one specimen) in AE.

Family GLOBOROTALIIDAE

Genus GLOBOROTALIA Cushman, 1927

Globorotalia menardii "praemenardii" (Cushman and Stainforth) Pl. 4, figs. 1,9,10.

1945. Globorotalia praemenardii Cushman and Stainforth, Cushman Lab. Foram. Res., Sp. Pub. 14, p. 70, pl. 13, figs. 14a-c.

1959. Globorotalia menardii praemenardii (Cushman and Stainforth), Blow, Bull. Amer. Paleont., v. 39, no. 178, p. 215, pl. 18, figs. 118a-c.

This variation is smaller and more equally biconvex than typical G. menardii, with which it intergrades in the uppermost part of the Globorotalia fohsi barisanensis Zone in Venezuela (Blow, 1959, p. 215). It is extremely rare in the Heywood section, one specimen only being obtained from core AA. The reason for its rarity has been suggested in the section on "Influence of oceanic circulation on planktonic fauna."

Occurrence: Rare in core AA.

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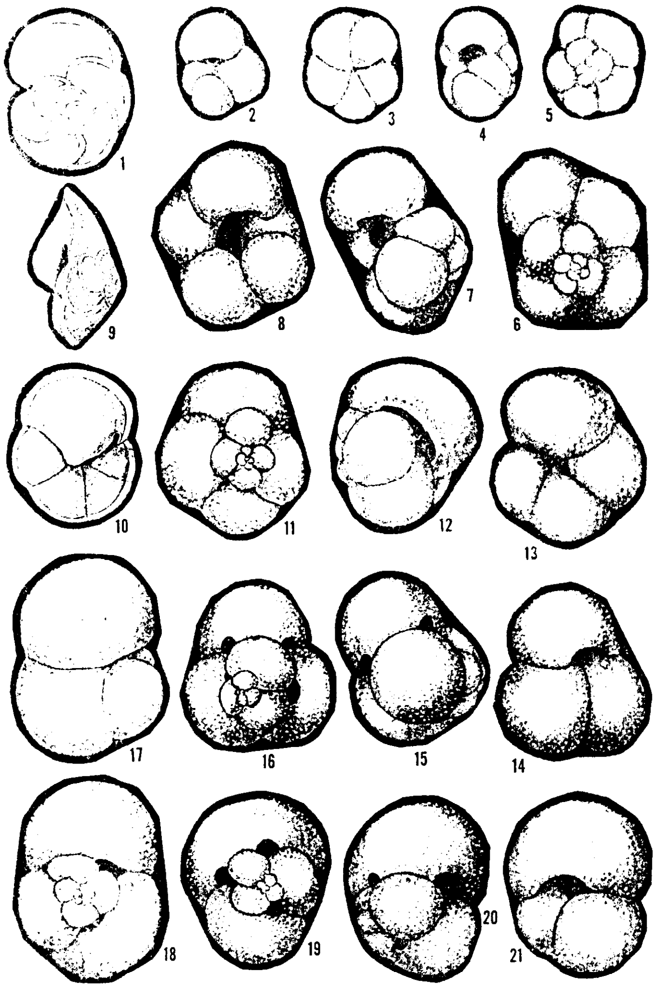

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