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MICROPALEONTOLOGY OF MIOCENE SEDIMENTS IN THE SHALLOW SUBSURFACE OF ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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PREFACE

With the development of detailed magneto-, chrono- and biostratigraphic organizational schemes (Berggren and others, 1985; Bolli and others, 1985; Haq and others, 1987), geologists working on more limited regional and stratigraphic scales have a powerful framework within which to interpret their findings. Conversely, results from smaller-scale studies are now relevant to a broad spectrum of workers around the globe.

The meticulous attention to detail so essential to small-scale studies can, in turn, provide information that may be useful in refining global schemes. For example, the chronology and patterns of fluctuating sea levels (Haq and others, 1987) can be tested in order to distinguish eustatic from local effects. Although individual small-scale studies cannot justify modifying larger-scale models, their cumulative contribution eventually may be significant.

Miocene sediments beneath the North Carolina continental shelf record a complex history related to changes in the world ocean and to their local geographic setting with respect to changing circulation patterns along the ocean margin. Paleontological analyses, an essential element in reconstructing that history, are the focus of this volume. Samples are from vibracores (maximum length of 9 meters), but data from the shallow subsurface can be extrapolated into down-dip sections on the basis of high-resolution seismic analyses.

I extend my appreciation to the authors, the reviewers and the Special Publications Editor (S. J. Culver), all of whom maintained the highest level of enthusiasm and professionalism. This publication was based on work supported in part by National Science Foundation Grants OCE-7908949, OCE-8110907, OCE-8118164 and OCE-8342777 (S. R. Riggs and A. C. Hine, principal investigators) and the National Office of Sea Grant, NOAA, Grants NA83AA-D-00012 and NA85AA-D-SG022 to the UNC Sea Grant College (S. W. Snyder and S. R. Riggs, principal investigators). Publication costs were provided by National Science Foundation Grant OCE-8609161 (S. R. Riggs, A. C. Hine and S. W. Snyder, principal investigators).

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OVERVIEW OF SEISMIC STRATIGRAPHY AND LITHOFACIES RELATIONSHIPS IN PUNGO RIVER FORMATION SEDIMENTS OF ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

The Miocene Pungo River Formation of the North Carolina continental shelf (Onslow Bay) comprises 18 fourth-order seismic sequences that can be grouped into three larger-scale sections which correlate approximately with third-order coastal onlap events. Fourth-order seismic sequences generally correspond to discrete depositional sequences. Seven regional lithofacies occur within these sequences. Microfossil distributional patterns can best be understood within the context of this seismic and lithologic framework.

INTRODUCTION

Although the focus of this volume is on paleontology, evidence from various fossil groups can be more completely understood within the context of a well-defined stratigraphic framework. This article presents a generalized summary of seismic stratigraphy and lithofacies relationships within the Pungo River Formation of Onslow Bay. It provides a stratigraphic perspective from which the paleontologic data presented in the following papers can be evaluated. More detailed seismic and lithologic analyses either have been or will be published elsewhere. A synthesis of individual paleontologic studies is provided in the final article of this volume.

REGIONAL PERSPECTIVE

The cuspate shoreline of North Carolina includes several capes separated by broadly concave embayments. Onslow Bay is a modern coastal embayment bordered by Cape Lookout to the north and by Cape Fear to the south (Fig. 1). Raleigh Bay and Long Bay are similar geomorphic features located to the north and south, respectively.

The continental shelf in Onslow Bay extends southeastward from the barrier islands to the 50-meter isobath. Attaining a maximum width of 100 km, the modern shelf consists of Tertiary strata, including the Miocene Pungo River Formation, which crop out on the seafloor, dip gently seaward, and are partially covered by a patchy veneer of Quaternary sands and gravels. Erosional remnants of indurated carbonates and calcareous sandstones of mostly Pleistocene age occur locally as mesa-like platforms overlying the Tertiary sediments (Mearns, 1986; Riggs and others, 1986).

Distribution of Mesozoic and Cenozoic sediments along the continental margin of North Carolina has been influenced by large-scale structural and smaller-scale paleotopographic features. Principal among these is the Carolina Platform, a broad region of gently seaward-dipping pre-Jurassic crust that forms a major structural ramp along the trailing edge of the North American continental margin (Sheridan, 1974; Dillon and others, 1979; Grow and Sheridan, 1981; Popenoe and others, 1982; Popenoe, 1985). The Mid-Carolina Platform High, traditionally called the Cape Fear Arch (Maher, 1971; Baum and others, 1979) but now recognized as the southeastern border of the Carolina Platform, extends from Cape Romain, S.C. to Cape Fear,

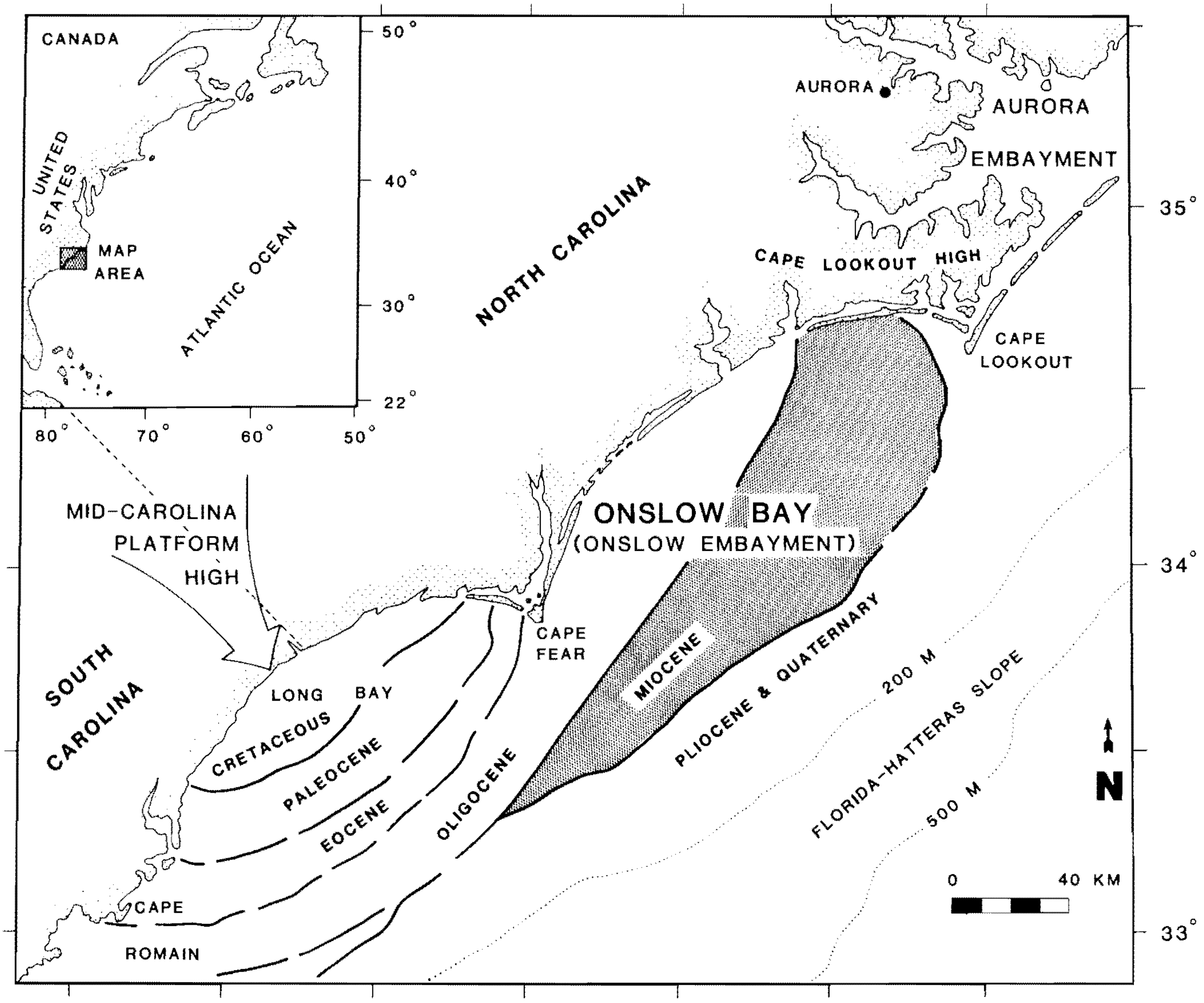

FIGURE 1. Locality map showing embayments, paleotopographic features and distribution of Cretaceous and Cenozoic strata along the North Carolina margin.

N.C. (Klitgord and Behrendt, 1979). It represents the landward effect of an offshore offset in the continental crustal edge. The most obvious influence of the Mid-Carolina Platform High on Cretaceous and Cenozoic sedimentation is seaward displacement of sediment sequences (Fig. 1). But regional subsidence history of the Carolina Platform also controlled lateral progradation of the margin. Seaward progradation of the continental shelf occurred primarily during the Tertiary via a succession of onlap and downlap accretional sequences at the shelf edge. The present outcrop pattern was produced by subsequent beveling in association with severe shoreface truncation during Neogene and Quaternary erosional transgressions (Stephen W. Snyder, 1982; Matteucci, 1984; Hine and Stephen W. Snyder, 1985; Popenoe, 1985).

Smaller-scale paleotopographic features controlled the location of individual depocenters (Riggs and others, 1985). For example, Neogene sediments infilled two embayments which existed along the North Carolina continental margin: the Aurora Embayment to the north and the Onslow Embayment to the south (Fig. 1). They were separated by the Cape Lookout High, an elongate, roughly east-west trending paleotopographic ridge that was built eastward by pre-Miocene sediment drift along the merge-point of the Gulf

Stream and south-flowing shelf currents (Stephen W. Snyder and others, 1982; Stephen W. Snyder, 1982; Riggs and others, 1985; Popenoe, 1985). Seismic evidence indicates the Cape Lookout High remained topographically positive during early and middle Miocene deposition along the North Carolina margin (Stephen W. Snyder, 1982). Sediments and associated faunas along flanks of the High suggest a shallow water depositional setting (Scarborough and others, 1982; Katrosh and Scott W. Snyder, 1982; Gibson, 1983).

GENERAL STRATIGRAPHIC SETTING

Phosphatic sediments that were later assigned to the Pungo River Formation were first delineated in Beaufort County, N.C. by Brown (1958). Kimrey (1964, 1965) named and formally described the formation, designating a core taken from near Belhaven, N.C. as the type section. There the formation consists of interbedded phosphate sands, variably phosphatic silts and clays, diatomaceous clays, limestones, and dolomite. The Miocene Pungo River Formation occurs in the subsurface of the emerged coastal plain (the Aurora Embayment) and crops out on the continental shelf in Onslow Bay (the Onslow Embayment).

In general, Pungo River sediments correlate with the Calvert and Choptank Formations of the Chesapeake Group in Virginia and Maryland, and with numerous formations in South Carolina, Georgia, and Florida where most have been included within the Hawthorn Group (Gibson, 1983; Carter, 1984; Riggs, 1984). Most of these sediments contain unusually high concentrations of authigenic minerals, including phosphate, glauconite, zeolites, Mg-rich clays, dolomite, and opal-CT (Riggs, 1984). This mineral assemblage sharply contrasts with predominantly carbonate and siliciclastic sediments of underlying and overlying formations.

In the Aurora Embayment, Pungo River sediments unconformably overlie Eocene, Oligocene, or questionable lower Miocene strata, depending upon geographic locality (Scarborough and others, 1982; Riggs and others, 1982; Gibson, 1983). In the Onslow Embayment, Oligocene strata lie unconformably below the Pungo River Formation which is, in turn, unconformably overlain by patches of Pliocene and Quaternary sediments (Stephen W. Snyder, 1982; Waters and Scott W. Snyder, 1986).

PREVIOUS WORK

Regional stratigraphic and lithologic studies of coastal plain Pungo River Formation sediments were initiated by Gibson (1967), who correlated upper calcareous beds from the Lee Creek phosphate mine near Aurora with the Calvert Formation. Miller (1971, 1982) and Brown and others (1972) utilized data from wells to trace Pungo River units throughout the subsurface of eastern North Carolina. Riggs and others (1982) and Scarborough and others (1982) described Pungo River lithofacies across the central coastal plain of North Carolina and recognized four lithostratigraphic units (A through D from oldest to youngest). Units A through C each contain a similar lithologic succession (predominantly siliciclastics, followed by increasing phosphate, capped by carbonate), and each is separated from units above and below by unconformities. Unit D, a barnacle/bryozoan hash which caps the formation, has negligible phosphate content. Riggs (1984) interpreted units A through C to represent smaller-scale sea level cycles within a third-order marine transgression. Unit D was interpreted to represent the initial phase of the subsequent third-order regression. Units A and B are of Burdigalian age (Powers, 1987), while units C and D are Langhian (Katrosh and Scott W. Snyder, 1982; Gibson, 1983).

Phosphate in surface sediments of the North Carolina continental shelf in Onslow Bay was first noted by Luternauer (1966), Pilkey and Luternauer (1967), and Riggs and Freas (1967). While conducting a survey for beach replenishment materials, Meisburger (1979) encountered Pungo River sediments in vibracores along the inner shelf of northern Onslow Bay. Steele (1980) described Pungo River sediments underlying Bogue Banks along the northern shore of Onslow Bay. Submarine Miocene outcrops were mapped by Blackwelder and others (1982) on the basis of rock-dredge samples.

Lewis (1981) and Lewis and others (1982) first described in detail the lithologies of Pungo River Formation outcrops in Onslow Bay. Stephen W. Snyder (1982) provided the initial seismic stratigraphic framework, an updated version of which is presented in this article. Others have focused on more narrowly defined aspects of Pungo River sediments in Onslow Bay. Lyle (1984) studied clay mineralogy, Ellington (1984) analyzed the major and trace element composition of phosphorites, Allen (1985) utilized isotopic studies to evaluate the origin of selected dolomites, and Stewart (1985) described the carbonate petrology of selected stratigraphic horizons.

STRATIGRAPHY OF MIOCENE SEDIMENTS IN ONSLOW BAY

The data base summarized in this paper was generated through eight research cruises directed by Stan-

TABLE 1. North Carolina continental margin research project (modified from Hine and Riggs, 1986).

Ship	Data	Dates
R/V Eastward	VC, SS, HRS	May 1980
R/V Endeavor	VC, SS, HRS	Oct 1980
R/V Columbus Iselin	VC, SS, HRS	May 1981
R/V Cape Hatteras	VC, SS, HRS	May 1982
R/V Cape Hatteras	VC, SS, HRS, SSS	May 1983
R/V Cape Hatteras	BC, SS, HRS, SSS	Oct 1983
R/V Cape Hatteras	BC, SS, HRS, SSS	Dec 1984
R/V Peirce	BC, SS, HRS, SSS	Dec 1985

VC = vibracoring; SS = surface sampling; SSS = side-scan sonar profiling; BC = box coring; HRS = high-resolution seismic profiling.

TABLE 2. Description of data base (modified from Hine and Riggs, 1986).

Type of data	Number	Units
Nine-meter vibracores	144	
Stratigraphic section	923	meters
Surface samples (Shipek)	340	
Rock-dredge hauls	26	
Box cores	18	
High resolution seismic profiles		
UNIBOOM	4,251	km
Sparker	917	km
3.5 kHz	7,643	km
One cubic inch air gun	208	km
Side-scan sonar profiles	340	km

ley R. Riggs of East Carolina University and Albert C. Hine of the University of South Florida (Table 1). The extent of each data set is summarized in Table 2.

SEISMIC STRATIGRAPHY

Seismic analyses of the Miocene section have provided a chronostratigraphic framework based solely on physical stratigraphic relationships. Sequence stratigraphy is based on the identification of physical surfaces of discontinuity (Vail and others, 1977; Haq and others, 1987). Regardless of the length of time represented by such surfaces, they are used to delimit genetically related strata (depositional sequences) which can be arranged in order of occurrence to provide a standard reference section composed of discrete, mappable time-stratigraphic intervals.

High-frequency (0.5 kHz to 15 kHz), high-resolution (<1 meter vertically) seismic data were collected, interpreted, and graphically reduced to stratigraphic line-drawings. Graphic reduction horizontally compresses the large volume of seismic data produced during a cross-shelf transect. For example, 100 km of UNIBOOM profiling yields more than 10 m of seismic data (Hine and Riggs, 1986). Publication of original seismic charts has, therefore, not been attempted here. Only reduced line drawings are included, but original data from limited portions of several traverses are published elsewhere (Hine and Stephen W. Snyder, 1985; Hine and Riggs, 1986).

In seismic reflection profiles, unconformities are identified by erosional truncation and the lateral termination of stratal reflectors in onlap, toplap, or downlap relationships. Within the North Carolina continental margin, unconformities were most commonly erosional horizons, with downlap surfaces frequently superimposed directly on them. The unconformities identified from seismic reflection data have been traced throughout the southern and central North Carolina continental margin (Stephen W. Snyder, 1982), demonstrating that they represent regional, possibly interregional, hiatuses. The stratigraphic section was subdivided using the intervening depositional sequences as the fundamental time-stratigraphic units.

At least 18 discrete, unconformity-bound depositional sequences have been delineated within the Miocene of Onslow Bay. Lithologic changes and the nature of seismic reflectors suggest that these 18 sequences can be grouped into three larger-scale sections. Seismic stratigraphic subdivisions recognized here have been updated from Stephen W. Snyder (1982), where 16 sequences were recognized. The terminology he used to describe sequences has also been modified. Because other publications (Riggs and others, 1985; Waters and Scott W. Snyder, 1986) followed the earlier seismic scheme, its relationship to the updated nomenclature used in this volume is graphically summarized in Figure 2.

The three larger-scale Miocene seismic sections correlate approximately with third-order coastal onlap events (Vail and others, 1977; Haq and others, 1987), an interpretation based largely on paleontological evidence to be outlined in other papers of this volume. These sections are hereafter referred to as the Frying Pan, Onslow Bay and Bogue Banks Sections (Fig. 2). Smaller-scale sequences, presumably linked to fourth-order eustatic events of shorter duration, are indicated by abbreviated form (FPS-1, FPS-2, etc.), where the letters specify the appropriate third-order section and the number indicates relative stratigraphic position of fourth-order sequences within that section (Fig. 2). The Frying Pan Section comprises FPS-1 through FPS-6; the Onslow Bay Section, OBS-1 through OBS-4; and the Bogue Banks Section, BBS-1 through BBS-8. Fundamental changes from the scheme of Stephen W. Snyder (1982) to that used here are in terminology ("formation" to "section") and in the subdivision of his BBF-1 into BBS-1 through BBS-3 (Fig. 2).

SEISMIC STRATIGRAPHIC NOMENCLATURE OF THE PUNGO RIVER FORMATION; NORTH CAROLINA CONTINENTAL SHELF

EPOCH	STAGE	SNYDER (1982)		THIS VOLUME	
		THIRD-ORDER SEISMIC SEQUENCE	FOURTH-ORDER SEISMIC SEQUENCE	THIRD-ORDER SEISMIC SECTION	FOURTH-ORDER SEISMIC SEQUENCE
MIOCENE	Serravallian	BOGUE BANKS "FORMATION"	BBF-6	BOGUE BANKS SECTION	BBS-8
			BBF-5		BBS-7
			BBF-4		BBS-6
			BBF-3		BBS-5
			BBF-2		BBS-4
			BBF-1		BBS-3
					BBS-2
					BBS-1
	Langhian	AURORA "FORMATION"	AF-4	ONSLOW BAY SECTION	OBS-4
			AF-3		OBS-3
			AF-2		OBS-2
			AF-1		OBS-1
	middle Burdigalian	FRYING PAN "FORMATION"	FPF-6	FRYING PAN SECTION	FPS-6
			FPF-5		FPS-5
			FPF-4		FPS-4
			FPF-3		FPS-3
			FPF-2		FPS-2
			FPF-1		FPS-1

FIGURE 2. Summary of seismic stratigraphic nomenclature and relative stratigraphic position of Miocene seismic sequences in Onslow Bay (update from Stephen W. Snyder, 1982).

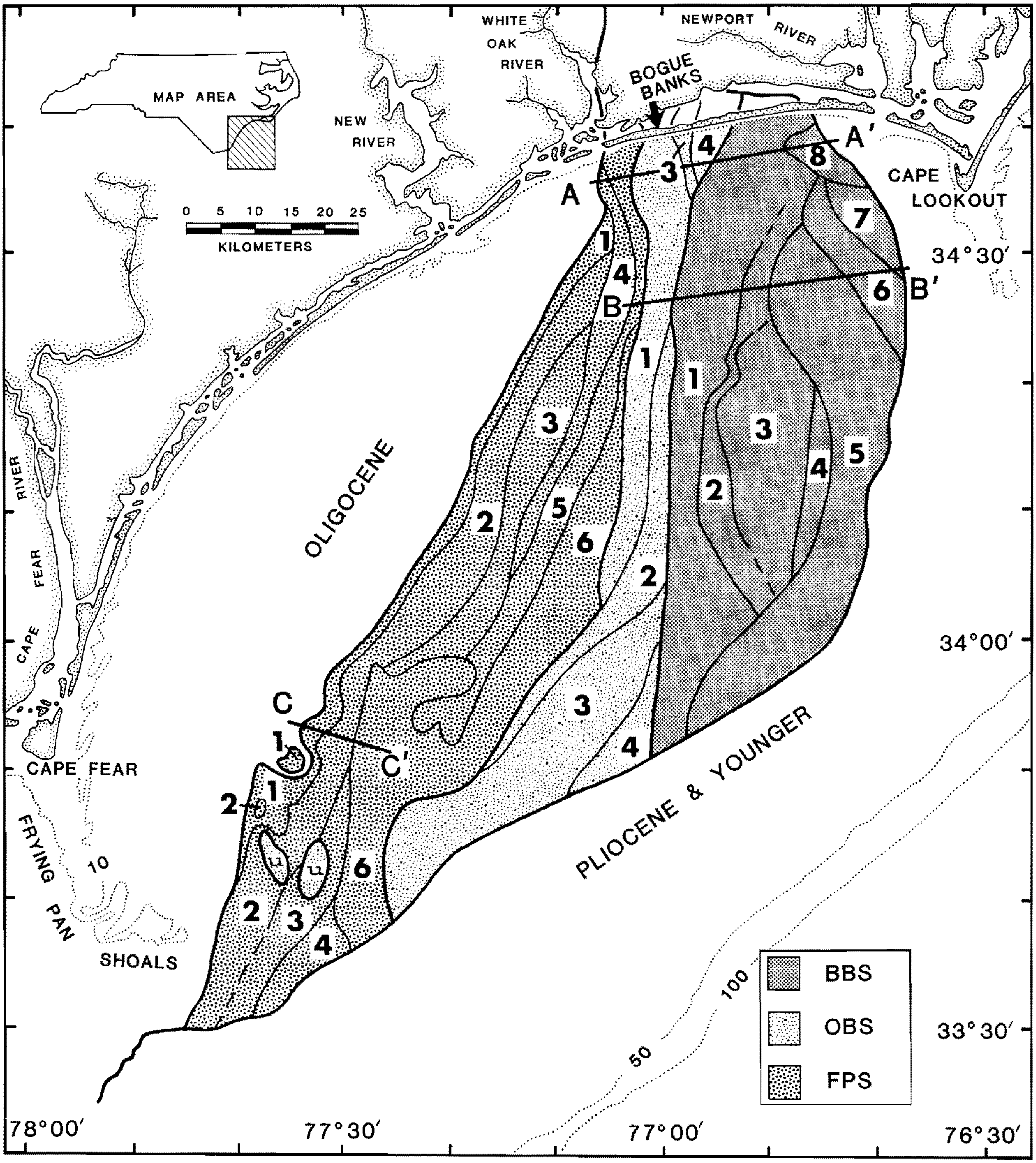

FIGURE 3. Map showing outcrop/shallow subcrop pattern of Miocene seismic sequences in Onslow Bay (modified from Stephen W. Snyder, 1982). The symbol "u" indicates sediments of the Onslow Bay Section which are undifferentiated with regard to fourth-order sequence. Note that these sediments occur as erosional outliers within the southern part of the Frying Pan Section outcrop belt. Lines A-A′, B-B′ and C-C′ locate the "15-meter," "22-meter" and "EN-8C" seismic profiles, respectively. These profiles are shown in Figures 4–6.

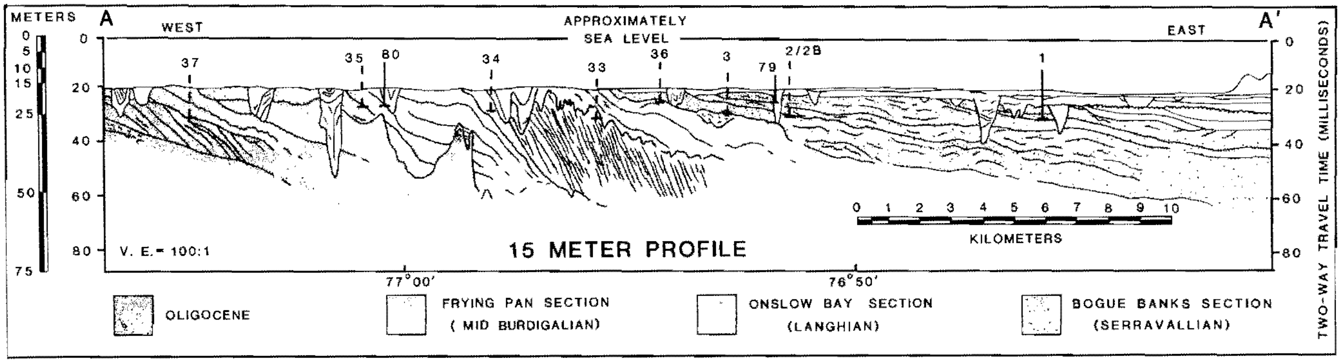

FIGURE 4. The 15-meter seismic profile across northern Onslow Bay (modified from Stephen W. Snyder, 1982). Vertical exaggeration is 100:1. The location of the profile and its relation to seismic sequences is shown by line A-A' in Figure 3. Cores indicated by dashed lines lie near but not precisely on the profile.

All unconformities were traced throughout a mosaic of intersecting seismic tracklines to generate an outcrop/shallow subcrop map of 18 depositional sequences within the Miocene section (Fig. 3). The Miocene "outcrops" delineated on the shelf represent only the updip, erosional feather-edges of their respective depositional sequences, which dip and thicken in a seaward direction (Figs. 4–6). Commonly, these "outcrop" belts are: 1) overlain by thin (<2 meters), discontinuous Holocene sands; 2) covered by thin erosional outliers of Pleistocene carbonates that form modern hardgrounds; 3) extensively dissected by fluvial paleochannel-fill sequences. Younger materials are not depicted on Figure 3 in order to clearly show Miocene patterns, but channeling and the thin cover of post-Miocene sediments can be seen in Figures 4–6 (shallow subbottom strata not marked by any pattern).

As demonstrated by the map (Fig. 3) and the interpreted seismic sections (Figs. 4–6), the Miocene stratigraphic section of Onslow Bay is not the "layer-cake" stratigraphy traditionally associated with coastal plains. Regional correlations between stratigraphic control sites cannot be made assuming continuous, flat-lying strata. Rather, Miocene sequences are characterized by numerous local and regional truncation surfaces produced by erosional episodes. The result is an extremely complex stratigraphic section, perhaps best exemplified by the "22 meter profile," which shows an erosional escarpment some 20 meters high (Fig. 5, between cores 39 and 6/6B) separating an earlier episode of shelf aggradation (Frying Pan Section) from one that was predominantly progradational (Onslow Bay Section).

Paleontologic and lithologic analyses of samples from cores along this and other transects would be most confusing if not viewed within the context of the seis-

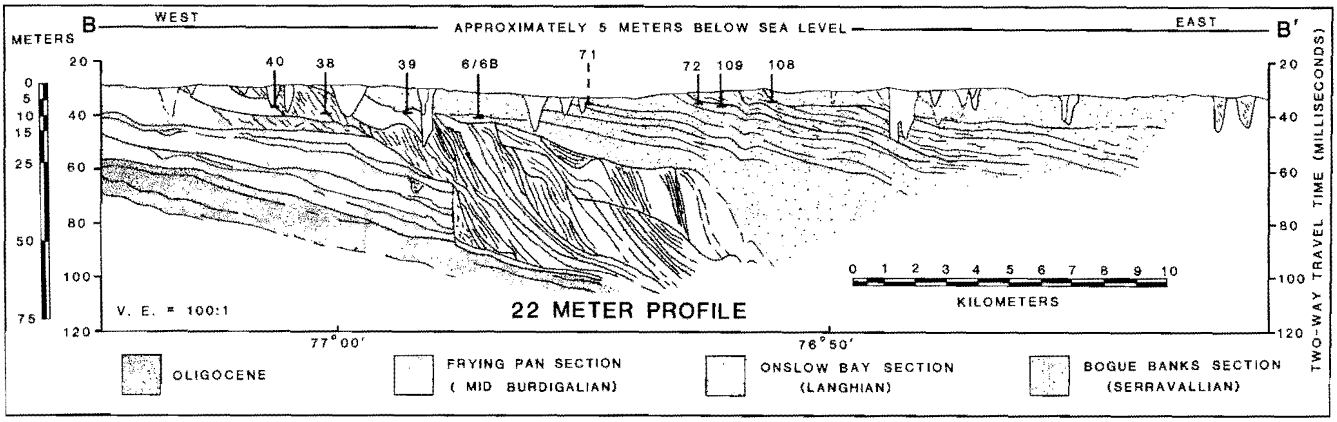

FIGURE 5. The 22-meter seismic profile across north-central Onslow Bay (modified from Stephen W. Snyder, 1982). Vertical exaggeration is 100:1. The location of the profile and its relation to seismic sequences is shown by line B-B' in Figure 3. Cores indicated by dashed lines lie near but not precisely on the profile.

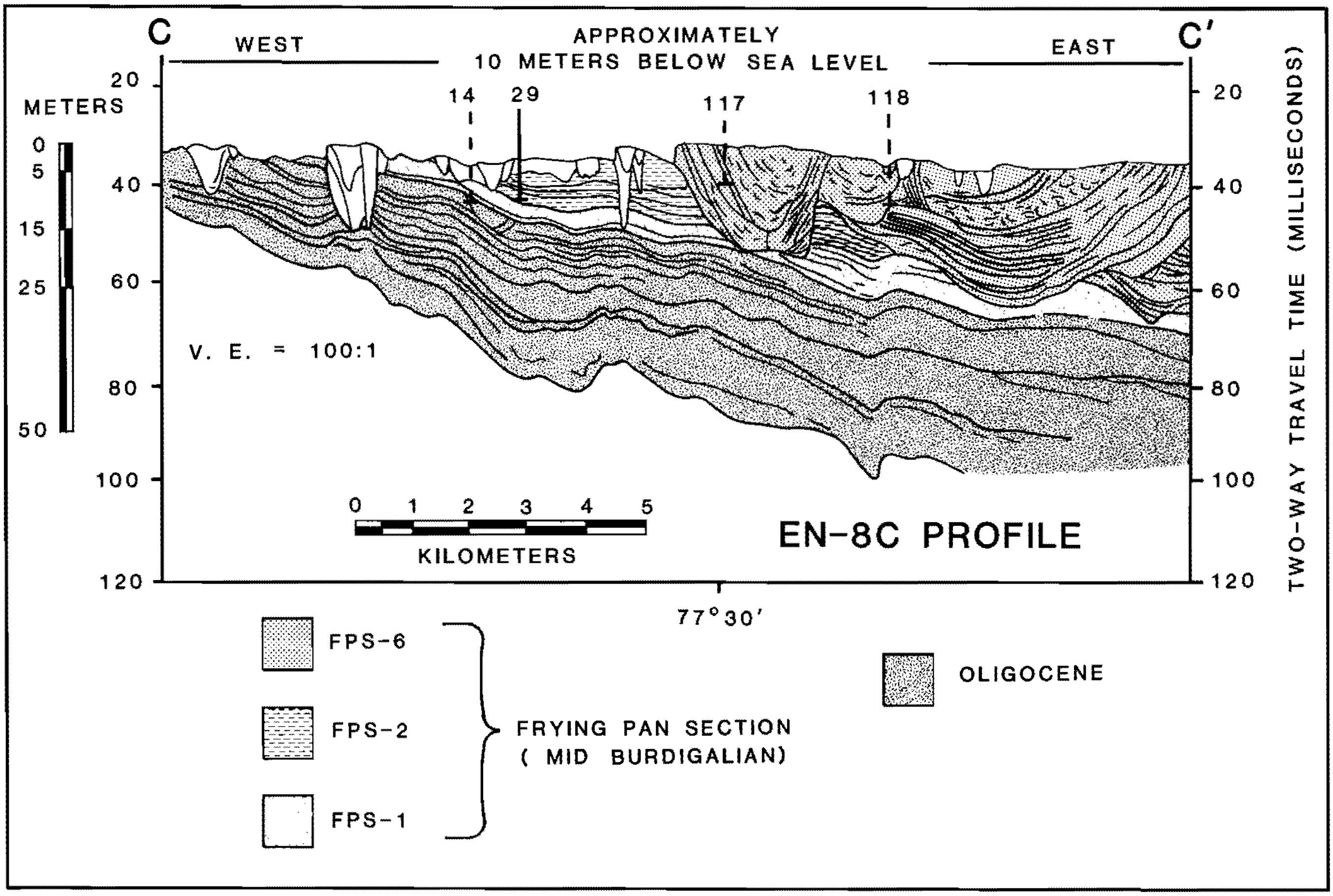

FIGURE 6. The EN-8C seismic profile across southern Onslow Bay (modified from Stephen W. Snyder, 1982). Vertical exaggeration is 100:1. The location of the profile and its relation to seismic sequences is shown by line C-C′ in Figure 3. Cores indicated by dashed lines lie near but not precisely on the profile.

mic stratigraphic framework. The continuous nature of high-resolution seismic reflection data provides a level of stratigraphic detail beyond that which can be generated by correlating among widely spaced core holes. Because sequences and sequence boundaries can be physically traced throughout the depositional basin, knowledge of what lies between stratigraphic control sites (i.e., cores) permits accurate location of sampled intervals within the composite stratigraphic section. The stratigraphic framework generated through seismic sequence analyses serves as a reference for all of the paleontologic studies within this volume.

LITHOFACIES RELATIONSHIPS

Samples for lithologic and paleontologic analyses were obtained using a vibracore system, a remotely controlled coring device lowered from a vessel onto the seafloor for operation. It employs a nine-meter shaft enclosing a core liner which is driven into the seafloor by means of a pneumatic hammer. Because maximum core length is nine meters, only the updip limit of any given seismic sequence could be penetrated.

Research cruises were generally organized to obtain vibracores during daylight hours and to do seismic profiling at night. Shipboard examination of seismic profiles was used to select vibracore sites. Loran-C navigation was employed to determine the location of vibracores. The accuracy of this system ranged from plus-or-minus 200 to 400 meters. Of one hundred forty-four vibracores, 100 located at 95 separate sites penetrated the Pungo River Formation (Fig. 7). Other vibracores penetrated only Oligocene or Quaternary sediments, or were located in post-Miocene channel-fill deposits. A total of 473 meters (an average of 4.7 meters per core) of Pungo River section were recovered (Table 3).

Lithologic analyses were carried out in two phases. First, cores penetrating Pungo River sediments were

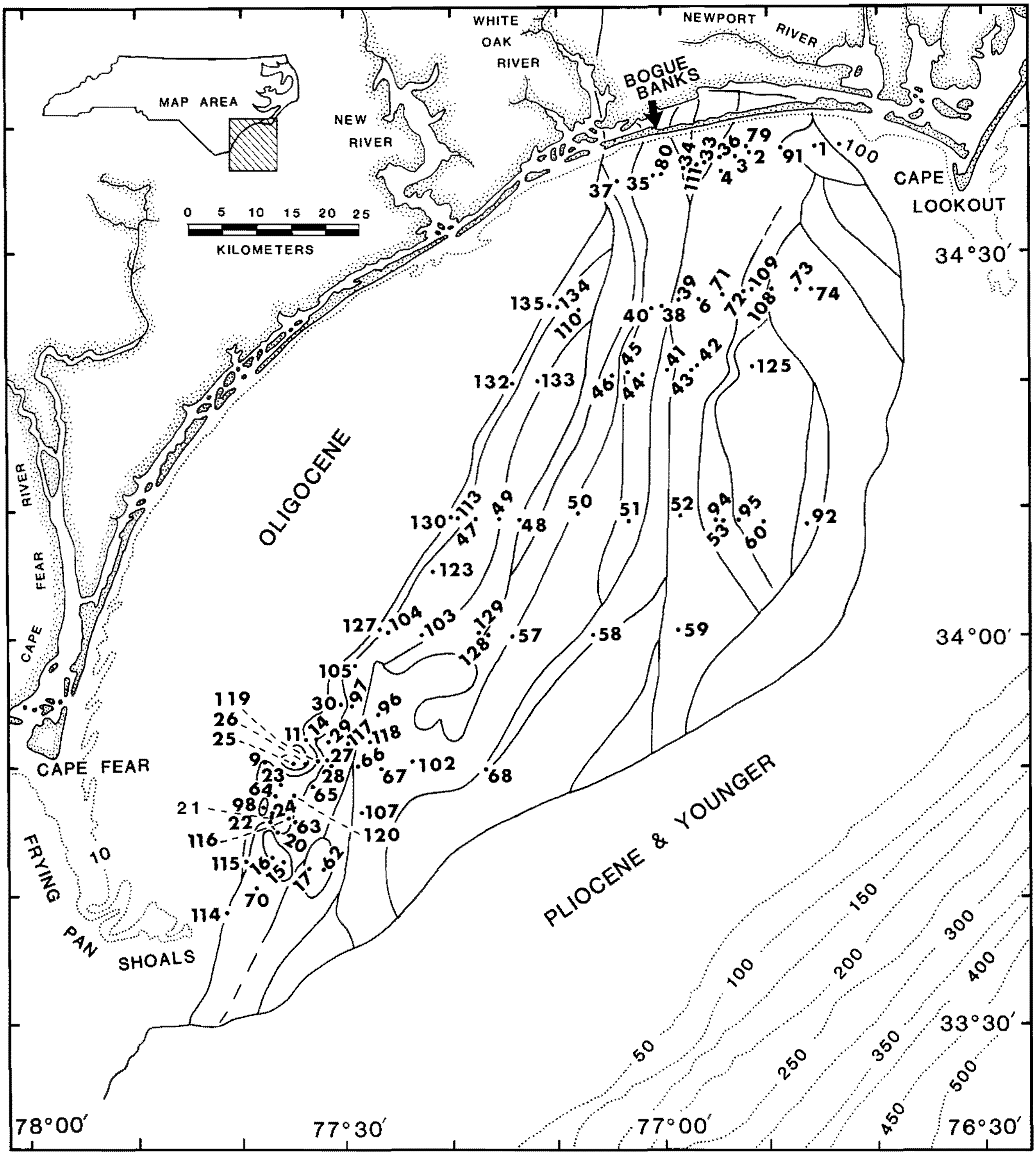

FIGURE 7. Location of vibracores (dots) that penetrated Pungo River sediments in Onslow Bay (meters of Pungo River section in each vibracore given in Table 3).

TABLE 3. Vibracore coverage within the Pungo River section (penetration not corrected for core expansion).

Core	Meters of Pungo River	Core	Meters of Pungo River
1	6.0	62	2.5
2A	4.0	63	2.7
2B	6.6	64	3.0
3	8.5	65	2.7
4	8.5	66	2.5
6A	7.6	67	4.5
6B	7.5	68	4.5
9	2.7	70	1.9
11	2.1	71	1.0
14	4.2	72	4.0
15	2.0	74	2.0
16	6.1	79	1.3
17	4.2	80	0.8
20	6.0	91	3.5
21	0.6	92	3.2
22	3.0	94	1.4
23	1.5	95	1.4
24	1.6	96	6.3
25	0.5	97	6.6
26	4.3	98	2.8
27	7.4	100	4.4
28	3.7	102	8.8
29A	1.3	103	5.2
29B	7.2	104	2.7
30	2.1	105	8.0
33	9.2	107	2.5
34	5.8	108	3.7
35	7.2	109	6.0
36	3.9	110	5.9
37	8.4	111	8.6
38	9.2	113A	2.1
39	9.9	113B	3.7
40	1.6	114	2.9
41	6.3	115	2.0
42	6.0	116	3.5
43	4.3	117	6.8
44	4.6	118	7.3
45	5.0	119	3.5
46	6.6	120	3.1
47	9.3	123	6.6
48	7.8	125	5.2
49	8.5	127	8.6
50	8.5	128	5.0
51	8.6	129	6.4
52	1.7	130	3.5
53	5.9	131	6.4
57	9.3	132	1.5
58	8.0	133	0.1
59	3.8	134	0.2
60	6.0	135	5.7

described on the basis of macroscopic and binocular microscopic examination. Next, these data were used to select specific cores for grain size, mineralogical point count, acid insoluble and bulk sediment geochemical analyses. These criteria formed the basis for distinguishing among Miocene lithofacies that were mapped throughout the Onslow Embayment (Fig. 8). Mallette (1986) demonstrated that fourth-order seismic sequences in the Pungo River Formation generally conform to depositional sequences recognized on lithologic criteria. Fine-scale primary depositional changes occur upward within most such sequences, and evidence of erosion and diagenetic alteration marks most unconformities. However, generalized lithofacies often cross boundaries between fourth-order depositional sequences. Therefore, lithofacies patterns are related to the larger, third-order seismic sections (Frying Pan, Onslow Bay, Bogue Banks).

The Frying Pan Section is divisible into five regional lithofacies (Fig. 8). In its southern portion, a phosphorite facies composed of muddy, quartzitic phosphorite sand lies above the Oligocene/Miocene unconformity. Above the phosphorite is a siliciclastic mud facies composed of organic-rich, slightly phosphatic siliciclastic mud with crystalline aggregates of zeolite (clinoptilolite) in the sand and silt fractions. This mud facies grades northward into a muddy siliciclastic sand facies which occupies most of the Frying Pan Section in central Onslow Bay. Siliciclastic components become coarser and more predominant toward the north. A mixed carbonate and quartz sand facies composed of molluscan-barnacle shell gravels interbedded with clean quartz sands occurs in the northernmost portion of the outcrop belt. The stratigraphically highest lithofacies in the Frying Pan Section is a foraminiferal quartz sand which truncates both the siliciclastic sand and mud facies in southern Onslow Bay (Fig. 8). Seismic reflectors indicate that the foraminiferal quartz sand facies forms a large-scale channel (FPS-6 in profile EN-8C in Fig. 6), the origin of which has not yet been unequivocally determined.

The Onslow Bay Section contains three regional lithofacies. A mixed carbonate and quartz sand facies occupies its northernmost portion (Fig. 8). Sediments consist of calcareous muds and biogenic sands and gravels with varying amounts of siliciclastic sands and cherts. Barnacle plates are common in the sand and gravel fractions. This facies is similar to the mixed carbonate and siliciclastic facies in the northern portion of the Frying Pan Section except that its carbonate content is generally higher. An interbedded siliciclastic sand and mud facies occupies most of the remainder of the Onslow Bay Section. Quartz sands alternate with clays containing disseminated silt-sized dolomite. As with siliciclastic components in the underlying Frying Pan Section, siliciclastics of the Onslow Bay Section fine southward. A siliciclastic mud facies occurs in outliers of the Onslow Bay Section which are located in the southern portion of the Frying Pan Section outcrop belt (Figs. 3 and 8). These outliers contain up to

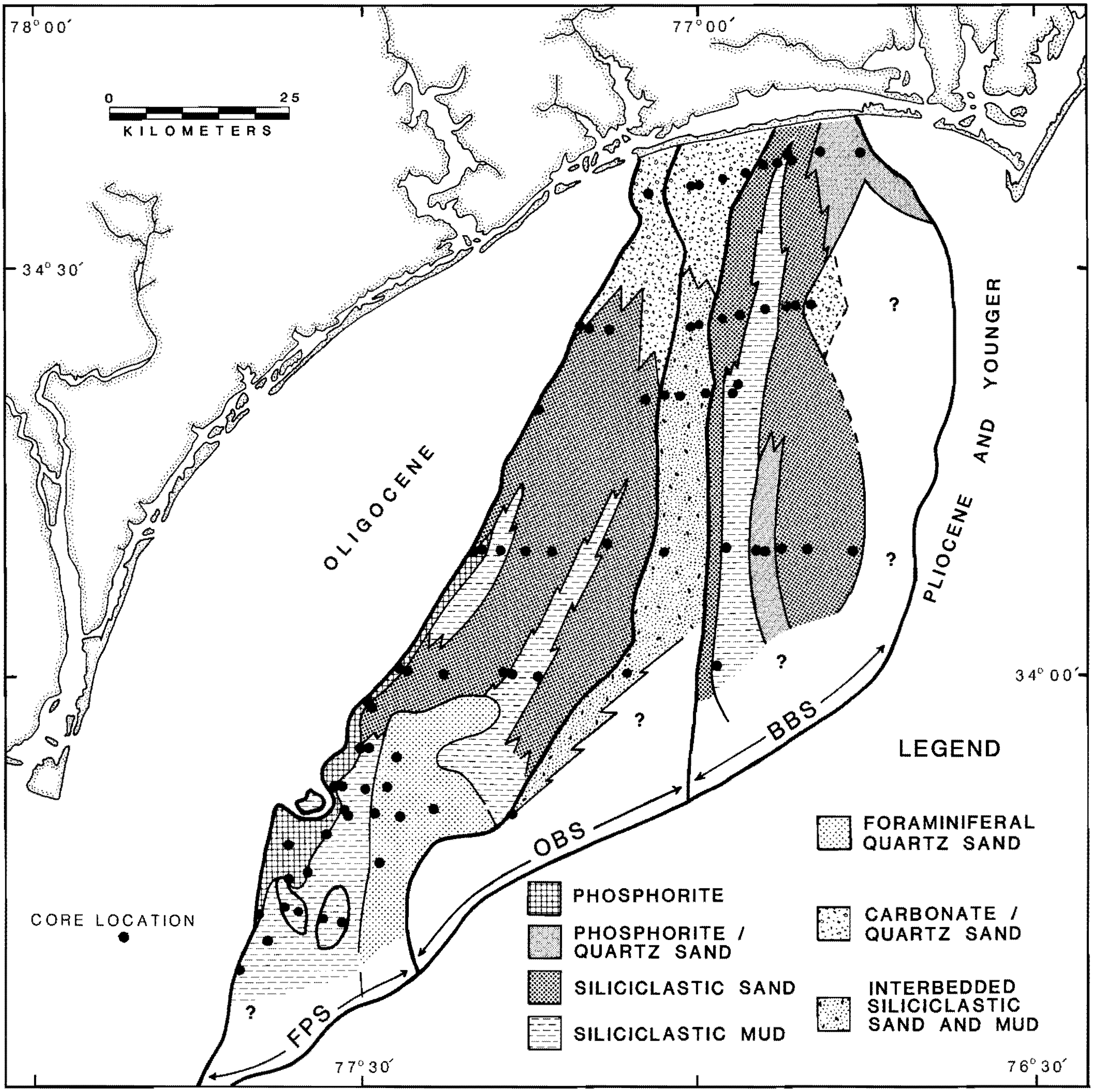

FIGURE 8. Generalized lithofacies distribution map within the Miocene section of Onslow Bay (modified from Mallette, 1986). Only third-order seismic sections are shown. Sections are designated as follows: FPS = Frying Pan Section, OBS = Onslow Bay Section, BBS = Bogue Banks Section.

10% siliceous microfossils, while surrounding muds of the Frying Pan Section contain no siliceous fossil remains.

Four regional lithofacies are present within the Bogue Banks Section (Fig. 8). Again siliciclastic mud and sand facies are areally most extensive, but there is no fining southward trend as noted in the previous sequences. Variably muddy quartz sands occur below and above muds containing silt-sized dolomite. Lithologically, these sands and muds are similar to those described in the Frying Pan Section. Most of the siliciclastic sands of the Bogue Banks Section contain some phosphate.

Where it exceeds 10% of the total sediment, a phosphorite/quartz sand facies was differentiated. This facies occurs in portions of the southern and northern parts of the outcrop belt. A carbonate and quartz sand facies occurs in one core, and though its lateral extent is unknown, an extensive carbonate-rich facies comparable to those of the Frying Pan and Onslow Bay Sections has not been encountered in the Bogue Banks Section. However, younger portions of the Bogue Banks Section, unknown because of a lack of vibracore coverage, may contain carbonates that have not yet been sampled.

General lithofacies patterns (Fig. 8) indicate that the Miocene history of Onslow Bay was characterized by distinct environments, each influenced by different modes of sedimentation. During deposition of the Frying Pan and Onslow Bay Sections, carbonates and quartz sands accumulated in northern Onslow Bay along the southern flank of the Cape Lookout High. This pattern apparently changed during deposition of the Bogue Banks Section when siliciclastic sands became predominant in this region. The carbonates, composed largely of molluscan and barnacle fragments, were derived from shoaling environments across the Cape Lookout High. Siliciclastic sands derived from a point source to the west intermixed with the carbonates. The Cape Lookout High remained a prominent topographic feature during carbonate deposition in the Frying Pan and Onslow Bay Sections, but it was buried by the time siliciclastic sands of the Bogue Banks Section were being deposited.

The central portion of all three third-order sections is composed predominantly of siliciclastic sands and muds. The interbedded nature of such deposits, particularly in the Onslow Bay Section, suggests that the slow accumulation of fine-grained, organic-rich sediments was periodically interrupted by episodes, possibly of shorter duration, when quartz sands were introduced from a point source to the west/northwest. Both high-resolution seismic profiling and geologic evidence suggest the presence of a buried deltaic system in the underlying Oligocene (late Chattian) sequences in this same area (Stephen W. Snyder, unpubl. data; Lawrence, 1975). Reactivation of a similar point source during the Miocene may have introduced recurrent pulses of siliciclastic sediments into central Onslow Embayment. The southward decrease in grain size and abundance of siliciclastic sediments allowed authigenic sedimentation to play a progressively more important role in southern Onslow Bay. The most obvious manifestation of this is a higher concentration of phosphate, dolomite, and microfossils.

The species content and distribution of microfossil assemblages changed vertically, through the succession of Miocene depositional sequences, and laterally, through environmental variations reflected by changing lithofacies. It is within the framework of seismic and lithic stratigraphy that paleontological trends described by other papers in this volume can best be appreciated.

ACKNOWLEDGMENTS

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OCCURRENCE AND BIOSTRATIGRAPHY OF PLANKTONIC FORAMINIFERA AND CALCAREOUS NANNOFOSSILS IN PUNGO RIVER FORMATION SEDIMENTS FROM ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

Planktonic foraminifera and calcareous nannofossils recovered from Pungo River Formation sediments in Onslow Bay permit correlation of three stratigraphic sections, each of which approximates a third-order coastal onlap event, with standard ages: Frying Pan Section = middle Burdigalian, Onslow Bay Section = Langhian, and Bogue Banks Section = upper Serravallian. Integrated foraminiferal and nannofossil data also provide biostratigraphic constraints for some fourth-order seismic sequences: FPS-1 and FPS-2 = lower Zone N6, FPS-6 = upper N6 to lower N7, OBS-2 and OBS-3 = mid N8 to upper N9, and BBS-1 to BBS-5 = N12 through N14. The durations of hiatuses between successive third-order sections are approximately 1.0 to 1.5 Ma, whereas those between fourth-order sequences cannot be resolved biostratigraphically.

INTRODUCTION

This study records for the first time the occurrence, preservation and biostratigraphy of planktonic foraminifera and calcareous nannofossils in outcropping/shallow subcropping Pungo River Formation sediments throughout Onslow Bay. The only other work on calcareous nannofossils from this area is a recently published abstract dealing with Oligocene sediments (Laws and Worsley, 1986).

Planktonic foraminifera from the Pungo River Formation have been extensively studied, but previous work has focused on subsurface occurrences in the emerged coastal plain of North Carolina. Miller (1971), as part of a regional study on Pungo River units in the subsurface of eastern North Carolina, encountered foraminiferal species diagnostic of a middle Miocene age. His interpretation of the entire formation as middle Miocene was modified by Gibson (1982), who used planktonic and key benthic foraminifera to reinterpret portions of the Calvert and Pungo River formations as late early Miocene. Miller (1982) concurred with Gibson's interpretation. Katrosh and Snyder (1982) assigned upper Pungo River sediments exposed at Texasgulf's Lee Creek Mine to planktonic foraminiferal Zone N8 (Blow, 1969, 1979). Lower portions of the formation could not be dated as they are nearly barren of planktonic specimens. Gibson (1983) assigned Pungo River strata extending from Norfolk, Virginia to the Neuse River in North Carolina to planktonic foraminiferal Zone N8. He encountered planktonic assemblages assignable to Zone N11, but they were limited to extreme northeastern North Carolina. Gibson did not recognize strata equivalent to zones N9 and N10, nor did he elaborate on the duration or geographic extent of intraformational unconformities.

The only previously-published article on planktonic foraminifera from Onslow Bay examined the lower portion of the Pungo River Formation section in southern Onslow Bay (Waters and Snyder, 1986). Sediments were assigned to planktonic foraminiferal zones N6/N7. The present study incorporates data from Waters

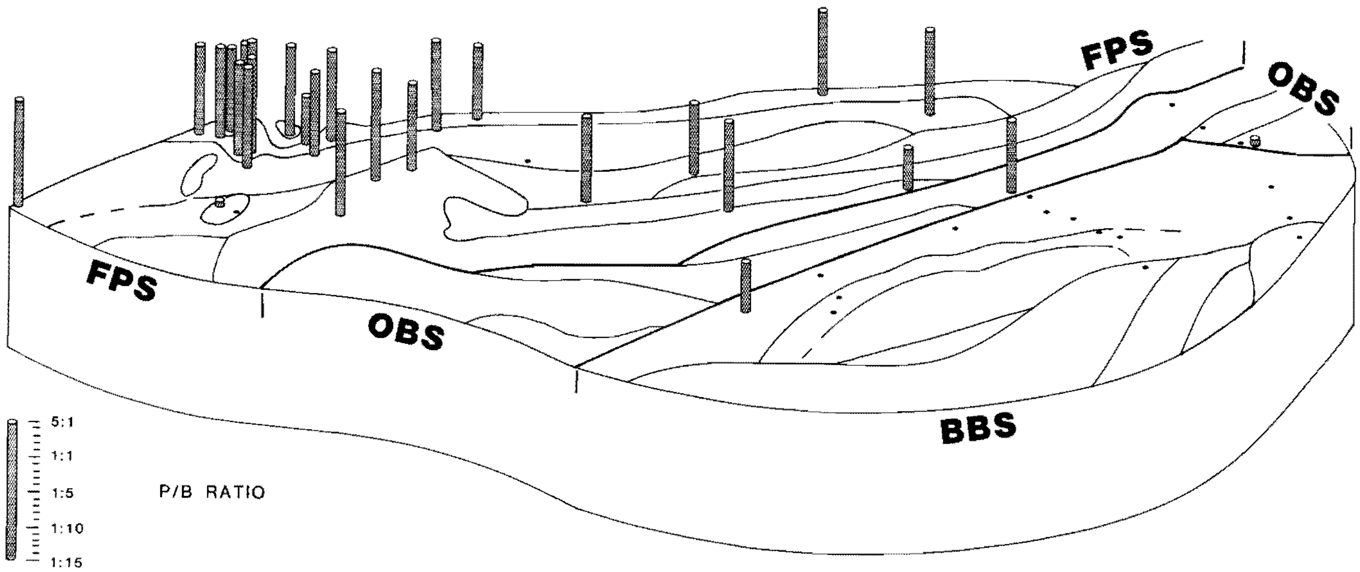

FIGURE 1. Oblique schematic view of Miocene seismic sequences showing planktonic to benthic ratios. The ratio at each locality (represented by length of cylinder) is a mean value for all samples within that vibracore. Vibracore sites represented by dots indicate an average P:B ratio of less than 1:15.

and Snyder (1986) and expands both geographically and stratigraphically to address the entire outcropping/shallow subcropping Miocene section throughout Onslow Bay. The seismic stratigraphic framework outlined by Snyder and others (this volume) provides the perspective from which biostratigraphic data are presented. Taxa are listed in Appendices I and II and illustrated in Plates 1–6.

MATERIALS AND METHODS

PLANKTONIC FORAMINIFERA

Samples for foraminiferal analyses were taken at half-meter intervals within each of 144 vibracores. Each sample spanned a 10 to 15 cm stratigraphic interval that was extracted from the central portion of split vibracores (in order to minimize contamination from along the walls of the core liner). After soaking in a dilute Calgon solution for at least 24 hours, clays were further deflocculated by boiling for 20 minutes in a very dilute solution of "Quaternary-O" (alkyl imidazolinium chloride), and then removed by wet sieving. The size fraction which passed through a U.S. Standard Sieve No. 14 (1.41 mm openings) but was retained on a No. 230 sieve (63 μm openings) was dried at 70°C and examined for foraminiferal content.

Although all vibracores were examined for foraminifera, not all yielded samples that could be biostratigraphically dated. Only those seismic sequences which contain age-diagnostic assemblages are discussed in this paper. From oldest to youngest, these sequences are FPS-1, FPS-2, FPS-3, FPS-6, OBS-2, OBS-3, BBS-1 and BBS-5.

Standard planktonic foraminiferal zonal schemes (e.g., Blow, 1969, 1979; Stainforth and others, 1975) are based on primary indicator species, most of which inhabit tropical-subtropical regions. Such species are often absent in middle to high latitudes or, when present, occur so rarely that they are difficult to find. Where primary indicator species were not encountered, Onslow Bay sediments were interpreted by approximating standard zonal boundaries on the basis of first and last occurrences of secondary indicator species. Such species, though not used to define zones, have first or last appearances known to occur at or near zonal boundaries. A number of secondary indicator species are abundant and conspicuous members of Pungo River Formation assemblages within Onslow Bay. Planktonic foraminiferal interpretations are expressed in terms of the zonation of Blow (1969, 1979), although taxonomic and stratigraphic information from other sources has also been utilized.

The relative abundance of each species, expressed as a percentage of the total planktonic foraminiferal assemblage, was estimated from examination of 100 to 150 randomly selected specimens per sample. Results were tabulated into four categories: 1) rare, less than 3%; 2) few, 3 to 15%; 3) common, 15 to 30%; 4) abundant, more than 30%. Larger volumes of sample material were routinely examined to ensure that rare taxa were encountered. The planktonic to benthic ratio for each sample was calculated by counting all specimens of both types from predetermined segments of a picking tray until a minimum of 300 benthic specimens had been encountered.

CALCAREOUS NANNOFOSSILS

Sediment samples from 13 of the 18 seismic sequences recognized in the Pungo River Formation of Onslow Bay were available for the study of calcareous nannofossils. The sequences examined, in stratigraphic order upsection, are: FPS-1, FPS-2, FPS-4, FPS-5, FPS-6, OBS-1, OBS-2, OBS-3, OBS-4, BBS-1, BBS-2, BBS-3 and BBS-8.

As with the foraminifera, samples were taken from only the interior portions of split cores. Smear slides were prepared, and they were examined at ×600 magnification using a standard research polarizing microscope equipped with phase contrast optics. The relative abundances of all taxa, together with the abundance and preservation of the entire assemblage, were estimated according to the order of magnitude of frequency per field of view (Hay, 1970). The overall preservation of assemblages was assessed by using one of three letter designations.

G = good preservation. Fossils lack evidence of dissolution and overgrowth.
F = fair preservation. All taxa may be easily identified and diversity is normal; but most specimens are slightly etched or overgrown, fine structures are missing or obscured, and rim margins of placoliths are slightly serrate.
P = poor preservation. Diversity is low, most specimens are deeply etched or overgrown, and the identity of many centerless and fragmented specimens is questionable.

The geologic ranges of nannofossil taxa were taken primarily from Perch-Nielsen (1985). Biostratigraphic ages are expressed in terms of NN and NP zones (Martini, 1971).

RESULTS

PLANKTONIC FORAMINIFERA

Pre-Pungo River Formation sediments were not examined in detail, but an age of Zone N4 or older is indicated by the presence of several widely accepted zonal index markers. *Globorotalia kugleri* (including Blow's two variant species, *G. pseudokugleri* and *G. mendacis*) is diagnostic of the uppermost Oligocene through lowest Miocene. In the absence of *G. kugleri,* the occurrence of *Globorotalia opima nana* or *Globigerina ciperoensis* may indicate pre-Miocene material. However, both *G. ciperoensis* and a form nearly homeomorphic with *Globorotalia opima nana* have been reported from lower Miocene beds (Blow, 1969, 1979; Stainforth and others, 1975). Laws and Worsley (1986) assigned pre-Pungo River Formation sediments of Onslow Bay to nannofossil zones NP24-NN1, which also suggests an age of lower Aquitanian or slightly older.

Within the Miocene sediments of Onslow Bay, the Frying Pan Section contains abundant planktonic foraminifera, while the Onslow Bay and Bogue Banks sections have sparser assemblages. Abundance trends are illustrated by planktonic to benthic ratios (Fig. 1). Based upon published stratigraphic ranges of species (Fig. 2) and their occurrences in Onslow Bay sediments (Fig. 3), each section has been dated: Frying Pan Section = zones N6/lower N7 (middle Burdigalian); Onslow Bay Section = zones N8/N9 (Langhian); and Bogue Banks Section = zones N12 to N14 (upper Serravallian) (Fig. 4). Rationale for these age assignments is outlined below.

Sediments of the Frying Pan Section are consistently characterized by rich, diverse planktonic assemblages (Table 1). As shown in Figure 3, numerous samples have yielded reliable biostratigraphic data. Assemblages from FPS-1 differ from those within pre-Pungo River Formation strata by the appearance of several species with first appearance datums (FAD's) within or near the base of Zone N5: *Globoquadrina dehiscens, Globigerinoides quadrilobatus altiapertura, Globigerinoides subquadratus, Globigerinoides quadrilobatus sacculifer* and *Globigerinoides quadrilobatus triloba. Globigerinoides quadrilobatus praeimmaturus, Globorotalia fohsi peripheroronda* and *Globigerinatella insueta,* all of which first appear at or near the base of Zone N6, are consistently present upward from the base of FPS-1. Hence, the oldest Pungo River sediments encountered during this study can be no older than Zone N6. *Catapsydrax unicavus* and *C. dissimilis,* both of which have last appearance datums (LAD's) at the N6/N7 zonal boundary, occur with the taxa listed above, indicating an age no younger than N6. Sediments of FPS-1, FPS-2 and the lower portion of FPS-6 contain assemblages assignable to Zone N6. According to Blow (1979), the base of Zone N6 is defined by the FAD of *Globigerinatella insueta,* and the zone is characterized by the concurrence of *G. insueta* with *Catapsydrax dissimilis* and *C. unicavus.* Because *G. insueta* occurs rarely and sporadically in Onslow Bay, Zone N6 is most easily recognized by the concurrence

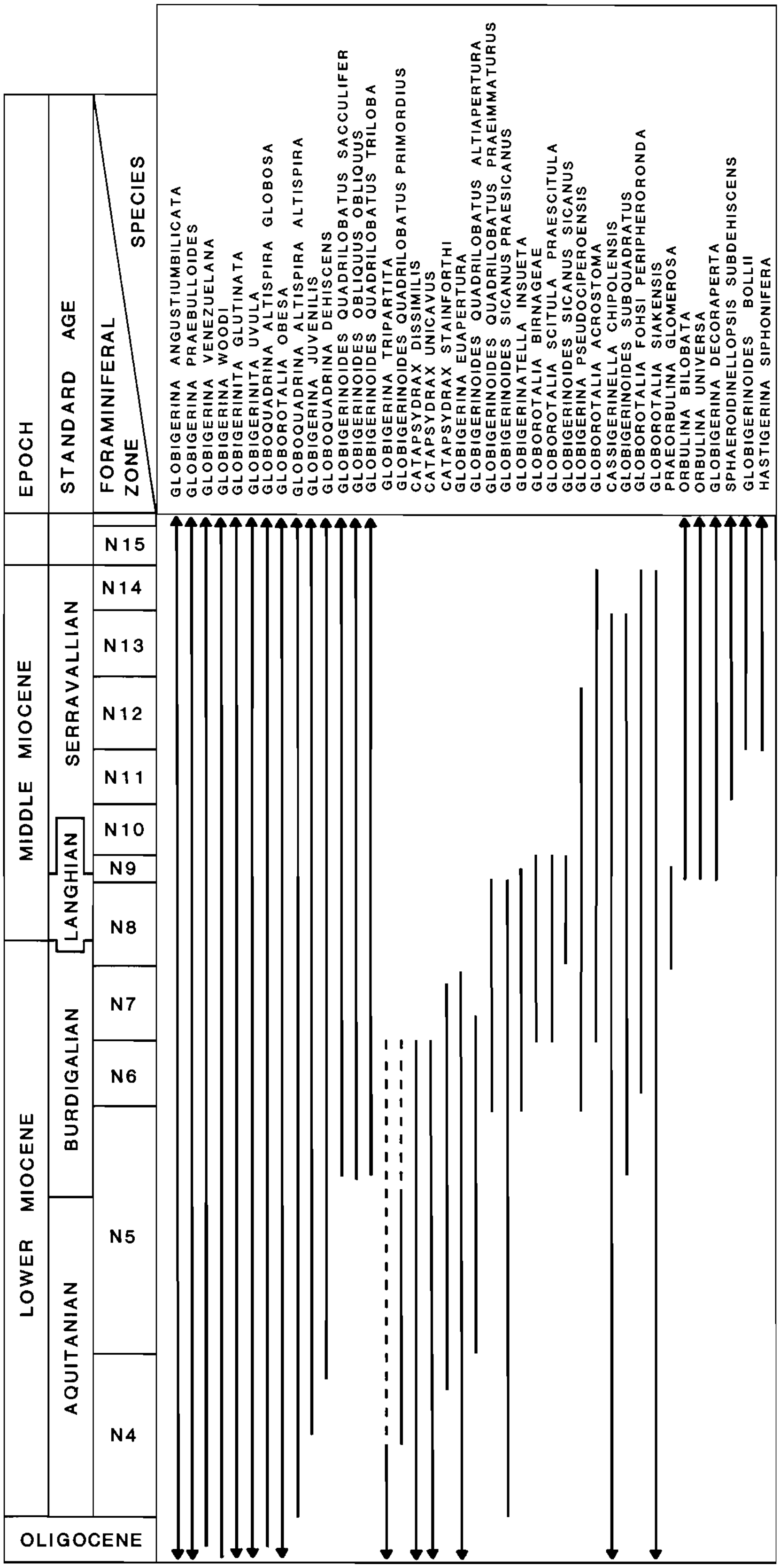

FIGURE 2. Published stratigraphic ranges of planktonic foraminiferal species identified from Miocene sections within Onslow Bay vibracores (data from Blow, 1969, 1979; Brönnimann and Resig, 1971; Stainforth and others, 1975; Poore, 1978; Kennett and Srinivasan, 1983). Arrows denote continuation of range.

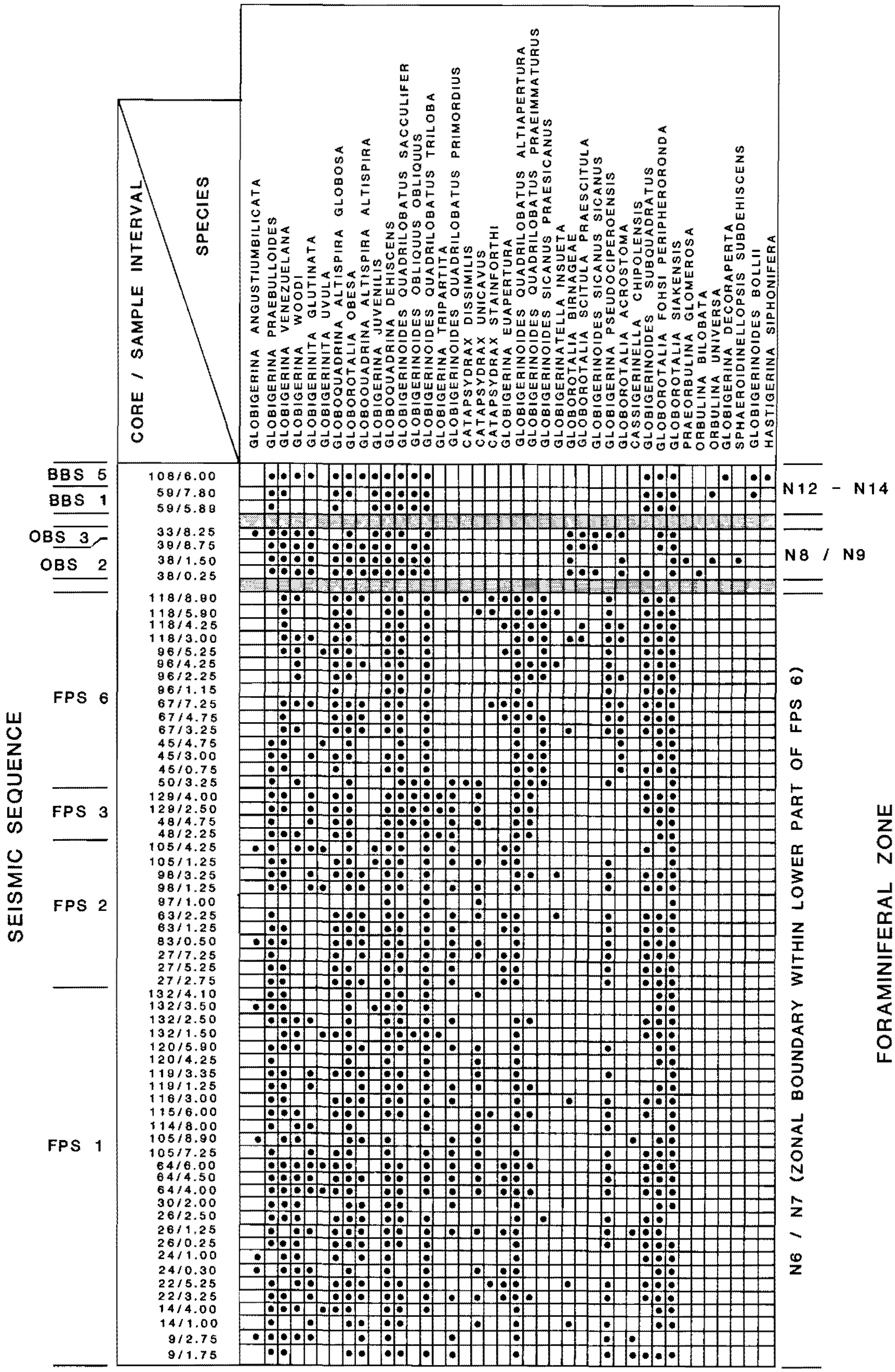

FIGURE 3. Occurrences of planktonic foraminiferal species and resultant biostratigraphic zonal assignments for the Miocene of Onslow Bay. Samples are grouped according to seismic sequence, but their order within any given sequence is numerical (i.e., *not* stacked in stratigraphic order).

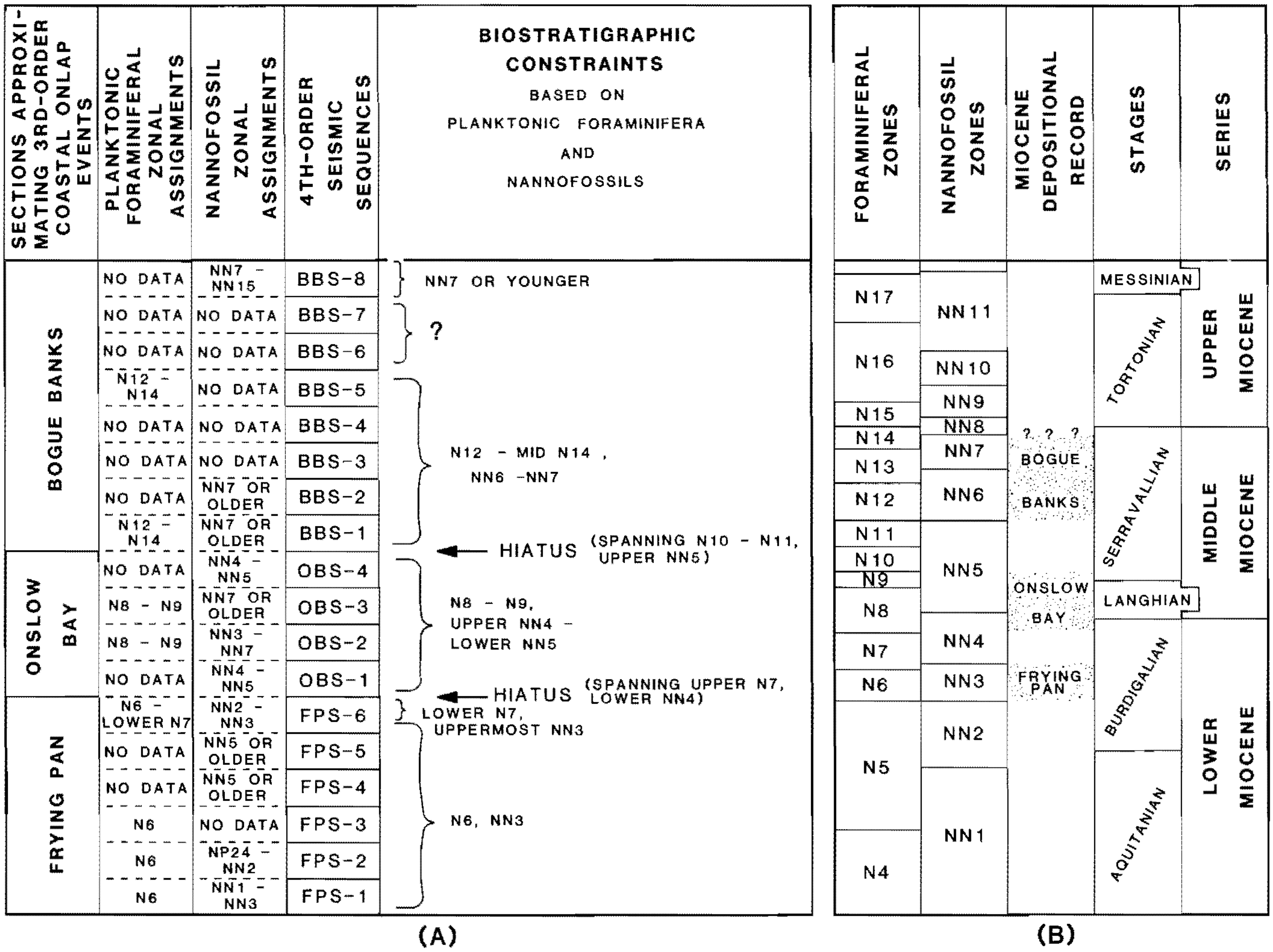

FIGURE 4. Summary of biozonation based upon the calcareous microfossils. Foraminiferal zones are after Blow (1969, 1979) and nannofossil zones are after Martini (1971). (A) Zonal assignments related to seismic stratigraphic framework. (B) Sections approximating third-order events related to standardized zonal schemes (relationship of foraminiferal and nannofossil zones after Haq and others, 1987). The plotted Bogue Banks Section represents only BBS-1 through BBS-5. Data for BBS-6 through BBS-8 are too imprecise to permit plotting.

of *Catapsydrax* with the more common secondary indicator species discussed above (Fig. 3).

Catapsydrax unicavus and *C. dissimilis* have LAD's in the lower portion of FPS-6. The extinction level of *C. dissimilis* defines the base of Zone N7 (Blow, 1979). The extinction of *C. unicavus,* which also occurs at the base of N7 (Blow, 1979), is more easily recognized in Onslow Bay because this species occurs much more commonly (Table 1, Fig. 3). At this same level *Globorotalia birnageae* first appears consistently, accompanied by the FAD's of *Globorotalia scitula praescitula* and *Globorotalia acrostoma* (Figs. 2 and 3). These faunal transitions mark the N6/N7 zonal boundary. In Onslow Bay, *G. acrostoma* is the most useful of these secondary indicator species because it occurs consistently above the extinction level of *C. unicavus* (Table 1). *Globigerinoides quadrilobatus altiapertura,* which last occurs in mid-N7, persists through uppermost FPS-6, indicating that this sequence includes only the lower portion of Zone N7. Hence, the entire Frying Pan Section (FPS-1 through FPS-6) lies within the interval of zones N6/lower N7 (Fig. 4).

Interpretation of the Onslow Bay Section is based on four samples representing two fourth-order seismic sequences (OBS-2 and OBS-3) (Fig. 3). Core coverage in these sequences is rather sparse, and only these few samples contain age-diagnostic planktonic taxa. The scarcity of planktonic specimens is dramatically illustrated by planktonic to benthic ratios (Fig. 1).

A number of taxa that characterize sediments of the

TABLE 1
Occurrence and relative abundance of planktonic species in Onslow Bay
(R = rare, F = few, C = common, A = abundant).

	BBS-5	BBS-1	OBS-3	OBS-2	FPS-6	FPS-3	FPS-2	FPS-1
Globigerina angustiumbilicata	-	-	R	-	-	-	R	R
Globigerina praebulloides	F	C	F	F	F	C	A	C
Globigerina venezuelana	F	F	R	R	R	R	R	R
Globigerina woodi	R	-	R	R	R	R	R	R
Globigerinita glutinata	R	-	R	R	R	R	R	R
Globigerinita uvula	-	-	-	-	R	-	R	R
Globoquadrina altispira globosa	F	F	-	F	R	R	R	R
Globorotalia obesa	R	R	R	R	R	R	R	F
Globoquadrina altispira altispira	R	-	-	R	R	-	R	R
Globigerina juvenilis	R	R	R	R	-	-	R	R
Globoquadrina dehiscens	F	R	F	F	C	F	F	F
Globigerinoides quadrilobatus sacculifer	R	R	F	F	R	R	R	R
Globigerinoides obliquus obliquus	R	R	-	R	R	R	-	R
Globigerinoides quadrilobatus triloba	C	C	A	A	C	C	F	F
Globigerina tripartita	-	-	-	-	-	R	-	R
Globigerinoides quadrilobatus primordius	-	-	-	-	-	R	R	F
Catapsydrax dissimilis	-	-	-	-	R	-	-	-
Catapsydrax unicavus	-	-	-	-	R	R	R	R
Catapsydrax stainforthi	-	-	-	-	R	-	-	R
Globigerina euapertura	-	-	-	-	R	-	R	R
Globigerinoides quadrilobatus altiapertura	-	-	-	-	F	F	F	F
Globigerinoides quadrilobatus praeimmaturus	-	-	-	-	R	R	R	R
Globigerinoides sicanus praesicanus	-	-	-	-	R	-	-	R
Globigerinatella insueta	-	-	-	-	R	-	-	R
Globorotalia birnageae	-	-	R	R	R	-	R	R
Globorotalia scitula praescitula	-	-	R	R	R	-	-	-
Globigerinoides sicanus sicanus	-	-	R	R	-	-	-	-
Globigerina pseudociperoensis	-	-	R	-	F	-	C	R
Globorotalia acrostoma	-	-	R	R	R	-	-	-
Cassigerinella chipolensis	-	-	-	-	-	-	-	R
Globigerinoides subquadratus	C	C	-	F	F	R	R	R
Globorotalia fohsi peripheroronda	F	F	F	F	R	F	F	F
Globorotalia siakensis	F	F	F	F	C	F	F	F
Praeorbulina glomerosa	-	-	-	R	-	-	-	-
Orbulina bilobata	-	-	-	R	-	-	-	-
Orbulina universa	-	R	-	R	-	-	-	-
Globigerina decoraperta	F	-	-	-	-	-	-	-
Sphaeroidinellopsis subdehiscens	-	-	-	R	-	-	-	-
Globigerinoides bollii	R	R	-	-	-	-	-	-
Hastigerina siphonifera	R	-	-	-	-	-	-	-

underlying Frying Pan Section are no longer present in OBS-2 and OBS-3 (*Globigerinatella insueta, Globigerinoides quadrilobatus praeimmaturus, G. quadrilobatus altiapertura, Globigerina euapertura* and *Catapsydrax* spp.) (Fig. 3). The base of Zone N8 is defined by the first evolutionary appearance of *Globigerinoides sicanus* (Blow, 1979). We follow Brönnimann and Resig (1971) in recognizing two subspecies: *G. sicanus praesicanus,* which ranges back through the early Miocene (Figs. 2 and 3), and *G. sicanus sicanus,* which evolves from *praesicanus* at the base of Zone N8. In Onslow Bay, the transition from *G. sicanus praesicanus* to *G. sicanus sicanus* appears to coincide with the boundary between the Frying Pan and Onslow Bay sections. In Core 39, *G. sicanus sicanus* is the only taxon present which indicates Zone N8 or younger sediments. In Core 38 it occurs with *Praeorbulina glomerosa* (range N8 to lower N9), *Orbulina bilobata* and *O. universa.* Because the N8/N9 zonal boundary is defined by the "*Orbulina* Datum" (Stainforth and others, 1975; Blow, 1979), concurrence of the above taxa indicates the lower portion of N9. Zone N9 is also indicated for OBS-3 (Core 33) by the presence of *G. sicanus sicanus* and *Globorotalia birnageae* (Fig. 3).

Zone N8, though not well documented, may be represented by part of OBS-2 (Core 39, which contains *G. sicanus sicanus* but lacks members of the *Orbulina* lineage). It is also possible that OBS-1, which yielded no age-diagnostic assemblages, lies within Zone N8. Zone N9 is represented by part of OBS-2 and by OBS-3. No datable samples were available from OBS-4. Hence, the Onslow Bay Section is assigned to zones N8/N9, but lack of age-diagnostic planktonic foraminifera in its lowest and highest fourth-order sequences limits biostratigraphic precision (Fig. 4).

Owing to the general scarcity of planktonic specimens (Fig. 1), there are very few biostratigraphic control points in the Bogue Banks Section (Fig. 3). Two samples from BBS-1 and a single sample from BBS-5 contain age-diagnostic assemblages which include several species that do not occur in the underlying Onslow Bay Section. Rare but persistent *Globigerinoides bollii* and extremely rare *Sphaeroidinellopsis subdehiscens* and *Hastigerina siphonifera* suggest that BBS-1 and

TABLE 2
Occurrence of nannofossils by sample

Core	Depth Within Core (m)	Barren	Diatoms	Dolomite	No Carbonate	Recrystallized	Abundance	Preservation	Braarudosphaera bigelowii	Calcidiscus leptoporus	Calcidiscus macintyrei	Coccolithus miopelagicus	Coccolithus pelagicus	Coronocyclus nitescens	Cyclicargolithus abisectus	Cyclicargolithus floridanus	Dictyococcites bisectus	Dictyococcites scrippsae	Discoaster adamanteus	Discoaster deflandrei	Discoaster druggii	Discoaster kugleri	Discoaster variabilis	Gephyrocapsa caribbeanica	Gephyrocapsa oceanica	Helicosphaera ampliaperta	Helicosphaera carteri	Helicosphaera intermedia	Pontosphaera multipora	Pontosphaera sp.	Reticulofenestra pseudoumbilica	Sphenolithus abies	Sphenolithus belemnos	Sphenolithus ciperoensis	Sphenolithus dissimilis	Sphenolithus heteromorphus	Sphenolithus moriformis	Thoracosphaera heimii	Thoracosphaera sp.	Zyghrablithus bijugatus	Discoaster asymmetricus	Discoaster brouweri	Discoaster challengeri	Discoaster quinqueramus	Helicosphaera mediterranea	Core	Depth Within Core (m)
1	4.8	.	.	.	.	.	F	F	.	.	R	.	F	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	1	4.8
1	8.8	.	.	.	.	.	F	F	.	F	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	F	R	.	.	.	.	.	.	.	.	.	R	.	.	.	1	8.8
2	3.8	.	.	.	.	.	F	F	.	.	R	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	R	.	2	3.8
2	7.2	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	7.2
3	1.1	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1.1
3	8.1	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	8.1
3	8.8	.	.	.	.	X	F	P	.	.	.	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	3	8.8
5	5.4	.	.	.	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5.4
5	6.1	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	6.1
5	7.25	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	7.25
6	0.6	.	.	X	.	.	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	0.6
6	7.5	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	7.5
14	4.0	.	.	X	.	.	F	F	R	.	.	F	F	R	R	F	F	.	.	F	.	.	.	.	.	F	F	F	R	.	.	R	R	.	.	.	.	.	.	?	.	.	.	.	F	14	4.0
14	6.0	.	.	X	.	X	F	P	.	.	.	R	F	.	.	F	.	F	.	R	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	14	6.0
15	1.5	.	.	X	.	.	R	P	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	1.5
15	0.5	.	.	.	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	0.5
16	4.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16	4.75
17	2.0	.	.	X	.	.	F	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	17	2.0
17	3.0	.	X	X	.	.	F	F	.	.	.	R	F	.	.	R	.	.	.	F	.	.	.	R	R	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	17	3.0
17	5.75	.	X	X	.	.	F	F	.	.	.	F	F	.	.	R	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	17	5.75
18	0.5	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	18	0.5
18	1.5	.	.	.	.	.	R	P	.	.	R	.	R	.	.	.	.	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	18	1.5
18	4.75	.	.	X	.	X	R	P	.	.	.	.	R	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	18	4.75
22	0.25	.	.	.	.	X	R	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	0.25
22	1.25	.	.	.	.	X	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	1.25
22	4.25	.	.	.	.	.	F	F	.	.	.	F	F	.	.	R	F	F	.	F	.	.	.	.	.	R	F	F	.	.	F	.	R	.	.	.	R	.	.	.	.	.	.	.	F	22	4.25
24	1.5	.	.	.	.	X	F	P	.	.	.	F	F	.	F	.	F	F	.	R	.	.	.	.	.	.	R	.	.	.	F	.	R	.	.	.	.	.	.	.	.	.	.	.	.	24	1.5
24	2.25	.	.	.	.	X	F	P	.	.	.	.	F	.	.	F	F	.	.	R	.	.	.	.	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	24	2.25
24	7.75	.	.	X	.	X	F	P	.	.	.	.	F	.	.	F	F	F	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	24	7.75
25	1.0	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	1.0
25	1.5	.	.	.	.	.	F	P	.	.	.	R	F	.	.	.	F	F	.	R	.	.	.	.	F	.	R	.	.	.	F	.	R	.	.	.	.	.	.	.	.	.	.	.	.	25	1.5
25	3.0	.	.	.	.	X	F	P	.	.	.	R	F	.	.	F	F	F	.	.	.	.	.	.	F	.	.	R	.	.	.	.	.	.	R	.	R	.	.	.	.	.	.	.	.	25	3.0
26	2.5	.	.	X	.	.	F	F	.	.	.	F	F	.	.	.	.	F	.	F	.	.	.	.	.	R	.	F	.	.	F	.	R	.	.	.	.	.	.	.	.	.	.	.	R	26	2.5
26	4.75	.	.	X	.	.	F	F	.	.	.	.	F	.	.	F	F	F	.	.	.	.	.	.	.	.	.	F	F	.	F	.	.	.	.	.	F	.	.	.	.	.	.	.	.	26	4.75
27	1.5	X	.	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	27	1.5
27	3.25	.	.	X	.	.	F	F	.	.	F	.	F	.	.	.	R	.	.	R	.	.	R	.	.	R	R	.	.	.	F	.	.	.	.	.	.	R	.	.	.	.	.	.	.	27	3.25
27	4.75	.	.	X	.	.	F	F	.	.	.	R	F	.	.	.	R	.	.	F	?	.	R	.	.	.	.	.	.	.	F	.	.	?	R	.	R	.	R	.	.	.	.	.	.	27	4.75
27	5.25	.	.	X	.	.	F	F	.	.	F	R	F	R	.	F	R	R	.	F	.	.	.	.	.	.	F	R	.	.	F	.	.	.	.	.	.	.	R	.	.	.	.	.	.	27	5.25
27	7.25	.	.	X	.	.	F	F	.	.	.	.	F	R	.	F	F	F	.	F	.	.	.	.	.	R	.	F	.	.	.	F	.	.	.	.	.	R	R	.	.	.	.	.	.	27	7.25
28	3.25	.	.	X	.	.	F	F	.	.	.	.	F	.	.	F	F	F	R	F	.	.	.	.	.	R	F	.	.	.	F	.	.	R	.	.	.	.	.	.	.	.	.	.	.	28	3.25
30	0.5	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	0.5

BBS-5 are no older than Zone N12. The presence of *Globorotalia fohsi peripheroronda* and *Globorotalia siakensis* upward into BBS-5 indicates that this sequence can be no younger than Zone N14. Hence, the base of the Bogue Banks Section lies within Zone N12, while its upper boundary could not be firmly established. Although BBS-5 represents Zone N14 or older, BBS-6 through BBS-8 have not yielded age-diagnostic taxa (Fig. 4).

CALCAREOUS NANNOFOSSILS

Table 2 summarizes results of the nannofossil analyses, showing the occurrence of fossil taxa through samples arranged by vibracore number and sample interval. Also recorded are the degree of preservation of respective assemblages and the relative abundance of all nannofossil taxa. Abundance estimates for the entire assemblage, as well as for individual taxa, were made according to magnitude of frequency per field of view (Table 3).

Smear-slide abundances of calcareous nannofossils in Onslow Bay sediments typically range from rare to few, with the latter designation characterizing most samples (Table 2). The presence of silt-sized terrigenous material, diatoms and diatom fragments, dolomite rhombohedra, and miscellaneous calcareous particles (foraminifer fragments and possible recrystallized

TABLE 2 (continued)

Core	Depth Within Core (m)	Barren	Diatoms	Dolomite	No Carbonate	Recrystallized	Abundance	Preservation	Braarudosphaera bigelowii	Calcidiscus leptoporus	Calcidiscus macintyrei	Coccolithus miopelagicus	Coccolithus pelagicus	Coronocyclus nitescens	Cyclicargolithus abisectus	Cyclicargolithus floridanus	Dictyococcites bisectus	Dictyococcites scrippsae	Discoaster adamanteus	Discoaster deflandrei	Discoaster druggii	Discoaster kugleri	Discoaster variabilis	Gephyrocapsa caribbeanica	Gephyrocapsa oceanica	Helicosphaera ampliaperta	Helicosphaera carteri	Helicosphaera intermedia	Pontosphaera multipora	Pontosphaera sp.	Reticulofenestra pseudoumbilica	Sphenolithus abies	Sphenolithus belemnos	Sphenolithus ciperoensis	Sphenolithus dissimilis	Sphenolithus heteromorphus	Sphenolithus moriformis	Thoracosphaera heimii	Thoracosphaera sp.	Zyghrablithus bijugatus	Discoaster asymmetricus	Discoaster brouweri	Discoaster challengeri	Discoaster quinqueramus	Helicosphaera mediterranea	Core	Depth Within Core (m)
30 /	2.0	.	.	.	.	.	F	F	.	.	.	F	F	.	.	.	.	.	.	F	.	.	F	.	.	.	F	F	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30 /	2.0
30 /	5.75	.	.	.	.	X	F	P	.	.	.	.	F	.	.	F	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30 /	5.75
33 /	0.8	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	33 /	0.8
33 /	4.0	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	33 /	4.0
33 /	6.5	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	33 /	6.5
33 /	8.0	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	33 /	8.0
34 /	3.5	.	X	X	.	.	F	P	.	.	.	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	F	R	.	.	.	R	R	.	.	.	.	.	.	.	.	34 /	3.5
34 /	4.5	.	X	X	.	.	F	P	.	.	.	R	F	.	.	R	.	.	.	R	.	.	.	.	.	.	R	.	.	.	R	.	.	.	.	R	R	.	.	.	.	.	.	.	.	34 /	4.5
34 /	7.8	.	X	X	.	.	F	P	.	.	R	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	R	.	.	.	.	.	.	.	.	34 /	7.8
35 /	2.3	.	.	X	.	X	F	P	.	.	.	R	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	35 /	2.3
35 /	7.9	.	.	X	.	X	F	P	.	.	R	R	F	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	35 /	7.9
36 /	3.3	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	36 /	3.3
36 /	5.2	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	36 /	5.2
37 /	4.9	.	.	.	.	.	F	F	.	.	.	.	R	.	.	R	.	R	.	R	.	.	.	.	.	.	.	R	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	37 /	4.9
37 /	6.2	.	.	.	.	.	F	F	.	.	.	.	F	.	.	F	.	F	.	F	.	.	.	.	.	.	.	R	.	R	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	37 /	6.2
37 /	8.0	.	.	.	.	.	R	P	R	.	.	.	R	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	37 /	8.0
37 /	8.6	.	.	.	.	.	R	F	.	.	.	.	R	.	.	R	.	R	.	R	.	.	.	.	.	.	.	R	.	R	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	37 /	8.6
38 /	1.7	.	.	X	.	.	F	P	.	.	R	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	38 /	1.7
38 /	2.2	.	.	X	.	.	F	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	38 /	2.2
38 /	8.3	X	.	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	38 /	8.3
38 /	8.8	X	.	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	38 /	8.8
39 /	6.0	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	39 /	6.0
39 /	6.5	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	39 /	6.5
40 /	8.0	.	.	X	.	.	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40 /	8.0
45 /	1.75	.	.	X	.	X	R	P	.	.	.	.	R	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	45 /	1.75
45 /	2.75	.	.	X	.	X	F	P	.	.	.	R	F	.	.	R	.	.	.	R	.	.	.	.	.	.	R	.	.	.	F	.	.	.	.	R	.	.	.	.	.	.	.	.	.	45 /	2.75
45 /	3.75	.	.	X	.	X	F	P	.	.	.	R	F	.	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.	.	F	.	.	.	.	.	R	.	.	.	.	.	.	.	.	45 /	3.75
45 /	4.75	.	.	.	.	X	F	P	.	.	.	R	R	.	.	R	.	R	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	45 /	4.75
45 /	5.75	.	.	.	.	X	F	P	.	.	.	R	F	.	.	R	.	.	.	R	.	.	.	.	.	R	.	.	.	.	F	.	.	.	.	R	.	.	.	.	.	.	.	.	.	45 /	5.75
51 /	2.25	.	.	.	.	.	F	P	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	2.25
51 /	3.25	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	3.25
51 /	4.25	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	4.25
51 /	5.25	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	5.25
51 /	6.25	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	6.25
51 /	7.25	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51 /	7.25
53 /	1.25	X	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	53 /	1.25
53 /	5.25	.	.	.	.	.	F	P	.	.	.	.	F	.	.	.	.	.	.	.	.	R	.	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	53 /	5.25
53 /	6.25	.	.	.	.	.	F	P	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	53 /	6.25
58 /	3.5	.	.	.	.	X	R	F	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	58 /	3.5
58 /	4.5	.	.	X	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	58 /	4.5
58 /	6.5	.	.	X	.	.	R	P	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	58 /	6.5

coccoliths) contribute to reduced nannofossil abundance. In only one sample (Core 64 at 6.2 m in sequence FPS-1) were nannofossils designated as common.

The overall preservation of nannofossils ranges from fair to poor. In samples where dolomite or recrystallized carbonate is present, preservation is usually poor. The preservation of nannofossils is evenly split between fair and poor where diatoms are present.

Coccolithophorid assemblages are known to be more diverse in continental shelf environments than in the open ocean (Perch-Nielsen, 1985). However, this is not the case for Onslow Bay sediments. For the time intervals studied, assemblages have meager diversity. Moreover, genera more common to shelf areas (*Braarudosphaera, Pontosphaera, Scyphosphaera*) are seldom observed and, when present, are always rare. The overall lack of diversity may be related to the influence of oceanic currents on the Miocene shelf of the Onslow Bay region or to repeated episodes of diagenesis during sea-level lowstands (Riggs, 1984).

Occurrence data from Table 2 are grouped according to seismic sequence and listed in stratigraphic order in Table 4. The abundance of each taxon in Table 4 corresponds to the maximum frequency recorded for that same taxon in Table 2. Based on nannofossil taxa in assemblages, and on their respective geologic ranges (mostly recorded in Perch-Nielsen, 1985), ages were

TABLE 2 (continued)

Core	Depth Within Core (m)	Barren	Diatoms	Dolomite	No Carbonate	Recrystallized	Abundance	Preservation	Braarudosphaera bigelowii	Calcidiscus leptoporus	Calcidiscus macintyrei	Coccolithus miopelagicus	Coccolithus pelagicus	Coronocyclus nitescens	Cyclicargolithus abisectus	Cyclicargolithus floridanus	Dictyococcites bisectus	Dictyococcites scrippsae	Discoaster adamanteus	Discoaster deflandrei	Discoaster druggii	Discoaster kugleri	Discoaster variabilis	Gephyrocapsa caribbeanica	Gephyrocapsa oceanica	Helicosphaera ampliaperta	Helicosphaera carteri	Helicosphaera intermedia	Pontosphaera multipora	Pontosphaera sp.	Reticulofenestra pseudoumbilica	Sphenolithus abies	Sphenolithus belemnos	Sphenolithus ciperoensis	Sphenolithus dissimilis	Sphenolithus heteromorphus	Sphenolithus moriformis	Thoracosphaera heimii	Thoracosphaera sp.	Zyghrablithus bijugatus	Discoaster asymmetricus	Discoaster brouweri	Discoaster challengeri	Discoaster quinqueramus	Helicosphaera mediterranea	Core	Depth Within Core (m)
58	7.5	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	58	7.5
58	8.5	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	58	8.5
59	2.0	.	.	.	.	X	F	P	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	2.0
59	3.0	.	.	.	.	X	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	3.0
59	4.0	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	4.0
59	5.0	.	.	X	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	5.0
59	6.0	.	.	X	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	59	6.0
60	1.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60	1.75
60	2.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60	2.75
60	3.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60	3.75
60	4.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60	4.75
60	5.75	X	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60	5.75
62	3.0	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62	3.0
62	5.0	.	X	X	.	.	F	F	.	.	.	.	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62	5.0
63	2.5	.	.	X	.	.	F	F	.	.	.	F	F	.	.	.	.	F	.	F	.	.	.	.	.	F	F	.	R	.	F	R	.	.	.	.	.	.	R	.	.	.	.	.	.	63	2.5
64	2.0	.	.	.	.	X	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	64	2.0
64	6.2	.	.	.	.	.	C	F	.	.	.	F	F	F	.	F	F	F	.	F	.	.	.	.	.	F	F	F	.	.	F	.	R	.	.	.	.	.	.	.	.	.	.	.	F	64	6.2
67	2.5	.	.	.	.	.	F	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	67	2.5
67	3.5	.	.	.	.	.	F	F	.	.	R	.	F	R	.	.	.	F	.	R	.	.	.	F	F	R	F	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	67	3.5
67	7.0	.	.	.	.	.	F	F	.	.	.	F	F	.	.	.	.	.	.	F	.	.	.	.	.	R	F	.	.	.	F	.	.	.	.	R	F	.	.	.	.	.	.	.	.	67	7.0
68	2.25	.	.	X	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	68	2.25
68	3.75	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	68	3.75
72	1.5	.	.	.	.	.	F	P	.	.	.	.	R	.	.	.	.	.	.	.	.	R	.	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	R	.	R	.	.	72	1.5
72	2.5	.	.	.	.	.	F	P	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	R	.	.	.	.	.	.	.	.	72	2.5
72	3.5	.	.	X	.	.	R	P	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	72	3.5
77	2.0	.	.	X	.	X	F	P	.	.	.	F	F	.	F	F	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	77	2.0
77	7.0	.	.	X	.	.	F	F	.	.	.	F	F	.	F	F	.	.	.	F	.	.	.	.	.	.	.	R	.	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	.	77	7.0
96	0.5	.	.	X	.	.	F	F	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	96	0.5
96	1.4	.	.	.	.	X	F	P	.	.	.	R	F	.	.	R	R	F	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	96	1.4
96	4.5	.	.	X	.	.	F	P	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	.	R	R	R	.	.	F	R	.	.	.	.	R	.	.	.	.	.	.	.	.	96	4.5
96	5.5	.	.	X	.	.	F	P	.	.	.	.	F	.	.	R	.	.	.	R	.	.	.	.	.	R	R	.	.	.	F	.	R	.	.	R	R	.	.	.	.	.	.	.	.	96	5.5
97	1.0	.	.	X	.	.	F	F	.	.	.	.	F	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	97	1.0
97	3.0	X	.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	97	3.0
97	6.5	.	.	X	.	.	F	F	.	.	.	.	.	.	.	.	.	.	.	R	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	97	6.5
98	1.5	.	X	X	.	.	F	F	.	.	.	.	F	.	.	.	F	.	R	F	.	R	.	.	.	F	.	F	.	.	F	R	.	.	.	.	.	.	.	.	.	.	.	.	.	98	1.5
98	3.5	.	X	X	.	.	F	F	.	.	.	.	F	.	.	.	F	.	R	F	.	.	.	.	.	F	F	F	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	98	3.5
110	2.0	.	.	.	.	.	F	F	.	.	.	.	F	F	.	F	.	.	.	F	.	.	.	.	.	.	R	.	.	R	F	R	.	.	.	.	.	.	R	.	.	.	.	.	.	110	2.0
110	3.0	.	.	.	.	.	F	F	.	.	.	F	F	.	.	F	.	.	.	F	.	.	.	.	.	.	F	.	R	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	110	3.0
110	4.0	.	.	.	.	.	F	F	.	.	.	F	F	.	.	F	.	.	.	F	.	.	.	.	.	.	F	.	.	R	F	R	.	.	.	.	R	.	.	.	.	.	.	.	.	110	4.0
110	5.0	.	.	.	.	.	F	P	.	.	.	F	F	.	.	F	.	.	.	R	.	.	.	.	.	.	R	.	R	R	F	R	.	.	.	.	R	.	.	.	.	.	.	.	.	110	5.0
110	6.0	.	.	.	.	.	F	P	.	.	.	F	F	.	.	F	.	.	.	R	.	.	.	.	.	.	R	.	.	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	110	6.0

derived for the seismic sequences. Figure 4 lists the ages of the seismic sequences in terms of NN and NP zones (Martini, 1971).

As with the planktonic foraminifera, sediments of the Frying Pan Section contain calcareous nannofossil assemblages which are more diverse than those of the Onslow Bay and Bogue Banks sections. The co-occurrence of *Helicosphaera ampliaperta* and *Sphenolithus belemnos* in the Frying Pan Section confine the age to early Miocene zones NN2 and NN3. The presence of *Cyclicargolithus abisectus, Sphenolithus ciperoensis,* and *Sphenolithus dissimilis* indicate an older age (NN1 or older), but they occur rarely and sporadically enough to suggest that they are reworked. *Dictyococcites bisectus* and *D. scrippsae* occur regularly enough and in sufficient numbers to suggest that they are not reworked. Although these species of *Dictyococcites* are commonly cited as being no younger than late Oligocene Zone NP25 (Perch-Nielsen, 1985), they do occur

TABLE 3. Abundance estimate designations for nannofossils (after Hay, 1970).

Abundance of specimens	Designation	Letter
10–100 specimens per field of view	Abundant	A
1–10 specimens per field of view	Common	C
Single specimen per field of view	Few	F
Single specimen in 10–100 fields of view	Rare	R

TABLE 4
Occurrence and relative abundance of nannofossil species in Onslow Bay
(R = rare, F = few)

	BBS-8	BBS-3	BBS-2	BBS-1	OBS-4	OBS-3	OBS-2	OBS-1	FPS-6	FPS-5	FPS-4	FPS-2	FPS-1
Braarudosphaera bigelowii	.	.	.	.	.	.	.	R	R	.	R	.	R
Calcidiscus leptoporus	F	.	.	.	.	.	.	.	.	.	.	.	.
Calcidiscus macintyrei	R	.	.	R	.	.	R	R	R	.	.	F	.
Coccolithus miopelagicus	.	.	.	R	R	.	.	R	F	.	.	F	F
Coccolithus pelagicus	F	.	F	F	F	R	R	F	F	R	F	F	F
Coronocyclus nitescens	.	.	.	.	.	.	.	.	R	.	.	F	F
Cyclicargolithus abisectus	.	.	.	.	.	.	.	.	.	.	.	.	F
Cyclicargolithus floridanus	.	.	.	.	.	.	.	R	R	R	F	F	F
Dictyococcites bisectus	.	.	.	.	.	.	.	.	R	.	.	F	F
Dictyococcites scrippsae	.	.	.	.	.	.	.	.	F	R	F	F	F
Discoaster adamanteus	.	.	.	.	.	.	.	.	.	.	.	R	.
Discoaster asymmetricus	.	.	R	.	.	.	.	.	.	.	.	.	.
Discoaster brouweri	R	.	.	F	.	.	.	.	.	.	.	.	.
Discoaster challengeri	.	.	R	.	.	.	.	.	.	.	.	.	.
Discoaster deflandrei	.	.	.	.	.	R	R	F	F	R	F	F	F
Discoaster druggii	.	.	.	.	.	.	.	.	.	.	.	?	.
Discoaster kugleri	.	.	R	.	.	.	.	.	.	.	.	R	.
Discoaster quinqueramus	.	barren .	.	R	.	.	.	.	.	.	.	.	.
Discoaster variabilis	.	.	.	.	.	.	.	.	.	.	.	R	F
Gephyrocapsa caribbeanica	.	.	F	F	.	.	.	F	F	.	.	.	F
Gephyrocapsa oceanica	R	.	.	.	.	.	.	R	F	.	.	.	F
Helicosphaera ampliaperta	.	.	.	.	.	.	.	.	R	.	.	F	F
Helicosphaera carteri	F	.	.	.	.	.	.	R	F	.	.	F	F
Helicosphaera intermedia	.	.	.	.	.	.	.	.	R	R	R	F	F
Helicosphaera mediterranea	.	.	.	.	.	.	.	.	.	.	.	.	F
Pontosphaera multipora	.	.	.	.	.	.	.	.	.	.	.	R	R
Pontosphaera sp.	.	.	.	.	.	.	.	.	.	R	R	R	.
Reticulofenestra pseudoumbilica	F	.	F	F	R	.	R	F	F	R	.	F	F
Sphenolithus abies	R	.	.	.	.	.	R	R	R	.	R	F	R
Sphenolithus belemnos	.	.	.	.	.	.	.	.	R	.	.	.	R
Sphenolithus ciperoensis	.	.	.	.	.	.	.	.	.	.	.	R	.
Sphenolithus dissimilis	.	.	.	.	.	.	.	.	.	.	.	R	.
Sphenolithus heteromorphus	.	.	.	.	R	.	.	R	R	.	.	.	.
Sphenolithus moriformis	.	.	R	.	.	.	.	R	F	.	.	R	R
Thoracosphaera heimii	.	.	R	.	.	.	.	.	.	.	.	R	.
Thoracosphaera sp.	.	.	.	.	.	.	.	.	.	.	.	R	.
Zygrhablithus bijugatus	.	.	.	.	.	.	.	.	.	.	R	.	?

occasionally in other sections dated as early Miocene (Steinmetz, unpub. data). Longer-ranging species distinguishing the Frying Pan Section from the Onslow Bay and Bogue Banks sections are *Coronocyclus nitescens, Cyclicargolithus floridanus, Helicosphaera intermedia*, and *Pontosphaera* sp.

Sediments of the Onslow Bay Section generally exhibit lower diversity than the other Miocene sections. Interpretation of their age is constrained only by the presence of *Sphenolithus heteromorphus,* which ranges from early to middle Miocene (zones NN4–NN5). The presence of long-ranging *Braarudosphaera bigelowii* and particularly *Discoaster deflandrei,* two species shared in common by the Frying Pan and Onslow Bay sections, separates these older assemblages from the younger Bogue Banks Section.

Nannofossil assemblages of the Bogue Banks Section have a slightly higher diversity than those of the Onslow Bay Section, but this diversity does not contribute to any greater zonal control. A narrow and convincing age determination using calcareous nannofossils is not possible. Of the four sequences examined within the Bogue Banks Section, BBS-3 is entirely barren of nannofossils, BBS-1 and BBS-2 are either barren or contain poorly preserved assemblages, and only BBS-8 shows fair preservation. The species characterizing BBS-8 are *Calcidiscus leptoporus, Coccolithus pelagicus, Discoaster brouweri, Helicosphaera carteri, Reticulofenestra pseudoumbilica,* and *Sphenolithus abies. Gephyrocapsa oceanica* is also present, but it is judged to be downhole Pleistocene contamination. Collectively, members of this assemblage indicate a long range of time from the early Pleistocene to the middle Miocene (NN15 to about NN7). An age older than Zone NN8 is suggested in the assemblages of BBS-1 and BBS-2 by the rare occurrences of *Coccolithus miopelagicus, Discoaster kugleri,* and *Sphenolithus moriformis.*

CONCLUSIONS

Combining planktonic foraminiferal and nannofossil data provides slightly better biostratigraphic resolution than can be attained independently using either group. Unfortunately, many taxa are long-ranging and some important stratigraphic intervals are either barren or contain only forms which are not age-diagnostic. Absence of the keeled globorotaliid lineages used to zone the middle Miocene (e.g., the *Globorotalia fohsi* plexus) is particularly troublesome. Nevertheless, reasonably accurate estimates of age are possible (Fig. 4).

The Frying Pan Section is middle Burdigalian in age. FPS-1 and FPS-2 lie in the lower portion of foraminiferal Zone N6, and the associated nannofossil assemblages are limited to Zone NN3 or older. FPS-3 through FPS-5 lie within zones N6 and NN3. FPS-6 straddles the N6/N7 zonal boundary, incorporating uppermost N6 through lower N7. Nannofossils from FPS-6 indicate Zone NN3 or older.

The lowermost portion of the Onslow Bay Section (OBS-1) cannot be precisely dated. Diagnostic foraminifera are absent and nannofossil assemblages can only restrict OBS-1 to the NN4–NN5 zonal interval. OBS-2 and OBS-3 represent parts of zones N8 and N9, respectively. OBS-4 does not contain age-diagnostic foraminifera. Nannofossils from OBS-2 through OBS-4 do not provide any finer time resolution than the generalized NN4–NN5 interval. Hence, the top and bottom of the Onslow Bay Section, as suggested in Figure 4, may require revision should continuous coring through down-dip portions of these sections yield better assemblages. At present, the Onslow Bay Section is presumed to lie almost entirely within the Langhian Stage.

The Bogue Banks Section represents the latter portion of the Serravallian Stage (Fig. 4). There is no evidence for the presence of foraminiferal zones N10 and N11, but the N12–N14 zonal interval is represented by BBS-1 and BBS-5. Foraminiferal interpretations are supported by nannofossil evidence. BBS-1 and BBS-2 consist of Zone NN7 or older sediments. Although BBS-5 lies within Zone N14, sequences BBS-6 through BBS-8 are barren of planktonic foraminifera. BBS-8 contains nannofossils indicative of Zone NN7 or younger. Because seismic evidence incorporates BBS-8 within the Bogue Banks Section, it is presumed to be late middle Miocene. However, biostratigraphic evidence constraining the Bogue Banks Section to the Serravallian exists only through sequence BBS-5.

The hiatus between the Frying Pan and Onslow Bay sections spans approximately 1.0 to 1.5 Ma. The one between the Onslow Bay and Bogue Banks sections spans approximately 1.5 Ma. The duration of hiatuses between the fourth-order seismic sequences which compose the three larger-scale sections cannot be estimated on the basis of biostratigraphy.

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APPENDIX I

ANNOTATED REFERENCE LIST OF PLANKTONIC FORAMINIFERA

(Taxa listed in alphabetical order)

Cassigerinella chipolensis (Cushman and Ponton), Pl. 5, figs. 1–2
Cassidulina chipolensis CUSHMAN and PONTON, 1932, Fla. Geol. Soc. Survey Bull. 9, p. 98, pl. 15, fig. 2.

Catapsydrax dissimilis (Cushman and Bermudez), Pl. 4, figs. 1–2
Globigerina dissimilis CUSHMAN and BERMUDEZ, 1937, Contr. Cushman Lab. Foram. Research, v. 13, p. 25, pl. 3, figs. 4–6.

Catapsydrax stainforthi Bolli, Loeblich and Tappan, Pl. 4, figs. 5–6
Catapsydrax stainforthi BOLLI, LOEBLICH and TAPPAN, 1957, U.S. Natl. Museum Bull. 215, p. 37, pl. 7, fig. 11.

Catapsydrax unicavus Bolli, Loeblich and Tappan, Pl. 4, figs. 3–4
Catapsydrax unicavus BOLLI, LOEBLICH and TAPPAN, 1957, U.S. Natl. Museum Bull. 215, p. 37, pl. 7, fig. 9.

Globigerina angustiumbilicata Bolli, Pl. 1, figs. 1–2
Globigerina ciperoensis angustiumbilicata BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 109, pl. 22, figs. 12–13.

Globigerina ciperoensis Bolli, Pl. 1, figs. 3–4
Globigerina ciperoensis BOLLI, 1954, Contr. Cushman Found. Foram. Research, v. 5, p. 1–3, figs. 3–4.

Globigerina decoraperta Takayanagi and Saito, Pl. 1, figs. 5–6
Globigerina druryi decoraperta TAKAYANAGI and SAITO, 1962, Sci. Repts. Tohoku Univ., ser. 2 (Geology), Spec. Vol. 5, p. 85, pl. 28, fig. 10.

Globigerina euapertura Jenkins, Pl. 1, figs. 7–8
Globigerina euapertura JENKINS, 1960, Micropaleontology, v. 6, n. 4, p. 351, pl. 1, fig. 8.

Globigerina juvenilis Bolli, Pl. 1, figs. 9–10
Globigerina juvenilis BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 110, pl. 24, figs. 5–6.

Globigerina praebulloides Blow, Pl. 1, figs. 11–12
Globigerina praebulloides BLOW, 1959, Bull. American Paleontology, v. 39, p. 180, pl. 8, fig. 47, pl. 9, fig. 48.

Globigerina pseudociperoensis Blow, Pl. 1, figs. 13–14
Globigerina praebulloides pseudociperoensis BLOW, 1969, Proc. First Internatl. Conf. Planktonic Microfossils, p. 381–382, pl. 17, figs. 8–9.

Globigerina tripartita Koch, Pl. 1, figs. 15–16
Globigerina bulloides tripartita KOCH, 1926, Eclogae Geol. Helvetiae, v. 19, p. 746, fig. 21.

This species is generally considered to range from the late Eocene through the Oligocene. However, it has also been recognized in the early Miocene if the species concept is not defined too rigidly (Stainforth and others, 1975). Rare and sporadic occurrences in the Frying Pan Section of Onslow Bay probably represent forms transitional with the *G. venezuelana* lineage. Unless encountered in abundance, it is evidently not a reliable pre-Miocene indicator.

Globigerina venezuelana Hedberg, Pl. 1, figs. 17–18
Globigerina venezuelana HEDBERG, 1937, Jour. Paleontology, v. 11, p. 681, pl. 92, fig. 7.

Globigerina woodi Jenkins, Pl. 1, figs. 19–20
Globigerina woodi JENKINS, 1960, Micropaleontology, v. 6, n. 4, p. 252, pl. 2, fig. 2.

Globigerinatella insueta Cushman and Stainforth, Pl. 5, fig. 6
Globigerinatella insueta CUSHMAN and STAINFORTH, 1945, Cushman Lab. Foram. Research, Spec. Pub. 14, p. 69, pl. 13, figs. 7–9.

Globigerinita glutinata (Egger), Pl. 5, figs. 3–4
Globigerina glutinata EGGER, 1893, Abh. K. Bayer. Akad. Wiss. Munchen, Cl. II, v. 18, p. 371, pl. 13, figs. 19–20.

Globigerinita uvula (Ehrenberg), Pl. 5, fig. 5
Pylodexia uvula EHRENBERG, 1861, K. Preuss. Akad. Wiss. Berlin, Monatsber., p. 276–277, 308.

Globigerinoides bollii Blow, Pl. 2, figs. 3–4
Globigerinoides bollii BLOW, 1959, Bull. American Paleontology, v. 39, p. 189, pl. 10, fig. 65.

Globigerinoides obliquus obliquus Bolli, Pl. 2, figs. 5–6
Globigerinoides obliqua BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 113, pl. 25, figs. 9–10.

Globigerinoides quadrilobatus altiapertura Bolli, Pl. 2, figs. 1–2
Globigerinoides triloba altiapertura BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 113, pl. 25, figs. 7–8.

Globigerinoides quadrilobatus praeimmaturus Brönnimann and Resig, Pl. 2, figs. 7–8
Globigerinoides quadrilobatus praeimmaturus BRÖNNIMANN and RESIG, 1971, Init. Repts. Deep Sea Drilling Project, v. 7, p. 1272, pl. 9, figs. 1–4.

Globigerinoides quadrilobatus primordius Blow and Banner, Pl. 2, figs. 9–10
Globigerinoides quadrilobatus primordius BLOW and BANNER, 1962, *in* Eames, F. and others, Fundamentals of mid-Tertiary Stratigraphical Correlation, p. 115, pl. 9, figs. Dd–Ff.

According to Blow (1969, 1979), this species ranges from basal N4 to early N5. However, Stainforth and others (1975) stated that it persists to the base of Zone N3 in both the Atlantic and Gulf of Mexico, suggesting that its FAD cannot be rigidly defined on a worldwide basis. In Onslow Bay, it occurs with Zone N6 faunal elements and appears, at least in this region, to be of marginal value as a zonal marker.

Globigerinoides quadrilobatus sacculifer (Brady), Pl. 2, figs. 11–12

Globigerina sacculifera BRADY, 1877, Geol. Mag., Dec. 2, v. 4, p. 535.

Globigerinoides quadrilobatus triloba (Reuss), Pl. 2, figs. 19–20

Globigerina triloba REUSS, 1850, Akad. Wiss. Wien Denkschr., Math. Nat. Kl., v. 1, p. 347, pl. 47, fig. 11.

Globigerinoides sicanus praesicanus Brönnimann and Resig, Pl. 2, figs. 13–14

Globigerinoides sicanus praesicanus BRÖNNIMANN and RESIG, 1971, Init. Repts. Deep Sea Drilling Project, v. 7, p. 1273, pl. 10, figs. 5–6, 8.

This subspecies, described from the southwestern Pacific, has a 'typical' form (two supplementary apertures on the spiral side) that ranges from Zone N4 through N6. The 'affine' form, with only one supplementary spiral-side aperture, ranges from N7 through N8. The 'affine' form occurs in Onslow Bay, where it is restricted to FPS-6, which is partially equivalent to the early portion of Zone N7.

Globigerinoides sicanus sicanus de Stefani, Pl. 2, figs. 15–16

Globigerinoides sicanus DE STEFANI, 1950, Plinia, v. 3, note 4, p. 9.

This subspecies, with its more embracing final chamber and narrower, slit-like aperture, is restricted to zones N8 and early N9. It first appears in the Onslow Bay Section (OBS-2). It does not co-occur with *G. sicanus praesicanus* in Onslow Bay.

Globigerinoides subquadratus Brönnimann, Pl. 2, figs. 17–18

Globigerinoides subquadratus BRÖNNIMANN, 1954, *in* Todd, Cloud, Low and Schmidt, Amer. Jour. Sci., v. 252, p. 680, pl. 1, fig. 5.

Globoquadrina altispira altispira (Cushman and Jarvis), Pl. 4, figs. 7–8

Globoquadrina altispira CUSHMAN and JARVIS, 1936, Contr. Cushman Lab. Foram. Research, v. 12, pt. 1, p. 5, pl. 1, figs. 13–14.

Globoquadrina altispira globosa Bolli, Pl. 4, figs. 9–10

Globoquadrina altispira globosa BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 111, pl. 24, figs. 9–10.

Globoquadrina dehiscens (Chapman, Parr and Collins), Pl. 4, figs. 11–12

Globorotalia dehiscens CHAPMAN, PARR and COLLINS, 1934, Linn. Soc. London Jour. Zoology, v. 38, n. 262, p. 569, pl. 11, fig. 36.

Stainforth and others (1975) treat the morphologically variable *G. dehiscens* lineage as a group which includes numerous species concepts of many workers. Because there is a lack of consensus concerning many of these subdivisions, we follow Stainforth and others (1975) in assigning Pungo River specimens to this general category.

Globorotalia acrostoma Wezel, Pl. 3, figs. 1–2

Globorotalia acrostoma WEZEL, 1966, Rev. Ital. Paleontologia Stratigrafia, v. 72, p. 1298, pl. 101, figs. 1–12.

Globorotalia birnageae Blow, Pl. 3, figs. 3–4

Globorotalia birnageae BLOW, 1959, Bull. American Paleontology, v. 39, p. 210–211, pl. 17, fig. 108.

The FAD of this species seems to be somewhat in doubt. Blow (1979) recognized its range as N7 to N9, while Brönnimann and Resig (1971) and Poore (1978) recorded it within Zone N6. It occurs sporadically within N6 sediments of the Frying Pan Section, but is consistently present only above the N6/N7 boundary in Onslow Bay.

Globorotalia fohsi peripheroronda Blow and Banner, Pl. 3, figs. 11–12

Globorotalia (*Turborotalia*) *peripheroronda* BLOW and BANNER, 1966, Micropaleontology, v. 12, n. 3, p. 294, pl. 1, fig. 1, pl. 2, figs. 1–3.

The faunal association in the Bogue Banks Section of Onslow Bay suggests that *G. peripheroronda* ranges above Zone N11 (its LAD according to Blow, 1979). The relationships seen in Onslow Bay are consistent with those reported by Poore (1978).

Globorotalia kugleri Bolli, Pl. 3, figs. 5–6

Globorotalia kugleri BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 118, pl. 28, figs. 5–6.

Globorotalia obesa Bolli, Pl. 3, figs. 7–8

Globorotalia obesa BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 119, pl. 29, figs. 2–3.

Globorotalia opima nana Bolli, Pl. 3, figs. 9–10

Globorotalia opima nana BOLLI, 1957, U.S. Natl. Museum Bull. 215, p. 118, pl. 28, fig. 3.

Globorotalia siakensis Leroy, Pl. 3. figs. 15–16

Globorotalia siakensis LEROY, 1939, Natuurk. Tijdschr. Nederl.-Indie, v. 99, n. 6, p. 262, pl. 4, figs. 20–22.

Globorotalia scitula praescitula Blow, Pl. 3, figs. 13–14

Globorotalia scitula praescitula BLOW, 1959, Bull. American Paleontology, v. 39, p. 221, pl. 19, fig. 128.

Hastigerina siphonifera (d'Orbigny), Pl. 5, fig. 7

Globigerina siphonifera D'ORBIGNY, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. de Cuba, "Foraminiferes," p. 83, pl. 4, figs. 15–18.

Orbulina bilobata (d'Orbigny), Pl. 5, fig. 8

Globigerina bilobata D'ORBIGNY, 1846, Foraminiferes fossiles du Bassin Tertiaire de Vienne, p. 164, pl. 9, figs. 11–14.

Orbulina universa d'Orbigny, Pl. 5, fig. 9

Orbulina universa D'ORBIGNY, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. de Cuba, "Foraminiferes," p. 2, pl. 1, fig. 1.

Praeorbulina glomerosa (Blow), Pl. 5, figs. 10–12

Globigerinoides glomerosa BLOW, 1956, Micropaleontology, v. 2, p. 64–65, figs. 1–2.

Sphaeroidinellopsis subdehiscens (Blow), Pl. 5, fig. 13

Sphaeroidinella dehiscens subdehiscens BLOW, 1959, Bull. American Paleontology, v. 39, p. 195, pl. 12, figs. 71–72.

APPENDIX II

ALPHABETICAL LISTING OF NANNOFOSSIL TAXA

Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947

Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978

Calcidiscus macintyrei (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978

Coccolithus miopelagicus Bukry, 1971

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930

Coronocyclus nitescens (Kamptner, 1963) Bramlette and Wilcoxon, 1967

Cyclicargolithus abisectus (Müller, 1970) Wise, 1973

Cyclicargolithus floridanus (Roth and Hay *in* Hay and others, 1967) Bukry, 1971

Dictyococcites bisectus (Hay, Mohler and Wade, 1966) Bukry and Percival, 1971

Dictyococcites scrippsae Bukry and Percival, 1971

Discoaster adamanteus Bramlette and Wilcoxon, 1967

Discoaster asymmetricus Gartner, 1969

Discoaster brouweri Tan Sin Hok, 1927

Discoaster challengeri Bramlette and Riedel, 1954

Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster druggii Bramlette and Wilcoxon, 1967
Discoaster kugleri Martini and Bramlette, 1963
Discoaster quinqueramus Gartner, 1969
Discoaster variabilis Martini and Bramlette, 1963
Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Gephyrocapsa oceanica Kamptner, 1943
Helicosphaera ampliaperta Bramlette and Wilcoxon, 1967
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954
Helicosphaera intermedia Martini, 1965
Helicosphaera mediterranea Müller, 1981
Helicosphaera recta (Haq, 1966) Jafar and Martini, 1975
Pontosphaera multipora (Kamptner, 1948) Roth, 1970
Reticulofenestra pseudoumbilica (Gartner, 1967) Gartner, 1969
Sphenolithus abies Deflandre *in* Deflandre and Fert, 1954
Sphenolithus belemnos Bramlette and Wilcoxon, 1967
Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967
Sphenolithus dissimilis Bukry and Percival, 1971
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Brönnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
Thoracosphaera heimii (Lohmann, 1919) Kamptner, 1941
Zygrhablithus bijugatus (Deflandre *in* Deflandre and Fert, 1954) Deflandre, 1959

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PLATE 1
GLOBIGERINA
Each scale bar = 100 microns

1-2 *G. angustiumbilicata* Bolli. 1. Umbilical view (Core 106, 9.1 m). 2. Spiral view (Core 106, 9.1 m).
3-4 *G. ciperoensis* Bolli. 3. Umbilical view (Core 106, 6.0 m). 4. Spiral view (Core 106, 6.0 m).
5-6 *G. decoraperta* Takayanagi and Saito. 5. Umbilical view (Core 108, 6.0 m). 6. Spiral view (Core 108, 6.0 m).
7-8 *G. euapertura* Jenkins. 7. Umbilical view (Core 26, 1.25 m). 8. Spiral view (Core 105, 4.5 m).
9-10 *G. juvenilis* Bolli. 9. Umbilical view (Core 105, 4.5 m). 10. Spiral view (Core 108, 6.0 m).
11-12 *G. praebulloides* Blow. 11. Umbilical view (Core 64, 4.5 m). 12. Spiral view (Core 64, 4.5 m).
13-14 *G. pseudociperoensis* Blow. 13. Umbilical view (Core 22, 3.25 m). 14. Spiral view (Core 63, 2.5 m).
15-16 *G. tripartita* Koch. 15. Umbilical view (Core 50, 3.25 m). 16. Spiral view (Core 50, 3.25 m).
17-18 *G. venezuelana* Hedberg. 17. Umbilical view (Core 67, 5.0 m). 18. Spiral view (Core 22, 3.25 m).
19-20 *G. woodi* Jenkins. 19. Umbilical view (Core 26, 2.75 m). 20. Spiral view (Core 64, 4.5 m).

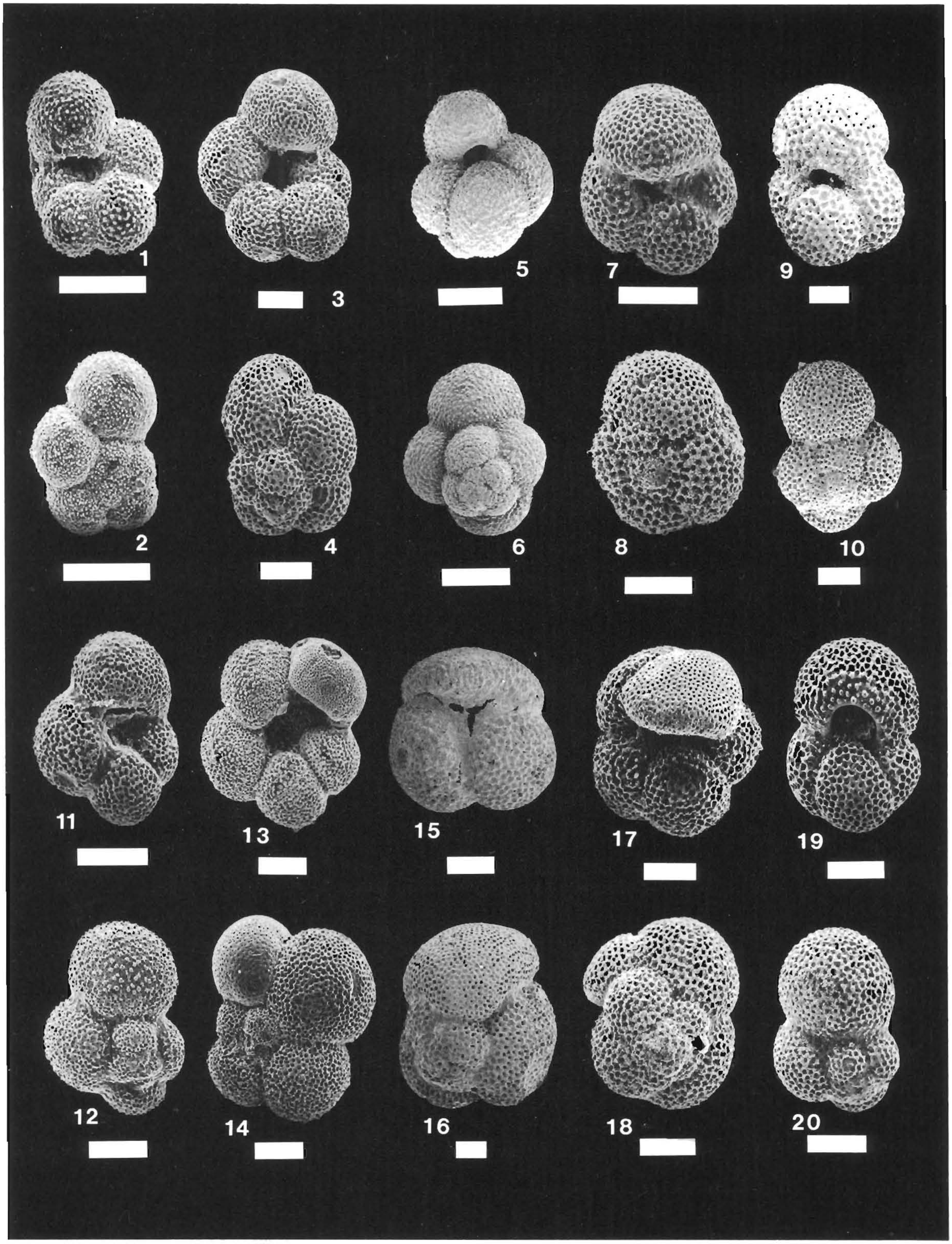
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PLATE 2
GLOBIGERINOIDES

Each scale bar = 100 microns

1-2 *G. quadrilobatus altiapertura* Bolli. 1. Umbilical view (Core 118, 6.0 m). 2. Spiral view (Core 118, 6.0 m).
3-4 *G. bollii* Blow. 3. Umbilical view (Core 108, 6.0 m). 4. Spiral view (Core 108, 6.0 m).
5-6 *G. obliquus obliquus* Bolli. 5. Umbilical view (Core 108, 6.0 m). 6. Spiral view (Core 50, 3.25 m).
7-8 *G. quadrilobatus praeimmaturus* Brönnimann and Resig. 7. Umbilical view (Core 67, 5.0 m). 8. Spiral view (Core 118, 9.0 m).
9-10 *G. quadrilobatus primordius* Blow and Banner. 9. Umbilical view (Core 107, 7.5 m). 10. Spiral view (Core 63, 2.5 m).
11-12 *G. quadrilobatus sacculifer* (Brady). 11. Umbilical view (Core 118, 6.0 m). 12. Spiral view (Core 118, 6.0 m).
13-14 *G. sicanus praesicanus* Brönnimann and Resig. 13. Umbilical view (Core 67, 5.0 m). 14. Spiral view (Core 118, 6.0 m).
15-16 *G. sicanus sicanus* de Stefani. 15. Umbilical view (Core 131, 3.0 m). 16. Spiral view (Core 108, 6.0 m).
17-18 *G. subquadratus* Brönnimann. 17. Umbilical view (Core 118. 6.0 m). 18. Oblique spiral view (Core 96, 2.5 m).
19-20 *G. quadrilobatus triloba* (Reuss). 19. Umbilical view (Core 96, 2.5 m). 20. Spiral view (Core 96, 2.5 m).

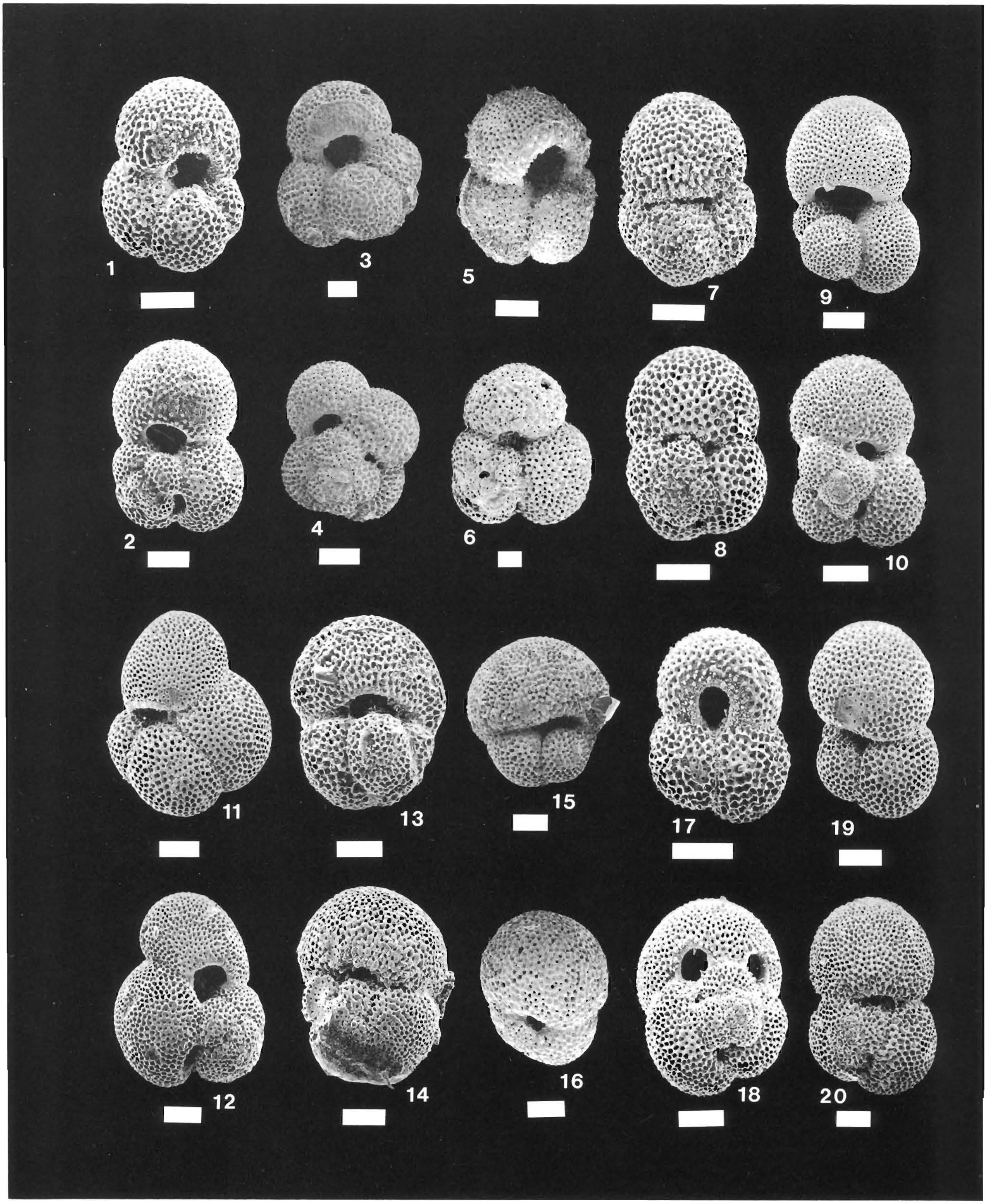
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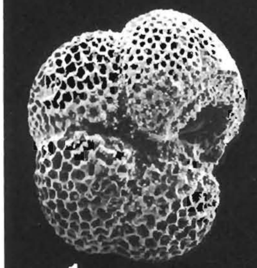
PLATE 3
GLOBOROTALIA
Each scale bar = 100 microns

1-2 *G. acrostoma* Wezel. 1. Umbilical view (Core 67, 3.5 m). 2. Edge view (Core 118, 4.5 m).
3-4 *G. birnageae* Blow. 3. Umbilical view (Core 118, 3.0 m). 4. Edge view (Core 67, 3.5 m).
5-6 *G. kugleri* Bolli. 5. Umbilical view (Core 24, 8.75 m). 6. Edge view (Core 106, 6.0 m).
7-8 *G. obesa* Bolli. 7. Umbilical view (Core 22, 3.25 m). 8. Edge view (Core 67, 3.5 m).
9-10 *G. opima nana* Bolli. 9. Umbilical view (Core 106, 9.1 m). 10. Edge view (Core 106, 6.0 m).
11-12 *G. fohsi peripheroronda* Blow and Banner. 11. Umbilical view (Core 118, 6.0 m). 12. Spiral view (Core 118, 6.0 m).
13-14 *G. scitula praescitula* Blow. 13. Umbilical view (Core 118, 4.5 m). 14. Edge view (Core 118, 3.0 m).
15-16 *G. siakensis* Leroy. 15. Umbilical view (Core 118, 6.0 m). 16. Edge view (Core 118, 6.0 m).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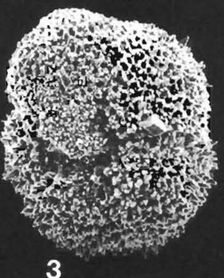
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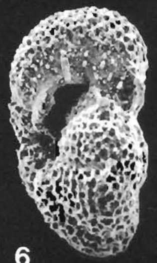
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PLATE 4
CATAPSYDRAX, GLOBOQUADRINA

Each scale bar = 100 microns

1-2 *C. dissimilis* (Cushman and Bermudez). 1. Umbilical view (Core 67, 7.5 m). 2. Edge view (Core 118, 4.5 m).
3-4 *C. unicavus* Bolli, Loeblich and Tappan. 3. Umbilical view (Core 26, 1.25 m). 4. Edge view (Core 105, 7.5 m).
5-6 *C. stainforthi* Bolli, Loeblich and Tappan. 5. Umbilical view (Core 22, 5.25 m). 6. Edge view (Core 67, 7.5 m).
7-8 *G. altispira altispira* (Cushman and Jarvis). 7. Oblique umbilical view (Core 26, 1.25 m). 8. Edge view (Core 67, 3.5 m).
9-10 *G. altispira globosa* Bolli. 9. Umbilical view (Core 26, 1.25 m). 10. Edge view (Core 63, 2.5 m).
11-12 *G. dehiscens* (Chapman, Parr and Collins). 11. Umbilical view (Core 64, 4.5 m). 12. Edge view (Core 26, 3.0 m).

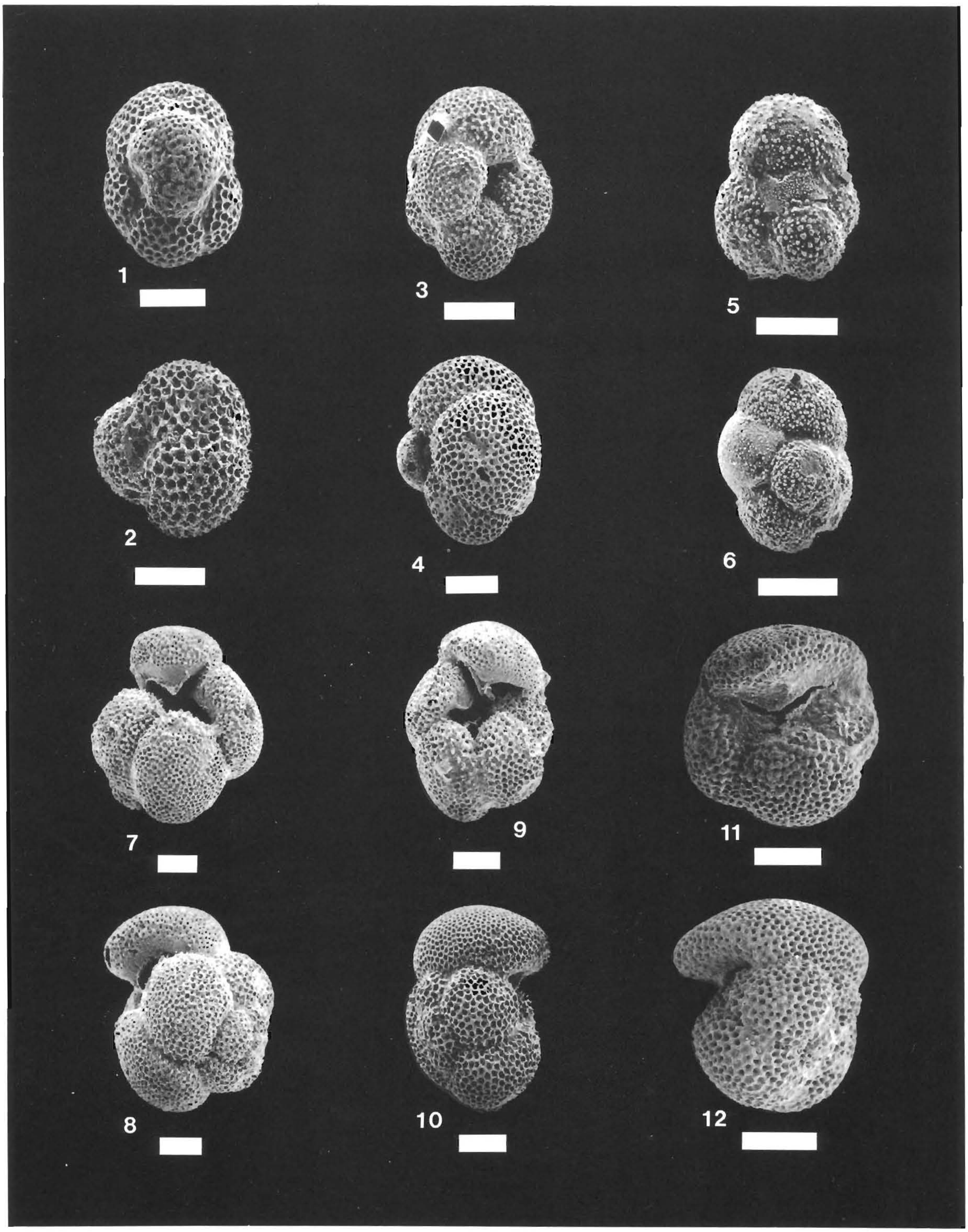
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PLATE 5

ASSORTED PLANKTONIC FORAMINIFERAL GENERA

Each scale bar = 100 microns

1-2 *Cassigerinella chipolensis* (Cushman and Ponton). 1. Side view (Core 106, 6.0 m). 2. Edge view (Core 106, 9.1 m).
3-4 *Globigerinita glutinata* (Egger). 3. Umbilical view (Core 98, 3.5 m). 4. Edge view (Core 64, 6.2 m).
5 *Globigerinita uvula* (Ehrenberg). 5. Side view (Core 106, 6.0 m).
6 *Globigerinatella insueta* Cushman and Stainforth. 6. Random view (Core 63, 2.5 m).
7 *Hastigerina siphonifera* (d'Orbigny). 7. Edge view (Core 108, 6.0 m).
8 *Orbulina bilobata* (d'Orbigny). 8. Random view (Core 38, 0.25 m).
9 *Orbulina universa* d'Orbigny. 9. Random view (Core 38, 0.25 m).
10-12 *Praeorbulina glomerosa* (Blow). 10–12. Random views (Core 38, 1.5 m).
13 *Sphaeroidinellopsis subdehiscens* (Blow). 13. Umbilical view, decorticated specimen (Core 38, 1.5 m).

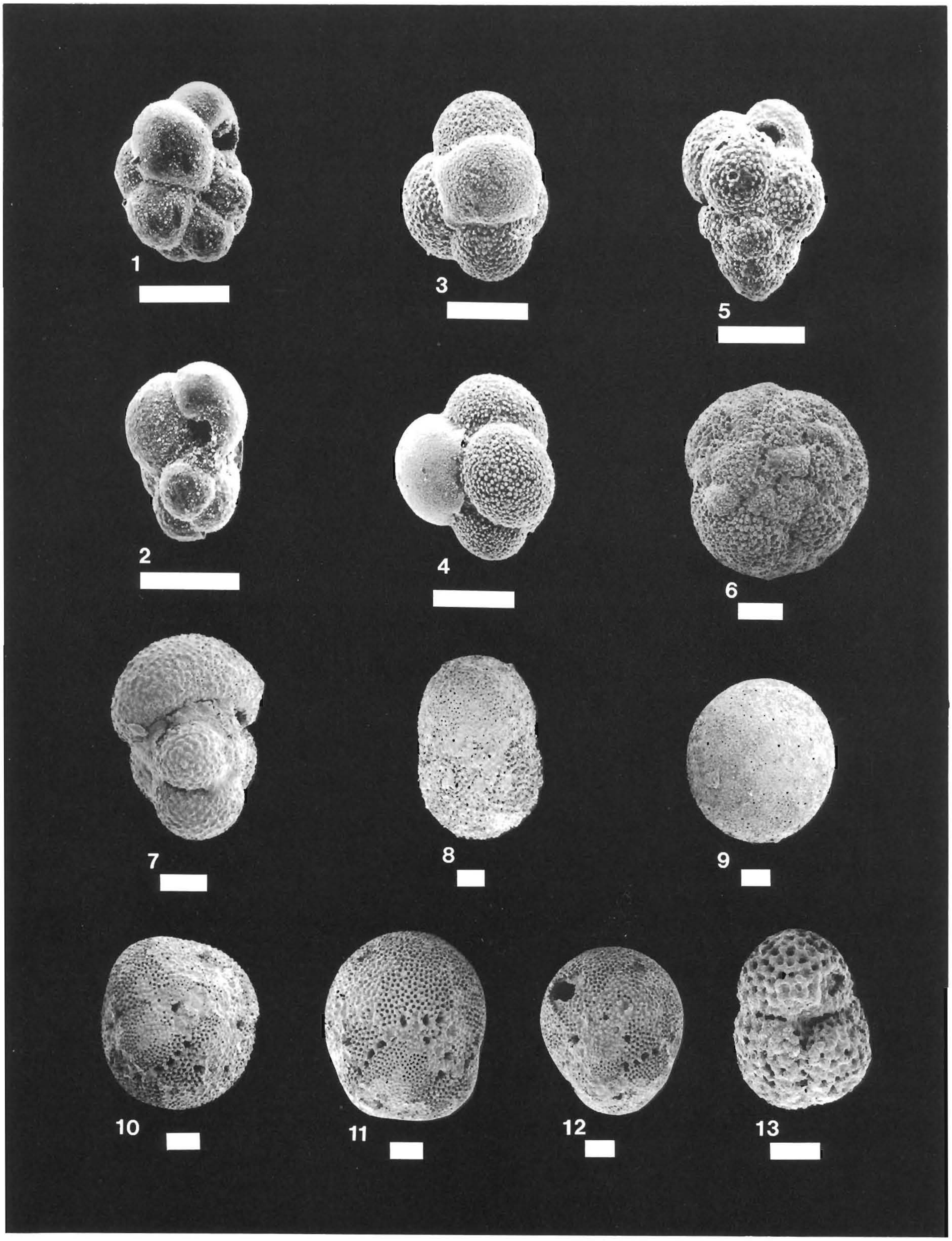
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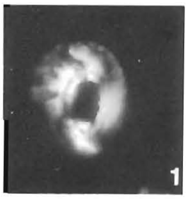
PLATE 6

CALCAREOUS NANNOFOSSILS TYPICAL OF ONSLOW BAY SEDIMENTS

Black background = crossed polarizers,
grey background = phase contrast,
magnification = ×2,800

1-3 *Helicosphaera ampliaperta* Bramlette and Wilcoxon (1967). 1. 0°. 2. 45°.
4, 10 *Coccolithus pelagicus* (Wallich, 1877) Schiller (1930).
5, 11 *Coccolithus miopelagicus* Bukry (1971).
6, 12 *Pontosphaera multipora* (Kamptner, 1948) Roth (1970).
7-9 *Helicosphaera carteri* (Wallich, 1877) Kamptner (1954). 7. 0°. 8. 45°.
13-15 *Helicosphaera intermedia* Martini (1965). 13. 0°. 14. 45°.
16, 22 *Dictyococcites bisectus* (Hay, Mohler and Wade, 1966) Bukry and Percival (1971).
17, 23 *Dictyococcites scrippsae* Bukry and Percival (1971).
18, 24 *Reticulofenestra pseudoumbilica* (Gartner, 1967) Gartner (1969).
19-21 *Helicosphaera mediterranea* Müller (1981). 19. 0°. 20. 45°.
25-27 *Sphenolithus abies* Deflandre *in* Deflandre and Fert (1954). 25, 26. Lateral views. 27. Apical view.
28, 34 *Cyclicargolithus abisectus* (Müller, 1970) Wise (1973).
29, 35 *Cyclicargolithus floridanus* (Roth and Hay *in* Hay and others, 1967) Bukry (1971).
30, 36 *Calcidiscus macintyrei* (Bukry and Bramlette, 1969) Loeblich and Tappan (1978).
31-33 *Sphenolithus moriformis* (Brönnimann and Stradner, 1960) Bramlette and Wilcoxon (1967). 31, 32. Lateral views. 33. Apical view.
37-39 *Sphenolithus belemnos* Bramlette and Wilcoxon (1967). 37–39. Lateral views. 37. 0°. 38. 45°.
40-41 *Coronocyclus nitescens* (Kamptner, 1963) Bramlette and Wilcoxon (1967).
42 *Discoaster deflandrei* Bramlette and Riedel (1954).
43-48 *Sphenolithus heteromorphus* Deflandre (1953). 43–48. Lateral views. 43, 46. 0°. 44, 47. 45°.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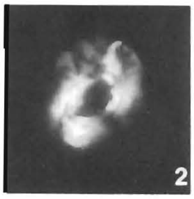
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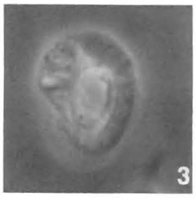
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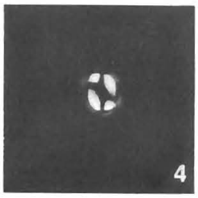
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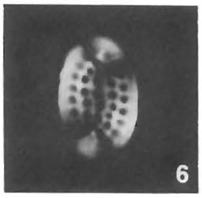
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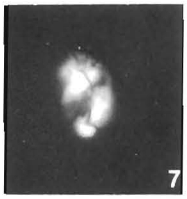
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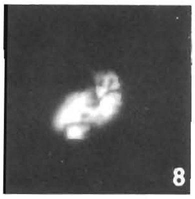
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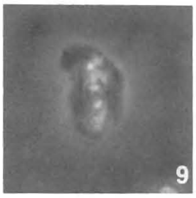
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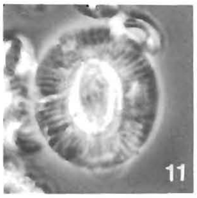
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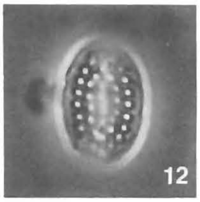
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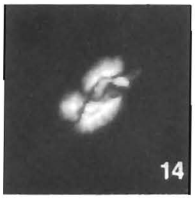
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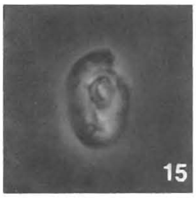
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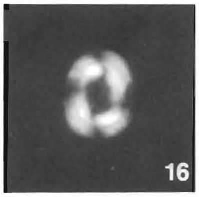
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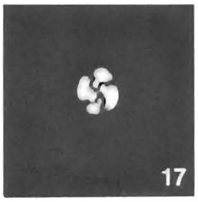
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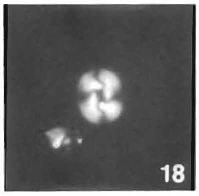
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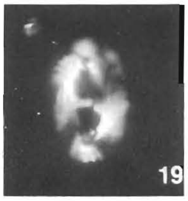
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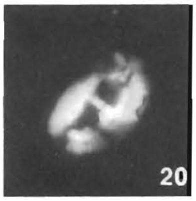
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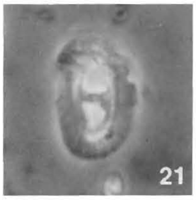
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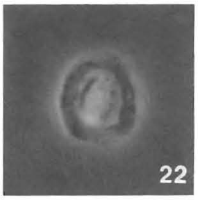
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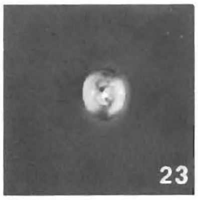
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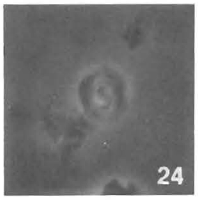
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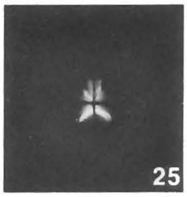
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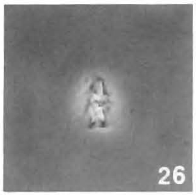
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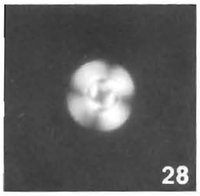
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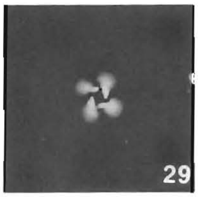
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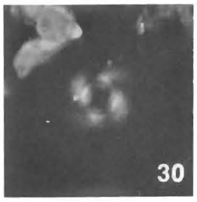
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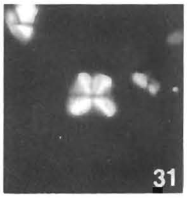
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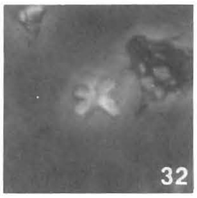
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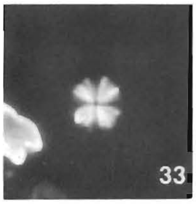
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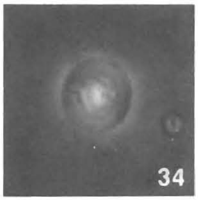
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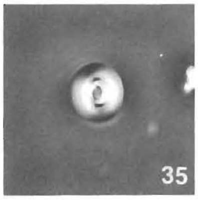
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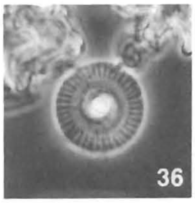
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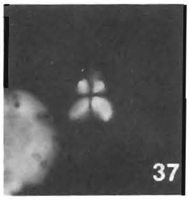
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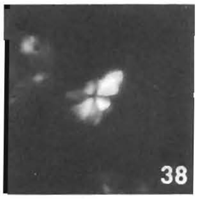
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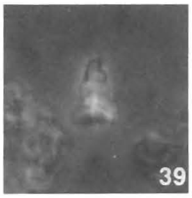
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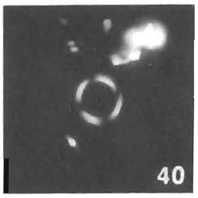
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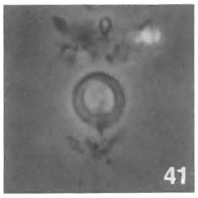
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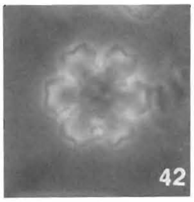
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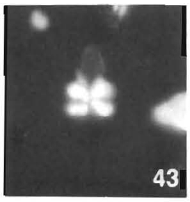
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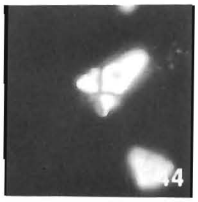
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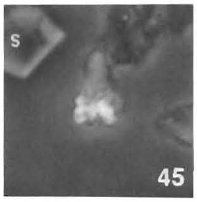

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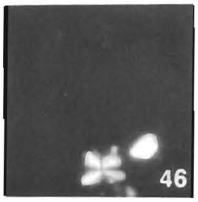
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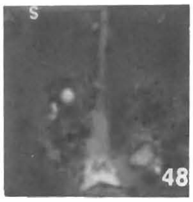

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BENTHIC FORAMINIFERA AND PALEOECOLOGY OF MIOCENE PUNGO RIVER FORMATION SEDIMENTS IN ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

Of 104 benthic foraminiferal species identified from Miocene strata in Onslow Bay, 27 occur commonly enough to be useful in paleoenvironmental interpretations. Variations in the abundance and distribution of six species (*Bolivina paula, Buliminella elegantissima, Valvulineria floridana, Lenticulina americana, Hanzawaia concentrica* and *Cibicides floridanus*) account for about 84% of the total variance in benthic foraminiferal assemblages. *B. paula* and *B. elegantissima* thrive under conditions of nutrient enrichment and oxygen depletion. The other species thrive in well-oxygenated bottom waters. Biofacies, which are largely defined by the relative abundance of these six species, indicate that changing water mass properties, particularly with reference to nutrient and dissolved oxygen content, exerted control over Miocene benthic foraminiferal distributions.

Individual biofacies, each defined by cluster analysis, generally coincide with specific lithofacies, indicating that substrate type also influenced benthic faunal distributions. Lithofacies were related to some extent to water mass chemistry, as phosphate accumulated in nutrient-enriched, oxygen-depleted waters associated with coastal upwelling: siliciclastics predominated under well-oxygenated conditions. Hence, water mass properties and substrate type combined to partially control the species content and distribution of Miocene benthic foraminiferal biofacies. Other environmental factors and diagenetic processes obscured details of faunal-sediment relationships such that only generalized, larger-scale patterns remain.

INTRODUCTION

This report represents the first comprehensive treatment of benthic foraminifera from Miocene Pungo River deposits of the North Carolina continental shelf in Onslow Bay. Several articles have addressed Pungo River benthic foraminiferal distributions in subsurface strata of the emerged coastal plain (Gibson, 1967, 1982, 1983; Katrosh and Snyder, 1982; Snyder and others, 1982). However, the only previously published information on faunas from the offshore Miocene section is a series of abstracts (Snyder and others, 1983; Snyder, 1983; Snyder and others, 1984; Moore and Snyder, 1985).

The data base for this report consists of 144 vibracores (maximum penetration of 9 meters) distributed across the Miocene outcrop/shallow subcrop belt in Onslow Bay. Vibracores could penetrate only the updip, feather-edge limits of Pungo River seismic sequences (see Snyder and others, this volume, for more detail).

MATERIALS AND METHODS

Among the 144 vibracores, 95 penetrated some part of the Miocene section. Sixty-five of these were selected for benthic foraminiferal faunal analyses. Because the richest faunas and densest sampling are in southern Onslow Bay, selected cores were examined in order to provide maximum stratigraphic and geographic cov-

TABLE 1

Seismic stratigraphic position, species diversity and equitability, and P/B ratio values of samples utilized in this study. Samples are sequenced and grouped by cluster analysis.

SAMPLE	CORE/INTERVAL (meters sub-bottom)	SEISMIC SEQUENCE	CLUSTER	DIVERSITY (Shannon-Wiener)	EQUITABILITY	P/B RATIO
1	53/1.25	BBS 2	A	1.10	0.23	1:89
2	53/4.75	BBS 2	A	1.15	0.23	1:78
3	53/5.25	BBS 2	A	1.22	0.31	1:100
4	53/6.25	BBS 2	A	1.33	0.25	1:103
5	59/6.75	BBS 1	A	1.53	0.29	1:6
6	94/1.00	BBS 2	A	1.20	0.28	1:55
7	109/5.50	BBS 1	A	1.65	0.27	*
8	53/2.75	BBS 2	A	1.11	0.22	1:69
9	53/3.30	BBS 2	A	1.23	0.21	1:64
10	108/2.50	BBS 5	A	1.18	0.20	1:106
11	67/7.25	FPS 6	A	1.75	0.24	1:1
12	59/5.89	BBS 1	B	1.91	0.35	1:4
13	105/4.50	FPS 2	C	2.08	0.35	1:2
14	103/5.90	FPS 2	C	1.76	0.34	1:17
15	109/2.50	BBS 1	C	1.74	0.48	1:106
16	103/5.00	FPS 2	C	1.85	0.40	1:77
17	109/6.00	BBS 2	C	1.69	0.45	*
18	105/1.50	FPS 2	C	2.42	0.45	1:2
19	129/2.50	FPS 3	C	2.15	0.39	1:1
20	129/4.00	FPS 3	C	2.21	0.48	1:1
21	129/5.50	FPS 3	C	2.13	0.44	1:6
22	109/4.00	BBS 1	C	2.01	0.42	1:35
23	71/1.00	BBS 1	C	1.74	0.63	*
24	71/0.50	BBS 1	C	1.74	0.52	*
25	72/1.00	BBS 1	C	2.07	0.38	1:142
26	6/7.00	OBS 3	C	2.32	0.48	1:53
27	45/3.00	FPS 6	C	1.99	0.43	1:2
28	45/4.75	FPS 6	C	2.04	0.33	1:6
29	50/3.25	FPS 6	C	2.01	0.35	1:2
30	43/1.00	BBS 1	C	1.70	0.39	*
31	27/2.75	FPS 2	D	2.29	0.47	1:2
32	63/1.25	FPS 2	D	2.23	0.37	1:1
33	63/2.25	FPS 2	D	2.47	0.47	1:1
34	27/5.25	FPS 2	D	1.99	0.32	1:3
35	98/3.25	FPS 2	D	2.18	0.47	1:1
36	27/7.25	FPS 2	D	2.38	0.36	1:4
37	119/3.35	FPS 1	D	2.29	0.41	1:8
38	64/4.50	FPS 1	D	2.27	0.29	1:3
39	120/4.25	FPS 1	D	2.33	0.33	1:2
40	116/3.00	FPS 1	D	2.48	0.31	1:2
41	9/2.75	FPS 1	D	2.13	0.38	1:6
42	14/1.00	FPS 1	D	2.25	0.32	1:2
43	26/2.75	FPS 1	D	2.26	0.29	1:2
44	105/7.25	FPS 1	D	2.15	0.32	1:3
45	64/4.00	FPS 1	D	2.65	0.43	1:2
46	14/4.00	FPS 1	D	2.33	0.37	1:2
47	26/1.25	FPS 1	D	2.55	0.37	1:2
48	64/6.00	FPS 1	D	2.50	0.35	1:2
49	22/3.25	FPS 1	D	2.55	0.43	1:3
50	9/1.75	FPS 1	D	2.13	0.38	1:2
51	120/5.90	FPS 1	D	2.34	0.35	1:1
52	22/5.25	FPS 1	D	2.76	0.47	1:2
53	24/0.30	FPS 1	D	2.54	0.42	1:2
54	24/1.00	FPS 1	D	2.62	0.42	1:2
55	17/5.75	OBS (undiff.)	D	2.23	0.52	1:8
56	105/1.25	FPS 2	D	2.00	0.32	1:3

* indicates no planktonic specimens observed

erage. The sparser and more widely spaced vibracore network in central and northern Onslow Bay required that all available cores be examined.

Samples were taken from cores at half-meter intervals and soaked in a weak Calgon solution for approximately 24 hours. Clays were further deflocculated by boiling for 20–30 minutes in a very dilute solution of "Quaternary O" (alkyl imidazolinium chloride) and removed by wet sieving. Gentle washing through U.S. Standard Sieves No. 14 (1.41 mm openings) and No. 230 (63 μm openings) trapped the sand-sized fraction and separated the coarser and finer fractions. The sand-sized fraction, dried at 70°C, was then examined for benthic foraminifera. Flotation of foraminiferal tests was not employed because many specimens are filled with secondary mineral matter, and their failure to float would seriously distort estimates of species abundances. Washed samples were reduced to workable size using a microsplitter.

Using a picking tray divided into a systematic grid

TABLE 1 (continued)

SAMPLE	CORE/INTERVAL (meters sub-bottom)	SEISMIC SEQUENCE	CLUSTER	DIVERSITY (Shannon-Wiener)	EQUITABILITY	P/B RATIO
57	105/7.50	FPS 1	E	2.46	0.42	1:1
58	127/4.50	FPS 1	E	2.17	0.42	1:9
59	127/5.50	FPS 1	E	2.37	0.38	1:5
60	127/7.00	FPS 1	E	2.64	0.47	1:1
61	132/1.50	FPS 1	E	2.54	0.53	1:1
62	132/2.00	FPS 1	E	2.37	0.49	1:1
63	132/3.50	FPS 1	E	2.55	0.44	1:1
64	132/4.10	FPS 1	E	2.36	0.51	1:3
65	132/2.50	FPS 1	E	2.66	0.49	1:1
66	17/3.00	OBS (undiff.)	E	2.13	0.56	1:20
67	96/5.25	FPS 6	E	2.25	0.43	1:3
68	34/3.75	OBS 1	E	2.36	0.44	1:28
69	34/6.75	OBS 1	E	2.57	0.55	1:33
70	34/5.75	OBS 1	E	2.43	0.42	1:25
71	35/1.75	OBS 1	F	2.38	0.45	1:18
72	35/5.75	OBS 1	F	2.45	0.48	1:19
73	35/7.20	OBS 1	F	2.53	0.44	1:13
74	33/8.25	OBS 3	F	2.55	0.51	1:11
75	111/4.50	OBS 3	F	2.59	0.46	1:29
76	111/5.00	OBS 3	F	2.51	0.46	1:28
77	111/6.30	OBS 3	F	2.50	0.44	1:17
78	105/8.90	FPS 1	G	2.18	0.38	*
79	1/3.75	BBS 8	H	2.16	0.46	1:174
80	1/4.75	BBS 8	H	1.97	0.38	1:77
81	2/3.25	BBS 1	H	2.07	0.30	1:68
82	1/7.75	BBS 8	H	1.73	0.35	*
83	110/6.00	FPS 2	H	2.24	0.41	1:3
84	67/3.25	FPS 6	H	2.57	0.41	3:1
85	67/4.75	FPS 6	H	2.49	0.34	2:1
86	114/6.35	FPS 1	H	2.11	0.33	1:10
87	96/2.25	FPS 6	H	1.76	0.29	1:2
88	39/4.25	BBS 1	H	2.01	0.36	1:132
89	1/6.75	BBS 8	H	2.20	0.32	1:29
90	1/5.75	BBS 8	H	2.34	0.40	*
91	1/8.75	BBS 8	H	2.20	0.32	1:133
92	118/3.00	FPS 6	H	2.39	0.34	2:1
93	118/4.25	FPS 6	H	2.57	0.41	2:1
94	38/2.25	OBS 1	H	2.76	0.46	1:4
95	38/1.50	OBS 2	H	2.76	0.44	1:6
96	38/0.25	OBS 2	H	2.90	0.42	1:3
97	118/5.90	FPS 6	H	2.71	0.43	2:1
98	118/8.90	FPS 6	H	2.87	0.51	2:1
99	108/6.00	BBS 5	H	2.76	0.48	1:1
100	39/8.75	BBS 1	H	2.74	0.52	1:4
101	33/6.50	OBS 3	H	2.66	0.46	1:18
102	59/7.80	BBS 1	I	2.15	0.39	1:10
103	6/6.50	BBS 1	I	2.37	0.40	1:52
104	48/2.25	FPS 3	J	2.23	0.47	1:5
105	48/4.75	FPS 3	J	2.04	0.33	1:5
106	45/0.75	FPS 6	J	1.99	0.49	1:20
107	72/4.00	BBS 1	K	1.64	0.32	*
108	72/4.50	BBS 1	K	1.53	0.39	*
109	91/3.50	BBS 1	K	2.02	0.54	*
110	91/6.00	BBS 1	K	2.31	0.48	*
111	98/1.25	FPS 2	L	1.93	0.41	1:6
112	105/9.10	FPS 1	M	2.19	0.50	*
113	127/8.00	FPS 1	M	2.22	0.37	1:1
114	59/4.75	BBS 1	N	1.06	0.26	1:9
115	52/3.75	BBS 1	N	0.79	0.20	1:25

* indicates no planktonic specimens observed

pattern, a minimum of 300 benthic foraminiferal specimens were selected at random, identified to species level and statistically analyzed. Chang (1967) showed that identification of 300 randomly selected specimens from a larger assemblage provides a valid data base for statistical analysis, and that results are not significantly improved by examining greater numbers of specimens. Very rare forms were occasionally encountered while examining larger volumes of sediment. Their presence was recorded but they were not used in any statistical calculations. Only those samples which yielded 300 or more specimens are included in this report.

For all statistically reliable samples, several faunal characteristics were routinely determined. The relative abundance of each species was calculated as a percentage of the total benthic foraminiferal assemblage. Species diversity was computed using the Shannon-Wiener Information Function, H(S), which is largely independent of sample size variation and the occurrence of rare species (Sanders, 1968; Gibson and Buzas, 1973). Faunal equitability (e^H/S), a measurement of apportionment of individuals among taxa, is commonly used in conjunction with the Shannon-Wiener index. Values may range from one (all species of equal abundance) to zero (only one species present) (Phillips, 1982). These values are summarized for all samples in Table 1. Cluster analysis was accomplished using software from the Statistical Analysis System (SAS) in order to define major biofacies. Clusters were computed by using an average linkage method to group samples which contained similar species with similar abundances (SAS Institute Inc., 1982). Principal component analysis was also performed using SAS.

A total of 167 samples from 65 vibracores were examined. Seventeen of these samples from 8 vibracores were determined to be Oligocene and are not included in this report. Another 35 samples from 11 cores were either barren or contained too few benthic foraminifera to allow reliable statistical characterization. One hundred fifteen samples from 46 cores form the basis for this report.

RESULTS

One hundred four benthic foraminiferal species and subspecies were identified from Pungo River sediments in Onslow Bay (Appendix I). All but one (*Dentalina communis*, a species which is always highly fragmented) are illustrated in Plates 1–10. Most species occur sporadically and, when present, account for less than 1% of the benthic foraminiferal assemblage. Such species generally do not provide reliable information about paleoenvironmental setting; therefore, the more commonly occurring species are the focus of this study. Interpretations are based on species that satisfy at least one of the following criteria:

1) accounts for 5% or more of the benthic foraminiferal assemblage in two or more samples;

2) occurs (in any abundance) in 75% or more of the samples. The 27 species which meet these requirements (Table 2) form the basis of our paleoenvironmental analyses. Collectively, these species account for an average of 93% of the benthic foraminiferal assemblage (based on 115 samples).

Dissolved oxygen content, one of the most important variables of benthic ecology, is a limiting factor related to basic metabolism in some foraminifera (Leutenegger and Hansen, 1979), but its control also stems from nutrient availability, which controls the amount and quality of available food (Van der Zwaan, 1982). Supply of inorganic nutrients does not directly affect foraminifera, but its direct control over their food supplies results in certain species of the benthic genera *Bolivina, Uvigerina, Bulimina* and *Globobulimina* having affinities for nutrient-rich, oxygen-depleted biotopes (Poag, 1985). Our subsequent reference to certain foraminiferal species as tolerant of nutrient enrichment and oxygen depletion simply recognizes a well-established relationship that, despite being indirect or secondary, is recognizable in both modern and ancient marine sediments. We are *not* implying that inorganic nutrient supply directly controls foraminiferal distributions. Nevertheless, distributional patterns of certain foraminiferal species appear to be useful indicators of geochemical aspects of marine paleoenvironments.

A survey of literature on modern oxygen-minimum zones and sewage outfall areas (characterized by nutrient enrichment and oxygen depletion) reveals a predominance of species belonging to *Bolivina, Bulimina* and *Buliminella* (Table 3). Whether conditions occur naturally or are man-induced, some species of these genera thrive where nutrient enrichment and oxygen depletion are intense. Some species of *Florilus, Globobulimina, Nonionella* and *Uvigerina* appear to characterize zones that are marginal to the cores of oxygen depletion and nutrient concentration (see Snyder [in press] for more complete discussion).

Species belonging to the genera discussed above form a prominent part of Pungo River assemblages in Onslow Bay. Though few of the extant species in Table 3 occur in Miocene sediments, most of them are morphologically similar to extinct species of the same genera. It is reasonable to assume that numerical dominance of such forms in Miocene assemblages reflects environmental conditions similar to those indicated by their modern counterparts. Therefore, abundance trends of common benthic species in Miocene sediments of Onslow Bay are graphically summarized by grouping species according to their presumed ecological optima, specifically with reference to nutrient levels and oxygen content (Figs. 1–4). Just as the taxa discussed above reflect nutrient enrichment/oxygen depletion, others characterize highly oxygenated bottoms (Van der Zwaan, 1982; Snyder, in press). Species belonging to *Hanzawaia, Cibicides, Lenticulina* and *Valvulineria* are the most abundant of these indicators in Onslow Bay assemblages. Based on their faunal and

TABLE 2. Commonly occurring benthic foraminiferal species.

Species	Mean relative abundance (115 samples)	Rank
Bolivina		
calvertensis	1.7%	13
lowmani	1.4%	14
marginata multicostata	0.6%	25
paula	24.8%	1
robusta	0.8%	22
subdilatata	3.6%	6
Buccella inusitata	0.7%	24
Bulimina elongata	2.3%	10
Buliminella elegantissima	8.2%	4
Cassidulina laevigata	0.9%	19
Cibicides		
americanus	2.8%	7
floridanus	2.3%	11
lobatulus	2.6%	8
Epistominella danvillensis	1.9%	12
Florilus		
grateloupi	1.0%	18
pizarrensis	5.0%	5
Globocassidulina crassa	0.8%	20
Hanzawaia concentrica	12.9%	2
Lenticulina americana americana	2.4%	9
Oridorsalis umbonatus	0.3%	27
Rosalina cavernata	1.3%	15
Rotorbinella bassleri	0.8%	21
Siphogenerina		
lamellata	1.2%	16
transversa	0.8%	23
Uvigerina		
auberiana	1.1%	17
subperegrina	0.5%	26
Valvulineria floridana	10.2%	3
Total	92.9%	

TABLE 3. Ecological optima of selected modern benthic foraminiferal species.

Species	Ecology	Source
Bolivina		
argentea	**	5
interjuncta	**	4
pacifica	**	6
rankini	**	4
seminuda	**	6
skagerrakensis	*	7
spissa	**	4, 5
subadvena	**	10
subaenariensis	**	9
vaughni	**	1
Bulimina		
marginata	**	7, 8
marginata denudata	*	2, 3
striata	*	4
Buliminella		
elegantissima	**	2, 3, 8, 11
silviae	**	8
Florilus		
atlanticus	*	8
grateloupi	*	8
Globobulimina hoeglundi	*	6
Nonionella		
opima	*	8
stella	*	1, 6
spp.	*	2, 3
Uvigerina		
peregrina	*	4, 7
spp.	*	5

* Indicates tolerance of moderate nutrient enrichment and reduced levels of dissolved oxygen.

** Indicates tolerance of intense nutrient enrichment and near depletion of dissolved oxygen.

Sources: 1) Bandy, Ingle, and Resig (1964a); 2) Bandy, Ingle, and Resig (1964b); 3) Bandy, Ingle, and Resig (1965); 4) Ingle, Keller, and Kolpack (1980); 5) Mullins, Thompson, McDougall, and Vercoutere (1985); 6) Phleger and Soutar (1973); 7) Qvale and Van Weering (1985); 8) Seiglie (1968); 9) Sen Gupta, Lee, and May (1981); 10) Streeter (1972); 11) Watkins (1961).

sediment associations within this study, three species of *Bolivina,* a genus generally linked with nutrient enrichment (Poag, 1985), are grouped with taxa that mark oxygenated conditions.

ASSEMBLAGES OF THE FRYING PAN SECTION

The Frying Pan Section is characterized by assemblages in which nutrient-tolerant species are generally diverse and abundant (Figs. 1 and 2). *Bolivina paula* is usually predominant, and *Buliminella elegantissima* becomes proportionately more abundant when *B. paula* declines. *Florilus pizarrensis* maintains a fairly stable relative abundance pattern in all cores. Several taxa (*Siphogenerina lamellata, Uvigerina auberiana* and *Bulimina elongata*) are particularly prominent in FPS-2 (Fig. 2).

Sequences FPS-1 through FPS-5 exhibit a similar regional trend: nutrient-tolerant species are generally more abundant toward southern Onslow Bay (Figs. 1 and 2). The trend is most apparent in the relative abundance values for *Bolivina paula,* but it is also expressed by reduced diversity among other nutrient-tolerant species in a northward direction. Species adapted to well-oxygenated bottoms occur in moderate, rather stable abundances in southern Onslow Bay, but increase northward in proportion to declining numbers of nutrient-tolerant taxa. *Hanzawaia concentrica* is clearly the most abundant of these species in FPS-1, while *Valvulineria floridana* is equally abundant in FPS-2 through FPS-5. *Lenticulina americana* occurs in moderate numbers in nearly all cores, while *Cibicides americanus* increases markedly in FPS-3 and FPS-5.

Benthic foraminiferal trends parallel sedimentological trends in FPS-1 through FPS-5. There is a general southward fining of the sediments, accompanied by a reduction in siliciclastic material and a concomitant increase in authigenic mineral content (Mallette, 1986).

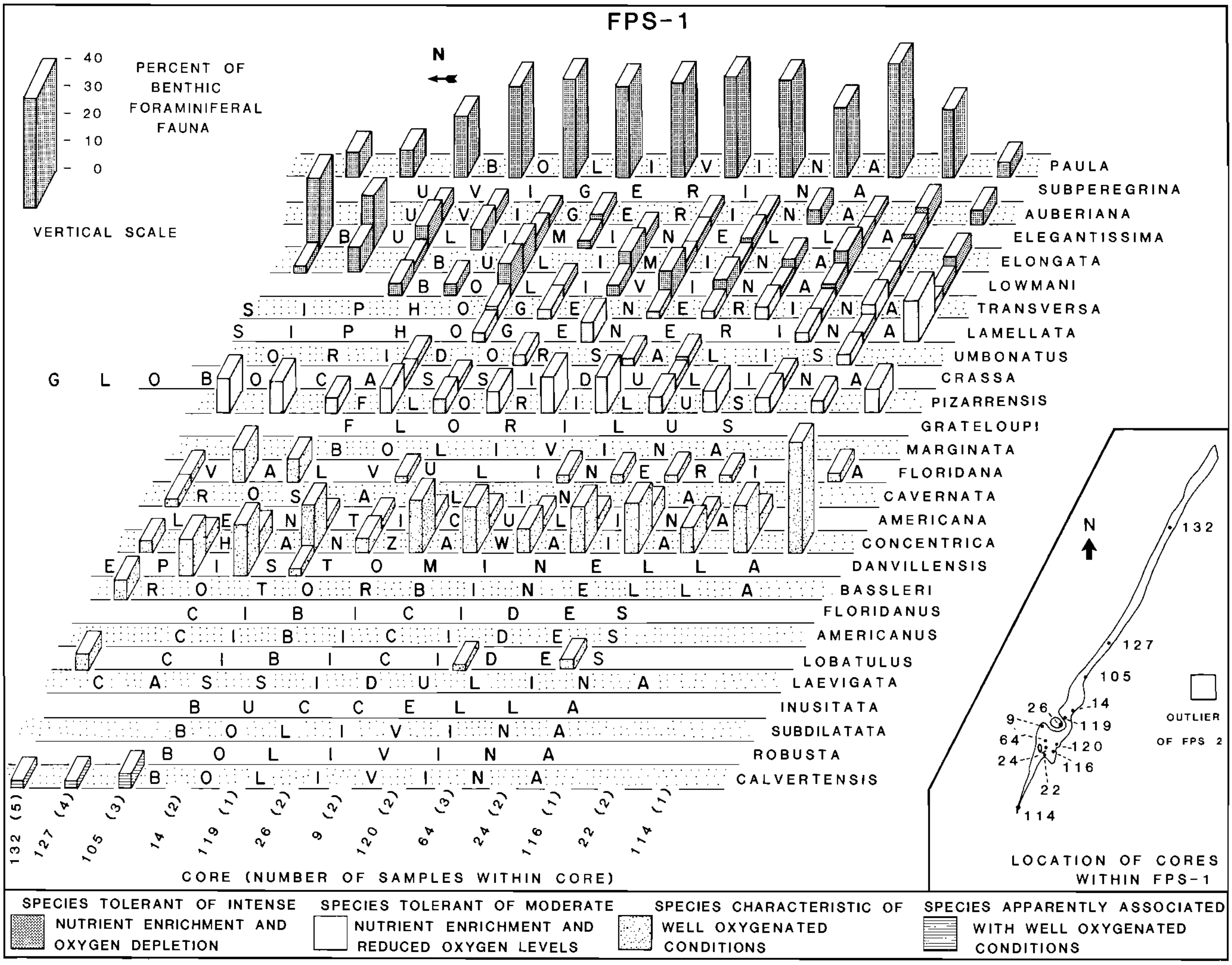

FIGURE 1. Mean relative abundance of the most commonly occurring benthic foraminiferal species within vibracores penetrating FPS-1. Vibracores are arranged from north to south. Species are grouped according to similar ecological tolerances. Occurrences of less than 2% of the benthic foraminiferal fauna are not plotted.

Phosphate increases sharply in a southward direction within FPS-1 and FPS-2.

FPS-6 is distinctive in its geometry, sediment type and faunal composition. Nutrient-tolerant species, particularly *Bolivina paula,* are less abundant (Fig. 2). *Hanzawaia concentrica* is generally the predominant species. Sediments generally fine in a southward direction, but they remain predominantly siliciclastic. FPS-6 in southern Onslow Bay is composed of foraminiferal quartz sands that are part of large-scale channel-fill deposits which truncate other seismic sequences (Snyder and others, this volume). The authigenic minerals, particularly carbonate fluorapatite, that characterize most of the other sequences are absent in FPS-6.

ASSEMBLAGES OF THE ONSLOW BAY SECTION

Benthic foraminiferal faunas of the Onslow Bay Section differ from those of the Frying Pan Section. This may be due to changing environments through time, but it may also reflect that most samples from the Onslow Bay Section come from the northern part of the Bay (Fig. 3). Here *Bolivina paula,* though still common and occasionally the most abundant species, is less abundant than in the underlying Frying Pan Section. Many of the less common nutrient-tolerant types have disappeared (Fig. 3). Taxa characteristic of oxygenated bottoms are more diverse and abundant. *Hanzawaia concentrica* and *Cibicides* spp. are particularly

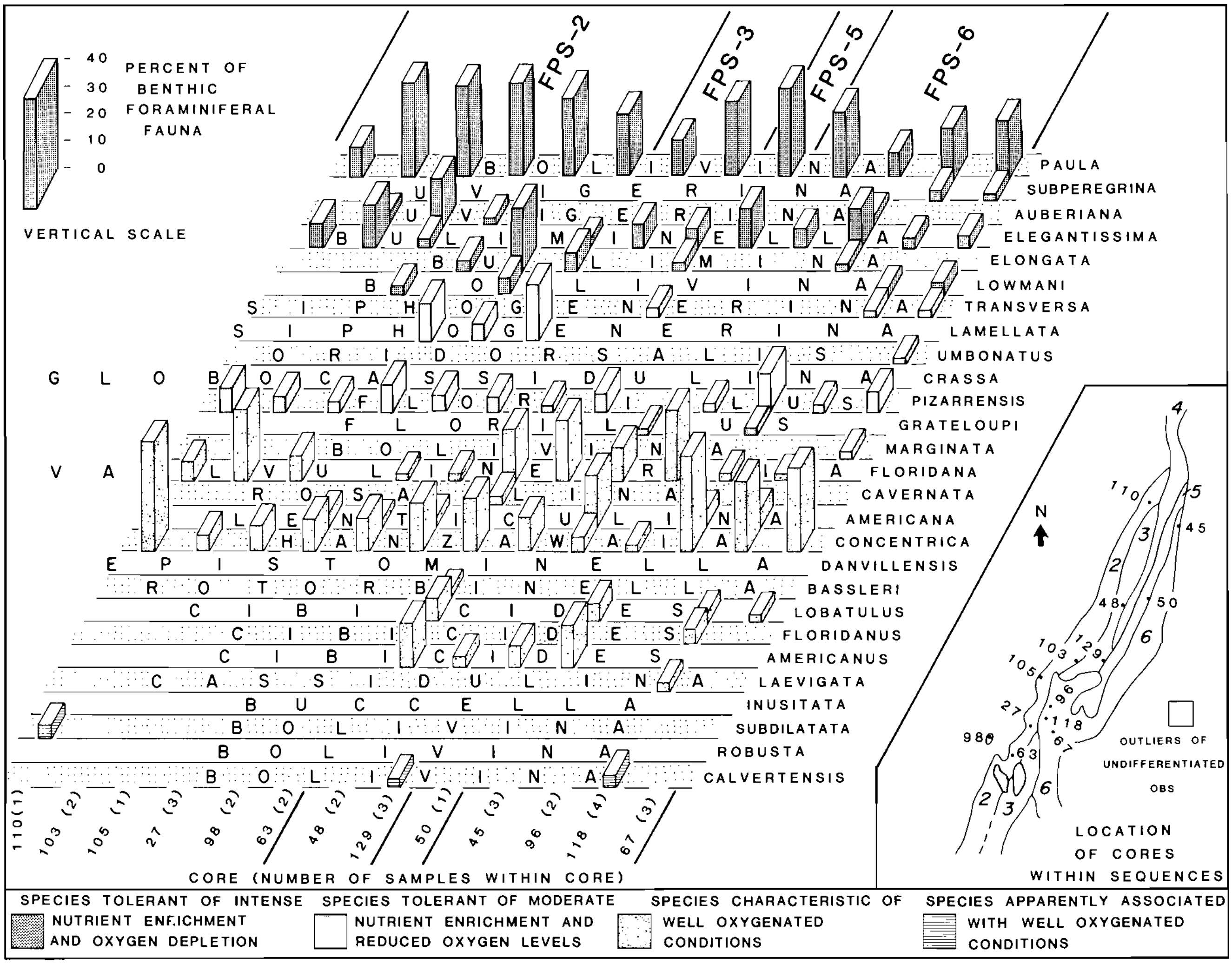

FIGURE 2. Mean relative abundance of the most commonly occurring benthic foraminiferal species within vibracores penetrating FPS-2, FPS-3, FPS-5 and FPS-6. Vibracores are grouped by seismic sequence and arranged from north to south within each sequence. North to south corresponds with left to right within any given sequence. Species are grouped according to similar ecological tolerances. Occurrences of less than 2% of the benthic foraminiferal fauna are not plotted.

abundant, while *Rosalina floridana* becomes a more common species. Robust, rather thick-shelled, coarsely ornamented species of *Bolivina* (*B. calvertensis, B. robusta* and *B. subdilatata*) also become conspicuous faunal elements (Fig. 3).

Sediments of the Onslow Bay Section are predominantly quartzitic and calcareous sands. The occasionally significant gravel fraction consists largely of barnacle fragments. Interbedded muds are generally diatomaceous but contain few foraminifera. Dolomite, present largely in the silt-sized fraction, is the only significant authigenic mineral, as phosphate content is generally negligible. Sediments become finer southward, but central and southern portions of this section are usually devoid of foraminifera.

One core in an undifferentiated Onslow Bay Section outlier in southern Onslow Bay (Fig. 3) contains an assemblage similar to those in the surrounding Frying Pan Section sediments. Nutrient-tolerant species predominate. Muds in these OBS outliers are similar to those of FPS-2 and FPS-3 except that they contain siliceous microfossils.

ASSEMBLAGES OF THE BOGUE BANKS SECTION

Except for parts of BBS-2, benthic foraminiferal faunas of the Bogue Banks Section are similar in many

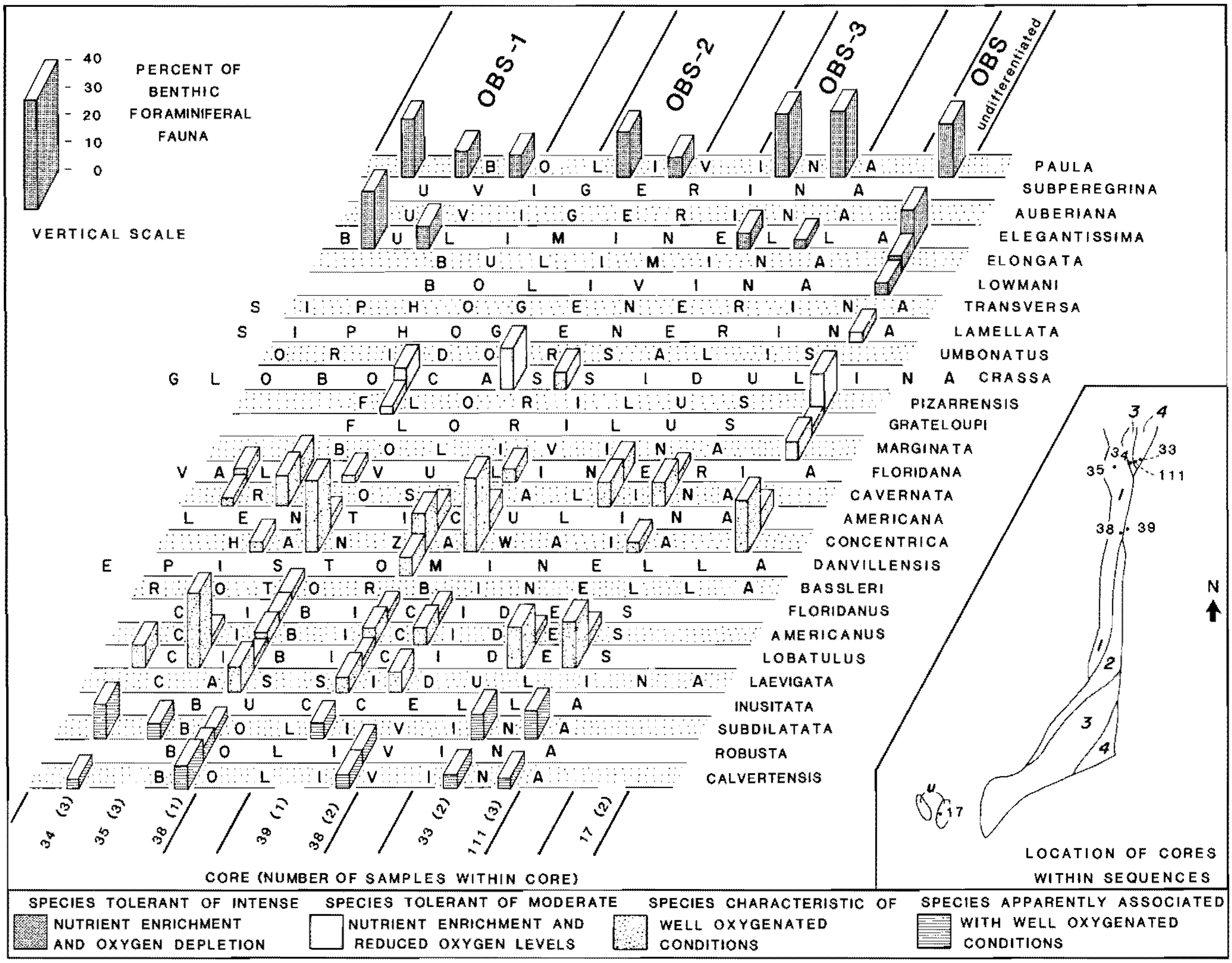

FIGURE 3. Mean relative abundance of the most commonly occurring benthic foraminiferal species within vibracores penetrating OBS-1, OBS-2, OBS-3 and OBS outliers. Vibracores are grouped by seismic sequence and arranged from north to south within each sequence. North to south corresponds with left to right within any given sequence. Species are grouped according to similar ecological tolerances. Occurrences of less than 2% of the benthic foraminiferal fauna are not plotted.

respects to those of the underlying Onslow Bay Section. *Bolivina paula,* though still prominent, is less abundant overall than it is in the Frying Pan Section (Fig. 4). With the exception of *Buliminella elegantissima,* other nutrient-tolerant species are generally absent, and forms adapted to oxygenated bottoms are abundant and diverse. *Valvulineria floridana, Hanzawaia concentrica* and *Cibicides floridanus* are abundant and often predominant. The robust, coarsely ornamented bolivinids, particularly *Bolivina subdilatata,* are now a common and conspicuous faunal element.

Two cores (53 and 94) where the pattern described above does not apply lie in the southern portion of BBS-2. Here *Bolivina paula* and *Buliminella elegantissima* constitute nearly the entire benthic assemblage. Species characteristic of oxygenated bottoms are nearly absent (Fig. 4).

As with the Onslow Bay Section, cores penetrating the Bogue Banks Section are located largely in the northern part of Onslow Bay. Only in BBS-1 and BBS-2 are cores in the southern part of the outcrop belt available. BBS-1 is composed of interbedded sands (quartzitic with variable but minor amounts of phosphate and glauconite) and muds (dolomitic, sometimes diatomaceous) (Mallette, 1986). BBS-2 grades from a muddy, slightly phosphatic quartz sand southward into phosphorite and quartz sands interbedded with muds. BBS-5 is a muddy, quartzitic and calcareous sand, while

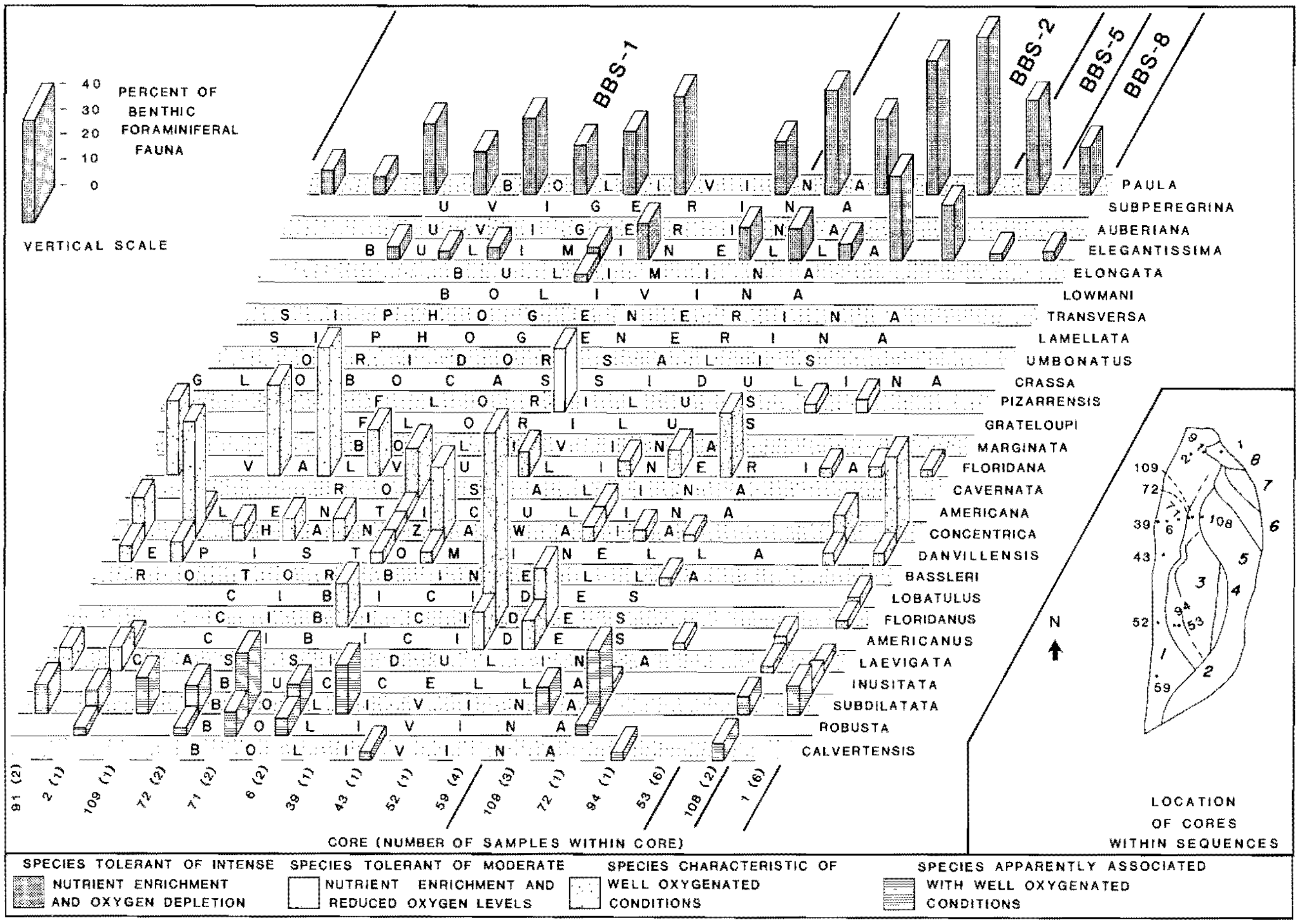

FIGURE 4. Mean relative abundance of the most commonly occurring benthic foraminiferal species within vibracores penetrating BBS-1, BBS-2, BBS-5 and BBS-8. Vibracores are grouped by seismic sequence and arranged from north to south within each sequence. North to south corresponds with left to right within any given sequence. Species are grouped according to similar ecological tolerances. Occurrences of less than 2% of the benthic foraminiferal fauna are not plotted.

BBS-8 is a muddy phosphorite and quartz sand. The remaining sequences are unsampled.

ASSEMBLAGES VS. SEDIMENTS

A qualitative assessment of benthic foraminiferal distributions suggests that both species composition and relative abundances vary with changes in sediment type. Because the commonly occurring Miocene species were probably influenced by nutrient and dissolved-oxygen levels at and just below the sediment/water interface, water chemistry was also an important factor. The presence of appreciable phosphate provides an independent means of assessing geochemical aspects of the paleoenvironment. Though the environments in which and the mechanisms by which phosphate forms may vary, most workers postulate nutrient-enriched (and probably oxygen-deficient) conditions for the genesis of marine sedimentary phosphorite (S. R. Riggs, pers. comm.). Because the phosphorites of North Carolina are among the least altered in the world (McClellan and others, 1986), faunal/phosphatic sediment relationships are likely to reflect, at least to some degree, geochemical aspects of the depositional environment.

The distribution of phosphate in Pungo River sediments of Onslow Bay is graphically depicted in Figures 5 and 6. Whether measured as percent phosphatic grains in the sand fraction or as percent P_2O_5 in the bulk sediment, it is apparent that phosphate is concentrated primarily in the southern part of FPS-1. Isolated, smaller-scale concentrations also occur in the southern part of BBS-2 and in BBS-8.

Figure 7 is a graphic display of the cumulative abundance of species which tolerate intense nutrient en-

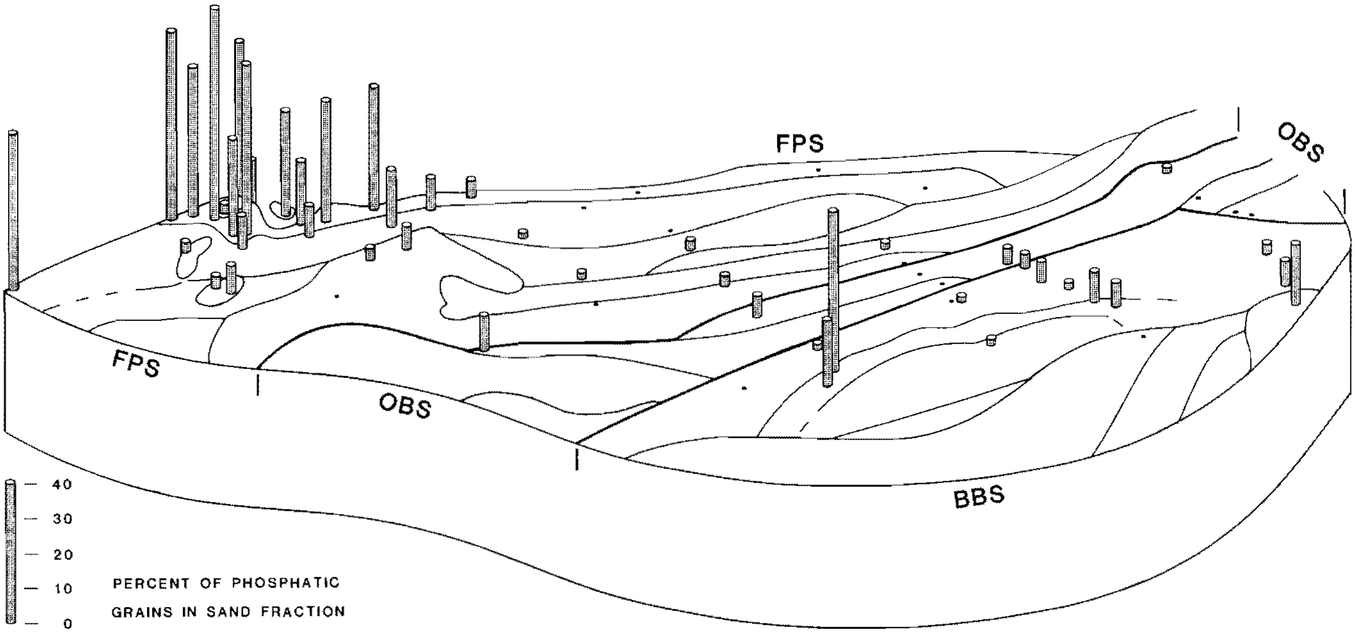

FIGURE 5. Oblique schematic diagram showing the mean percentage of phosphatic grains in the sand-sized fraction of Miocene sediments in Onslow Bay. Vibracores represented by dots have a mean abundance of less than 2%.

richment and oxygen depletion (as defined in Figs. 1–4) through Pungo River seismic sequences. Although these species are common in nearly all vibracores, the phosphatic sediments of FPS-1 and BBS-2 are characterized by cumulative abundances greater than 60%. Non-phosphatic sequences generally have cumulative abundances of 35% or less. The relationship to phosphate content is far from perfect, suggesting that other environmental factors also influence foraminiferal distributions. FPS-2 in southern Onslow Bay has a greater abundance of nutrient-tolerant species than might be expected from its phosphate concentrations. However, muds of FPS-2 have high concentrations of organic carbon that range up to 5.74% of the bulk sediment (Mallette, 1986). Foraminifera may have responded to organic enrichment that simply was not related to the

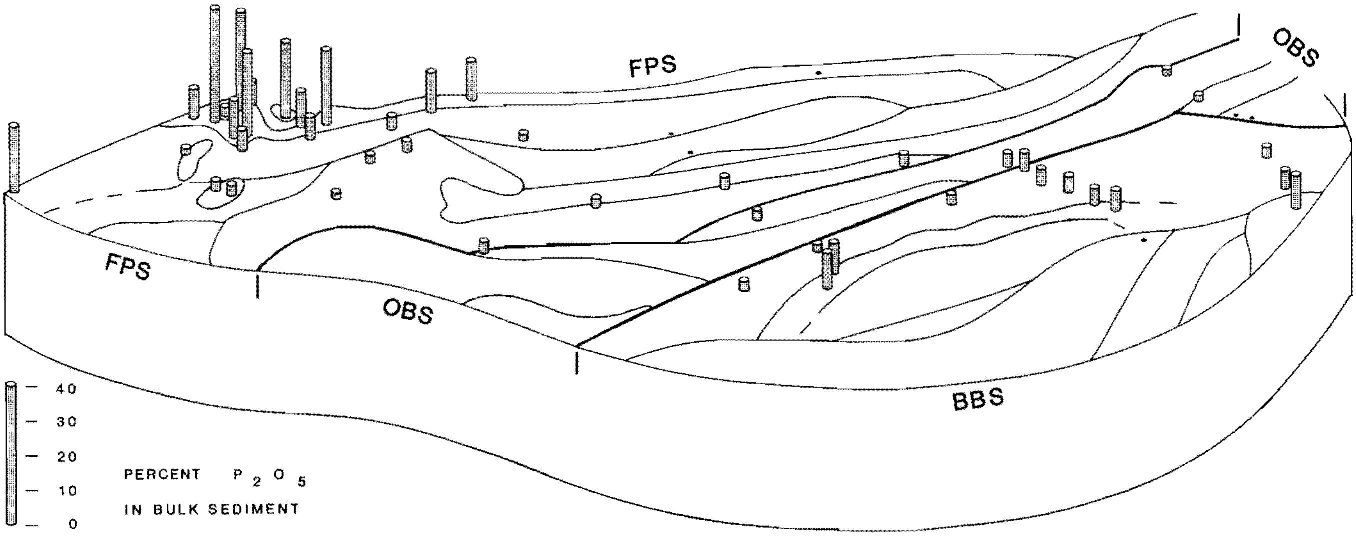

FIGURE 6. Oblique schematic diagram showing the mean percentage of P_2O_5 in bulk samples of Miocene sediment from Onslow Bay. Vibracores represented by dots have a mean abundance of less than 2%.

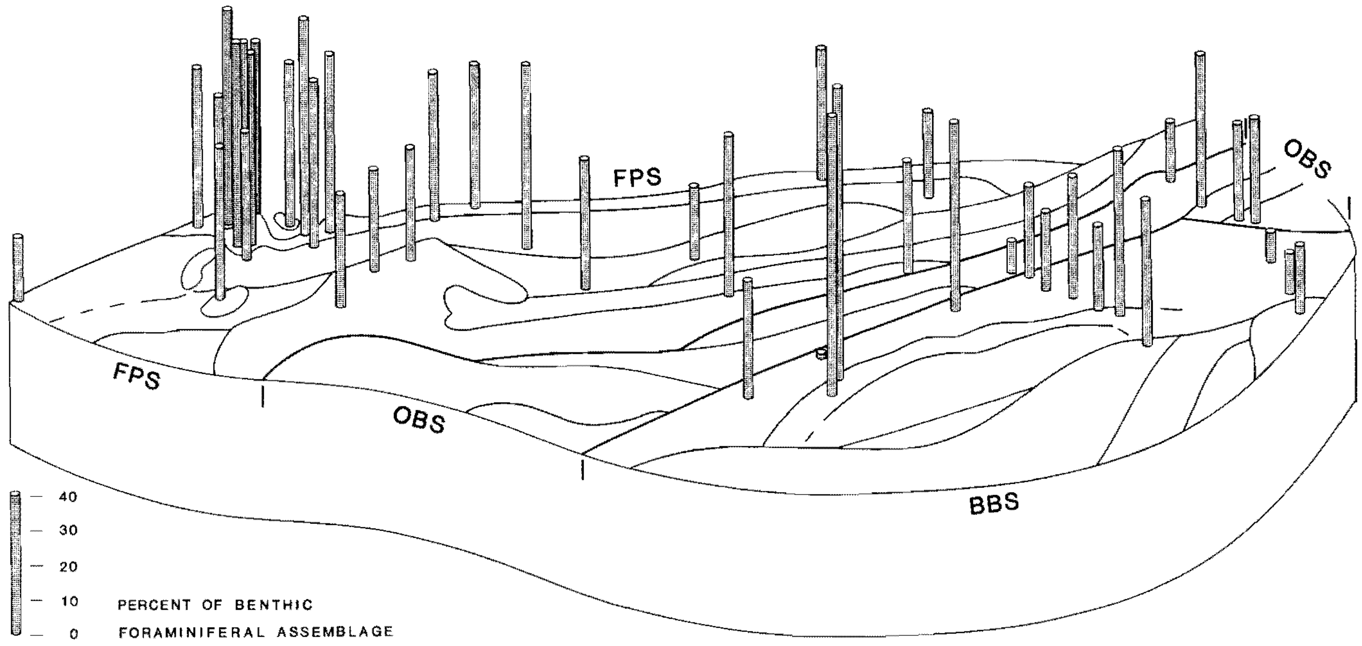

FIGURE 7. Oblique schematic diagram showing the relative abundance of species tolerant of intense nutrient enrichment and oxygen depletion. Values, indicated by height of the cylinders, are means of all samples within individual vibracores.

production of phosphate. Conversely, nutrient-tolerant species are much less abundant than might be expected in the phosphorite and quartz sands of BBS-8. Phosphate grains in this sequence are predominantly large intraclasts with surface characteristics that suggest transport. Such grains may have been reworked into an environment where phosphate was not actively forming, and so became associated with foraminifera adapted to oxygenated conditions.

The cumulative abundance of species adapted to moderate nutrient concentrations and reduced oxygen levels (as defined in Figs. 1–4) also mirrors the abundance of phosphate (Fig. 8). Persistent and common occurrences (> 15%) of these taxa are limited to FPS-1

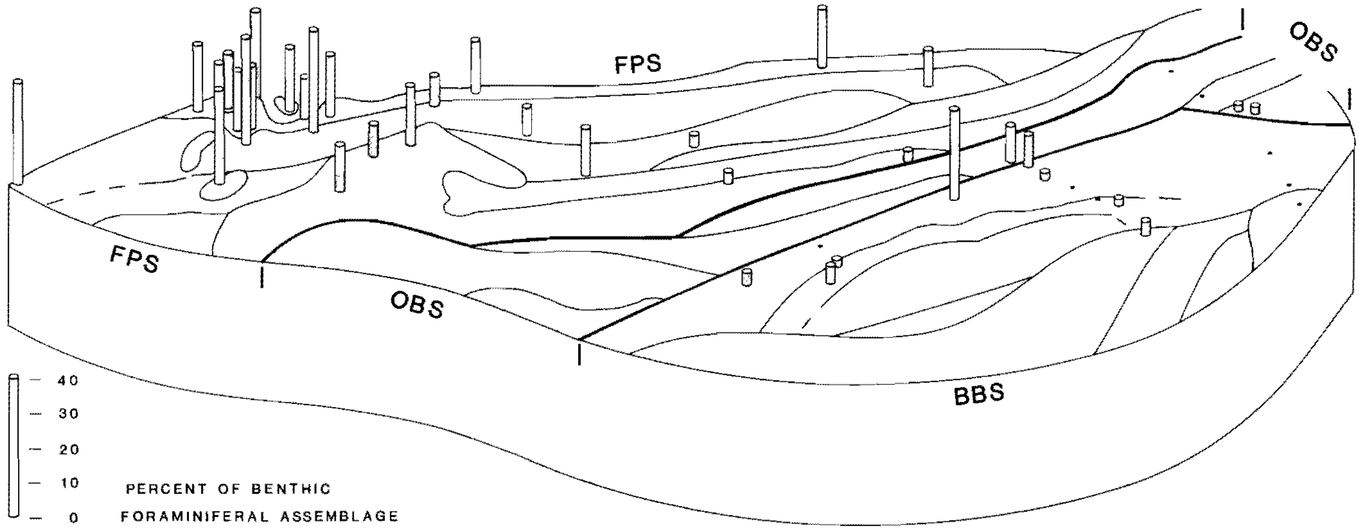

FIGURE 8. Oblique schematic diagram showing the relative abundance of species tolerant of moderate nutrient enrichment and reduced oxygen levels. Values, indicated by height of the cylinders, are means of all samples within individual vibracores.

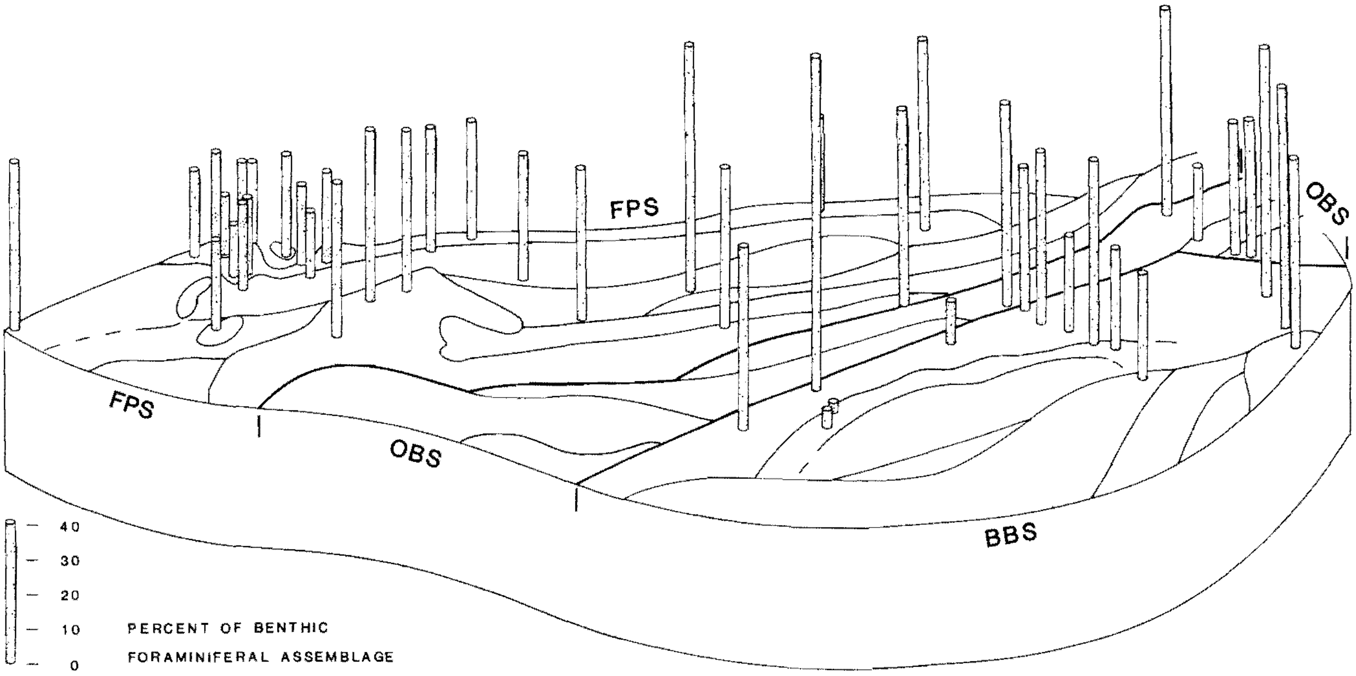

FIGURE 9. Oblique schematic diagram showing the relative abundance of species adapted to well-oxygenated bottom conditions. Values, indicated by height of the cylinders, are means of all samples within individual vibracores.

and FPS-2 in southern Onslow Bay. High abundances in a few cores farther to the north probably reflect organic enrichment not associated with phosphate formation.

Taxa adapted to well-oxygenated bottom conditions (Figs. 1–4) also occur commonly in all Pungo River sequences (Fig. 9). However, sequences with high phosphate or organic carbon content generally have cumulative abundances of 25% or less. Remaining sequences rich in clastic sediments are generally characterized by abundances of 40 to 50% or more.

The faunal trends described above are not related in

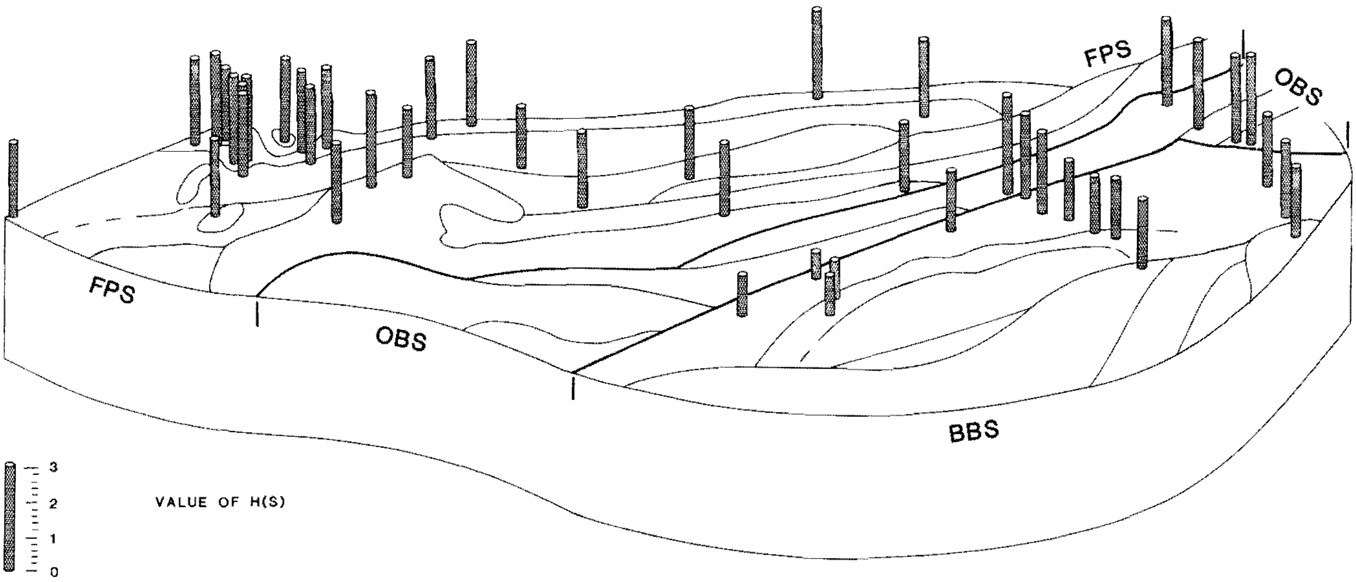

FIGURE 10. Oblique schematic diagram showing values of benthic species diversity [Shannon-Wiener Information Function, H(S)] within vibracores from Onslow Bay. Values, indicated by height of the cylinders, are means of all samples within individual vibracores.

TABLE 4. Principal component analysis (covariance matrix). Boldface type indicates high positive and negative loadings for each factor.

	Factor pattern					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
B. paula	**−0.56021**	**0.80150**	−0.06002	0.18282	−0.02979	0.04944
U. subperegrina	0.44279	0.12188	0.07344	−0.09004	0.20625	−0.14333
U. auberiana	0.13510	0.28463	0.00661	0.04768	0.10709	−0.06835
B. elegantissima	−0.48150	0.05896	0.19901	**−0.70598**	0.09618	**0.34579**
B. elongata	0.10882	0.13385	0.07484	−0.24025	0.20705	0.00063
B. lowmani	0.30762	0.54239	0.08153	0.04017	0.09027	−0.10260
S. transversa	0.37615	0.31374	0.03647	0.09220	0.16840	−0.16355
S. lamellata	0.13800	0.21267	0.04421	0.00150	0.05540	−0.12077
O. umbonatus	0.44008	0.23018	0.06625	0.04232	0.09456	−0.14416
G. crassa	0.08277	−0.04379	−0.03223	0.00806	−0.13274	−0.09051
F. pizarrensis	0.22901	0.24033	0.11931	−0.47420	0.33364	0.26342
F. grateloupi	0.17785	−0.04048	0.16060	−0.44266	0.10964	−0.02209
B. marginata	−0.05579	0.02629	0.07190	−0.08364	−0.01610	−0.20319
V. floridana	−0.30603	**−0.46782**	**−0.49272**	0.26094	**0.58961**	0.14759
R. cavernata	−0.13709	−0.32589	0.10755	−0.16388	−0.14299	**−0.57455**
L. americana	**0.81900**	0.45994	0.09523	0.01315	0.28420	−0.08637
H. concentrica	**0.82231**	0.06603	−0.34871	0.05450	−0.31069	0.29455
E. danvillensis	−0.07927	−0.28972	−0.06012	−0.16752	−0.10350	−0.17982
R. bassleri	−0.08443	−0.32018	0.19965	−0.35039	−0.06995	−0.01733
C. floridanus	0.06062	−0.32456	**0.74992**	**0.50264**	−0.00706	0.24697
C. americanus	−0.11157	−0.41929	0.36284	0.16179	0.09413	0.04608
C. lobatulus	−0.02291	−0.32855	−0.03387	−0.04945	−0.15175	**−0.49081**
C. laevigata	0.23187	−0.22315	−0.22216	0.11417	−0.31998	0.01741
B. calvertensis	−0.06285	−0.15296	0.12065	−0.22130	−0.09046	−0.41242
B. inusitata	0.00697	−0.12535	−0.12953	0.07474	−0.27839	−0.08385
B. subdilatata	−0.24064	−0.27056	−0.41429	0.28769	**−0.34513**	−0.08228
B. robusta	−0.12783	−0.29454	−0.17065	0.20923	−0.09328	−0.22074

any obvious way to benthic foraminiferal species diversity patterns (Fig. 10, Table 1). The only large-scale trend in diversity values is a prominent reduction in the Bogue Banks Section. This probably reflects increased influx of coarser siliciclastic sediments that produced more mobile substrates, the effects of which may have been exacerbated by introduction of a cooler water mass (Powers, this volume; Palmer, this volume). It is also possible that coarser sediments result from winnowing by bottom currents, and that low diversity foraminiferal faunas are residual (see Bock, 1982). In any case, well-oxygenated bottom conditions that were less than favorable for some nutrient-tolerant species are indicated.

BIOFACIES

Although qualitative assessment of faunal patterns suggests that foraminifera were influenced by water mass properties and substrate types, quantitative definition of faunal assemblages provides more reliable and detailed biofacies mapping. In order to accomplish this, principal component and Q-mode cluster analyses were performed on a data matrix composed of the relative abundance of the 27 most common benthic foraminiferal species through 115 samples.

PRINCIPAL COMPONENT ANALYSIS

Principal component analysis indicated that six factors account for 84% of the total variance within the data matrix. SAS retained these six by the "mineigenvalue criterion." Eigenvalues of the covariance matrix reveal that each of these factors accounts for the following proportions of total variance: Factor 1 = 0.3151; Factor 2 = 0.2262; Factor 3 = 0.1019; Factor 4 = 0.0829; Factor 5 = 0.0719; Factor 6 = 0.0427.

The factor pattern and factor loadings are summarized in Table 4. The greatest positive and negative loadings within Factors 1–6 are associated with nine species. However, communality estimates for only six of these species closely approach a value of one: *Bolivina paula* = 0.996602; *Buliminella elegantissima* = 0.902160; *Valvulineria floridana* = 0.992797; *Lenticulina americana* = 0.979778; *Hanzawaia concentrica* = 0.988410; *Cibicides floridanus* = 0.985088. The distribution and abundance of *Bolivina subdilitata, Rosalina cavernata* and *Cibicides lobatulus* are less adequately explained by this set of factors, as indicated by communality values ranging from 0.375991 to 0.513978.

Hence, variations in the abundance and distribution of six species account for nearly 84% of the total vari-

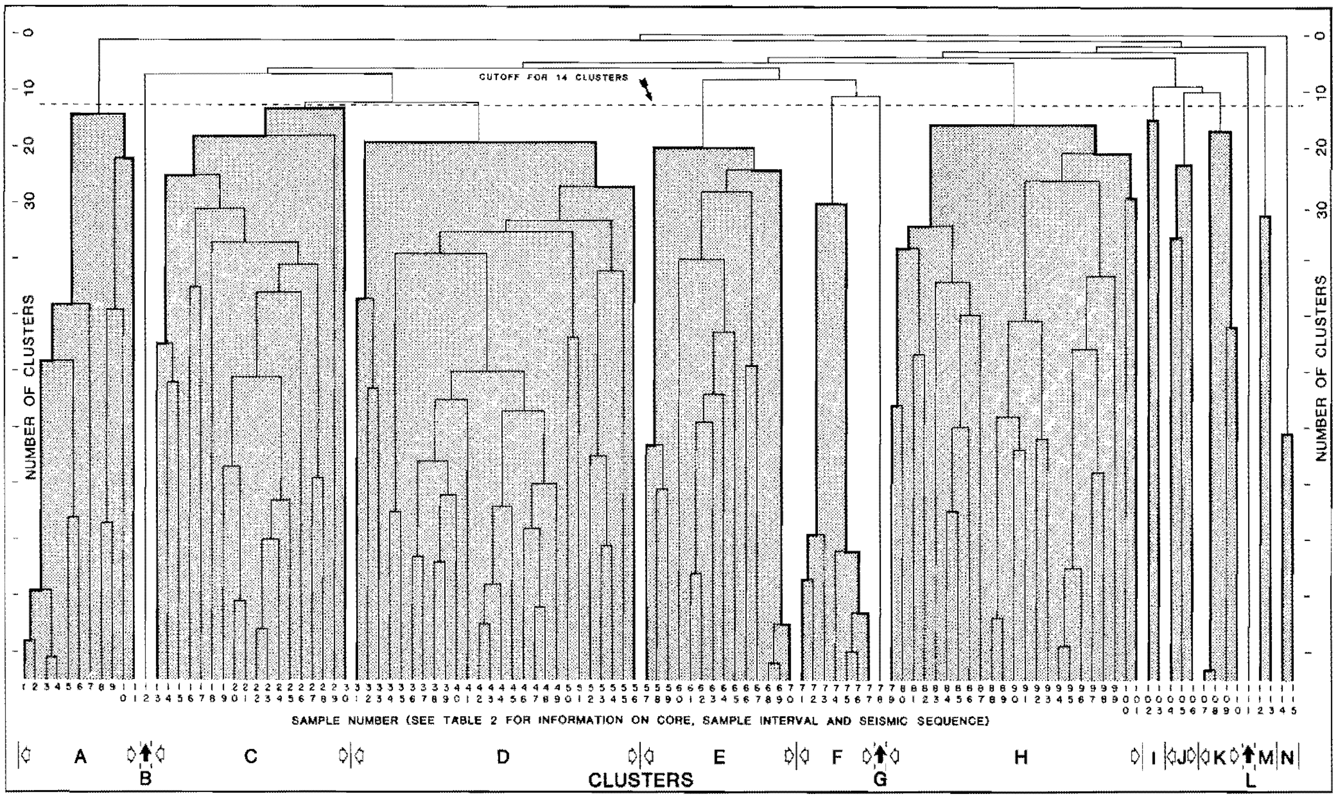

FIGURE 11. Cluster diagram grouping samples according to degree of between-station faunal similarity.

ance. Additionally, these same six species (*Bolivina paula, Buliminella elegantissima, Valvulineria floridana, Lenticulina americana, Hanzawaia concentrica* and *Cibicides floridanus*) were repeatedly mentioned during the preceding qualitative assessment of faunal patterns. Two of them, when present in great abundance, indicate moderate to intense nutrient enrichment and accompanying oxygen depletion. Abundance of the other four reliably indicates highly oxygenated bottom waters.

CLUSTER ANALYSIS

Clustering techniques were utilized to group samples according to the degree of between-sample faunal similarity. Figure 11 is a dendrogram showing the clustering pattern produced by the average linkage method, which groups samples containing similar species in similar relative abundances. The selection of 14 clusters was based on "R-Squared" values and the "Cubic Clustering Criterion," as explained by the SAS Institute, Inc. (1982).

Not all of the 14 clusters can be directly related to environments of deposition within the Pungo River Formation. A number of clusters contain only one or two samples. Given the stratigraphic and geographic range through which these 115 samples were taken, it is likely that differences due to diagenesis, microenvironmental variation and/or faunal reworking would produce a small number of statistical outliers. For example, Cluster M (Fig. 11) comprises two samples which both lie near the base of FPS-1 (Core 105, 9.1 m, Core 127, 8.0 m) (Table 1). These samples cluster together because each has an unusually high abundance of *Epistominella danvillensis,* a species which occurs in moderate numbers throughout the Pungo River section but is quite abundant in underlying Oligocene sands. Hence, reworking of underlying assemblages upward into the base of the Miocene section is probably responsible for this cluster.

Single-sample and two-sample clusters are difficult to interpret because, like Cluster M, many may be the product of post-depositional processes. Others may reveal important information about an original environment which was areally small or temporally short-lived. Sample coverage is not dense enough to adequately delineate such small environments. Hence, we choose to focus on clusters that reveal larger-scale, regional environmental changes. There are eight such clusters

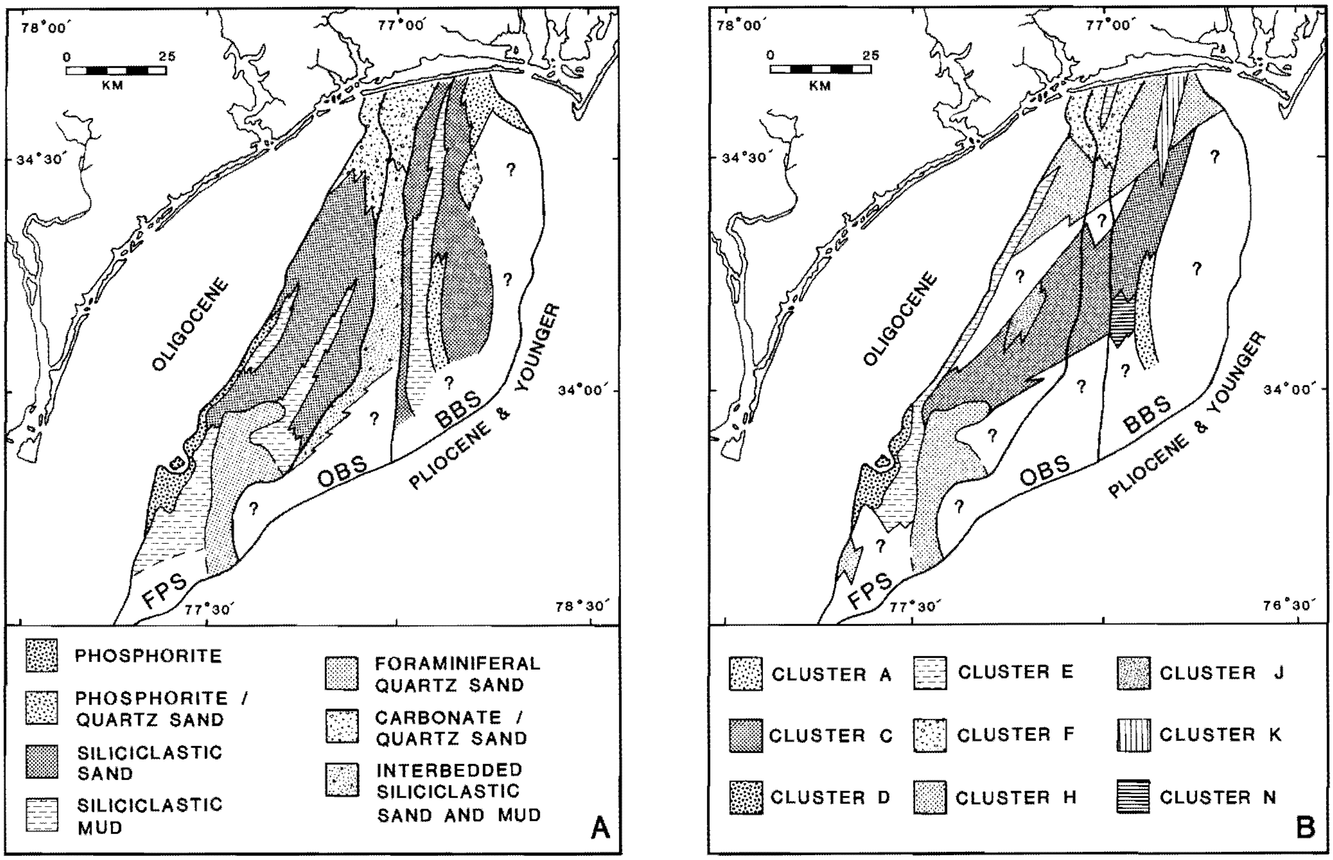

FIGURE 12. A. Distribution of major lithofacies superimposed on third-order seismic sections within the Miocene of Onslow Bay. Areas with question marks lack adequate core coverage to characterize lithofacies. B. Distribution of biofacies (as defined by clustering) superimposed on third-order seismic sections within the Miocene of Onslow Bay. Areas with question marks either lack core coverage or yield too few specimens to characterize biofacies.

recognized in data from the Miocene of Onslow Bay. Each of these is described below. Frequent reference to Table 1 and Figures 11 and 12B will be helpful.

Cluster A—This cluster, which contains 11 samples, is characterized by the predominance of *Bolivina paula* (mean abundance of 58%) and *Buliminella elegantissima* (21%). Nearly all samples within it come from cores in the southern part of BBS-2.

Cluster C—This cluster has 18 samples in which *Bolivina paula* averages 32% of the assemblage, followed by *Valvulineria floridana* at 19%. Though *B. paula* is the most abundant species, the cumulative abundance of nutrient-tolerant forms is about the same as for types adapted to oxygenated bottom conditions (Figs. 7–9). It occurs through the central portion of Onslow Bay from FPS-2 stratigraphically upward into BBS-5.

Cluster D—The largest of the clusters (26 samples), it is predominated by *Bolivina paula* (mean abundance of 32%), followed by *Hanzawaia concentrica* and *Lenticulina americana* with a combined abundance of 35%. Many nutrient-tolerant taxa occur in abundances from 1 to 7%, so that the cumulative abundance of such forms averages 65% of the benthic fauna. This cluster occurs only in the southern portions of FPS-1.

Cluster E—The predominant species in the 14 samples of this cluster is *Buliminella elegantissima* (mean abundance of 24%). *Bolivina paula* (13%) and *Florilus pizarrensis* (11%) are the next most abundant species. Nutrient-tolerant species account for nearly 60% of the fauna. This cluster occurs in the southern portion of FPS-2 and the northern portion of FPS-1.

Cluster F—*Cibicides lobatulus* (mean abundance of 19%) and *Bolivina paula* (18%) are predominant through the seven samples of this cluster. Species characteristic of oxygenated bottoms constitute nearly 50% of the benthic assemblage, about twice

TABLE 5. Generalized faunal composition of clusters (biofacies). Clusters with two or fewer samples are not included.

Cluster	Cumulative abundance of species adapted to intense nutrient enrichment	Cumulative abundance of species adapted to moderate nutrient enrichment	Cumulative abundance of species adapted to well-oxygenated conditions
A	80%	5%	10%
C	41%	8%	37%
D	49%	16%	35%
E	43%	15%	29%
F	23%	1%	47%
H	19%	8%	69%
J	18%	4%	69%
K	17%	1%	64%

the abundance of nutrient-tolerant types. This cluster occurs only in the northern part of the Onslow Bay Section.

Cluster H—*Hanzawaia concentrica,* the predominant species, and *Valvulineria floridana* combine to account for an average of 50% of the benthic fauna. *Bolivina paula* (13%) is considerably less abundant than in most previous clusters. Cluster H includes 23 samples which occur in northern Onslow Bay from FPS-2 stratigraphically upward into BBS-8.

Cluster J—This three-sample cluster occurs only in one small portion of FPS-3 in central Onslow Bay. *Valvulineria floridana, Cibicides americanus* and *Hanzawaia concentrica* average 22%, 19% and 13% of the fauna, respectively. *Bolivina paula* accounts for only 12%.

Cluster K—The four samples of this cluster come from the northern portion of BBS-1. *Valvulineria floridana* (mean abundance of 41%), *Bolivina paula* (14%) and *Hanzawaia concentrica* (13%) are the most abundant species.

BIOFACIES-LITHOFACIES RELATIONSHIPS

The clusters described above delineate faunal associations that can be mapped regionally across the Miocene outcrop/shallow subcrop belt in Onslow Bay (Fig. 12B). Some degree of generalization was required in order to generate the biofacies map because each vibracore must serve as a single data point. However, multiple samples were analyzed from most vibracores, and in some instances those samples fell within different clusters. The reasons for this seeming inconsistency include: 1) a core penetrating more than one seismic sequence; 2) environmental changes through a short stratigraphic interval within a single depositional sequence (e.g., fourth-order onlap, high-stand and downlap systems tracts represented in the collection from the same area and seismic sequence); 3) variations in diagenetic history through short stratigraphic intervals; and 4) presence of reworked specimens. Regardless of cause, samples from the same core which fell within different clusters were handled in the same way. If more than 50% of the samples fell within one cluster, the vibracore was plotted as a point within that cluster. If samples were randomly scattered among several clusters, data from that vibracore were considered invalid and the core was not included on the biofacies map. Among 46 vibracores, only 11 contained samples that fell into different clusters (Table 1). Of these, only 2 had samples belonging to three or more clusters. Core 105 penetrates two seismic sequences (FPS-1 and FPS-2). It has been plotted in Cluster D because samples from lower FPS-1 cluster elsewhere due to reworking from the underlying Oligocene (as discussed previously). Because every sample from Core 59 falls within a different cluster, it has been treated as a point for which no data exist (Fig. 12B). Hence, biofacies distributions appear to be reliable, as most cores can be readily categorized in a single cluster. Blank areas exist on the map (Fig. 12B) where samples are barren and where vibracore coverage is lacking.

The distribution of biofacies can be graphically compared to the distribution of major lithofacies in Onslow Bay (Figs. 12A and 12B). Although the relationships are not exact, biofacies distributions do tend to mirror the distributions of specific lithofacies. During the following discussion, reference to Table 5 will also be helpful.

The distribution of Cluster A coincides with the phosphorite/quartz sand lithofacies in southern BBS-2. The benthic foraminiferal assemblage in this phosphatic facies consists of 85% nutrient-tolerant species.

Cluster C extends across numerous seismic sequences in central Onslow Bay. It conforms in a general way to the southern portion of a widespread siliciclastic sand facies, which also includes interbedded muds. Nutrient-tolerant species are only slightly more abundant than species adapted to well-oxygenated conditions.

The distribution of Cluster D conforms precisely with the phosphorite facies in southern FPS-1. Nutrient-tolerant species (65% of the fauna) are clearly predominant within this facies.

Cluster E occurs largely within the organic-rich siliciclastic mud facies of FPS-2. It also persists into the northern portion of FPS-1 where slightly higher percentages of coarser siliciclastics occur. This fa-

TABLE 6

CORRELATION COEFICIENTS OF SELECTED SEDIMENTOLOGICAL AND PALEONTOLOGICAL CHARACTERISTICS

	BOL PAUL	BUL ELE	VAL FLO	ROS CAV	LEN AME	HAN CON	CIB FLO	CIB LOB	TOT NUT TOL	TOT WELL OXY	RATIO NUT/ OXY
P205 IN BULK SEDIMENT	0.41673	-0.24710	-0.25220	-0.50290	0.50764	0.29794	-0.18519	-0.55957	0.48216	-0.41828	0.31573
% PHOSPHATE GRAINS IN SAND	0.57345	-0.10157	-0.41695	-0.46102	0.53355	0.23483	-0.15169	-0.51257	**0.62082**	-0.51997	0.58342
PERCENT SAND	-0.19977	-0.41253	**0.70580**	-0.51276	-0.35328	0.41245	0.30819	-0.28070	-0.44094	**0.62010**	-0.23476
PERCENT MUD	0.21231	0.43122	**-0.69818**	0.45370	0.39379	-0.41460	-0.34025	0.22344	0.47610	**-0.65255**	0.24896
% ACID INSOLUBLES	-0.07275	0.30809	0.44745	**-0.78717**	0.12879	0.13149	0.15829	**-0.74048**	0.08788	0.08631	0.04679
% CARBONATE	-0.23037	-0.42342	-0.31591	**0.86136**	-0.19014	-0.00780	-0.06128	**0.84697**	-0.34653	0.17805	-0.34718

BOL PAU = Bolivina paula
BUL ELE = Buliminella elegantissima
VAL FLO = Valvulineria floridana
ROS CAV = Rosalina cavernata
LEN AME = Lenticulina americana
HAN CON = Hanzawaia concentrica
CIB FLO = Cibicides floridana
CIB LOB = Cibicides lobatulus
TOT NUT TOL = total of nutrient-tolerant species
TOT WELL OXY = total of species adapted to well oxygenated bottom conditions
RATIO NUT / OXY = ratio of nutrient-tolerant species to those adapted to well oxygenated conditions

cies contains foraminiferal assemblages predominated by nutrient-tolerant species (58%). Here the organic enrichment was not directly associated with accumulation of concentrated phosphates. Cluster E also characterizes muddy sediments in OBS-3 in northern Onslow Bay.

Cluster F occupies a portion of the carbonate/quartz sand facies in northern Onslow Bay. Foraminiferal assemblages consist primarily of species adapted to oxygenated conditions (47%), while nutrient-tolerant types account for only 24% of the fauna.

Cluster H conforms in a general way to the northern portion of a widespread siliciclastic sand facies. It also encompasses a phosphorite/quartz sand facies in BBS-8. As previously discussed, these phosphates appear to be reworked. Species characteristic of well-oxygenated conditions predominate (69%). Nutrient-tolerant species account for only 27% of the fauna.

Clusters J and K each occupy small regions within the siliciclastic sand facies of central and northern Onslow Bay. Though they clustered separately, their overall faunal composition is environmentally consistent with that of Cluster H. The only differences among them are changes in the relative abundance of certain species, all of which characterize well-oxygenated bottoms.

Cluster N is also predominated by species adapted to oxygenated conditions. It lies in the southeast portion of the widespread siliciclastic sand facies.

To further evaluate biofacies-lithofacies relationships, selected sedimentological and faunal characteristics were compiled for all available samples (Appendix II). Pearson correlation coefficients between each sedimentological parameter and each faunal measurement never exceed 0.35, suggesting that no clear linear relationship exists between any two of the variables being compared. Because numerous environmental factors may influence foraminiferal species, values for any single factor should not be expected to correlate strongly with observed species abundances. Additionally, between-sample variations in microenvironment, diagenetic history, and extent of reworking would tend to obscure any relationships which may have existed.

To overcome the "noise" in the data, and to again focus on larger-scale patterns, mean values of the same sedimentological and faunal characteristics were calculated for each cluster (Appendix III). Correlation coefficients among these mean values were then calculated (Table 6). What constitutes a "high" correlation is a relative matter. It differs markedly for different types of situations, and there is no single classification applicable in all situations. Given that many environmental factors may influence foraminifera and that diagenetic processes may alter faunal assemblages, we view coefficients greater than 0.60 for any single factor (shown in bold-face type in Table 6) as meaningful. Additionally, differences in life habit among foraminiferal species (infaunal vs. epifaunal) may reduce coefficient values. Species indicating disparate environmental conditions may occur in the same sample because some reflect bottom water conditions whereas others reflect conditions in interstitial waters. Hence, we consider 0.60 to be a conservative cutoff point to indicate meaningful correlation.

Utilizing mean values within each cluster, *Valvulineria floridana* is positively correlated with percent sand, while *Rosalina cavernata* and *Cibicides lobatulus* correlate with percent carbonate. These species are among a larger group of taxa adapted to well-oxygenated bottom conditions. The cumulative abundance of such species is positively correlated with percent sand and negatively correlated with percent mud. The cumulative abundance of nutrient-tolerant species correlates with percent phosphate grains in the sand fraction, which is itself a rough indicator of degree of nutrient enrichment. Observed correlations are not evidence for cause and effect, but knowledge about the ecological optima of modern foraminiferal species supports the contention that water mass properties and substrate type combined to influence the species composition of these Miocene assemblages.

DISCUSSION

Benthic foraminiferal assemblages within the outcrop/shallow subcrop belt of Miocene sediments in Onslow Bay have been influenced by the chemistry of changing water masses and by the nature of the substrate. Nutrient-rich conditions, which often coincide with phosphate deposits or organic-rich muds, are associated with predominance by species known to tolerate nutrient enrichment and reduced levels of dissolved oxygen. Coarser clastic sediments (quartzitic and carbonate) with lower nutrient levels supported species associations known to be adapted to well-oxygenated bottom conditions. Faunal changes are not expressed by presence or absence of species, but rather by changing relative abundances of taxa that range through most environments. Numerous factors obscure specific faunal/sediment relationships such that only gross, larger-scale patterns remain.

Benthic foraminiferal species compositions, values of benthic species diversity, and planktonic to benthic ratios are all consistent with middle shelf to upper slope environments of deposition. However, paleobathymetry and proximity to ancient shoreline were not the primary influence on benthic faunal patterns. Changes that might routinely be interpreted to reflect paleobathymetry and proximity to shore occur parallel to depositional strike. Structural contour and isopach maps of Miocene sequences indicate that the depositional strike of these sequences generally paralleled the ancient shelf edge (Stephen W. Snyder, 1982). Changing chemical conditions of bottom and interstitial waters, along with sediment type (authigenic vs. clastic), exerted primary influence on benthic assemblages. Nutrient-enriched, oxygen-poor waters and authigenic sedimentation characterized several intervals in southern and southeastern portions of the Miocene outcrop belt. Well-oxygenated conditions associated with the influx of siliciclastics from a point source to the northwest characterized most sequences in central and northern Onslow Bay.

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APPENDIX I

ANNOTATED REFERENCE LIST OF BENTHIC FORAMINIFERAL SPECIES

(Taxa listed in alphabetical order)

Ammonia beccarii (Linne), Pl. 9, figs. 1–3

Nautilus beccarii LINNE, 1758, Systema Naturae, ed. 10, v. 1, Stockholm, p. 710.

Astacolus dubius (Neugeboren), new combination, Pl. 1, figs. 14–15

Marginulina dubia NEUGEBOREN, 1851, Siebenburg. Ver. Naturwiss. Verh. u. Mitt., v. 2, p. 120, pl. 4, fig. 1.

The genera *Marginulina, Astacolus* and *Vaginulinopsis* are vaguely defined and sometimes difficult to differentiate. We recognize *Astacolus* as compressed, with a slightly enrolled early stage and an arcuate later stage having oblique sutures. *Marginulina* differs in being variably compressed, and in having a slightly coiled (not enrolled) early stage and a later rectilinear stage. *Vaginulinopsis* differs in being variably compressed, and in having a later stage with sutures more nearly perpendicular to the long axis of the test.

Astacolus sp. A, Pl. 1, figs. 18–19

Test arcuate, strongly compressed, lightly keeled; early chambers slightly enrolled, becoming uniserial and increasingly elongate; aperture produced on flattened, slightly indented portion of final chamber.

Astacolus sp. B, Pl. 1, figs. 16–17

Test compressed, most strongly in early stage, lightly keeled; early portion slightly enrolled, later becoming uniserial with oblique sutures; aperture terminal, radiate, somewhat produced.

Baggina sp., Pl. 6, figs. 6–7

Bolivina advena Cushman, Pl. 4, fig. 7

Bolivina advena CUSHMAN, 1925, Contr. Cushman Lab. Foram. Research, v. 1, pt. 2, p. 29, pl. 5, fig. 1.

Bolivina brevior Cushman, Pl. 4, fig. 8

Bolivina brevior CUSHMAN, 1925, Contr. Cushman Lab. Foram. Research, v. 1, pt. 2, p. 31–32, pl. 5, fig. 8.

Bolivina calvertensis Dorsey, Pl. 4, fig. 9

Bolivina calvertensis DORSEY, 1948, Maryland Dept. Geology, Mines, Water Resources Bull. 2, p. 306, pl. 36, fig. 17.

Bolivina floridana Cushman, Pl. 4, fig. 10

Bolivina floridana CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 49, pl. 10, fig. 4.

Although Gibson (1983) has described a similar species (*B. pungoensis*) from the Aurora area, specimens from Onslow Bay more closely resemble *B. floridana*, which has a highly variable morphology (C. W. Poag, pers. comm.). *B. pungoensis* Gibson may be a subspecific variant.

Bolivina lowmani Phleger and Parker, Pl. 4, fig. 11

Bolivina lowmani PHLEGER and PARKER, 1951, Geol. Soc. America Mem. 46, pt. 2, p. 13, pl. 6, figs. 20–21.

Bolivina marginata multicostata Cushman, Pl. 4, fig. 12

Bolivina marginata CUSHMAN var. *multicostata* CUSHMAN, 1930, Fla. Geol. Survey Bull. 4, p. 46, pl. 8, figs. 13–14.

Bolivina paula Cushman and Cahill, Pl. 4, fig. 13

Bolivina paula CUSHMAN and CAHILL, 1932, *in* Cushman and Ponton, Fla. Geol. Survey Bull. 9, p. 84, pl. 12, fig. 6.

Bolivina robusta Brady, Pl. 4, fig. 14

Bolivina robusta BRADY, 1881, Notes on reticularian rhizopoda of "Challenger Expedition," Pt. III, Quart. Jour. Micr. Sci., v. 21, p. 57.

Bolivina subdilatata Pishvanova, Pl. 4, fig. 15

Bolivina subdilatata PISHVANOVA, 1960, Leningrad Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. [All-Union Petroleum Scientific-Research Geological-Prospecting Institute], vypusk 153, sbornik 11, p. 109, 110.

Bolivinopsis fairhavenensis Gibson, Pl. 1, fig. 10

Bolivinopsis fairhavenensis GIBSON, 1983, Smith. Contr. Paleobiol., n. 53, p. 379, pl. 20, figs. 1–4.

Buccella frigida (Cushman), Pl. 9, figs. 4–6

Pulvinulina frigida CUSHMAN, 1922, Contr. Canadian Biol., n. 9, p. 144 (no figures).

Buccella inusitata Andersen, Pl. 9, figs. 7–9

Buccella inusitata ANDERSEN, 1952, Jour. Wash. Acad. Sci., v. 42, n. 5, p. 148, figs. 10–11.

Bulimina elongata d'Orbigny, Pl. 4, figs. 16–17

Bulimina elongata D'ORBIGNY, 1846, Foraminiferes fossiles du Bassin Tertiaire de Vienne, p. 187, pl. 11, figs. 19–20.

We include within this species forms that are elongate and slender, with variably inflated chambers arranged triserially to biserially. Though often difficult to observe, some specimens have a juvenile discorbine stage, a characteristic which would suggest generic assignment to *Caucasina*. Detailed study is still needed to determine proper taxonomic treatment of this plexus. For purposes of this report, we follow convention in placing all specimens in *B. elongata*.

Bulimina ovula d'Orbigny, Pl. 4, fig. 19

Bulimina ovula D'ORBIGNY, 1839, Voy. Amer. Merid., v. 5, pt. 5, "Foraminiferes," p. 51, pl. 1, figs. 10–11.

Bulimina striata mexicana Cushman, Pl. 4, fig. 18

Bulimina striata d'Orbigny var. *mexicana* CUSHMAN, 1922, U.S. Natl. Museum Bull. 104, pt. 3, p. 95, pl. 21, fig. 2.

Buliminella brevior Cushman, Pl. 4, fig. 5

Buliminella brevior CUSHMAN, 1925, Contr. Cushman Lab. Foram. Research, v. 1, n. 8, p. 33, pl. 5, fig. 14.

Buliminella elegantissima (d'Orbigny), Pl. 4, fig. 6

Bulimina elegantissima D'ORBIGNY, 1839, Voy. Amer. Merid., v. 5, pt. 5, "Foraminiferes," p. 51, pl. 7, figs. 13–14.

Cancris sagra (d'Orbigny), Pl. 6, figs. 8–10

Rotalina (Rotalina) sagra D'ORBIGNY, 1839, *in* de la Sagra, Hist. Pol. Nat. de Cuba, "Foraminiferes," p. 77, tab. 5, figs. 13–15.

? *Cassidella* sp., Pl. 8, fig. 3

Although similar in most respects to the generic description of Loeblich and Tappan (1964), Pungo River specimens differ in their apertural characteristics (a narrow slit at the top of the final chamber ending in a slight indentation extending downward to the chamber base). No tooth plate is visible in these specimens, perhaps because the slight indentation is caused by partial closure of the aperture. The wall structure of crushed specimens appears to be granular.

Cassidulina laevigata d'Orbigny, Pl. 8, fig. 10

Cassidulina laevigata D'ORBIGNY, 1826, Annales Sci. Nat., v. 7, p. 282, tab. 15, figs. 4–5, modele 41.

Cassidulinoides cf. *C. bradyi* (Norman), Pl. 4, figs. 3–4

Cassidulina bradyi NORMAN, 1881, *in* Brady, Quart. Jour. Micro. Sci., n. s., v. 21, p. 59, pl. 5, fig. 2.

Chilostomella oolina Schwager, Pl. 8, fig. 15

Chilostomella oolina SCHWAGER, 1878, Bol. Com. Geol. Ital., v. 9, p. 527, pl. 1, fig. 16.

Cibicides americanus (Cushman), Pl. 7, figs. 4–5

Truncatulina americana CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 63, pl. 20, figs. 2–3, pl. 21, fig. 1.

Cibicides floridanus (Cushman), Pl. 7, figs. 6–8

Truncatulina floridana CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 62, pl. 19, fig. 2.

Cibicides lobatulus (Walker and Jacob), Pl. 7, figs. 9–10

Nautilus lobatulus WALKER and JACOB, 1798, *in* Kanmacher, Adam's Essays on the Microscope, ed. 2, p. 642, pl. 14, fig. 36.

Coryphostoma georgiana (Cushman), new combination, Pl. 8, figs. 4–6

Loxostomum georgianum CUSHMAN, 1935, Contr. Cushman Lab. Foram. Research, v. 11, p. 82, pl. 12, figs. 14–15.

Crushed specimens appear to have granular wall structure.

Dentalina communis (d'Orbigny)

Nodosaria (Dentalina) communis D'ORBIGNY, 1826, Annales Sci. Nat., ser. 1, v. 7, p. 254, modele 35.

Ehrenbergina caribbea Galloway and Heminway, Pl. 8, figs. 13–14

Ehrenbergina caribbea GALLOWAY and HEMINWAY, 1941, Sci. Survey of Puerto Rico and Virgin Islands, v. 3, pt. 4: Tertiary foraminifera of Puerto Rico, p. 426, pl. 32, fig. 4.

Elphidium sp., Pl. 7, fig. 11

Epistominella danvillensis Howe and Wallace, Pl. 6, fig. 2
Epistominella danvillensis HOWE and WALLACE, 1932, Louisiana Dept. Conserv. Bull. 2, p. 71, pl. 13, fig. 7.

Eponides sp., Pl. 10, figs. 7–9

Estorffina mayi (Cushman and Parker), Pl. 3, figs. 12–13
Estorffina mayi CUSHMAN and PARKER, 1931, Contr. Cushman Lab. Foram. Research, v. 7, p. 10–11, pl. 2, fig. 7.

Fissurina lucida (Williamson), Pl. 3, fig. 18
Entosolenia marginata (Montagu) var. *lucida* WILLIAMSON, 1848, Ann. Nat. Hist., v. 1, ser. 2, p. 17, pl. 2, fig. 17.

Florilus chesapeakensis Gibson, Pl. 9, figs. 12–13
Florilus chesapeakensis GIBSON, 1983, Smith. Contr. Paleobiol., n. 53, p. 398–399, pl. 11, figs. 7–8, pl. 18, figs. 7–8, 11–12.

Florilus grateloupi (d'Orbigny), Pl. 10, figs. 1–3
Nonionina grateloupi D'ORBIGNY, 1826, Annales Sci. Nat., v. 7, n. 12, p. 294, modele 19.

Florilus pizarrensis (Berry), Pl. 10, figs. 4–6
Nonion pizarrensis BERRY, 1928, Jour. Paleontology, v. 1, n. 2, p. 269, fig. 1.

Fursenkoina fusiformis (Williamson), Pl. 8, fig. 1
Bulimina pupoides d'Orbigny var. *fusiformis* WILLIAMSON, 1858, On Recent foraminifera of Great Britain, p. 63, pl. 5, figs. 129–130.

Fursenkoina sp., Pl. 8, fig. 2

Globocassidulina crassa (d'Orbigny), Pl. 8, figs. 11–12
Cassidulina crassa D'ORBIGNY, 1839, Voy. Amer. Merid., "Foraminiferes," v. 5, pt. 5, p. 56, pl. 7, figs. 18–20.

Globulina gibba d'Orbigny, Pl. 3, fig. 6
Globulina gibba D'ORBIGNY, 1826, Annales Sci. Nat., v. 7, n. 10, p. 266, modele 63.

Globulina inaequalis Reuss, Pl. 3, fig. 9
Globulina inaequalis REUSS, 1850, Denkschr. Kais. Akad. Wiss. Wien., v. 1, p. 377, p. 48, fig. 9.

Guttulina austriaca d'Orbigny, Pl. 3, fig. 7
Guttulina austriaca D'ORBIGNY, 1846, Foraminiferes fossiles du Bassin Tertiaire de Vienne, p. 233, pl. 12, figs. 23–25.

Guttulina cf. *G. caudata* d'Orbigny, Pl. 3, fig. 8
Guttulina caudata D'ORBIGNY, 1826, Annales Sci. Nat., v. 7, p. 266, modele 16.

Gyroidinoides nipponica (Ishizaki), Pl. 10, figs. 10–12
Gyroidina nipponica ISHIZAKI, 1944, Trans. Nat. Hist. Soc. Taiwan, v. 34, p. 102, pl. 3, fig. 3.

Hanzawaia concentrica (Cushman), Pl. 10, figs. 13–15
Truncatulina concentrica CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 64, pl. 21, fig. 3.

Hopkinsina bononiensis (Fornasini), Pl. 5, fig. 5
Uvigerina bononiensis FORNASINI, 1888, Bol. Soc. Geol. Ital., v. 7, p. 48, pl. 3, fig. 12.

Islandiella sp., Pl. 4, figs. 1–2

Lagena intermedia Rzehak, Pl. 2, fig. 1
Lagena striata (d'Orbigny) var. *intermedia* RZEHAK, 1885, Vereins. Brunn, Verhandl., v. 23, p. 81, pl. 1, fig. 6.

Lagena laevis (Montagu), Pl. 2, fig. 2
Vermiculum laeve MONTAGU, 1803, Testacea Britannica, p. 524.

Lagena cf. *L. palmerae* McLean, Pl. 2, fig. 3
Lagena palmerae MCLEAN, 1956, Bull. Amer. Paleontology, v. 36, n. 160, p. 332, pl. 39, figs. 5–6.

Lagena pseudosulcata McLean, Pl. 2, fig. 4
Lagena pseudosulcata MCLEAN, 1956, Bull. Amer. Paleontology, v. 36, n. 160, p. 332–333, pl. 39, fig. 11.

Lagena substriata Williamson, Pl. 2, fig. 5
Lagena substriata WILLIAMSON, 1848, Annals Mag. Nat. Hist., ser. 2, v. 1, p. 15, pl. 1, fig. 2.

Lenticulina americana americana (Cushman), Pl. 2, figs. 6–7
Cristellaria americana CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 50, pl. 10, figs. 5–6.

Lenticulina americana spinosa (Cushman), Pl. 2, fig. 8
Cristellaria americana var. *spinosa* CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 51, pl. 10, fig. 7.

Loxostomum gunteri Cushman, Pl. 8, figs. 8–9
Loxostomum gunteri CUSHMAN, 1930, Fla. Geol. Survey Bull. 4, p. 47, pl. 8, fig. 11.

Melonis sp., Pl. 9, fig. 11

Nodosaria longiscata d'Orbigny, Pl. 1, fig. 11
Nodosaria longiscata D'ORBIGNY, 1846, Foraminiferes fossiles du Bassin Tertiaire de Vienne, p. 32, pl. 1, figs. 10–12.

Nodosaria cf. *N. raphanistrum caribbeana* Hedberg, Pl. 1, fig. 12
Nodosaria raphanistrum (Linne) var. *caribbeana* HEDBERG, 1937, Jour. Paleontology, v. 11, n. 8, p. 671, pl. 91, fig. 1.

Nodosaria sp., Pl. 1, fig. 13

Nonion marylandicum Dorsey, Pl. 9, fig. 10
Nonion marylandicum DORSEY, 1948, Maryland Dept. Geology, Mines, Water Resources Bull. 2, p. 305, pl. 35, fig. 2.

Nonionella miocenica Cushman, Pl. 8, fig. 16
Nonionella miocenica CUSHMAN, 1926, Contr. Cushman Lab. Foram. Research, v. 2, pt. 3, p. 64 (no figure).

Oolina hexagona (Williamson), Pl. 3, fig. 15
Entosolenia squamosa Montagu var. *hexagona* WILLIAMSON, 1848, Annals Mag. Nat. Hist., ser. 2, v. 1, p. 20, pl. 2, fig. 3.

Oridorsalis umbonatus (Reuss), Pl. 7, figs. 12–14
Rotalina umbonata REUSS, 1851, Zeitschr. deutsch. geol. Ges., v. 3, p. 75, pl. 5, fig. 35.

Paradentalina sp., Pl. 3, fig. 10

Planularia cf. *P. clara* Cushman and Jarvis, Pl. 2, figs. 16–18
Planularia clara CUSHMAN and JARVIS, 1929, Contr. Cushman Lab. Foram. Research, v. 5, pt. 1, p. 7, pl. 2, figs. 14–15.

Plectofrondicularia cf. *P. alazanensis* Cushman, Pl. 3, figs. 1–2
Plectofrondicularia alazanensis CUSHMAN, 1927, Contr. Cushman Lab. Foram. Research, v. 3, p. 113, pl. 22, fig. 12.

Plectofrondicularia floridana Cushman, Pl. 3, figs. 3–4
Plectofrondicularia floridana CUSHMAN, 1930, Fla. Geol. Survey Bull. 4, p. 41, pl. 8, fig. 1.

Plectofrondicularia morreyae Cushman, Pl. 3, fig. 5
Plectofrondicularia morreyae CUSHMAN, 1929, Contr. Cushman Lab. Foram. Research, v. 5, p. 92, pl. 13, fig. 23.

Pseudopolymorphina rutila (Cushman), Pl. 3, fig. 14
Polymorphina regina Brady, Parker and Jones var. *rutila* CUSHMAN, 1923, U.S. Geol. Survey Prof. Paper 133, p. 34, pl. 5, figs. 7–8.

Pullenia salisburyi R. E. and K. C. Stewart, Pl. 8, figs. 17–18
Pullenia salisburyi R. E. and K. C. STEWART, 1930, Jour. Paleontology, v. 4, p. 72, pl. 8, fig. 2.

Reussella miocenica Cushman, Pl. 4, fig. 20
Reussella miocenica CUSHMAN, 1945, Contr. Cushman Lab. Foram. Research, v. 21, pt. 2, p. 36, pl. 6, figs. 19–20.

Rosalina cavernata (Dorsey), Pl. 6, figs. 3–4
Discorbis cavernata DORSEY, 1948, Maryland Dept. Geology, Mines, Water Resources Bull. 2, p. 311, pl. 37, fig. 2.

Rosalina floridana (Cushman), Pl. 6, fig. 5
Discorbis floridanus CUSHMAN, 1922, Carnegie Inst. Wash. Bull. 311, p. 39, pl. 5, figs. 11–12.

Rotorbinella bassleri (Cushman and Cahill), Pl. 6, fig. 1
Rotalia bassleri CUSHMAN and CAHILL, 1933, U.S. Geol. Survey Prof. Paper 175-A, p. 30, pl. 10, fig. 7.

Saracenaria cf. *S. italica* DeFrance, Pl. 2, fig. 9
Saracenaria italica DEFRANCE, 1824, Dict. Sci. Nat., v. 32, p. 177.

Saracenaria latifrons (Brady), Pl. 2, fig. 11
Cristellaria latifrons BRADY, 1884, Rept. Challenger, Zoology, v. 9, p. 544, pl. 113, fig. 11.

Saracenaria senni Hedberg, Pl. 2, fig. 10
Saracenaria senni HEDBERG, 1937, Jour. Paleontology, v. 11, n. 8, p. 674, pl. 90, fig. 18.

Sigmoidella kagaensis Cushman and Ozawa, Pl. 3, fig. 11
Sigmoidella kagaensis CUSHMAN and OZAWA, 1928, Contr. Cushman Lab. Foram. Research, v. 4, pt. 1, p. 19, pl. 2, fig. 14.

Siphogenerina lamellata Cushman, Pl. 5, figs. 9–11
Siphogenerina lamellata CUSHMAN, 1918, U.S. Geol. Survey Bull. 676, p. 55–56, pl. 12, fig. 3.

Siphogenerina transversa Cushman, Pl. 5, figs. 12–15
Siphogenerina raphanus (Parker and Jones) var. *transversa* CUSHMAN, 1918, U.S. Natl. Museum Bull. 103, p. 64, pl. 22, fig. 8.

Siphonodosaria sp., Pl. 5, figs. 1–2

Sphaeroidina bulloides d'Orbigny, Pl. 3, figs. 16–17
Sphaeroidina bulloides D'ORBIGNY, 1826, Annales Sci. Nat., v. 7, p. 267, modele 65.

Spiroplectammina exilis Dorsey, Pl. 1, fig. 3
Spiroplectammina exilis DORSEY, 1948, Maryland Dept. Geology, Mines, Water Resources Bull. 2, p. 275, pl. 27, figs. 1–2.

Spiroplectammina mississippiensis (Cushman), Pl. 1, figs. 1–2
Textularia mississippiensis CUSHMAN, 1922, U.S. Geol. Survey Prof. Paper 129-E, p. 90, Pl. 14, fig. 4.

Stilostomella recta (Palmer and Bermudez), Pl. 5, figs. 3–4
Ellipsonodosaria recta PALMER and BERMUDEZ, 1936, Mem. Soc. Cubana Hist. Nat., v. 10, p. 297, pl. 18, figs. 6–7.

Textularia agglutinans d'Orbigny, Pl. 1, figs. 4–5
Textularia agglutinans D'ORBIGNY, 1839, *in* de la Sagra, Hist. Pol. Nat. de Cuba, "Foraminiferes," p. 136, pl. 1, figs. 17–18, 32–34.

Textularia articulata d'Orbigny, Pl. 1, figs. 6–7
Textularia articulata D'ORBIGNY, 1846, Foraminiferes fossiles du Bassin Tertiaire de Vienne, p. 250, pl. 15, figs. 16–18.

Textularia candeiana d'Orbigny, Pl. 1, figs. 8–9
Textularia candeiana D'ORBIGNY, 1839, *in* de la Sagra, Hist. Pol. Nat. de Cuba, "Foraminiferes," p. 143, tab. 1, figs. 19–20.

Trifarina illingi (Cushman and Renz), Pl. 5, fig. 16
Angulogerina illingi CUSHMAN and RENZ, 1941, Contr. Cushman Lab. Foram. Research, v. 17, pt. 1, p. 21, pl. 3, figs. 19–20.

Trifarina occidentalis (Cushman), Pl. 5, fig. 17
Uvigerina occidentalis CUSHMAN, 1923, U.S. Natl. Museum Bull. 104, pt. 4, p. 169.

Uvigerina auberiana d'Orbigny, Pl. 5, fig. 6
Uvigerina auberiana D'ORBIGNY, 1839, *in* de la Sagra, Hist. Pol. Nat. de Cuba, "Foraminiferes," p. 106, pl. 2, figs. 23–24.

Uvigerina calvertensis Cushman, Pl. 5, fig. 7
Uvigerina calvertensis CUSHMAN, 1948, Maryland Dept. Geology, Mines, Water Resources Bull. 2, p. 22, pl. 15, figs. 9–10.

Uvigerina subperegrina Cushman and Kleinpell, Pl. 5, fig. 8
Uvigerina subperegrina CUSHMAN and KLEINPELL, 1934, Contr. Cushman Lab. Foram. Research, v. 10, pt. 1, p. 12, pl. 2, figs. 9, 11.

Vaginulina sp., Pl. 2, figs. 14–15

Vaginulinopsis sp., Pl. 2, figs. 12–13

Valvulineria floridana Cushman, Pl. 6, figs. 11–13
Valvulineria floridana CUSHMAN, 1930, Fla. Geol. Survey Bull. 4, p. 54, pl. 10, fig. 6.

Valvulineria laevigata Phleger and Parker, Pl. 6, figs. 14–16
Valvulineria laevigata PHLEGER and PARKER, 1951, Geol. Soc. America Mem. 46, p. 25, pl. 13, figs. 11–12.

Valvulineria venezuelana Hedberg, Pl. 7, figs. 1–3
Valvulineria venezuelana HEDBERG, 1937, Jour. Paleontology, v. 11, n. 8, p. 678, pl. 91, fig. 21.

Virgulinella miocenica (Cushman and Ponton), Pl. 8, fig. 7
Virgulina miocenica CUSHMAN and PONTON, 1931, Contr. Cushman Lab. Foram. Research, v. 7, p. 32, pl. 4, figs. 14–16.

APPENDIX II

SEDIMENTS, GEOCHEMISTRY AND RELATIVE ABUNDANCE OF SELECTED FAUNAL ELEMENTS

Samples are listed in order of clusters defined by factor analysis. BOL PAU = Bolivina paula, BUL ELE = Buliminella elegantissima, TOT 1 = BOL PAU + BUL ELE, VAL FLO = Valvulineria floridana, ROS CAV = Rosalina cavernata, LEN AME = Lenticulina americana, HAN CON = Hanzawaia concentrica, CIB FLO = Cibicides floridana, CIB LOB = Cibicides lobatulus, TOT 2 = sum of VAL FLO through CIB LOB, TOT 3 = sum of all nutrient-tolerant species, TOT 4 = sum of all species adapted to well oxygenated conditions. Species listed here are those with highest loadings within the six factors defined by principal components analysis.

% P205 is based on bulk sediment chemical analyses, % phosphate in sand is based on grain counts of the sand fraction.

SAMPLE	CORE & INTERVAL (meters sub-bottom)	SEISMIC SEQUENCE	% P205	% PHOS. IN SAND	% SAND	% MUD	% ACID INSOL.	% CARB.	BOL PAU	BUL ELE	TOT 1	VAL FLO	ROS CAV	LEN AME	HAN CON	CIB FLO	CIB LOB	TOT 2	TOT 3	TOT 4	RAT. 3/4
1	53/1.25	BBS 2	3.56	4	75	23	82.5	<1.0	59	31	90	1	0	0	0	0	1	2	91	8	11.4
2	53/4.75	BBS 2	4.53	27	63	37	59.8	1.0	61	27	88	3	0	0	0	1	0	4	91	6	15.2
3	53/5.25	BBS 2	5.01	24	62	38	59.9	2.0	57	29	86	3	0	0	0	0	0	3	91	4	22.8
4	53/6.25	BBS 2	-	28	70	29	59.7	2.0	57	24	81	4	0	0	0	0	0	4	89	8	11.1
5	59/6.75	BBS 1	1.27	0	16	83	67.5	2.0	44	36	80	3	0	0	1	2	0	6	85	12	7.1
6	94/1.00	BBS 2	3.33	46	47	49	44.0	9.2	53	35	88	0	0	0	0	0	0	0	91	6	15.2
7	109/5.50	BBS 1	2.89	10	55	43	66.6	3.0	46	20	66	1	0	0	1	0	1	3	71	24	3.0
8	53/2.75	BBS 2	5.24	14	78	21	75.8	3.0	72	10	82	8	0	0	0	1	0	9	85	9	9.4
9	53/3.30	BBS 2	3.90	20	74	24	75.5	2.0	69	7	76	4	0	0	0	0	1	5	87	5	17.4
10	108/2.50	BBS 5	0.47	0	-	-	-	-	69	1	70	0	0	0	1	0	1	2	71	27	2.6
11	67/7.25	FPS 6	1.03	3	70	30	58.6	24.9	53	9	62	0	2	0	13	0	4	19	74	21	3.5
12	59/5.89	BBS 1	2.28	0	-	-	-	-	35	14	49	2	1	0	1	15	1	20	51	45	1.1
13	105/4.50	FPS 2	5.58	5	-	-	-	-	41	3	44	16	2	1	3	0	0	22	58	32	1.8
14	103/5.90	FPS 2	1.13	3	75	25	86.2	1.0	46	12	58	19	0	2	5	0	0	26	71	28	2.5
15	109/2.50	BBS 1	3.41	7	63	37	81.3	<1.0	46	7	53	10	0	0	5	0	0	15	56	41	1.4
16	103/5.00	FPS 2	1.16	2	77	23	84.3	1.0	22	19	41	35	0	0	8	0	0	43	52	45	1.2
17	109/6.00	BBS 2	1.17	3	30	61	41.0	27.4	29	6	35	37	0	0	6	0	1	44	35	61	0.6
18	105/1.50	FPS 2	-	2	-	-	-	-	30	2	32	18	2	2	3	0	0	25	54	38	1.4
19	129/2.50	FPS 3	-	0	-	-	-	-	26	7	33	20	0	3	9	0	0	32	54	42	1.3
20	129/4.00	FPS 3	-	2	-	-	-	-	29	5	34	23	0	2	14	0	1	40	51	45	1.1
21	129/5.50	FPS 3	-	5	-	-	-	-	26	8	34	24	1	0	15	0	3	43	46	52	0.9
22	109/4.00	BBS 1	3.15	6	74	36	83.1	<1.0	30	5	35	25	0	0	10	0	2	37	36	58	0.6
23	71/1.00	BBS 1	1.42	3	38	62	65.0	2.0	28	4	32	20	0	0	11	0	0	31	33	65	0.5
24	71/0.50	BBS 1	1.02	1	35	65	67.6	2.0	33	4	37	17	0	0	6	0	0	23	37	59	0.6
25	72/1.00	BBS 1	2.30	15	-	-	-	-	26	7	33	22	0	0	2	0	0	24	34	62	0.5
26	6/7.00	OBS 3	2.54	4	96	4	89.0	1.0	26	2	28	18	0	2	3	10	0	33	28	64	0.4
27	45/3.00	FPS 6	2.19	1	76	23	56.1	25.7	33	14	47	23	2	1	5	3	3	37	51	47	1.1
28	45/4.75	FPS 6	2.75	0	72	27	62.8	17.8	31	7	38	26	3	2	3	1	4	39	41	57	0.7
29	50/3.25	FPS 6	2.03	3	81	14	71.7	19.5	33	14	47	12	0	20	5	1	0	38	50	46	1.1
30	43/1.00	BBS 1	1.98	0	-	-	-	-	39	15	54	10	0	0	0	0	0	10	81	15	5.4
31	27/2.75	FPS 2	0.61	3	-	-	-	-	23	0	23	3	0	7	10	0	0	20	77	20	3.9
32	63/1.25	FPS 2	1.10	8	34	66	50.6	28.0	28	2	30	2	0	3	15	0	0	20	70	20	3.5
33	63/2.25	FPS 2	9.24	13	45	55	51.4	17.0	18	2	20	3	0	4	21	0	0	28	60	28	2.1
34	27/5.25	FPS 2	-	7	27	73	-	-	40	2	42	0	0	6	12	0	0	18	82	18	4.6
35	98/3.25	FPS 2	1.02	0	-	-	-	-	37	1	38	2	0	3	12	0	0	17	74	17	4.4
36	27/7.25	FPS 2	5.93	18	45	55	-	-	36	3	39	0	0	3	15	0	0	18	76	18	4.2
37	119/3.35	FPS 1	4.92	18	-	-	-	-	35	4	39	2	0	3	16	0	0	21	72	22	3.3
38	64/4.50	FPS 1	15.13	54	-	-	-	-	42	4	46	1	0	4	16	0	2	23	67	23	2.9
39	120/4.25	FPS 1	8.36	42	-	-	-	-	41	3	44	2	0	5	10	0	0	17	71	17	4.2
40	116/3.00	FPS 1	7.58	28	-	-	-	-	41	3	44	2	0	3	9	0	0	14	74	14	5.3
41	9/2.75	FPS 1	3.20	12	-	-	-	-	37	3	40	0	0	4	15	0	0	19	74	19	3.9
42	14/1.00	FPS 1	5.41	17	61	39	45.4	42.0	35	2	37	0	0	3	22	0	0	25	65	25	2.6

APPENDIX II (continued)

SAMPLE	CORE & INTERVAL (meters sub-bottom)	SEISMIC SEQUENCE	% P205	% PHOS. IN SAND	% SAND	% MUD	% ACID INSOL.	% CARB.	BOL PAU	BUL ELE	TOT 1	VAL FLO	ROS CAV	LEN AME	HAN CON	CIB FLO	CIB LOB	TOT 2	TOT 3	TOT 4	RAT. 3/4
43	26/0.75	FPS 1	12.90	40	71	29	-	-	37	2	39	0	0	3	22	0	0	25	66	25	2.6
44	105/7.25	FPS 1	4.38	18	-	-	-	-	39	3	42	2	0	4	23	0	2	31	61	32	1.9
45	64/4.00	FPS 1	12.47	27	56	43	43.1	22.6	30	2	32	0	0	6	20	0	0	26	63	27	2.3
46	14/4.00	FPS 1	14.58	53	77	23	42.3	20.0	33	11	44	0	0	2	16	0	0	18	70	21	3.3
47	26/1.25	FPS 1	10.18	37	66	34	-	-	33	3	36	0	0	4	14	0	0	18	57	20	2.9
48	64/6.00	FPS 1	14.60	62	71	29	-	-	33	5	38	1	0	4	15	0	0	20	67	20	3.4
49	22/3.25	FPS 1	6.33	38	-	-	-	-	30	8	38	2	0	3	15	0	0	20	69	20	3.5
50	9/1.75	FPS 1	3.36	12	-	-	-	-	29	5	34	1	0	6	18	0	0	25	71	25	2.8
51	120/5.90	FPS 1	15.50	56	-	-	-	-	31	3	34	3	0	3	17	0	0	23	68	27	2.5
52	22/5.25	FPS 1	2.31	47	-	-	-	-	20	2	22	0	0	7	19	0	1	27	59	28	2.1
53	24/0.30	FPS 1	9.26	58	-	-	-	-	27	0	27	3	0	8	18	0	0	29	55	32	1.7
54	24/1.00	FPS 1	23.20	64	-	-	-	-	24	0	24	0	0	6	19	0	0	25	52	30	1.7
55	17/5.75	OBS (u)	1.22	4	16	84	42.4	7.8	19	8	27	1	0	12	23	0	0	36	63	36	1.8
56	105/1.25	FPS 2	1.20	6	71	29	-	-	36	3	39	0	0	2	16	0	0	18	72	19	3.8
57	105/7.50	FPS 1	4.38	0	83	17	87.6	-	12	19	31	17	1	0	2	0	0	20	63	31	2.0
58	127/4.50	FPS 1	-	3	-	-	-	-	13	26	39	18	1	0	5	0	0	24	71	27	2.6
59	127/5.50	FPS 1	2.31	6	68	32	-	-	7	20	27	22	0	1	3	0	0	26	62	29	2.1
60	127/7.00	FPS 1	1.45	1	-	-	-	-	13	21	34	7	1	2	4	0	0	14	62	30	2.1
61	132/1.50	FPS 1	0.44	0	73	25	83.1	3.0	8	28	36	3	2	0	5	0	2	12	56	32	1.8
62	132/2.00	FPS 1	0.37	0	-	-	-	-	8	33	41	2	4	1	4	0	1	12	62	29	2.1
63	132/3.50	FPS 1	0.36	0	83	16	81.6	3.0	16	26	42	5	1	1	5	0	4	16	62	29	2.1
64	132/4.10	FPS 1	0.34	0	-	-	-	-	4	26	30	2	1	2	3	0	2	10	45	22	2.0
65	132/2.50	FPS 1	0.81	0	67	28	71.9	3.0	9	20	29	1	2	1	5	1	1	11	55	33	1.6
66	17/3.00	OBS (u)	1.76	4	6	94	85.8	1.5	20	21	41	3	0	0	16	0	0	19	82	19	4.3
67	96/5.25	FPS 6	1.54	6	59	41	72.6	14.4	15	28	43	0	3	2	20	0	0	25	71	25	2.8
68	34/3.75	OBS 1	1.09	0	22	78	-	-	22	20	42	5	2	0	1	0	8	16	43	39	1.1
69	34/6.75	OBS 1	1.00	2	12	88	-	-	20	20	40	6	2	0	2	0	10	20	41	41	1.0
70	34/5.75	OBS 1	1.08	0	10	90	73.0	3.7	22	24	46	4	4	0	0	0	7	15	46	36	1.3
71	35/1.75	OBS 1	1.23	3	30	69	-	-	11	8	19	13	7	0	4	0	28	52	19	63	0.3
72	35/5.75	OBS 1	1.08	2	39	61	38.4	24.2	10	6	16	8	11	0	4	0	30	53	18	65	0.3
73	35/7.20	OBS 1	1.10	0	45	55	31.1	34.0	7	9	16	9	14	0	4	0	24	51	16	63	0.3
74	33/8.25	OBS 3	1.00	0	32	68	-	-	23	6	29	8	11	0	1	0	16	36	31	56	0.6
75	111/4.50	OBS 3	0.42	0	73	24	6.5	68.5	25	2	27	2	9	0	2	0	14	27	29	49	0.6
76	111/5.00	OBS 3	0.29	0	43	55	18.9	43.8	26	3	29	3	9	0	4	0	16	31	31	51	0.6
77	111/6.30	OBS 3	-	0	54	27	5.8	71.1	24	4	28	4	8	0	5	0	20	37	29	56	0.5
78	105/8.90	FPS 1	-	4	-	-	-	-	6	18	24	0	0	0	4	0	0	4	44	52	0.8
79	1/3.75	BBS 8	3.35	17	-	-	-	-	8	1	9	2	0	2	38	1	14	57	9	79	0.1
80	1/4.75	BBS 8	4.10	13	79	21	67.9	3.8	17	0	17	5	0	0	39	0	7	51	17	76	0.2
81	2/3.25	BBS 1	1.26	3	79	21	87.8	<1.0	7	2	9	1	0	3	46	0	1	51	10	82	0.1
82	1/7.75	BBS 8	5.18	25	83	17	80.8	<1.0	13	3	16	0	0	0	51	0	0	51	18	66	0.3
83	110/6.00	FPS 2	-	0	87	13	-	-	10	10	20	7	1	2	40	1	1	52	31	60	0.5
84	67/3.25	FPS 6	1.01	0	76	24	51.4	35.0	4	1	5	0	0	6	38	5	3	52	28	61	0.5
85	67/4.75	FPS 6	1.15	0	-	-	-	-	4	0	4	0	0	5	41	3	3	52	33	52	0.6
86	114/6.35	FPS 1	7.09	45	53	47	47.2	39.4	5	0	5	0	0	0	41	0	1	42	24	42	0.6
87	96/2.25	FPS 6	1.73	8	74	24	-	-	3	2	5	4	0	8	51	0	2	65	28	65	0.4
88	39/4.25	BBS 1	-	3	50	49	92.6	<1.0	26	5	31	2	0	0	30	0	0	32	32	55	0.6
89	1/6.75	BBS 8	6.21	25	79	21	76.7	1.0	27	3	30	1	0	0	26	0	1	28	31	58	0.5
90	1/5.75	BBS 8	4.07	14	74	26	78.7	1.8	15	5	20	3	0	0	30	0	1	34	21	62	0.3
91	1/8.75	BBS 8	5.25	15	80	20	-	-	21	6	27	3	0	0	32	0	0	35	30	59	0.5

APPENDIX II (continued)

SAMPLE	CORE & INTERVAL (meters sub-bottom)	SEISMIC SEQUENCE	% P205	% PHOS. IN SAND	% SAND	% MUD	% ACID INSOL.	% CARB.	BOL PAU	BUL ELE	TOT 1	VAL FLO	ROS CAV	LEN AME	HAN CON	CIB FLO	CIB LOB	TOT 2	TOT 3	TOT 4	RAT. 3/4
92	118/3.00	FPS 6	1.06	2	-	-	-	-	26	8	34	2	0	4	29	0	3	38	46	45	1.0
93	118/4.25	FPS 6	1.33	3	-	-	-	-	26	4	30	2	1	4	23	5	4	39	45	49	0.9
94	38/2.25	OBS 1	1.42	4	70	30	75.7	<1.0	8	0	8	2	1	4	26	2	2	37	20	70	0.3
95	38/1.50	OBS 2	3.33	5	-	-	-	-	7	0	7	5	2	5	28	2	2	44	16	72	0.2
96	38/0.25	OBS 2	1.93	6	64	19	-	-	8	0	8	4	1	7	25	4	0	41	19	66	0.3
97	118/5.90	FPS 6	1.15	2	-	-	-	-	10	2	12	5	0	8	30	7	3	53	27	62	0.4
98	118/8.90	FPS 6	1.05	6	-	-	-	-	10	2	12	0	0	9	23	8	3	43	31	55	0.6
99	108/6.00	BBS 5	0.34	0	40	55	43.4	23.7	8	4	12	10	1	0	22	5	1	39	24	64	0.4
100	39/8.75	BBS 1	2.93	5	86	13	36.4	56.2	17	1	18	0	0	6	13	2	3	24	35	52	0.7
101	33/6.50	OBS 3	0.91	0	32	68	-	-	25	4	29	0	1	7	7	2	0	17	32	49	0.7
102	59/7.80	BBS 1	2.16	2	81	19	-	-	6	0	6	22	1	22	19	11	1	76	15	82	0.2
103	6/6.50	BBS 1	2.85	8	95	5	88.9	<1.0	14	1	15	22	0	3	4	24	0	53	18	72	0.3
104	48/2.25	FPS 3	0.90	2	86	14	85.9	6.1	11	15	26	14	4	0	17	0	10	45	28	66	0.4
105	48/4.75	FPS 3	0.74	4	90	10	79.4	12.1	15	2	17	23	2	1	22	2	7	57	22	76	0.3
106	45/0.75	FPS 6	1.24	0	54	45	15.7	45.7	11	1	12	28	0	0	1	0	12	41	16	67	0.2
107	72/4.00	BBS 1	3.32	5	-	-	-	-	17	3	20	50	0	0	9	0	0	59	21	76	0.3
108	72/4.50	BBS 1	2.75	6	-	-	-	-	18	3	21	52	0	0	8	0	0	60	20	78	0.3
109	91/3.50	BBS 1	4.52	10	81	19	77.6	<1.0	8	3	11	28	0	0	23	0	6	57	11	85	0.1
110	91/6.00	BBS 1	1.10	3	78	22	87.1	<1.0	12	2	14	32	0	0	11	0	3	46	15	78	0.2
111	98/1.25	FPS 2	1.53	5	-	-	-	-	24	2	26	2	0	0	12	0	0	14	79	14	5.6
112	105/9.10	FPS 1	-	4	-	-	-	-	3	9	12	18	3	0	2	0	0	23	17	73	0.2
113	127/8.00	FPS 1	1.45	3	83	17	87.6	<1.0	7	14	21	4	2	0	5	0	1	12	31	58	0.5
114	59/4.75	BBS 1	0.47	0	-	-	-	-	0	0	0	0	1	1	0	69	4	75	1	94	0.0
115	52/3.75	BBS 1	1.40	2	12	88	58.3	<1.0	1	0	1	0	1	0	0	79	0	80	1	96	0.0

APPENDIX III

Mean Values of Selected Sedimentological, Geochemical and Paleontological Characteristics

CLUSTER	HIGH NUT TOL	MOD NUT TOL	HIGH PLUS MOD	WELL OXY BOT	P205 BULK SED	% PHOS SAND	% SAND	% MUD	% ACID INSOL	% CARB	BOL PAU	BUL ELE	VAL FLO	ROS CAV	LEN AME	HAN CON	CIB FLO	CIB LOB	RATIO NUT TOL TO WELL OXY
A	80.1	4.8	84.9	10.0	3.12	16.0	61.0	37.7	64.9	2.5	53.3	20.7	2.3	0.2	1.8	1.5	0.4	0.7	8.49
C	41.4	7.7	49.1	36.5	2.27	3.4	65.1	34.3	71.6	9.0	31.9	7.7	19.4	0.6	2.4	5.6	0.9	0.8	1.35
D	48.6	18.2	66.8	22.2	7.76	28.5	53.3	46.6	45.8	22.9	32.1	3.2	1.2	0.0	4.5	16.5	0.0	0.2	3.01
E	43.4	14.6	58.0	29.1	1.30	1.6	48.3	50.9	79.3	4.8	13.5	23.6	6.7	1.6	3.3	5.3	0.1	2.4	1.99
F	23.2	1.3	24.5	47.3	0.73	0.7	45.1	51.3	20.1	48.3	18.0	5.3	6.5	9.8	0.2	3.5	0.2	18.7	0.52
H	18.5	17.5	36.0	68.8	2.65	8.7	69.1	29.3	67.1	14.9	13.2	2.7	2.1	1.2	3.7	30.8	1.8	2.4	0.52
J	18.2	3.5	21.7	69.1	0.96	2.0	76.7	23.0	60.3	21.3	12.3	5.7	22.0	2.1	0.4	13.2	0.5	9.6	0.31
K	16.2	0.5	16.7	64.0	2.92	6.0	79.5	20.5	82.4	1.0	13.6	2.6	40.5	0.1	0.0	12.6	0.0	2.3	0.27

HIGH NUT TOL = relative abundance of species tolerant of intense nutrient concentration and low dissolved oxygen
MOD NUT TOL = relative abundance of species tolerant of moderate nutrient concentration and moderately low dissolved oxygen
WELL OXY BOT = relative abundance of species adapted to well oxygenated bottom conditions
P205 BULK SED = percent P205 in total sediment (determined chemically)
% PHOS SAND = percent of sand fraction composed of phosphatic grains (determined by grain counts)
BOL PAU = Bolivina paula BUL ELE = Buliminella elegantissima VAL FLO = Valvulineria floridana
ROS CAV = Rosalina cavernata LEN AME = Lenticulina americana HAN CON = Hanzawaia concentrica
CIB FLO = Cibicides floridanus CIB LOB = Cibicides lobatulus
RATIO NUT TOL TO WELL OXY BOT = ratio of relative abundances of these groups (including all constituent species in each)

Clusters with two or less samples are not included. However, Clusters A, C , D, E, F, H, J and K account for 106 of the 115 samples in this study.

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core/ Interval	Ammonia beccarii	Astacolus dubius	Astacolus sp. A	Astacolus sp. B	Baggina sp.	Bolivina advena	Bolivina brevior	Bolivina calvertensis	Bolivina floridana	Bolivina lowmani	Bolivina marginata multicostata	Bolivina paula	Bolivina robusta	Bolivina subdilatata	Bolivinopsis fairhavenensis	Buccella frigida	Buccella inusitata	Bulimina elongata	Bulimina ovula	Bulimina striata mexicana	Buliminella brevior	Buliminella elegantissima	Cancris sagra	?Cassidella sp.	Cassidulina laevigata	Cassidulinoides cf. C. bradyi	Chilostomella oolina
1 / 3.75	--	--	--	--	--	--	--	--	--	--	--	8	--	3	--	4	11	--	--	--	--	1	--	--	3	--	--
1 / 4.75	--	--	--	--	--	2	--	--	--	--	--	17	--	11	--	1	11	--	--	--	1	*	--	--	1	--	--
1 / 5.75	--	--	--	--	--	3	--	--	--	--	*	15	--	13	--	1	6	--	*	--	4	5	--	--	2	--	--
1 / 6.75	--	--	--	--	--	3	--	--	*	--	--	27	1	15	--	1	*	--	--	--	2	3	--	--	3	--	--
1 / 7.75	--	--	--	--	--	--	--	--	--	--	--	13	--	11	--	1	*	--	--	--	--	3	--	--	--	--	--
1 / 8.75	--	--	--	--	--	--	--	--	*	--	--	21	--	14	--	1	2	--	--	--	4	6	*	--	7	--	--
2 / 3.25	--	--	--	--	--	3	--	--	--	--	--	7	2	9	--	--	1	*	--	--	--	2	--	--	10	--	--
6 / 6.50	--	*	--	--	--	1	--	--	*	--	--	14	5	11	--	--	--	1	2	--	--	1	--	--	--	--	--
6 / 7.00	--	--	--	--	--	1	--	--	--	--	--	26	10	12	--	--	--	1	2	--	--	2	--	*	--	--	--
9 / 1.75	--	--	--	--	--	--	--	--	--	4	1	29	--	--	--	--	--	2	--	--	--	5	1	--	--	1	--
9 / 2.75	--	--	--	*	--	--	--	--	--	4	1	37	--	--	--	--	--	13	--	*	--	3	2	--	--	1	--
14 / 1.00	--	--	*	--	--	--	--	--	--	5	--	35	--	--	--	--	--	*	--	*	--	2	*	--	1	1	1
14 / 4.00	--	*	--	--	--	--	--	--	--	4	*	33	--	--	--	--	--	2	--	3	--	11	*	--	--	--	--
17 / 3.00	--	--	--	*	--	--	--	--	--	5	6	20	--	--	--	--	--	5	--	--	--	21	--	--	--	*	--
17 / 5.75	--	*	--	--	--	--	--	--	--	5	7	19	--	--	--	--	--	6	--	--	--	8	--	--	--	--	--
22 / 3.25	--	--	--	--	--	--	--	--	--	5	1	30	--	--	--	--	--	7	--	*	--	8	1	*	--	2	--
22 / 5.25	--	*	*	--	--	--	--	--	--	3	*	20	--	--	--	--	--	3	--	--	--	2	4	--	*	2	--
24 / 0.30	--	*	--	--	--	--	--	--	--	4	--	27	--	--	--	--	--	4	--	--	--	--	2	*	--	1	*
24 / 1.00	--	--	--	--	--	--	--	--	--	--	--	24	--	--	--	--	--	6	--	3	--	--	*	1	--	4	--
26 / 0.25	--	*	--	*	--	--	--	--	--	4	1	37	--	--	--	--	--	3	--	--	--	2	1	--	--	1	--
26 / 2.75	--	--	--	*	*	--	--	--	--	4	*	33	--	--	--	--	--	1	--	1	--	3	1	--	1	--	--
27 / 2.75	--	--	--	--	--	--	--	--	--	2	*	23	--	--	--	--	--	3	--	--	--	1	3	--	--	--	--
27 / 5.25	--	--	--	*	--	--	--	--	--	2	1	40	--	--	--	--	--	7	--	--	--	2	2	--	--	*	--
27 / 7.25	--	--	--	--	--	--	--	--	--	7	2	36	--	--	--	--	--	6	--	--	--	3	1	*	--	1	--
33 / 6.50	--	--	--	--	--	1	--	4	1	--	1	25	1	10	--	--	1	1	2	--	--	4	--	--	1	--	--
33 / 8.25	--	--	--	--	--	2	--	5	--	--	1	23	2	8	--	--	--	2	--	--	--	6	--	--	--	--	--
34 / 3.75	*	--	--	--	--	*	1	2	--	--	1	22	2	14	--	--	--	1	*	--	--	20	--	--	*	--	--
34 / 5.75	--	--	--	--	--	1	1	4	--	--	--	22	2	12	--	--	--	1	1	--	--	24	*	--	*	--	--
34 / 6.75	--	--	--	--	--	1	3	5	--	--	1	20	2	10	--	--	--	3	1	--	--	20	2	--	--	--	--
35 / 1.75	1	*	--	--	--	1	1	*	1	--	--	11	1	6	--	--	*	*	--	--	--	8	--	--	--	--	--
35 / 5.75	6	--	--	--	--	1	--	2	1	--	*	10	*	5	--	--	--	--	--	--	--	6	--	--	*	--	--
35 / 7.20	4	--	--	--	--	1	*	1	--	--	--	7	2	5	--	--	--	*	--	--	--	9	*	--	1	--	--
38 / 0.25	--	*	*	--	--	2	--	8	3	--	*	8	5	1	--	--	*	1	*	--	--	*	*	--	9	--	--
38 / 1.50	--	*	--	--	--	1	--	7	7	--	--	7	4	*	--	--	--	1	--	--	--	--	--	--	9	--	--
38 / 2.25	--	*	1	--	--	1	--	3	8	--	--	8	4	2	--	1	--	1	1	--	--	--	--	--	6	--	--
39 / 4.25	--	--	--	--	--	3	--	--	1	--	--	26	--	19	--	*	--	3	1	--	1	5	--	--	*	--	--
39 / 8.75	--	--	--	--	--	3	--	*	*	--	--	17	1	6	--	--	1	*	1	*	--	1	--	--	6	--	--
43 / 1.00	--	--	--	--	--	--	--	3	--	--	--	39	--	--	--	--	--	1	--	--	2	15	--	--	--	--	--
45 / 0.75	--	--	--	--	--	--	--	--	--	--	--	11	1	--	--	--	--	*	--	--	--	1	--	--	--	--	--
45 / 3.00	--	--	--	--	--	--	--	1	--	--	--	33	--	--	1	--	--	*	--	--	--	14	--	--	--	--	--
45 / 4.75	--	--	--	--	--	*	--	2	--	--	--	31	--	--	*	--	--	*	--	--	*	7	--	--	--	--	--
48 / 2.25	--	--	--	--	--	--	--	*	--	--	--	11	--	--	--	--	--	*	--	--	--	15	1	*	--	--	--
48 / 4.75	--	--	--	--	--	--	--	1	--	--	--	15	--	1	--	--	--	--	--	1	--	2	--	--	--	--	--
50 / 3.25	--	*	--	--	--	--	--	--	--	--	--	33	--	*	1	--	--	*	--	--	--	14	--	*	--	--	--
52 / 3.75	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--
53 / 1.25	--	--	--	--	--	--	--	4	--	--	--	59	--	1	--	--	--	1	--	--	--	31	--	--	--	--	--
53 / 2.75	--	--	--	--	--	1	--	--	1	--	--	72	--	--	--	--	--	*	--	--	*	10	--	--	--	--	--
53 / 3.30	--	--	--	--	--	--	--	--	1	--	*	69	--	--	--	--	--	*	--	--	--	7	*	--	--	1	--
53 / 4.75	--	--	--	--	--	--	--	2	--	--	--	61	--	*	--	--	--	--	--	--	*	27	--	1	--	--	--
53 / 5.25	--	--	--	--	--	2	--	1	--	--	--	57	--	*	--	--	--	--	--	--	*	29	--	--	--	--	--
53 / 6.25	--	--	--	--	--	--	--	3	1	--	--	57	--	*	--	--	--	*	--	--	*	24	--	--	--	1	--
59 / 4.75	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59 / 5.89	--	--	--	--	--	--	--	*	--	--	*	35	--	1	--	--	--	--	--	--	--	14	--	--	--	--	--
59 / 6.75	--	--	--	--	--	--	--	2	--	--	--	45	--	*	--	--	--	--	--	--	--	36	--	--	--	--	--
59 / 7.80	--	--	--	--	--	--	--	*	--	--	--	6	--	--	--	--	--	*	--	--	--	*	*	--	--	*	--
63 / 1.25	--	--	--	--	--	--	--	--	--	3	1	28	--	--	--	--	--	9	--	--	--	2	2	--	--	3	--
63 / 2.25	--	--	*	*	--	--	--	--	--	3	1	18	--	--	--	--	--	4	--	--	--	2	2	--	--	5	--
64 / 4.00	--	*	--	--	--	--	--	--	--	5	1	30	--	--	--	--	--	3	--	*	--	2	2	--	--	2	--
64 / 4.50	--	--	*	--	--	--	--	--	--	7	1	42	--	--	--	--	--	3	--	1	--	4	*	1	*	1	--
64 / 6.00	--	--	--	*	--	--	--	--	--	6	1	33	--	--	--	--	--	3	--	2	--	5	*	*	--	3	*
67 / 3.25	--	*	--	--	--	--	--	2	1	2	--	4	--	--	--	--	--	1	--	--	--	1	--	--	2	*	--
67 / 4.75	--	--	--	--	--	--	--	1	*	2	*	4	--	--	--	--	--	1	--	*	--	1	--	--	1	--	--
67 / 7.25	--	--	--	--	--	--	--	2	*	9	--	53	--	--	--	--	--	1	--	--	--	9	--	--	--	--	--

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core / Interval	Ammonia beccarii	Astacolus dubius	Astacolus sp. A	Astacolus sp. B	Baggina sp.	Bolivina advena	Bolivina brevior	Bolivina calvertensis	Bolivina floridana	Bolivina lowmani	Bolivina marginata multicostata	Bolivina paula	Bolivina robusta	Bolivina subdilatata	Bolivinopsis fairhavenensis	Buccella frigida	Buccella inusitata	Bulimina elongata	Bulimina ovula	Bulimina striata mexicana	Buliminella brevior	Buliminella elegantissima	Cancris sagra	?Cassidella sp.	Cassidulina laevigata	Cassidulinoides cf. C. bradyi	Chilostomella oolina
71 / 0.50	--	--	--	--	--	3	--	--	--	--	--	33	11	25	--	--	--	--	--	--	--	4	--	--	--	--	--
71 / 1.00	--	--	--	--	--	2	--	--	--	--	--	28	8	25	--	--	--	--	--	--	--	4	--	--	*	--	--
72 / 1.00	--	--	--	--	--	1	--	--	--	--	--	26	4	25	--	*	2	*	--	--	--	7	--	--	1	--	--
72 / 4.00	--	--	--	--	--	1	--	--	--	--	--	17	4	10	--	1	2	--	1	--	--	3	--	--	--	--	--
72 / 4.50	--	--	--	--	--	1	--	--	--	--	--	18	3	12	--	*	2	--	*	--	--	3	--	--	--	--	--
91 / 3.50	--	--	--	--	--	--	--	--	--	--	--	8	--	12	--	--	--	--	--	--	--	3	--	--	12	--	--
91 / 6.00	--	--	--	--	--	2	--	--	--	--	1	12	1	11	--	--	4	--	2	--	--	2	--	--	7	--	--
94 / 1.00	--	--	--	--	--	1	--	3	--	--	--	53	--	--	--	--	--	1	--	--	--	35	--	--	--	--	--
96 / 2.25	--	1	--	--	--	--	--	--	--	1	--	3	--	--	--	--	--	2	--	--	--	2	--	--	--	*	--
96 / 5.25	--	*	--	--	--	--	--	--	--	3	--	15	--	--	--	--	--	5	--	--	--	28	--	--	--	--	--
98 / 1.25	--	--	--	*	--	--	--	--	--	8	*	24	--	--	--	--	--	37	--	--	--	2	--	--	--	1	--
98 / 3.25	--	--	--	--	--	--	--	--	--	4	*	37	--	--	--	--	--	10	--	--	--	1	2	--	--	4	--
103 / 5.00	--	--	--	--	--	--	--	1	--	--	--	22	--	1	1	--	--	2	--	--	--	19	--	--	--	--	--
103 / 5.90	--	--	--	--	--	--	--	1	--	--	1	46	--	--	--	--	--	1	--	--	*	12	--	--	--	--	--
105 / 1.25	--	*	--	*	*	--	--	--	--	6	--	36	--	--	--	--	--	1	--	4	--	3	--	--	--	--	--
105 / 1.50	--	--	--	--	1	--	--	4	*	--	--	30	--	*	--	--	--	2	--	3	--	2	--	--	--	--	--
105 / 4.50	--	--	--	--	--	--	--	1	--	--	*	42	--	--	--	--	--	*	--	7	*	3	--	--	--	--	--
105 / 7.25	--	*	--	--	--	--	--	--	--	5	--	39	--	--	--	--	--	1	--	4	--	3	--	--	--	*	*
105 / 7.50	--	--	--	--	--	--	--	2	--	--	1	12	--	--	1	--	--	15	--	--	1	19	--	--	--	--	--
105 / 8.90	--	--	--	--	--	--	--	--	--	12	1	6	--	--	--	--	--	--	--	*	--	18	--	*	--	--	--
105 / 9.10	--	--	--	--	--	--	--	13	--	--	3	3	--	--	3	--	--	2	--	--	--	9	--	--	--	--	--
108 / 2.50	--	--	--	--	--	--	--	3	--	--	*	69	--	12	--	--	--	--	--	--	--	1	--	--	3	--	--
108 / 6.00	--	--	--	--	--	--	--	13	*	--	--	8	--	1	--	--	1	--	1	--	--	4	--	--	3	--	--
109 / 2.50	--	--	--	--	--	2	--	--	--	--	3	46	--	19	--	--	2	--	--	--	2	7	--	--	1	--	--
109 / 4.00	--	--	--	--	--	2	--	--	--	--	--	30	--	16	--	--	1	--	1	--	--	5	--	--	2	--	--
109 / 5.50	--	--	--	--	--	3	*	--	--	--	3	47	--	19	--	--	--	*	--	--	--	20	--	--	--	--	--
109 / 6.00	--	--	--	--	--	*	1	--	--	--	--	29	--	15	--	--	1	--	1	--	--	6	--	--	--	--	--
110 / 6.00	--	--	--	--	--	--	--	2	--	--	--	10	--	4	--	--	--	2	--	--	1	10	--	--	*	--	--
111 / 4.50	*	--	--	--	--	1	1	4	--	--	1	25	*	10	--	--	--	--	*	--	--	2	--	--	--	--	--
111 / 5.00	*	--	--	--	--	*	--	3	--	--	1	26	2	9	--	--	--	*	--	--	--	3	--	--	*	--	--
111 / 6.30	--	--	--	--	--	1	1	3	--	--	*	24	1	11	--	--	--	*	--	--	--	4	--	--	*	--	--
114 / 6.35	--	--	--	--	--	--	--	--	--	2	--	5	--	--	--	--	--	6	--	1	--	*	1	--	--	--	--
116 / 3.00	--	--	--	--	--	--	--	--	--	4	1	41	--	--	--	--	--	8	--	1	--	3	1	1	--	1	*
118 / 3.00	--	*	--	*	--	--	--	4	--	2	--	26	--	--	--	--	--	--	--	--	--	8	--	--	1	*	--
118 / 4.25	--	--	--	*	--	--	--	7	--	4	*	26	--	--	--	--	--	2	--	--	--	4	--	--	3	--	--
118 / 5.90	--	1	--	*	--	--	--	5	--	1	--	10	--	--	--	--	--	*	--	*	--	2	--	--	3	--	*
118 / 8.90	--	*	--	--	--	--	--	3	--	3	*	10	--	--	--	--	--	3	--	--	--	2	--	--	6	--	--
119 / 3.35	--	--	--	--	--	--	--	--	--	10	--	35	--	--	--	--	--	9	--	1	--	4	*	--	--	--	--
120 / 4.25	--	--	--	--	--	--	--	--	--	10	--	41	--	--	--	--	--	3	--	*	--	3	1	1	--	1	--
120 / 5.90	--	--	--	*	--	--	--	--	--	8	--	31	--	--	--	--	--	2	--	2	--	3	1	1	--	1	--
127 / 4.50	--	--	--	--	--	--	--	*	--	--	*	13	--	--	--	--	--	12	--	--	1	26	--	--	--	--	--
127 / 5.50	--	--	--	--	--	--	--	1	*	--	--	7	--	--	--	--	--	14	--	--	*	20	--	--	--	--	--
127 / 7.00	--	--	--	--	--	--	--	4	*	--	*	13	--	--	1	*	--	6	--	*	1	21	--	--	--	--	--
127 / 8.00	--	--	--	--	--	--	--	5	*	--	1	6	--	--	1	--	--	4	--	--	*	14	--	--	--	--	--
129 / 2.50	--	--	*	--	--	--	--	5	--	--	1	26	--	--	--	--	--	5	--	*	*	7	1	--	--	--	--
129 / 4.00	--	--	--	--	--	--	--	2	--	--	1	29	--	--	--	--	--	3	--	--	--	5	4	--	--	--	--
129 / 5.50	--	--	--	--	--	--	--	1	--	--	1	26	--	--	--	--	--	1	--	--	--	8	1	--	--	--	--
132 / 1.50	--	--	--	--	--	--	--	5	--	--	1	8	--	--	--	--	--	4	--	--	--	28	--	*	--	--	--
132 / 2.00	--	--	--	--	--	--	--	3	--	--	--	8	--	--	--	--	--	2	--	--	--	33	--	--	--	--	--
132 / 2.50	--	--	--	--	--	--	--	3	--	--	1	9	--	--	*	--	--	2	--	--	--	20	--	--	--	--	--
132 / 3.50	--	--	--	--	--	--	--	*	--	--	1	16	*	--	--	--	--	2	--	--	2	26	--	--	--	--	--
132 / 4.10	--	--	--	--	--	--	--	--	--	--	*	4	--	--	*	--	--	2	--	--	26	24	--	--	--	--	--

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core/ Interval	Cibicides americanus	Cibicides floridanus	Cibicides lobatulus	Coryphostoma georgiana	Dentalina communis	Ehrenbergina caribbea	Elphidium sp.	Epistominella danvillensis	Eponides sp.	Estorffina mayi	Fissurina lucida	Florilius chesapeakensis	Florilus grateloupi	Florilus pizarrensis	Fursenkoina fusiformis	Fursenkoina sp.	Globocassidulina crassa	Globulina gibba	Globulina inequalis	Guttulina austriaca	Guttulina cf. G. caudata	Gyroidinoides nipponica	Hanzawaia concentrica	Hopkinsina bononiensis	Islandiella sp.	Lagena intermedia	Lagena laevis
1 / 3.75	2	1	14	--	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	1	--	38	--	--	--	--
1 / 4.75	1	--	7	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	39	--	--	--	--
1 / 5.75	--	--	1	--	--	--	--	8	--	--	--	--	--	*	1	*	--	--	--	--	--	*	35	--	--	--	--
1 / 6.75	3	--	1	--	--	--	--	9	--	--	--	--	--	--	*	--	*	--	--	--	--	--	27	*	--	--	--
1 / 7.75	--	--	1	--	--	--	--	1	--	--	--	--	1	1	1	--	--	--	--	--	--	--	61	--	--	--	--
1 / 8.75	--	--	*	--	--	--	--	--	--	--	--	1	1	2	--	--	*	--	--	--	*	--	32	--	*	--	--
2 / 3.25	2	--	1	--	--	--	1	8	*	--	*	--	--	*	--	--	*	--	--	--	*	--	46	--	--	--	--
6 / 6.50	1	24	--	--	--	--	--	3	--	--	--	--	1	3	1	*	--	--	--	--	--	--	4	*	--	--	--
6 / 7.00	2	10	--	--	--	--	--	6	--	--	*	--	*	*	3	*	--	--	--	--	--	--	3	--	--	--	--
9 / 1.75	*	--	--	--	--	*	--	--	--	--	--	--	2	17	--	--	1	--	--	--	--	--	18	--	--	*	--
9 / 2.75	--	--	*	--	--	--	--	--	--	--	--	--	2	10	--	--	1	--	--	--	--	--	15	--	--	*	--
14 / 1.00	1	--	*	*	--	1	--	1	--	*	--	--	1	9	--	*	2	--	--	--	--	--	22	--	--	--	--
14 / 4.00	1	--	2	1	--	--	--	3	--	--	--	--	2	10	--	*	2	--	--	--	--	--	16	--	*	--	--
17 / 3.00	--	--	--	--	--	--	--	--	--	--	--	--	3	17	--	--	--	--	--	--	--	--	16	--	--	--	--
17 / 5.75	--	--	--	--	--	--	--	--	--	--	*	--	2	12	--	--	1	--	--	--	--	--	23	--	--	--	--
22 / 3.25	1	--	*	*	--	--	--	1	--	--	--	--	1	3	--	*	3	--	--	--	--	--	15	--	--	*	--
22 / 5.25	1	--	1	*	--	--	--	--	1	*	1	--	1	7	--	*	1	--	--	*	--	--	19	*	--	--	--
24 / 0.30	3	1	*	*	--	--	--	--	--	1	--	--	1	7	--	--	1	--	--	--	--	--	18	--	--	--	--
24 / 1.00	5	*	1	--	--	*	--	*	--	1	--	--	2	10	1	1	2	--	*	--	--	--	19	--	--	--	*
26 / 1.25	1	1	--	--	--	*	--	1	*	--	1	--	1	4	*	--	3	--	--	*	*	*	22	--	--	--	--
26 / 2.75	2	1	1	*	--	1	--	*	--	*	--	--	3	5	--	--	1	--	--	--	--	--	17	*	--	--	--
27 / 2.75	--	--	*	*	--	--	--	--	--	--	*	--	3	15	--	--	1	--	--	--	--	--	10	--	--	--	--
27 / 5.25	--	--	*	*	--	--	--	--	--	--	*	--	*	9	--	--	1	--	--	--	--	--	12	--	--	--	--
27 / 7.25	--	*	1	*	*	--	--	--	--	--	*	--	3	6	--	*	1	--	--	*	--	*	15	--	--	*	--
33 / 6.50	3	--	14	--	--	--	--	2	--	--	*	--	--	1	1	--	1	--	1	--	--	--	2	--	--	--	--
33 / 8.25	1	--	16	*	--	--	--	2	--	--	--	--	--	*	*	--	1	--	--	--	--	--	1	--	--	--	*
34 / 3.75	1	--	8	--	--	--	--	3	--	--	--	--	--	--	2	--	--	--	--	--	--	--	1	--	--	--	--
34 / 5.75	1	--	7	*	--	--	*	1	--	--	--	--	--	--	2	--	--	--	--	--	--	1	--	--	--	--	--
34 / 6.75	3	--	10	--	--	--	--	1	--	--	--	--	--	*	2	--	--	--	--	--	--	--	2	--	--	--	--
35 / 1.75	1	--	28	--	--	--	--	*	--	--	--	--	--	*	--	--	--	--	--	--	--	--	4	--	--	--	--
35 / 5.75	2	--	30	--	--	--	--	1	--	--	--	--	--	*	--	--	1	--	--	--	--	--	4	--	--	--	--
35 / 7.20	3	--	24	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	4	--	--	--	--
38 / 0.25	5	3	2	--	--	--	--	2	--	--	--	*	1	1	1	--	8	--	--	--	--	--	25	--	--	--	--
38 / 1.50	6	5	*	--	--	*	--	3	--	--	--	--	*	3	--	--	5	--	--	--	*	--	28	--	--	--	--
38 / 2.25	7	3	2	--	--	--	--	2	--	--	--	--	--	3	*	--	8	--	--	--	1	--	26	--	--	--	--
39 / 4.25	--	--	--	--	--	--	--	5	--	--	--	--	*	2	--	--	--	--	--	--	--	--	30	--	--	--	--
39 / 8.75	6	2	3	--	--	--	--	8	--	--	--	--	*	1	1	--	15	--	--	--	--	--	13	--	--	--	--
43 / 1.00	2	--	--	--	--	--	*	--	--	--	--	--	2	25	*	--	--	--	--	--	--	--	*	--	--	--	--
45 / 0.75	23	--	12	--	--	--	1	--	--	--	--	--	--	4	--	--	--	--	*	--	--	--	1	--	--	--	--
45 / 3.00	9	3	3	--	--	--	--	--	--	--	--	--	--	4	--	--	*	--	*	--	1	--	5	--	--	--	--
45 / 4.75	14	1	4	--	--	--	*	--	--	--	--	--	*	2	--	--	*	--	--	--	*	--	3	--	--	--	--
48 / 2.25	19	--	10	--	--	--	4	*	--	--	--	--	*	1	--	*	--	--	--	--	--	--	17	--	--	--	--
48 / 4.75	14	2	7	--	--	--	--	*	--	--	--	--	2	3	--	--	--	--	*	--	--	--	22	--	--	--	--
50 / 3.25	8	1	--	--	--	--	*	--	--	*	--	--	2	1	--	--	--	--	--	--	--	--	5	--	--	--	--
52 / 3.75	14	79	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	*	--	--
53 / 1.25	1	*	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	*
53 / 2.75	*	1	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	*	--	--	--	*	--	--	--	--
53 / 3.30	*	--	1	--	--	--	--	--	--	--	--	--	--	11	1	--	--	--	--	--	--	--	--	--	--	--	--
53 / 4.75	--	1	*	--	--	--	--	--	--	--	--	--	--	3	--	*	--	--	--	--	--	--	--	--	--	--	--
53 / 5.25	--	--	--	--	--	--	--	--	--	--	--	--	*	5	--	--	--	--	--	--	--	--	--	--	--	--	--
53 / 6.25	1	--	--	--	--	--	--	--	--	--	--	--	--	7	--	1	--	--	--	--	--	--	--	--	--	--	--
59 / 4.75	18	69	4	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	*	--	--	--	*	--	--	--	--
59 / 5.89	21	15	1	--	--	--	*	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	1	--	--	--	--
59 / 6.75	2	2	--	--	--	--	--	--	--	--	--	--	2	2	--	--	*	--	--	--	--	--	1	--	--	--	--
59 / 7.80	5	11	2	--	--	--	--	--	--	--	--	--	3	3	--	--	1	--	*	--	--	--	19	--	--	--	--
63 / 1.25	--	--	1	*	--	--	--	*	--	--	--	--	2	5	--	--	1	--	--	--	--	--	15	--	--	*	--
63 / 2.25	--	--	*	*	*	--	--	1	--	--	*	--	2	6	--	*	--	--	--	--	--	--	21	--	--	*	--
64 / 4.00	1	*	*	1	--	*	--	--	*	--	*	--	1	4	--	*	3	--	--	--	--	*	20	*	--	--	--
64 / 4.50	1	1	2	*	--	--	--	1	--	--	--	--	--	4	*	--	1	--	*	*	--	--	16	--	--	--	--
64 / 6.00	1	1	1	*	*	*	--	*	--	1	*	--	2	9	--	1	3	*	--	*	--	--	15	*	*	*	--
67 / 3.25	4	8	3	--	--	--	--	--	--	--	--	--	*	9	--	--	--	--	--	--	--	--	38	--	--	--	--
67 / 4.75	1	5	3	*	1	--	--	--	--	--	--	--	2	12	--	--	--	--	--	--	--	1	41	--	--	*	--
67 / 7.25	*	1	4	*	--	--	--	--	--	--	*	--	*	2	*	--	1	--	--	--	*	--	13	--	--	*	--

Values rounded to nearest whole percent

* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core / Interval	Cibicides americanus	Cibicides floridanus	Cibicides lobatulus	Coryphostoma georgiana	Dentalina communis	Ehrenbergina caribbea	Elphidium sp.	Epistominella danvillensis	Eponides sp.	Estorffina mayi	Fissurina lucida	Florilius chesapeakensis	Florilus grateloupi	Florilus pizarrensis	Fursenkoina fusiformis	Fursenkoina sp.	Globocassidulina crassa	Globulina gibba	Globulina inequalis	Guttulina austriaca	Guttulina cf. G. caudata	Gyroidinoides nipponica	Hanzawaia concentrica	Hopkinsina bononiensis	Islandiella sp.	Lagena intermedia	Lagena laevis
71 / 0.50	*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	—	—	—
71 / 1.00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11	—	—	—	—
72 / 1.00	1	—	*	—	—	—	—	1	—	—	—	—	—	—	1	—	2	—	—	—	—	—	2	—	—	—	—
72 / 4.00	—	—	—	—	—	—	—	*	—	—	—	—	—	*	—	—	—	—	—	—	—	—	9	—	—	—	—
72 / 4.50	1	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	—	—	—	—
91 / 3.50	—	—	6	—	—	—	—	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	23	—	—	—	—
91 / 6.00	1	—	3	—	—	—	—	9	—	—	—	—	—	—	—	—	—	—	1	—	—	—	11	—	—	—	—
94 / 1.00	2	*	—	—	—	—	—	—	—	—	—	—	—	3	—	*	—	—	—	—	—	—	—	—	—	—	—
96 / 2.25	—	1	2	—	—	*	—	—	—	—	—	—	2	15	—	—	1	—	—	—	—	—	51	—	—	*	—
96 / 5.25	*	2	1	—	*	—	—	—	—	—	—	—	3	14	*	—	*	—	—	—	—	—	20	—	—	—	—
98 / 1.25	—	—	—	—	—	—	—	*	—	—	—	—	1	6	3	—	1	—	—	—	—	—	12	—	—	—	—
98 / 3.25	—	—	*	—	—	—	—	*	—	—	—	—	2	5	*	—	1	—	—	—	—	—	12	—	—	*	—
103 / 5.00	2	—	—	—	—	—	*	*	—	—	—	—	1	6	—	—	—	—	—	—	—	—	8	—	—	—	—
103 / 5.90	1	—	—	—	—	—	—	1	—	—	—	—	1	7	—	—	—	—	—	—	—	—	5	—	—	—	—
105 / 1.25	1	—	1	—	—	—	—	*	—	*	—	—	*	5	—	—	1	*	—	—	—	—	16	—	*	—	—
105 / 1.50	3	—	—	—	—	—	—	6	—	—	—	—	1	4	—	—	2	1	1	—	—	—	3	—	1	—	—
105 / 4.50	1	—	—	—	—	—	—	9	—	—	—	—	1	7	1	—	4	—	—	—	—	—	3	—	*	—	—
105 / 7.25	*	1	2	—	—	*	—	1	—	*	—	—	2	6	1	*	1	—	—	—	—	*	23	—	—	—	—
105 / 7.50	2	—	—	—	—	—	1	7	—	—	—	—	1	10	*	—	3	*	1	—	—	—	2	—	—	—	—
105 / 8.90	2	—	1	—	—	—	—	47	—	—	—	—	*	3	—	*	—	—	—	—	—	—	4	—	—	—	—
105 / 9.10	4	—	*	—	—	—	4	32	—	—	—	—	—	2	—	—	—	—	—	—	—	—	2	—	—	—	—
108 / 2.50	1	—	1	—	—	—	—	8	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—
108 / 6.00	8	5	1	—	—	1	—	1	—	—	—	—	1	2	—	—	1	—	—	—	—	—	22	—	—	—	—
109 / 2.50	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—
109 / 4.00	1	—	2	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	10	—	—	—	—
109 / 5.50	1	—	1	—	—	—	—	—	—	—	—	—	*	1	—	—	—	—	—	—	—	—	1	—	—	—	—
109 / 6.00	1	—	1	—	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	—	—	—
110 / 6.00	1	1	1	—	—	—	—	—	1	—	—	—	1	9	1	—	1	—	—	—	—	—	40	—	—	—	—
111 / 4.50	6	—	14	—	—	—	—	2	—	—	—	—	—	—	—	—	*	—	2	—	—	—	2	—	*	—	—
111 / 5.00	2	—	16	—	—	—	—	1	—	—	—	—	—	—	—	—	*	—	1	—	*	—	4	—	—	*	—
111 / 6.30	3	—	20	—	—	—	*	—	—	—	—	—	—	*	—	—	*	*	1	—	—	—	5	—	—	—	—
114 / 6.35	1	—	1	—	—	—	—	*	—	—	—	—	—	11	*	—	*	—	—	—	—	—	41	—	—	—	—
116 / 3.00	*	*	*	*	*	—	—	*	—	—	1	—	*	6	1	—	3	—	—	—	*	—	9	—	*	—	*
118 / 3.00	*	3	3	—	*	*	—	1	—	—	*	—	2	3	*	—	2	—	*	—	—	—	29	—	—	*	—
118 / 4.25	1	7	4	*	—	*	—	—	—	—	—	—	1	2	1	—	1	—	*	*	—	—	23	—	—	—	—
118 / 5.90	1	9	3	*	*	1	*	*	—	—	—	—	2	4	—	—	1	*	*	—	—	—	30	—	—	—	—
118 / 8.90	3	9	3	*	—	*	—	*	—	—	—	—	1	2	—	—	1	—	—	*	—	—	23	—	—	—	—
119 / 3.35	1	*	—	*	—	—	—	*	—	—	—	—	—	5	—	—	2	—	—	—	*	—	16	—	—	—	—
120 / 4.25	*	—	*	*	—	—	—	1	—	*	*	—	—	6	—	*	1	—	—	—	—	—	10	—	—	—	—
120 / 5.90	4	1	*	*	—	—	—	*	—	—	*	—	—	18	1	—	1	—	—	—	—	—	17	—	—	—	*
127 / 4.50	1	—	—	—	—	—	—	1	—	—	—	—	2	13	—	—	—	—	*	—	—	—	5	—	—	—	—
127 / 5.50	1	—	—	—	—	—	*	2	—	—	—	—	1	16	2	—	3	1	1	—	—	—	3	—	—	—	—
127 / 7.00	3	—	—	—	—	—	*	10	—	—	*	—	2	14	1	—	3	—	1	—	—	—	4	—	—	—	—
127 / 8.00	—	—	1	—	—	—	1	41	—	—	—	—	1	4	1	—	—	—	2	—	—	—	5	—	—	—	—
129 / 2.50	2	—	*	—	—	—	—	2	—	—	—	—	1	10	—	—	1	—	—	—	—	—	9	—	—	—	—
129 / 4.00	3	—	1	—	—	—	—	*	—	—	—	—	1	5	—	—	3	—	—	—	—	—	14	—	—	—	—
129 / 5.50	6	—	3	—	—	—	—	2	—	—	—	—	1	6	—	—	*	—	*	—	—	—	15	—	—	—	—
132 / 1.50	4	—	2	—	—	—	*	*	—	*	—	—	5	11	1	1	*	—	3	—	—	—	5	—	—	—	—
132 / 2.00	5	—	1	—	—	—	*	1	—	*	—	—	4	14	—	1	—	—	4	—	—	—	4	—	—	—	—
132 / 2.50	7	1	1	—	—	—	1	2	—	—	—	—	4	19	*	1	—	—	1	—	—	—	5	—	—	—	—
132 / 3.50	7	*	4	—	—	—	*	1	—	—	—	—	4	11	1	1	—	—	2	—	—	—	5	—	—	—	—
132 / 4.10	6	—	2	—	—	—	—	3	—	—	—	—	5	7	5	4	—	—	1	—	—	—	3	—	—	—	—

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core/ Interval	Lagena cf. L. palmerae	Lagena pseudosulcata	Lagena substriata	Lenticulina americana americana	Lenticulina americana spinosa	Loxostomum gunteri	Melonis sp.	Nodosaria longiscata	N. cf. N. raphanistrum caribbeana	Nodosaria sp.	Nonion marylandicum	Nonionella miocenica	Oolina hexagona	Oridorsalis umbonatus	Paradentalina sp.	Planularia cf. P. clara	Plectofrondicularia cf. P. alazanensis	Plectofrondicularia floridana	Plectofrondicularia morreyae	Pseudopolymorphina rutila	Pullenia salisburyi	Reussella miocenica	Rosalina cavernata	Rosalina floridana	Rotorbinella bassleri	Saracenaria cf. S. italica	Saracenaria latifrons
1 / 3.75	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
1 / 4.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1 / 5.75	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--
1 / 6.75	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--
1 / 7.75	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1 / 8.75	--	--	--	*	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--
2 / 3.25	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	*	--	--
6 / 6.50	*	--	--	3	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--
6 / 7.00	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--
9 / 1.75	--	--	--	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9 / 2.75	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--
14 / 1.00	--	--	--	3	*	--	--	*	--	--	--	*	--	4	--	*	*	*	--	--	--	--	*	--	--	--	--
14 / 4.00	*	--	--	2	*	--	--	1	--	--	--	--	--	--	--	*	*	--	--	--	--	--	--	--	--	--	--
17 / 3.00	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17 / 5.75	--	--	--	12	--	--	--	--	--	--	--	--	--	--	*	--	*	--	--	--	--	--	1	--	--	--	--
22 / 3.25	*	--	*	3	*	--	--	*	*	--	--	--	--	1	--	*	--	--	--	--	*	--	--	--	--	--	--
22 / 5.25	*	1	*	7	*	--	*	1	*	--	--	--	*	5	--	*	--	--	--	--	--	--	--	--	--	--	--
24 / 0.30	--	--	*	8	--	--	--	*	--	*	--	1	--	--	--	*	--	--	--	--	--	--	1	--	--	--	--
24 / 1.00	--	--	--	6	*	--	--	*	--	--	--	3	*	--	--	--	--	--	--	--	--	--	--	--	*	--	--
26 / 1.25	*	--	--	3	*	--	--	*	--	--	--	--	--	3	*	*	--	--	--	--	*	--	1	--	--	--	--
26 / 2.75	*	--	--	6	*	--	1	--	*	--	--	--	--	4	*	*	--	1	*	--	*	--	*	--	1	--	*
27 / 2.75	--	--	--	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27 / 5.25	--	--	--	6	--	--	--	--	--	--	--	--	--	--	*	*	--	--	--	--	--	--	--	--	--	--	--
27 / 7.25	--	--	--	3	--	--	--	*	--	--	--	--	--	*	--	*	--	*	--	--	--	--	*	--	--	--	--
33 / 6.50	--	--	--	1	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	7	3	2	--	--
33 / 8.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11	5	2	--	--
34 / 3.75	--	--	--	--	--	--	--	--	--	--	1	*	--	--	--	--	--	--	--	--	--	--	2	*	--	--	--
34 / 5.75	--	--	--	--	--	--	--	--	--	--	1	*	--	--	--	--	--	--	--	--	--	--	4	1	1	--	--
34 / 6.75	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	2	1	1	--	--
35 / 1.75	--	--	--	*	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	7	2	*	--	--
35 / 5.75	--	--	--	*	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	11	5	1	--	--
35 / 7.20	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	14	9	1	--	--
38 / 0.25	--	--	*	4	--	--	--	--	--	--	--	*	--	1	--	--	--	--	--	--	--	*	1	*	*	--	--
38 / 1.50	--	--	--	5	--	--	--	*	--	--	--	1	--	*	--	--	--	--	--	--	--	--	2	*	1	--	--
38 / 2.25	--	--	--	4	--	--	--	1	--	--	1	--	--	--	--	--	--	--	--	--	--	--	1	--	3	--	--
39 / 4.25	--	--	--	--	--	--	--	*	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--
39 / 8.75	--	--	--	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2	--	--
43 / 1.00	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
45 / 0.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	15	2	--	--
45 / 3.00	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--
45 / 4.75	--	--	--	2	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	3	*	1	--	--
48 / 2.25	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	1	1	--	--
48 / 4.75	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	3	--	--
50 / 3.25	--	--	--	20	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	*	1	--	--	--
52 / 3.75	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--
53 / 1.25	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
53 / 2.75	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
53 / 3.30	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--
53 / 4.75	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--
53 / 5.25	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
53 / 6.25	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59 / 4.75	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--
59 / 5.89	--	--	--	*	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	1	*	2	--	--
59 / 6.75	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--
59 / 7.80	--	--	--	22	--	--	--	--	--	*	--	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
63 / 1.25	--	--	--	3	*	--	--	*	--	--	--	--	--	--	*	*	--	--	--	--	--	--	*	--	--	--	--
63 / 2.25	--	--	--	4	--	--	--	*	--	--	--	*	--	--	--	*	*	*	--	--	--	--	--	--	--	--	--
64 / 4.00	*	*	--	6	*	--	*	1	*	--	--	--	--	5	*	--	--	*	--	--	--	--	1	--	*	--	--
64 / 4.50	*	--	--	4	*	*	--	1	--	*	--	*	--	1	*	*	--	--	--	--	--	--	1	--	--	--	--
64 / 6.00	*	*	*	4	*	--	--	*	--	*	--	1	--	2	*	*	--	--	*	--	*	--	--	--	*	*	*
67 / 3.25	--	--	*	6	--	--	--	--	*	--	--	--	--	3	--	--	--	--	--	--	--	--	1	--	1	--	*
67 / 4.75	--	--	--	5	*	--	--	--	--	*	--	--	--	3	--	--	--	*	--	--	*	--	1	--	--	--	--
67 / 7.25	--	--	--	*	--	--	--	--	--	*	--	*	--	*	--	--	--	--	--	--	--	--	2	--	--	--	--

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core / Interval	Lagena cf. L. palmerae	Lagena pseudosulcata	Lagena substriata	Lenticulina americana americana	Lenticulina americana spinosa	Loxostomum gunteri	Melonis sp.	Nodosaria longiscata	N. cf. N. raphanistrum caribbeana	Nodosaria sp.	Nonion marylandicum	Nonionella miocenica	Oolina hexagona	Oridorsalis umbonatus	Paradentalina sp.	Planularia cf. P. clara	Plectofrondicularia cf. P. alazanensis	Plectofrondicularia floridana	Plectofrondicularia morreyae	Pseudopolymorphina rutila	Pullenia salisburyi	Reussella miocenica	Rosalina cavernata	Rosalina floridana	Rotorbinella bassleri	Saracenaria cf. S. italica	Saracenaria latifrons
71 / 0.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
71 / 1.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
72 / 1.00	*	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--
72 / 4.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	*	*	--	--
72 / 4.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
91 / 3.50	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
91 / 6.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--
94 / 1.00	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
96 / 2.25	--	--	--	8	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	*	--	1	--	--	--	--
96 / 5.25	--	--	--	2	--	--	*	--	--	--	--	--	--	--	--	--	*	*	--	--	--	--	3	--	--	--	--
98 / 1.25	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
98 / 3.25	--	--	--	3	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
103 / 5.00	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
103 / 5.90	--	--	*	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--
105 / 1.25	--	--	*	2	1	--	--	*	--	--	--	--	--	*	--	*	--	--	*	--	--	--	*	--	--	--	--
105 / 1.50	--	*	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--
105 / 4.50	--	--	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	2	--	--	--	--
105 / 7.25	*	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--
105 / 7.50	--	--	*	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	1	--	*	--	--
105 / 8.90	--	--	*	1	--	1	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	*	--	2	--	*
105 / 9.10	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	3	*	--	--	--
108 / 2.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
108 / 6.00	--	--	--	--	--	--	--	--	--	--	--	5	--	1	--	--	--	--	--	--	--	--	1	1	1	--	--
109 / 2.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
109 / 4.00	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--
109 / 5.50	--	--	--	*	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
109 / 6.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
110 / 6.00	--	--	--	2	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	1	2	2	--	--
111 / 4.50	--	--	--	*	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	9	3	*	--	--
111 / 5.00	--	--	--	--	--	--	--	--	--	--	1	*	--	--	--	--	--	--	--	--	--	--	9	1	2	--	--
111 / 6.30	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	8	4	1	--	--
114 / 6.35	--	--	--	*	--	--	*	*	--	--	--	--	--	1	--	--	*	1	--	--	--	--	--	--	--	--	--
116 / 3.00	--	--	--	3	--	--	--	1	--	--	--	--	--	--	--	*	*	*	--	--	--	--	1	--	--	--	--
118 / 3.00	--	1	--	4	--	--	--	--	--	--	--	--	--	1	--	--	*	--	--	--	*	--	1	--	3	--	--
118 / 4.25	--	--	--	4	--	--	--	*	--	--	--	--	*	1	--	*	*	*	--	--	--	--	1	--	1	*	--
118 / 5.90	*	*	*	8	--	--	--	*	--	*	--	--	--	3	--	*	--	*	--	--	--	--	*	--	--	*	*
118 / 8.90	--	--	--	9	--	--	--	--	*	--	--	--	--	3	--	*	--	--	--	--	--	--	*	--	--	--	--
119 / 3.35	--	1	*	3	*	--	--	*	--	--	--	--	--	1	--	*	*	*	--	--	--	--	*	--	--	--	--
120 / 4.25	*	--	--	4	--	--	--	*	--	--	--	--	--	5	--	--	--	*	--	--	--	--	--	--	--	--	--
120 / 5.90	--	--	*	2	--	--	--	--	--	--	--	--	--	--	--	*	--	--	*	--	--	--	--	--	--	--	*
127 / 4.50	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	1	--	*	--	--
127 / 5.50	--	--	*	1	--	--	*	--	--	--	--	--	--	--	--	*	--	--	--	*	--	--	--	--	*	--	--
127 / 7.00	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	1	*	--	--	--
127 / 8.00	--	--	--	*	--	--	*	--	--	--	--	3	--	--	--	*	--	--	--	--	--	--	2	--	--	--	--
129 / 2.50	--	--	--	3	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	*	--	1	--	--
129 / 4.00	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	*	--	--	--	--	1	--	--
129 / 5.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
132 / 1.50	--	--	--	*	--	--	--	--	--	--	--	5	--	--	--	--	--	--	--	--	--	--	2	--	10	--	--
132 / 2.00	*	--	--	1	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	4	--	8	--	--
132 / 2.50	1	--	--	1	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	2	--	10	--	--
132 / 3.50	--	--	--	1	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	1	*	5	--	--
132 / 4.10	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core/ Interval	Saracenaria senni	Sigmoidella kagaensis	Siphogenerina lamellata	Siphogenerina transversa	Siphonodosaria sp.	Sphaeroidina bulloides	Spiroplectammina exilis	Spiroplectammina mississippiensis	Stilostomella recta	Textularia agglutinans	Textularia articulata	Textularia candeiana	Trifarina illingi	Trifarina occidentalis	Uvigerina auberiana	Uvigerina calvertensis	Uvigerina subperegrina	Vaginulina sp.	Vaginulinopsis sp.	Valvulineria floridana	Valvulineria laevigata	Valvulineria venezuelana	Virgulinella miocenica	Indeterminate	TOTAL
1 / 3.75	--	--	--	--	--	--	--	1	--	--	5	1	--	--	--	--	1	--	--	2	--	--	--	--	102
1 / 4.75	--	--	--	--	--	--	--	1	--	--	*	--	--	1	--	--	--	--	--	5	1	--	--	--	100
1 / 5.75	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--	--	3	--	--	--	1	100
1 / 6.75	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1	1	--	--	1	1	*	--	--	100
1 / 7.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	--	--	98
1 / 8.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	3	1	--	--	--	97
2 / 3.25	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	1	--	--	--	--	95
6 / 6.50	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	22	1	--	--	--	100
6 / 7.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	18	--	--	--	--	100
9 / 1.75	--	--	12	1	*	--	--	--	--	--	--	--	--	--	1	--	--	--	1	1	--	--	--	--	103
9 / 2.75	--	--	4	*	--	--	--	--	--	--	--	--	--	--	1	1	--	--	*	1	--	--	--	--	100
14 / 1.00	*	--	2	2	*	--	--	--	--	--	--	--	--	--	6	*	--	--	*	*	--	*	--	--	99
14 / 4.00	--	--	*	2	--	--	--	--	--	--	--	--	--	--	4	*	*	--	--	1	--	--	--	--	100
17 / 3.00	--	--	5	--	--	--	--	--	--	--	--	--	--	--	*	--	*	--	--	3	--	--	--	--	102
17 / 5.75	--	--	3	--	*	--	--	--	--	--	--	--	--	--	1	--	1	--	--	1	--	--	--	--	102
22 / 3.25	--	--	1	3	*	--	--	--	2	--	--	--	--	*	7	--	1	--	*	2	--	--	*	--	98
22 / 5.25	--	--	3	8	--	--	--	*	1	--	--	--	--	--	6	*	*	--	*	1	--	1	--	--	100
24 / 0.30	--	--	--	5	1	--	--	*	1	2	*	--	--	--	7	--	1	--	*	3	--	--	--	--	100
24 / 1.00	--	--	--	3	--	--	--	*	*	*	--	--	--	--	4	--	*	--	*	2	--	--	*	--	98
26 / 1.25	--	--	1	4	--	--	--	*	1	--	--	--	--	--	4	1	1	*	1	1	--	*	--	--	104
26 / 2.75	*	--	1	6	1	--	--	--	--	1	--	--	--	--	4	--	--	*	*	1	--	*	--	--	102
27 / 2.75	--	--	22	*	--	--	--	1	--	*	--	--	--	--	3	--	5	--	--	3	--	--	--	--	102
27 / 5.25	--	--	15	1	*	--	--	--	--	--	--	--	--	--	1	--	--	--	1	1	--	--	--	--	101
27 / 7.25	--	--	5	4	1	--	--	*	--	--	--	--	--	--	4	*	1	--	*	*	--	--	--	--	100
33 / 6.50	--	--	--	--	--	--	--	5	--	1	--	--	--	--	--	--	1	--	--	7	--	--	--	--	105
33 / 8.25	--	--	--	--	--	--	--	2	--	--	1	--	--	--	--	--	--	--	--	8	1	--	--	--	100
34 / 3.75	--	--	--	--	--	--	*	--	*	--	--	--	--	--	--	--	--	--	--	5	--	--	--	12	98
34 / 5.75	--	--	--	--	--	--	*	--	--	--	--	--	--	*	--	--	--	--	--	4	--	--	--	8	99
34 / 6.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6	1	--	--	5	102
35 / 1.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	--	--	--	10	95
35 / 5.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	--	--	--	2	95
35 / 7.20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	9	*	--	--	5	100
38 / 0.25	--	--	--	--	--	--	--	2	*	1	--	--	--	--	--	--	1	--	--	4	--	*	--	--	99
38 / 1.50	--	--	--	--	--	--	--	2	--	1	--	--	1	1	--	*	*	--	--	5	--	*	--	--	105
38 / 2.25	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	1	--	--	--	2	1	--	--	--	104
39 / 4.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	*	1	--	--	99
39 / 8.75	--	--	--	*	--	--	--	--	--	--	*	--	--	--	--	*	1	--	--	--	--	--	--	--	95
43 / 1.00	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	10	--	--	--	--	100
45 / 0.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	28	--	--	--	--	99
45 / 3.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	23	--	--	--	--	100
45 / 4.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	26	--	--	--	--	97
48 / 2.25	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	14	--	--	--	--	98
48 / 4.75	--	--	--	--	--	--	--	--	--	--	1	*	--	--	--	--	--	--	--	23	--	--	--	--	100
50 / 3.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12	--	--	--	--	99
52 / 3.75	--	--	--	--	--	--	--	--	--	--	--	*	--	1	--	--	--	--	--	--	--	--	--	--	99
53 / 1.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	101
53 / 2.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8	--	--	4	--	100
53 / 3.30	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	4	--	--	4	--	100
53 / 4.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--	1	--	99
53 / 5.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--	1	--	99
53 / 6.25	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	4	--	--	1	--	101
59 / 4.75	--	--	--	--	--	--	--	--	--	--	--	5	--	--	--	--	--	--	--	--	--	--	--	--	99
59 / 5.89	--	--	--	--	--	--	--	--	--	--	--	3	--	*	--	--	--	--	--	2	--	--	--	--	98
59 / 6.75	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	3	--	--	*	--	100
59 / 7.80	--	--	--	*	--	*	--	--	*	--	--	--	--	*	--	--	--	--	--	22	--	--	--	--	96
63 / 1.25	--	--	21	1	*	--	--	--	--	--	--	--	--	--	*	--	*	--	*	2	--	--	--	--	99
63 / 2.25	--	--	20	2	1	--	--	*	--	--	--	--	--	--	3	--	--	--	1	3	1	--	*	--	100
64 / 4.00	--	--	2	5	--	*	--	--	1	--	--	--	--	*	3	--	1	*	*	*	--	*	--	--	100
64 / 4.50	--	--	*	2	*	--	--	--	*	*	--	--	--	--	3	--	*	--	*	1	--	*	*	--	99
64 / 6.00	*	*	1	1	*	--	--	*	1	*	--	*	--	--	3	--	--	--	*	1	*	*	*	--	101
67 / 3.25	--	--	*	4	1	--	--	*	--	--	--	--	--	--	1	4	3	*	2	1	--	--	--	--	102
67 / 4.75	--	--	1	4	--	*	--	1	--	--	--	--	--	--	2	2	4	1	1	1	--	*	--	--	102
67 / 7.25	--	--	*	--	--	--	--	--	--	--	--	--	--	--	--	--	2	*	*	--	--	--	--	--	99

Values rounded to nearest whole percent
* indicates value less than 0.5%

APPENDIX IV

Abundance of Species in Each Sample

Species Name Core / Interval	Saracenaria senni	Sigmoidella kagaensis	Siphogenerina lamellata	Siphogenerina transversa	Siphonodosaria sp.	Sphaeroidina bulloides	Spiroplectammina exilis	Spiroplectammina mississippiensis	Stilostomella recta	Textularia agglutinans	Textularia articulata	Textularia candeiana	Trifarina illingi	Trifarina occidentalis	Uvigerina auberiana	Uvigerina calvertensis	Uvigerina subperegrina	Vaginulina sp.	Vaginulinopsis sp.	Valvulineria floridana	Valvulineria laevigata	Valvulineria venezuelana	Virgulinella miocenica	Indeterminate	TOTAL
71 / 0.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	17	1	--	--	--	100
71 / 1.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20	*	--	--	--	98
72 / 1.00	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	22	*	--	--	--	105
72 / 4.00	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	50	--	--	--	--	98
72 / 4.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	52	--	--	--	--	100
91 / 3.50	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	28	1	--	--	2	104
91 / 6.00	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--	1	--	--	32	1	--	--	--	105
94 / 1.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	1	--	100
96 / 2.25	--	*	--	*	--	--	--	--	1	--	--	--	--	--	4	--	--	--	2	4	--	--	--	--	103
96 / 5.25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	*	1	--	--	1	--	101
98 / 1.25	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	100
98 / 3.25	--	--	12	1	*	--	--	--	--	--	--	--	--	--	1	--	*	--	--	2	--	--	--	--	97
103 / 5.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	35	--	--	--	--	102
103 / 5.90	--	--	--	1	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	19	--	--	--	--	100
105 / 1.25	--	--	1	*	--	--	--	--	--	--	--	--	--	--	21	--	*	--	--	1	--	--	--	--	100
105 / 1.50	--	--	--	1	--	--	--	--	--	--	--	--	--	--	12	--	2	--	--	18	--	--	--	--	101
105 / 4.50	--	--	--	--	--	--	--	--	--	--	--	--	--	*	1	--	--	--	--	16	--	--	--	--	100
105 / 7.25	--	--	--	1	--	--	--	--	--	--	--	--	1	--	3	--	1	--	--	2	--	--	*	--	101
105 / 7.50	--	--	--	--	--	--	--	--	1	--	--	--	--	*	1	--	1	--	--	17	--	--	*	--	101
105 / 8.90	--	--	--	--	--	--	--	1	*	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	102
105 / 9.10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	18	--	--	--	--	99
108 / 2.50	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1	--	--	--	--	--	1	--	--	--	104
108 / 6.00	--	--	1	2	--	1	--	1	1	--	--	--	--	1	--	--	4	--	--	10	1	--	--	--	103
109 / 2.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10	--	--	--	--	101
109 / 4.00	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	25	1	--	--	--	102
109 / 5.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1	--	--	*	--	99
109 / 6.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	37	3	--	--	--	101
110 / 6.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	2	--	--	--	103
111 / 4.50	--	--	--	--	--	--	--	*	--	--	--	--	2	*	*	--	--	--	--	2	*	--	--	9	96
111 / 5.00	--	--	--	--	--	--	--	1	--	--	*	--	--	--	--	--	--	--	--	3	*	--	--	10	95
111 / 6.30	--	--	--	--	--	--	--	*	--	--	*	--	1	*	--	--	--	--	--	4	--	--	--	5	98
114 / 6.35	--	--	15	3	2	--	--	--	*	--	--	--	--	--	6	--	1	--	--	4	--	--	--	--	102
116 / 3.00	--	--	4	3	1	--	--	--	1	--	--	--	--	--	2	--	1	--	--	2	*	--	1	--	101
118 / 3.00	--	--	--	*	1	--	--	*	--	--	--	--	*	*	--	--	2	*	*	2	--	--	--	--	99
118 / 4.25	--	--	--	2	1	--	--	*	*	--	--	--	--	--	--	--	5	*	1	2	--	--	--	--	104
118 / 5.90	--	--	*	3	1	--	--	*	*	--	*	--	*	--	*	1	3	1	1	5	--	--	--	--	99
118 / 8.90	--	*	*	4	4	*	--	*	*	1	--	--	--	--	--	--	6	*	2	1	--	--	--	--	99
119 / 3.35	--	--	--	4	--	--	--	--	1	--	--	--	--	--	2	--	1	--	*	2	--	--	--	--	97
120 / 4.25	--	--	*	5	*	--	--	--	1	--	--	--	--	--	1	--	1	--	*	2	--	*	--	--	97
120 / 5.90	--	--	--	1	*	--	--	--	--	--	--	--	--	--	4	--	1	--	--	3	--	--	*	--	102
127 / 4.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	3	--	--	18	--	--	*	--	98
127 / 5.50	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	--	1	--	--	21	--	--	*	--	96
127 / 7.00	--	--	--	*	--	--	--	--	1	--	--	--	--	*	1	--	6	--	--	7	--	--	--	--	98
127 / 8.00	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	4	--	--	--	--	96
129 / 2.50	--	--	--	4	--	--	--	--	--	*	--	--	--	--	*	--	--	--	--	20	--	--	--	--	100
129 / 4.00	--	--	--	4	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	23	--	--	--	--	102
129 / 5.50	--	--	--	2	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	24	--	--	--	--	98
132 / 1.50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	97
132 / 2.00	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	2	--	--	--	--	99
132 / 2.50	--	--	--	--	--	--	--	1	--	1	--	2	--	*	--	--	*	--	--	1	--	--	--	--	98
132 / 3.50	--	--	--	--	--	--	--	*	--	*	--	--	--	--	--	--	1	--	--	5	*	--	--	--	98
132 / 4.10	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	97

Values rounded to nearest whole percent
* indicates value less than 0.5%

Totals not equal to 100% are caused largely by rounding estimates to the nearest whole percent. The cumulative effect of species indicated by an * is less important, but significant in some cases.

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PLATE 1

Each scale bar = 100 microns

1-2 *Spiroplectammina mississippiensis* Cushman. 1. Side view (Core 64, 6.2 m). 2. Edge view (Core 64, 6.2 m).
3 *Spiroplectammina exilis* Dorsey. 3. Side view (Core 34, 5.75 m).
4-5 *Textularia agglutinans* d'Orbigny. 4. Side view (Core 24, 1.0 m). 5. Edge view (Core 64, 6.2 m).
6-7 *Textularia articulata* d'Orbigny. 6. Side view (Core 118, 6.0 m). 7. Edge view (Core 26, 3.0 m).
8-9 *Textularia candeiana* d'Orbigny. 8. Side view (Core 106, 6.0 m). 9. Edge view (Core 98, 0.5 m).
10 *Bolivinopsis fairhavenensis* Gibson. 10. Side view (Core 50, 3.25 m).
11 *Nodosaria longiscata* d'Orbigny. 11. Side view (Core 64, 6.2 m).
12 *Nodosaria* cf. *N. raphanistrum caribbeana* Hedberg. 12. Side view (Core 22, 3.5 m).
13 *Nodosaria* sp. 13. Side view (Core 67, 5.0 m).
14-15 *Astacolus dubius* (Neugeboren). 14. Side view (Core 118, 3.0 m). 15. Edge view (Core 96, 2.5 m).
16-17 *Astacolus* sp. B. 16. Side view (Core 105, 1.5 m). 17. Edge view (Core 96, 2.5 m).
18-19 *Astacolus* sp. A. 18. Side view (Core 64, 6.2 m). 19. Edge view (Core 63, 2.5 m).

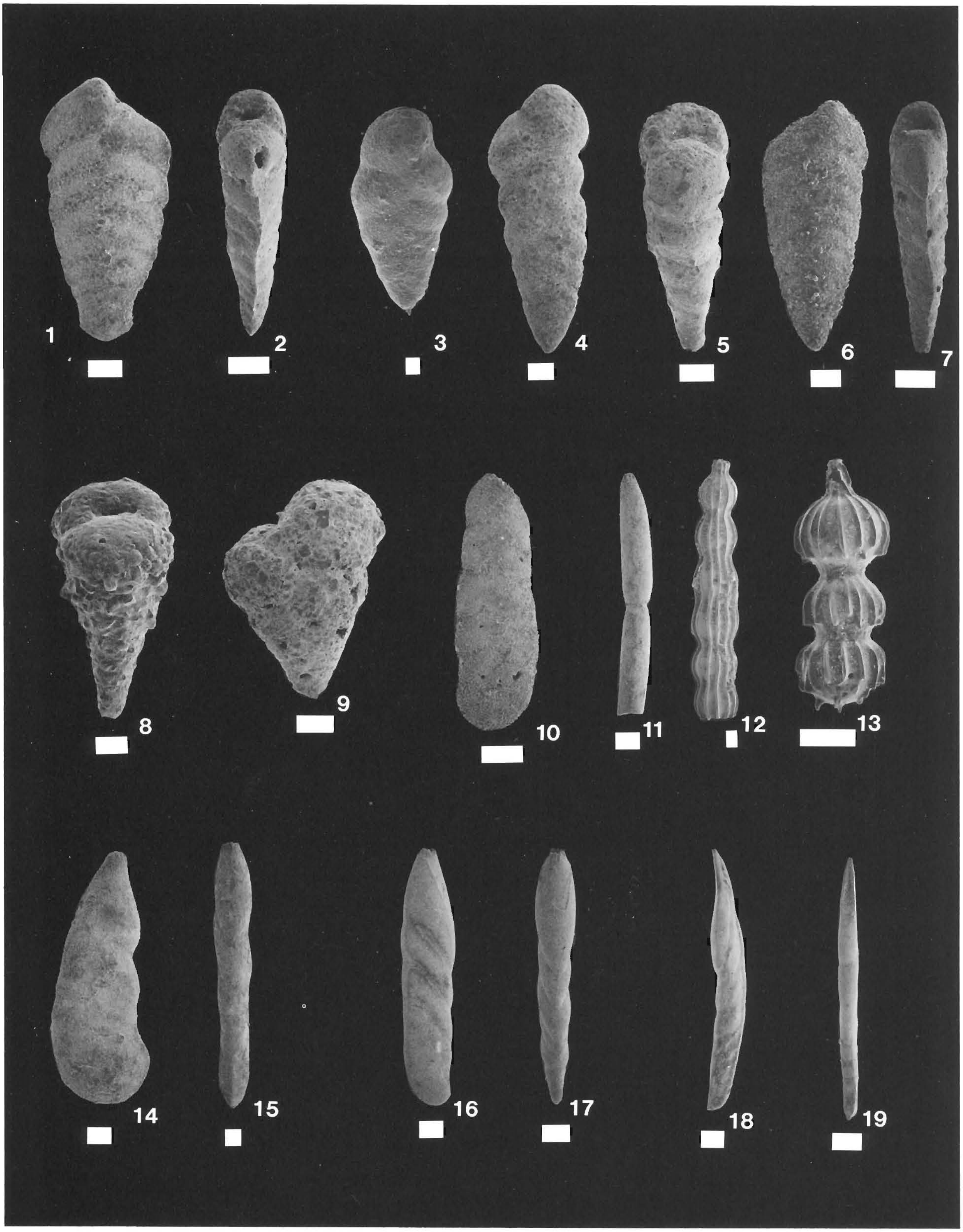
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PLATE 2

Each scale bar = 100 microns

1 *Lagena intermedia* Rzehak. 1. Side view (Core 64, 6.2 m).
2 *Lagena laevis* (Montagu). 2. Side view (Core 116, 3.0 m).
3 *Lagena* cf. *L. palmerae* McLean. 3. Side view (Core 118, 6.0 m).
4 *Lagena pseudosulcata* McLean. 4. Side view (Core 118, 6.0 m).
5 *Lagena substriata* Williamson. 5. Side view (Core 64, 6.2 m).
6-7 *Lenticulina americana americana* (Cushman). 6. Side view (Core 64, 6.2 m). 7. Edge view (Core 64, 6.2 m).
8 *Lenticulina americana spinosa* (Cushman). 8. Side view (Core 119, 2.6 m).
9 *Saracenaria* cf. *S. italica* Defrance. 9. Oblique side view (Core 64, 6.2 m).
10 *Saracenaria senni* Hedberg. 10. Oblique side view (Core 64, 6.2 m).
11 *Saracenaria latifrons* (Brady). 11. Oblique side view (Core 118, 6.0 m).
12-13 *Vaginulinopsis* sp. 12. Side view (Core 67, 3.5 m). 13. Edge view (Core 67, 3.5 m).
14-15 *Vaginulina* sp. 14. Side view (Core 64, 6.2 m). 15. Edge view (Core 64, 6.2 m).
16-18 *Planularia* cf. *P. clara* Cushman and Jarvis. 16. Apertural view (Core 26, 3.0 m). 17. Side view (Core 26, 3.0 m). 18. Edge view (Core 64, 4.5 m).

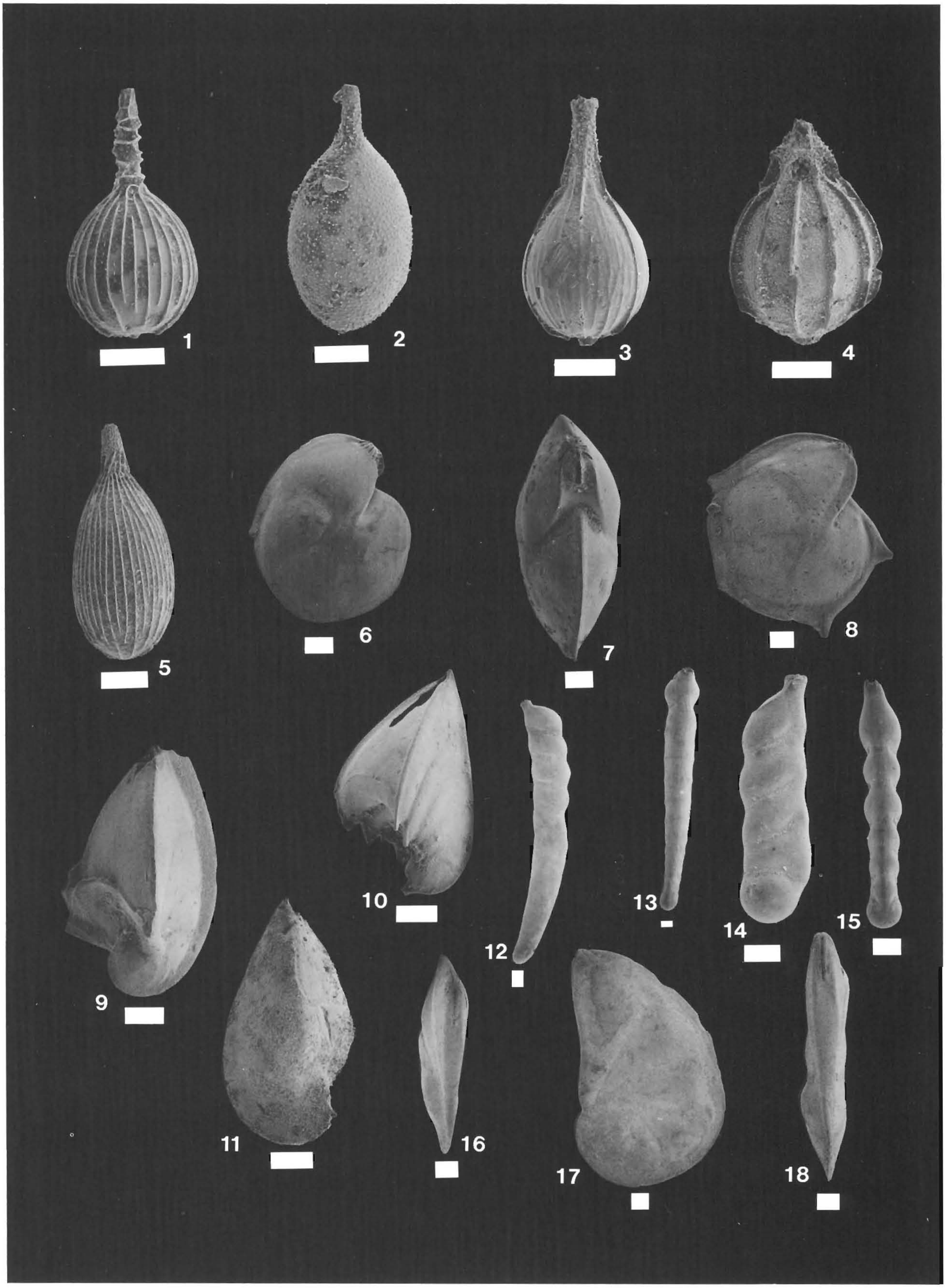
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PLATE 3

Each scale bar = 100 microns

1-2 *Plectofrondicularia* cf. *P. alazanensis* Cushman. 1. Side view (Core 63, 2.5 m). 2. Edge view (Core 63, 2.5 m).
3-4 *Plectofrondicularia floridana* Cushman. 3. Side view (Core 26, 3.0 m). 4. Edge view (Core 116, 3.0 m).
5 *Plectofrondicularia morreyae* Cushman. 5. Side view (Core 64, 6.2 m).
6 *Globulina gibba* d'Orbigny. 6. Side view (Core 118, 6.0 m).
7 *Guttulina austriaca* d'Orbigny. 7. Side view (Core 64, 4.5 m).
8 *Guttulina* cf. *G. caudata* d'Orbigny. 8. Side view (Core 26, 2.5 m).
9 *Globulina inaequalis* Reuss. 9. Side view (Core 118, 6.0 m).
10 *Paradentalina* sp. 10. Side view (Core 26, 1.5 m).
11 *Sigmoidella kagaensis* Cushman and Ozawa. 11. Side view (Core 26, 3.0 m).
12-13 *Estorffina mayi* (Cushman and Parker). 12. Side view (Core 64, 6.2 m). 13. Apertural view (Core 26, 2.0 m).
14 *Pseudopolymorphina rutila* (Cushman). 14. Side view (Core 105, 7.5 m).
15 *Oolina hexagona* (Williamson). 15. Side view (Core 64, 6.2 m).
16-17 *Sphaeroidina bulloides* d'Orbigny. 16. Apertural view (Core 118, 9.0 m). 17. Spiral view (Core 67, 5.0 m).
18 *Fissurina lucida* (Williamson). 18. Side view (Core 116, 3.0 m).

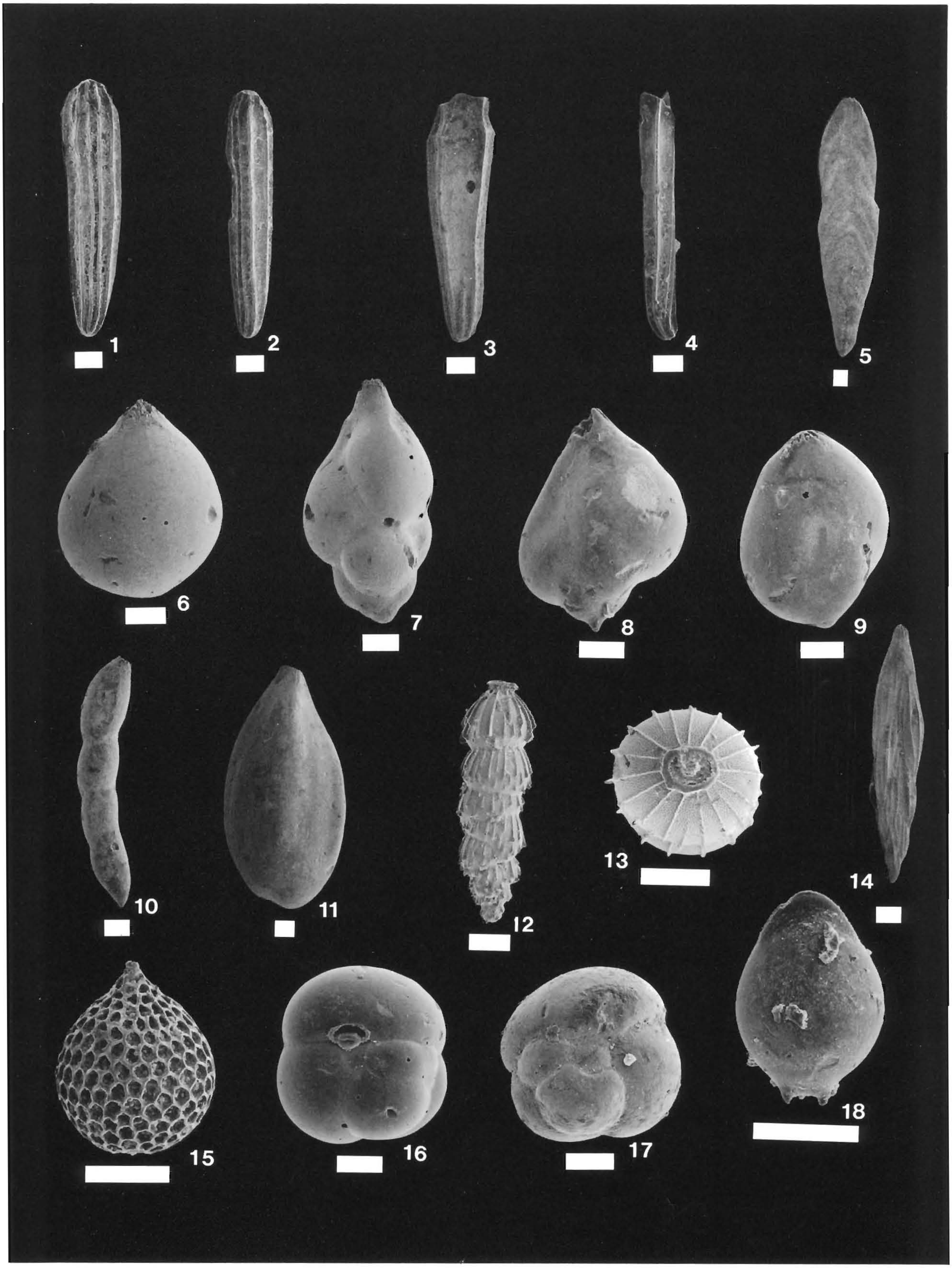
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PLATE 4

Each scale bar = 100 microns

1-2 *Islandiella* sp. 1. Side view (Core 105, 1.5 m). 2. Edge view (Core 64, 6.2 m).
3-4 *Cassidulinoides* cf. *C. bradyi* (Norman). 3. Side view (Core 64, 6.2 m). 4. Edge view (Core 64, 6.2 m).
5 *Buliminella brevior* Cushman. 5. Side view (Core 127, 7.0 m).
6 *Buliminella elegantissima* (d'Orbigny). 6. Side view (Core 45, 3.0 m).
7 *Bolivina advena* Cushman. 7. Side view (Core 39, 4.25 m).
8 *Bolivina brevior* Cushman. 8. Side view (Core 34, 6.75 m).
9 *Bolivina calvertensis* Dorsey. 9. Side view (Core 105, 4.5 m).
10 *Bolivina floridana* Cushman. 10. Side view (Core 67, 3.5 m).
11 *Bolivina lowmani* Phleger and Parker. 11. Side view (Core 105, 1.5 m).
12 *Bolivina marginata multicostata* Cushman. 12. Side view (Core 22, 3.5 m).
13 *Bolivina paula* Cushman and Cahill. 13. Side view (Core 26, 0.5 m).
14 *Bolivina robusta* Brady. 14. Side view (Core 6, 7.0 m).
15 *Bolivina subdilatata* Pishvanova. 15. Side view (Core 109, 5.5 m).
16-17 *Bulimina elongata* d'Orbigny. 16. Side view (Core 118, 6.0 m). 17. Side view, juvenile specimen (Core 98, 1.5 m).
18 *Bulimina striata mexicana* Cushman. 18. Side view (Core 105, 1.5 m).
19 *Bulimina ovula* d'Orbigny. 19. Side view (Core 6, 6.5 m).
20 *Reussella miocenica* Cushman. 20. Side view (Core 38, 0.25 m).

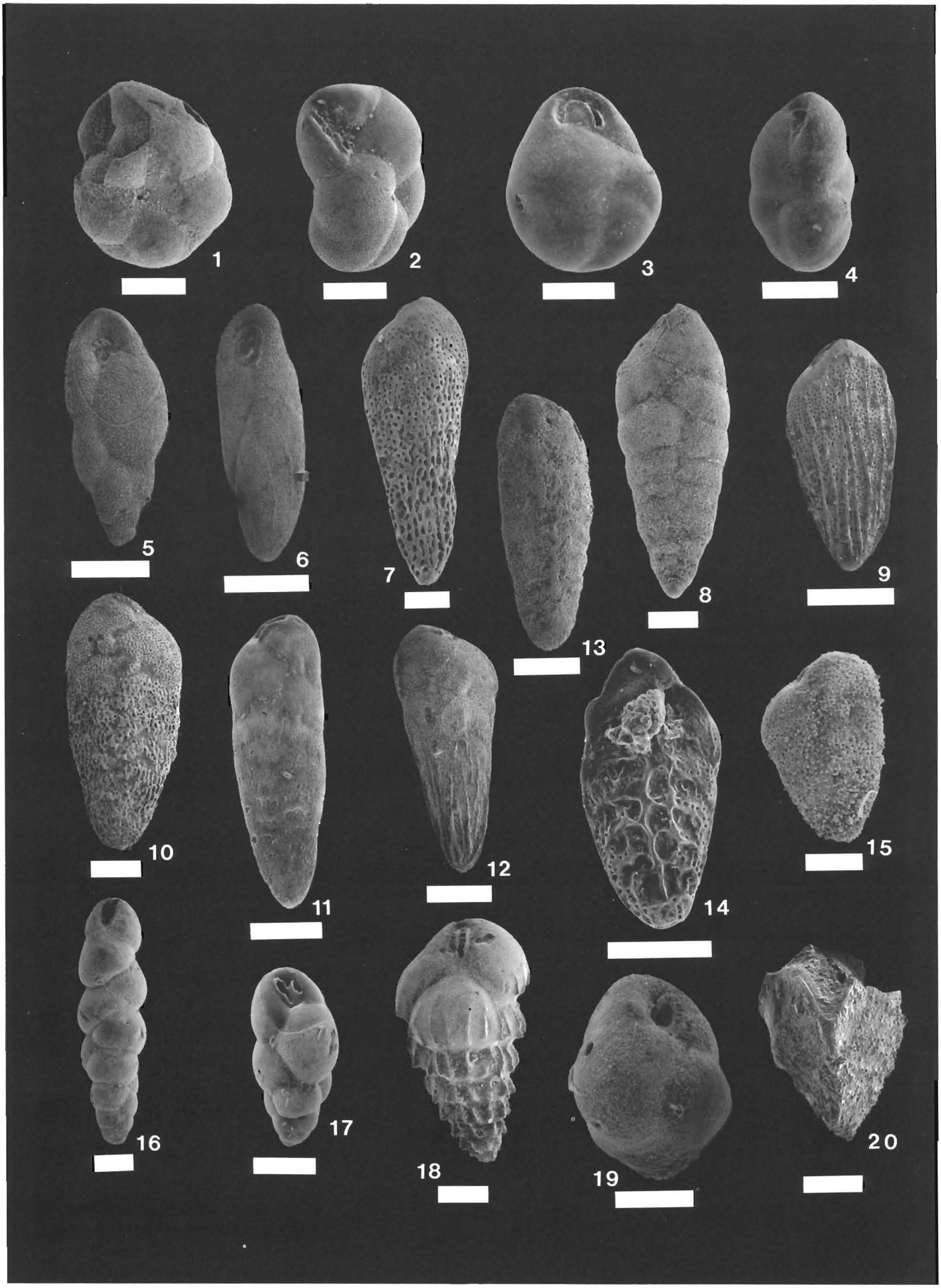
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PLATE 5

Each scale bar = 100 microns

1-2 *Siphonodosaria* sp. 1. Side view (Core 64, 6.2 m). 2. Apertural view (Core 64, 6.2 m).

3-4 *Stilostomella recta* (Palmer and Bermudez). 3. Side view (Core 119, 2.6 m). 4. Apertural view (Core 119, 2.6 m).

5 *Hopkinsina bononiensis* (Fornasini). 5. Side view (Core 26, 2.0 m).

6 *Uvigerina auberiana* d'Orbigny. 6. Side view (Core 63, 2.5 m).

7 *Uvigerina calvertensis* Cushman. 7. Side view (Core 67, 5.0 m).

8 *Uvigerina subperegrina* Cushman and Kleinpell. 8. Side view (Core 27, 7.5 m).

9-11 *Siphogenerina lamellata* Cushman. 9. Side view, megalospheric specimen (Core 27, 7.5 m). 10. Side view, microspheric specimen (Core 98, 3.5 m). 11. Apertural view (Core 98, 3.5 m).

12 *Siphogenerina* sp., probably *S. transversa* Cushman. 12. Side view, megalospheric juvenile (Core 64, 6.2 m).

13-15 *Siphogenerina transversa* Cushman. 13. Side view, megalospheric specimen (Core 26, 3.0 m). 14. Side view, microspheric specimen (Core 26, 3.0 m). 15. Apertural view (Core 64, 6.2 m).

16 *Trifarina illingi* (Cushman and Renz). 16. Side view (Core 118, 6.0 m).

17 *Trifarina occidentalis* (Cushman). 17. Side view (Core 118, 3.0 m).

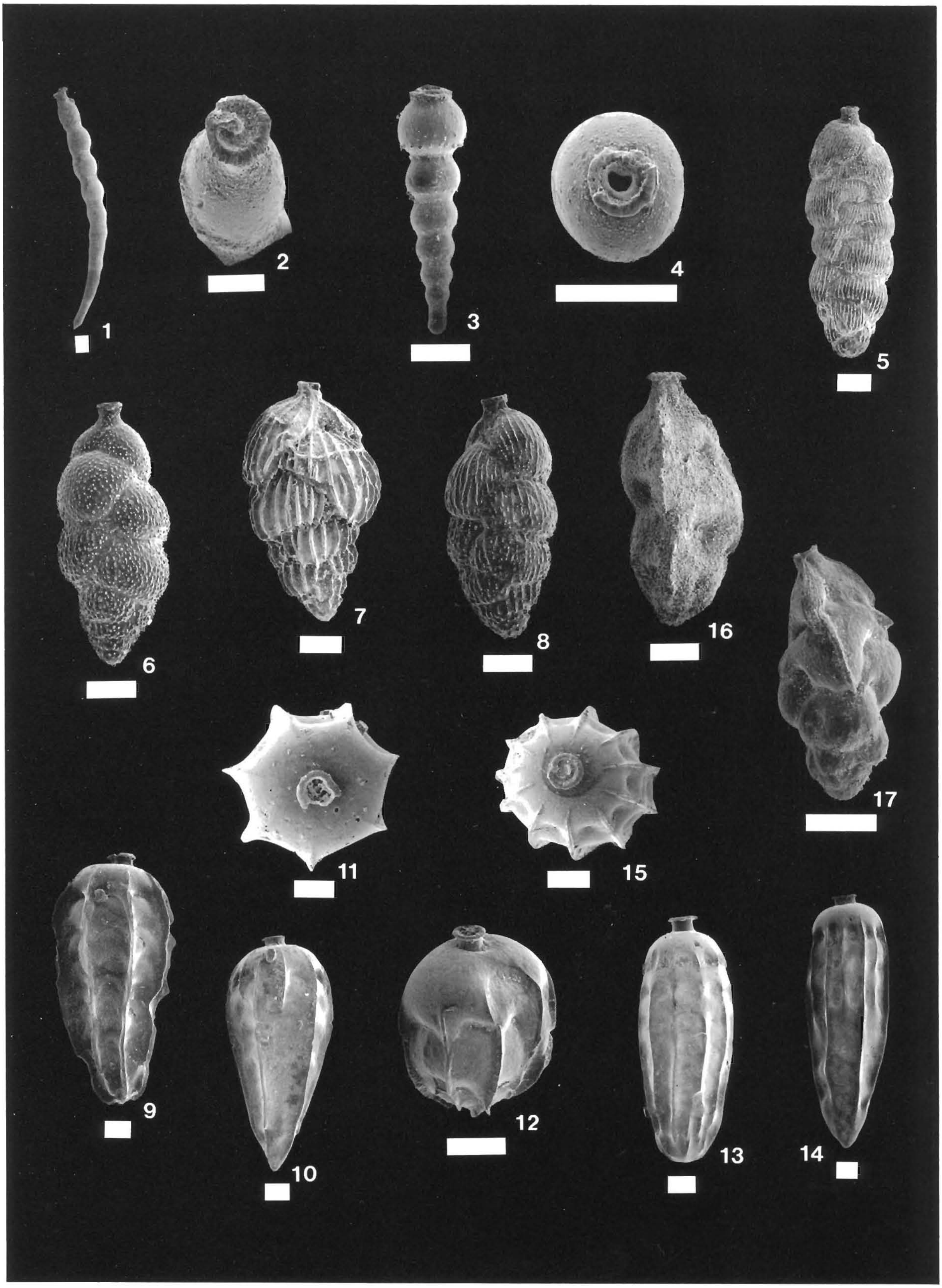
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PLATE 6

Each scale bar = 100 microns

1 *Rotorbinella bassleri* (Cushman and Cahill). 1. Umbilical view (Core 64, 4.0 m).
2 *Epistominella danvillensis* Howe and Wallace. 2. Umbilical view (Core 63, 2.5 m).
3-4 *Rosalina cavernata* (Dorsey). 3. Umbilical view (Core 105, 7.5 m). 4. Spiral view (Core 118, 3.0 m).
5 *Rosalina floridana* (Cushman). 5. Umbilical view (Core 35, 7.2 m).
6-7 *Baggina* sp. 6. Umbilical view (Core 64, 6.2 m). 7. Spiral view (Core 105, 1.5 m).
8-10 *Cancris sagra* (d'Orbigny). 8. Umbilical view (Core 64, 6.2 m). 9. Spiral view (Core 64, 6.2 m). 10. Edge view (Core 113, 3.0 m).
11-13 *Valvulineria floridana* Cushman. 11. Umbilical view (Core 64, 6.2 m). 12. Spiral view (Core 64, 6.2 m). 13. Edge view (Core 64, 6.2 m).
14-16 *Valvulineria laevigata* Phleger and Parker. 14. Umbilical view (Core 64, 6.2 m). 15. Spiral view (Core 116, 3.0 m). 16. Edge view (Core 64, 6.2 m).


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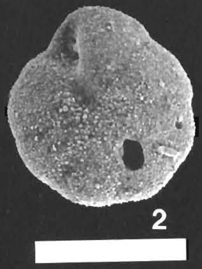
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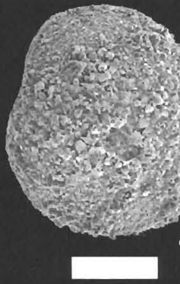
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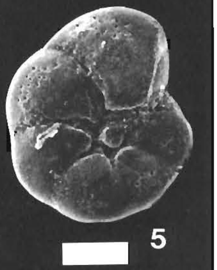
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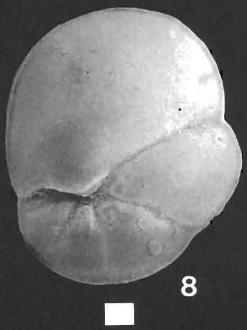
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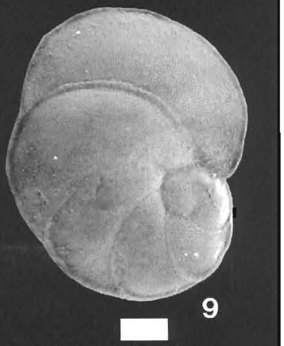
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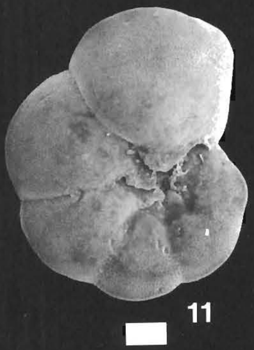
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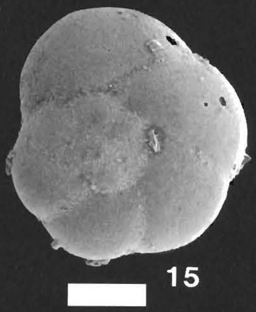
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PLATE 7

Each scale bar = 100 microns

1-3 *Valvulineria venezuelana* Hedberg. 1. Umbilical view (Core 64, 4.5 m). 2. Spiral view (Core 64, 4.5 m). 3. Edge view (Core 26, 1.5 m).
4-5 *Cibicides americanus* (Cushman). 4. Umbilical view (Core 64, 6.2 m). 5. Spiral view (Core 67, 3.5 m).
6-8 *Cibicides floridanus* (Cushman). 6. Spiral view (Core 64, 6.2 m). 7. Umbilical view (Core 64, 6.2 m). 8. Edge view (Core 64, 6.2 m).
9-10 *Cibicides lobatulus* (Walker and Jacob). 9. Spiral view (Core 64, 6.2 m). 10. Umbilical view (Core 116, 3.0 m).
11 *Elphidium* sp. 11. Side view (Core 45, 0.75 m).
12-14 *Oridorsalis umbonatus* (Reuss). 12. Umbilical view (Core 64, 6.2 m). 13. Spiral view (Core 64, 4.5 m). 14. Oblique edge view (Core 64, 4.5 m).


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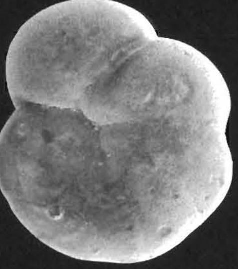
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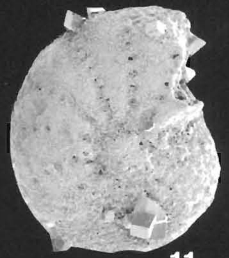
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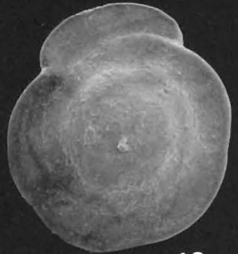
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PLATE 8

Each scale bar = 100 microns

1 *Fursenkoina fusiformis* (Williamson). 1. Side view (Core 98, 1.5 m).
2 *Fursenkoina* sp. 2. Side view (Core 64, 6.2 m).
3 *?Cassidella* sp. 3. Side view (Core 64, 6.2 m).
4-6 *Coryphostoma georgiana* (Cushman). 4. Side view (Core 116, 3.0 m). 5. Side view (Core 64, 4.5 m). 6. Apertural view (Core 26, 1.5 m).
7 *Virgulinella miocenica* (Cushman and Ponton). 7. Side view (Core 64, 6.2 m).
8-9 *Loxostomum gunteri* Cushman. 8. Side view (Core 106, 6.0 m). 9. Edge view (Core 106, 9.1 m).
10 *Cassidulina laevigata* d'Orbigny. 10. Side view (Core 118, 9.0 m).
11-12 *Globocassidulina crassa* (d'Orbigny). 11. Apertural side view (Core 26, 0.5 m). 12. Edge view (Core 105, 7.5 m).
13-14 *Ehrenbergina caribbea* Galloway and Heminway. 13. Apertural side view (Core 64, 6.2 m). 14. Opposite side view (Core 26, 3.0 m).
15 *Chilostomella oolina* Schwager. 15. Side view (Core 64, 6.2 m).
16 *Nonionella miocenica* Cushman. 16. Side view (Core 64, 6.2 m).
17-18 *Pullenia salisburyi* R. E. and K. C. Stewart. 17. Side view (Core 64, 6.2 m). 18. Edge view (Core 64, 6.2 m).


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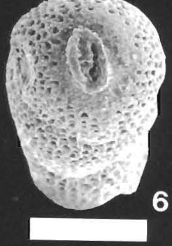
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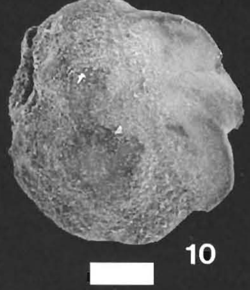
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PLATE 9

Each scale bar = 100 microns

1-3 *Ammonia beccarii* (Linne). 1. Umbilical view (Core 35, 5.75 m). 2. Edge view (Core 35, 7.2 m). 3. Spiral view (Core 35, 5.75 m).
4-6 *Buccella frigida* (Cushman). 4. Umbilical view (Core 1, 3.75 m). 5. Edge view (Core 1, 3.75 m). 6. Spiral view (Core 1, 3.75 m).
7-9 *Buccella inusitata* Andersen. 7. Umbilical view (Core 1, 4.75 m). 8. Edge view (Core 1, 4.75 m). 9. Spiral view (Core 1, 4.75 m).
10 *Nonion marylandicum* Dorsey. 10. Side view (Core 34, 3.75 m).
11 *Melonis* sp. 11. Side view (Core 127, 8.0 m).
12-13 *Florilus chesapeakensis* Gibson. 12. Side view (Core 1, 8.75 m). 13. Oblique edge view (Core 1, 8.75 m).


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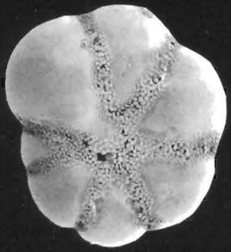
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PLATE 10

Each scale bar = 100 microns

1-3 *Florilus grateloupi* (d'Orbigny). 1. Side view (Core 26, 3.0 m). 2. Edge view (Core 26, 3.0 m). 3. Opposite side view (Core 26, 3.0 m).

4-6 *Florilus pizarrensis* (Berry). 4. Side view (Core 64, 6.2 m). 5. Edge view (Core 26, 3.0 m). 6. Side view (Core 26, 3.0 m).

7-9 *Eponides* sp. 7. Umbilical view (Core 26, 0.5 m). 8. Edge view (Core 26, 0.5 m). 9. Oblique spiral view (Core 26, 0.5 m).

10-12 *Gyroidinoides nipponica* (Ishizaki). 10. Umbilical view (Core 64, 6.2 m). 11. Edge view (Core 64, 6.2 m). 12. Spiral view (Core 64, 6.2 m).

13-15 *Hanzawaia concentrica* (Cushman). 13. Spiral view (Core 64, 6.2 m). 14. Oblique edge view (Core 64, 6.2 m). 15. Umbilical view (Core 26, 0.5 m).


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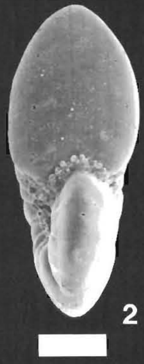
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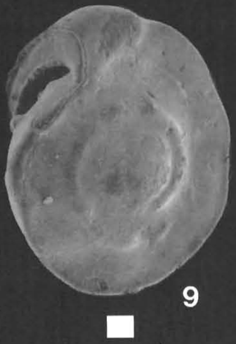
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p. 97–161, 1988

DIATOM BIOSTRATIGRAPHY AND PALEOECOLOGY OF THE MIOCENE PUNGO RIVER FORMATION, ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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Department of Geology, East Carolina University, Greenville, North Carolina 27858

ABSTRACT

Diatom floras in Pungo River Formation sediments of the North Carolina continental margin indicate an age of late early to middle Miocene. Biostratigraphic age assignments of stratigraphic sections approximating third-order coastal onlap events (Frying Pan, Onslow Bay and Bogue Banks sections, from oldest to youngest) are based on zonal indicator species of Abbott's (1978) Atlantic Miocene Diatom Zones (AMDZ). The Frying Pan Section is assigned to Zone I (Burdigalian), the Onslow Bay Section to Zones II and III (Langhian) and the Bogue Banks Section to Zone VI (Serravallian).

Diatom assemblages indicate shallow marine deposition. Influx of oceanic waters varied through time, probably as a response to changes in sea level and intensity of upwelling currents. Predominantly benthic assemblages in the Frying Pan Section give way to greater proportions of planktonic species in overlying sections. Shelf waters cooled and upwelling intensified during deposition of the Bogue Banks Section. Preservation of the diatom assemblages varied as a function of the permeability of enclosing sediments and the composition of associated sediment particles.

INTRODUCTION

Biosiliceous sediments (diatomite, porcelanite, diatomaceous clays and silts) are common constituents of cyclic marine phosphorite sequences which have been linked to ancient upwelling systems (Riggs, 1984). Diatom assemblages in modern regions of upwelling have distinctive characteristics. These can be used to recognize stratigraphic intervals deposited during increased surface water productivity which may have resulted from upwelling. Additionally, diatom biostratigraphy has proven useful in dating stratigraphic intervals containing diatoms characteristic of high surface water productivity due to upwelling events, particularly in sediments lacking calcareous microfossils.

Diatomaceous clays and silts within Neogene phosphorite sequences of the southeastern U.S. Atlantic margin contain assemblages that are, in many respects, similar to those found in modern coastal upwelling zones (South West Africa, Peru-Chile, and California). If upwelling occurred in Onslow Bay Embayment during the Miocene, changes in the abundance and preservation of Pungo River Formation diatom assemblages will allow recognition of increased productivity (presumably due to upwelling) and determination of the age of such events. Integration of diatom-based biostratigraphic and paleoecologic data with those of other microfossil groups from the same strata will enhance the interpretation of Pungo River depositional history. This study represents the first published account of diatoms from Miocene sediments in Onslow Bay.

PREVIOUS WORK

GENERAL

Use of fossil diatoms as biostratigraphic indicators was pioneered during the 1920's, but it was not until the 1960's and 1970's that diatoms were broadly applied to deep-sea biostratigraphy. The results of the Deep Sea Drilling Project and other major oceanographic studies in the 1970's and 1980's further advanced diatom biostratigraphy. Most studies concentrated on the Pacific Ocean where diatom datums were correlated with paleomagnetic, radiometric and other biostratigraphic datums (Burckle, 1972, 1977; Schrader, 1973a; Barron, 1976, 1985). Barron (1985) indirectly correlated Neogene diatom zonations for the Pacific and Indian Oceans, Norwegian Sea and Southern Oceans with the foraminiferal zones of Blow (1969), thus enhancing the value of diatoms for use in worldwide biostratigraphy.

Diatom biostratigraphic zonations in the Atlantic Basin are considerably less developed than those of the Pacific. Schrader and Fenner (1976) and Dzinoridze and others (1979) established zonal schemes for diatomaceous sediments from the Norwegian-Greenland Sea area (Fig. 1). However, these zonations are based mostly on endemic species which do not occur in assemblages from Onslow Bay sites, thus limiting their applicability. Baldauf (1984, 1986) defined early to middle Miocene diatom zones for the middle- and high-latitude North Atlantic. Though rare in occurrence, many indicator species of Baldauf's zonations occur in Onslow Bay sediments and can be used as secondary markers to correlate with deep sea zonations. Additionally, Baldauf and others (1986) correlated diatom events in the central North Atlantic Basin with paleomagnetic chrons/subchrons and radiometric ages.

Because marginal marine diatom deposits generally lack indicator species used in deep-sea zonal schemes, zonations have been developed for shallow-water diatom assemblages of the U.S. Atlantic margin. Diatom studies along the Atlantic margin have concentrated on the Calvert and Choptank Formations of Maryland and Virginia (Lohman, 1948; Cavallero, 1974; Andrews, 1976, 1978, 1979, 1986; Abbott, 1984) and the Hawthorne Group of the southeastern U.S. margin (Abbott and Andrews, 1979; Abbott and Huddlestun, 1977; Abbott, 1978, 1984; Hoenstine, 1984; Andrews and Abbott, 1985). Abundant diatoms in these strata have allowed preliminary zonations to be defined for the Miocene.

The rarity of oceanic species in Atlantic margin deposits makes deep-sea diatom zones from the Atlantic and Pacific difficult to use. Cavallero (1974) and Andrews (1978) used common nearshore species to develop zonations for Miocene deposits in Maryland (Fig. 1). While these zonations proved useful for local correlations, Abbott (1978) noted regional differences in the stratigraphic ranges of many indicator species. To overcome this problem, he developed a zonal scheme using nearshore planktonic and benthic species common in Atlantic margin deposits. Abbott's Atlantic Miocene Diatom Zones (AMDZ) utilize taxa that appear to have consistent stratigraphic ranges throughout the Atlantic margin. First and last appearances of species used in the AMDZ scheme have been correlated to Blow's (1969) foraminiferal zones in sediments containing both calcareous and siliceous microfossils (Abbott, 1978, 1980, 1984). Abbott further refined AMDZ by relating the occurrence of generally rare planktonic species in Atlantic coast sequences with their ranges in Schrader's (1973a) Northeast Pacific Diatom Zones (Fig. 1).

PUNGO RIVER FORMATION SEDIMENTS

All previous work has focused on the emerged coastal plain of North Carolina. Diatomaceous sediments in the Pungo River Formation were first reported by Kimrey (1964, 1965) in his original description of the formation from a core near Belhaven, North Carolina. Abbott and Ernissee (1983) recognized two diatom assemblages and one silicoflagellate assemblage in two cores taken near Kimrey's type core. Equivalence to Blow's (1969) foraminiferal Zones N8-N9 was established for the older assemblage while equivalence to Zone N11 was indicated for the younger assemblage. The diatomaceous intervals were deposited in a nearshore marine environment with reducing bottom conditions and nutrient-rich surface waters. Upwelling of cooler water onto the continental shelf may have occurred during deposition of the younger assemblage (Abbott and Ernissee, 1983).

Diatom-based age assignments for Pungo River strata at the Lee Creek mine and in nearby coreholes (Powers, 1986) utilized Abbott's (1978) Atlantic Miocene Diatom Zones. Lithologic units (A through D from oldest to youngest) defined by Riggs and others (1982) were assigned to Zones I, II and III of Abbott (1978). Lithologic units A and B were assigned to Zone I, although unit A may be older than the sediments from which Zone I was established. Units C and D were assigned to Zones II and III, respectively. They correlate with the lower diatom assemblage (assemblage 1) studied by Abbott and Ernissee (1983) in Pungo River strata 25 km northeast of the mine area. Strata equivalent to Abbott and Ernissee's upper assemblage were not observed in the mining district.

METHODS OF STUDY

Samples were obtained from among 95 vibracores which penetrated Miocene sediments in Onslow Bay (Snyder and others this volume). High resolution seismic profiles across Onslow Bay provide a regional

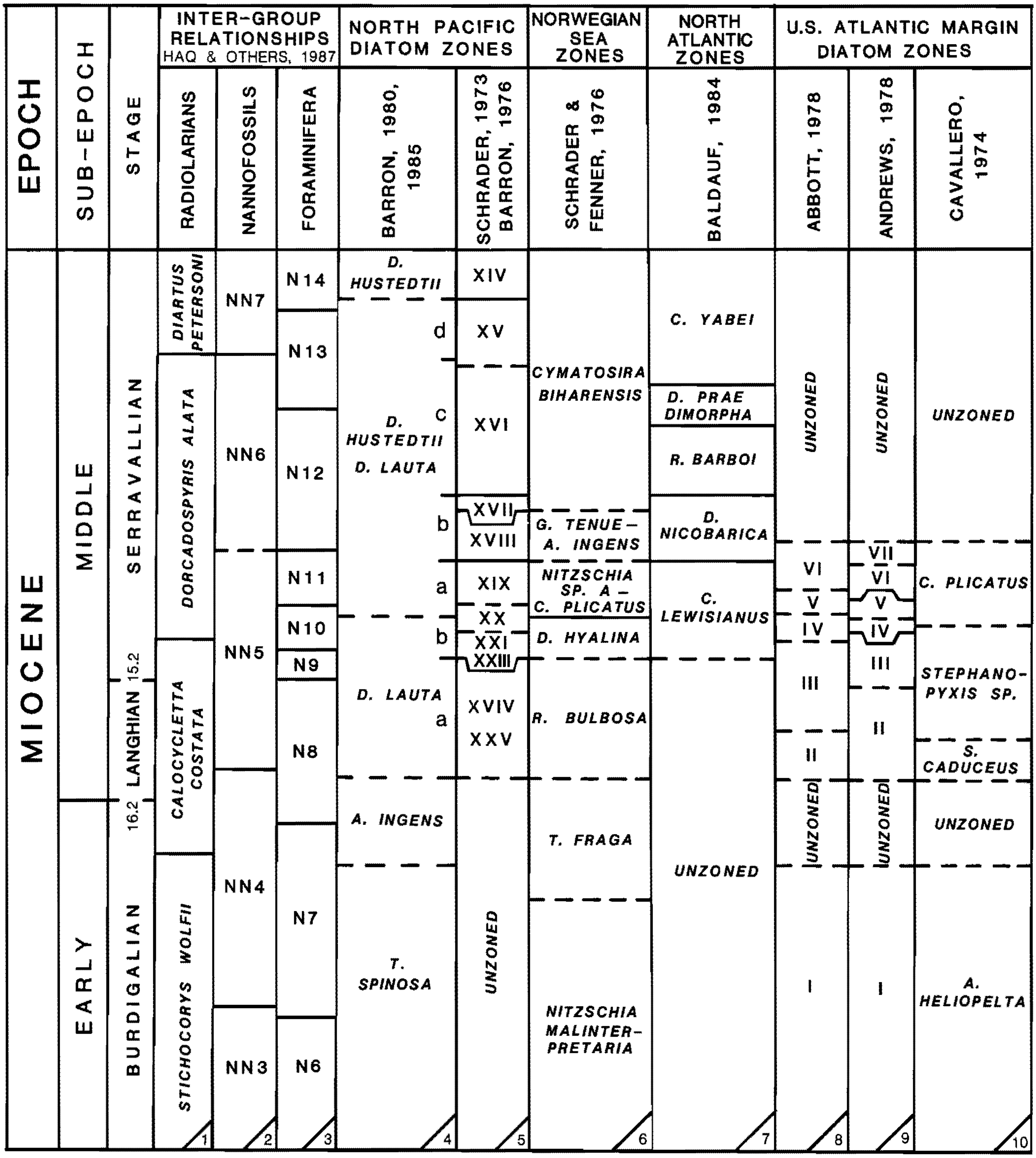


FIGURE 1. Correlation of Miocene diatom zonation schemes with other microfossil groups for the U.S. Atlantic Margin. Columns 1–4 are intergroup correlations of Haq and others (1987). Columns 5–7 are correlations of Baldauf (1984) and columns 8–10 are tied to other groups through Baldauf's correlation of Abbott's (1978) AMDZ scheme.

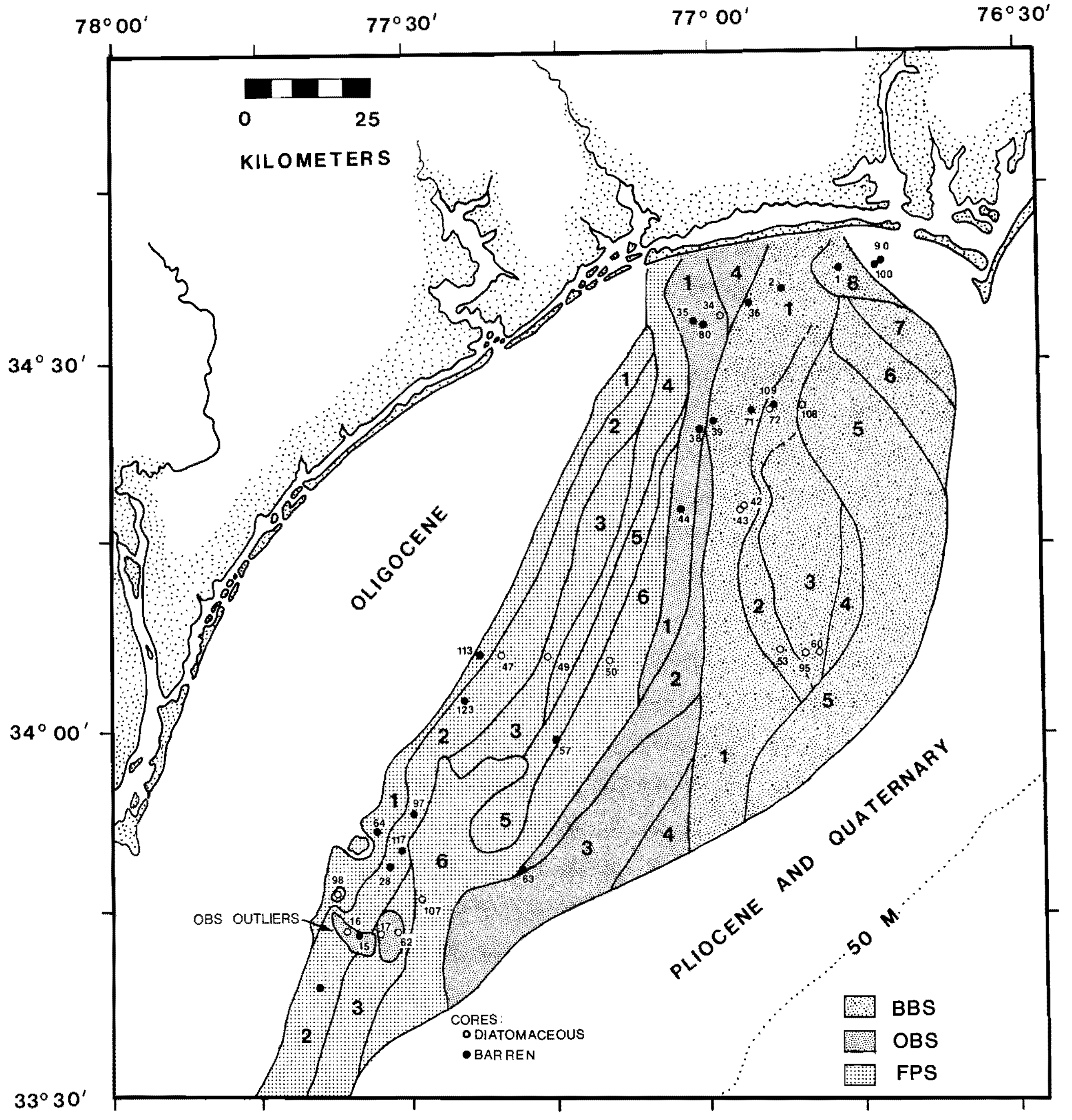


Figure 2. Location of core sites examined for diatoms in this study (base map redrafted from Hine and Riggs, 1986).

framework for biostratigraphic study. Lithologic descriptions by Lewis (1981) and Mallette (1986) were used to locate diatomaceous sediments within the cores. Two hundred fifty-three samples from 40 vibracores were examined for diatoms (Fig. 2).

Maximum core penetration was 9 m, so only the updip limit of any particular fourth-order sequence could be penetrated by one core. To overcome this limitation, a composite stratigraphic section was assembled by superimposing vibracores along three west-east transects (Fig. 3). Although gaps in core coverage result in an incomplete section, this technique allows

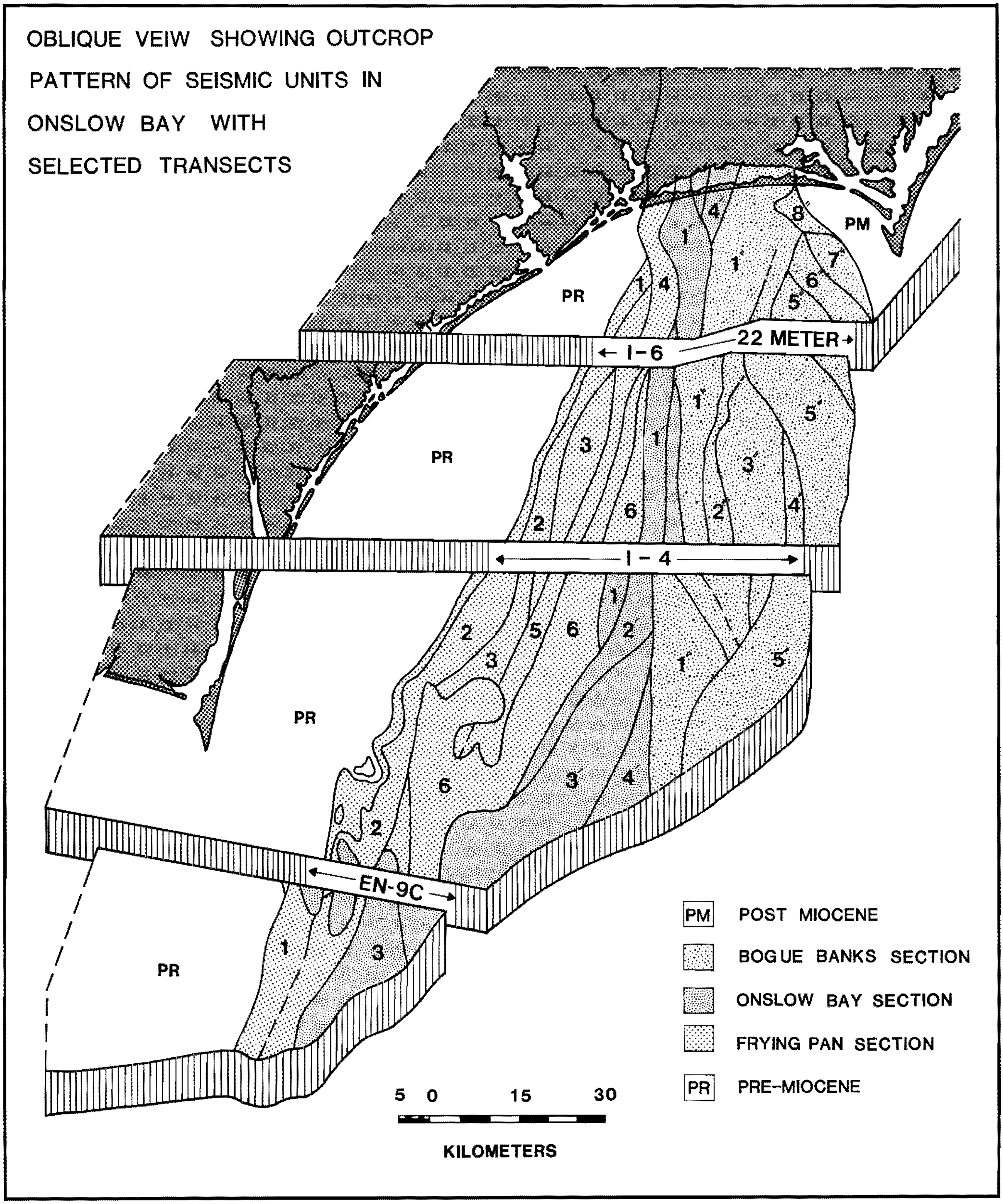


FIGURE 3. Location of seismic transects used in constructing the composite stratigraphic section (outcrop data redrafted from Hine and Riggs, 1986).

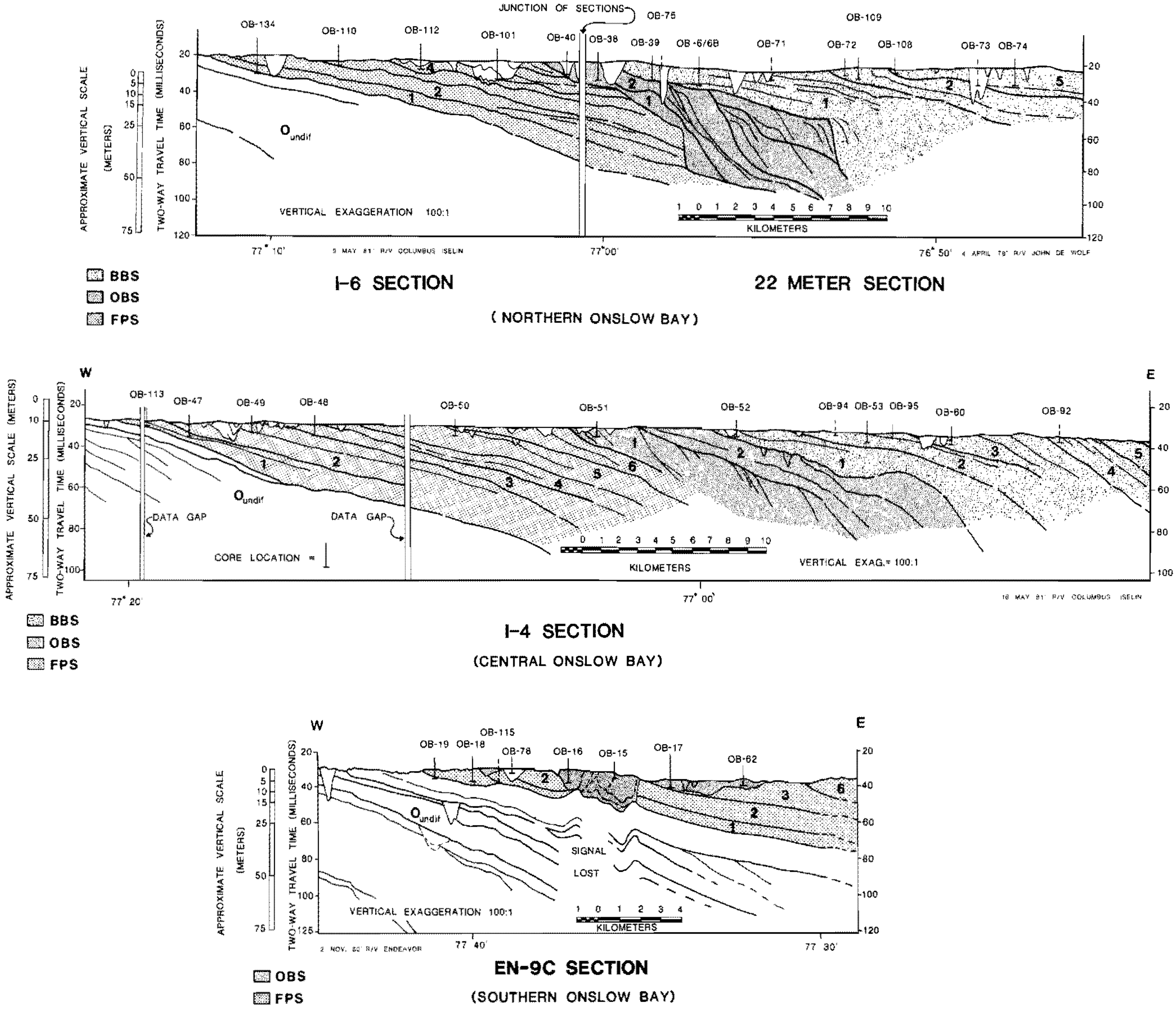


FIGURE 4. Interpreted seismic profiles from selected transects used in constructing the composite stratigraphic section used in this study (profiles redrafted from Snyder, 1982; Riggs and others, 1985; Hine and Riggs, 1986).

the relative stratigraphic position of each core to be approximated. Most diatomaceous intervals occur along three seismic profiles: the I-6/22 meter profile of northern Onslow Bay, the I-4 profile of central Onslow Bay and the EN-9C profile in southern Onslow Bay (Figs. 3, 4a, 4b and 4c). Inadequate core coverage along the northernmost transect required that cores slightly offset from the survey line be incorporated into the profile. Sediments cored along the I-6/22 meter profile are diatomaceous only in the Onslow Bay and Bogue Banks sections. Those along the I-4 profile are diatomaceous only in Frying Pan and Bogue Banks sections. Diatomaceous sediments along the EN-9C profile occur in outliers of the Onslow Bay Section in the map area of the Frying Pan Section. Seismic analyses cannot resolve stratigraphic relationships among cores in the EN-9C profile. Strata in these cores appear to be partly equivalent to OBS-1 in northern Onslow Bay.

A modified version of Schrader's (1974) method was used to prepare samples. First, 50 cc of sediment were placed in a 1,000 ml beaker containing 250 ml of a 1:1 solution of 0.5N HCL and 30–35% hydrogen peroxide. This solution was heated for 30–45 minutes or until all reactions had ceased. The remainder of the beaker was then filled with distilled water and allowed to settle overnight. Supernatant liquid was then removed from the beaker by means of a siphon, so as not to disturb the accumulated sediment. A series of seven wash, settle (2 hr), and decant cycles removed residual chemicals and most clay. Samples rich in clay and colloidal material were resoaked in a solution of 0.5% sodium pyrophosphate and given additional decant cycles. The solution was given final agitation and allowed to settle 1 to 2 minutes before a calibrated pipette was used to withdraw suspended sediment from the center of the beaker.

Three to six permanent slides were made from each sample by placing a drop of suspended sediment on a heated 22 × 22 mm, #1.5 coverslip. After drying, the coverslip was inverted and placed on a 25 × 75 mm glass microscope slide with a drop of Naphrax high resolution diatom mountant (refractive index 1.56). The slides were then heated to 150°C for 15 minutes and placed on a cool surface.

Slides from each sample were examined using a Leitz Orthoplan petrographic microscope at magnifications of 500 to 1,000×. Scanning electron microscopy resolved finer structures and aided in identification. Representative specimens of common genera in each seismic sequence were photographed, identified and catalogued.

Paleoecologic interpretations are based on counts of 300 specimens per slide, obtained by making systematic traverses across the slide at a magnification of 630×. Commonly fragmented species that were major constituents of the flora required qualitative estimates of their abundance based on the number of fragments observed in 10 randomly selected fields of view.

BIOSTRATIGRAPHIC INTERPRETATION

Biostratigraphic interpretation of Pungo River Formation sediments uses Abbott's (1978) Atlantic Miocene Diatom Zones (AMDZ; Fig. 5). Because Abbott (1984) correlated Atlantic diatom zones with oceanic diatom events, as well as with foraminiferal and calcareous nannofossil zones, shallow-water diatom assemblages can be related directly to widely accepted standardized zonations.

Twenty primary and eight secondary stratigraphic indicator species occur in the Miocene sequences of Onslow Bay (Fig. 6). Primary indicators are known from deep-sea sediments and have well-known stratigraphic ranges. Secondary indicators are restricted to shallow-water assemblages and cannot be directly correlated with deep-sea microfossil datums, but they are still useful stratigraphic markers. In addition, a number of other species observed in Onslow Bay appear to have regional biostratigraphic utility (Fig. 7).

Stratigraphically significant silicoflagellate species are also utilized for age assignments in this study. However, age-diagnostic species were not encountered in the Bogue Banks Section.

FRYING PAN SECTION

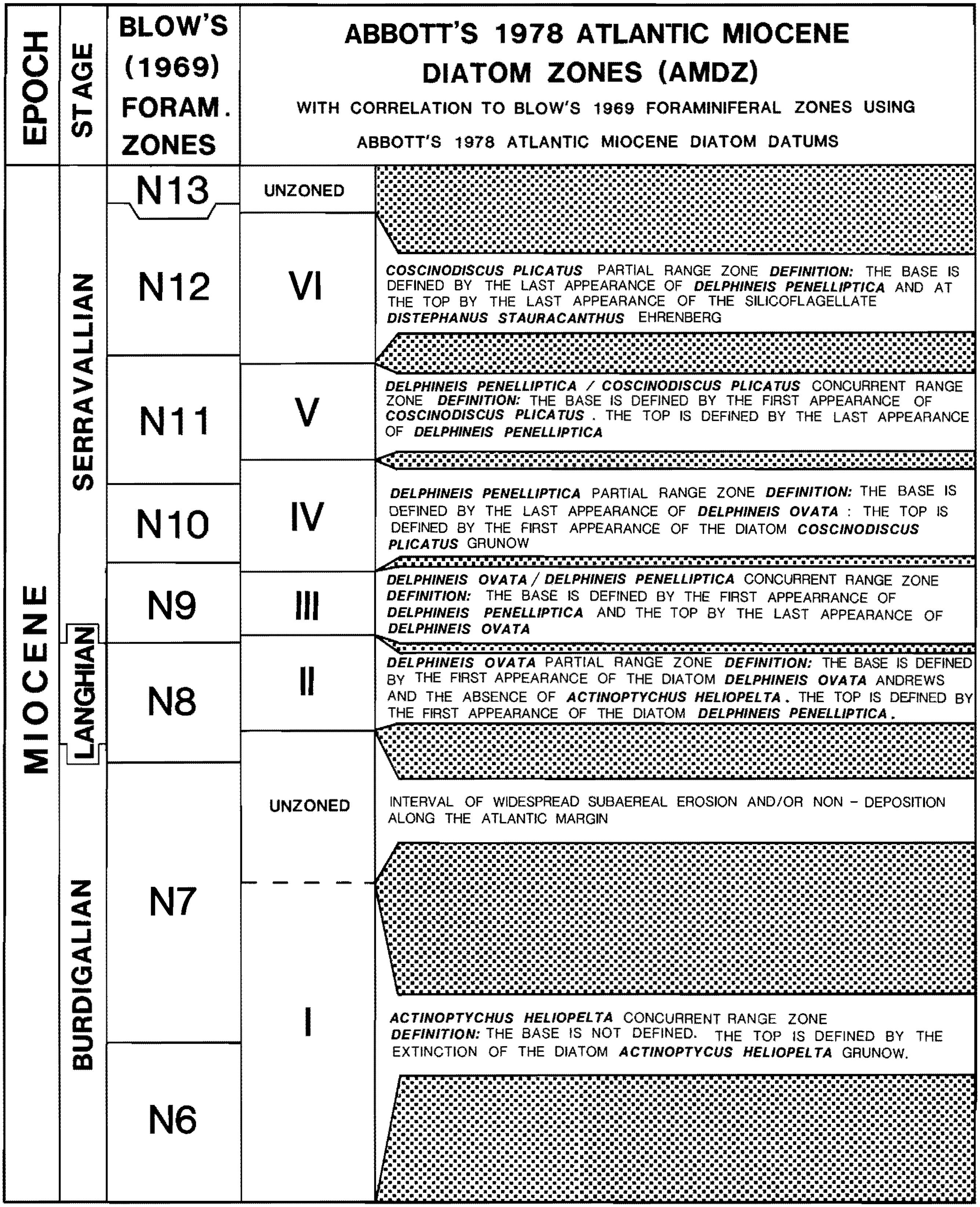
FPS-1, -2 and -5 are assigned to Abbott's *Actinoptychus heliopelta* Zone (Zone I) based on the occurrence of *A. heliopelta.* Diatoms were not recovered from FPS-3, -4 and -6. The base of Zone I has not been defined, so a lower age limit for Frying Pan sediments is based on silicoflagellates. Abbott (1984) correlated the last occurrence of *A. heliopelta* with lower Zone N7 of Blow (1969), which corresponds to the middle Burdigalian. However, a latest Burdigalian-early Langhian hiatus is recognized in many Atlantic margin siliceous sites, so the last occurrence of *A. heliopelta* must be inferred from its absence in middle Miocene deposits at other locations along the Atlantic margin. The co-occurrence of *Coscinodiscus rhombicus* with *A. heliopelta* (Fig. 8) restricts the age of FPS-1 and -2 to lower Zone N6 of Blow (1969) because the LAD of *C. rhombicus* occurs in the middle of N6 or at the top of the *Craspedodiscus elegans* Zone of Barron (1985). The occurrence of *Actinoptychus heliopelta* in FPS-5 indicates Zone I, while the disappearance of *C. rhombicus* suggests correlation with upper N6/lower N7 of Blow (1969) according to Barrons' (1985) correlations (Fig. 9).

The co-occurrence of *Naviculopsis quadrata* and *N. navicula* in FPS-1 and -2 is diagnostic of the *A. heliopelta* Zone. This co-occurrence also indicates the *Naviculopsis navicula* Zone of Martini and Muller (1976), which correlates with upper N6/lower N7 of Blow (1969). This zone was not recognized in FPS-5.

Other age-diagnostic diatoms present in the Frying Pan Section include: *Coscinodiscus lewisianus, C. praenitidus, Rhaphoneis capitata, R. margaritata, R. parilis* and *Sceptroneis caduceus.*

ONSLOW BAY SECTION

Outliers of the Onslow Bay Section located in the outcrop area of the Frying Pan Section in southern Onslow Bay (cores 16, 17, 62, 98, and 107) are assigned to Abbott's *Delphineis ovata* and *D. ovata/D. penelliptica* Zones based on the co-occurrence of *D. ovata* and *D. penelliptica* (Zones II and III in Fig. 9). More precise assignment is difficult because there are transitional forms between *D. ovata* and *D. penelliptica.* The co-



COSCINODISCUS PLICATUS PARTIAL RANGE ZONE ***DEFINITION:*** THE BASE IS DEFINED BY THE LAST APPEARANCE OF ***DELPHINEIS PENELLIPTICA*** AND AT THE TOP BY THE LAST APPEARANCE OF THE SILICOFLAGELLATE ***DISTEPHANUS STAURACANTHUS*** EHRENBERG

DELPHINEIS PENELLIPTICA / COSCINODISCUS PLICATUS CONCURRENT RANGE ZONE ***DEFINITION:*** THE BASE IS DEFINED BY THE FIRST APPEARANCE OF ***COSCINODISCUS PLICATUS*** . THE TOP IS DEFINED BY THE LAST APPEARANCE OF ***DELPHINEIS PENELLIPTICA***

DELPHINEIS PENELLIPTICA PARTIAL RANGE ZONE ***DEFINITION:*** THE BASE IS DEFINED BY THE LAST APPEARANCE OF ***DELPHINEIS OVATA*** : THE TOP IS DEFINED BY THE FIRST APPEARANCE OF THE DIATOM ***COSCINODISCUS PLICATUS*** GRUNOW

DELPHINEIS OVATA / DELPHINEIS PENELLIPTICA CONCURRENT RANGE ZONE ***DEFINITION:*** THE BASE IS DEFINED BY THE FIRST APPEARRANCE OF ***DELPHINEIS PENELLIPTICA*** AND THE TOP BY THE LAST APPEARANCE OF ***DELPHINEIS OVATA***

DELPHINEIS OVATA PARTIAL RANGE ZONE ***DEFINITION:*** THE BASE IS DEFINED BY THE FIRST APPEARANCE OF THE DIATOM ***DELPHINEIS OVATA*** ANDREWS AND THE ABSENCE OF ***ACTINOPTYCHUS HELIOPELTA*** . THE TOP IS DEFINED BY THE FIRST APPEARANCE OF THE DIATOM ***DELPHINEIS PENELLIPTICA*** .

INTERVAL OF WIDESPREAD SUBAEREAL EROSION AND/OR NON - DEPOSITION ALONG THE ATLANTIC MARGIN

ACTINOPTYCHUS HELIOPELTA CONCURRENT RANGE ZONE ***DEFINITION:*** THE BASE IS NOT DEFINED. THE TOP IS DEFINED BY THE EXTINCTION OF THE DIATOM ***ACTINOPTYCUS HELIOPELTA*** GRUNOW.

FIGURE 5. Definition of Abbott's (1978) Atlantic Miocene Diatom Zones and their correlation with the standard foraminiferal zones of Blow (1969); Data compiled from Abbott (1980 and 1984).

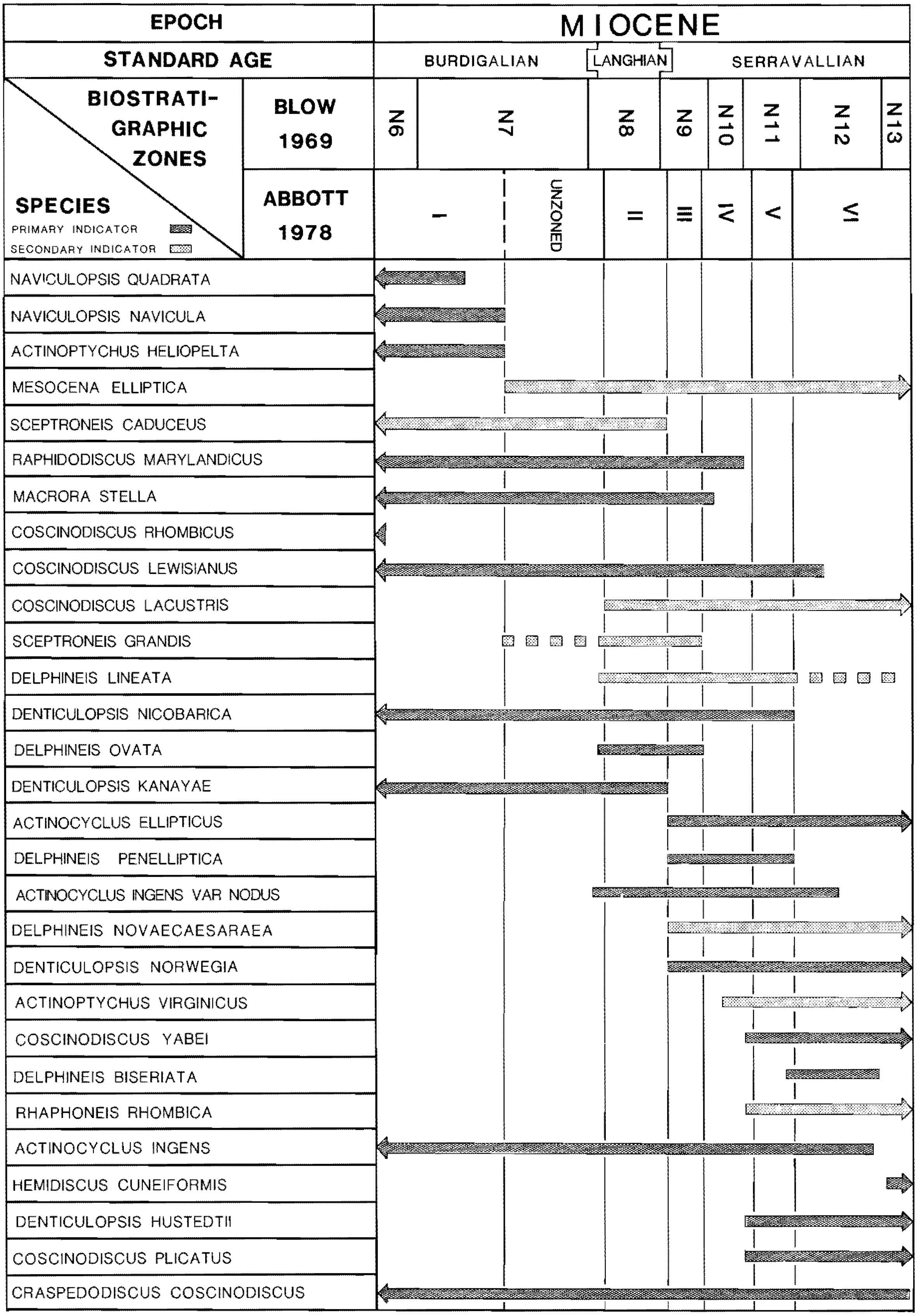


FIGURE 6. Known stratigraphic ranges for important diatom taxa encountered in Miocene sediments in Onslow Bay (data compiled from Abbott, 1978, 1980, 1984; Andrews, 1978; Barron, 1985).

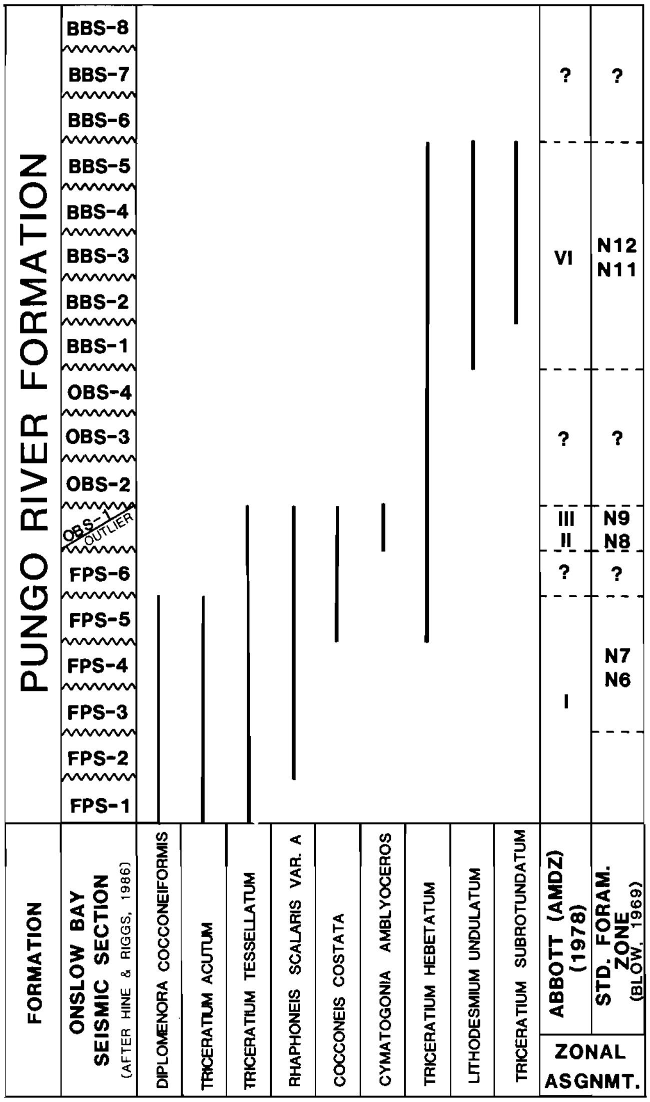


FIGURE 7. Stratigraphic occurrence of diatom taxa that are locally useful as stratigraphic markers in Miocene sequences in Onslow Bay.

occurrence of *Denticulopsis kanayae* with *Delphineis penelliptica* and *D. ovata* suggests that Onslow Bay Section outliers correlate with lower Zone N9 (Blow, 1969). Abbott (1984) correlated the co-occurrence of *D. ovata* and *D. kanayae* with the upper N8/lower N9 interval. *Actinocyclus ellipticus* also makes its first appearance in this sequence. Koizumi (1973) stated that this species ranges from Zone N9 to N15 (Blow, 1969), or throughout the middle Miocene. *Actinocyclus ingens* var. *nodus* is a rare but persistent form in Onslow Bay Section outliers. Baldauf and Barron (1980) concluded that this variant ranges throughout the early middle Miocene in Pacific coast sections. The restricted stratigraphic occurrence of this form in Onslow Bay may prove useful in correlations with other Atlantic margin deposits. *Sceptroneis caduceus,* present in the Frying Pan Section, is replaced by *S. grandis* in Onslow Bay Section outliers. Abbott (1978) noted a similar transition within the upper portion of the *D. ovata* Zone. However, he acknowledged that the range of this transition varies in different sections.

Other species characteristic of Onslow Bay Section outliers include: *Craspedodiscus coscinodiscus, Delphineis lineata, D. novaecaesaraea, Denticulopsis nicobarica, Macrora stella, Raphidodiscus marylandicus, Rhaphoneis adamantea, R. magnapunctata,* and *R. scalaris.*

OBS-1 in northern Onslow Bay is assigned to the *D. ovata/D. penelliptica* Zone (Zone III) because both of these definitive species are present. Abbott (1984) placed the boundaries of this zone entirely within Zone N9 of Blow (1969). The rare occurrence of *Denticulopsis norwegia* indicates an age no older than middle Miocene (Zone N9). Plicate forms of *Coscinodiscus* spp. first appear in OBS (*C. lacustris*). Andrews (personal communication, 1987) observed such forms in Miocene lake deposits of the western United States and suggested that their migration to the marine environment occurred during the middle Miocene.

Important last occurrences in this section are *Raphidodiscus marylandicus, Sceptroneis grandis, Macrora stella* and *Rhaphoneis scalaris.* Other important species include: *Delphineis lineata, D. angustata* and the silicoflagellate *Mesocena elliptica.*

BOGUE BANKS SECTION

All assemblages encountered in the Bogue Banks Section (BBS-1, -2, -3 and -5) are assigned to Abbott's *Coscinodiscus plicatus* Zone (Zone VI in Fig. 9). Three plicate forms of *Coscinodiscus* occur in the absence of *Delphineis penelliptica.* Abbott (1978, 1984) correlated the first occurrence of the two most common plicate forms, *C. plicatus* and *C. yabei,* with the middle of Zone N11 (Blow, 1969).

Abrupt proliferation of *Denticulopsis* spp. coincides with the first appearance of *D. hustedtii* in BBS-1. Abbott (1984) recognized the first appearance of *D. hustedtii* in Atlantic margin sites just below the first appearance of *C. plicatus* and *C. yabei,* or near the base of Zone N11 of Blow (1969). The rare occurrence of *Actinocyclus ingens* in BBS-5 indicates an upper-age limit equivalent to Zone N12, as Abbott (1984) correlated the last occurrence of both common forms of *A. ingens* with the top of N12. The occurrence of *Hemidiscus cuneiformis* in BBS-5 is problematic because Barron (1985) recognized its first occurrence in the

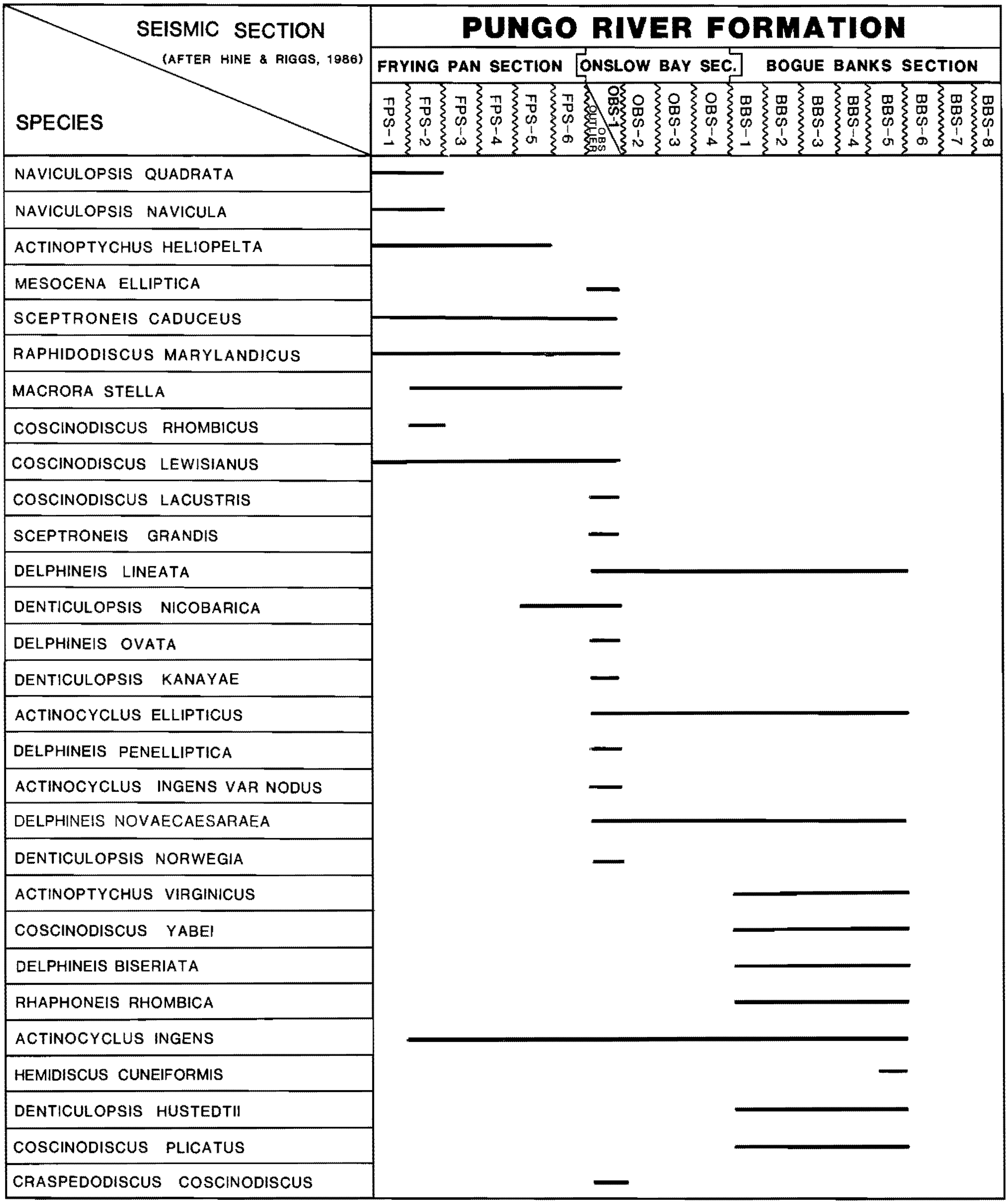


FIGURE 8. Stratigraphic occurrence of important diatom taxa encountered in Miocene sediments in Onslow Bay.

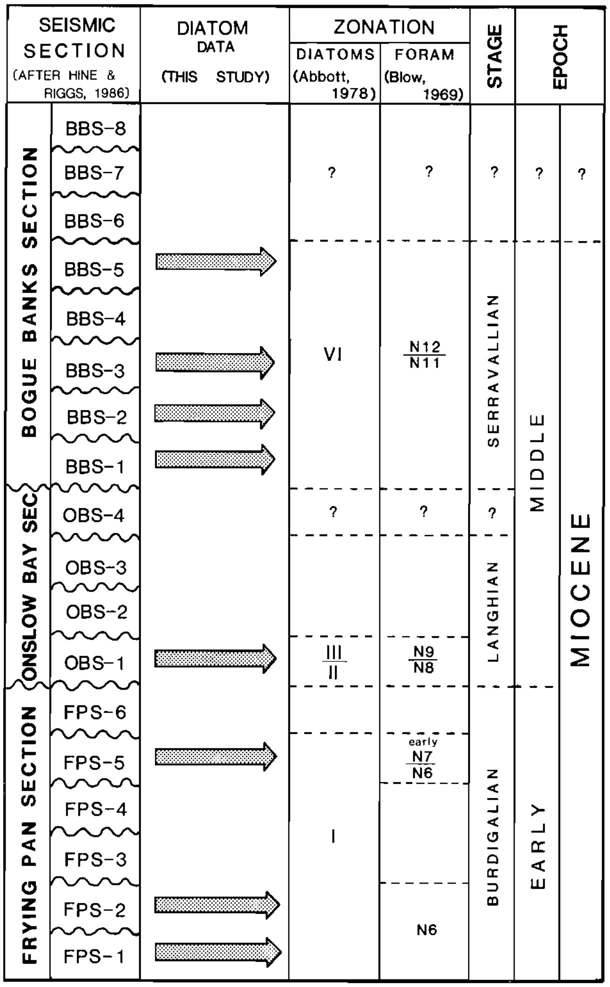


FIGURE 9. Summary of biostratigraphic age assignments for the Pungo River Formation in Onslow Bay based on diatoms. Correlation of Abbott's (1978) diatom zones to the standard foraminiferal zonation of Blow (1969) is based on Abbott's (1980 and 1984) correlations.

lower portion of Zone N13. The unexpected co-occurrence of *H. cuneiformis* and *A. ingens* may result from slight differences in ranges for these species between Atlantic and Pacific sites.

Other significant first appearances in the Bogue Banks Section include: *Actinoptychus marylandicus, A. virginicus, Delphineis biseriata, Rhaphoneis lancettula, R. diamantella* and *Rossiella paleacea.* Also occurring in but not necessarily restricted to this section are *Delphineis lineata* and *D. novaecaesaraea.* Specimens of *D. novaecaesaraea* in the Bogue Banks Section are distinguishable from older forms by a central marginal swelling. However, it is unknown if this is a consistent feature with widely applicable stratigraphic value.

Diatoms were not recovered from BBS-6 through -8. While BBS-5 appears to be no younger than Zone VI (based on the co-occurrence of *A. ingens* and *C. plicatus*), diatoms cannot provide age constraints for the upper three seismic sequences of the Bogue Banks Section.

ECOLOGICAL CONSIDERATIONS

TEMPERATURE

Recent diatom assemblages from the north Pacific (Kanaya and Koizumi, 1966; Barron, 1980) contain species characteristic of temperate to cold waters. Variations in their relative abundance in fossil assemblages record changing ecological conditions which may infer changes in paleoclimate (Barron and Baldauf, 1983; Barron and Keller, 1983). Paleotemperature curves based on diatoms from middle and late Miocene sediments in California are in close agreement with oxygen isotope curves for the same intervals (Barron and Keller, 1983), suggesting that changing relative abundance patterns for cold-water diatom taxa are reliable indicators of paleoclimatic trends. Relative abundance patterns for cold-water taxa in the Pungo River Formation should also reflect paleotemperature patterns. Ecologic tolerances of cold-water diatom taxa which occur commonly in Pungo River assemblages are briefly outlined below.

With the exception of *Denticulopsis nicobarica* and *D. punctata* var. *hustedtii,* the genus *Denticulopsis* is considered to be a cold-water planktonic species (Barron and Keller, 1983). Sancetta (1982) found that *Denticulopsis seminae,* a closely related modern relative of the extinct *D. hustedtii* (Schrader, 1973b), reaches its greatest abundance in the subarctic Pacific. The euryhaline species *Thalassiosira lacustris* (formerly *Coscinodiscus lacustris*) was also observed in nearshore samples from the Chukchi Shelf and Norton Sound, Alaska (Sancetta, 1982). Other species associated with cold waters include *Coscinodiscus curvatulus* and *C. decrescens* (Lohman, 1948).

The cosmopolitan species *Thalassionema nitzschioides* and *Thalassiothrix longissima,* which both attain maximum abundances in high latitudes and in zones of coastal upwelling, should increase in abundance during intervals of high latitude cooling and intensified oceanic circulation (Barron and Keller, 1983). They argued that such cooling would strengthen the California Current and thus displace colder water species southward. High latitude cooling during the middle Miocene (Woodruff and others, 1981; Savin and others, 1981), coupled with sea level rise, might also result in southward displacement of cool coastal waters along the southeastern Atlantic margin. Just as species composition in Miocene diatom assemblages reflects high frequency paleoclimatic oscillations (< 1 Ma) in the eastern Pacific (Baldauf and Barren, 1983; Barron and Keller, 1983), floral changes corresponding to glacioeustatic events which produced seismic sequences in Onslow Bay (Snyder, 1982) may record accompanying paleoclimatic changes.

UPWELLING

Phosphate formation has been associated with low rates of sedimentation and large supplies of nutrient phosphorus (Riggs, 1984). Upwelling of cool, nutrient-rich waters onto continental shelves is a probable mechanism for such nutrient enrichment. Modern upwelling sites have characteristic diatom biocoenoses and underlying taphocoenoses that can aid in recognition of upwelling sites in the geologic record. The abundance, degree of preservation and taxonomic composition of diatom assemblages in modern upwelling zones off South West Africa, Peru and the Gulf of California reflect recurrent nutrient enrichment by coastal upwelling. Such assemblages are distinguishable from those of adjacent coastal regimes. Diatom assemblages in sediments off South West Africa reflect "... a recurring biological response to coastal upwelling and this response is recorded in distinct distributional patterns of diatom taphocoenoses" (Schuette and Schrader, 1981).

Within upwelling assemblages, a distinction may be drawn between oceanic and coastal taphocoenoses, the boundary of which represents the seaward extent of upwelled coastal waters (Schuette and Schrader, 1981). Phytoplankton distributions off South West Africa include two associations of diatom biocoenoses: a "neritic" association (on the inner shelf) which includes *Chaetoceros* spp., *Delphineis karstenii, Thalassiosira* spp. and *Thalassionema* spp.; and a sparse "oceanic" assemblage (on the outer shelf) which includes *Coscinodiscus nodulifer, Pseudoeunotia doliolus, Thalassiosira eccentrica, Thalassionema nitzschioides* and *Roperia tesselata.*

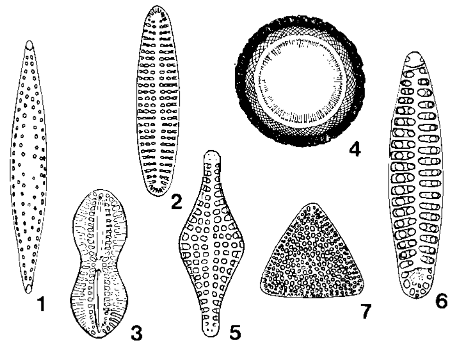
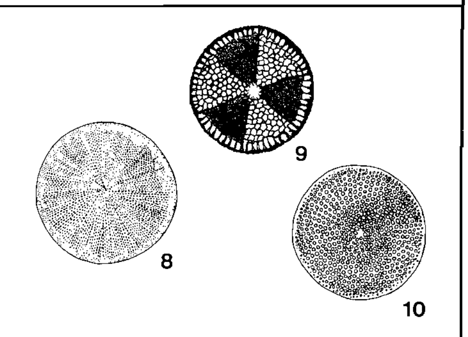
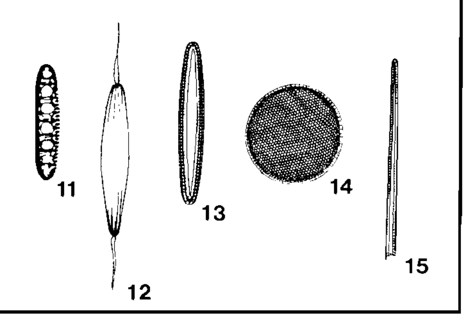
Off South West Africa, *Chaetoceros* spp. and *Delphineis karstenii* predominate nearshore assemblages in upwelling regions (Kollmer, 1962, 1963; Schuette and Schrader, 1981). Minor components of this assemblage are *Asterionella* spp. and *Thalassiosira* spp. *Chaetoceros* spp. numerically dominate both living (Guillen and others, 1971, 1972) and relict assemblages (Jousé and others, 1971; Schuette and Schrader, 1981) in upwelling zones off the Peruvian coast. *Chaetoceros* spores may occur in plankton during a *Chaetoceros*-dominated stage of species succession when nutrients are nearly exhausted (Schuette and Schrader, 1981). *Delphineis karstinii* appears to be a coastal pioneer species reaching its greatest abundance during the onset of nutrient enrichment of surface waters (Schuette and Schrader, 1981). Paleoecologic implications derived from observed distributions of *D. karstenii* are important because it is an extant relative of *Delphineis* spp. which are prolific in middle Miocene sediments of the southeastern Atlantic margin. *Paralia sulcata,* a prolific species in modern shallow water deposits of the southeastern U.S., is commonly associated with *D. karstenii.* Abrantes and Sancetta (1984) found that the cosmopolitan species *Paralia sulcata* and *Chaetoceros* spp. predominate assemblages associated with upwelling off the southwest coast of Spain and Portugal.

Meroplanktonic diatom species, those which produce resting spores or pursue a sedentary stage in their life cycle (Smayda, 1958), prefer turbulent nearshore waters. Species of this type observed in upwelling regions include: *Actinocyclus octonarius, Coscinodiscus perforatus, C. asteromphalus, C. gigas,* and *Actinoptychus senarius* (Schuette and Schrader, 1981). Large numbers of these robust species may accumulate in upwelling taphocoenoses through selective preservation (Schuette and Schrader, 1981) or by winnowing of smaller taxa from the sediments (Round, 1967).

Thalassionema nitzschioides, a cosmopolitan planktonic species is most abundant in waters influenced by upwelling (Kanaya and Koizumi, 1966; Jousé and others, 1971; Barron and Keller, 1983). The abundance of both *T. nitzschioides* and *Thalassiothrix* spp. in fossil deposits from Newport Beach California and from nearby DSDP sites reflects periodic increases in surface productivity during the middle Miocene (Barron and Keller, 1983).

High productivity associated with upwelling supplies large numbers of diatom frustules to the seafloor, thus producing pelagic oozes. In coastal areas lacking upwelling, diatom valves generally either dissolve in the water column or at the sediment/water interface. Dissolution also affects diatom taphocoenoses in upwelling regions by removing weakly silicified forms (Diester-Haas and Schrader, 1979). Significant differences between bottom assemblages and overlying plankton populations are caused by removal of smaller, weakly silicified forms from the water column before deposition (Hart and Currie, 1960). Thus, upwelling assemblages (taphocoenoses) tend to favor taxa which are larger and more heavily silicified (e.g., *Coscinodiscus* spp., *Actinoptychus* spp., *Actinocyclus* spp.).

TABLE 1. Species groups and their ecologic distribution based on observations of modern assemblages (data compiled from Hendey, 1964; Round, 1971; and Schuette and Schrader, 1981).

LIFE HABIT	COMMONLY OCCURRING GENERA	MOST ABUNDANT SPECIES * EXTINCT	ECOLOGIC TOLERANCES	COMMON SPECIES
BENTHIC SPECIES GROUP	***CYMATOSIRA***	* ***CYMATOSIRA IMMUNIS*** ***CYMATOSIRA BELGICA*** (1)	COSMOPOLITAN IN LITTORAL AND SUBLITTORAL MUD, SAND	
	DELPHINEIS	* ***DELPHINEIS OVATA*** (2) * ***DELPHINEIS PENELLIPTICA*** ***DELPHINEIS SURRIRELLA***	COSMOPOLITAN IN LITTORAL AND SUBLITTORAL; MUD, SAND; COMMON IN COOL WATERS; EURYHALINE	
	DIPLONEIS	***DIPLONEIS BOMBUS*** ***DIPLONEIS CRABRO*** (3)	COSMOPOLITAN IN LITTORAL SUBLITTORAL COMMON IN WATERS OF HIGH SALINITY	
	PARALIA	***PARALIA SULCATA*** (4)	COSMOPOLITAN IN LITTORAL, SUBLITTORAL AND DEEP SEA	
	RHAPHONEIS	****RHAPHONEIS MAGNIPUNCTATA*** (5) ***RHAPHONEIS PARILIS*** ***RHAPHONEIS AMPHICEROS***	COSMOPOLITAN IN LITTORAL AND SUBLITTORAL; MUD, SAND, ROCK, PLANTS; EURYHALINE	
	SCEPTRONEIS	****SCEPTRONEIS CADUCEA*** ****SCEPTRONEIS GRANDIS*** (6)	SUBLITTORAL: MUD, SAND	
	TRICERATIUM	***TRICERATIUM CONDECORUM*** (7) ****TRICERATIUM TESSELATUM***	COSMOPOLITAN IN LITTORAL AND SUBLITTORAL: MUD, SAND	
MEROPLANKTONIC SPECIES GROUP	***ACTINOCYCLUS***	***ACTINOCYCLUS OCTINARIUS*** (8) ***ACTINOCYCLUS TENELLUS***	COSMOPOLITAN IN NERITIC AND OCEANIC; (8) AN IMPORTANT SPECIES IN COASTAL UPWELLING ZONES; EURYHALINE	
	ACTINOPTYCHUS	****ACTINOPTYCHUS HELIOPELTA*** ***ACTINOPTYCHUS SENARIUS*** (9) ****ACTINOPTYCHUS MARYLANDICUS***	COSMOPOLITAN IN NERITIC; (9) AN IMPORTANT SPECIES IN COASTAL UPWELLING ZONES	
	COSCINODISCUS	***COSCINODISCUS APICULATUS*** ***COSCINODISCUS ASTEROMPHALUS*** ***COSCINODISCUS PERFORATUS*** (10)	COSMOPOLITAN IN NERITIC IMPORTANT SPECIES IN COASTAL UPWELLING ZONES AND OCEANIC	
PLANKTONIC SPECIES GROUP	***DENTICULOPSIS***	****DENTICULOPSIS HUSTEDTII*** (11)	OCEANIC; MOST ABUNDANT AT MID- AND HIGH LATITUDES	
	RHIZOSOLENIA	***RHIZOSOLENIA STYLIFORMIS*** (12)	COSMOPOLITAN IN OCEANIC	
	THALASSIONEMA	***THALASSIONEMA NITZCHOIDES*** (13) ****THALASSIONEMA OBTUSUM***	COSMOPOLITAN IN NERITIC AND OCEANIC: MOST ABUNDANT IN COASTAL AND EQUATORIAL UPWELLING ZONES	
	THALASSIOSIRA	***THALASSIOSIRA ECCENTRICA*** ***THALASSIOSIRA LEPTOPUS*** ***THALASSIOSIRA LINEATA*** (14)	COSMOPOLITAN IN OCEANIC AND NERITIC	
	THALASSIOTHRIX	***THALASSIOTHRIX LONGISSIMA*** (15)	COSMOPOLITAN IN OCEANIC AND NERITIC: ABUNDANT IN COASTAL AND EQUATORIAL UPWELLING ZONES	

In addition, large diatom cells are favored over smaller ones by faster nutrient uptake in upwelling zones (Parsons and Takahashi, 1973). The existence of downwelling fronts also favors the accumulation of diatom-rich sediments because downwelling accelerates the sinking process of diatom valves (Richert, 1976).

PALEOECOLOGIC INTERPRETATION

Diatom assemblages in the Pungo River Formation indicate deposition in shallow marine conditions. The predominance of benthic species in most assemblages indicates depths no greater than those to which light could penetrate. Absence of freshwater species indicates that continental shelf waters were not intruded by significant amounts of terrestrial runoff. Assemblages of sublittoral and neritic species mixed with varying proportions of oceanic forms suggest open marine circulation.

Pungo River Formation diatom species can be grouped (mostly at the generic level) according to ecologic tolerances: benthic forms which spend their entire life cycle attached to a substrate; meroplanktonic forms which spend part of their life cycle as plankton and the remainder attached to substrates; and planktonic forms which spend their entire life cycle in the water column. Specific ecologic tolerances of species within these groups are summarized in Table 1. These tolerances

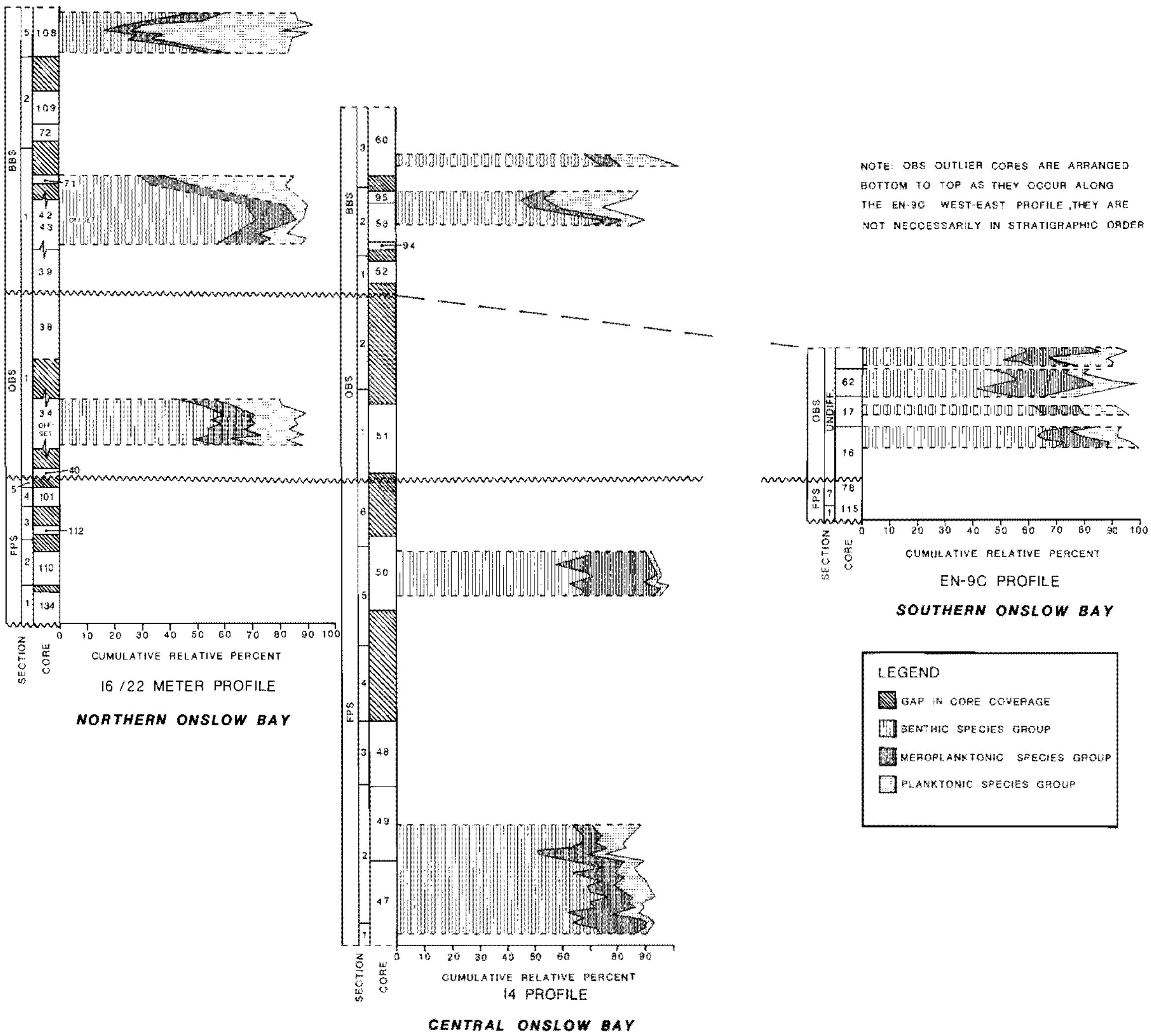


FIGURE 10. Relative abundance patterns of species groups with respect to the composite stratigraphic section of Pungo River Formation sediments in Onslow Bay.

apply only to the commonly occuring species listed in column 3. The relative abundance of each species group was plotted on a composite stratigraphic section (Figs. 10 and 11) so that abundance trends could be related to the seismic framework.

FRYING PAN SECTION ASSEMBLAGES

Diatom assemblages in FPS-1, -2 and -5 in central Onslow Bay are predominated by the benthic forms *Paralia sulcata, Rhaphoneis* spp., *Cymatosira* spp., *Sceptroneis* spp. and *Diploneis* spp. *P. sulcata,* a cosmopolitan form in modern littoral and sublittoral environments, constitutes 30 to 40% of the total assemblage. Although there are no extant representatives of *Sceptroneis* spp., its associates *Rhaphoneis* spp. and *Cymatosira* spp. inhabit sandy mud substrates in shallow coastal waters of modern temperate seas (Hustedt, 1955). The abundance of these species in association with sandy mud lithologies suggests turbid bottom conditions. *Sceptroneis* spp. is considerably less abundant in FPS-5 than in FPS-1 and -2.

Meroplanktonic forms such as *Coscinodiscus* spp., *Actinocyclus* spp. and *Actinoptychus* spp. are common (10–15%) in FPS-1 and -2 but increase in abundance (20–25%) in FPS-5. This trend, accompanied by a decrease in sublittoral forms, suggests a more offshore depositional environment for FPS-5. According to a Schuette and Schrader (1981), Von Stosch observed assemblages similar to those of the Frying Pan Section in coastal waters (less than 46 m deep) of the North Sea. These assemblages were markedly different from

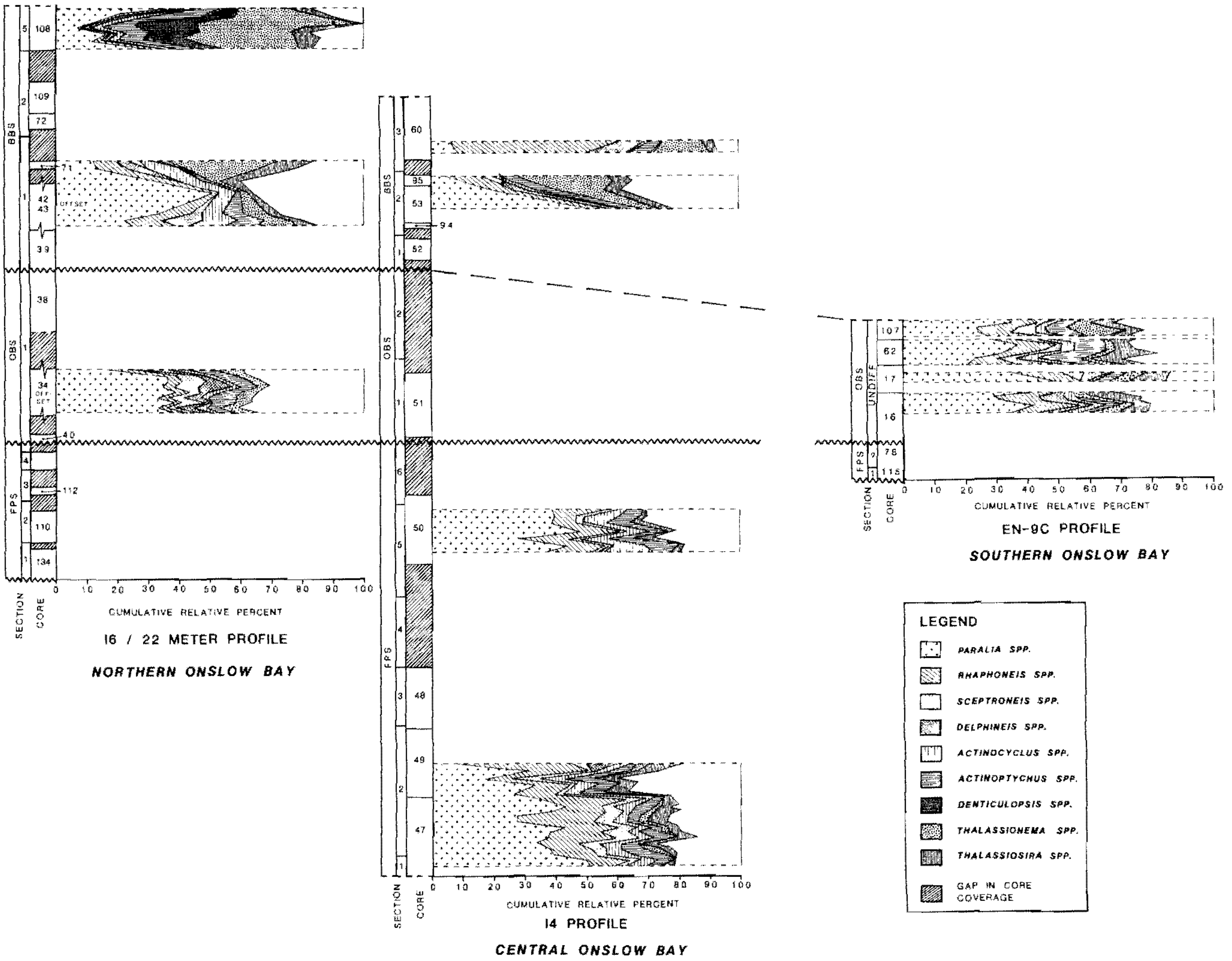


FIGURE 11. Relative abundance patterns of selected diatom genera occurring in the Pungo River Formation in Onslow Bay with respect to the composite stratigraphic section.

those found in adjacent waters at depths greater than 50 meters, suggesting the distribution of these species is at least partly dependent on water depth.

Planktonic forms such as *Thalassiosira* spp. occur in minor abundance in FPS-1, -2 and -5. Their presence suggests shelf waters mixed to some extent with oceanic waters in Onslow Embayment during deposition of the Frying Pan Section. Planktonic species commonly associated with upwelling (*Thalassiothrix* spp., *Thalassionema* spp.) are scarce in FPS-1, -2 and -5 in central Onslow Bay.

Assemblages in the Frying Pan Section are similar to those observed by Schuette and Schrader (1981) near inner shelf areas affected by upwelling. The rarity of upwelling species suggests upwelling was not centered in central Onslow Bay during deposition of Frying Pan sediments. Zeolitic muds in equivalent strata in southern Onslow Bay may have formed from the alteration of organic-rich diatomaceous muds accumulating beneath an upwelling center.

Onslow Bay Section Assemblages

Assemblages of the Onslow Bay Section are discussed as two subgroups: (1) those in undifferentiated outliers in southern Onslow Bay, and (2) a northern Onslow Bay assemblage in upper OBS-1. Assemblages from these two areas are at least partially time equivalent, although there may be a minor age disparity between them.

Diatom assemblages in undifferentiated Onslow Bay Section outliers in southern Onslow Bay are generally similar to Frying Pan Section assemblages. They are predominated by sublittoral forms (*Paralia sulcata, Rhaphoneis* spp. *Delphineis* spp.), but there is a slightly greater proportion of planktonic species, including some associated with regions of upwelling (*Thalassionema* spp., *Thalassiothrix* spp.). A modest increase in the relative abundance of *Delphineis* spp. in Onslow Bay Section assemblages is significant because extant species of *Delphineis* occur abundantly in inner-shelf sediments associated with upwelling (Schuette and Schrader, 1981). Large-celled meroplanktonic forms such as *Coscinodiscus* spp., *Actinocyclus* spp. and *Actinoptychus* spp. are also slightly more abundant in these assemblages. The association of common *Delphineis* spp. with large-celled meroplanktonic species and planktonic species linked to upwelling suggests that Onslow Bay Section outliers in southern Onslow Bay accumulated in environments with elevated concentrations of nutrients.

Diatom assemblages in OBS-1 in northern Onslow Bay suggest proximity to an upwelling zone. Well-preserved assemblages occur in diatom-rich muds, indicating deposition during a period of high organic productivity and low terrigenous influx. The sublittoral forms *Paralia sulcata, Rhaphoneis* spp., *Delphineis* spp. and *Sceptroneis* spp. predominate. Compared to Onslow Bay Section assemblages in southern Onslow Bay, notably fewer meroplanktonic species (*Coscinodiscus* spp., *Actinocyclus* spp. and *Actinoptychus* spp.) occur. Upwelling species (*Thalassionema* spp., *Thalassiothrix* spp.) are prominent, collectively composing over 15% of the assemblage.

BOGUE BANKS SECTION ASSEMBLAGES

Diatom assemblages in the Bogue Banks Section indicate cooling shelf waters and possibly intensified upwelling. Highly altered assemblages in BBS-1 are predominated by solution-resistant species such as *Paralia sulcata, Melosira westii* and *Rhaphoneis lancettula.* Assemblages in BBS-1 in northern Onslow Bay increase in diversity up-section, as does the quality of preservation. Assemblages near the top of BBS-1 are predominated by *Thalassionema* spp. and *Thalassiothrix* spp., suggesting high surface water productivity. The abundance (>15%) of oceanic species (*Denticulopsis* spp., *Thalassiosira* spp., *Rhizosolenia* spp.) and planktonic *Coscinodiscus* spp. suggests increased mixing of shelf waters with oceanic waters. Benthic species (*Paralia* spp., *Rhaphoneis* spp., *Delphineis* spp.) decrease up-section, suggesting increased water depths. *Delphineis* spp. is common in these assemblages, thus suggesting nutrient enrichment of shelf waters. Neritic, meroplanktonic species (*Actinocyclus octinarius, Actinoptychus* spp., *Coscinodiscus* spp.) constitute a relatively minor proportion of this assemblage.

Cold-water, planktonic species (*Denticulopsis* spp.) and upwelling species (*Thalassionema* spp., *Thalassiothrix* spp.) increase considerably in BBS-2 (35–40%) in central Onslow Bay. They are mixed with benthic species (*Rhaphoneis* spp., *Delphineis* spp.) which constitute 40–50% of the assemblage, thus indicating deposition in relatively shallow water with considerable mixing of oceanic waters. Diatom assemblages from BBS-2 in northern Onslow Bay are so extensively altered that counts of species abundance were not performed.

The benthic diatoms *Rhaphoneis amphiceros* and *R. rhombica* compose 50–60% of BBS-3 assemblages in central Onslow Bay. Combined with a decrease in planktonic forms, this suggests shallow conditions. Planktonic species in these assemblages are largely *Thalassionema* spp. and *Thalassiothrix* spp., thus suggesting the proximity of an upwelling zone. The benthic diatom *Delphineis lineata* is also important (8–12%) in BBS-3 assemblages, probably indicating nutrient-enriched shelf waters.

Diatoms were not recovered from sediments overlying BBS-3 in central Onslow Bay. Cool-water planktonic diatoms are predominant in BBS-5 sediments of northern Onslow Bay. The planktonic *Denticulopsis hustedtii* composes 15–18% of this assemblage. The co-predominance of this species with *Thalassionema* spp. indicates cooler shelf waters and perhaps intensified coastal upwelling. Benthic species (*Paralia sulcata, Rhaphoneis* spp., *Delphineis* spp.) are less abundant relative to other Onslow Bay assemblages, thus suggesting deeper water.

CLUSTER ANALYSIS

To aid in identifying biofacies (groups of samples with similar floral characteristics), cluster analysis was performed on all Onslow Bay samples which yielded 300 or more diatom specimens. Andrews (1972) cautioned against using quantitative approaches to diatom paleoecologic analyses. But when interpreted in a conservative manner, such analyses can be valuable as an independent check of trends recognized by qualitative assessment of the data. Only those species that account for more than 3% of the flora in one or more samples were entered into the data matrix. This technique eliminates spurious occurrences of uncommon species and allows clustering to concentrate on common forms that

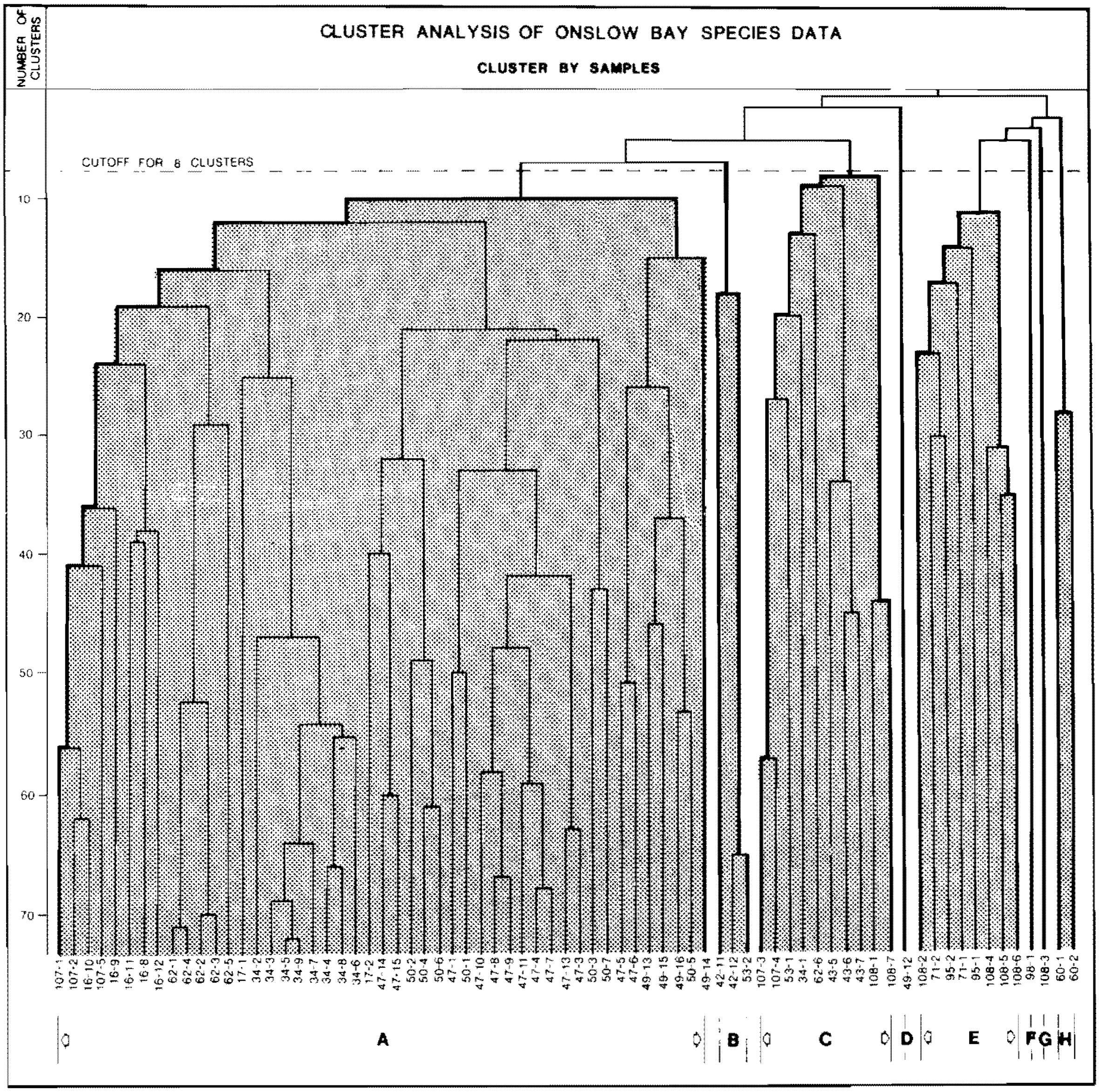


FIGURE 12. Dendrogram produced from a cluster analysis of relative abundances of commonly occurring diatom taxa encountered in Pungo River Formation sediments from Onslow Bay.

are consistently present. Data processing was performed using an IBM 4381 computer with SAS (Statistical Analysis System) software.

Eight clusters were recognized, partly on the basis of the "cubic clustering criterion," as suggested by the SAS user's guide (1985). Counting error (±4% based on duplicate counts on the same slide) was considered in interpreting clusters. The eight clusters delineated by the analysis (Fig. 12) are referred to by letters "A" through "H."

Cluster "A," which includes nearly all samples from Frying Pan and Onslow Bay Sections, contains diverse assemblages that have a high percentage of benthic (>50%) and meroplanktonic species (10–20%). Oceanic and upwelling indicator species constitute less than 5% of these assemblages, except in two Onslow Bay Section samples where taxa associated with upwelling reach a relative abundance near 15%. Cluster "B" consists of three samples from BBS-1 which have species-group compositions generally similar to those in cluster "A." However, the predominance of solution-resistant benthic forms such as *Paralia sulcata* creates a distinctive benthic assemblage which is less diverse than that of cluster "A." Samples in cluster "C" contain assemblages with species-group proportions similar to those of cluster "A." Cluster "C" samples occur in the

Onslow Bay Section and BBS-1 where a series of extinctions and first appearances occur within the benthic species group. Most species of *Rhaphoneis* spp. which typify cluster "A" (Frying Pan and Onslow Bay Sections) are absent or rare in cluster "C" (Onslow Bay and Bogue Banks Sections). It is these shifting floral characteristics within the benthic species group, rather than changes in the proportions of the three major species groups, that characterize cluster "C." Cluster "D" is a single sample cluster (core 49) that is unique largely because of its exceptionally low relative percentage of *Paralia sulcata* (7%). The reason for this abrupt decrease in *P. sulcata* is unclear. Samples in cluster "E," all from the Bogue Banks Section, are predominated by the planktonic species group, mostly composed of *Thalassionema nitzschioides* (25–50%). Benthic and meroplanktonic components are reduced in comparison with clusters "A," "B" and "C" (Frying Pan and Onslow Bay Section samples). Cluster "F" is a single sample cluster from core 98 that is predominated by large-celled meroplanktonic species and upwelling and oceanic species. Cluster "G" is a single sample cluster from core 108 (BBS-5, northern Onslow Bay). This assemblage is strongly predominated by the upwelling indicator species *Thalassionema nitzschioides,* but otherwise is very similar to other core 108 samples in cluster "E." The predominance of the benthic species *Rhaphoneis amphiceros* (50–60%) makes the assemblages in cluster "H" the most distinctive in Onslow Bay. These samples occur in core 60 from BBS-3 in central Onslow Bay. This assemblage also contains moderately abundant upwelling indicator species (*Thalassionema* spp.).

Cluster analysis of Onslow Bay diatom samples grouped diatom assemblages mainly as a function of: (1) relative proportion of major species-groups; (2) shifts in species composition within a particular species group, largely as a result of successive extinctions and appearances; (3) preservation and selective dissolution of weakly silicified forms leading to residual enrichment of resistant forms. Cluster analysis arranged the samples roughly in stratigraphic order, suggesting that processes responsible for floral differences in Onslow Bay are related to temporal changes in paleoenvironment during the late-early and middle Miocene.

PRESERVATION OF DIATOM ASSEMBLAGES

Factors responsible for preservation or destruction of diatom assemblages are difficult to assess. As Lohman (1960) stated: "The absence of these ubiquitous creatures in a sedimentary rock commonly requires a more searching explanation than does their presence." Several causal factors may interact to influence the extent to which they are preserved. Diatom dissolution occurs during early diagenesis, as sulfate reduction of organic matter by microbial activity elevates pore water alkalinity to silica-corrosive levels. Post-depositional alteration of carbonate sediment constituents in or adjacent to diatomaceous intervals also contributes to diatom dissolution by raising pore water alkalinity (Kastner and others, 1977). Stewart (1985) related silica authigenesis to the concentration of siliceous fossils and to permeability barriers within the sediment (clay content) which exclude silica-corrosive waters. Diester-Haas and Schrader (1979) concluded that volcanic SiO_2 in sediments increases the preservation potential of biogenous silica.

Four aspects of preservation were examined in Onslow Bay diatom assemblages (Table 2).

(1) Species composition of an assemblage. Predominance of heavily silicified taxa in association with corroded individuals of less resistant species indicates considerable leaching, during which original species composition has been altered.
(2) Overall condition of specimens. The presence of dissolution rims and corroded surfaces, and the absence of delicate structures suggest leaching.
(3) Associated sediment. Certain authigenic minerals, such as chert or zeolites, may originate from total dissolution of biogenic silica followed by recrystallization of liberated silica into other mineral phases.
(4) Abundance. Abundant siliceous skeletons indicate that favorable conditions for silica preservation persisted in the water column during deposition and in the sediment column after deposition.

Combining the first three criteria, an alteration index (1–5) was developed (Fig. 13). The index qualitatively compares samples to one another so that trends may be recognized.

Abundance was assessed using the following criteria: A = abundant, more than ten valves per field of view; M = moderate, 1–10 valves per field of view; S = sparse, less than 1 valve in each field of view (searching required).

Because the abundance of zeolites in Onslow Bay sediments generally varies inversely with the abundance and quality of diatom preservation in the sediment, abundance estimates for zeolites in each counted sample were also determined (Table 2): A = abundant, more than 25 laths per field of view; C = common, 10–25 laths per field of view; F = frequent, 1–10 laths per field of view; R = rare, less than 1 lath per field of view; * = not present. The following dis-

TABLE 2. Results of abundance and preservation analyses of Pungo River Formation diatom assemblages in Onslow Bay.

ABUNDANCE	PRESERVATION	ZEOLITE
S=sparce	1=poor	R=rare
M=moderate	2=fair	F=frequent
A=abundant	3=moderate	C=common
	4=very good	A=abundant
	5=excellent	

CORE SAMPLE #	INTERVAL	UNIT	ABUNDANCE	PRESERVATION	ZEOLITE	CORE SAMPLE #	INTERVAL	UNIT	ABUNDANCE	PRESERVATION	ZEOLITE
OB-108-1,	2.25-2.50	BBS-5	S	2	R	OB-62-2,	4.00-4.25	OBS-U	M	2	F
OB-108-2,	2.75-3.00	BBS-5	M	2	R	OB-62-3,	4.50-5.00	OBS-U	M	2	*
OB-108-3,	3.25-3.50	BBS-5	M	3	R	OB-62-4,	5.00-5.25	OBS-U	M	2	R
OB-108-4,	3.75-4.00	BBS-5	M	3	R	OB-62-5,	5.25-5.50	OBS-U	M	2	*
OB-108-5,	4.25-4.50	BBS-5	S	1	R	OB-62-6,	5.75-5.82	OBS-U	M	2	R
OB-108-6,	5.00-5.25	BBS-5	M	2	R	OB-17-1,	3.25-3.50	OBS-U	S	1	C
OB-108-7,	5.75-6.00	BBS-5	M	2	R	OB-17-2,	3.75-4.0	OBS-U	S	1	A
OB-60-1,	6.25-6.50	BBS-3	M	2	R	OB-98-1,	0.50-1.75	OBS-U	S	2	C
OB-60-2,	7.00-7.25	BBS-3	A	3	*	OB-16-8,	3.75-4.0	OBS-U	M	2	R
OB-95-1,	0.75-1.10	BBS-2	A	3	*	OB-16-9,	4.25-4.50	OBS-U	M	2	R
OB-95-2,	1.75-2.00	BBS-2	M	2	*	OB-16-10,	4.75-5.00	OBS-U	M	2	F
OB-53-1,	2.50-2.75	BBS-1	M	2	R	OB-16-11,	5.00-5.25	OBS-U	M	2	F
OB-53-2,	3.00-3.25	BBS-1	S	1	A	OB-16-12,	5.50-5.75	OBS-U	S	1	F
OB-71-1,	0.75-1.05	BBS-1	M	2	R	OB-50-1,	4.00-4.25	FPS-5	M	2	*
OB-71-2,	0.50-0.75	BBS-1	M	2	R	OB-50-2,	4.43-4.75	FPS-5	M	2	*
OB-42-11,	6.25-6.50	BBS-1	S	1	R	OB-50-3,	5.00-5.25	FPS-5	M	2	R
OB-42-12,	6.75-7.10	BBS-1	S	1	R	OB-50-4,	5.50-5.75	FPS-5	M	2	R
OB-43-5,	3.00-3.25	BBS-1	S	1	R	OB-50-5,	6.00-6.25	FPS-5	M	2	R
OB-43-6,	3.50-3.75	BBS-1	S	1	R	OB-50-6,	6.50-6.75	FPS-5	M	2	R
OB-43-7,	4.00-4.25	BBS-1	S	1	R	OB-50-7,	7.00-7.25	FPS-5	M	2	R
OB-34-1,	3.50-3.75	OBS-1	S	1	R	OB-49-12,	6.50-6.75	FPS-2	S	1	F
OB-34-2,	4.00-4.25	OBS-1	A	3	*	OB-49-13,	7.00-7.25	FPS-2	M	2	F
OB-34-3,	4.50-4.75	OBS-1	A	3	*	OB-49-14,	7.50-7.75	FPS-2	M	3	R
OB-34-4,	5.00-5.25	OBS-1	A	3	*	OB-49-15,	8.00-8.25	FPS-2	M	4	*
OB-34-5,	5.50-5.75	OBS-1	A	3	*	OB-49-16,	8.50-8.75	FPS-2	M	3	R
OB-34-6,	6.00-6.25	OBS-1	M	3	*	OB-47-1,	0.00-0.25	FPS-2	S	1	R
OB-34-7,	6.50-6.75	OBS-1	M	3	*	OB-47-3,	1.50-1.75	FPS-2	S	1	R
OB-34-8,	7.00-7.25	OBS-1	A	3	*	OB-47-4,	2.00-2.25	FPS-2	M	1	R
OB-34-9,	7.50-7.75	OBS-1	A	2	*	OB-47-5,	2.50-2.75	FPS-2	S	1	R
OB-107-1,	0.50-0.75	OBS-U	M	2	C	OB-47-6,	3.00-3.25	FPS-2	M	2	R
OB-107-2,	1.00-1.25	OBS-U	M	2	R	OB-47-7,	3.50-3.75	FPS-2	M	2	R
OB-107-3,	1.50-1.75	OBS-U	M	2	R	OB-47-8,	4.25-4.50	FPS-2	M	2	*
OB-107-4,	2.00-2.50	OBS-U	M	2	R	OB-47-9,	4.50-4.75	FPS-2	M	2	*
OB-107-5,	2.50-2.75	OBS-U	M	2	R	OB-47-10,	5.00-5.25	FPS-2	M	2	R
OB-62-1,	3.75-4.00	OBS-U	M	2	*	OB-47-11,	5.50-5.75	FPS-2	M	2	R
						OB-47-13,	6.25-6.50	FPS-2	M	2	F
						OB-47-14,	7.00-7.25	FPS-2	S	1	F
						OB-47-15,	7.50-7.75	FPS-2	S	1	A

Note: Samples are arranged in approximate stratigraphic order, starting with the youngest.

cussions are restricted to cores located along seismic profiles I-6/22 meter (northern Onslow Bay), I-4 (central Onslow Bay), and CH-1B (southern Onslow Bay) (Figs. 3–4).

ALTERATION OF FRYING PAN SECTION ASSEMBLAGES

Diatomaceous sediments in the Frying Pan Section occur only in cores located along the I-4 (central Onslow Bay) transect. Diatoms deposited in stratigraphically equivalent bioclastic sands to the north were diluted with clastic material and extensively altered due to the coarseness of the enclosing sediment and the presence of carbonate components. Stratigraphically equivalent muds in southern Onslow Bay contain zeolites that may have formed from the alteration of abundant diatom tests originally present in organic-rich muds.

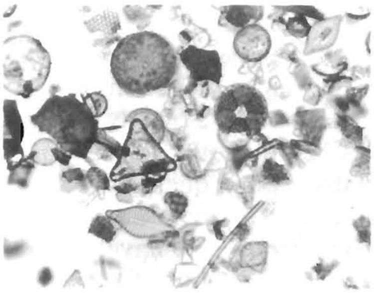
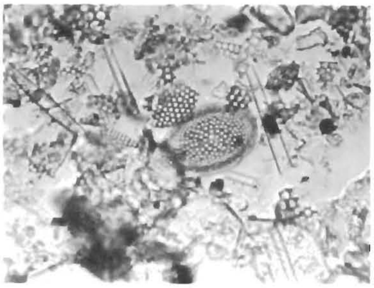
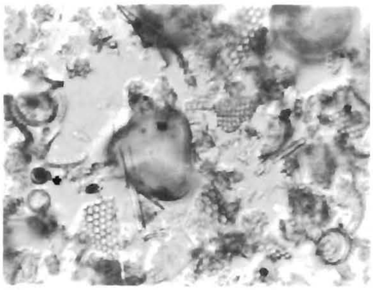
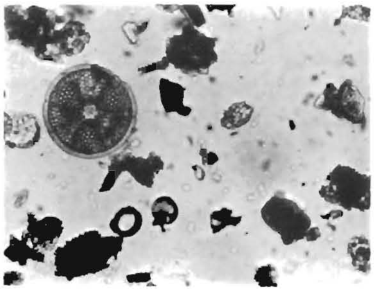
Condition 5	No evidence of alteration; most valves whole; clinoptilolite absent.	– NOT OBSERVED
Condition 4	indicated by the presence of diverse assemblages including many unbroken, uncorroded specimens; occassional corroded specimens and very rare clinoptilolite laths suggest some minor leaching.	
Condition 3	indicated by the presence of mostly broken or corroded specimens; species identification of most specimens is still possible. Whole, well preserved specimens are still common; clinoptilolite is generally rare.	
Condition 2	indicated by the dominance of fragments with whole specimens becoming less frequent than in condition 3. Dissolution rims, corroded valve rims and silica cast are common; delicate and lightly silicified species are rare or very poorly preserved clinoptilolite laths are usually frequent in occurrence.	
Condition 1	indicated by the dominance of heavily silicified forms such as *Paralia sulcata* in association with a lack of any delicate or lightly silicified forms; *P. sulcata* is often broken and corroded, often consisting of only the outer mantle or the inner hyaline area; clinoptilolite is often abundant; chert nodules may occur in associated sediments.	

FIGURE 13. Preservation scale utilized in this study.

Along the I-4 transect preservation fluctuates considerably in FPS-1 and FPS-2. Poorly preserved assemblages associated with chert horizons at the lower FPS-2 boundary (Mallette, 1986) suggest diatoms were a source of silica for chert formation. Clinoptilolite laths, though rare, are persistent in diatomaceous intervals of the Frying Pan Section. Preservation improves up-section in FPS-2 (nearly unaltered diatoms occur 5 meters below the FPS-3 boundary) followed by an upward decrease in quality of preservation that culminates in a chert horizon at the base of FPS-3. Diatom dissolution may also have provided a source of silica for this chert. South of the I-4 profile, opal lepispheres in laterally equivalent FPS-2 sediments that are barren of diatoms (Mallette, 1986) may have originated from biogenic silica. A moderately well-preserved assemblage occurs in upper FPS-5. Preservation then decreases upsection, with diatoms limited to isolated clayey pods where they were protected from silica corrosive pore waters moving through the surrounding sands. Clinoptilolite in these sands may have been, in part, formed from biogenic silica.

Alteration of Onslow Bay Section Assemblages

Preservation is very good throughout the upper 4.5 meters of OBS-1 in northern Onslow Bay. Lower OBS-1, though similar in lithology, lacks diatoms and contains chert nodules. Scarce, poorly preserved diatoms occur in sediments immediately below the OBS-1/OBS-2 boundary, suggesting diatom dissolution at this interval is related to development of the overlying unconformity.

Diatom preservation in Onslow Bay Section outliers located in southern Onslow Bay is inversely related to the occurrence of zeolites in the sediment. Abundant clinoptilolite in association with poorly preserved diatom assemblages suggests that dissolution of diatoms provided a source of silica for the formation of zeolites. Well-preserved assemblages in these outliers occur in tight, dolosilty clays which apparently excluded silica-corrosive fluids.

Alteration of Bogue Banks Section Assemblages

Diatom assemblages from the lower Bogue Banks Section are poorly preserved in cores from northern Onslow Bay (42, 43) and central Onslow Bay (53). Burrow structures within muds of northern Onslow Bay may have provided access for silica-poor waters that accelerated diatom dissolution. Moderate to well preserved assemblages occur in sandy, carbonate-rich (calcite) sediments in BBS-2 and BBS-5. This occurrence is unexpected because these sediments appear to have been subjected to considerable diagenesis. Siliceous molds of benthic foraminifera occur in less well-preserved assemblages between 2.25 and 6.00 m in core 108 (BBS-5). Well preserved assemblages in BBS-3 appear to be restricted to the muddiest intervals where preservation was favored by low permeability.

SUMMARY AND CONCLUSIONS

Diatom assemblages indicate a middle Burdigalian age for the lowermost third-order stratigraphic section (Frying Pan Section) in central Onslow Bay. Units FPS-1 through FPS-5 are assigned to Zone I of Abbott (1978) corresponding to an age of middle Burdigalian. Diatoms were not recovered from FPS-6. Diatom assemblages in Onslow Bay Section outliers in southern Onslow Bay are assigned to Zones II and III of Abbott (1978) and are, therefore, Langhian in age (early middle Miocene). Difficulty in distinguishing among forms of *Delphineis* spp. at this interval limits biostratigraphic resolution. Diatom assemblages from OBS-1 in northern Onslow Bay are also Langhian (early middle Miocene). They are assigned to Zone III of Abbott (1978). Although the age difference between Onslow Bay Section outliers and OBS-1 is slight, the more clearly distinguishable forms of *Delphineis* spp. in OBS-1 suggest it is younger. Diatom assemblages in BBS-1 through BBS-5 are assigned to Zone VI of Abbott (1978), indicating a Serravallian age.

Diatom-based biostratigraphic age assignments for Pungo River Formation strata in Onslow Bay indicate that the Frying Pan Sequence is equivalent in age to (1) the Fairhaven Diatomaceous Earth Member of the Calvert Formation of Maryland and (2) the lower commercial phosphorite bed (unit B of Riggs and others, 1982) of the Pungo River Formation at Aurora, N.C. The Onslow Bay Section is equivalent to (1) the Plum Point Marl Member of the Calvert Formation, and (2) the upper commercial phosphorite bed (unit C of Riggs and others, 1982) and unit D of the Pungo River Formation at Aurora. The Bogue Banks Section is equivalent to the Choptank Formation of Maryland and Virginia and is slightly younger than beds recognized by Abbott and Ernissee (1983) in cores taken near Belhaven, N.C.

Diatom assemblages in Onslow Bay indicate deposition in shallow marine conditions. Mixing with oceanic waters varied through time, probably as a response to changes in sea level, intensity of upwelling currents and influence of paleobathymetric features. Water depth was no greater than that to which light could penetrate.

Frying Pan Section assemblages are dominated by benthic and neritic species. The low relative abundance of planktonic species suggests shelf waters were not extensively mixed with oceanic water. Species indicative of upwelling are rare in central Onslow Bay, but phosphate-rich sediments in equivalent strata in southern Onslow Bay suggest upwelling during deposition of lower Frying Pan Section sediments. Assemblages in central Onslow Bay were deposited as facies equivalents to zeolitic muds in southern Onslow Bay, which probably formed from pre-existing organic-rich, diatomaceous muds. Assemblages associated with upwelling were simply not preserved in southern Onslow Bay. Large populations of benthic diatoms in central Onslow Bay were likely sustained by nutrient supplies within organic-rich muds.

Planktonic species indicative of upwelling increase in abundance in Onslow Bay Section assemblages. Upwelling associated with deposition of these assemblages may have been related to impingement of the ancestral Gulf Stream on the continental shelf during an early middle Miocene transgression (Snyder and others, 1982; Popenoe, 1983; Riggs, 1984), as well as to wind-induced upwelling and intensification of oceanic circulation (Scotese and Summerhayes, 1986).

Increases in planktonic cold-water and upwelling indicator species in the Bogue Banks Section indicate incursion of cool oceanic currents, overall climatic cooling or a combination of both. Oxygen isotope analyses of benthic foraminifera at low and high latitude DSDP sites indicate relatively small latitudinal temperature gradients in world oceans of the early Miocene (Savin and others, 1975). Middle Miocene divergence in high and low latitudinal temperatures coincided with the growth of the East Antarctic ice sheet (Woodruff and others, 1981; Savin and others, 1981). Steeper latitudinal temperature gradients during this period would likely be accompanied by both intensification of boundary currents and associated upwelling, as well as by equatorward intrusions of cold-water floras and faunas. Because the Cape Lookout High was no longer a prominent paleobathymetric feature during deposition of the Bogue Banks Section (Snyder, 1982), cool waters of an ancestral Labrador current may have intruded Onslow Bay from the north. Oscillations between largely benthic and planktonic predominated diatom assemblages suggest changing upwelling intensities, water depths or nutrient concentrations. Periodic deprivation of nutrients from shelf waters during sealevel low-stands or times of weakened upwelling may have allowed benthic dominated assemblages to flourish by using stored nutrients in organic-rich muds. This relationship was observed by Hendey (1964) in the littoral zone of British coastal waters and is probably significant in the sublittoral zone as well. Sea level fluctuations played an integral part in controlling the influence of these factors on diatom populations.

Diatom abundance in Pungo River sediments is related to three major factors: (1) availability of nutrients in the water column and sediments during deposition, (2) amount of diluent sediments, and (3) post-depositional alteration.

Preservation of diatom assemblages has been affected by two major factors: permeability of enclosing sediments and composition of associated sediment particles. Tight, dolosilty clays are the best matrix for diatom preservation. Assemblages are generally poorly preserved in sandier, more permeable sediments, particularly if they are carbonate rich. An inverse relationship between diatom preservation and occurrence of chert and zeolites suggests that these minerals crystallized from silica liberated by the dissolution of diatoms.

Although large-scale trends in quality of preservation were not recognized, diatomaceous sediments were not observed in phosphate-rich intervals. The presence of diatoms in phosphatic sands at Aurora (unit B) indicates that diatoms do occur in environments where phosphate forms. Their absence in Onslow Bay phosphorites probably results from destruction during diagenesis. It is unclear what role diatoms play in the formation of phosphatic sediments. However, the occurrence of diatomaceous facies within Pungo River Formation depositional cycles suggests that diatoms influence the flux of phosphorus from seawater to sediments.

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APPENDIX I

ANNOTATED FLORAL REFERENCE LIST

All diatom taxa observed in Onslow Bay are listed in alphabetical order by genus and species. Descriptions cited are those which are easily accessible in modern works. If descriptions from modern works are inadequate, the original description is given in addition to the work from which identification was made. Species concepts follow the works of Andrews, Abbott and Barron. Silicoflagellates are also included under a separate heading. However, they are tabulated along with diatom taxa in appendix tables. Species concepts for silicoflagellates follow Perch-Neilsen.

Species descriptions are presented only for undescribed forms that were commonly observed and appear to be of biostratigraphic importance. Though no formal taxonomic assignments are made here, samples containing specimens of these forms have been contributed to the USGS diatom collection at Reston, Virginia for further study.

Taxonomic considerations. Gradational evolution characterizes some taxa within Miocene sequences in Onslow Bay. Forms having morphologic characteristics intermediate between two or more taxa make species assignment difficult. This problem was most pronounced in the benthic genera *Delphineis, Rhaphoneis* and *Sceptroneis.* Late early Miocene forms of *Delphineis* from the Frying Pan Section closely resemble the early middle Miocene form *D. ovata* and in some cases *D. penelliptica.* However, overall smaller proportions and flatter valve surfaces suggest closer affinities to *D. surirella* Andrews and *D. surirelloides* Simonsen. *Delphineis* undergoes considerable morphologic diversification in early middle Miocene Onslow Bay Section outliers. Most forms are assignable to *D. ovata* or *D. penelliptica,* although distinction between them is sometimes arbitrary. Species assignments for *Delphineis* are less difficult in OBS-1 assemblages from northern Onslow Bay. Here, the distinctly tapered apices of *D. penelliptica* are clearly a distinguishing characteristic.

Late early Miocene forms of *Rhaphoneis* in the Frying Pan Section form a large complex of variable and gradational species. Most forms closely resemble either *R. margaritata* or *R. magnapunctata.* However, assignment of some individuals to these species is complicated by size-related morphotypic variation. Forms resembling *R. scalaris* (*R. scalaris* var. *A*) in the Frying Pan Section differ from specimens described by Andrews (1979) in having transversely oriented elliptical pores which lack any longitudinal divisions. *R. scalaris* s.s. makes its first appearance in early middle Miocene Onslow Bay Section outliers.

Diatoms assigned to *Sceptroneis* in the Frying Pan Section form a complex with closest affinities for *S. caduceus.* While most of these forms are similar to specimens of *S. caduceus* illustrated by Andrews (1978), the widely variable proportions of observed specimens often necessitate 'lumping' them at the generic level. *S. caduceus* is replaced by *S. grandis* Abbott in the Onslow Bay Section. The cooccurrence of *S. grandis* with forms resembling *S. caduceus* suggests that *S. caduceus* was ancestral to *S. grandis* and that these species fully intergrade during the late early Miocene. Further evaluation of *Sceptroneis* in these deposits may reveal forms which are useful stratigraphic markers.

DIATOMS

Actinocyclus ellipticus Grunow, Pl. 1, figs. 1–2
  Actinocyclus ellipticus Grunow.—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 13, pl. 3, figs. 5–6.

Actinocyclus ellipticus var. *javanicus* Reinhold, Pl. 1, fig. 3
  Actinocyclus ellipticus Reinhold.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 30, pl. 1, figs. 7–8.

Actinocyclus incertus Grunow
  Actinocyclus incertus Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 230, pl. 1, fig. 2.

Actinocyclus ingens Rattray, Pl. 1, fig. 4
  Actinocyclus ingens Rattray.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 230, pl. 1, fig. 3.

Actinocyclus ingens var. *nodus* Baldauf, Pl. 1, fig. 5
  Actinocyclus ingens var. *nodus* BALDAUF, *in* Baldauf and Barron, 1980, Micropaleontology, v. 26, p. 104, pl. 1, figs. 5–9.

Actinocyclus octonarius Ehrenberg, Pl. 1, fig. 6
  Actinocyclus octonarius Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 231, pl. 1, fig. 4.

Actinocyclus robustus Andrews, Pl. 1, fig. 7
  Actinocyclus robustus ANDREWS, *in* Abbott and Andrews, 1979, Micropaleontology, v. 25, p. 231, pl. 1, figs. 5–8; pl. 7, fig. 2.

Actinocyclus tennelus (Brébisson), Pl. 1, fig. 8
  Actinocyclus tennelus (Brébisson).—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 14, pl. 3, figs. 8–9.

Actinoptychus australis (Grunow), Pl. 1, fig. 9
  Actinoptychus australis (Grunow).—ANDREWS, 1978, Micropaleontology, v. 24, p. 382, pl. 1, fig. 5.

Actinoptychus heliopelta Grunow, Pl. 1, figs. 10–11

Actinoptychus heliopelta Grunow.—ANDREWS, 1978, Micropaleontology, v. 24, p. 382, pl. 1, figs. 7–8; pl. 6, fig. 2.

Actinoptychus marylandicus Andrews, Pl. 1, figs. 12–13
Actinoptychus marylandicus Andrews.—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 14–15, pl. 4, figs. 3–6.

Actinoptychus senarius (Ehrenberg), Pl. 1, fig. 14
Actinoptychus senarius (Ehrenberg).—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 15, pl. 4, figs. 7–8.

Actinoptychus virginicus (Grunow)
Actinoptychus virginicus (Grunow).—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 15, pl. 4, figs. 9–12.

Actinoptychus thumii (Schmidt)
Actinoptychus thumii (Schmidt).—ANDREWS, 1978, Micropaleontology, v. 24, p. 382, pl. 2, fig. 6.

Anaulus sp., Pl. 1, fig. 16

Asteromphalus aff. *A. imbricatus* Wallich, Pl. 1, fig. 15
Asteromphalus aff. *A. imbricatus* Wallich.—ABBOTT, 1985, Initial Reports D.S.D.P., v. 84, p. 527, pl. 1, fig. 2–3.

Aulacodiscus argus (Ehrenberg), Pl. 2, fig. 1
Aulacodiscus argus (Ehrenberg).—HENDEY, 1964, Ministry of Agriculture, Fish and Food Inventory Service, no. 4, p. 97.

Aulacodiscus crux Ehrenberg, Pl. 2, fig. 3
Aulacodiscus crux Ehrenberg.—ANDREWS, 1980, Micropaleontology, v. 26, p. 25, pl. 1, fig. 5.

Aulacodiscus sp., Pl. 2, fig. 2

Auliscus sculptus (Smith)
Auliscus sculptus (Smith).—ANDREWS, 1985, Bulletins of American Paleontology, v. 87, p. 72, pl. 7, figs. 2–3.

Biddulphia aurita (Lyngbye), Pl. 2, fig. 4
Biddulphia aurita (Lyngbye).—ANDREWS, 1985, Bulletins of American Paleontology, v. 87, p. 72, pl. 7, fig. 4.

Biddulphia aff. *B. decipiens* Grunow, Pl. 1, fig. 5
Biddulphia aff. *B. decipiens* Grunow.—LOHMAN, 1948, Maryland Dept. of Geol., Mines and Water Res. Bull., v. 2, p. 173, pl. 10, fig. 6.

Biddulphia rhombus (Ehrenberg), Pl. 2, fig. 6
Biddulphia rhombus (Ehrenberg).—ANDREWS, 1980, Micropaleontology, v. 26, p. 25, pl. 1, figs. 6–7.

Biddulphia toumeyii (J. W. Bailey), Pl. 2, figs. 7–8
Biddulphia toumeyii (J. W. Bailey).—ANDREWS, 1980, Micropaleontology, v. 26, pl. 1, figs. 10–11; pl. 4, fig. 5.

Chaetoceros sp., Pl. 4, fig. 1

Cocconeis costata Gregory, Pl. 2, fig. 9
Cocconeis costata Gregory.—LOHMAN, 1948, Maryland Dept. of Geol., Mines and Water Res. Bull., v. 2, pl. 2, fig. 9.

Coscinodiscus apiculatus Ehrenberg, Pl. 2, fig. 10
Coscinodiscus apiculatus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 235, pl. 2, fig. 6.

Coscinodiscus argus Ehrenberg
Coscinodiscus argus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 235, pl. 2, fig. 7.

Coscinodiscus asteromphalus Ehrenberg, Pl. 2, fig. 11
Coscinodiscus asteromphalus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 235, pl. 2, fig. 7.

Coscinodiscus biangulatus Schmidt
Coscinodiscus biangulatus Schmidt.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 235, pl. 2, fig. 9.

Coscinodiscus curvatulus Grunow, Pl. 2, fig. 12
Coscinodiscus curvatulus Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 236, pl. 2, fig. 10.

Coscinodiscus aff. *C. denarius* Schmidt
Coscinodiscus aff. *C. denarius* Schmidt.—LOHMAN, 1941, U.S.G.S. Prof. Paper 910-B, p. 75, pl. 15, fig. 6.

Coscinodiscus decrescens Grunow, Pl. 2, fig. 13
Coscinodiscus decrescens Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 236, pl. 2, fig. 12.

Coscinodiscus gigas var. *diorama* (Schmidt), Pl. 2, figs. 14–15
Coscinodiscus gigas var. *diorama* (Schmidt).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 236, pl. 2, fig. 14.

Coscinodiscus hirosakiensis Kanaya
Coscinodiscus hirosakiensis Kanaya.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 237, pl. 2, fig. 15.

Coscinodiscus kurzii Grunow
Coscinodiscus kurzii Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 237, pl. 2, fig. 16.

Coscinodiscus lacustris Grunow, Pl. 3, fig. 1
Coscinodiscus lacustris Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 237, pl. 2, fig. 17.

Coscinodiscus lewisianus Greville, Pl. 3, fig. 2
Coscinodiscus lewisianus Greville.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 236, pl. 2, fig. 10.

Coscinodiscus marginatus Ehrenberg, Pl. 3, fig. 3
Coscinodiscus marginatus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 238, pl. 3, fig. 2.

Coscinodiscus monicae Grunow, Pl. 3, fig. 4
Coscinodiscus monicae Grunow.—LOHMAN, 1948, Maryland Dept. of Geol., Mines and Water Res. Bull., v. 2, p. 162, pl. 7, fig. 6.

Coscinodiscus nodulifer Schmidt, Pl. 3, fig. 5
Coscinodiscus nodulifer Schmidt.—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 781, pl. 10, figs. 10–11.

Coscinodiscus obscurus Schmidt, Pl. 3, fig. 6
Coscinodiscus obscurus Schmidt.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 3.

Coscinodiscus oculis-iridis Ehrenberg
Coscinodiscus oculis-iridis Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 238, pl. 3, fig. 4.

Coscinodiscus perforatus Ehrenberg, Pl. 3, fig. 7
Coscinodiscus perforatus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 5.

Coscinodiscus perforatus var. *cellulosa* Grunow, Pl. 3, fig. 8
Coscinodiscus perforatus var. *cellulosa* Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 6.

Coscinodiscus plicatus Grunow, Pl. 3, fig. 9
Coscinodiscus plicatus Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 7.

Coscinodiscus praenitidus Fenner, Pl. 3, fig. 10
Coscinodiscus praenitidus FENNER, *in* Schrader and Fenner, 1976, Initial Repts. D.S.D.P., v. 38, p. 972, pl. 14, figs. 7–9; pl. 27, fig. 8; pl. 35, fig. 24; pl. 36, fig. 5.

Coscinodiscus radiatus Ehrenberg, Pl. 3, fig. 11
Coscinodiscus radiatus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 8

Coscinodiscus rhombicus Castracane, Pl. 3, fig. 12
Coscinodiscus rhombicus Castracane.—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 729, pl. 7, figs. 1–4.

Coscinodiscus rothii (Ehrenberg), Pl. 3, fig. 13
Coscinodiscus rothii (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 239, pl. 3, fig. 9.

Coscinodiscus vetustissimus Pantocsek
Coscinodiscus vetustissimus Pantocsek.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 240, pl. 3, fig. 11.

Coscinodiscus yabei Kanaya, Pl. 3, fig. 14

Coscinodiscus yabei Kanaya.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 240, pl. 3, fig. 12.

Craspedodiscus coscinodiscus Ehrenberg, Pl. 4, figs. 2–3

Craspedodiscus coscinodiscus Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 240, pl. 3, fig. 13.

Cymatogonia amblyoceros (Ehrenberg), Pl. 4, fig. 4

Cymatogonia amblyoceros (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 241, pl. 3, fig. 16.

Cymatosira immunis (Lohman), Pl. 4, figs. 5–6

Cymatosira immunis (Lohman).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 242, pl. 3, fig. 18.

Cymatosira belgica Grunow, Pl. 4, figs. 7–8

Cymatosira belgica Grunow.—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 76, pl. 8, figs. 4–5.

Delphineis angustata (Pantocsek), Pl. 4, figs. 9–10

Delphineis angustata (Pantocsek).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 77, pl. 8, figs. 9–10.

Delphineis biseriata (Grunow), Pl. 4, fig. 11

Delphineis biseriata (Grunow).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 242, pl. 4, fig. 2.

Delphineis lineata Andrews, Pl. 4, figs. 12–13

Delphineis lineata Andrews.—ANDREWS, 1978, Micropaleontology, v. 24, p. 392, pl. 5, figs. 6–8.

Delphineis novaecaesaraea (Kain and Schultz), Pl. 4, figs. 14–15

Delphineis novaecaesaraea (Kain and Schultz).—ANDREWS, 1978, Micropaleontology, v. 24, p. 392, pl. 5, figs. 9–11; pl. 8, fig. 7.

Delphineis aff. *D. novaecaesaraea* (Kain and Schultz), Pl. 4, fig. 17

Delphineis aff. *D. novaecaesaraea* (Kain and Schultz).—ANDREWS, 1978, Micropaleontology, v. 24, p. 392, pl. 5, figs. 9–11; pl. 8, fig. 7.

Delphineis ovata Andrews, Pl. 4, figs. 18–20

Delphineis ovata Andrews.—ANDREWS, 1978, Micropaleontology, v. 24, p. 392–393, pl. 5, figs. 12–14; pl. 8, figs. 5–6.

Delphineis sp. A, Pl. 4, fig. 16

Delphineis penelliptica Andrews, Pl. 4, figs. 21–24

Delphineis penelliptica Andrews.—ANDREWS, 1978, Micropaleontology, v. 24, p. 394–395, pl. 5, figs. 5–17; pl. 8, fig. 8.

Delphineis surirella (Ehrenberg), Pl. 4, fig. 25

Delphineis surirella (Ehrenberg).—ANDREWS, 1978, Micropaleontology, v. 24, p. 83–84, pl. 1, figs. 1–5; pl. 2, figs. 6–7.

Delphineis aff. *D. surirelloides* (Simonsen), Pl. 4, fig. 26

Delphineis aff. *D. surirelloides* (Simonsen).—ANDREWS, 1980, *in* Simonsen, R. (ed.), Fourth Symposium on Recent and Fossil Marine Diatoms, Nova Hedwigia, v. 64, p. 86–87.

Denticulopsis hustedtii (Simonsen and Kanaya), Pl. 5, figs. 1–3

Denticulopsis hustedtii (Simonsen and Kanaya).—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 784, pl. 13, fig. 17.

Denticulopsis kanayae (Akiba), Pl. 5, figs. 4–6

Denticulopsis kanayae (Akiba).—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 284, pl. 13, figs. 20–21.

Denticulopsis lauta (Bailey)

Denticulopsis lauta (Bailey).—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 785, pl. 13, figs. 28–29.

Denticulopsis nicobarica (Grunow), Pl. 5, fig. 7

Denticulopsis nicobarica (Grunow).—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 785, pl. 13, fig. 19.

Denticulopsis norwegica Schrader, Pl. 5, fig. 8

Denticulopsis norwegica Schrader.—SCHRADER and FENNER, 1976, Initial Repts. D.S.D.P., v. 38, p. 963, pl. 1, fig. 38.

Denticulopsis sp., Pl. 13, fig. 3

Diploneis bombus (Ehrenberg), Pl. 5, fig. 9

Diploneis bombus (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 243, pl. 4, fig. 6.

Diploneis crabro (Ehrenberg), Pl. 5, fig. 10

Diploneis crabro (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 243, pl. 4, fig. 7.

Diplomenora cocconeiformis (Schmidt), Pl. 5, figs. 11–12

Diplomenora cocconeiformis (Schmidt).—BLAZE, 1984, British Phycological Journal, v. 19, p. 218, pl. 1, figs. 1–8; pl. 2, figs. 9–12.

Dossetia hyalina Andrews, Pl. 5, fig. 13

Dossetia hyalina ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 19, pl. 6, figs. 4–7.

Endictya oceana Ehrenberg, Pl. 5, fig. 14

Endictya oceana Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 244, pl. 4, fig. 10.

Eucampia virginica Grunow, Pl. 5, fig. 15

Eucampia virginica Grunow.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 244, pl. 4, fig. 11.

Goniothecium rogersii Ehrenberg, Pl. 5, fig. 16

Goniothecium rogersii Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 244, pl. 4, figs. 12–13.

Grammatophora angulosa Ehrenberg

Grammatophora angulosa Ehrenberg.—ANDREWS, 1980, Micropaleontology, v. 26, p. 30, pl. 2, figs. 12–13.

Grammatophora marina (Lyngbye), Pl. 5, fig. 18

Grammatophora marina (Lyngbye).—ANDREWS, 1980, Micropaleontology, v. 26, p. 30, pl. 2, fig. 14.

Grammatophora aff. *G. marina* (Lyngbye), Pl. 5, fig. 17

Grammatophora aff. *G. marina* (Lyngbye).—ANDREWS, 1980, Micropaleontology, v. 26, p. 30, pl. 2, fig. 14.

Hemiaulus bipons (Ehrenberg), Pl. 5, fig. 19

Hemiaulus bipons (Ehrenberg).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 79, pl. 8, figs. 21–22.

Hemidiscus cuneiformis Wallich, Pl. 5, fig. 20

Hemidiscus cuneiformis Wallich.—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 786, pl. 9, fig. 13.

Herotheca mamillaris Ehrenberg

Herotheca mamillaris Ehrenberg.—BARRON, 1975, Paleontographica, v. 151, p. 143, pl. 9, fig. 13.

Hyalodiscus laevis Ehrenberg, Pl. 5, fig. 21

Hyalodiscus laevis Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 245, pl. 4, fig. 16

Liradiscus asperulus Andrews, Pl. 6, fig. 2

Liradiscus asperulus ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 16, pl. 5, figs. 3–5.

Liradiscus bipolaris Lohman, Pl. 6, fig. 3

Liradiscus bipolaris LOHMAN, 1972, Naturf. Ges. Basel Verhandl., p. 346, pl. 4, fig. 11.

Lithodesmium undulatum Ehrenberg, Pl. 6, fig. 1

Lithodesmium undulatum Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 246, pl. 4, fig. 21.

Macrora stella (Azpeitia), Pl. 6, fig. 4

Macrora stella (Azpeitia).—SCHRADER, 1973, Initial Repts. D.S.D.P., v. 38, p. 706, pl. 12, figs. 21–24.

Mediara splendida Sheshukova-Poretzkaya, Pl. 6, fig. 6

Mediara splendida Sheshukova-Poretzkaya.—SCHRADER, 1973, Initial Repts. D.S.D.P., v. 38, p. 706, pl. 3, figs. 14–15.

Melosira westii W. Smith, Pl. 6, fig. 5

Melosira westii W. Smith.—ABBOTT and ANDREWS, 1979, Micropaleontology, p. 246, pl. 4, fig. 23.

Navicula directa (Smith)

Navicula directa (Smith).—HENDEY, 1964, Ministry of Agriculture, Fish and Food Inventory Service, no. 4, p. 202; ABBOTT and ERNISSEE, 1983, Smithsonian Contributions to Paleobiology, no. 53, p. 333, pl. 14, fig. 2.

Navicula hennedyii W. Smith, Pl. 6, fig. 7

Navicula hennedyii W. Smith.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 246, pl. 4, fig. 24.

Navicula lyra Ehrenberg, Pl. 6, fig. 8

Navicula lyra Ehrenberg.—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 22, pl. 7, fig. 19.

Navicula pennata Schmidt, Pl. 6, figs. 9–10

Navicula pennata Schmidt.—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 22, pl. 7, figs. 20–21.

Navicula praetexta Ehrenberg, Pl. 6, fig. 11

Navicula praetexta Ehrenberg.—HENDEY, 1964, Ministry of Agriculture, Fish and Food Inventory Service, no. 4, p. 213, pl. 33, fig. 1.

Nitzschia aff. *N. pseudocylindrica* Frenguelli, Pl. 6, figs. 12–14

Nitzschia aff. *N. pseudocylindrica* Frenguelli.—SCHRADER and FENNER, 1976, Initial Repts. D.S.D.P., v. 38, p. 992, pl. 1, figs. 3–5, 12, 15–18.

Opephora schwartzii (Grunow), Pl. 6, fig. 15

Opephora schwartzii (Grunow).—WORNARDT, 1967, Calif. Acad. Sci. Occas. Papers, no. 63, p. 75, figs. 161–165.

Paralia sulcata (Ehrenberg), Pl. 6, figs. 16–17

Paralia sulcata (Ehrenberg).—ANDREWS, 1980, Micropaleontology, v. 26, p. 31, pl. 2, fig. 23.

Perissonoë spp.

Plagiogramma aff. *P. staurophorum* (Gregory), Pl. 7, fig. 1

Plagiogramma aff. *P. staurophorum* (Gregory).—HENDEY, 1964, Ministry of Agriculture, Fish and Food Inventory Service, no. 4, p. 166, pl. 36, fig. 1.

Pleurosigma affine var. *marylandica* Grunow, Pl. 7, figs. 2–3

Pleurosigma affine var. *marylandica* Grunow.—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 23, pl. 7, fig. 24.

Podosira stelligera (J. W. Bailey), Pl. 7, fig. 4

Podosira stelligera (J. W. Bailey).—ANDREWS, 1980, Micropaleontology, v. 26, p. 32, pl. 3, fig. 4.

Pyrgupyxis johnsoniana Hendey, Pl. 7, figs. 5–6

Pyrgupyxis johnsoniana Hendey.—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 82, pl. 9, fig. 6.

Pyxidicula cruciata Ehrenberg, Pl. 7, figs. 13–14

Pyxidicula cruciata Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 249, pl. 5, fig. 7, pl. 8, fig. 5.

Pyxidicula aff. *P. cruciata* Ehrenberg, Pl. 7, figs. 11–12

Pyxidicula aff. *cruciata* Ehrenberg.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 249, pl. 5, fig. 7; pl. 8, fig. 5.

Pseudodimerogramma elongatum Schrader, Pl. 7, figs. 7–8

Pseudodimerogramma elongatum SCHRADER, *in* Schrader and Fenner, 1976, Initial Reports D.S.D.P., v. 38, p. 933, pl. 3, fig. 14.

Pseudodimerogramma elliptica Schrader, Pl. 7, figs. 9–10

Pseudodimerogramma elliptica SCHRADER, *in* Schrader and Fenner, 1976, Initial Reports D.S.D.P., v. 38, p. 933, pl. 3, fig. 5.

Rattrayella inconspicua (Rattray), Pl. 7, fig. 15

Rattrayella inconspicua (Rattray).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 250, pl. 5, fig. 8.

Raphidodiscus marylandicus Christian, Pl. 7, fig. 16

Raphidodiscus marylandicus Christian.—ANDREWS, 1978, Micropaleontology, v. 24, p. 400, pl. 5, figs. 23–24.

Rhaphoneis aff. *R. adamantea* Andrews, Pl. 7, fig. 17

Rhaphoneis aff. *R. adamantea* Andrews.—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 82, pl. 9, figs. 7–8; pl. 13, figs. 2–3.

Rhaphoneis amphiceros (Ehrenberg), Pl. 7, fig. 18

Rhaphoneis amphiceros (Ehrenberg).—ANDREWS, 1978, Micropaleontology, v. 24, p. 385, pl. 2, figs. 7–8; pl. 6, fig. 8.

Rhaphoneis capitata Andrews

Rhaphoneis capitata ANDREWS, 1978, Micropaleontology, v. 24, p. 385, pl. 3, figs. 1–3.

Rhaphoneis diamantella Andrews, Pl. 7, fig. 19

Rhaphoneis diamantella Andrews.—ANDREWS, 1978, Micropaleontology, v. 24, p. 386, pl. 3, figs. 8–9.

Rhaphoneis gemmifera Ehrenberg, Pl. 8, fig. 1

Rhaphoneis gemmifera Ehrenberg.—ANDREWS, 1978, Micropaleontology, v. 24, p. 387, pl. 3, figs. 17–19; pl. 7, fig. 8.

Rhaphoneis lancettula Grunow, Pl. 8, fig. 2

Rhaphoneis lancettula Grunow.—ANDREWS, 1978, Micropaleontology, v. 24, p. 387, pl. 3, figs. 20–21; pl. 7, fig. 4.

Rhaphoneis magnapunctata Andrews, Pl. 8, figs. 3–4

Rhaphoneis magnapunctata ANDREWS, 1978, Micropaleontology, v. 24, p. 387, pl. 4, figs. 1–4; pl. 7, fig. 2.

Rhaphoneis margaritata Andrews, Pl. 8, figs. 5–6

Rhaphoneis margaritata ANDREWS, 1978, Micropaleontology, v. 24, p. 388, pl. 4, figs. 5–9; pl. 7, fig. 1.

Rhaphoneis parilis Hanna, Pl. 8, figs. 7–9

Rhaphoneis parilis Hanna.—ANDREWS, 1978, Micropaleontology, v. 24, p. 388, pl. 3, figs. 22–23; pl. 7, fig. 5.

Rhaphoneis parvula Andrews, Pl. 8, figs. 10–11

Rhaphoneis parvula ANDREWS, 1978, Micropaleontology, v. 24, p. 388, pl. 3, figs. 24–26; pl. 7, fig. 5.

Rhaphoneis rhombica (Grunow), Pl. 8, fig. 12

Rhaphoneis rhombica (Grunow).—ANDREWS, 1978, Micropaleontology, v. 24, p. 388, pl. 3, figs. 30–31.

Rhaphoneis scalaris Ehrenberg, Pl. 8, figs. 13–15

Rhaphoneis scalaris Ehrenberg.—ANDREWS, 1978, Micropaleontology, v. 24, p. 389, pl. 4, figs. 10–11; pl. 7, fig. 6.

Rhaphoneis scalaris Ehrenberg var. A, Pl. 8, figs. 16–17

Rhaphoneis scalaris Ehrenberg.—ANDREWS, 1978, Micropaleontology, v. 24, p. 389, pl. 4, figs. 10–11.

Rhaphoneis scutula Andrews, Pl. 8, fig. 18

Rhaphoneis scutula ANDREWS, 1978, Micropaleontology, v. 24, p. 389, pl. 3, figs. 27–29; pl. 7, fig. 7.

Rhizosolenia miocenica Schrader, Pl. 9, fig. 1

Rhizosolenia miocenica Schrader.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 251, pl. 5, fig. 23.

Rhizosolenia styliformis Brightwell, Pl. 9, figs. 2–4

Rhizosolenia styliformis Brightwell.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 251, pl. 5, figs. 24–25.

Rhizosolenia spp., Pl. 9, figs. 5–6

Rossiella paleacea (Grunow), Pl. 9, figs. 10–12

Rossiella paleacea (Grunow).—BARRON, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 790, pl. 9, figs. 6–7.

Rossiella praepaleacea (Schrader), Pl. 9, figs. 8–9

Rossiella praepaleacea (Schrader).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 84; ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 241, pl. 3, fig. 15.

Sceptroneis caduceus Ehrenberg, Pl. 9, figs. 13–15

Sceptroneis caduceus Ehrenberg.—ANDREWS, 1978, Micropaleontology, v. 24, p. 396, pl. 5, figs. 18–20; pl. 8, figs. 9–10.

Sceptroneis grandis Abbott, Pl. 9, figs. 16–18

Sceptroneis grandis ABBOTT, *in* Abbott and Ernisse, 1983, Smithsonian Contributions to Paleobiology, no. 53, p. 302, pl. 11, fig. 7; pl. 12, fig. 1.

Sceptroneis sp., Pl. 9, fig. 19

Stephanogonia actinoptychus (Ehrenberg), Pl. 10, figs. 5–6

Stephanogonia actinoptychus (Ehrenberg).—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 19, pl. 6, fig. 8.

Stephanopyxis corona (Ehrenberg), Pl. 10, figs. 3–4

Stephanopyxis corona (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 252, pl. 5, fig. 27.

Stephanopyxis lineata (Ehrenberg), Pl. 10, figs. 1–2

Stephanopyxis lineata (Ehrenberg).—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 252, pl. 5, fig. 28.

Stephanopyxis turris (Greville and Arnott), Pl. 10, fig. 7

Stephanopyxis turris (Greville and Arnott).—ANDREWS, 1976, U.S.G.S. Prof. Paper 910, p. 10, pl. 2, figs. 1–2.

Synedra jouseana Sheshukova-Poretzkaya, Pl. 10, fig. 8

Synedra jouseana Sheshukova-Poretzkaya.—SCHRADER, 1973, Initial Reports D.S.D.P., v. 38, p. 710, pl. 23, figs. 21–23, 25, 38.

Thalassionema nitzschioides (Grunow), Pl. 10, figs. 12–13

Thalassionema nitzschioides (Grunow).—ANDREWS and ABBOTT , 1985, Bulletins of American Paleontology, v. 87, p. 86, pl. 9, fig. 25.

Thalassionema obtusum (Grunow), Pl. 10, figs. 9–11

Thalassionema obtusum (Grunow).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 86, pl. 9, fig. 24.

Thalassiothrix longissima Cleve and Grunow, Pl. 11, fig. 4

Thalassiothrix longissima Cleve and Grunow.—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 86, pl. 9, fig. 26.

Thalassiosira eccentrica (Ehrenberg), Pl. 10, figs. 15–16

Thalassiosira eccentrica (Ehrenberg).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 86, pl. 9, fig. 28.

Thalassiosira leptopus (Grunow), Pl. 11, fig. 1

Thalassiosira leptopus (Grunow).—HASLE and FRYXELL, 1977, Nova Hedwigia, v. 45, p. 20, pl. 1, figs. 1–4; pl. 2, figs. 5–6.

Thalassiosira lineata (Ehrenberg), Pl. 11, fig. 2

Thalassiosira lineata (Ehrenberg).—HASLE and FRYXELL, 1977, Nova Hedwigia, v. 45, p. 22, pls. 5–6, figs. 15–25.

Triceratium acutum=Biddulphia acutum (Ehrenberg), Pl. 11, fig. 5

Triceratium acutum=Biddulphia acutum (Ehrenberg).—BOYER, 1904, Md. Geol. Survey, Miocene, p. 492, pl. 134, fig. 6.

Triceratium condecorum (Ehrenberg), Pl. 11, fig. 6

Triceratium condecorum (Ehrenberg).—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 87, pl. 9, fig. 32.

Triceratium hebetatum (Grunow), Pl. 11, fig. 7

Triceratium hebetatum (Grunow).—ANDREWS, 1980, Micropaleontology, v. 26, p. 35, pl. 3, figs. 20–21; pl. 6, fig. 6.

Triceratium spinosum Bailey, Pl. 11, fig. 8

Triceratium spinosum Bailey.—ANDREWS and ABBOTT, 1985, Bulletins of American Paleontology, v. 87, p. 87, pl. 9, figs. 33–34; pl. 12, fig. 4.

Triceratium subrotundatum Schmidt, Pl. 11, fig. 9

Triceratium subrotundatum SCHMIDT, *in* Schmidt and others, 1886, pl. 93, fig. 4.

Triceratium tessellatum Greville, Pl. 11, figs. 10–11

Triceratium tessellatum Greville.—ABBOTT and ANDREWS, 1979, Micropaleontology, v. 25, p. 254, pl. 6, figs. 16–17.

Triceratium sp. A, Pl. 11, fig. 12

Xanthiopyxis spp.

Genus and species indet. 1, Pl. 11, fig. 13

Genus and species indet. 2, Pl. 11, figs. 14–15

SILICOFLAGELLATES

Cannopilus aff. *C. hemisphaericus* (Ehrenberg), Pl. 2, fig. 1

Cannopilus aff. *C. hemisphaericus* (Ehrenberg).—BUKRY and FOSTER, 1973, Initial Reports D.S.D.P., v. 16, p. 862, pl. 1, fig. 3.

Corbisema aff. *C. triacantha triacantha* (Ehrenberg) Pl. 12, figs. 6–7

Corbisema aff. *C. triacantha triacantha* (Ehrenberg).—BUKRY, 1978, Initial Reports D.S.D.P., v. 44, p. 816, pl. 1, fig. 18.

Dictyocha rhombica (Schulz), Pl. 12, figs. 8–10

Dictyocha rhombica (Schulz).—DEFLANDRE, 1941, C.R. Seances Acad. Sci. Paris, v. 212, p. 101, figs. 1–7.

Distephanus aff. *D. binoculus* (Ehrenberg), Pl. 12, figs. 2–3

Distephanus aff. *D. binoculus* (Ehrenberg).—BUKRY, 1976, Initial Reports D.S.D.P., v. 38, p. 871, pl. 9, fig. 1.

Distephanus crux (Ehrenberg), Pl. 12, figs. 11–12

Distephanus crux (Ehrenberg).—HAECKEL, 1887, Report of Scientific Results, H.M.S. Challenger 1873–1876, v. 18, p. 1553; PERCH-NIELSEN, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 832, fig. 18.

Distephanus sp., Pl. 12, figs. 4–5

Distephanus sp.—PERCH-NIELSEN, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 833, pl. 19, figs. 1–28.

Mesocena aff. *M. diodon* (Ehrenberg)

Mesocena aff. *M. diodon* (Ehrenberg).—BUKRY and FOSTER, 1973, Initial Reports D.S.D.P., v. 16, p. 828, pl. 6, figs. 6–7.

Mesocena aff. *M. elliptica* (Ehrenberg), Pl. 12, fig. 13

Mesocena aff. *M. elliptica* (Ehrenberg).—LOEBLICH and others, 1968, G.S.A. Mem. 106, p. 126–127; ABBOTT and ERNISSEE, 1983, Smithsonian Contributions to Paleobiology, no. 53, p. 353, pl. 26, fig. 9.

Mesocena elliptica (Ehrenberg), Pl. 12, fig. 14

Mesocena elliptica (Ehrenberg).—LOEBLICH and others, 1968, G.S.A. Mem. 106, p. 126–127; PERCH-NIELSEN, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy p. 836, pl. 23, figs. 13–14.

Naviculopsis contraria Bukry

Naviculopsis contraria Bukry.—PERCH-NIELSEN, 1985, *in* Bolli, H. M., Saunders, J. B., Perch-Nielsen, K. (eds.), Plankton Stratigraphy, p. 839, pl. 26, fig. 5.

Naviculopsis navicula (Ehrenberg), Pl. 12, fig. 15

Naviculopsis navicula (Ehrenberg).—BUKRY, 1976, Initial Reports D.S.D.P., v. 38, p. 873, pl. 4, fig. 9; pl. 9, figs. 12, 16.

Naviculopsis quadrata (Ehrenberg), Pl. 12, figs. 16–17

Naviculopsis quadrata (Ehrenberg).—BUKRY, 1976, Initial Reports D.S.D.P., v. 38, p. 874, pl. 4, fig. 12; pl. 12, fig. 18.

APPENDIX II

SAMPLES EXAMINED FROM ONSLOW BAY

Key: B = Barren TR = Trace * = Quant. data collected

Core/ samp. #	Interval	Diatoms	Quant.	Unit
OB-100-1,	4.50–4.75	B		Plio
OB-100-2,	5.00–5.25	B		Plio
OB-100-3,	5.50–5.75	B		Plio
OB-100-4,	6.00–6.25	B		Plio
OB-100-5,	6.50–6.75	B		Plio
OB-100-6,	7.00–7.25	B		Plio
OB-100-7,	7.50–7.75	B		Plio
OB-100-8,	8.00–8.25	B		Plio
OB-90-1,	3.50–3.75	B		Plio
OB-90-2,	4.14–4.24	B		Plio
OB-90-3,	4.50–4.75	B		Plio
OB-90-4,	5.10–5.20	B		Plio
OB-90-5,	5.50–5.67	B		Plio
OB-90-6,	5.83–5.87	B		Plio
OB-1-1,	6.50–6.75	B		BBS-8
OB-1-2,	7.00–7.25	B		BBS-8
OB-1-3,	7.50–7.75	B		BBS-8
OB-1-4,	8.00–8.25	B		BBS-8
OB-1-5,	8.50–8.75	B		BBS-8
OB-108-1,	2.25–2.50	D	*	BBS-5
OB-108-2,	2.75–3.00	D	*	BBS-5
OB-108-3,	3.25–3.50	D	*	BBS-5
OB-108-4,	3.75–4.00	D	*	BBS-5
OB-108-5,	4.25–4.50	D	*	BBS-5
OB-108-6,	5.00–5.25	D	*	BBS-5
OB-108-7,	5.75–6.00	D	*	BBS-5
OB-60-1,	6.25–6.50	D	*	BBS-3
OB-60-2,	7.00–7.25	D	*	BBS-3
OB-95-1,	0.75–1.10	D	*	BBS-2
OB-95-2,	1.75–2.00	D	*	BBS-2
OB-72-1,	0.50–0.75	B		BBS-2
OB-72-2,	1.00–1.25	B		BBS-2
OB-72-3,	1.50–1.75	B		BBS-2
OB-72-4,	2.20–2.50	B		BBS-2
OB-72-5,	2.75–3.00	B		BBS-2
OB-72-6,	3.25–3.50	B		BBS-2
OB-72-7,	3.75–4.00	D		BBS-2
OB-72-8,	4.00–4.25	D		BBS-2
OB-71-1,	0.50–0.75	D	*	BBS-1
OB-71-2,	0.75–1.05	D	*	BBS-1
OB-53-1,	2.50–2.75	D	*	BBS-1
OB-53-2,	3.00–3.25	D	*	BBS-1
OB-53-3,	3.50–3.75	D		BBS-1
OB-53-4,	4.00–4.25	TR		BBS-1
OB-53-5,	4.50–4.75	TR		BBS-1
OB-53-6,	5.00–5.25	TR		BBS-1
OB-53-7,	5.50–5.75	TR		BBS-1
OB-53-8,	6.00–6.25	TR		BBS-1
OB-42-1,	1.25–1.50	B		BBS-1
OB-42-2,	1.75–2.00	B		BBS-1
OB-42-3,	2.25–2.50	B		BBS-1
OB-42-4,	2.75–3.00	B		BBS-1
OB-42-5,	3.25–3.50	TR		BBS-1
OB-42-6,	3.75–4.00	D	*	BBS-1
OB-42-7,	4.25–4.50	D		BBS-1
OB-42-8,	4.75–5.00	D		BBS-1
OB-42-9,	5.25–5.50	D		BBS-1
OB-42-10,	5.75–6.00	D		BBS-1
OB-42-11,	6.25–6.50	D	*	BBS-1
OB-42-12,	6.75–7.10	D	*	BBS-1
OB-43-1,	1.00–1.25	TR		BBS-1
OB-43-2,	1.50–1.75	TR		BBS-1
OB-43-3,	2.00–2.25	D		BBS-1
OB-43-4,	2.50–2.75	D		BBS-1
OB-43-5,	3.00–3.25	D	*	BBS-1
OB-43-6,	3.50–3.75	D	*	BBS-1
OB-43-7,	4.00–4.25	D	*	BBS-1
OB-43-8,	4.25–4.50	D		BBS-1
OB-36-1,	4.00–4.25	B		BBS-1
OB-36-2,	4.50–4.75	B		BBS-1
OB-36-3,	5.00–5.25	B		BBS-1
OB-2-1,	3.25–3.50	B		BBS-1
OB-2-2,	4.00–4.25	B		BBS-1
OB-2-3,	4.50–4.75	B		BBS-1
OB-2-4,	5.25–5.50	B		BBS-1
OB-2-5,	5.75–6.00	B		BBS-1
OB-2-6,	6.25–6.50	B		BBS-1
OB-2-7,	7.00–7.25	B		BBS-1
OB-34-1,	3.50–3.75	D	*	OBS-1
OB-34-2,	4.00–4.25	D	*	OBS-1
OB-34-3,	4.50–4.75	D	*	OBS-1
OB-34-4,	5.00–5.25	D	*	OBS-1
OB-34-5,	5.50–5.75	D	*	OBS-1
OB-34-6,	6.00–6.25	D	*	OBS-1
OB-34-7,	6.50–6.75	D	*	OBS-1
OB-34-8,	7.00–7.25	D	*	OBS-1
OB-34-9,	7.50–7.75	D	*	OBS-1
OB-35-1,	1.75–2.00	B		OBS-1
OB-35-2,	2.25–2.50	B		OBS-1
OB-35-3,	2.75–3.00	B		OBS-1
OB-35-4,	3.63–3.75	B		OBS-1
OB-35-5,	4.00–4.25	B		OBS-1
OB-35-6,	4.50–4.75	B		OBS-1
OB-35-7,	5.00–5.25	B		OBS-1
OB-35-8,	5.75–6.00	B		OBS-1
OB-35-9,	6.25–6.50	B		OBS-1
OB-35-10,	6.75–7.00	B		OBS-1
OB-35-11,	7.25–7.50	B		OBS-1
OB-44-1,	1.55–1.75	B		OBS-1
OB-44-2,	2.00–2.25	B		OBS-1
OB-44-3,	2.50–2.75	B		OBS-1
OB-44-4,	3.00–3.25	B		OBS-1
OB-44-5,	3.50–3.75	B		OBS-1
OB-44-6,	4.00–4.25	B		OBS-1
OB-44-7,	4.50–4.75	B		OBS-1
OB-44-8,	5.00–5.25	B		OBS-1
OB-44-9,	5.50–5.75	B		OBS-1
OB-38-1,	4.75–5.00	B		OBS-1
OB-38-2,	5.25–5.50	B		OBS-1
OB-38-3,	5.75–6.00	B		OBS-1
OB-38-4,	6.25–6.50	B		OBS-1
OB-38-5,	6.75–7.00	B		OBS-1
OB-38-6,	7.25–7.50	B		OBS-1
OB-38-7,	7.75–8.00	B		OBS-1
OB-68-1,	0.45–0.75	B		OBS-1
OB-68-2,	1.50–1.75	B		OBS-1
OB-68-3,	2.00–2.25	B		OBS-1
OB-68-4,	2.50–2.75	B		OBS-1
OB-68-5,	3.00–3.25	B		OBS-1
OB-68-6,	3.55–3.75	B		OBS-1
OB-68-7,	4.00–4.25	B		OBS-1
OB-68-8,	4.50–5.00	B		OBS-1
OB-80-1,	5.50–5.70	B		OBS-1
OB-107-1,	0.50–0.75	D	*	OBS-U
OB-107-2,	1.00–1.25	D	*	OBS-U
OB-107-3,	1.50–1.75	D	*	OBS-U
OB-107-4,	2.00–2.50	D	*	OBS-U
OB-107-5,	2.50–2.75	D	*	OBS-U
OB-62-1,	3.75–4.00	D	*	OBS-U

Core/ samp. #	Interval	Diatoms	Quant.	Unit
OB-62-2,	4.00–4.25	D	*	OBS-U
OB-62-3,	4.50–5.00	D	*	OBS-U
OB-62-4,	5.00–5.25	D	*	OBS-U
OB-62-5,	5.25–5.50	D	*	OBS-U
OB-62-6,	5.75–5.82	D	*	OBS-U
OB-17-1,	3.25–3.50	D	*	OBS-U
OB-17-2,	3.75–4.00	D	*	OBS-U
OB-17-3,	4.25–4.50	D		OBS-U
OB-98-1,	0.50–1.75	D	*	OBS-U
OB-98-2,	2.00–2.25	TR		OBS-U
OB-98-3,	2.75–3.00	B		OBS-U
OB-16-1,	0.50–0.75	B		OBS-U
OB-16-2,	1.00–1.25	B		OBS-U
OB-16-3,	1.25–1.50	TR		OBS-U
OB-16-4,	1.75–2.00	D		OBS-U
OB-16-5,	2.50–2.75	D		OBS-U
OB-16-6,	3.00–3.25	D		OBS-U
OB-16-7,	3.50–3.75	D		OBS-U
OB-16-8,	3.75–4.00	D	*	OBS-U
OB-16-9,	4.25–4.50	D	*	OBS-U
OB-16-10,	4.75–5.00	D	*	OBS-U
OB-16-11,	5.00–5.25	D	*	OBS-U
OB-16-12,	5.50–5.75	D	*	OBS-U
OB-15-1,	0.00–0.25	TR		OBS-U
OB-15-2,	0.50–0.75	B		OBS-U
OB-15-3,	1.00–1.25	B		OBS-U
OB-15-4,	1.50–1.75	B		OBS-U
OB-57-1,	8.00–8.25	B		FPS-5
OB-57-2,	8.25–8.50	B		FPS-5
OB-57-3,	8.50–8.75	B		FPS-5
OB-50-1,	4.00–4.25	D	*	FPS-5
OB-50-2,	4.43–4.75	D	*	FPS-5
OB-50-3,	5.00–5.25	D	*	FPS-5
OB-50-4,	5.50–5.75	D	*	FPS-5
OB-50-5,	6.00–6.25	D	*	FPS-5
OB-50-6,	6.50–6.75	D	*	FPS-5
OB-50-7,	7.00–7.25	D	*	FPS-5
OB-50-8,	7.50–7.75	D		FPS-5
OB-50-9,	8.00–8.25	D		FPS-5
OB-50-10,	8.50–8.75	D		FPS-5
OB-70-1,	0.75–1.00	B		FPS-2
OB-70-2,	1.25–1.50	B		FPS-2
OB-70-3,	1.75–2.00	B		FPS-2
OB-117-1,	2.50–2.75	TR		FPS-2
OB-117-2,	3.00–3.25	B		FPS-2
OB-117-3,	3.50–3.75	B		FPS-2
OB-117-4,	4.00–4.25	B		FPS-2
OB-117-5,	4.50–4.75	B		FPS-2
OB-117-6,	5.00–5.25	B		FPS-2
OB-117-7,	5.50–5.75	B		FPS-2
OB-117-8,	6.00–6.25	B		FPS-2
OB-117-9,	6.50–6.75	B		FPS-2
OB-117-10,	7.00–7.25	B		FPS-2
OB-117-11,	7.50–7.75	B		FPS-2
OB-117-12,	8.00–8.25	B		FPS-2
OB-117-13,	8.50–8.75	B		FPS-2
OB-49-2,	1.50–1.75	B		FPS-2
OB-49-3,	2.00–2.25	B		FPS-2
OB-49-4,	2.50–2.75	B		FPS-2
OB-49-5,	3.00–3.25	B		FPS-2
OB-49-6,	3.50–3.75	B		FPS-2
OB-49-7,	4.00–4.25	B		FPS-2
OB-49-8,	4.50–4.75	TR		FPS-2
OB-49-9,	5.00–5.25	TR		FPS-2
OB-49-10,	5.50–5.75	TR		FPS-2
OB-49-11,	6.00–6.25	TR		FPS-2
OB-49-12,	6.50–6.75	D	*	FPS-2
OB-49-13,	7.00–7.25	D	*	FPS-2
OB-49-14,	7.50–7.75	D	*	FPS-2
OB-49-15,	8.00–8.25	D	*	FPS-2
OB-49-16,	8.50–8.75	D	*	FPS-2
OB-123-1,	0.50–0.75	B		FPS-2
OB-27-1,	1.25–1.50	B		FPS-2
OB-27-2,	1.75–2.00	B		FPS-2
OB-27-3,	2.25–2.50	B		FPS-2
OB-27-4,	2.75–3.00	B		FPS-2
OB-27-5,	3.25–3.50	B		FPS-2
OB-27-6,	3.75–4.00	B		FPS-2
OB-27-7,	4.25–4.50	B		FPS-2
OB-27-8,	4.75–5.00	B		FPS-2
OB-27-9,	5.25–5.50	B		FPS-2
OB-27-10,	5.75–6.00	B		FPS-2
OB-27-11,	6.25–6.50	B		FPS-2
OB-27-12,	6.75–7.00	B		FPS-2
OB-27-13,	7.25–7.50	B		FPS-2
OB-27-14,	7.75–8.00	B		FPS-2
OB-28-1,	1.00–1.25	TR		FPS-2
OB-28-2,	1.50–1.75	TR		FPS-2
OB-28-3,	2.00–2.25	TR		FPS-2
OB-28-4,	2.50–2.75	TR		FPS-2
OB-28-5,	3.00–3.25	TR		FPS-2
OB-28-6,	3.50–3.75	TR		FPS-2
OB-97-1,	2.00–2.25	B		FPS-2
OB-97-2,	2.50–2.75	B		FPS-2
OB-97-3,	3.00–3.25	B		FPS-2
OB-97-4,	3.50–3.75	B		FPS-2
OB-97-5,	4.00–4.25	B		FPS-2
OB-97-6,	4.50–4.75	B		FPS-2
OB-97-7,	5.00–5.25	B		FPS-2
OB-97-8,	5.50–5.75	B		FPS-2
OB-97-9,	6.00–6.25	B		FPS-2
OB-97-10,	6.50–6.75	B		FPS-2
OB-47-1,	0.00–0.25	D	*	FPS-2
OB-47-3,	1.50–1.75	D	*	FPS-2
OB-47-4,	2.00–2.25	D	*	FPS-2
OB-47-5,	2.50–2.75	D	*	FPS-2
OB-47-6,	3.00–3.25	D	*	FPS-2
OB-47-7,	3.50–3.75	D	*	FPS-2
OB-47-8,	4.25–4.50	D	*	FPS-2
OB-47-9,	4.50–4.75	D	*	FPS-2
OB-47-10,	5.00–5.25	D	*	FPS-2
OB-47-11,	5.50–5.75	D	*	FPS-2
OB-47-13,	6.25–6.50	D	*	FPS-2
OB-47-14,	7.00–7.25	D	*	FPS-2
OB-47-15,	7.50–7.75	D	*	FPS-2
OB-47-16,	8.00–8.25	D		FPS-2
OB-47-17,	8.75–9.13	D		FPS-2
OB-113-1,	1.00–1.25	B		FPS-1
OB-113-2,	1.50–1.75	B		FPS-1
OB-113-3,	2.00–2.25	B		FPS-1
OB-113-4,	2.50–2.50	B		FPS-1
OB-113-5,	3.00–3.25	B		FPS-1
OB-113-6,	3.50–3.75	B		FPS-1
OB-113-7,	4.00–4.25	B		FPS-1
OB-113-8,	4.50–4.75	B		FPS-1
OB-127-1,	4.00–4.25	B		FPS-1
OB-127-2,	4.75–5.00	B		FPS-1
OB-127-3,	5.50–5.75	B		FPS-1
OB-127-4,	6.00–6.25	B		FPS-1
OB-127-5,	6.50–6.75	B		FPS-1
OB-127-6,	7.00–7.25	B		FPS-1
OB-127-7,	7.50–7.75	B		FPS-1
OB-127-8,	8.00–8.25	B		FPS-1

APPENDIX III

STRATIGRAPHIC DISTRIBUTION OF ALL DIATOM SPECIES ENCOUNTERED IN PUNGO RIVER FORMATION SEDIMENTS FROM ONSLOW BAY

Numbers tabulated are the frequency of occurrence in a count of approximately 300 valves. The notation (*) indicates occurrences not encountered during systematic traversing (observed during cursory examination). Samples are arranged in approximate stratigraphic order.

TR=TRACE
• =DID NOT OCCUR IN COUNT

CORE	INTERVAL	ACTINOCYCLUS ELLIPTICUS	A. ELLIPTCUS VAR. JAVAN.	A. INCERTIS	A. INGENS	A. INGENS VAR. NODUS	A. OCTONARIUS	A. TENNELUS	A. ROBUSTUS	A. SPP.	ACTINOPTYCHUS AUSTRALIS	A. HELIOPELTA	A. MARYLANDICUS	A. SENARIUS	A. VIRGINICUS	A. THUMII	A. SPP.	ANAULUS SP. A	ANAULUS SPP.	AULACODISCUS CRUX	A. ARGUS	A. SPP.	AULISCUS SCULPTUS
OB-108-1,	2.25-2.50	TR					TR	TR		TR			TR	29		TR						TR	
OB-108-2,	2.75-3.00				TR		2	1		TR			TR	48	5							TR	
OB-108-3,	3.25-3.50				TR		1	TR					TR	15	TR								
OB-108-4,	3.75-4.00						TR	TR						28		TR							
OB-108-5,	4.25-4.50						4	4					TR	22								TR	
OB-108-6,	5.00-5.25					TR	5						TR	21	TR								
OB-108-7,	5.75-6.00						TR	4	TR				TR	16								3	
OB-60-1,	6.25-6.50	TR	TR	TR			TR		TR	TR			TR	16	TR							TR	
OB-60-2,	7.00-7.25													18									
OB-95-1,	0.75-1.10						TR							12	TR								
OB-95-2,	1.75-2.00				TR		TR							13	TR								
OB-53-1,	2.50-2.75		TR				TR			4			TR	21			TR						
OB-53-2,	3.00-3.25						TR							9	4							TR	
OB-71-1,	0.75-1.05						5							7								TR	
OB-71-2,	0.50-0.75	TR					6	4	TR					29	4					TR			
OB-42-11,	6.25-6.50		TR	TR			TR	TR						16	TR							3	
OB-42-12,	6.75-7.10		TR		TR				TR				TR	13								TR	
OB-43-5,	3.00-3.25	TR			4	TR							TR	21	4								
OB-43-6,	3.50-3.75	TR			TR		TR	TR						34	6							TR	
OB-43-7,	4.00-4.25	TR			TR		4						TR	24	5							TR	
OB-34-1,	3.50-3.75							5		TR	TR			15									
OB-34-2,	4.00-4.25				TR		TR	4		TR				16		TR	TR						
OB-34-3,	4.50-4.75				TR			6			TR			16									
OB-34-4,	5.00-5.25				TR		TR	4			TR			19									
OB-34-5,	5.50-5.75						6	TR						19			TR		*				
OB-34-6,	6.00-6.25				TR		TR	TR			TR			27		TR							
OB-34-7,	6.50-6.75							4		TR	TR			26									
OB-34-8,	7.00-7.25						TR	8		TR				11		TR						TR	
OB-34-9,	7.50-7.75						6		3					15									
OB-107-1,	0.50-0.75	6					6	5	TR					15									
OB-107-2,	1.00-1.25	TR		TR	TR		9	4	TR					26									
OB-107-3,	1.50-1.75	TR			TR	TR	5	5	TR					24									
OB-107-4,	2.00-2.50	TR			TR		TR	8	5					35									
OB-107-5,	2.50-2.75	TR			TR		TR	TR	TR					27									
OB-62-1,	3.75-4.00				4		6	4	TR					48									
OB-62-2,	4.00-4.25				4		6	6		6				38					*				
OB-62-3,	4.50-5.00				TR		5	8						37									
OB-62-4,	5.00-5.25				TR		7	6		TR				56									
OB-62-5,	5.25-5.50				TR		10	7	4	TR				49									
OB-62-6,	5.75-5.82				TR		5	TR						21						TR			
OB-17-1,	3.25-3.50					TR	TR	TR	TR	TR				15									
OB-17-2,	3.75-4.00						TR	TR						11								TR	
OB-98-1,	0.50-1.75	TR			6	8	TR	TR						17									
OB-16-8,	3.75-4.00	TR					4	TR						9									
OB-16-9,	4.25-4.50					TR	TR	6	TR	TR				TR			TR						
OB-16-10,	4.75-5.00	TR			TR	TR	10	TR	5					17									
OB-16-11,	5.00-5.25				TR		8	TR	TR	TR				11									
OB-16-12,	5.50-5.75	TR					5	6						19		TR							
OB-50-1,	4.00-4.25						4	9						17								TR	
OB-50-2,	4.43-4.75						22	15		4				22			TR						
OB-50-3,	5.00-5.25						21	4				15		11			TR	*			TR		
OB-50-4,	5.50-5.75				TR		13	10	TR			9		13		TR							
OB-50-5,	6.00-6.25				TR		18	5		TR	TR	TR		28								TR	
OB-50-6,	6.50-6.75				TR		18	15			TR	15		17								TR	
OB-50-7,	7.00-7.25				TR		40	6		TR•	TR	8		12								TR	
OB-49-12,	6.50-6.75				TR		13			TR				8								TR	
OB-49-13,	7.00-7.25				7		4	6	7			TR		17									
OB-49-14,	7.50-7.75				TR		9	9		11		12		25				TR				TR	
OB-49-15,	8.00-8.25				15		21	TR		TR				23			TR						
OB-49-16,	8.50-8.75				6		13	6		TR		9		18									TR
OB-47-1,	0.00-0.25						4	6		TR		TR		10			TR						TR
OB-47-3,	1.50-1.75				6		20	4				6		19									
OB-47-4,	2.00-2.25				5		6	3				TR		15									
OB-47-5,	2.50-2.75				8		5	TR	TR			TR		15								TR	
OB-47-6,	3.00-3.25				TR		9	4	4					12								TR	
OB-47-7,	3.50-3.75				TR		8	6	4			TR		11				*					
OB-47-8,	4.25-4.50						5	3	3	5				18									
OB-47-9,	4.50-4.75				2		12	3	TR			TR		20									
OB-47-10,	5.00-5.25				TR		16	6	TR			TR		13									
OB-47-11,	5.50-5.75				TR		11	3	TR			9		15									
OB-47-13,	6.25-6.50				TR		15	11	TR			6		27									
OB-47-14,	7.00-7.25				TR		16	5		TR		TR		13									
OB-47-15,	7.50-7.75						12	8	TR			8		6								TR	

CORE	INTERVAL	A. SPP.	ASTEROMPHALUS SPP.	A. CF. A. IMBRICATUS	BIDDULPHIA AURITA	B. DECIPIENS	B. RHOMBUS	B. TOUMEYII	CORBESEMA SPP.	COCCONEIS COSTATA	COSCINODISCUS APICULATUS	C. ARGUS	C. ASTEROMPHALUS	C. BIANGULATUS	C. CURVATULUS	C. DENARIUS	C. DECRESCENS	C. GIGAS VAR. DIORAMA	C. HIROSAKIENSIS	C. KURZII	C. LACUSTRIS	C. LEWISIANUS	C. MARGINATUS
OB-108-1,	2.25-2.50						TR	TR							TR								6
OB-108-2,	2.75-3.00						TR				TR		TR										3
OB-108-3,	3.25-3.50																						TR
OB-108-4,	3.75-4.00																						TR
OB-108-5,	4.25-4.50														TR								3
OB-108-6,	5.00-5.25							TR										TR					TR
OB-108-7,	5.75-6.00														TR								7
OB-60-1,	6.25-6.50	TR										TR			TR								
OB-60-2,	7.00-7.25						4																
OB-95-1,	0.75-1.10						TR																
OB-95-2,	1.75-2.00						TR	TR															
OB-53-1,	2.50-2.75						TR	TR							7			TR					TR
OB-53-2,	3.00-3.25										TR				6								6
OB-71-1,	0.75-1.05						TR								3	TR							
OB-71-2,	0.50-0.75					TR	14	TR	TR			TR	TR		TR	TR							
OB-42-11,	6.25-6.50						TR						TR										6
OB-42-12,	6.75-7.10						TR						3		TR			TR					8
OB-43-5,	3.00-3.25												TR										4
OB-43-6,	3.50-3.75							TR	TR														5
OB-43-7,	4.00-4.25						TR								TR		TR						TR
OB-34-1,	3.50-3.75						TR				TR				TR					TR	3		
OB-34-2,	4.00-4.25					TR	TR	TR			TR		TR					TR			TR		
OB-34-3,	4.50-4.75					4		TR			4		TR					TR			TR		TR
OB-34-4,	5.00-5.25			TR							7		3								TR		
OB-34-5,	5.50-5.75					TR	TR				TR										4		3
OB-34-6,	6.00-6.25			TR			TR						TR		TR		TR				TR	TR	
OB-34-7,	6.50-6.75						TR	TR			TR						TR	TR					TR
OB-34-8,	7.00-7.25				TR			TR			TR										4		3
OB-34-9,	7.50-7.75		TR					TR					4				TR						
OB-107-1,	0.50-0.75		TR							9			TR				TR						16
OB-107-2,	1.00-1.25									8	7		5				TR						9
OB-107-3,	1.50-1.75			TR		TR		TR		8	8		TR				TR						5
OB-107-4,	2.00-2.50		TR							3	3		TR		TR		TR						
OB-107-5,	2.50-2.75					TR				14	3		TR				TR						TR
OB-62-1,	3.75-4.00							TR		4		TR	TR				TR						9
OB-62-2,	4.00-4.25		TR							TR				*			TR						11
OB-62-3,	4.50-5.00		TR					3					TR				4						7
OB-62-4,	5.00-5.25							TR		3			TR				TR						16
OB-62-5,	5.25-5.50							TR	TR		TR		3			TR	6	TR					10
OB-62-6,	5.75-5.82									7				*	TR		TR						
OB-17-1,	3.25-3.50									8					TR	TR	4						7
OB-17-2,	3.75-4.00									3	3	TR	TR										8
OB-98-1,	0.50-1.75					TR				TR		4	11				3						12
OB-16-8,	3.75-4.00									6			TR				TR						TR
OB-16-9,	4.25-4.50					TR				3	TR		TR		TR								5
OB-16-10,	4.75-5.00							TR		5	TR	TR	TR			TR	TR	TR					7
OB-16-11,	5.00-5.25					TR		TR		4	4												4
OB-16-12,	5.50-5.75									3			TR										7
OB-50-1,	4.00-4.25											TR							TR			TR	
OB-50-2,	4.43-4.75							4				TR			TR				TR				
OB-50-3,	5.00-5.25	TR						TR								TR	TR	TR					3
OB-50-4,	5.50-5.75						TR	TR		TR	4							TR					TR
OB-50-5,	6.00-6.25										3	TR						TR					3
OB-50-6,	6.50-6.75							TR		TR													TR
OB-50-7,	7.00-7.25						TR																4
OB-49-12,	6.50-6.75					TR	TR									TR							
OB-49-13,	7.00-7.25		TR			TR	TR																
OB-49-14,	7.50-7.75				TR	TR					TR	TR				TR		TR					
OB-49-15,	8.00-8.25					TR		TR				TR	TR				TR						TR
OB-49-16,	8.50-8.75					TR	TR				TR					TR		TR					TR
OB-47-1,	0.00-0.25					TR					TR								TR				
OB-47-3,	1.50-1.75	TR				TR										TR							
OB-47-4,	2.00-2.25					TR																	3
OB-47-5,	2.50-2.75																						7
OB-47-6,	3.00-3.25						TR					TR											8
OB-47-7,	3.50-3.75																						5
OB-47-8,	4.25-4.50																						TR
OB-47-9,	4.50-4.75	TR					TR	TR					TR										TR
OB-47-10,	5.00-5.25	TR				TR																	3
OB-47-11,	5.50-5.75					TR	TR									TR							3
OB-47-13,	6.25-6.50					TR	TR						TR										6
OB-47-14,	7.00-7.25							TR															TR
OB-47-15,	7.50-7.75							TR															9

CORE INTERVAL	C. MONICAE	C. NODULIFER	C. OBSCURUS	C. OCULUS-IRIDIS	C. PERFORATUS	C. PERFORATUS VAR. CEL.	C. PLICATUS	C. PRAENITIDUS	C. RADIATUS	C. RHOMBICUS	C. ROTHII	C. VETUSSTISSIMUS	C. YABEI	C. SPP.	CHAETOCEROS SPP.	CRASPEDODISCUS COSCINODISCUS	CYMATOGONIA AMBLYOCEROS	CYMATOSIRA BELGICA	C. IMMUNIS	C. SPP.	DELPHINEIS ANGUSTATA	D. BISERIATA
OB-108-1, 2.25-2.50						3	8				TR											
OB-108-2, 2.75-3.00		TR			3		12		TR		3	TR										
OB-108-3, 3.25-3.50		TR					4															
OB-108-4, 3.75-4.00		TR	TR		TR	TR	9														TR	TR
OB-108-5, 4.25-4.50							11		TR			TR										
OB-108-6, 5.00-5.25						4	9					TR										
OB-108-7, 5.75-6.00			TR		TR	3	6		TR		TR		TR					TR				
OB-60-1, 6.25-6.50		TR			TR	3	TR	TR			TR	TR					TR					
OB-60-2, 7.00-7.25							TR				TR						TR	TR				
OB-95-1, 0.75-1.10							6											48				TR
OB-95-2, 1.75-2.00						3	7										4	21				
OB-53-1, 2.50-2.75	TR					10	TR				TR			TR			11					TR
OB-53-2, 3.00-3.25		TR					6							TR								
OB-71-1, 0.75-1.05							TR		5		TR		16					8				
OB-71-2, 0.50-0.75						TR	TR	TR					7					TR	4			
OB-42-11, 6.25-6.50			TR		TR	6					7											
OB-42-12, 6.75-7.10					3	11					4											TR
OB-43-5, 3.00-3.25					3	TR			TR		TR						TR	TR				
OB-43-6, 3.50-3.75	TR	TR				5		TR						TR								
OB-43-7, 4.00-4.25		TR			TR	8					TR											TR
OB-34-1, 3.50-3.75		3			5	2								TR			TR		11			
OB-34-2, 4.00-4.25		TR			7	TR								TR					16			
OB-34-3, 4.50-4.75		TR			3	5			TR		TR			TR			3		6			
OB-34-4, 5.00-5.25		TR			TR	5			TR		TR								7		TR	
OB-34-5, 5.50-5.75		5			3	5			TR										8		TR	
OB-34-6, 6.00-6.25		4			3	3			TR		TR				TR		TR		5	TR		
OB-34-7, 6.50-6.75		3	3		11	8								TR	TR		TR		15		TR	
OB-34-8, 7.00-7.25		8			3	8			4		TR				TR		TR		7			
OB-34-9, 7.50-7.75		3			TR	7			TR									T	3			
OB-107-1, 0.50-0.75		TR			4	11					TR			TR			4	T	TR			
OB-107-2, 1.00-1.25					9	16			TR							TR	TR					
OB-107-3, 1.50-1.75					4	23													TR			
OB-107-4, 2.00-2.50					3	6													TR			
OB-107-5, 2.50-2.75					5	14											TR		TR			
OB-62-1, 3.75-4.00		3			9	31	TR		6		3						TR					
OB-62-2, 4.00-4.25		6			8	15			3		3	TR							TR			
OB-62-3, 4.50-5.00		7			6	14			TR			TR										
OB-62-4, 5.00-5.25		2			4	27			4		4					TR						
OB-62-5, 5.25-5.50		3			6	21			7		4			TR		TR	TR					
OB-62-6, 5.75-5.82						10												TR	TR			
OB-17-1, 3.25-3.50					5	15			TR													
OB-17-2, 3.75-4.00					TR	5			TR		3					TR	5					
OB-98-1, 0.50-1.75		TR		TR		6			3		16			TR		TR	TR					
OB-16-8, 3.75-4.00					7	9					3						TR					
OB-16-9, 4.25-4.50	TR				4	9			3		6					TR				TR		
OB-16-10, 4.75-5.00					3	13			TR		TR						TR	TR				
OB-16-11, 5.00-5.25					3	14					TR			TR			TR					
OB-16-12, 5.50-5.75					7	16			TR		TR											
OB-50-1, 4.00-4.25					16									TR			TR					
OB-50-2, 4.43-4.75					15	25					TR			TR			TR					
OB-50-3, 5.00-5.25			TR		14	12			5								TR					
OB-50-4, 5.50-5.75				TR	7	7					TR							3				
OB-50-5, 6.00-6.25		TR			10	12			4		TR							18	13			
OB-50-6, 6.50-6.75	TR		TR		15	11			TR									TR	TR			
OB-50-7, 7.00-7.25	TR				12	9			TR		TR							5	6			
OB-49-12, 6.50-6.75											TR								29			
OB-49-13, 7.00-7.25					TR	TR		4	TR		4				TR				11			
OB-49-14, 7.50-7.75		TR			TR	3		3	TR						TR				18			
OB-49-15, 8.00-8.25						3		3	TR		4											
OB-49-16, 8.50-8.75						TR		TR	TR		TR								6			
OB-47-1, 0.00-0.25								12						TR				TR	5			
OB-47-3, 1.50-1.75								21			TR								6			
OB-47-4, 2.00-2.25						TR		12		TR									TR			
OB-47-5, 2.50-2.75						TR		17			TR								9			
OB-47-6, 3.00-3.25						TR		12											10			
OB-47-7, 3.50-3.75					TR	TR		5											4			
OB-47-8, 4.25-4.50	TR				TR	3			TR		3								6			
OB-47-9, 4.50-4.75					TR	3		12			TR								5			
OB-47-10, 5.00-5.25					TR	TR		16			TR							4	TR			
OB-47-11, 5.50-5.75	TR				TR	TR		8						TR				TR	4			
OB-47-13, 6.25-6.50	TR				4	10												TR	TR			
OB-47-14, 7.00-7.25			TR			TR		15	4		TR											
OB-47-15, 7.50-7.75					3	3		7			4							TR				

CORE	INTERVAL	D. LINEATA	D. NOVAECAESARAEA	D. OVATA	D. SP. A	D. PENELLIPTICA	D. AFF. D. SURIRELLOIDES	D. SPP.	DENTICULOPSIS HUSTEDTII	D. KANAYAE	D. LAUTA	D. NICOBARICA	D. NORWEGICA	D. SPP.	DICTYOCHA RHOMBICA	DIPLONEIS BOMBUS	D. CRABRO	D. SPP.	DIPLOMENORA COCCONEIOF	D. SPP.	DISTEPHANUS CRUX	D. SPP.	DOSSETIA HYALINA
OB-108-1,	2.25-2.50	3							7														
OB-108-2,	2.75-3.00	8							10								TR						
OB-108-3,	3.25-3.50	24						TR	24														
OB-108-4,	3.75-4.00	TR	TR						51								TR						
OB-108-5,	4.25-4.50	9							58														
OB-108-6,	5.00-5.25	TR						TR	36					TR			TR				TR		
OB-108-7,	5.75-6.00	TR							18														
OB-60-1,	6.25-6.50	34	TR					TR	TR					TR									
OB-60-2,	7.00-7.25	40	TR						TR								TR						
OB-95-1,	0.75-1.10		TR				TR		5								TR						
OB-95-2,	1.75-2.00	TR	3						20									TR					
OB-53-1,	2.50-2.75	TR	8													TR		TR			TR		
OB-53-2,	3.00-3.25	TR	TR														TR						
OB-71-1,	0.75-1.05	17							12								TR						
OB-71-2,	0.50-0.75	21							6								6						
OB-42-11,	6.25-6.50								TR								TR					TR	
OB-42-12,	6.75-7.10	TR															TR						TR
OB-43-5,	3.00-3.25	4	9														TR						TR
OB-43-6,	3.50-3.75	10	31								TR						3						
OB-43-7,	4.00-4.25	8	7				TR		TR								5						TR
OB-34-1,	3.50-3.75			31	3	4						TI	*										
OB-34-2,	4.00-4.25		TR	8												TR							
OB-34-3,	4.50-4.75	3		13								TI	TR			TR							
OB-34-4,	5.00-5.25	TR		21		6										TR							
OB-34-5,	5.50-5.75			9	TR	TR							*								TR		
OB-34-6,	6.00-6.25		TR	16		TR		TR						TR		TR							
OB-34-7,	6.50-6.75			10																			
OB-34-8,	7.00-7.25	TR		8	TR	5																	
OB-34-9,	7.50-7.75	3		12		TR										TR	TR						
OB-107-1,	0.50-0.75			8		8											8						
OB-107-2,	1.00-1.25			TR		6											15						TR
OB-107-3,	1.50-1.75			14	TR	10											8						
OB-107-4,	2.00-2.50		6	16		7				3							8						
OB-107-5,	2.50-2.75		7	15		6											12						
OB-62-1,	3.75-4.00			8	TR												8						
OB-62-2,	4.00-4.25			TR		3										TR	3						
OB-62-3,	4.50-5.00			8		3				*							3						
OB-62-4,	5.00-5.25	TR		TR		3											7						
OB-62-5,	5.25-5.50		3	TR	3	11				TR							5	TR		TR			
OB-62-6,	5.75-5.82		12	46		8				8							15						
OB-17-1,	3.25-3.50			12		11																	
OB-17-2,	3.75-4.00			TR		TR											TR						
OB-98-1,	0.50-1.75			6	TR																		
OB-16-8,	3.75-4.00		TR	20		TR											TR						
OB-16-9,	4.25-4.50		9	9		6											16						
OB-16-10,	4.75-5.00			10		4											9						
OB-16-11,	5.00-5.25			9		2											21						
OB-16-12,	5.50-5.75			6		4											26						
OB-50-1,	4.00-4.25		TR				9					TR					5						
OB-50-2,	4.43-4.75						3										TR						
OB-50-3,	5.00-5.25						7										3						
OB-50-4,	5.50-5.75				TR		7										3						
OB-50-5,	6.00-6.25				TR		7										6						
OB-50-6,	6.50-6.75						2																
OB-50-7,	7.00-7.25						5										TR						
OB-49-12,	6.50-6.75						TR												17				
OB-49-13,	7.00-7.25						TR										7		4				
OB-49-14,	7.50-7.75				4										TR		5		3				TR
OB-49-15,	8.00-8.25															TR	6						
OB-49-16,	8.50-8.75				3												8		TR				TR
OB-47-1,	0.00-0.25				8		13										5		4		TR		
OB-47-3,	1.50-1.75				TR												5						
OB-47-4,	2.00-2.25				4		2										8		TR				
OB-47-5,	2.50-2.75				11		2										TR		TR				
OB-47-6,	3.00-3.25				10		4										TR		TR				
OB-47-7,	3.50-3.75				10		3										3						
OB-47-8,	4.25-4.50				TR												6						
OB-47-9,	4.50-4.75				3		TR										7						
OB-47-10,	5.00-5.25				7		TR										9						
OB-47-11,	5.50-5.7				10		2										5		TR				
OB-47-13,	6.25-6.50				5												10		TR				TR
OB-47-14,	7.00-7.25																8						
OB-47-15,	7.50-7.75																8						TR

CORE	INTERVAL	ENDICTYA OCEANA	E. SPP.	EUCAMPIA VIRGINICA	HEMIAULUS BIPONS	H. SPP.	HEMIDISCUS CUNEIFORMIS	GONIOTHECIUM ROGERSII	GRAMMATOPHORA ANGULOSA	G. MARINA	HEROTHECA MAMMILARIS	HYALODISCUS LAEVIS	H. SCOTICUS	H SPP.	LITHODESMIUM UNDULATUM	LYRADISCUS ASPERULUS	L. BIPOLARIS	MACRORA STELLA	MEDIARA SPLENDIDA	MELOSIRA WESTII	MESOCENA ELLIPTICA	NAVICULA HENNEDYII	N. DIRECTA
OB-108-1,	2.25-2.50						TR					8			TR	TR				7			
OB-108-2,	2.75-3.00											TR			TR	TR				6			
OB-108-3,	3.25-3.50					TR						3								8			
OB-108-4,	3.75-4.00											3			TR	TR				5			
OB-108-5,	4.25-4.50	TR										5			TR					5		*	
OB-108-6,	5.00-5.25					TR														12			
OB-108-7,	5.75-6.00	3				TR				TR										TR			
OB-60-1,	6.25-6.50	TR						TR												10			
OB-60-2,	7.00-7.25																			8			
OB-95-1,	0.75-1.10					TR														5			
OB-95-2,	1.75-2.00														TR	TR				8			
OB-53-1,	2.50-2.75			TR				TR	TR				7	8		TR				25			
OB-53-2,	3.00-3.25											TR								40			
OB-71-1,	0.75-1.05	3								TR										8			
OB-71-2,	0.50-0.75					TR						TR								3			
OB-42-11,	6.25-6.50	6										26								50			
OB-42-12,	6.75-7.10	7						TR		TR		9								41			
OB-43-5,	3.00-3.25	TR										17								28			
OB-43-6,	3.50-3.75	TR										16								25			
OB-43-7,	4.00-4.25									TR		11							TR	30			
OB-34-1,	3.50-3.75					6													TR	TR	TR		TR
OB-34-2,	4.00-4.25	TR				11												TR			3		
OB-34-3,	4.50-4.75	TR				3													TR	TR	4		
OB-34-4,	5.00-5.25	TR				5													TR	TR	3		
OB-34-5,	5.50-5.75	3																	TR	TR			
OB-34-6,	6.00-6.25	5				TR													TR	TR	3		TR
OB-34-7,	6.50-6.75	4				TR														TR	3		
OB-34-8,	7.00-7.25					TR				TR						TR				6	TR		TR
OB-34-9,	7.50-7.75					TR														TR			TR
OB-107-1,	0.50-0.75	TR															TR			10			
OB-107-2,	1.00-1.25	TR						3												10			
OB-107-3,	1.50-1.75	TR										3								7			
OB-107-4,	2.00-2.50	TR										TR								3			
OB-107-5,	2.50-2.75	TR				TR														3			
OB-62-1,	3.75-4.00	TR	TR		TR			5				TR				TR				TR			
OB-62-2,	4.00-4.25		TR									TR											
OB-62-3,	4.50-5.00					TR											TR			3			
OB-62-4,	5.00-5.25									TR										4			
OB-62-5,	5.25-5.50		TR		TR	TR																	
OB-62-6,	5.75-5.82	TR		TR												TR	TR			TR			
OB-17-1,	3.25-3.50			TR		TR		3								TR	TR						
OB-17-2,	3.75-4.00			TR				TR		TR													
OB-98-1,	0.50-1.75	TR						3								TR	TR			TR			
OB-16-8,	3.75-4.00											9	TR							19			
OB-16-9,	4.25-4.50					TR		TR				3								15			TR
OB-16-10,	4.75-5.00	TR				TR												TR		23			
OB-16-11,	5.00-5.25											TR								9			
OB-16-12,	5.50-5.75	TR																		10			
OB-50-1,	4.00-4.25																			TR			
OB-50-2,	4.43-4.75							TR															
OB-50-3,	5.00-5.25																						TR
OB-50-4,	5.50-5.75																			TR			
OB-50-5,	6.00-6.25		TR		TR														TR				
OB-50-6,	6.50-6.75																						
OB-50-7,	7.00-7.25																						
OB-49-12,	6.50-6.75					TR				TR									4	TR			
OB-49-13,	7.00-7.25									TR		TR		TR		4			5				
OB-49-14,	7.50-7.75	3	TR		3							TR					TR			TR			TR
OB-49-15,	8.00-8.25	TR		TR		TR				TR		TR	TR	TR		TR	TR		TR	9			
OB-49-16,	8.50-8.75	TR				TR						TR				TR			TR	TR	TR		TR
OB-47-1,	0.00-0.25																		TR	5	TR		TR
OB-47-3,	1.50-1.75				TR	TR														TR			
OB-47-4,	2.00-2.25									TR						TR				12			
OB-47-5,	2.50-2.75									TR		3								11			
OB-47-6,	3.00-3.25									TR		TR							TR	10			
OB-47-7,	3.50-3.75	3								TR									TR	9			
OB-47-8,	4.25-4.50			TR		TR				TR		3							TR				TR
OB-47-9,	4.50-4.75											TR							TR	TR			
OB-47-10,	5.00-5.25									TR		4							TR	5		TR	TR
OB-47-11,	5.50-5.75									TR	TR						TR		TR	TR		TR	
OB-47-13,	6.25-6.50							TR	TR										TR	4			TR
OB-47-14,	7.00-7.25									TR		3					TR		TR	3			TR
OB-47-15,	7.50-7.75					TR				3	TR	TR							TR	5			TR

CORE INTERVAL	N. LYRA	N. PRAETEXTA	N. PENNATA	N SPP.	NAVICULOPSIS QUADRATA	N. NAVICULA	NITZSCHIA AFF. N. PORTERII	N. SP. A	N. SPP.	OPEPHORA SCHWARTZII	PARALIA COMPLEXA	P. SULCATA	PERISINOE SPP.	PLAGIOGRAMMA AFF. P. STAUR.	PLEUROSIGMA AFFINE	P. SPP.	PODOSIRA STELLIGERA	PYXIDICULA CRUCIATA	P. SPP.	PYRGUPYXIS JOHNSONIANA	P. SPP.	PSEUDODIMEROGRAMMA ELONGATA
OB-108-1, 2.25-2.50		TR	5									108				TR	17					
OB-108-2, 2.75-3.00			5									70				5	13					
OB-108-3, 3.25-3.50			TR									49				TR	4					
OB-108-4, 3.75-4.00			6	TR								29			TR		4					
OB-108-5, 4.25-4.50									TR			50				TR	11					
OB-108-6, 5.00-5.25			3						TR			36				TR	7					
OB-108-7, 5.75-6.00			TR						TR			93					22					
OB-60-1, 6.25-6.50	TR		TR									23				6						
OB-60-2, 7.00-7.25			TR									43										
OB-95-1, 0.75-1.10			TR						9			16			TR							
OB-95-2, 1.75-2.00			4				5	8				42		TR		TR	TR					3
OB-53-1, 2.50-2.75	TR	*	TR	TR								80			TR	TR			TR			TR
OB-53-2, 3.00-3.25	TR		TR									149					TR	TR				
OB-71-1, 0.75-1.05			TR							TR		42										
OB-71-2, 0.50-0.75			TR									49					TR	TR				
OB-42-11, 6.25-6.50	TR		TR									107				TR	TR					
OB-42-12, 6.75-7.10												149						3				
OB-43-5, 3.00-3.25	3		TR	TR								105				TR	TR	7				
OB-43-6, 3.50-3.75	TR		TR	TR								73				TR		TR				
OB-43-7, 4.00-4.25	4											80						4				
OB-34-1, 3.50-3.75												56			TR			5		TR		TR
OB-34-2, 4.00-4.25												116			TR		TR				TR	
OB-34-3, 4.50-4.75												113	TR									
OB-34-4, 5.00-5.25												108			TR		6	TR				TR
OB-34-5, 5.50-5.75												108										
OB-34-6, 6.00-6.25												100			3		3	3				TR
OB-34-7, 6.50-6.75												117			3		5	5				
OB-34-8, 7.00-7.25									TR			120					TR		TR	TR		TR
OB-34-9, 7.50-7.75									TR			116				TR	6	TR		TR		5
OB-107-1, 0.50-0.75												101				4		6	3			
OB-107-2, 1.00-1.25												116						4		4		
OB-107-3, 1.50-1.75												88						5		5		
OB-107-4, 2.00-2.50												78				3		5		4		
OB-107-5, 2.50-2.75												100				TR		6		TR		
OB-62-1, 3.75-4.00												105				TR		15		3		
OB-62-2, 4.00-4.25							*					118				6		6		4		
OB-62-3, 4.50-5.00												112				3		4		TR		
OB-62-4, 5.00-5.25							TR					106				3		16		TR		
OB-62-5, 5.25-5.50							TR					81				4		13				TR
OB-62-6, 5.75-5.82	TR						TR					69				TR		5		4		TR
OB-17-1, 3.25-3.50	TR											108		TR				TR		5		TR
OB-17-2, 3.75-4.00												107						6				
OB-98-1, 0.50-1.75	TR					*						32	TR			TR		3				
OB-16-8, 3.75-4.00												126						6		4		
OB-16-9, 4.25-4.50												100				TR		3		4		TR
OB-16-10, 4.75-5.00												104						5		3		
OB-16-11, 5.00-5.25												135						TR		8		
OB-16-12, 5.50-5.75												113						14		3		
OB-50-1, 4.00-4.25				TR					TR			126					10	TR			TR	
OB-50-2, 4.43-4.75				TR							TR	134		TR	TR		TR	4				TR
OB-50-3, 5.00-5.25									TR			118					3					
OB-50-4, 5.50-5.75												149				TR	6					
OB-50-5, 6.00-6.25												97					3	6				
OB-50-6, 6.50-6.75												134					6	5				
OB-50-7, 7.00-7.25												136				TR	TR	TR		TR		
OB-49-12, 6.50-6.75												24			TR					TR		TR
OB-49-13, 7.00-7.25					TR					TR		105			TR			TR				
OB-49-14, 7.50-7.75									TR			66			TR			4				TR
OB-49-15, 8.00-8.25											TR	126					TR			TR		
OB-49-16, 8.50-8.75	TR											84			TR			TR		3		
OB-47-1, 0.00-0.25								TR				107					TR			TR		TR
OB-47-3, 1.50-1.75	TR											149				TR	4					
OB-47-4, 2.00-2.25					TR	TR						120				TR	4	TR				
OB-47-5, 2.50-2.75												99				TR	TR	TR				TR
OB-47-6, 3.00-3.25												96		TR		TR				TR		TR
OB-47-7, 3.50-3.75												149		TR		TR	4	3				
OB-47-8, 4.25-4.50				TR						TR		114						6				
OB-47-9, 4.50-4.75				TR								125						TR				
OB-47-10, 5.00-5.25				TR								105		TR		TR		TR				
OB-47-11, 5.50-5.75				TR								118				TR		3				
OB-47-13, 6.25-6.50										TR		123					TR	3				
OB-47-14, 7.00-7.25												168					TR	TR				
OB-47-15, 7.50-7.75												160		TR			TR	7				

CORE	INTERVAL	P. ELLIPTICA	P. SPP.	RATTRAYELLA INCONSPICUA	RAPHIDODISCUS MARYLANDICUS	RHAPHONEIS ADAMANTEA	R. AMPHICEROS	R. CAROLINICA	R. CAPITATA	R. DIAMANTELLA	R. FOSSILE	R. FUSIFORMIS	R. GEMMIFERA	R. LANCETTULA	R. MAGNAPUNCTATA	R. MARGARITATA	R. MARGARITATA VAR.	R. PARILIS	R. PARVULA	R. RHOMBICA	R. SCALARIS	R. SCALARIS VAR. A	R. SCUTULA
OB-108-1,	2.25-2.50													TR									TR
OB-108-2,	2.75-3.00		TR	TR										TR									
OB-108-3,	3.25-3.50	TR	TR											TR									
OB-108-4,	3.75-4.00						TR						TR										TR
OB-108-5,	4.25-4.50		TR											TR									
OB-108-6,	5.00-5.25	4												TR									
OB-108-7,	5.75-6.00	6												TR									
OB-60-1,	6.25-6.50			TR			115			TR										113			TR
OB-60-2,	7.00-7.25						56													76			
OB-95-1,	0.75-1.10	TR					19			5				20					TR	36			
OB-95-2,	1.75-2.00						15			8				12					6	22			TR
OB-53-1,	2.50-2.75	TR					16							9					TR	16			
OB-53-2,	3.00-3.25		TR				11			TR				8					TR				
OB-71-1,	0.75-1.05						3							21									TR
OB-71-2,	0.50-0.75						6						TR	18						6			
OB-42-11,	6.25-6.50													13									
OB-42-12,	6.75-7.10													3									
OB-43-5,	3.00-3.25						7	TR						26					TR				
OB-43-6,	3.50-3.75													25					4	4			
OB-43-7,	4.00-4.25						5							37					3	3			
OB-34-1,	3.50-3.75				4									4							12		
OB-34-2,	4.00-4.25														TR				TR		3		
OB-34-3,	4.50-4.75																				6		
OB-34-4,	5.00-5.25			TR	TR										TR				TR		5		
OB-34-5,	5.50-5.75														4				TR		6		
OB-34-6,	6.00-6.25			TR	TR																9		
OB-34-7,	6.50-6.75				5														6		6		
OB-34-8,	7.00-7.25				TR														TR		3		
OB-34-9,	7.50-7.75	TR																	3		4		
OB-107-1,	0.50-0.75			TR		6									TR	3		11			TR	TR	
OB-107-2,	1.00-1.25					4									10	3		11	3		TR	2	
OB-107-3,	1.50-1.75					5									8	5		20	3		TR	8	
OB-107-4,	2.00-2.50					5									9			6	TR		4	11	
OB-107-5,	2.50-2.75					3					*				15	4		13	TR		3	11	
OB-62-1,	3.75-4.00			TR											17			3			3		
OB-62-2,	4.00-4.25			TR		3									20			7			4		
OB-62-3,	4.50-5.00			TR		TR						TR			12			9			13		
OB-62-4,	5.00-5.25			TR											15			5			TR		
OB-62-5,	5.25-5.50			TR		TR									47			6			5	TR	
OB-62-6,	5.75-5.82	TR		TR														29			12		
OB-17-1,	3.25-3.50	TR		TR		10									2	26		TR			3	4	
OB-17-2,	3.75-4.00			TR		6									3	8		TR			TR	TR	
OB-98-1,	0.50-1.75					12									18	3		3				4	
OB-16-8,	3.75-4.00					TR									6	10		6	TR		TR	4	
OB-16-9,	4.25-4.50					TR									3	TR		28	TR			6	
OB-16-10,	4.75-5.00														13	TR		8	TR		4	5	
OB-16-11,	5.00-5.25			TR		TR									13	5		12			3	6	
OB-16-12,	5.50-5.75					6									15			7	TR				
OB-50-1,	4.00-4.25															31		17				13	
OB-50-2,	4.43-4.75					TR							TR			15		6				TR	
OB-50-3,	5.00-5.25					TR										7		11				3	
OB-50-4,	5.50-5.75															17		18				3	
OB-50-5,	6.00-6.25			TR		5										26		15				6	
OB-50-6,	6.50-6.75			TR												29		7				TR	
OB-50-7,	7.00-7.25					6										15		32				4	
OB-49-12,	6.50-6.75				TR											28		50	23			18	
OB-49-13,	7.00-7.25		TR			3										42		6	6			11	
OB-49-14,	7.50-7.75				TR	26										19			TR			8	
OB-49-15,	8.00-8.25				TR														TR			3	
OB-49-16,	8.50-8.75				TR	33									TR	19		5	3			10	
OB-47-1,	0.00-0.25				TR	6							10			30		17				33	
OB-47-3,	1.50-1.75				TR	21										16						4	
OB-47-4,	2.00-2.25					5										22		10	3			8	
OB-47-5,	2.50-2.75	TR				8										31		17	8			25	
OB-47-6,	3.00-3.25	TR			TR	16										27		35	5			3	
OB-47-7,	3.50-3.75	TR			TR	12									TR	19		6	5			19	
OB-47-8,	4.25-4.50	TR				13										18		4	6			10	
OB-47-9,	4.50-4.75				TR	29										24		14	TR			7	
OB-47-10,	5.00-5.25	TR				17										9		4	TR			11	
OB-47-11,	5.50-5.75	TR				6			TR							20		7	TR			12	
OB-47-13,	6.25-6.50					20									TR	21		3	3				
OB-47-14,	7.00-7.25					18						TR				18		7				4	
OB-47-15,	7.50-7.75					TR						TR				13		TR	7			TR	

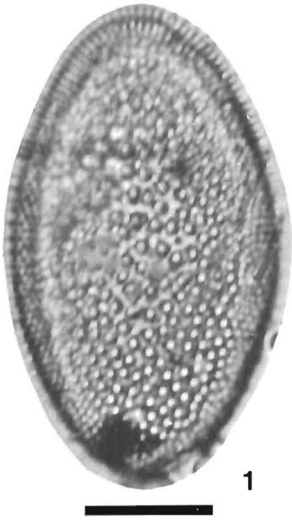
CORE	INTERVAL	R. SP. A	R. SPP.	RHIZOSOLENIA STYLIFORMIS	R. SP. A	R. SPP.	ROSSIELLA PRAEPALEACEA	R. PALEACEA	SCEPTRONEIS GRANDIS	S. CADUCEUS	STEPANOGONIA SPP.	STEPHANOPYXIS LINEATA	S. CORONA	S. SPP.	S. TURRIS	STICTODISCUS KITTONIANUS	S. SP.	SYNEDRA JOUSEANA	THALASSIONEMA NITZS.	T. OBTUSUM	THALASSIOSIRA ECCENTRICA	T. LEPTOPUS	T. LINEATA
OB-108-1,	2.25-2.50			3	TR			TR											76	9		TR	TR
OB-108-2,	2.75-3.00			6	TR			TR										TR	90	3			3
OB-108-3,	3.25-3.50		3	4	TR			TR										TR	187	7	TR	TR	TR
OB-108-4,	3.75-4.00			TR	TR	TR		TR											86	21		3	6
OB-108-5,	4.25-4.50			3				TR											88	3	TR	4	4
OB-108-6,	5.00-5.25		TR	TR				3										TR	108	8	TR	6	10
OB-108-7,	5.75-6.00		4	4				TR											73	5	TR	TR	TR
OB-60-1,	6.25-6.50		TR													TR			35	6			7
OB-60-2,	7.00-7.25		TR	TR				TR											45	TR	TR	3	TR
OB-95-1,	0.75-1.10			TR				5											79	12	7	TR	
OB-95-2,	1.75-2.00			4	TR			3											90	6	6	TR	
OB-53-1,	2.50-2.75			TR	6	4						TR		TR					46	7			
OB-53-2,	3.00-3.25				5														17				
OB-71-1,	0.75-1.05			42	TR						3								115	8	TR		
OB-71-2,	0.50-0.75			27	3			TR											81	4			5
OB-42-11,	6.25-6.50				TR										7				3	5			
OB-42-12,	6.75-7.10											TR		TR					TR	3			TR
OB-43-5,	3.00-3.25				TR						TR								5	20			
OB-43-6,	3.50-3.75				3	TR		TR							4				8	23			TR
OB-43-7,	4.00-4.25			5	5														15	21		TR	
OB-34-1,	3.50-3.75		6						17						5				20	18			
OB-34-2,	4.00-4.25		7	TR					25					TR	3	TR			27	27			
OB-34-3,	4.50-4.75		10						24						6				35	11			4
OB-34-4,	5.00-5.25		4	TR					10						TR			TR	28	13			3
OB-34-5,	5.50-5.75		7	TR					19						6				36	7		TR	
OB-34-6,	6.00-6.25		TR	TR	TR	TR			10						4				26	10	TR	TR	
OB-34-7,	6.50-6.75		3						19						TR				21	11	TR	6	6
OB-34-8,	7.00-7.25		TR						20						TR		TR		36	16	TR	TR	TR
OB-34-9,	7.50-7.75			3	3				12						3				32	5	TR		
OB-107-1,	0.50-0.75				5							TR							22		TR	TR	TR
OB-107-2,	1.00-1.25					3					TR								9	3		TR	TR
OB-107-3,	1.50-1.75			4	6							3							43	4	4	3	3
OB-107-4,	2.00-2.50			TR	TR							TR			TR				51	TR	5	3	
OB-107-5,	2.50-2.75			TR	3						TR	5							28	8	4	3	TR
OB-62-1,	3.75-4.00			TR		TR						TR			TR				TR	TR		TR	TR
OB-62-2,	4.00-4.25														TR				TR	TR	3		4
OB-62-3,	4.50-5.00			5					TR			3			TR				5	TR			3
OB-62-4,	5.00-5.25				3							4							3	TR	TR		
OB-62-5,	5.25-5.50											6			3				3		TR	TR	6
OB-62-6,	5.75-5.82	TR		TR						TR	3						TR		15		TR	3	TR
OB-17-1,	3.25-3.50			TR	TR							12			TR				17				4
OB-17-2,	3.75-4.00			TR	4							TR			TR				10				TR
OB-98-1,	0.50-1.75			12	37	TR						3	TR		TR				42	6			TR
OB-16-8,	3.75-4.00			TR	7						3	TR							4		TR	TR	4
OB-16-9,	4.25-4.50			4	10							21		TR	8				12				TR
OB-16-10,	4.75-5.00				8						TR								7	TR	TR		7
OB-16-11,	5.00-5.25	TR			3														8			TR	
OB-16-12,	5.50-5.75				3						TR	5	TR		TR				TR	TR			4
OB-50-1,	4.00-4.25																		TR				
OB-50-2,	4.43-4.75																	TR	TR				
OB-50-3,	5.00-5.25	7				TR				3	TR				TR								3
OB-50-4,	5.50-5.75	6		TR	TR										TR				TR				TR
OB-50-5,	6.00-6.25	4				TR									3					TR	TR		TR
OB-50-6,	6.50-6.75	TR								TR									TR				
OB-50-7,	7.00-7.25	6								TR					TR				TR		TR		TR
OB-49-12,	6.50-6.75	10		4						8									11				
OB-49-13,	7.00-7.25	3				TR				13					TR				5			TR	
OB-49-14,	7.50-7.75	TR		4						29										TR	TR	TR	4
OB-49-15,	8.00-8.25					3									TR								TR
OB-49-16,	8.50-8.75	3			TR					11					TR						TR		TR
OB-47-1,	0.00-0.25	TR				TR				18				TR					19		TR		TR
OB-47-3,	1.50-1.75			TR	TR					7	TR				3				5		TR		TR
OB-47-4,	2.00-2.25	TR								18	TR				TR				3		4	TR	
OB-47-5,	2.50-2.75			TR	TR					25	TR								3	TR	3	3	2
OB-47-6,	3.00-3.25			TR	TR					22	TR				TR				7		TR	4	3
OB-47-7,	3.50-3.75	TR					TR			20					4				3		TR	TR	
OB-47-8,	4.25-4.50	TR			TR					26					TR				3		TR		
OB-47-9,	4.50-4.75			TR	TR					21	TR						TR					TR	TR
OB-47-10,	5.00-5.25			TR						19	4				TR						4	TR	TR
OB-47-11,	5.50-5.75	TR								12					3				15	TR			
OB-47-13,	6.25-6.50			TR	TR					8									TR				TR
OB-47-14,	7.00-7.25					TR				8					5								
OB-47-15,	7.50-7.75			TR						3													TR

CORE	INTERVAL	T. SP. A	T. SPP.	THALASSIOTHRIX LONGISSIMA	TRICERATIUM ACUTUM	T. CONDECORUM	T. HEBETATUM	T. SUBROTUNDATUM	T. TESSELLATUM	T. SP. A	T. SPP.	XANTHIOPYXIS SPP.	GENUS AND SP. INDET. 1	GENUS AND SP. INDET. 2	SEISMIC SECTION
OB-108-1,	2.25-2.50			C							TR	TR	3	TR	BBS-5
OB-108-2,	2.75-3.00	TR		C		3		TR				TR	3	TR	BBS-5
OB-108-3,	3.25-3.50			A		TR		TR					TR	TR	BBS-5
OB-108-4,	3.75-4.00	16		A		3	TR	TR				TR			BBS-5
OB-108-5,	4.25-4.50	5		F		TR						TR	TR		BBS-5
OB-108-6,	5.00-5.25	6		C		3		TR					TR	TR	BBS-5
OB-108-7,	5.75-6.00			M		TR									BBS-5
OB-60-1,	6.25-6.50	TR		C		TR						TR	3		BBS-3
OB-60-2,	7.00-7.25	TR		A		TR	TR	TR					TR		BBS-3
OB-95-1,	0.75-1.10	3		A		TR					2		TR		BBS-2
OB-95-2,	1.75-2.00			C											BBS-2
OB-53-1,	2.50-2.75			A		TR						7	10		BBS-1
OB-53-2,	3.00-3.25	TR		C								11	TR	TR	BBS-1
OB-71-1,	0.75-1.05	TR		A								9			BBS-1
OB-71-2,	0.50-0.75			A		TR	TR				2	8	4	2	BBS-1
OB-42-11,	6.25-6.50			R		TR						9	TR	TR	BBS-1
OB-42-12,	6.75-7.10			R		TR						9	TR		BBS-1
OB-43-5,	3.00-3.25			C								7			BBS-1
OB-43-6,	3.50-3.75			A			TR			TR		20	TR		BBS-1
OB-43-7,	4.00-4.25	TR		C		TR						27	TR		BBS-1
OB-34-1,	3.50-3.75	7		R		5				TR			5		OBS-1
OB-34-2,	4.00-4.25		TR	A		7							3		OBS-1
OB-34-3,	4.50-4.75			C		3				TR			3		OBS-1
OB-34-4,	5.00-5.25	TR	TR	F		6			TR	TR			4		OBS-1
OB-34-5,	5.50-5.75			R			TR		TR						OBS-1
OB-34-6,	6.00-6.25			R		TR	TR			TR			6		OBS-1
OB-34-7,	6.50-6.75	TR		R		TR	TR						4		OBS-1
OB-34-8,	7.00-7.25	TR		A		TR	TR			TR			TR		OBS-1
OB-34-9,	7.30-7.75	TR		A		3									OBS-1
OB-107-1,	0.50-0.75			F								3			OBS-U
OB-107-2,	1.00-1.25			F		3						TR			OBS-U
OB-107-3,	1.50-1.75		TR	C		TR				TR		4	3		OBS-U
OB-107-4,	2.00-2.50			C		TR						3	3		OBS-U
OB-107-5,	2.50-2.75		TR	C		4						3	TR		OBS-U
OB-62-1,	3.75-4.00	TR	TR	C					TR			8	7	2	OBS-U
OB-62-2,	4.00-4.25			R								7	3		OBS-U
OB-62-3,	4.50-5.00		TR	F		TR						9	11		OBS-U
OB-62-4,	5.00-5.25			R						TR		5	TR		OBS-U
OB-62-5,	5.25-5.50			F					TR	TR		3	10		OBS-U
OB-62-6,	5.75-5.82			C								9	5		OBS-U
OB-17-1,	3.25-3.50			C		TR						8			OBS-U
OB-17-2,	3.75-4.00			R								6			OBS-U
OB-98-1,	0.50-1.75			A								8	3		OBS-U
OB-16-8,	3.75-4.00			C		TR			TR			6			OBS-U
OB-16-9,	4.25-4.50			C		3									OBS-U
OB-16-10,	4.75-5.00			C		TR				TR		3	3		OBS-U
OB-16-11,	5.00-5.25			F					TR				TR		OBS-U
OB-16-12,	5.50-5.75			F		TR						3	TR		OBS-U
OB-50-1,	4.00-4.25			R	TR				3				TR		FPS-5
OB-50-2,	4.43-4.75		TR	R		TR			6						FPS-5
OB-50-3,	5.00-5.25			R					3	TR			3		FPS-5
OB-50-4,	5.50-5.75			R					3	TR			TR	TR	FPS-5
OB-50-5,	6.00-6.25		TR	R	TR	TR						4	TR		FPS-5
OB-50-6,	6.50-6.75			R					6				TR	TR	FPS-5
OB-50-7,	7.00-7.25		TR	R					9				TR	TR	FPS-5
OB-49-12,	6.50-6.75		16	R		4				TR		3			FPS-2
OB-49-13,	7.00-7.25		TR	C					5				3		FPS-2
OB-49-14,	7.50-7.75		TR	C					TR	3			5	TR	FPS-2
OB-49-15,	8.00-8.25		16	R	TR	TR		TR				5	12		FPS-2
OB-49-16,	8.50-8.75		5	R		5			TR			4	3		FPS-2
OB-47-1,	0.00-0.25		TR	R								TR	5		FPS-2
OB-47-3,	1.50-1.75			R		TR			6				TR		FPS-2
OB-47-4,	2.00-2.25		TR	F					TR			TR	TR	3	FPS-2
OB-47-5,	2.50-2.75			R	TR	TR			TR			7	3	TR	FPS-2
OB-47-6,	3.00-3.25		TR	F	TR	TR			TR			4	3		FPS-2
OB-47-7,	3.50-3.75		TR	R	TR				TR				TR		FPS-2
OB-47-8,	4.25-4.50		7	F	TR	TR				TR			TR		FPS-2
OB-47-9,	4.50-4.75		7	R		TR			TR	TR			TR		FPS-2
OB-47-10,	5.00-5.25		4	R	3	TR			5					3	FPS-2
OB-47-11,	5.50-5.75		4	R		4			TR	TR		TR	TR	TR	FPS-2
OB-47-13,	6.25-6.50			R	TR	TR			TR						FPS-2
OB-47-14,	7.00-7.25			R		TR				TR		TR			FPS-1
OB-47-15,	7.50-7.75		TR	R	TR					TR			TR		FPS-1

→

PLATE 1
Each scale bar = 10 microns
v = valvar view

1-2 *Actinocyclus ellipticus* Grunow. 1. v (Core OB-53, 2.5–2.75 m). 2. v (Core OB-107, 0.5–1.0 m).
3 *Actinocyclus ellipticus* var. *javanicus* Reinhold. 3. v (Core OB-53, 2.5–2.75 m).
4 *Actinocyclus ingens* Rattray. 4. v (Core OB-62, 5.75–5.82 m).
5 *Actinocyclus ingens* var. *nodus* Baldauf. 5. v (Core OB-107, 2.5–2.75 m).
6 *Actinocyclus octonarius* Ehrenberg. 6. v (Core OB-50, 4.5–4.75 m).
7 *Actinocyclus robustus* Andrews. 7. v (Core OB-47, 2.0–2.25 m).
8 *Actinocyclus tennelus* (Brebisson) Andrews. 8. v (Core OB-108, 3.75–4.0 m).
9 *Actinoptychus australis* (Grunow) Andrews. 9. v (Core OB-108, 5.75–6.0 m).
10-11 *Actinoptychus heliopelta* Grunow. 10. v (Core OB-50, 4.0–4.25 m). 11. v (Core OB-50, 6.5–6.75 m).
12-13 *Actinoptychus marylandicus* Andrews. 12. v (Core OB-108, 5.25–5.5 m). 13. v (Core OB-53, 2.5–2.75 m).
14 *Actinoptychus senarius* (Ehrenberg) Ehrenberg. 14. v (Core OB-53, 2.5–2.75 m).
15 *Asteromphalus* aff. *A. imbricatus* Wallich. 15. v (Core OB-49, 8.0–8.25 m).
16 *Anaulus* sp. 16. v (Core OB-49, 8.0–8.25 m).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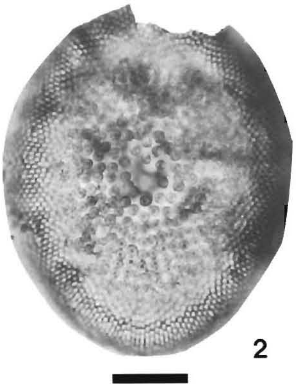
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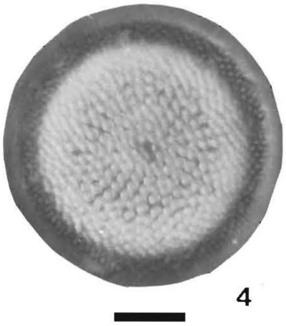
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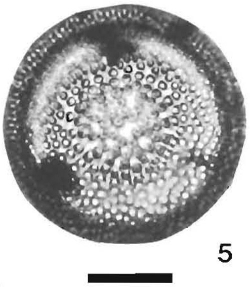
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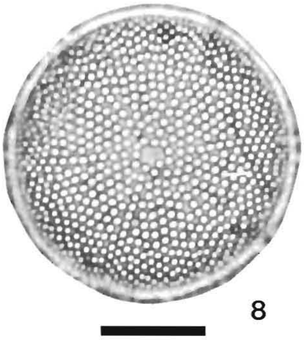
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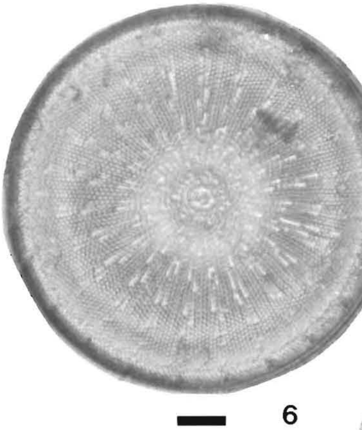
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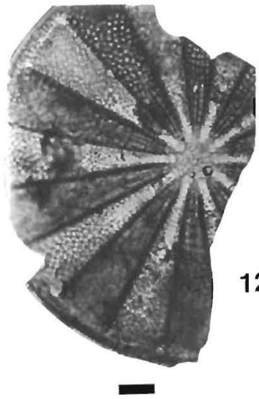
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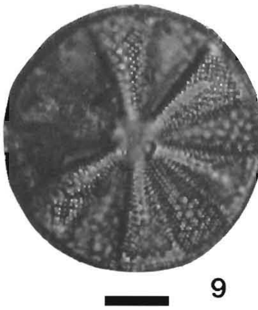
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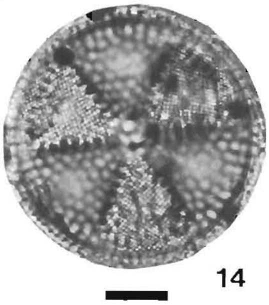
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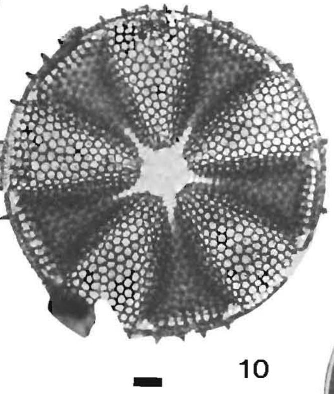
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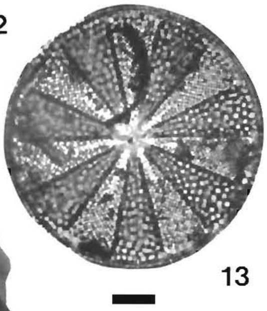
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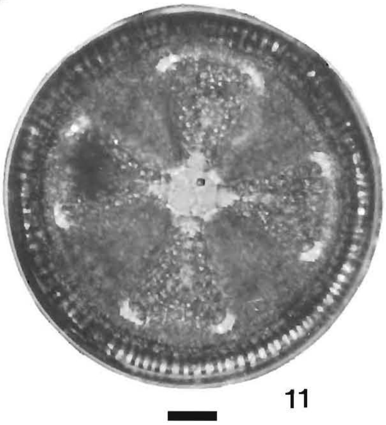
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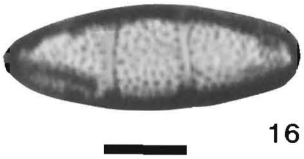
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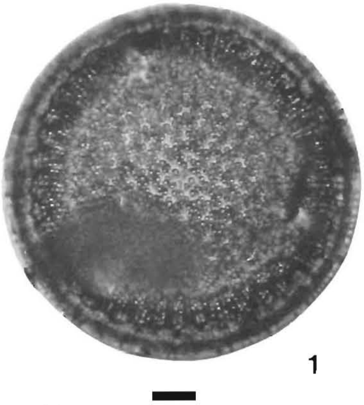
PLATE 2

Each scale bar = 10 microns unless otherwise stated

v = valvar view, g = girdle view

1 *Aulacodiscus argus* (Ehrenberg) Schmidt. 1. v (Core OB-50, 4.0–4.25 m).
2 *Aulacodiscus* sp. 2. v (Core OB-108, 3.75–4.0 m) scale = 25 μ.
3 *Aulacodiscus crux* Ehrenberg. 3. v (Core OB-34, 5.5–5.75 m) scale = 20 μ.
4 *Biddulphia aurita* (Lyngbye) Brebisson and Godey. 4. v (OB-95, 0.75–1.0 m).
5 *Biddulphia* aff. *B. decipiens* Grunow. 5. v (OB-49, 8.0–8.25 m).
6 *Biddulphia rhombus* (Ehrenberg) Wm. Smith. 6. v (OB-95, 0.75–1.0 m).
7-8 *Biddulphia toumeyii* (Bailey) Roper. 7. v (OB-108, 3.75–4.0 m). 8. g (OB-49, 6.5–6.75 m).
9 *Cocconeis costata* Gregory. 9. v (OB-107, 0.5–0.75 m).
10 *Coscinodiscus apiculatus* Ehrenberg. 10. v (OB-50, 4.5–4.75 m).
11 *Coscinodiscus asteromphalus* Ehrenberg. 11. v (OB-108, 3.75–4.0 m).
12 *Coscinodiscus curvatulus* Grunow. 12. v (OB-108, 3.75–4.0 m).
13 *Coscinodiscus decrescens* Grunow. 13. v (OB-34, 5.5–5.75 m).
14-15 *Coscinodiscus gigas* var. *diorama* (Schmidt) Grunow. 14. v (OB-108, 3.75–4.0 m) scale = 50 μ. 15. v same specimen.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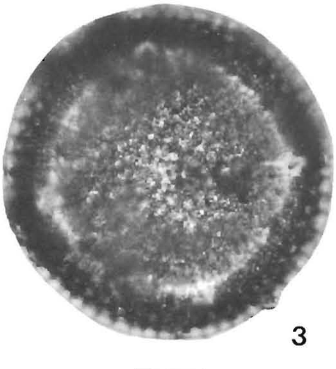
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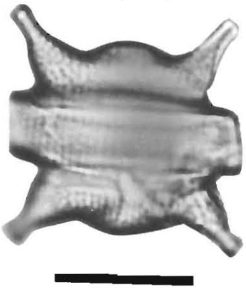
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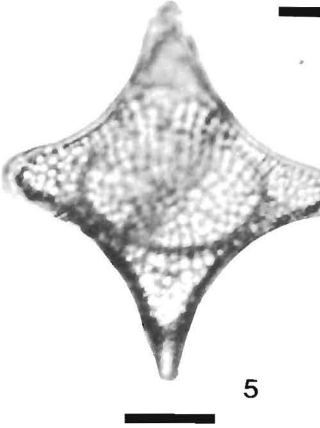
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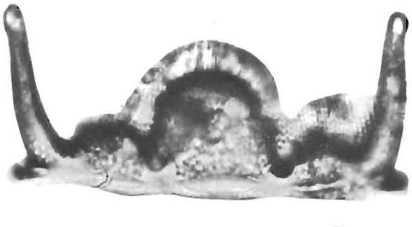
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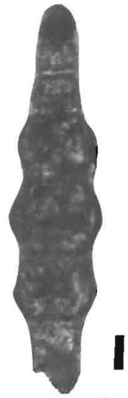
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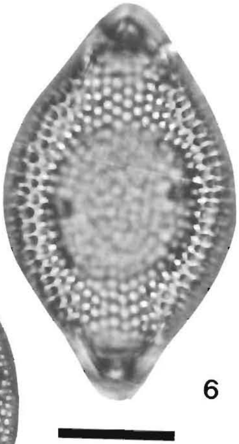
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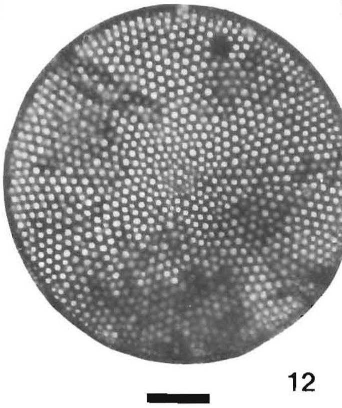
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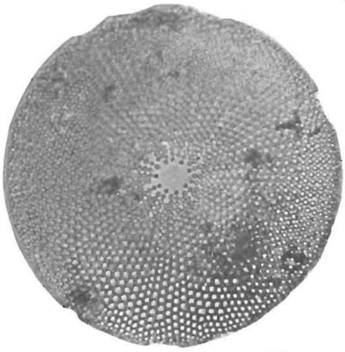
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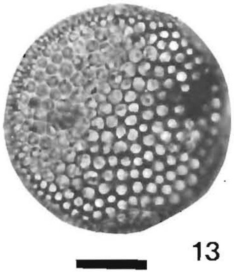
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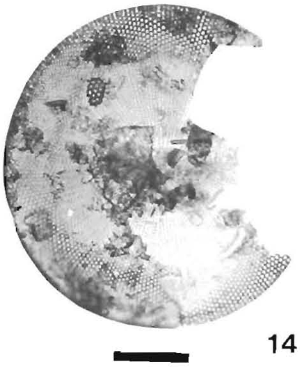
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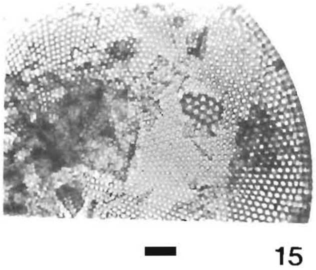
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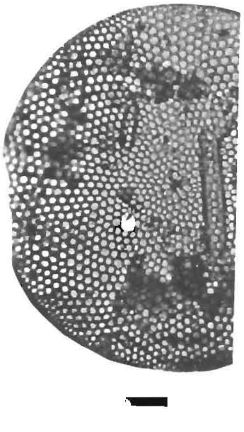
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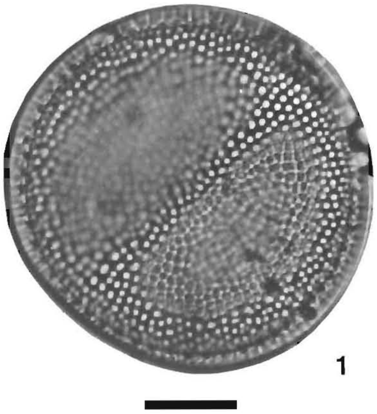
PLATE 3
Each scale bar = 10 microns
v = valvar view

1 *Coscinodiscus lacustris* Grunow. 1. v (OB-34, 6.0–6.25 m).
2 *Coscinodiscus lewisianus* Greville. 2. v (OB-34, 6.0–6.25 m).
3 *Coscinodiscus marginatus* Ehrenberg. 3. v (OB-49, 8.0–8.25 m).
4 *Coscinodiscus monicae* Grunow. 4. v (OB-34, 5.5–5.75 m).
5 *Coscinodiscus nodulifer* Schmidt. 5. v (OB-34, 6.0–6.25 m).
6 *Coscinodiscus obscurus* Schmidt. 6. v (OB-50, 4.0–4.25 m).
7 *Coscinodiscus perforatus* Ehrenberg. 7. v (OB-49, 8.0–8.25 m).
8 *Coscinodiscus perforatus* var. *cellulosa* Grunow. 8. v (OB-34, 5.5–5.75 m).
9 *Coscinodiscus plicatus* Grunow. 9. v (OB-108, 3.75–4.0 m).
10 *Coscinodiscus praenitidus* Fenner. 10. v (OB-47, 2.5–2.75 m).
11 *Coscinodiscus radiatus* Ehrenberg. 11. v (OB-50, 4.5–4.75 m).
12 *Coscinodiscus rhombicus* Castracane. 12. v (OB-47, 4.0–4.25 m).
13 *Coscinodiscus rothii* (Ehrenberg) Grunow. 13. v (OB-49, 8.0–8.25 m).
14 *Coscinodiscus yabei* Kanayae. 14. v (OB-71, 0.75–1.0 m).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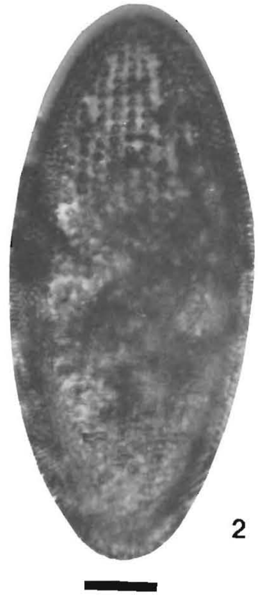
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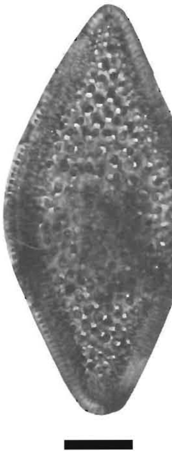
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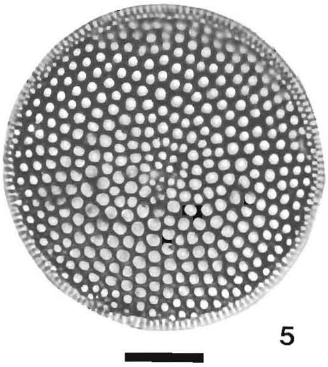
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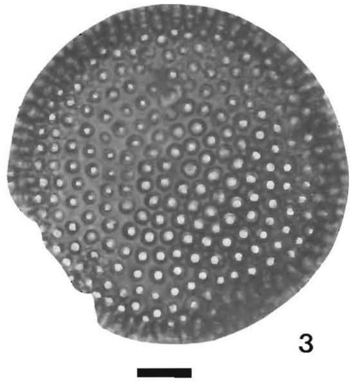
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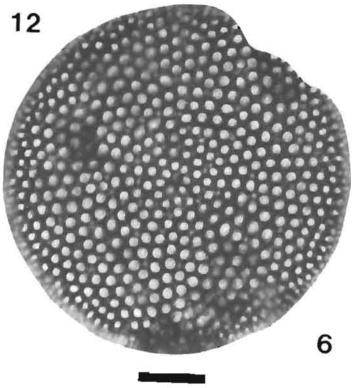
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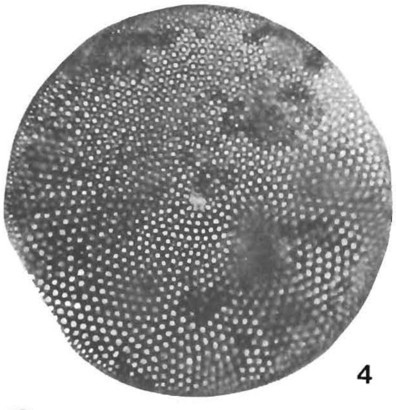
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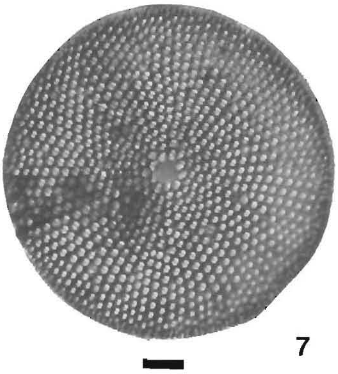
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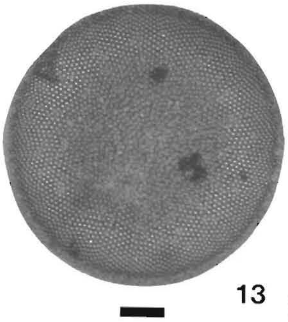
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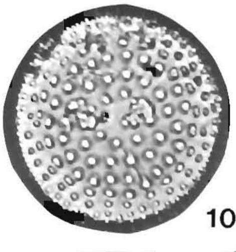
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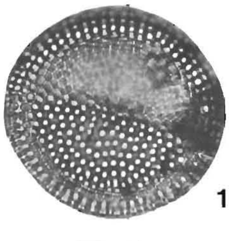
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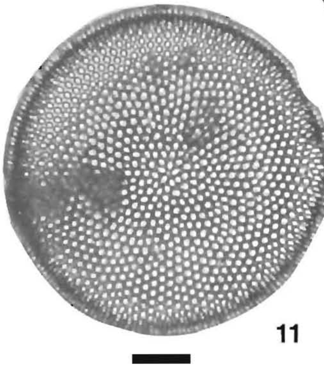
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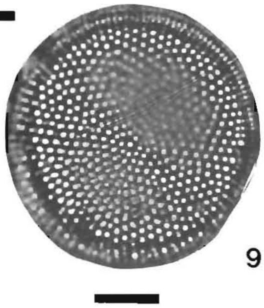
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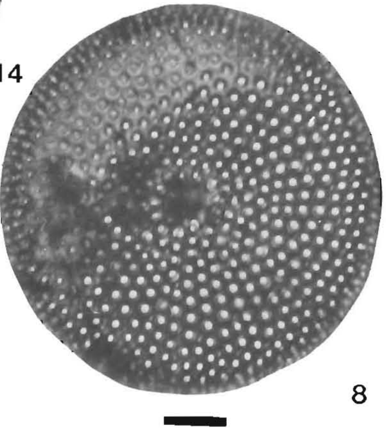
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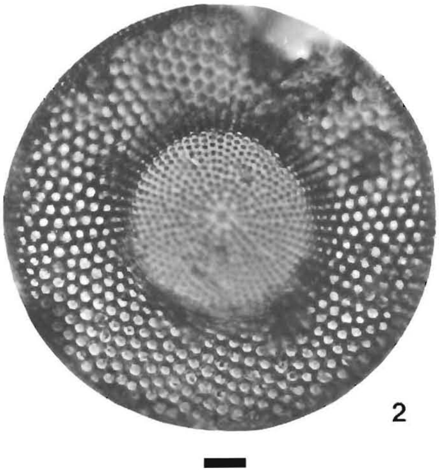
PLATE 4

Each scale bar = 10 microns
v = valvar view, g = girdle view

1 *Chaetoceros* sp. 1. g (OB-49, 8.0–8.25 m).
2-3 *Craspedodiscus coscinodiscus* Ehrenberg. 2. v (OB-62, 5.25–5.50 m). 3. v (OB-62, 5.25–5.50 m).
4 *Cymatogonia amblyoceros* (Ehrenberg) Hanna. 4. v (OB-34, 4.5–4.75 m).
5-6 *Cymatosira immunis* (Lohman) Abbott. 5. v (OB-49, 6.5–6.75 m). 6. v (OB-49, 6.5–6.75 m).
7-8 *Cymatosira belgica* Grunow. 7. v (OB-62, 4.0–4.25 m). 8. v (OB-49, 8.0–8.25 m).
9-10 *Delphineis angustata* (Pantoscek) Andrews. 9. v (OB-34, 5.5–5.75 m). 10. v (OB-34, 5.5–5.75 m).
11 *Delphineis biseriata* (Grunow) Andrews. 11. v (OB-108, 4.25–4.5 m).
12-13 *Delphineis lineata* Andrews. 12. v (OB-95, 0.75–1.0 m). 13. v (OB-34, 5.0–5.25 m).
14-15 *Delphineis novaecaesaraea* (Kain and Schultz) Andrews. 14. v (OB-107, 2.5–2.75 m). 15. v (OB-16, 4.5–5.0 m).
16 *Delphineis* sp. A. 16. v (OB-49, 6.5–6.75 m).
17 *Delphineis* aff. *D. novaecaesaraea* (Kain and Schultz) Andrews. 17. v (OB-16, 5.0–5.25 m).
18 *Delphineis ovata* Andrews. 18. v (OB-16, 5.0–5.25 m).
19-20 *Delphineis ovata* Andrews (transitional with *D. penelliptica* Andrews). 19. v (OB-16, 5.0–5.25 m). 20. v (OB-107, 2.5–2.75 m).
21-24 *Delphineis penelliptica* Andrews. 21. v (OB-34, 5.0–5.25 m). 22. v (OB-107, 3.0–3.25 m). 23. v (OB-34, 4.0–4.25 m). 24. v (OB-16, 4.5–4.75 m).
25 *Delphineis surirella* Andrews. 25. v (OB-49, 6.0–6.25 m).
26 *Delphineis* aff. *D. surirelloides* (Simonsen). 26. v (OB-49, 6.5–6.75 m).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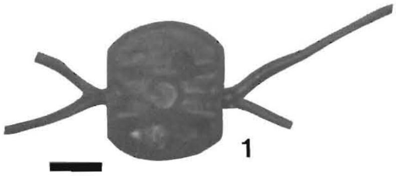
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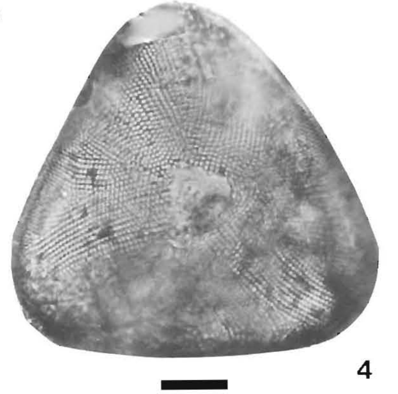
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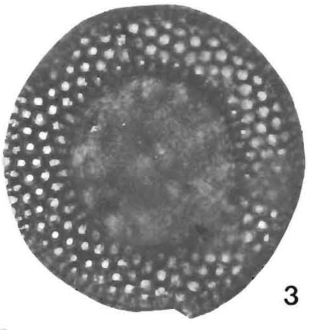
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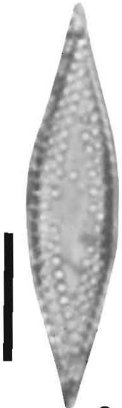
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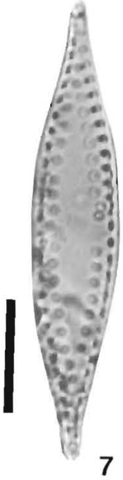
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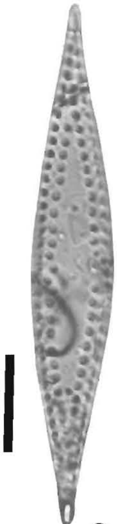
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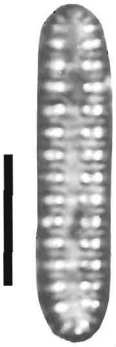
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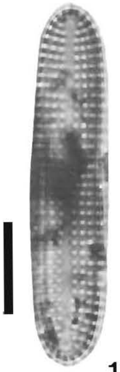
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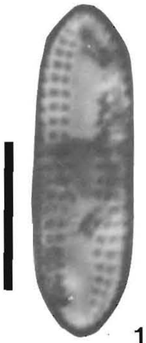
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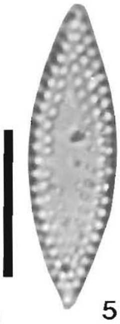
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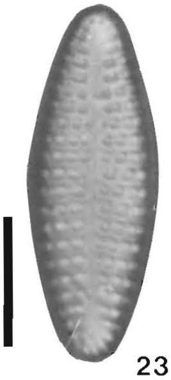
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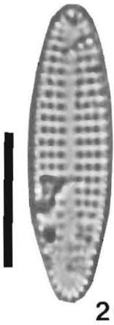
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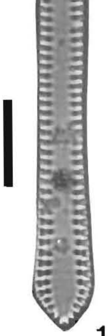
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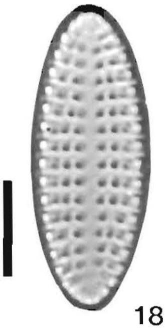
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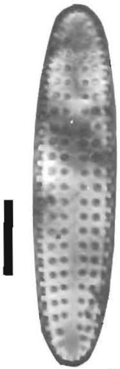
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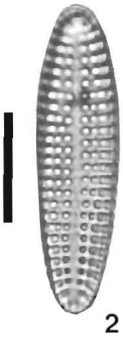
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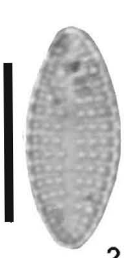
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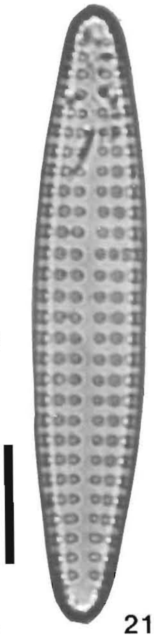
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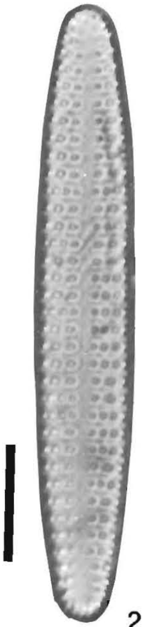
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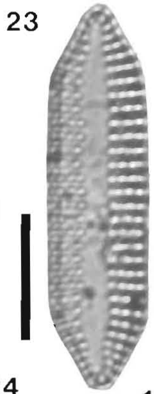
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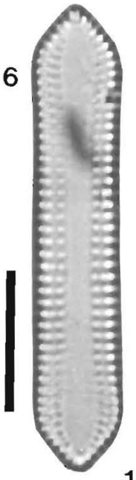
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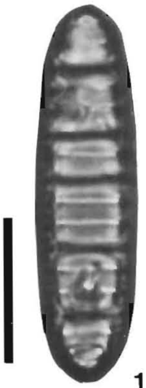
PLATE 5
Each scale bar = 10 microns
v = valvar view

1-3 *Denticulopsis hustedtii* (Simonsen and Kanayae) Simonsen. 1. v (OB-108, 4.25–4.5 m). 2. v (OB-108, 4.25–4.5 m). 3. v (OB-108, 4.25–4.5 m).
4-5 *Denticulopsis* aff. *D. kanayae* (Akiba) Barron. 4. v (OB-62, 5.0–5.25 m). 5. v (OB-62, 5.0–5.25 m).
6 *Denticulopsis kanayae* (Akiba) Barron. 6. v (OB-62, 5.0–5.25 m).
7 *Denticulopsis nicobarica* (Grunow) Simonsen. 7. v (OB-107, 2.0–2.5 m).
8 *Denticulopsis norwegia* Schrader. 8. v (OB-34, 5.0–5.25 m).
9 *Diploneis bombus* (Ehrenberg) Ehrenberg. 9. v (OB-108, 4.25–4.5 m).
10 *Diploneis crabro* (Ehrenberg) Ehrenberg. 10. v (OB-107, 2.0–2.5 m).
11-12 *Diplomenora cocconeiformis* (Schmidt) Blaze. 11. v (OB-49, 6.5–6.75 m). 12. v (OB-49, 6.5–6.75 m).
13 *Dossetia hyalina* Andrews. 13. v (OB-53, 4.0–4.25 m).
14 *Endictya oceana* Ehrenberg. 14. v (OB-34, 5.0–5.5 m).
15 *Eucampia virginica* Grunow. 15. v (OB-53, 3.0–3.25 m).
16 *Goniothecium rogersii* Ehrenberg. 16. v (OB-107, 2.5–2.75 m).
17 *Grammatophora* aff. *G. marina* (Lyngbye) Kutzing. 17. v (OB-53, 2.5–2.75 m).
18 *Grammatophora marina* (Lyngbye) Kutzing. 18. v (OB-47, 3.0–3.25 m).
19 *Hemiaulus bipons* (Ehrenberg) Grunow. 19. v (OB-49, 6.5–6.75 m).
20 *Hemidiscus cuneiformis* Wallich. 20. v (OB-108, 4.25–4.5 m).
21 *Hyalodiscus laevis* Ehrenberg. 21. v (OB-108, 4.25–4.5 m).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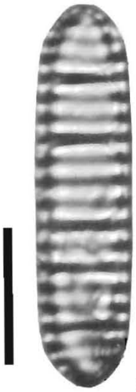
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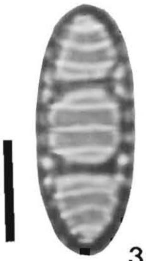
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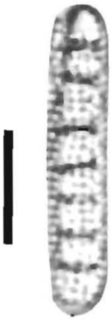
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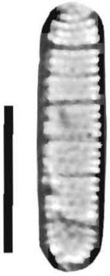
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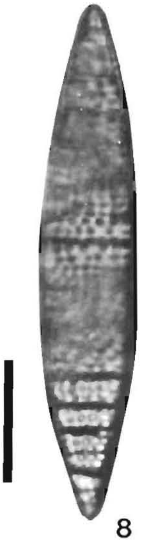
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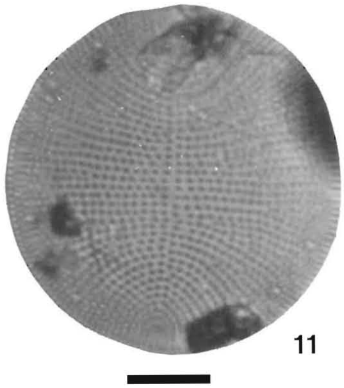
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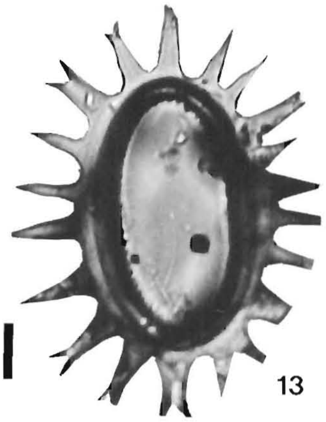
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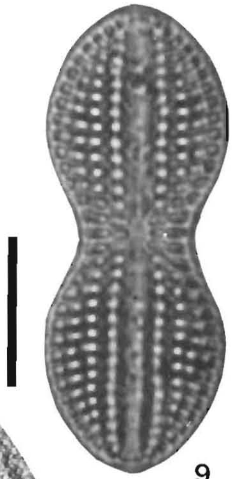
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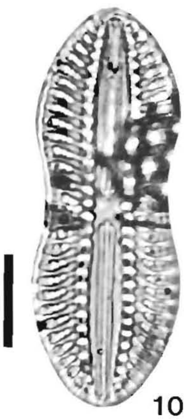
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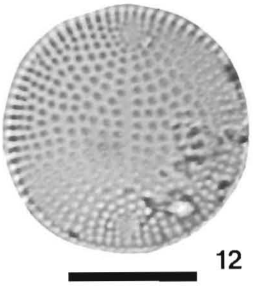
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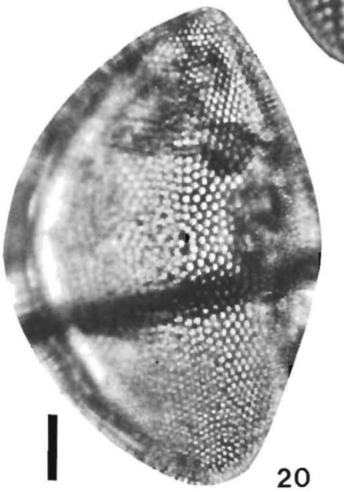
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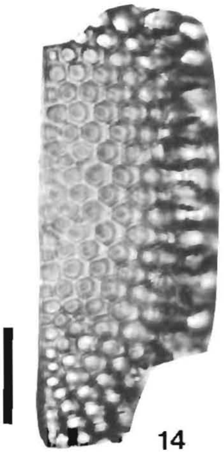
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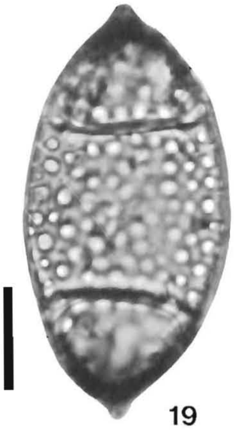
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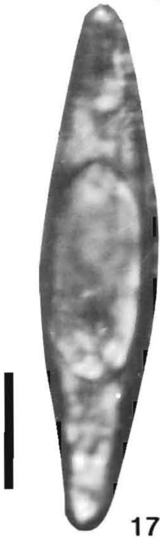
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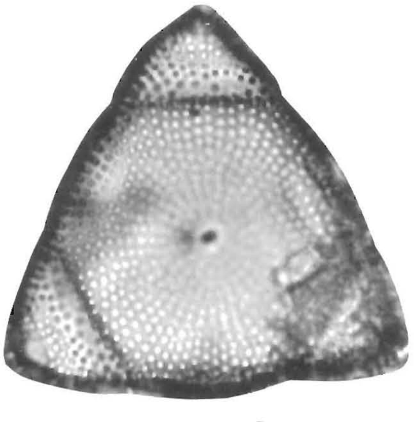
PLATE 6

Each scale bar = 10 microns

v = valvar view

1 *Lithodesmium undulatum* Ehrenberg. 1. v (OB-108, 4.25–4.5 m).
2 *Liradiscus asperulus* Andrews. 2. v (OB-49, 6.5–6.75 m).
3 *Liradiscus bipolaris* Lohman. 3. v (OB-107, 2.0–2.25 m).
4 *Macrora stella* (Azpeita) Hanna. 4. v (OB-47, 4.5–4.75 m).
5 *Melosira westii* Smith. 5. v (OB-108, 3.75–4.0 m).
6 *Mediara splendida* Sheshukova-Poretzkaya. 6. v (OB-34, 4.25–4.5 m).
7 *Navicula hennedyii* Wm Smith. 7. v (OB-108, 4.25–4.5 m).
8 *Navicula lyra* Ehrenberg. 8. v (OB-47, 2.5–2.75 m).
9-10 *Navicula pennata* Schmidt. 9. v (OB-108, 4.5–4.75 m). 10. v (OB-53, 2.5–2.75 m).
11 *Navicula praetexta* Ehrenberg. 11. v (OB-53, 2.5–2.75 m).
12-14 *Nitszchia* aff. *N. pseudocylindrica* Frenguelli. 12. v (OB-62, 5.0–5.25 m). 13. v (OB-62, 5.0–5.25 m). 14. v (OB-62, 5.0–5.25 m).
15 *Opephora schwartzii* (Grunow) Petit. 15. v (OB-49, 6.5–6.75 m).
16 *Paralia sulcata* (Ehrenberg) Cleve. 16. v (OB-108, 4.25–4.5 m).
17 *Paralia sulcata* (Ehrenberg) Cleve. 17. v (OB-108, 4.25–4.5 m).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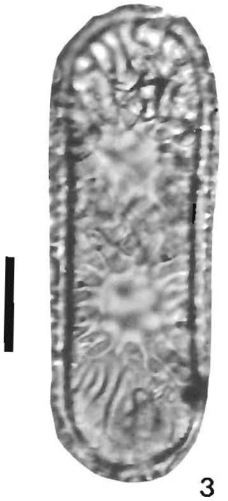
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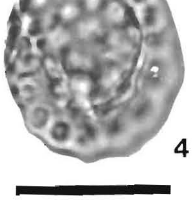
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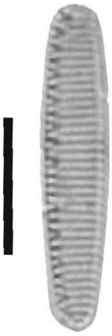
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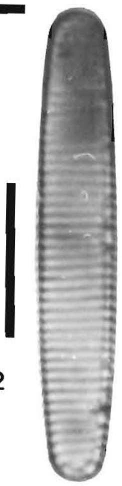
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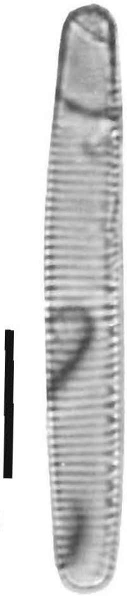
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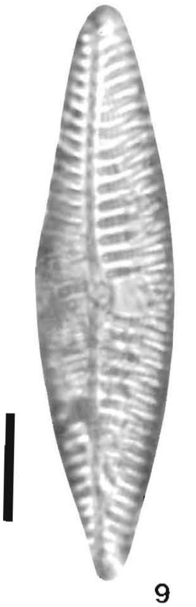
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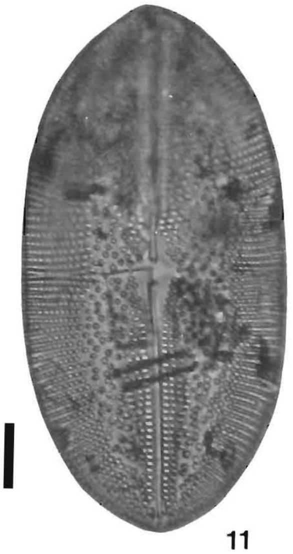
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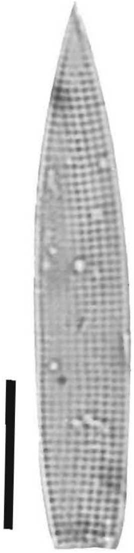
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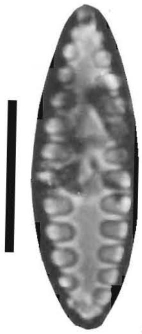
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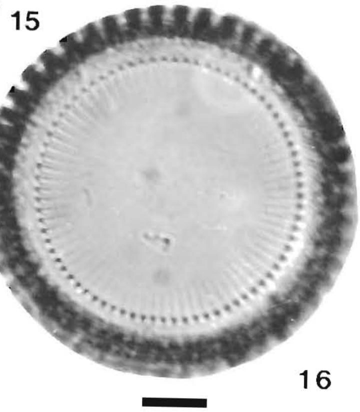
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PLATE 7

Each scale bar = 10 microns

v = valvar view, g = girdle view, uf = up focus, df = down focus

1 *Plagiogramma* aff. *P. staurophorum* (Gregory) Heiberg. 1. v (OB-47, 2.5–2.75 m).
2-3 *Pleurosigma affine* var. *marylandica* Grunow. 2. v (OB-34, 5.5–5.75 m). 3. v (OB-49, 6.5–6.75 m).
4 *Podosira stelligera* (Bailey) Mann. 4. v (OB-108, 3.75–4.0 m).
5-6 *Pyrgupyxis johnsoniana* Hendey. 5. g (OB-107, 2.0–2.5 m). 6. g (OB-34, 5.5–5.75 m).
7-8 *Pseudodimerogramma elongatum* Schrader. 7. v (OB-107, 2.0–2.25 m). 8. v (OB-34, 5.5–5.75 m).
9-10 *Pseudodimerogramma elliptica* Schrader. 9. v (OB-108, 3.75–4.0 m). 10. v (OB-108, 3.75–4.0 m).
11-12 *Pyxidicula* aff. *P. cruciata* Ehrenberg. 11. v (OB-50, 5.5–5.75 m). 12. v (OB-50, 5.5–5.75 m).
13-14 *Pyxidicula cruciata* Ehrenberg. 13. df (OB-53, 2.5–2.75 m). 14. uf (same specimen).
15 *Rattrayella inconspicua* (Rattray) Hanna. 15. v (OB-108, 3.75–4.00 m).
16 *Raphidodiscus marylandicus* Christian. 16. v (OB-34, 5.5–5.75 m).
17 *Rhaphoneis* aff. *R. adamantea* Andrews. 17. v (OB-49, 6.5–6.75 m).
18 *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg. 18. v (OB-53, 2.5–2.75 m).
19 *Rhaphoneis diamantella* Andrews. 19. v (OB-95, 0.75–1.0 m).


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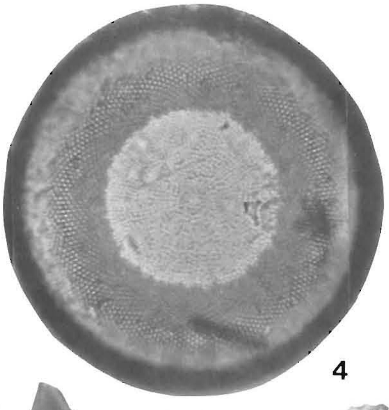
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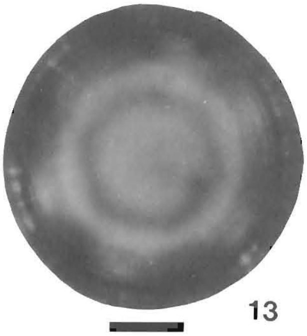
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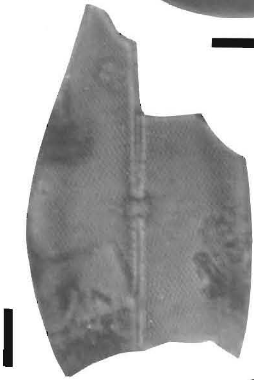
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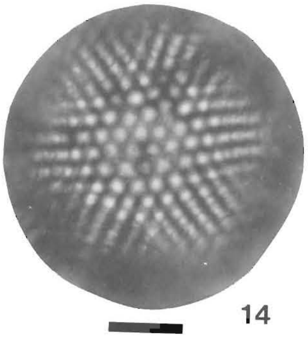
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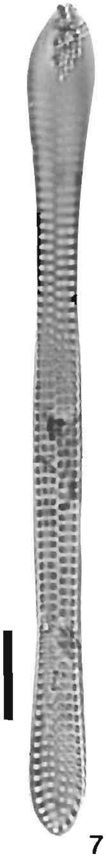
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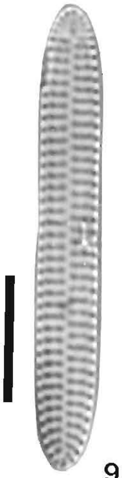
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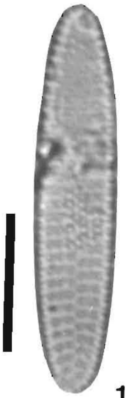
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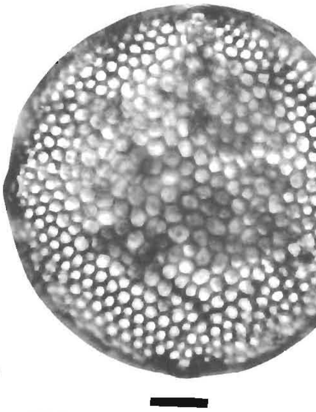
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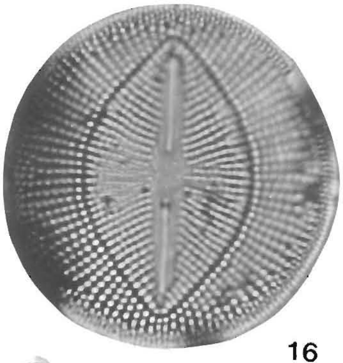
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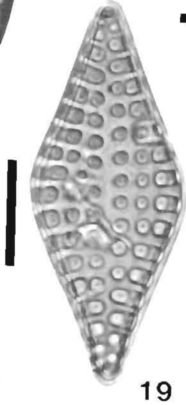
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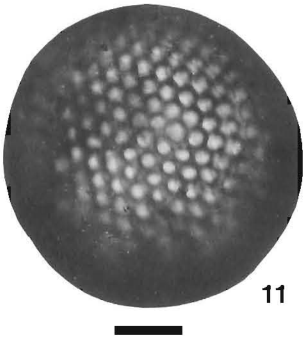
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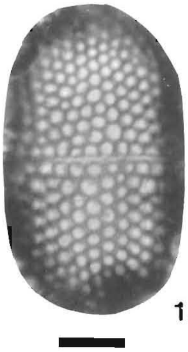
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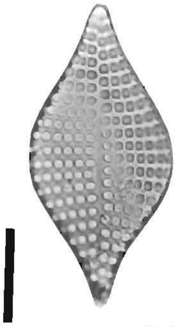
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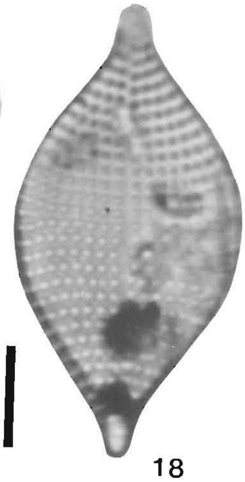
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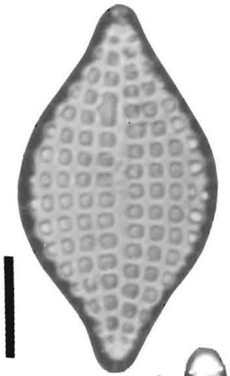
PLATE 8

Each scale bar = 10 microns

v = valvar view

1 *Rhaphoneis gemmifera* Ehrenberg. 1. v (OB-49, 6.5–6.75 m).
2 *Rhaphoneis lancettula* Grunow. 2. v (OB-53, 2.5–2.75 m).
3-4 *Rhaphoneis magnapunctata* Andrews. 3. v (OB-62, 5.0–5.25 m). 4. v (OB-62, 5.0–5.25 m).
5-6 *Rhaphoneis margaritata* Andrews. 5. v (OB-107, 2.5–2.75 m). 6. v (OB-107, 2.5–2.75 m).
7-9 *Rhaphoneis parilis* Hanna. 7. v (OB-50, 4.0–4.25 m). 8. v (OB-107, 2.0–2.25 m). 9. v (OB-107, 2.0–2.25 m).
10-11 *Rhaphoneis parvula* Andrews. 10. v (OB-49, 6.5–6.75 m). 11. v (OB-49, 6.5–6.75 m).
12 *Rhaphoneis rhombica* (Grunow) Andrews. 12. v (OB-53, 2.5–2.75 m).
13-15 *Rhaphoneis scalaris* Ehrenberg. 13. v (OB-34, 5.0–5.25 m). 14. v (OB-34, 5.0–5.25 m). 15. v (OB-34, 5.0–5.25 m).
16-17 *Rhaphoneis scalaris* (Ehrenberg) var. A. 16. v (OB-49, 6.5–6.75 m). 17. v (OB-50, 3.75–4.0 m).
18 *Rhaphoneis scutula* Andrews. 18. v (OB-108, 3.75–4.0 m).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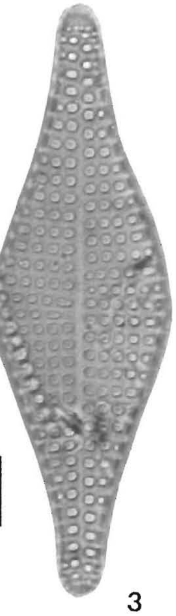
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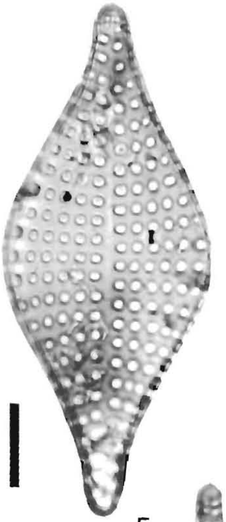
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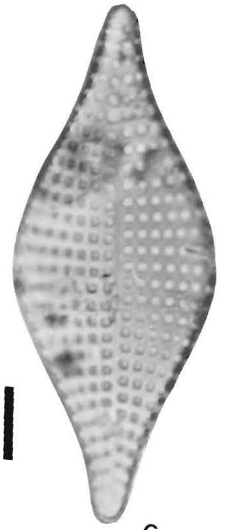
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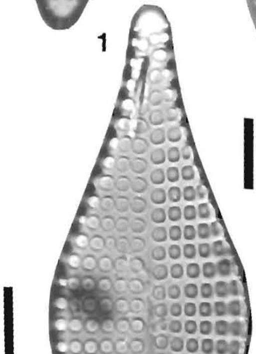
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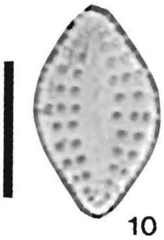
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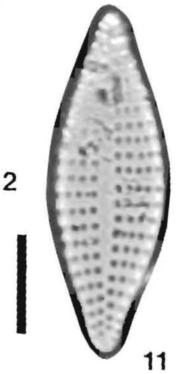
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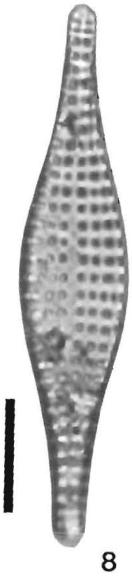
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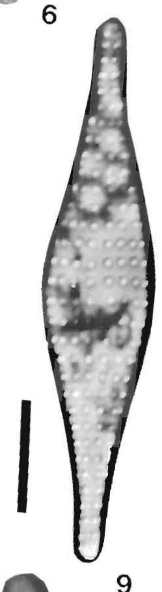
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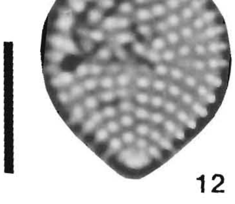
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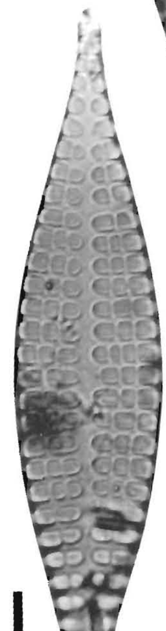
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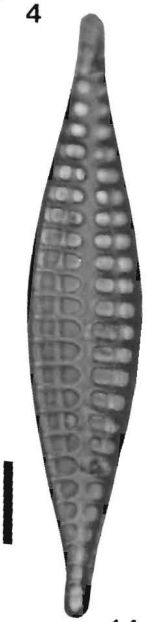
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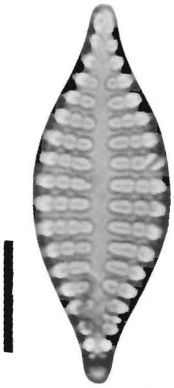
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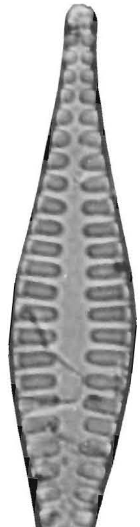
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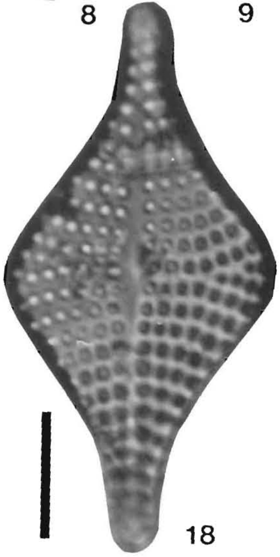
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PLATE 9
Each scale bar = 10 microns
v = valvar view

1 *Rhizosolenia miocenica* Schrader. 1. v (OB-53, 2.5–2.75 m).
2-4 *Rhizosolenia styliformis* Brightwell. 2. v (OB-108, 3.75–4.0 m). 3. v (OB-108, 3.75–4.0 m). 4. v (OB-108, 3.75–4.0 m).
5 *Rhizosolenia* sp. 5. v (OB-34, 5.0–5.25 m).
6 *Rhizosolenia* sp. 6. v (OB-49, 6.5–6.75 m).
7 *Rossiella* aff. *R. praepaleacea* (Schrader) Andrews. 7. v (OB-47, 5.5–5.75 m).
8-9 *Rossiella praepaleacea* (Schrader) Andrews. 8. v (OB-49, 6.5–6.75 m). 9. v (OB-49, 6.5–6.75 m).
10-12 *Rossiella paleacea* (Grunow) Desikachary and Maheshwari. 10. v (OB-108, 3.75–4.0 m). 11. v (OB-108, 3.75–4.0 m). 12. v (OB-95, 0.75–1.0 m).
13-14 *Sceptroneis caduceus* Ehrenberg. 13. v (OB-49, 6.5–6.75 m). 14. v (partial close-up of the same specimen).
15 *Sceptroneis* aff. *S. caduceus* Ehrenberg. 15. v (OB-47, 3.0–3.25 m).
16-17 *Sceptroneis grandis* Abbott. 16. v (OB-34, 5.0–5.5 m). 17. v (OB-34, 5.0–5.5 m).
18 *Sceptroneis* aff. *S. grandis* Abbott. 18. v (OB-34, 5.0–5.5 m).
19 *Sceptroneis* sp. 19. v (OB-49, 8.0–8.25 m).


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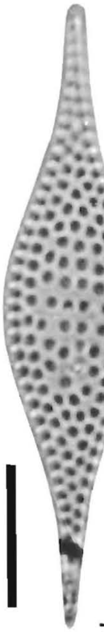
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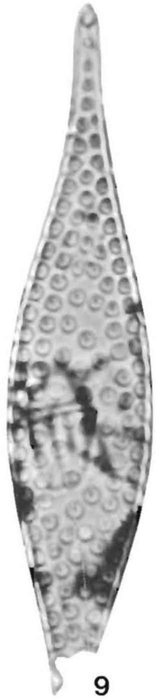
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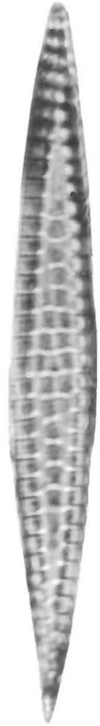
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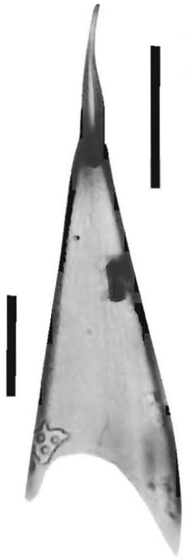
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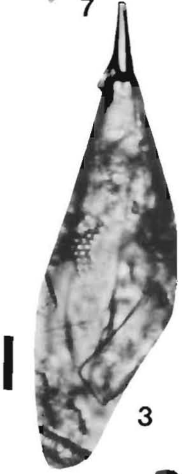
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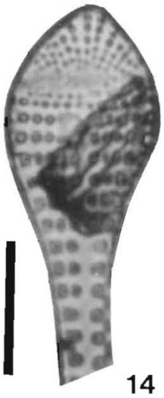
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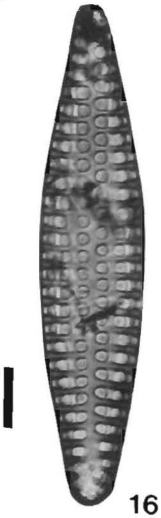
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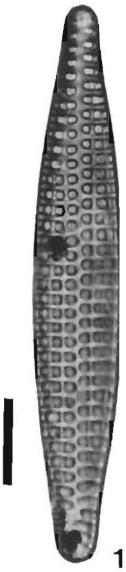
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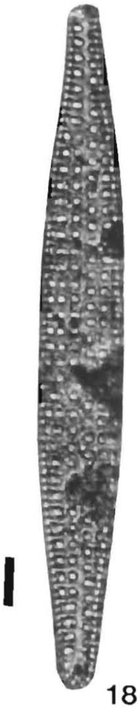
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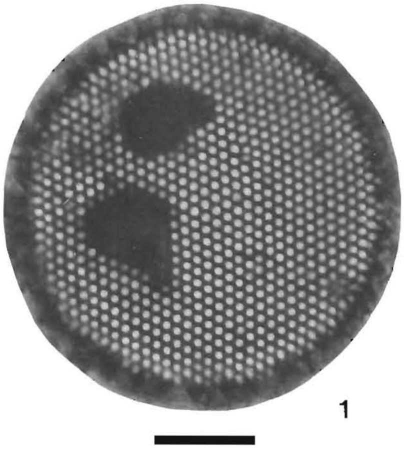
PLATE 10

Each scale bar = 10 microns

v = valvar view, g = girdle view, uf = up focus, df = down focus

1-2 *Stephanopyxis lineata* (Ehrenberg) Forti. 1. v (OB-53, 2.5–2.75 m). 2. v (OB-53, 2.5–2.75 m).
3-4 *Stephanopyxis corona* (Ehrenberg) Grunow. 3. df (OB-53, 2.5–2.75 m). 4. uf (same specimen).
5-6 *Stephanogonia actinoptychus* (Ehrenberg) Grunow. 5. v (OB-107, 2.5–2.75 m). 6. v (OB-107, 2.5–2.75 m).
7 *Stephanopyxis turris* (Greville and Arnott) Ralfs. 7. g (OB-34, 5.0–5.5 m).
8 *Synedra jouseana* Sheshukova-Poretzkaya. 8. v (OB-47, 4.5–4.75 m).
9-11 *Thalassionema obtusum* (Grunow) Andrews. 9. v (OB-34, 5.0–5.5 m). 10. v (OB-34, 5.0–5.5 m). 11. v (OB-108, 3.75–4.0 m).
12-13 *Thalassionema nitzschioides* (Grunow) Hustedt. 12. v (OB-108, 3.75–4.0 m). 13. v (OB-108, 3.75–4.0 m).
14 *Thalassiosira* sp. 14. v (OB-34, 5.0–5.25 m).
15-16 *Thalassiosira eccentrica* (Ehrenberg) Cleve. 15. v (OB-108, 3.75–4.0 m). 16. v (OB-108, 3.75–4.0 m).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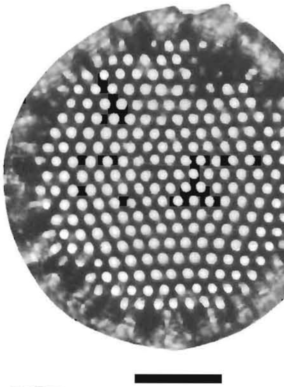
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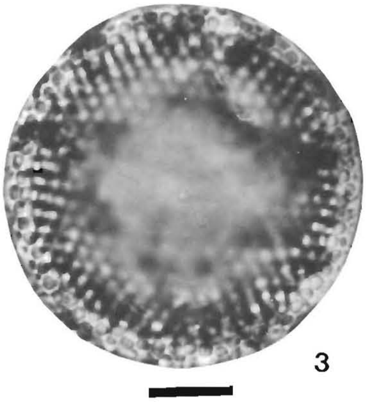
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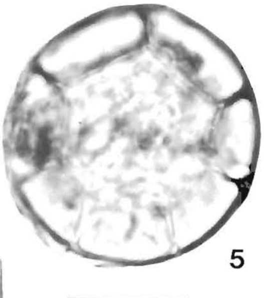
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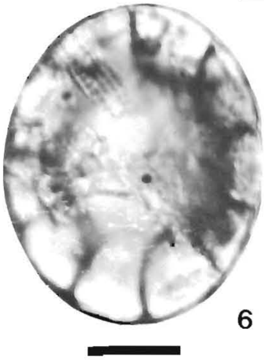
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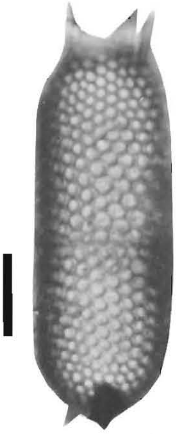
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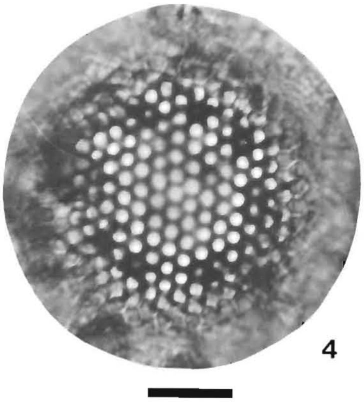
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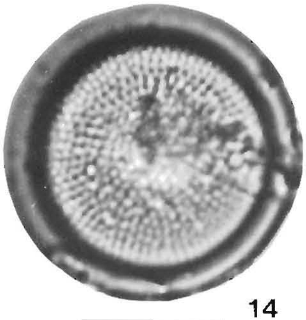
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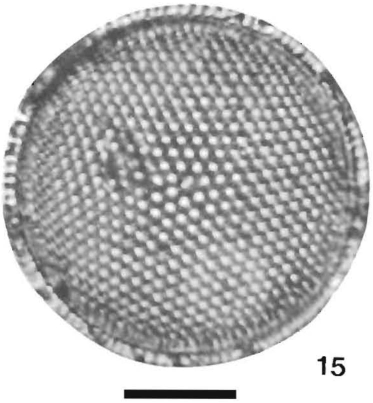
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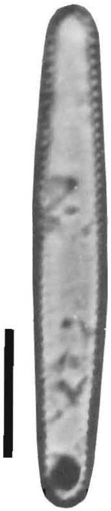
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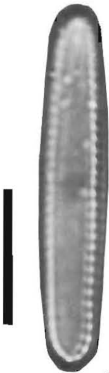
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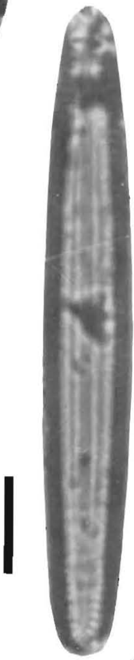
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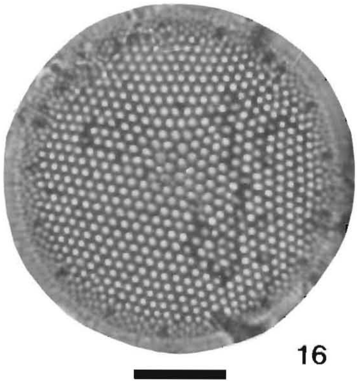
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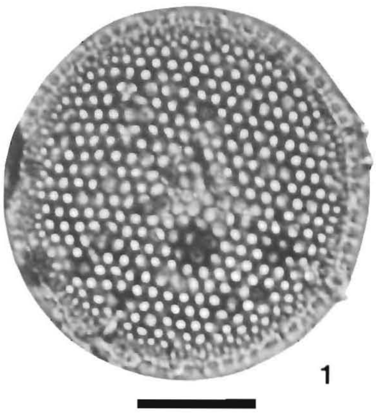
PLATE 11

Each scale bar = 10 microns

v = valvar view, g = girdle view

1 *Thalassiosira leptopus* (Grunow) Hasle and Fryxell. 1. v (OB-108, 3.75–4.0 m).
2 *Thalassiosira lineata* (Ehrenberg) Hasle and Fryxell. 2. v (OB-53, 2.5–2.75 m).
3 *Thalassiosira* sp. 3. v (OB-47, 0.25–0.5 m).
4 *Thalassiothrix longissima* Cleve and Grunow. 4. v (OB-62, 5.25–5.5 m).
5 *Triceratium acutum* (Ehrenberg) Boyer. 5. v (OB-47, 0.25–0.5 m).
6 *Triceratium condecorum* Ehrenberg. 6. v (OB-108, 3.75–4.0 m).
7 *Triceratium hebetatum* (Grunow) Andrews. 7. v (OB-34, 5.0–5.25 m).
8 *Triceratium spinosum* Bailey. 8. v (OB-34, 5.0–5.25 m).
9 *Triceratium subrotundatum* Schmidt. 9. v (OB-108, 3.75–4.0 m).
10-11 *Triceratium tessellatum* Greville. 10. v (OB-50, 4.5–4.75 m). 11. g (OB-50, 4.5–4.75 m).
12 *Triceratium* sp. A. 12. v (OB-34, 5.0–5.5 m).
13 Genus and species indet. A. 13. v (OB-62, 5.25–5.5 m).
14-15 Genus and species indet. B. 14. v (OB-49, 5.0–5.25 m). 15. v (OB-49, 5.0–5.25 m).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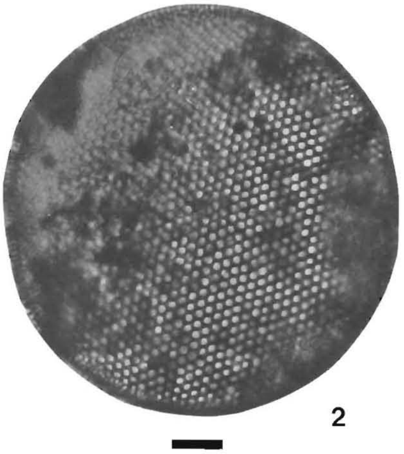
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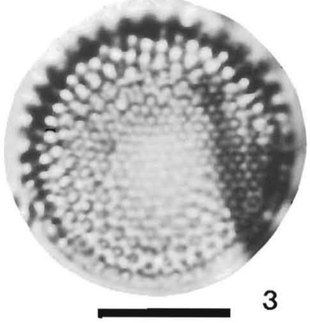
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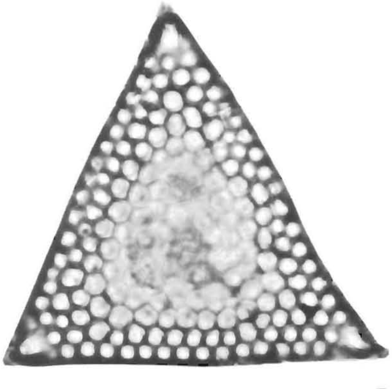
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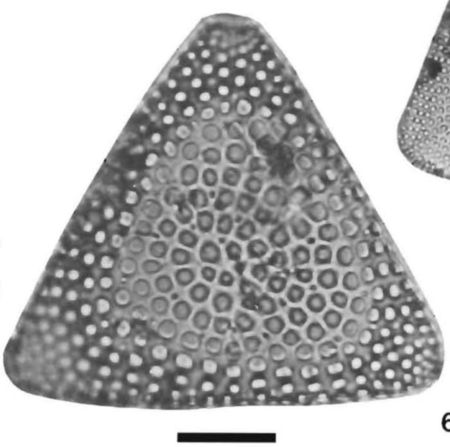
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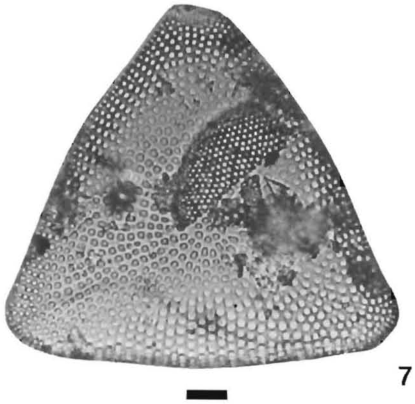
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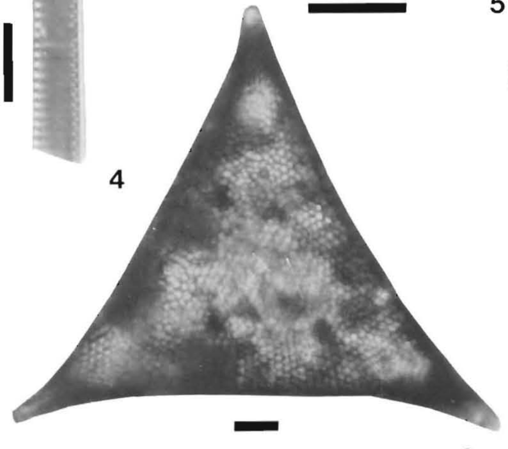
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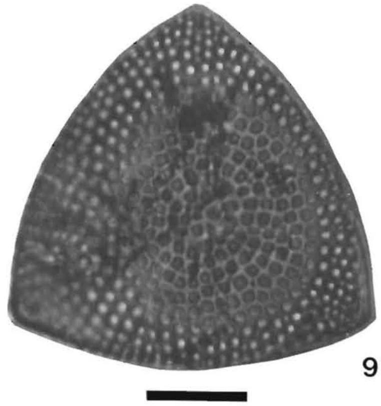
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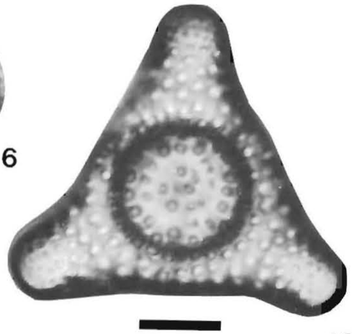
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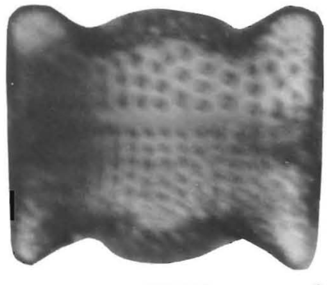
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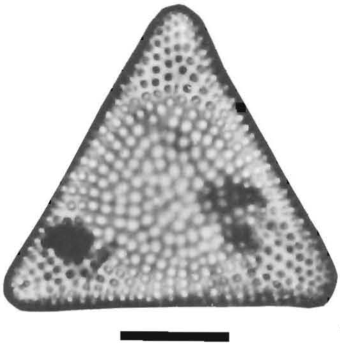
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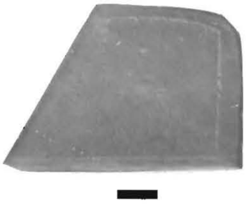
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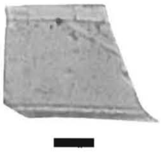
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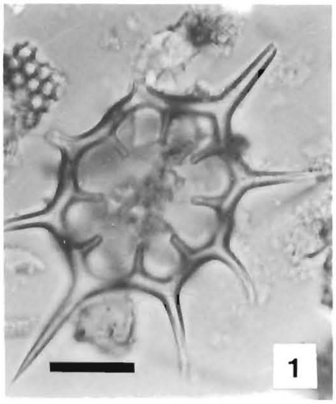
PLATE 12

Each scale bar = 10 microns
uf = up focus, df = down focus

1 *Cannopilus* aff. *C. hemisphaericus* (Ehrenberg). 1. (OB-34, 5.0–5.5 m).
2-3 ?*Distephanus* aff. *D. binoculus* (Ehrenberg). 2. uf (OB-108, 3.75–4.0 m). 3. df (same specimen).
4-5 ?*Distephanus* sp. 4. df (OB-34, 5.5–5.75 m). 5. uf (same specimen).
6-7 *Corbisema* (Ehrenberg) Bukry. 6. (OB-34, 5.5–5.75 m). 7. (OB-49, 6.5–6.75 m).
8-10 *Dictyocha rhombica* (Shultz) Deflandre. 8. (OB-47, 0.0–0.25 m). 9. (OB-49, 7.0–7.25 m). 10. (OB-34, 5.5–5.75 m).
11-12 *Distephanus crux* (Ehrenberg) Haeckel. 11. (OB-53, 2.5–2.75 m). 12. (OB-53, 2.5–2.75 m).
13 *Mesocena* aff. *M. elliptica* (Ehrenberg) Ehrenberg. 13. (OB-47, 0.0–0.25 m).
14 *Mesocena elliptica* (Ehrenberg) Ehrenberg. 14. (OB-34, 5.75–6.0 m).
15 *Naviculopsis navicula* (Ehrenberg) Locker. 15. (OB-49, 6.5–6.75 m).
16-17 *Naviculopsis quadrata* (Ehrenberg) Locker. 16. (OB-49, 6.5–6.75 m). 17. (OB-49, 6.5–6.75 m).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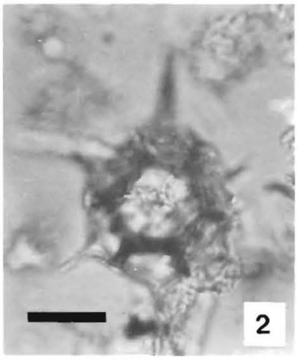
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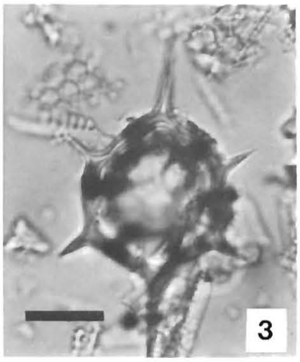
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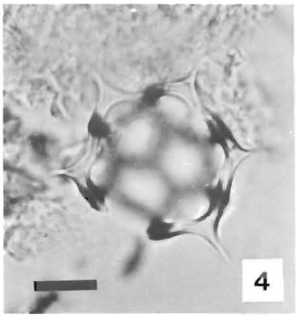
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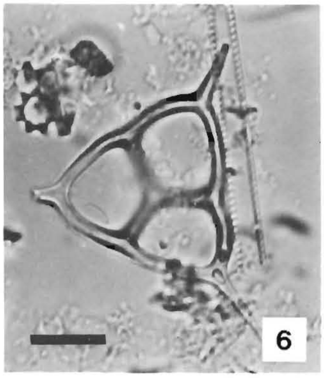
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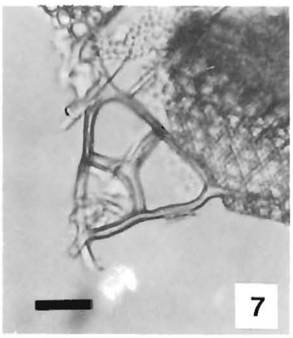
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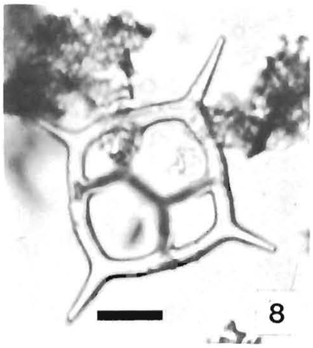
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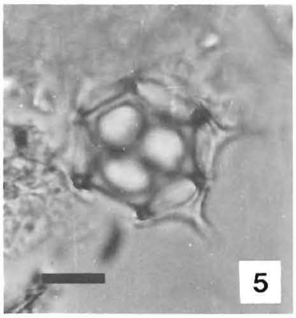
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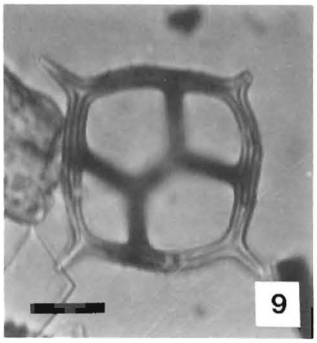
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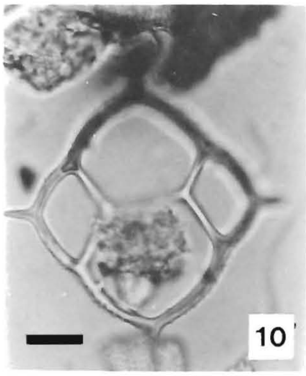
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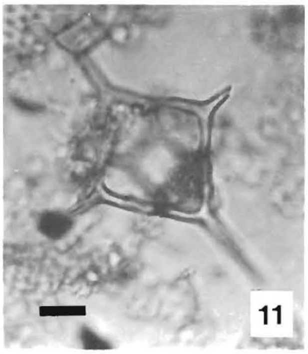
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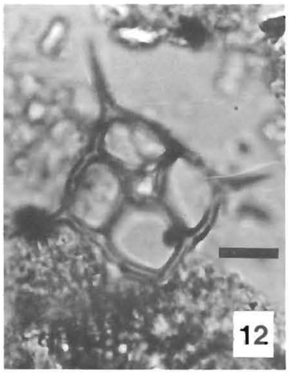
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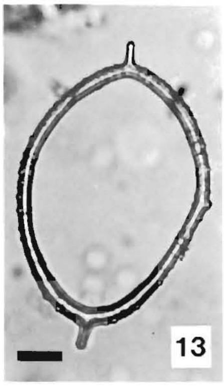
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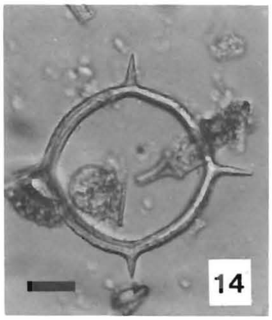
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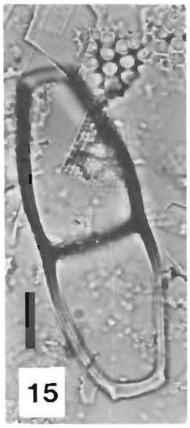
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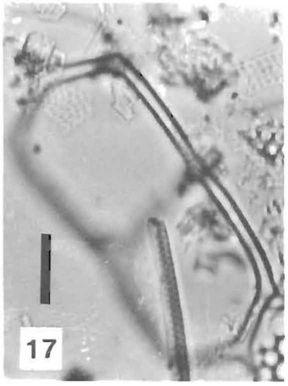
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RADIOLARIANS FROM THE MIOCENE PUNGO RIVER FORMATION OF ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

Samples from Onslow Bay vibracores containing siliceous microfossils were obtained for biostratigraphic and paleoenvironmental studies of radiolarians. Three early to middle Miocene radiolarian zones were recognized: *Stichocorys wolffii* Zone (Frying Pan Section), *Calocycletta costata* Zone (Onslow Bay Section) and *Dorcadospyris alata* Zone (Bogue Banks Section) on the basis of 22 age-diagnostic species.

An average of 16 taxa (of approximately generic level) per sample were observed in the Frying Pan and Onslow Bay sections, with subequal representation by spumellarians and nassellarians. Seven taxa were predominant (consistently >5% of the assemblage) in the Frying Pan Section, six in the Onslow Bay Section. Radiolarians were too sparse in samples of the Bogue Banks Section for quantitative studies.

The assemblages generally consist of shallow-dwelling groups, although a few specimens of deep-dwelling taxa occur in one core from the Bogue Banks Section, perhaps suggesting strong upwelling or intrusions from deep levels of the Gulf Stream. Abundance and diversity of radiolarians are lower in the Onslow Bay sections than in correlative units of the mid-Atlantic Miocene, suggesting that different paleoenvironmental factors prevailed in each region.

INTRODUCTION

Recent studies of radiolarians from the mid-Atlantic Coastal Plain (Palmer, 1986a, b) have provided biostratigraphic data for calcareous microfossil-poor Miocene deposits in Maryland, Virginia and New Jersey (the "Salisbury Embayment"). The Onslow Bay material offers the opportunity to investigate an age-equivalent fauna associated with the phosphatic deposits of North Carolina. Samples from Onslow Bay vibracores were examined in order to answer the following questions: 1) what biostratigraphic ages do radiolarians indicate, 2) how does the radiolarian fauna compare with age-equivalent faunas from the mid-Atlantic region, and 3) what paleoenvironmental information can be gathered from the radiolarian faunal composition?

METHODS

A total of 83 samples were obtained from 17 selected vibracores (cores found upon preliminary examination to contain siliceous microfossils) from Onslow Bay, North Carolina. Samples from 5 sites were barren of radiolarians, but the remainder contained (variably) sparse to abundant, poorly- to moderately-well preserved, early to middle Miocene radiolarians. Twenty-two age-diagnostic species, most of which previously had been observed in the Calvert Formation of Maryland and Virginia (Palmer, 1986a), were identified.

Samples were processed using standard radiolarian preparation techniques (Riedel and Sanfilippo, 1977), which include removal of carbonate and disaggregation by boiling in hydrochloric acid and hydrogen peroxide solutions (repeated treatments were necessary to break down some samples). Samples were also subjected to several seconds of treatment with an ultrasonic probe to assist in disaggregation, and were washed over a 63 micron mesh sieve. After sieving, special effort was made to concentrate the radiolarians from the detrital material by swirling the sieved residue in a beaker of water; sand is forced to the center of the beaker, and radiolarians can be pipetted from the sand. Strewn

Section	4th-order seismic sequence	Cores 47	49	98	50	34	15	16	17	62	42	43	Radiolarian Zone
Bogue Banks Section	8												*Dorcadospyris alata* Zone
	7												
	6												
	5												
	4												
	3												
	2												
	1										▨	▨	
Onslow Bay Section	4						▨	▨	▨	▨			*Calocycletta costata* Zone
	3					▨	▨	▨	▨	▨			
	2						▨	▨	▨	▨			
	1					▨	▨	▨	▨	▨			
Frying Pan Section	6				▨								*Stichocorys wolffii* Zone
	5				▨								
	4												
	3												
	2	▨	▨	▨									
	1	▨											

FIGURE 1. Radiolarian-bearing cores from the Frying Pan, Onslow Bay, and Bogue Banks Sections, Onslow Bay, North Carolina. Fourth-order sequences within each section are indicated according to relative stratigraphic position, as inferred from seismic stratigraphy and lithostratigraphy (Snyder, personal communication, 1986). Radiolarian zones (Riedel and Sanfilippo, 1978) identified for each section are indicated by shading.

TABLE 1. Radiolarians from the Frying Pan Section (*Stichocorys wolffii* Zone). Sample numbers correspond to depths (meters below sea floor) within vibracores. Radiolarian abundance is indicated as follows: r = very rare (1 specimen per slide); R = rare (2–5 specimens per slide); F = frequent (6–10 specimens per slide); C = common (10+ specimens per slide).

Core	Sampled interval	*S. marylandicus*	*E. diaphanes*	*D. prismatica*	*D. tubaria*	*D. violina*	*C. virginis*	*C. tetrapera*	*C. cornuta*	*S. wolffii*	*S. delmontensis*	*T. perforata*	*C. cingulata*	*L. stauropora*	*E. calvertense*
50	(6.20)	R	R	—	R	—	F	F	—	F	—	—	—	—	R
50	(7.70)	—	—	—	—	R	—	—	—	—	—	—	—	—	r
98	(1.75)	—	R	R	R	F	F	R	R	F	F	R	R	R	R
49	(7.25)	r	—	—	R	—	—	—	—	—	—	—	—	—	—
49	(8.75)	—	—	r	—	—	R	R	—	—	R	—	—	—	—
47	(0.25)	—	R	—	F	—	F	F	R	F	F	—	—	—	—
47	(1.75)	—	—	—	—	—	—	—	—	R	—	—	—	—	—
47	(3.25)	R	—	—	—	R	—	F	—	F	—	—	—	—	R
47	(4.75)	R	—	—	F	—	F	—	—	—	F	—	—	—	R
47	(6.25)	R	—	—	—	R	F	—	—	F	F	—	—	—	—

slides were then made and scanned with a Zeiss WL petrographic microscope (10× and 25× objectives).

BIOSTRATIGRAPHIC RESULTS

Cores found to contain radiolarians are shown in Figure 1 according to the Onslow Bay seismic units. Tables 1–3 list the age-diagnostic taxa identified in Onslow Bay samples (a species list appears in the Appendix). Some of the biostratigraphically important taxa are illustrated in Plates 1 and 2. Three zones (from the zonation of Riedel and Sanfilippo, 1978) were identified: the early Miocene *Stichocorys wolffii* Zone, the early to middle Miocene *Calocycletta costata* Zone, and the middle Miocene *Dorcadospyris alata* Zone (a biostratigraphic correlation chart appears in Fig. 2). Only a single zone was represented within the relatively short interval spanned by each vibracore (maximum length of nine meters). Zones are discussed individually below.

STICHOCORYS WOLFFII ZONE

The oldest zone recognized in the Onslow Bay material is the late early Miocene *Stichocorys wolffii* Zone (Fig. 2). This zone occurs above the first appearance of *Stichocorys wolffii* (Pl. 1, Fig. 3) and below the first appearance of *Calocycletta costata* (Pl. 1, Fig. 5). It includes the first appearance of *Liriospyris stauropora* (Pl. 1, Fig. 7) and the evolutionary transition of *Didymocyrtis tubaria* to *D. violina* (Pl. 1, Fig. 2), (all observed here). Palmer (1986a) found that *Spongasteriscus marylandicus* (Pl. 2, Fig. 6) is restricted to this zone in the Calvert Formation, as it appears to be in the Onslow Bay material. Other species characteristic of, but not necessarily restricted to, the *Stichocorys wolffii* Zone and observed in the Onslow Bay material are *Calocycletta virginis, Carpocanopsis cingulata* (Pl. 1, Fig. 10), *Cyrtocapsella cornuta, Calocycletta tetrapera* (Pl. 1, Fig. 9), *Didymocyrtis prismatica* (Pl. 1, Fig. 1), *Eucyrtidium calvertense, Eucyrtidium diaphanes, Stichocorys delmontensis* (Pl. 1, Fig. 6), and *Tepka perforata.*

As indicated in Table 1, the *Stichocorys wolffii* Zone was recognized in Cores 47, 49, 98 and 50. These cores have been assigned to the Frying Pan Section by Snyder and others (this volume). This interval is equivalent to the Dunkirk Beds of the Calvert Formation, which was also assigned to the *Stichocorys wolffii* Zone (Palmer, 1986a).

CALOCYCLETTA COSTATA ZONE

The *Calocycletta costata* Zone spans the early-middle Miocene boundary (Fig. 2). It occurs above the first occurrence of *Calocycletta costata* and below the evolutionary transition of *Dorcadospyris dentata* to *D. alata.* The latter event was not recognized in the Onslow Bay material; as a result of a similar absence in the Calvert Formation, Palmer (1986a) used the *Liriospyris stauropora* to *Liriospyris parkerae* evolutionary transition to approximate the top of the zone. As *L. stauropora* is present but *L. parkerae* is not seen in the Onslow Bay material, it appears that the upper part of the *C. costata* Zone may not be present. The zone also includes the last appearances of *Carpocanopsis cingulata* and *Eucyrtidium diaphanes,* both present in a few samples. Other species characteristic of, but not necessarily restricted to, the *C. costata* Zone and observed in the Onslow Bay vibracores are *Carpocanopsis bramlettei, Calocycletta virginis, Cyrtocapsella cornuta, Cyrtocapsella tetrapera, Eucyrtidium calvertense, Stichocorys wolffii, Stichocorys delmontensis,* and *Tepka perforata.*

As indicated in Table 2, the *Calocycletta costata*

TABLE 2. Radiolarians from the Onslow Bay Section (*Calocycletta costata* Zone). Sample designation and symbols as in Table 1.

Core	Sampled interval	*E. diaphanes*	*C. bramlettei*	*C. cingulata*	*D. tubaria*	*D. violina*	*D. mammifera*	*C. virginis*	*C. costata*	*C. tetrapera*	*C. cornuta*	*S. wolffii*	*S. delmontensis*	*E. calvertense*	*L. stauropora*	*T. perforata*
62	(4.25)	—	r	—	—	F	R	F	—	R	R	F	F	—	—	—
62	(5.40)	—	—	—	—	R	F	F	—	F	R	F	F	r	r	—
17	(2.85)	—	—	r	R	R	—	F	—	—	R	F	—	—	r	—
17	(4.35)	—	—	—	—	R	—	F	—	R	—	F	F	—	—	—
17	(5.85)	—	—	—	—	R	—	F	—	—	R	F	—	—	R	—
16	(1.35)	—	—	r	—	—	—	—	—	—	R	F	F	—	—	—
16	(2.85)	—	—	—	—	—	F	F	—	—	—	—	F	—	—	R
16	(4.35)	r	—	—	—	R	—	F	—	—	R	—	F	—	—	R
16	(5.85)	—	—	—	—	—	R	F	—	—	R	F	F	—	—	—
15	(0.30)	R	—	—	—	—	—	F	—	F	—	F	F	—	—	r
34	(3.25)	—	—	—	—	R	F	R	—	F	—	—	F	—	—	—
34	(4.75)	—	—	—	r	—	F	R	r	F	—	—	R	—	—	—
34	(6.25)	—	—	—	—	—	F	R	r	F	—	—	F	—	—	—
34	(7.75)	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—

Zone was recognized in Cores 34, 15, 16, 17 and 62. These cores have been assigned to the Onslow Bay Section (Snyder and others, this volume). This interval is equivalent to the Fairhaven Member of the Calvert Formation, also assigned to the *Calocycletta costata* Zone (Palmer, 1986a).

DORCADOSPYRIS ALATA ZONE

The early middle Miocene *Dorcadospyris alata* Zone (Fig. 2) occurs above the evolutionary transition of *Dorcadospyris dentata* to *Dorcadospyris alata* (not recognized in the Onslow Bay material, as noted above), and below the first appearance of *Diartus petterssoni* (not observed). The zone includes the last appearances of *Calocycletta costata* and *C. virginis* (neither of which was observed in this interval from Onslow Bay), the first appearance of *Lithopera thornburgi* and the evolutionary transition of *Lithopera renzae* to *L. neotera,* all three of which are present. The best marker for this zone in the mid-Atlantic region is *Didymocyrtis laticonus* (Pl. 1, Fig. 8) (Palmer, 1986a) which is also important here. *Calocycletta caepa,* not seen in the mid-Atlantic region, is another marker for this zone in the Onslow Bay material. Other age-diagnostic species which occur in the *Dorcadospyris alata* Zone in the Onslow Bay material are *Cyrtocapsella tetrapera, Stichocorys delmontensis,* and *Stichocorys wolffii.*

As indicated in Table 3, the *Dorcadospyris alata* Zone was recognized in Cores 42 and 43. These cores have been assigned to the Bogue Banks Section (Snyder and others, this volume). This interval appears to be slightly younger than the Plum Point Member of the Calvert Formation, also assigned to the *Dorcadospyris alata* Zone, because *Lithopera neotera, Lithopera thornburgi* and *Calocycletta capea* were not observed in the Calvert Formation (Palmer, 1986a). The occurrence of these species in the Onslow Bay material and the absence of *Calocycletta costata* and *Calocycletta virginis* (which range through the lower part of the *D. alata* Zone) suggest that only the upper part of the *D. alata* Zone occurs in the Onslow Bay material.

BIOSTRATIGRAPHIC SUMMARY

As shown in Figure 1, radiolarians indicate that the Frying Pan Section in the Onslow Bay region is of *Stichocorys wolffii* Zone age (late early Miocene, 20.0–17.0 Ma according to Haq and others, 1987), the Onslow Bay Section is of *Calocycletta costata* Zone age (latest early Miocene to earliest middle Miocene, 17.0–14.6 Ma), and the Bogue Banks Section is of *Dorcadospyris alata* Zone age (middle Miocene, 14.6–10.5 Ma).

Sufficient biostratigraphic markers are present to allow reasonable zonal determinations. However, the precision is somewhat diminished by the low abun-

TABLE 3. Radiolarians from the Bogue Banks Section (*Dorcadospyris alata* Zone). Sample designation and symbols as in Table 1.

Core	Sampled interval	*S. delmontensis*	*C. tetrapera*	*D. laticonus*	*C. caepa*	*S. wolffii*	*L. neotera*	*L. thornburgi*	*L. renzae*
43	(2.50)	R	—	R	r	—	r	—	—
43	(3.00)	r	r	—	—	—	—	—	—
43	(3.50)	—	—	R	—	—	—	r	—
42	(3.50)	R	—	F	R	—	r	—	r
42	(4.00)	R	R	—	—	—	—	—	—
42	(4.50)	R	—	R	r	—	—	—	—
42	(5.50)	r	r	R	—	—	r	—	—
42	(6.50)	R	—	R	—	—	—	—	—

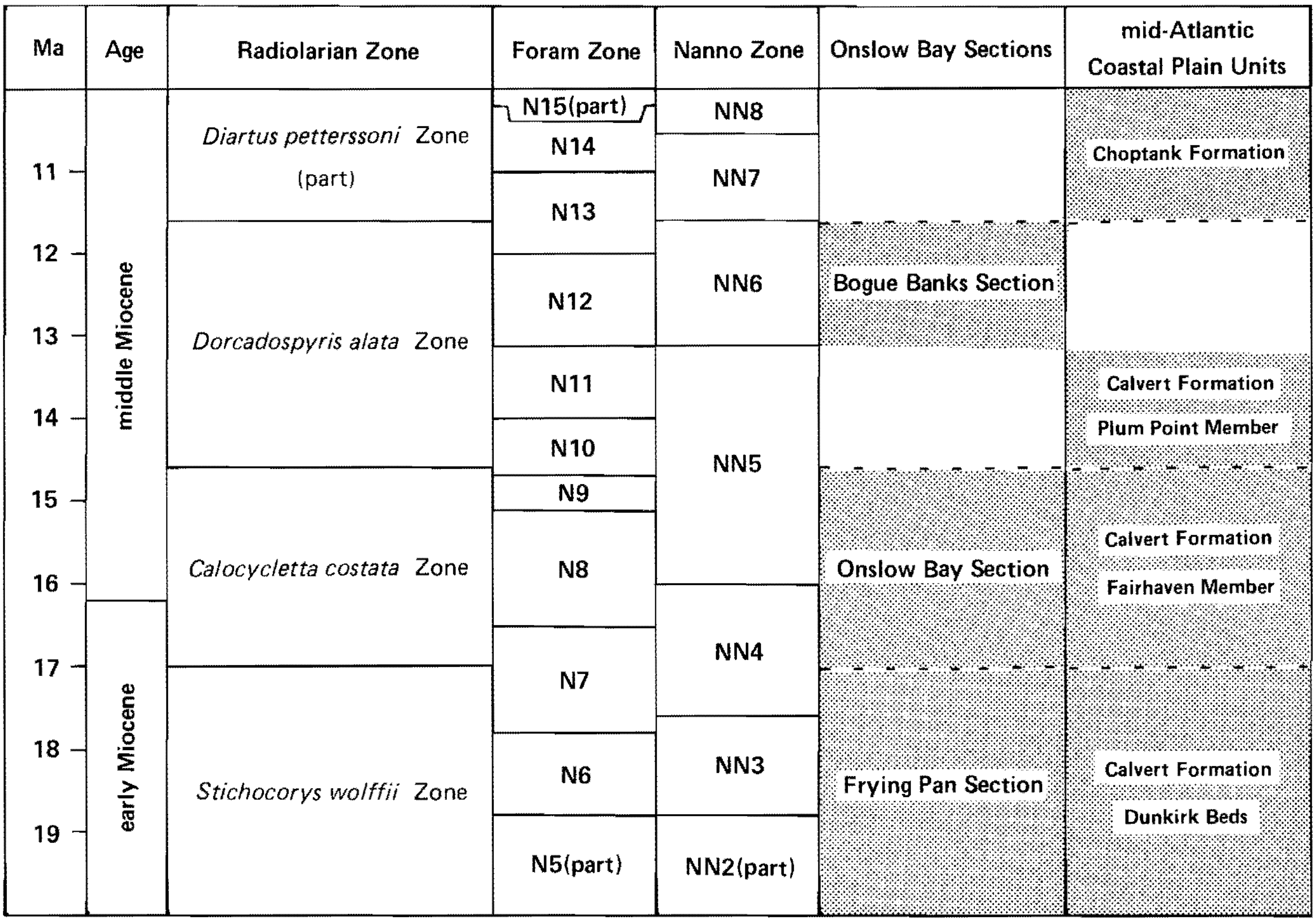

FIGURE 2. Biostratigraphic correlation chart for the Frying Pan, Onslow Bay and Bogue Banks Sections in Onslow Bay. Absolute age of standard radiolarian zones (Riedel and Sanfilippo, 1978), planktonic foraminiferal zones (Blow, 1969) and calcareous nannofossil zones (Martini, 1971) is after Haq and others (1987). Onslow Bay sections are plotted versus absolute age based on radiolarian data (this study). Mid-Atlantic Coastal Plain units (Calvert and Choptank Formations) are also plotted based on their radiolarian zonal age (Palmer, 1986a).

dance of many marker species and by the total absence of others. Thus it is not possible to identify what part of the *Stichocorys wolffii* Zone is present, although it appears that the lower part of the *Calocycletta costata* Zone and the upper part of the *Dorcadospyris alata* Zone occur in the samples examined.

PALEOENVIRONMENTAL INTERPRETATION AND COMPARISON WITH ASSEMBLAGES FROM SALISBURY EMBAYMENT

One of the first investigations of the paleoenvironmental significance of radiolarians in neritic deposits was an analysis of mid-Atlantic Coastal Plain faunas (Palmer, 1986b). The results suggested processes responsible for the occurrence of radiolarians in shelf settings, and demonstrated the unique responses of different radiolarian taxa to shelf conditions.

However, a major difficulty in attempting a paleoenvironmental analysis of radiolarian assemblages is that radiolarian systematics is currently inadequate to describe the majority of the species in any given assemblage; Westberg and Riedel (1978) estimated that only 10% of a fauna could be satisfactorily assigned to species. For this reason many radiolarian assemblage studies have relied on higher level taxonomic groups (families and genera) to describe faunal composition (Sanfilippo, 1971; Westberg and Riedel, 1982; Palmer, 1984, 1986b). A useful concept in this regard is the "counting group" (Riedel and others, 1982) of approximately generic level (rare forms may be grouped at the family level and abundant forms may be split into sub-generic groups). This approach was applied to the analysis of the Onslow Bay radiolarian fauna. Counting groups are listed in Table 4 and referred to

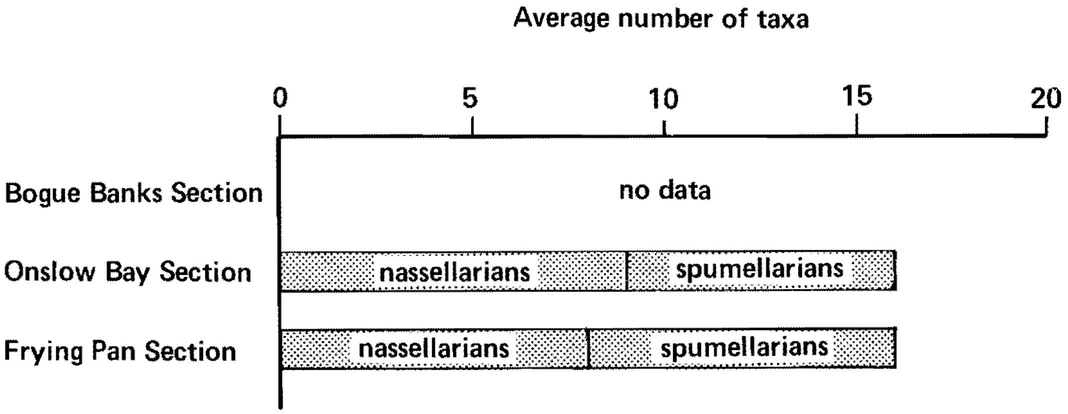

FIGURE 3. The average number of taxa observed in samples from the sections in Onslow Bay is shown by the overall length of the shaded bar; this is subdivided into average numbers of nassellarian and spumellarian taxa.

in the following discussions. In addition to the age-diagnostic taxa shown in Plates 1 and 2, some of the other taxa are shown in Plate 3.

FRYING PAN SECTION

The Frying Pan Section is the basal radiolarian-bearing unit in the Onslow Bay vibracores. An average of 16 taxa were observed per sample, eight spumellarian and eight nassellarian (Fig. 3). A total of seven taxa are considered predominant (defined here as taxa consistently comprising >5% of the assemblage, listed in decreasing order of abundance): *Stichocorys, Spongodiscus* (Pl. 2, Fig. 3), *Hexacontium* (Pl. 3, Fig. 2), *Porodiscus* narrow rings (Pl. 2, Fig. 1), *Cyrtocapsella, Calocycletta,* and *Lithomelissa* (Fig. 4). The average Shannon-Wiener diversity index H(S) equals 1.01 (Fig. 5). This index is useful in measuring diversity because it is relatively insensitive to the occurrence of rare taxa which may be discovered upon searching increasingly larger sample sizes.

TABLE 4. List of radiolarian counting groups in the Onslow Bay vibracores.

collosphaerids	other spyrids
Hexacontium	*Ceratocyrtis*
Stylosphaera	*Lithomelissa*
other actinommids	other plagoniids
phacodiscids	*Cornutella*
Didymocyrtis	*Peripyramis*
Dictyocoryne	*Cyrtocapsella*
Porodiscus—narrow rings	*Eucyrtidium*
Porodiscus—wide rings	*Gondwanaria*
Spongasteriscus	*Lithopera*
Spongodiscus	*Lychnocanoma*
other spongodiscids	*Stichocorys*
Lithelius	other theoperids
Pylospira	carpocaniids
other litheliids	*Calocycletta*
Dendrospyris	*Lamprocyclas*
Dorcadospyris	other pterocorythids
Liriospyris	artostrobiids
	cannobotryids
	Tepka

Radiolarian abundance and diversity are much lower in the Frying Pan Section than in the age-equivalent Dunkirk Beds Member of the Calvert Formation. An average of 22 species and a diversity index of 2.60 were recorded in the latter unit (Palmer, 1986b). Twelve predominant taxa were recorded in the Dunkirk Beds, five of which are also predominant in the Frying Pan Section. Differences in preservation are not likely to be responsible, as radiolarians in many Calvert samples were moderately to moderately poorly preserved, yet faunas were abundant and diverse.

These differences suggest that dissimilar environmental conditions prevailed in the Salisbury Embayment and the Onslow Bay region during *Stichocorys wolffii* Zone time. The diminished radiolarian abundance and diversity in the Onslow Bay deposits suggests conditions less favorable for radiolarians.

In addition, groups typical of low-latitude assemblages, such as collosphaerids (Pl. 3, Fig. 1) and *Dorcadospyris* (Pl. 3, Fig. 3) are present in Onslow Bay samples, whereas these groups are virtually absent from Salisbury Embayment material. This may be a function of the lower latitude of the Onslow Bay region and its position along the path of the Gulf Stream closer to the radiolarian "source" (tropical seas).

ONSLOW BAY SECTION

The Onslow Bay Section contained an average of 16 taxa per sample, nine nassellarian and seven spumel-

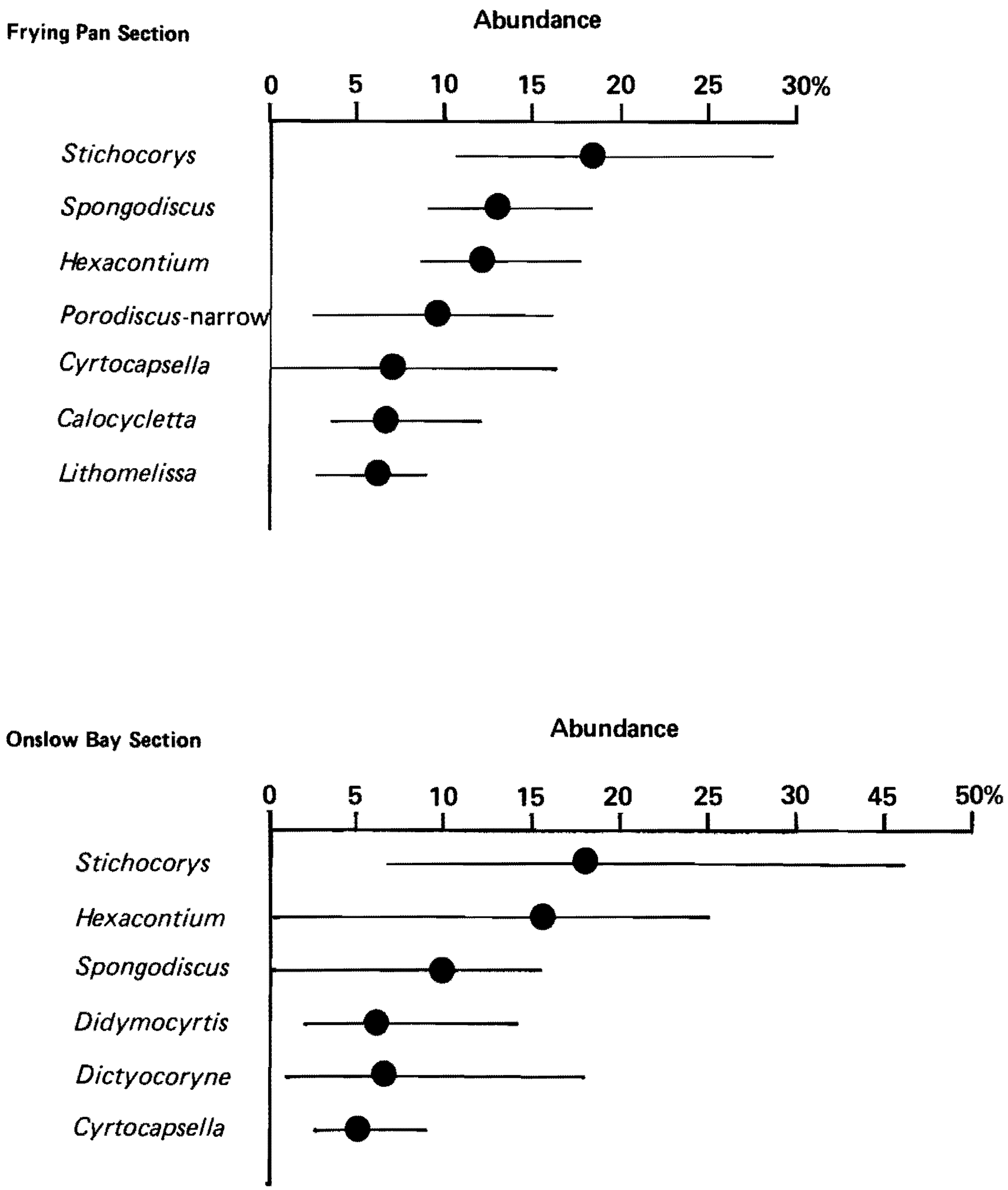

FIGURE 4. The abundance of predominant taxa in the Frying Pan and Onslow Bay Sections is shown (note condensed horizontal scale for Onslow Bay Section). The solid circle indicates the average level of abundance in terms of percent of all radiolarians present; the bar indicates the range of values.

larian (Fig. 3). A total of six predominant taxa were observed (listed in decreasing order): *Stichocorys, Hexacontium, Spongodiscus, Didymocyrtis, Dictyocoryne* (Pl. 2, Fig. 7), and *Cyrtocapsella* (Fig. 4). The average Shannon-Wiener diversity index H(S) equals 0.98 (Fig. 5).

As with the Frying Pan Section, radiolarian abundance and diversity is much lower for the Onslow Bay Section as compared to the age-equivalent Salisbury Embayment unit (Fairhaven Member of the Calvert Formation). An average of 24 taxa and a diversity index of 2.50 were observed in the latter unit (Palmer, 1986b). Eleven predominant taxa were present in the Fairhaven Member, of which six are also predominant in the Onslow Bay Section.

A significant difference, not attributable to preser-

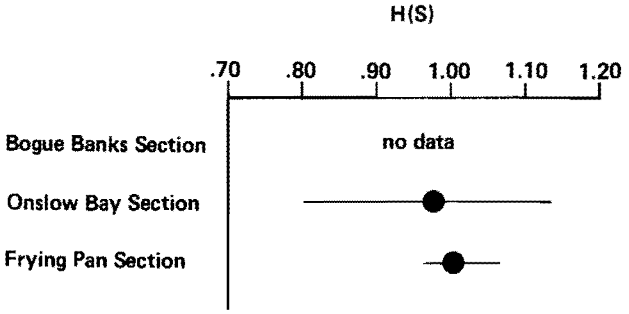

FIGURE 5. Shannon-Wiener diversity index H(S) values for the Frying Pan and Onslow Bay Sections. Solid circle indicates the average value; the bar indicates the range of values.

vational dissimilarities, exists between the fauna of the Onslow Bay Section and that of the Fairhaven Member. In fact, Frying Pan Section and Onslow Bay Section faunas are much more like each other (as are the Dunkirk and Fairhaven faunas) than are similar-age faunas from the two embayments. This suggests a major difference in environmental conditions in the two regions, with the Salisbury Embayment more favorable to radiolarians.

BOGUE BANKS SECTION

Radiolarians in the Bogue Banks Section were somewhat sparser and less well preserved than in the Frying Pan and Onslow Bay Sections. Therefore, no quantitative studies were attempted.

An interesting aspect of the Bogue Banks Section not observed in any other Onslow Bay samples is the pres-

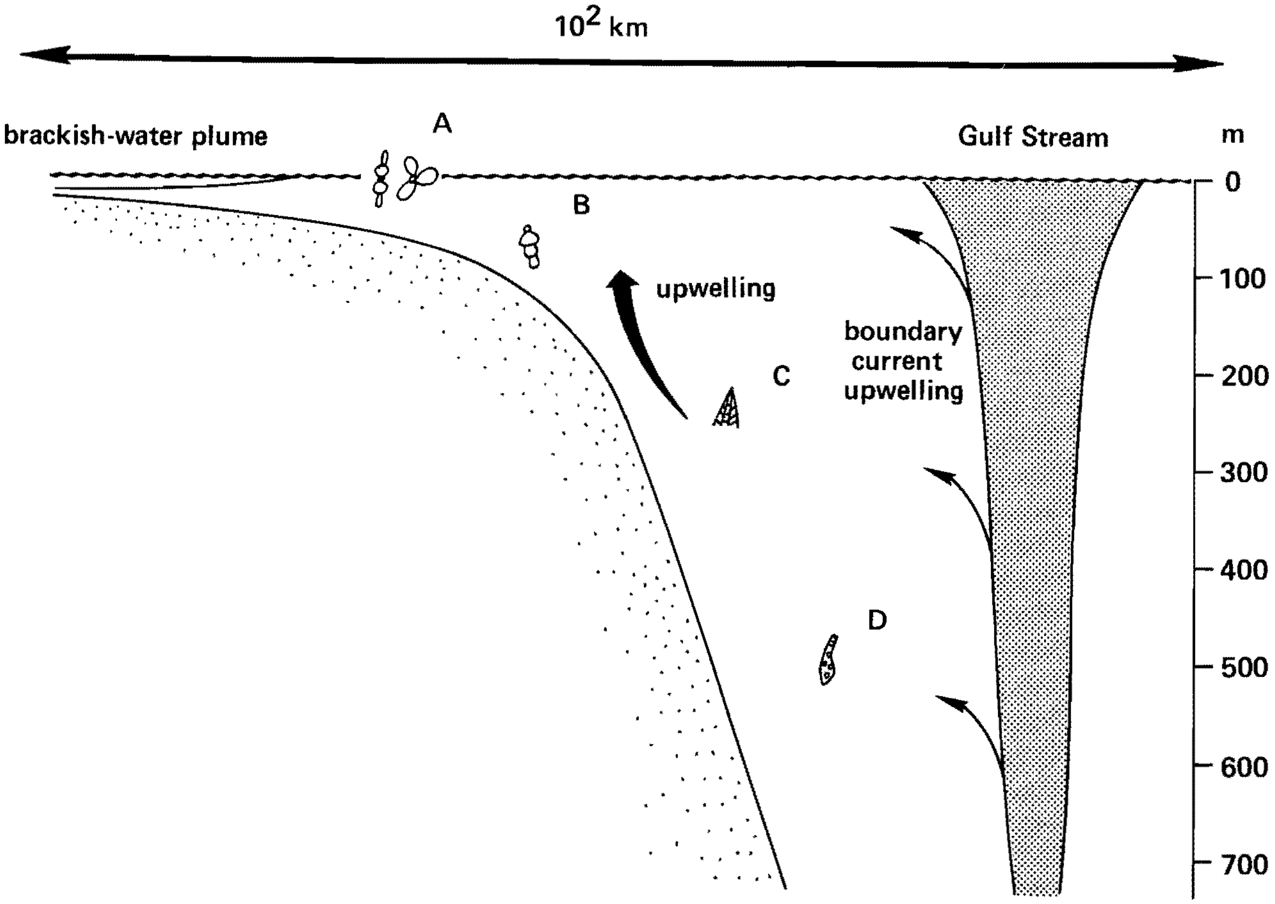

FIGURE 6. Schematic illustration showing different hypothetical processes by which radiolarians may be transported into shelf waters. Radiolarians in groups A and B are near surface to shallow subsurface dwellers which may be transported to the shelf in warm core rings or by shallow level intrusions from the Gulf Stream. Radiolarians in group C are deep-dwellers which may appear in shelf waters as a result of upwelling. Group D radiolarians are deep-dwellers unlikely to appear in shelf waters except by means of deep-level intrusions from the Gulf Stream (after Palmer, 1986b). Role of brackish-water plume is after Leavesley and others (1978).

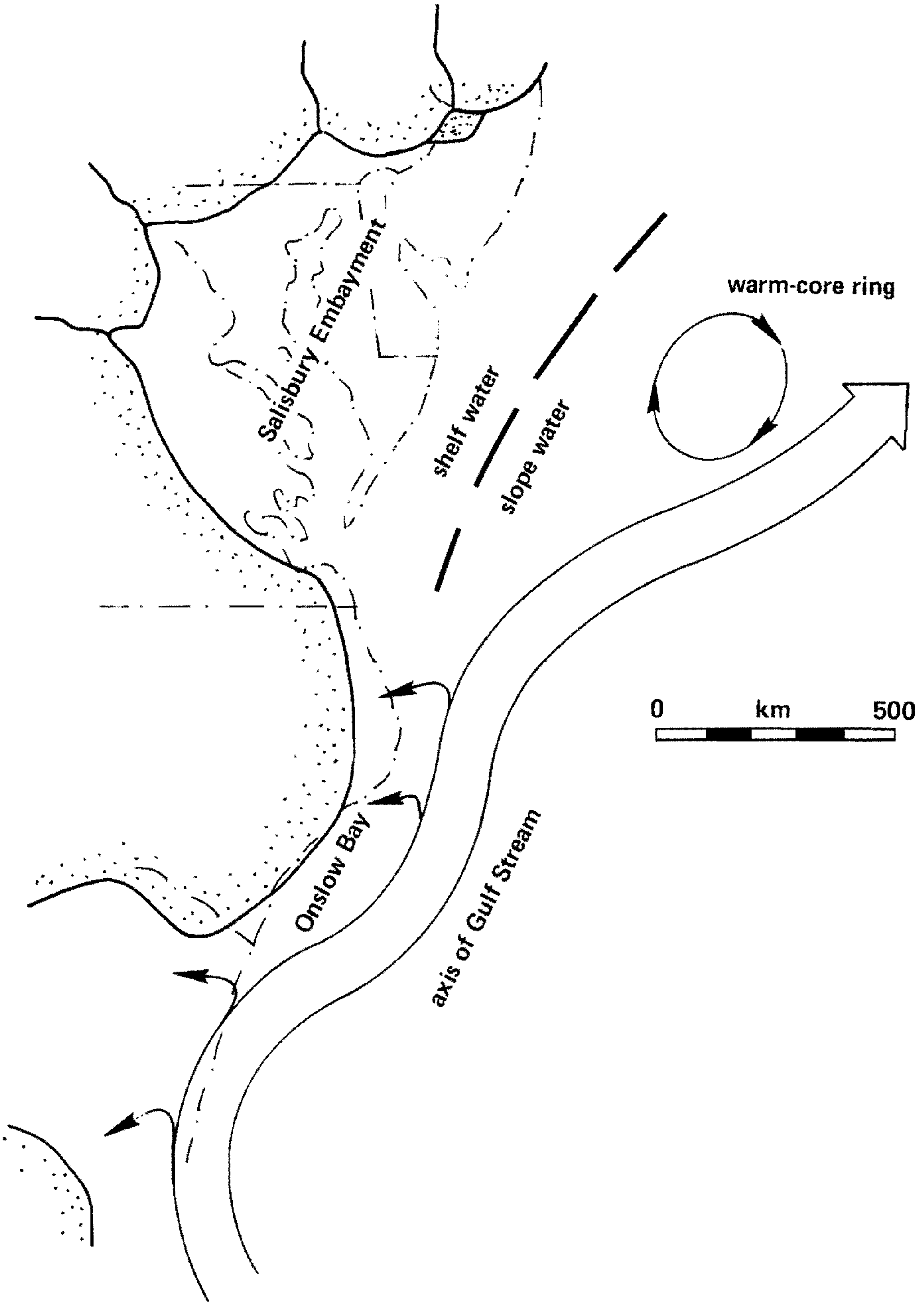

FIGURE 7. Schematic illustration of hypothetical mid-Atlantic to southeastern U.S. Miocene paleogeography and hypothetical Gulf Stream path (modified from Palmer, 1984 and Riggs, 1984). Location of topographically induced meanders and upwellings is after Riggs (1984); influence of "warm core" rings in the mid-Atlantic region was inferred by Palmer (1984).

ence of deep-dwelling radiolarians. Plankton studies have revealed that radiolarians live throughout the water column, although most individuals and species are relatively shallow-living, restricted to the upper 200 m (photic zone). As shelf waters are generally less than 200 m deep, radiolarians occurring in shelf waters would normally be shallow-living. Many of the predominant taxa observed in the Onslow Bay fauna were probably shallow-dwelling, including *Porodiscus, Spongodiscus, Dictyocoryne,* and *Didymocyrtis,* among others. The shallow-water affinity of such taxa has been demonstrated both in studies of modern shelf assemblages (Casey and others, 1979a, b, 1982) and in the Miocene Salisbury Embayment (Palmer, 1984; 1986b). The one exceptional circumstance in which deep-dwelling radiolarians appear in shelf environments involves upwelling of subsurface waters (Fig. 6). Casey and others (1979a, b, 1982) found that deeper-dwelling species appeared in Texas shelf waters during seasonal upwelling events. Palmer (1984, 1986b) attributed the occurrence of *Bathopyramis, Peripyramis* and *Lamprocyclas* within a single horizon of the Miocene Calvert Formation to upwelling. However, some radiolarian taxa apparently live in water masses too deep to be transported to the shelf by upwelling. An example is *Cornutella,* absent from the Calvert Formation but consistently present in Miocene material from the continental slope (Palmer, 1987).

A surprising discovery in Core 42 from Onslow Bay was that not only *Peripyramis* (Pl. 3, Fig. 5) and *Lamprocyclas* were present, but *Cornutella* (Pl. 3, Fig. 6) also occurs. In addition to these taxa, fragments of deep-dwelling orosphaerid radiolarians and hexactinellid sponges (the latter indicative of >400 m water depths) were observed. These occurrences could be interpreted as evidence for greater water depths than at any other Onslow Bay site (200–400 m or greater), but alternately could result from incursion of deep-layer Gulf Stream waters (as discussed by Riggs, 1984).

Discussion

A process by which radiolarians might have been transported from oceanic waters into shelf waters of the Salisbury Embayment involves "warm core rings," shown schematically in Figure 7. These dynamic features are essentially eddies which evolve from western boundary current meanders; modern examples originate as Gulf Stream eddies and pinch off masses of Sargasso Sea water. Leavesley and others (1978) have documented transport of radiolarians and other microzooplankton by anticyclonic rings in the modern-day Gulf of Mexico.

At present, these rings have been tracked by remote sensing techniques and monitored through chemical and biological oceanographic studies as they slowly become mixed with shelf water, and eventually impinge upon the continental shelf north of Cape Hatteras. Although the Miocene paleogeography of the Onslow Bay region and the Salisbury Embayment is imprecisely known, it appears that one or more positive structural features separated the two basins (Gibson, 1983), and that the Miocene Gulf Stream axis hugged the coastline in the vicinity of Onslow Bay, but turned seaward before reaching the mid-Atlantic region (Riggs, 1984).

A major difference between the two regions today is that a slope water mass exists between the shelf water and the Gulf Stream in the mid-Atlantic region, and is absent south of Cape Hatteras. If this were true also in the Miocene (as suggested in the paleogeography of Riggs, 1984), it would be unlikely that warm-core rings could have influenced the Onslow Bay region, although direct upwelling from the Gulf Stream may have been a factor in transporting radiolarians to the shelf waters of this region (Fig. 7). These very different influences help explain the dissimilarity between Miocene radiolarian assemblages of the Salisbury Embayment and the Onslow Bay vibracores.

ACKNOWLEDGMENTS

Many thanks are extended to members of the Geology Department at East Carolina University who helped in providing samples for this study. Frank Rack (ODP) assisted with sample preparation and Peggy Myre (ODP) with photography; their efforts are greatly appreciated. The author also wishes to express gratitude to Andrew C. Adamson for his help with the artwork, and to J. G. Baldauf, R. N. Benson, R. E. Casey, B. M. Clement, and S. W. Snyder for thoughtful reviews. This is ODP Contribution #ODP/P-87/21.

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APPENDIX

LIST OF BIOSTRATIGRAPHICALLY IMPORTANT RADIOLARIAN SPECIES

(Taxa listed in alphabetical order)

Calocycletta caepa Moore
  Calocycletta caepa MOORE, 1972, Micropaleontology, v. 18, p. 150, pl. 2, figs. 4–7.

Calocycletta costata Riedel, Pl. 1, fig. 5
  Calocycletta costata RIEDEL, 1959, Micropaleontology, v. 5, p. 296, pl. 2, fig. 9; Riedel and Sanfilippo, 1978, Micropaleontology, v. 24, p. 66, pl. 3, fig. 9.

Calocycletta virginis (Haeckel)
  Calocyclas virginis HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 1381, pl. 74, fig. 4.
  Calocycletta virginis (Haeckel).—MOORE, 1972, Micropaleontology, v. 18, p. 147, pl. 1, fig. 4.

Carpocanopsis bramlettei Riedel and Sanfilippo
  Carpocanopsis bramlettei RIEDEL and SANFILIPPO, 1971, Initial Reports Deep Sea Drilling Project, v. 7, p. 1597, pl. 2G, figs. 8–14; pl. 8, fig. 7.

Carpocanopsis cingulata Riedel and Sanfilippo, Pl. 1, fig. 10
  Carpocanopsis cingulata RIEDEL and SANFILIPPO, 1971, Initial Reports Deep Sea Drilling Project, v. 7, p. 1507, pl. 2G, figs. 17–21; pl. 8, fig. 8.

Cyrtocapsella cornuta (Haeckel)
  Cyrtocapsa (*Cyrtocapsella*) *cornuta* HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 1513, pl. 78, fig. 9.
  Cyrtocapsella cornuta (Haeckel).—SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 453, pl. 1, figs. 19–20.

Cyrtocapsella tetrapera (Haeckel), Pl. 1, fig. 9
  Cyrtocapsa (*Cyrtocapsella*) *tetrapera* HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 1512, pl. 78, fig. 5.
  Cyrtocapsella tetrapera (Haeckel).—SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 453, pl. 1, figs. 16–18.

Didymocyrtis laticonus (Riedel), Pl. 1, fig. 8
  Cannartus laticonus RIEDEL, 1959, Micropaleontology, v. 5, p. 291, pl. 1, fig. 5.
  Didymocyrtis laticonus (Riedel).—SANFILIPPO and RIEDEL, 1980, Journal of Paleontology, v. 54, p. 1010, text-fig. 1, e.

Didymocyrtis mammifera (Haeckel), Pl. 1, fig. 4
  Cannartidium mammiferum HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 375, pl. 39, fig. 16.
  Cannartus mammiferus (Haeckel).—RIEDEL, 1959, Micropaleontology, v. 5, p. 291, pl. 1, fig. 4.
  Didymocyrtis mammifera (Haeckel).—SANFILIPPO and RIEDEL, 1980, Journal of Paleontology, v. 54, p. 1010.

Didymocyrtis prismatica (Haeckel), Pl. 1, fig. 1
  Pipettella prismatica HAECKEL, 1887, Report on Scientific Re-

sults of Voyage of H. M. S. Challenger, Zoology 18, p. 305, pl. 39, fig. 6.

Didymocyrtis prismatica (Haeckel).—SANFILIPPO and RIEDEL, 1980, Journal of Paleontology, v. 54, p. 1010, text-fig. 1, c.

Didymocyrtis tubaria (Haeckel)

Pipettaria tubaria HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 339, pl. 39, fig. 15.

Cannartus tubarius (Haeckel).—RIEDEL, 1959, Micropaleontology, v. 5, p. 289, pl. 1, fig. 2.

Didymocyrtis tubaria (Haeckel).—SANFILIPPO and RIEDEL, 1980, Journal of Paleontology, v. 54, p. 1010.

Didymocyrtis violina (Haeckel), Pl. 1, fig. 2

Cannartus violina HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 358, pl. 39, fig. 10; SANFILIPPO, BURCKLE, MARTINI, and RIEDEL, 1973, Micropaleontology, v. 19, pl. 1, figs. 11–12.

Didymocyrtis violina (Haeckel).—SANFILIPPO and RIEDEL, 1980, Journal of Paleontology, v. 54, p. 1010.

Eucyrtidium calvertense Martin

Eucyrtidium calvertense MARTIN, 1904, *in* Miocene Volume: Baltimore (Maryland Geological Survey), p. 450, pl. 130, fig. 5.

Eucyrtidium diaphanes Sanfilippo and Riedel

Calocyclus coronata CARNVALE, 1908, Reale Instituto Veneto di Scienze, Lettre ed Arti, Memorie, v. 28, p. 33, pl. 4, fig. 24 (not *Eucyrtidium coronatum* Ehrenberg 1873).

Eucyrtidium diaphanes SANFILIPPO and RIEDEL, *in* Sanfilippo, Burckle, Martini and Riedel, 1973, Micropaleontology, v. 19, p. 221, pl. 5, figs. 12–14 (new name).

Liriospyris stauropora (Haeckel), Pl. 1, fig. 7

Trissocyclus stauropora HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 987, pl. 83, fig. 5.

Liriospyris stauropora (Haeckel).—GOLL, 1968, Journal of Paleontology, v. 42, p. 1431, pl. 75, figs. 1–3, 7 and text-fig. 9.

Lithopera neotera Sanfilippo and Riedel

Lithopera (Lithopera) neotera SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 454, pl. 1, figs. 24–26, 28.

Lithopera neotera Sanfilippo and Riedel.—SANFILIPPO, 1971, *in* Farinacci, A. (ed.), Proceedings of Second International Planktonic Conference, pl. 1F, figs. 14–15; pl. 2E, fig. 19.

Lithopera renzae Sanfilippo and Riedel

Lithopera (Lithopera) renzae SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 454, pl. 1, figs. 21–23, 27.

Lithopera renzae Sanfilippo and Riedel.—RIEDEL and SANFILIPPO, 1971, Initial Reports Deep Sea Drilling Project, v. 7, pl. 2E, figs. 17–18; pl. 7, fig. 14.

Lithopera thornburgi Sanfilippo and Riedel

Lithopera (Glomaria) thornburgi SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 455, pl. 2, figs. 4–6.

Lithopera thornburgi Sanfilippo and Riedel.—RIEDEL and SANFILIPPO, 1978, Micropaleontology, v. 24, p. 70, pl. 6, fig. 12.

Spongasteriscus marylandicus Martin, Pl. 2, fig. 6

Spongasteriscus marylandicus MARTIN, 1904, *in* Miocene Volume: Baltimore (Maryland Geological Survey), p. 453, pl. 130, fig. 10; PALMER, 1986a, Micropaleontology, v. 32, p. 28, pl. 1, fig. 2.

Stichocorys delmontensis (Campbell and Clark), Pl. 1, Fig. 6

Eucyrtidium delmontense CAMPBELL and CLARK, 1944, Geological Society of America Special Paper 51, p. 56, pl. 7, figs. 19–20.

Stichocorys delmontensis (Campbell and Clark).—SANFILIPPO and RIEDEL, 1970, Micropaleontology, v. 16, p. 451, pl. 1, fig. 9.

Stichocorys wolffii Haeckel, Pl. 1, fig. 3

Stichocorys wolffii HAECKEL, 1887, Report on Scientific Results of Voyage of H. M. S. Challenger, Zoology 18, p. 1479, pl. 80, fig. 10; RIEDEL and SANFILIPPO, 1971, Initial Reports Deep Sea Drilling Project, v. 7, pl. 2E, figs. 8–9.

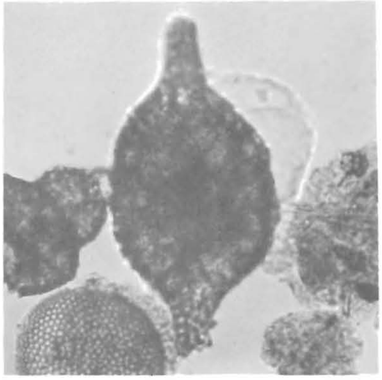
Tepka perforata Sanfilippo and Riedel

Tepka perforata SANFILIPPO and RIEDEL, *in* Sanfilippo, Burckle, Martini, and Riedel, 1973, Micropaleontology, v. 19, p. 228–230, pl. 6, figs. 18–20.

PLATE 1

Scale bar = 100 microns

1 *Didymocyrtis prismatica* (Haeckel). (Core 98, 1.75–2.00 m). **2** *Didymocyrtis violina* (Haeckel). (Core 98, 1.75–2.00 m). **3** *Stichocorys wolffii* Haeckel. (Core 98, 1.75–2.00 m). **4** *Didymocyrtis mammifera* (Haeckel). (Core 34, 3.25–3.50 m). **5** *Calocycletta costata* Riedel. (Core 34, 6.25–6.50 m). **6** *Stichocorys delmontensis* (Campbell and Clark). (Core 98, 1.75–2.00 m). **7** *Liriospyris stauropora* (Haeckel). (Core 98, 1.75–2.00 m). **8** *Didymocyrtis laticonus* (Riedel). (Core 42, 5.50–5.75 m). **9** *Cyrtocapsella tetrapera* (Haeckel). (Core 98, 1.75–2.00 m). **10** *Carpocanopsis cingulata* Riedel and Sanfilippo. (Core 98, 1.75–2.00 m).



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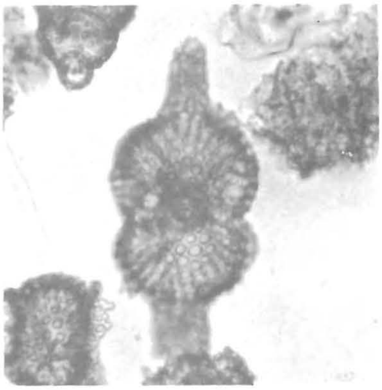

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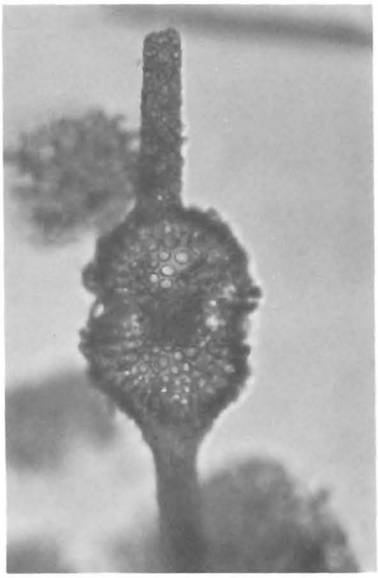

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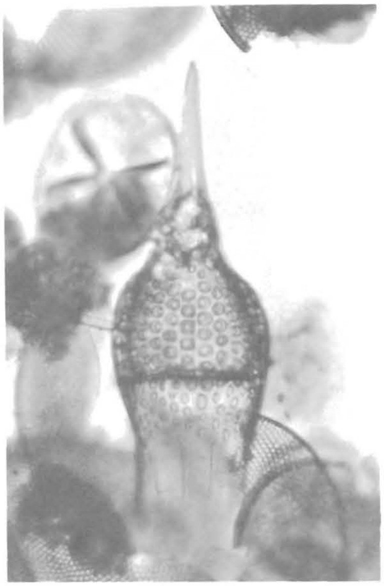

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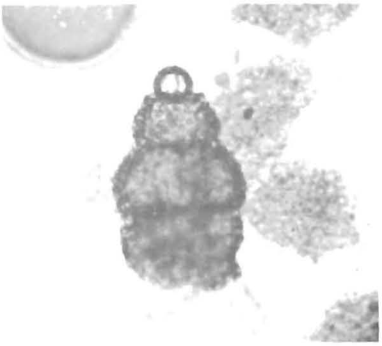

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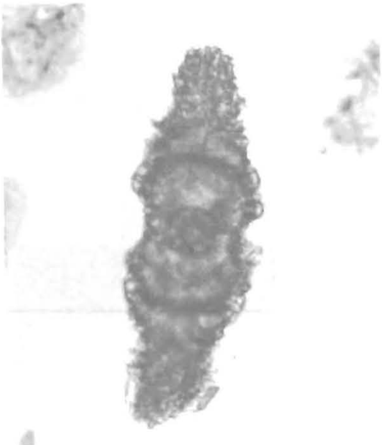

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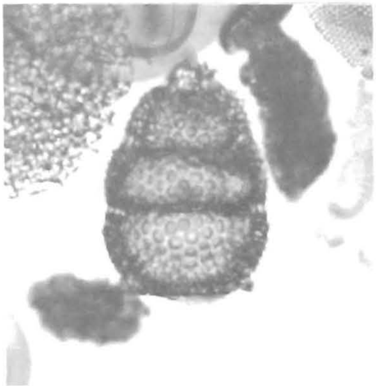

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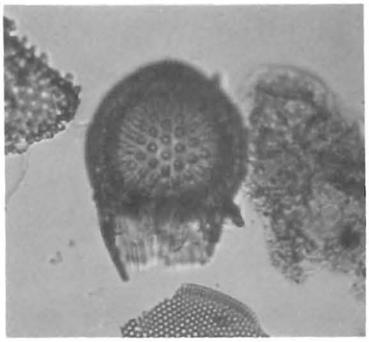

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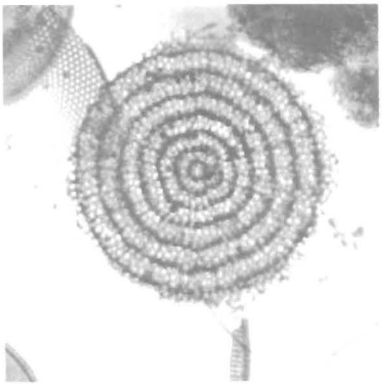
PLATE 2

Scale bar = 100 microns

1 *Porodiscus*, narrow rings. (Core 34, 6.25–6.50). **2** *Porodiscus*, wide rings. (Core 98, 1.75–2.00 m). **3** Spongodiscid. (Core 42, 6.00–6.25 m). **4** Litheliid. (Core 98, 1.75–2.00 m). **5** Phacodiscid. (Core 98, 1.75–2.00 m). **6** *Spongasteriscus marylandicus* Martin. (Core 49, 7.25–7.50 m). **7** *Dictyocoryne*. (Core 42, 5.50–5.75 m).



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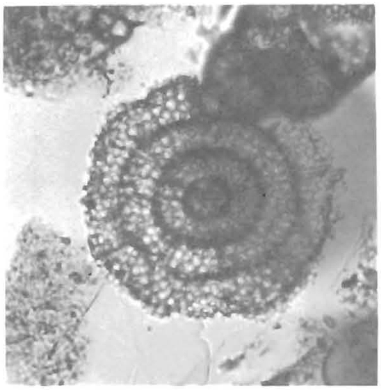

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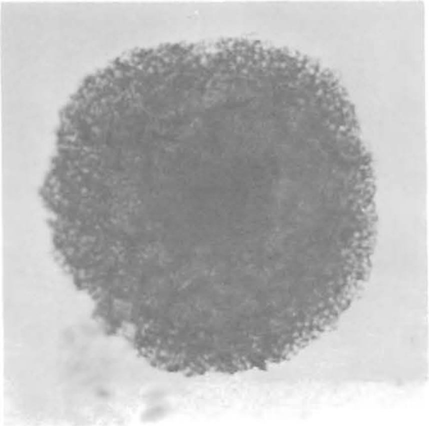

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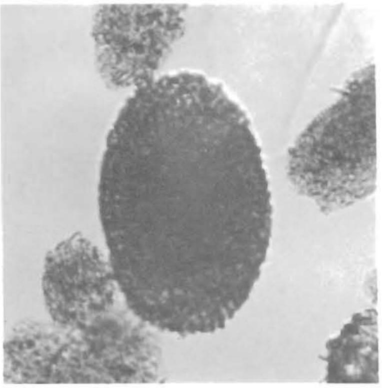

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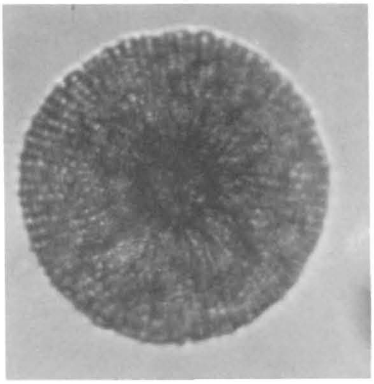

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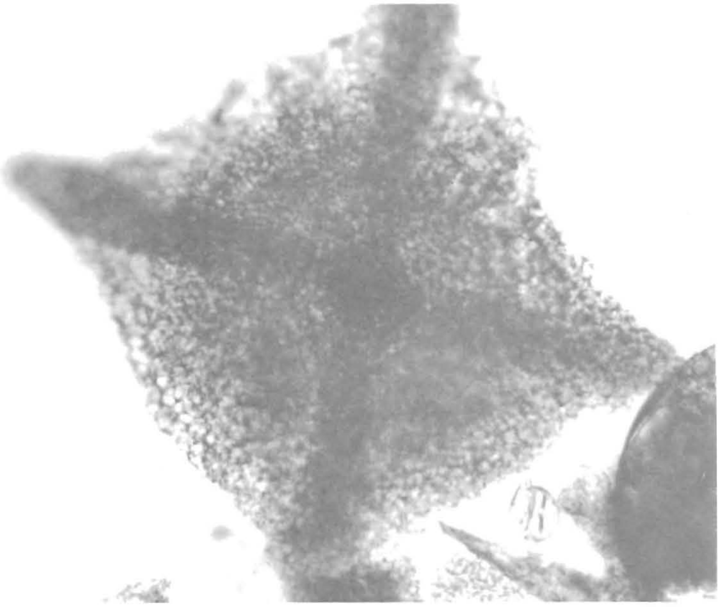

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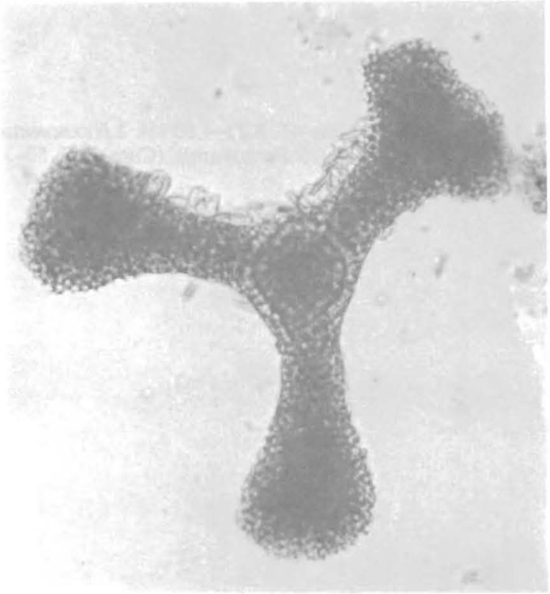

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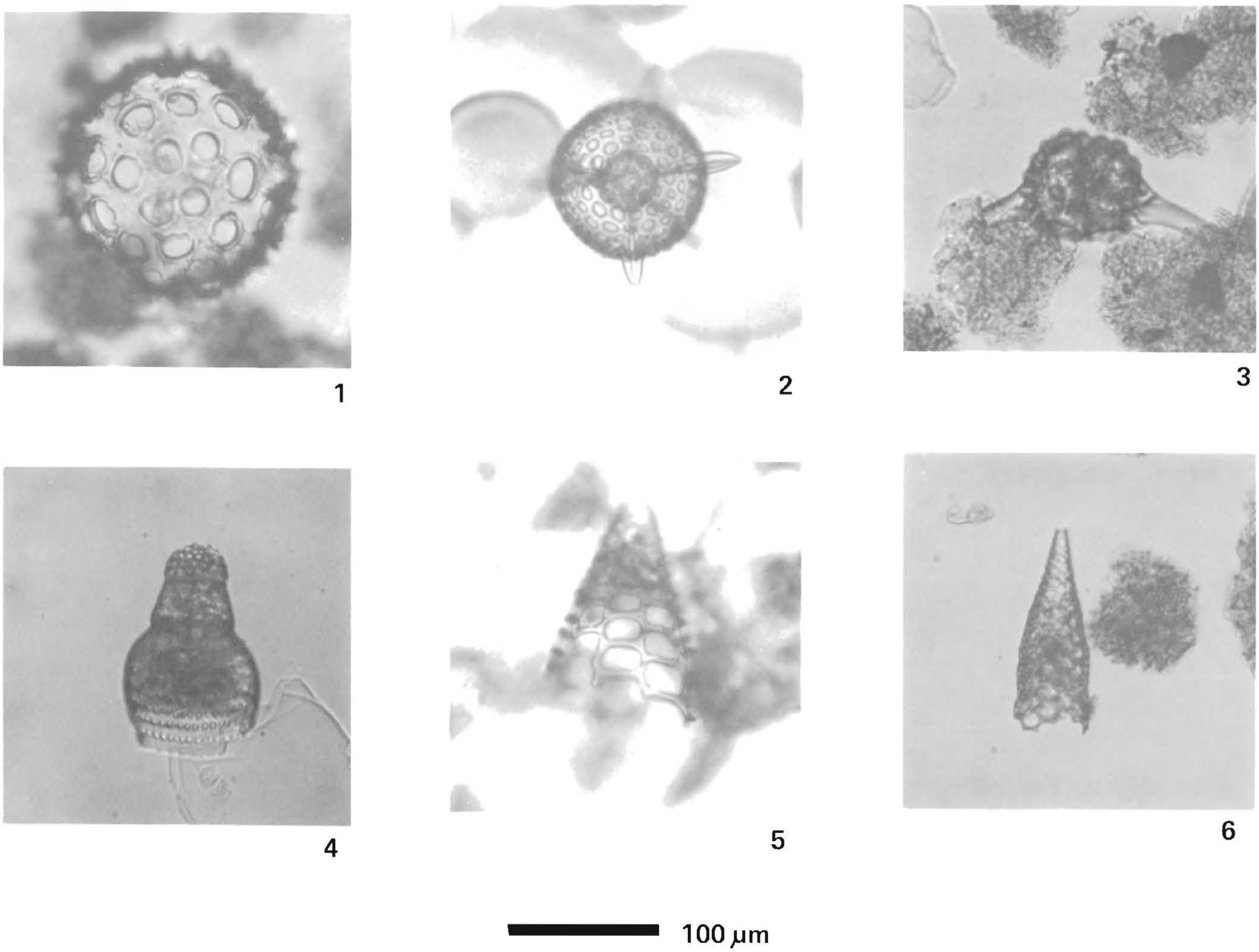

PLATE 3
Scale bar = 100 microns

1 Collosphaerid. (Core 43, 4.25–4.50 m). **2** *Hexacontium.* (Core 34, 7.75–8.00 m). **3** *Dorcadospyris.* (Core 98, 1.75–2.00 m). **4** Artostrobiid. (Core 98, 1.75–2.00 m). **5** *Peripyramis.* (Core 42, 3.50–3.75 m). **6** *Cornutella.* (Core 42, 6.50–6.75 m).

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SYNTHESIS OF BIOSTRATIGRAPHIC AND PALEOENVIRONMENTAL INTERPRETATIONS OF MIOCENE SEDIMENTS FROM THE SHALLOW SUBSURFACE OF ONSLOW BAY, NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

The Miocene Pungo River Formation in Onslow Bay represents three episodes of deposition, each with an estimated duration of approximately 1 million years. The Frying Pan Section is middle Burdigalian in age (18.4 to 17.4 Ma), the Onslow Bay Section spans the Langhian (15.9 to 14.9 Ma), and the Bogue Banks Section is middle Serravallian in age (13.0 to 12.0 Ma). Each section approximates a third-order seismic sequence within second-order supercycle TB2 of Haq and others (1987).

Pungo River Formation sediments were deposited in a middle sublittoral to upper bathyal bathymetric setting. The Frying Pan Section in southern Onslow Bay contains phosphorites which accumulated in nutrient-enriched, oxygen-poor waters introduced by marine upwelling. To the north, clastic sediments accumulated in more oxygen-enriched bottom waters. The Onslow Bay Section comprises prograding clinoforms of siliciclastic sediments that accumulated in high-energy, well oxygenated bottom conditions. Phosphorites in the Bogue Banks Section of central Onslow Bay coincide with a minor upwelling event, whereas mixed phosphorite-siliciclastic sediments in northern Onslow Bay correspond with the introduction of colder, well oxygenated waters, possibly from a northerly source.

INTRODUCTION

The purpose of this article is to summarize and synthesize conclusions of the preceding individual contributions. Rather than reiterate basic data, the focus is on combining results from the analyses of various fossil groups to form a more comprehensive interpretation. Readers interested in supportive data are referred to appropriate individual contributions.

BIOSTRATIGRAPHY

SELECTING A ZONAL SCHEME

Although standardized zonal schemes have been developed for many groups of microfossils, interpretations among contemporary workers vary with respect to 1) age and duration of some specific zones, 2) stratigraphic relationships among zones based on different groups, and 3) relationship of some zones to both standard ages and absolute time scale. Figure 1 illustrates interpretations from several of the most authoritative and widely cited available references. Depending upon which reference is followed, the assignment of a stratum to certain biostratigraphic zones may denote quite different ages and stage assignments. For example, assignment to nannofossil Zone NN6 signifies a markedly different absolute age and series assignment if interpreted according to Haq and others (1987) as compared to Bolli and others (1985). Indeed, the ages inferred from a zonal assignment to NN6 would not even overlap. The implied relationship of Zone NN6 to standard planktonic foraminiferal zones is also markedly different; Haq and others (1987) suggest correlation with Zones N12-mid N13, while Bolli and others (1985) indicate equivalence to Zones N9-mid N12. According to Berggren and others (1985), Zone NN6 correlates with planktonic foraminiferal Zones mid N10-mid N11 and implies yet another absolute age (Fig. 1).

Clearly, results from studies of limited geographic

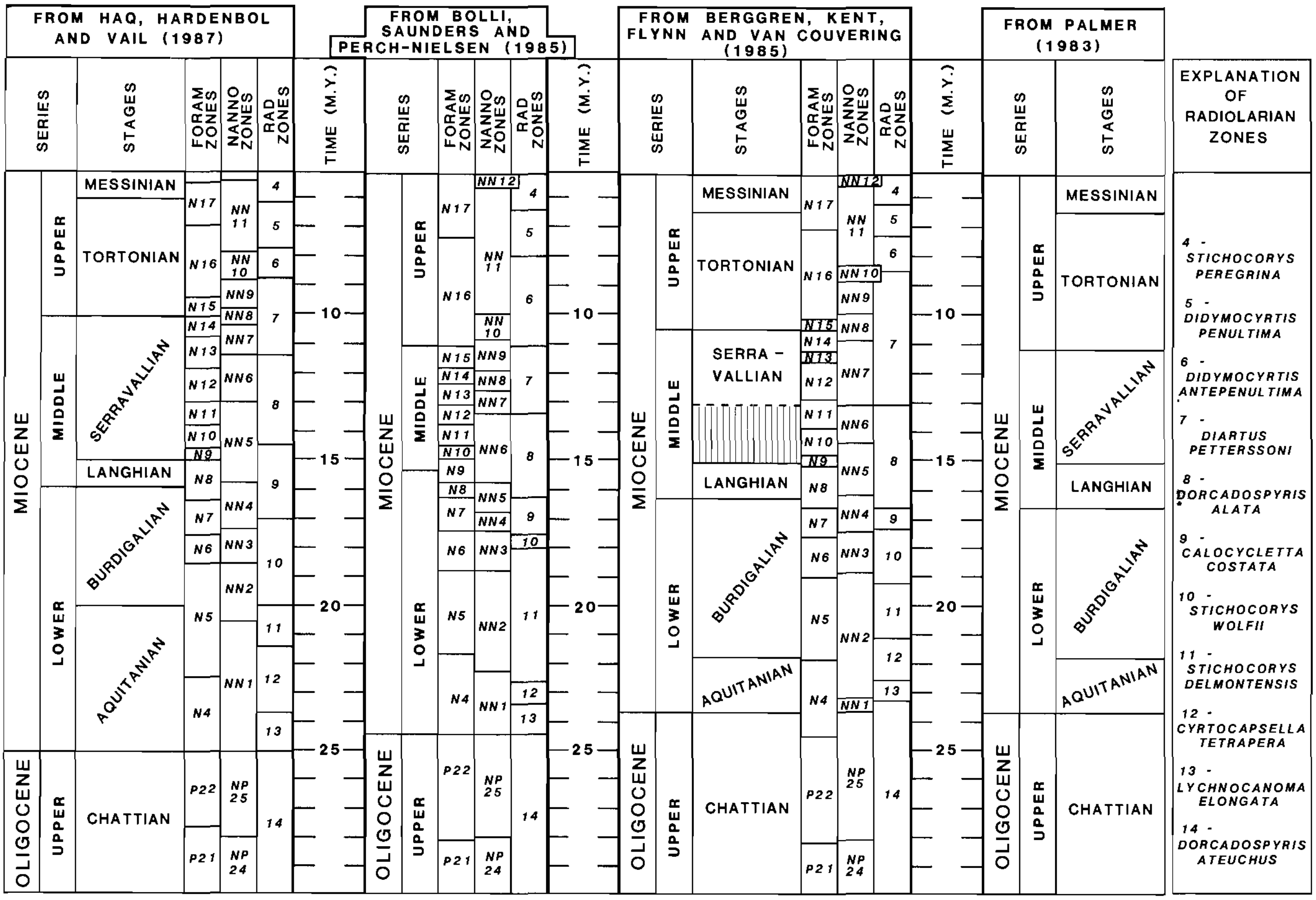

FIGURE 1. Comparison among selected biostratigraphic zonal schemes for the Miocene. Time (M.Y.) remains consistent across the diagram. Note that interpretations vary with respect to duration of some individual zones, relationships among zones based on different taxonomic groups, and relationships of zones to both standard stages and absolute time scale.

and stratigraphic extent, such as the Miocene of Onslow Bay, are widely relevant only within the context of a more comprehensive and expansive biostratigraphic/chronostratigraphic scheme. It is imperative, however, that one such scheme be selected and that results be consistently related to it. The interpretive framework of Haq and others (1987) was selected for Onslow Bay because: 1) zonal relationships within the independently generated data set from Onslow Bay agree closely with relationships indicated by their chart; 2) use of their scheme facilitates comparison with sequence stratigraphy, particularly with relative changes of coastal onlap.

INTERPRETATION OF ONSLOW BAY SECTIONS

Biostratigraphic analyses are able to resolve age differences among Onslow Bay sections that approximate third-order coastal onlap events. The fourth-order seismic sequences described by Snyder and others (this volume) represent time spans too short to be distinguished biostratigraphically.

As each third-order section is discussed, note that combining the data from all microfossil groups improves results by providing: 1) a cross-checking mechanism which allows the level of confidence in results from individual groups to be assessed; 2) more complete sample coverage than could be attained using any single group; 3) more precise biostratigraphic constraints than would generally be possible using any single group. Frequent reference to Figures 2a and 2b will be helpful during the following discussions. All zonal relationships are from Haq and others (1987).

Frying Pan Section

The Frying Pan Section is assigned to planktonic foraminiferal Zones N6-lower N7. Sequences FPS-1

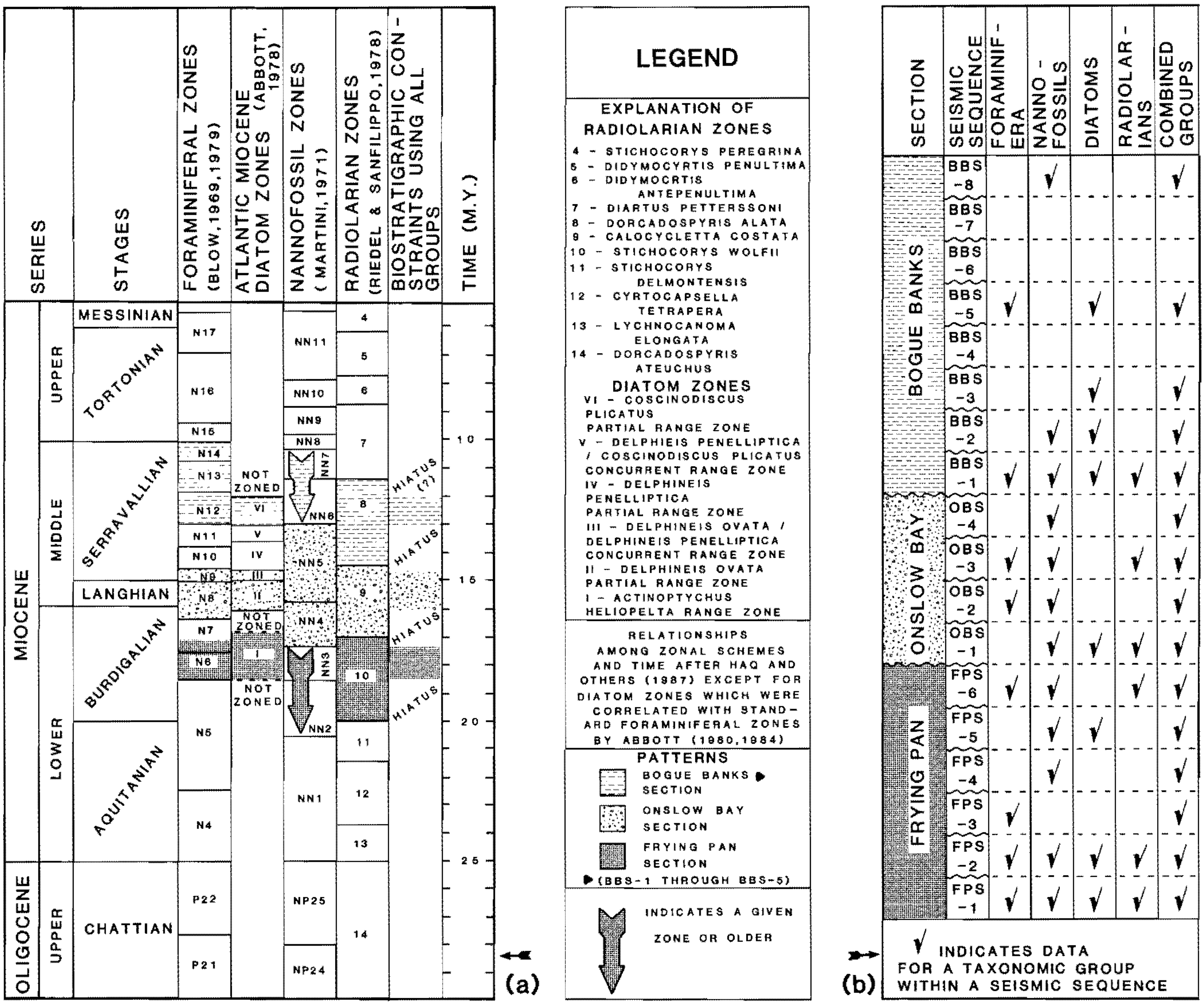

FIGURE 2. a. Biostratigraphic interpretations based on individual fossil groups compared to biostratigraphic constraints attained by combining data from all groups. Intervals with patterns represent depositional events corresponding to stratigraphic sections which approximate third-order coastal onlap events. Each blank area represents a hiatus, with initiation of the youngest marked as questionable because of insufficient data from sequences BBS-6 through BBS-8. Hence, data is reliable only for BBS-1 through BBS-5. b. Fourth-order seismic sequences for which data are available from each taxonomic group. Note that data from combined groups are more comprehensive than data from any single group, but that BBS-6 through BBS-8 are marked by a paucity of data.

through lower FPS-6 contain taxa indicative of Zone N6, whereas the upper portion of FPS-6 contains taxa which first appear at the base of Zone N7. Nannofossil assemblages represent Zone NN3 or older. Sporadic and rare occurrences of taxa indicating Zone NN1 or older are attributed to reworking. Diatom floras are assigned to Atlantic Miocene Diatom Zone (AMDZ) I, which corresponds generally to foraminiferal Zones N6-mid N7. Although the base of AMDZ I has not been defined, the co-occurrence of several silicoflagellate taxa suggest an age no older than foraminiferal Zone N6. Radiolarian faunas indicate Zone 10, which has an upper boundary approximately correlative with the middle of foraminiferal Zone N7.

Combining information from all these groups (Fig. 2a), the base of foraminiferal Zone N6 and the top of nannofossil Zone NN3 provide the greatest biostratigraphic precision. Based on the chart of Haq and others (1987), the age of the Frying Pan Section is middle Burdigalian, ranging from approximately 17.4 to 18.4

Ma. Although no single microfossil group occurs in all six fourth-order sequences, utilizing all groups provides data from all sequences (Fig. 2b). Faunas and floras are generally the most abundant and diverse encountered in the Miocene sediments of Onslow Bay, and there is a correspondingly high degree of confidence in biostratigraphic interpretation.

Onslow Bay Section

Because the Onslow Bay Section is less fossiliferous and was penetrated by fewer vibracores, biostratigraphic data are sparser than for the Frying Pan Section. Age-diagnostic planktonic foraminiferal faunas, recovered only from OBS-2 and OBS-3, are assigned to Zones N8-N9. Although assemblages are not rich enough to make a definitive statement, the N8-N9 boundary may be contained within OBS-2, and OBS-3 may represent only the lower portion of N9. Nannofossil assemblages do not constrain the age of the Onslow Bay Section except to limit it to the middle portion of the Miocene (Zones NN4 and NN5). Siliceous microfossils occur in undifferentiated OBS outliers in southern Onslow Bay, as well as in sequences OBS-1 and OBS-3. Sediments in the OBS outliers, which are assigned to AMDZ's II and III, are partly equivalent to but also slightly older than OBS-1 (which represents only AMDZ III). Diatom Zones II and III correlate with foraminiferal Zones lower N8-upper N9. Radiolarian faunas are assignable to Zone 9, which has an upper boundary almost coincident with those of foraminiferal Zone N9 and AMDZ III. Assemblages in OBS-1 and OBS-3 suggest that the uppermost part of radiolarian Zone 9 is absent.

Biostratigraphic constraints using all microfossil groups are no more refined than those based solely on diatoms (Fig. 2a). However, the interpretation based on planktonic foraminifera corroborates the diatom-based interpretation, and radiolarian faunas suggest that only the lower portions of AMDZ III and foraminiferal Zone N9 are present. Relative to the charts of Haq and others (1987), the Onslow Bay Section ranges in age from approximately 14.9 to 15.9 Ma. Although this time span includes the uppermost Burdigalian and the lowermost Serravallian, the Onslow Bay Section is largely Langhian. Again, using all groups provides meaningful data from all fourth-order sequences, whereas any single group does not (Fig. 2b).

Bogue Banks Section

The Bogue Banks Section is the most difficult of the three third-order sections to interpret. Faunas and floras are reasonably abundant and diverse in sequences BBS-1 through BBS-5, but BBS-6 through BBS-8 are generally devoid of age-diagnostic assemblages. The one exception is the presence of nannofossils in BBS-8. However, these assemblages do not constrain the age of BBS-8 except to indicate that it represents Zone NN7 or younger. Because of the paucity and imprecise nature of biostratigraphic data, sequences BBS-6 through BBS-8 are not included in the following discussion. Interpretations relate only to sequences BBS-1 through BBS-5. Uncertainty about the upper portion of the Bogue Banks Section is acknowledged by the questionable upper age limit in Figure 2a.

Planktonic foraminiferal assemblages in BBS-1 through BBS-5 contain several taxa which indicate an age no older than Zone N12 and no younger than Zone N14. Nannofossil assemblages from the same sequences restrict the age to older than Zone NN8. Diatom assemblages are assigned to AMDZ IV, which correlates with foraminiferal Zones uppermost N11-uppermost N12. Radiolarian faunas indicate Zone 8, but also suggest that only the latter part of this zone is present (an interpretation which corroborates assignments based on other groups).

Combining data from all microfossil groups, the base of foraminiferal Zone N12 and the top of AMDZ IV provide the greatest biostratigraphic precision (Fig. 2a). Relative to the chart of Haq and others (1987), these constraints imply an age ranging from approximately 12 to 13 Ma (middle Serravallian). Assemblages are sufficiently abundant and diverse to provide a high level of confidence in the older age limit. However, the younger age limit is based on data from sequence BBS-5 (Fig. 2b). The upper age limit of the Bogue Banks Section is, therefore, imprecise because of insufficient data from sequences BBS-6 through BBS-8.

DISCUSSION

The Miocene stratigraphic record preserved in the shallow subsurface of Onslow Bay represents three periods of deposition, each with an estimated duration of approximately 1 Ma. The actual duration of these depositional periods may have been shorter (deposition during only some portion of the time span definable by biostratigraphy) or longer (portions of the depositional record erased by subsequent erosion). Estimated durations of intervening hiatuses are, of course, subject to the same limitations in accuracy. The hiatus between the Frying Pan and Onslow Bay Sections represents about 1.5 Ma, and the hiatus between the Onslow Bay and Bogue Banks Sections spans approximately 1.9 Ma.

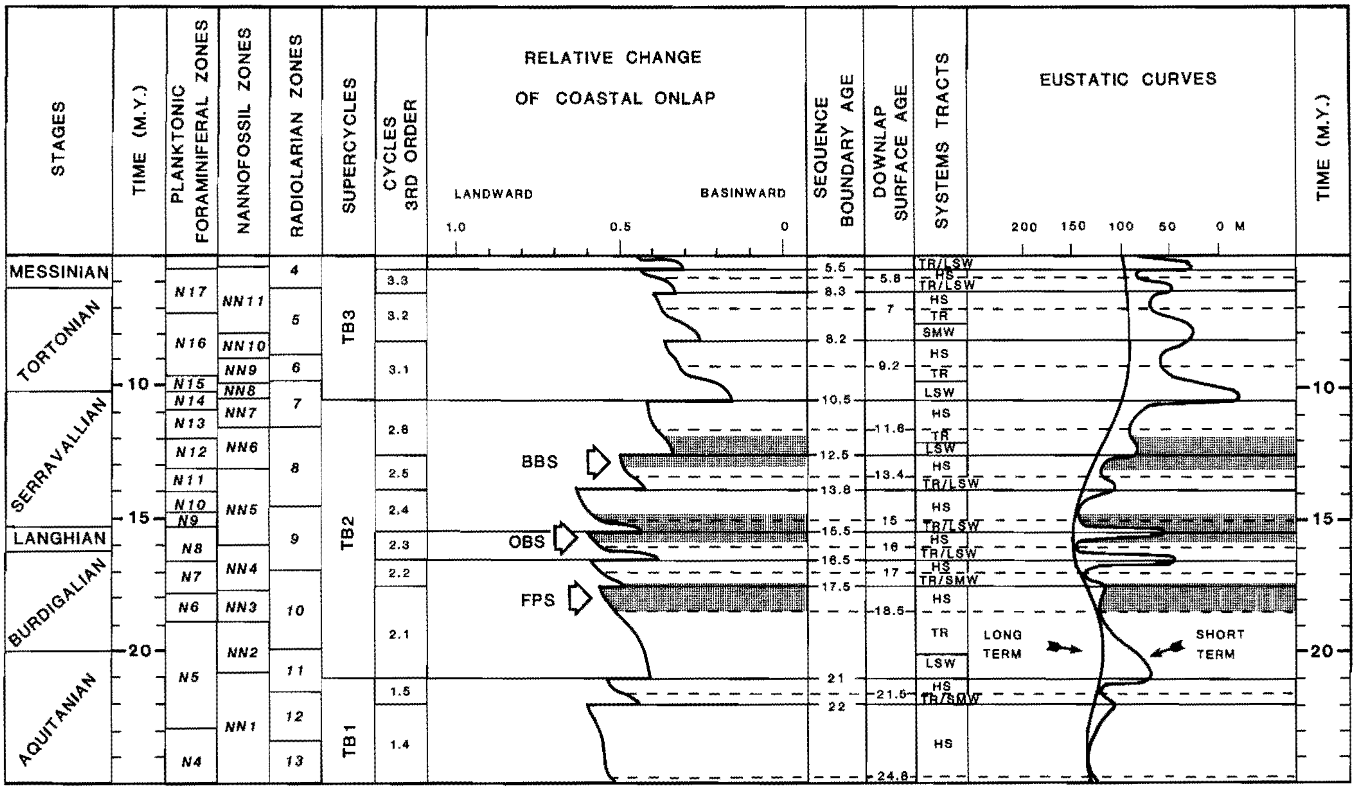

FIGURE 3. Relationship of third-order depositional sections in Onslow Bay to coastal onlap and eustatic curves of Haq and others (1987). Note that biostratigraphic constraints indicate that each depositional event brackets a landward "peak" on the coastal onlap curve, but that all such "peaks" in the Miocene did not leave a depositional record. The Bogue Banks Section represents only sequences BBS-1 through BBS-5.

Duration of the hiatus at the base of the Pungo River Formation section has not been accurately determined because pre-Pungo River sediments were not studied in detail. Planktonic foraminifera indicate that the age of pre-Pungo River deposits is Zone N4 or older, and nannofossil assemblages have been assigned to the NP24-NN1 zonal interval (Laws and Worsley, 1986). This suggests that the basal hiatus is equal to or longer than hiatuses within the Pungo River Formation section, but more detailed work is needed to accurately assess its duration. Regardless of its duration, the hiatus at the base of the Pungo River section coincides with a second-order supercycle boundary of Haq and others (1987) (Fig. 3). Poag and Ward (1987) demonstrated that this supercycle boundary is marked by an unconformity in three Atlantic Coastal Plain embayments, and in offshore composites from New Jersey and Ireland. There can be little doubt that it is linked with a major eustatic sea-level drop.

Likewise, duration of the hiatus above Pungo River Formation sediments in Onslow Bay is indeterminate. The three uppermost fourth-order seismic sequences of the Bogue Banks Section could not be biostratigraphically dated. Bogue Banks sediments are overlain by sporadic patches of younger sediments which range in age from Pliocene to Holocene. The absence of upper Serravallian and Tortonian sediments suggests that the post-Pungo River Formation unconformity also originated at a second-order supercycle boundary of Haq and others (1987) (Fig. 3). Miller and others (1987) recognized a latest middle Miocene unconformity in numerous cores and boreholes across the New Jersey continental slope. A correlative hiatus has also been noted on the Irish continental margin (Muller, 1985; Snyder and Waters, 1985; Scott W. Snyder and others, 1985). With the exception of the Salisbury Embayment, Poag and Ward (1987) noted a widespread late middle Miocene unconformity along the eastern and western North Atlantic continental margins, again suggesting control by eustatic oscillation.

The entire Pungo River Formation was deposited during second-order supercycle TB2 of Haq and others (1987). At first glance, third-order sections of the Formation do not appear to correlate with changes of relative coastal onlap (Haq and others, 1987). Biostratigraphic age constraints for each section encompass the following portions of the cycle chart:

Frying Pan—upper part of cycle 2.1;
Onslow Bay—upper part of cycle 2.3 and lower part of 2.4;
Bogue Banks—upper part of cycle 2.5 and lower part of 2.6 (Fig. 3).

Although depositional periods defined by biostratigraphic constraints do not conform exactly to landward "peaks" in the coastal onlap curve, each of the three sections (Frying Pan, Onslow Bay, Bogue Banks) does incorporate one and only one such "peak." time spans depicted by shaded areas on Figure 3 indicate best estimates of age based on biostratigraphic analyses. However, the three sections in Onslow Bay may represent only some portion of these respective time spans. Because the study area is near the updip limit of the Pungo River Formation, it is likely that deposits correspond, at least in part, to the maximum sea-level highstands during third-order cycles 2.1, 2.3 and 2.5. These eustatic highstands immediately precede landward "peaks" on the relative coastal onlap curve (Fig. 3). Consequently, correlation between depositional sections in Onslow Bay and third-order coastal onlap events may be more precise than biostratigraphic resolution can document.

Correspondence of the Frying Pan, Onslow Bay and Bogue Banks Sections with the curve of Haq and others (1987) indicates that third-order eustatic oscillations influenced the Miocene depositional record in Onslow Bay. However, not all third-order sea-level highstands and periods of maximum coastal onlap are represented in the Pungo River Formation. If third-order eustatic oscillations were the sole factor influencing deposition, sediments representing the maximum onlap of cycles 2.2 and 2.4 should have been encountered. Other factors which may have influenced the preservation of third-order depositional sequences include lateral migration of and erosion by the Gulf Stream in concert with eustatic sea-level change (Pinet and Popenoe, 1985; Popenoe, 1985; Stephen W. Snyder and others, in press), regional tectonic controls, variations in coastal lithosome preservation in response to shoreface truncation during relative coastal onlap (Hine and Stephen W. Snyder, 1985), paleoceanographic events not directly related to eustacy (Mullins and others, 1987), and paleoclimatic changes which steepened global temperature gradients and caused invigorated atmospheric and oceanic circulation (Kennett, 1982). Any combination of these factors may have contributed to the stratigraphic breaks spanning the landward "peaks" of cycles 2.2 and 2.4.

PALEOENVIRONMENT

Just as biostratigraphic analyses are improved by examining several microfossil groups, so too are paleoenvironmental analyses. Interpretations of floral and faunal assemblages complement one another, as do analyses of benthic and planktonic assemblages. Combined data provide a more comprehensive reconstruction than would be possible based on any single microfossil group.

Pungo River Formation sediments appear to have been deposited largely in a middle sublittoral to upper bathyal paleobathymetric setting. Numerical dominance of benthic diatoms throughout the formation indicates deposition within the photic zone. Benthic foraminiferal assemblages generally indicate a sublittoral setting, although planktonic to benthic ratios and species composition of the benthic assemblage occasionally suggest deposition in the upper bathyal zone. Diatom assemblages are also occasionally marked by an influx of meroplanktonic and planktonic taxa associated in modern seas with coastal upwelling systems. Radiolarian faunas, although largely composed of shallow-dwelling forms, sometimes contain taxa that typify deeper waters of the open ocean. Nannofossil assemblages have meager diversity (unlike most continental shelf environments) and genera common to shelf areas are usually rare. Even though diagenesis may have produced some of these effects, microfossil assemblages clearly indicate that Onslow Bay was influenced by deep, open-ocean water masses during the Miocene. However, as will be argued below, sediments were deposited across the middle shelf to upper slope in a region where paleoceanographic conditions periodically introduced deeper, colder, more nutrient-enriched waters onto the continental margin. Reference to Figure 4 will be helpful during the following discussions.

FRYING PAN SECTION

During deposition of sequences FPS-1 and FPS-2, southern Onslow Bay was the site of phosphorite and organic-rich, often zeolitic mud accumulation. Abundant and diverse planktonic foraminiferal faunas, along with benthic faunas indicative of nutrient enrichment and its resultant productivity and oxygen depletion, suggest the upwelling of deeper waters. Siliceous mi-

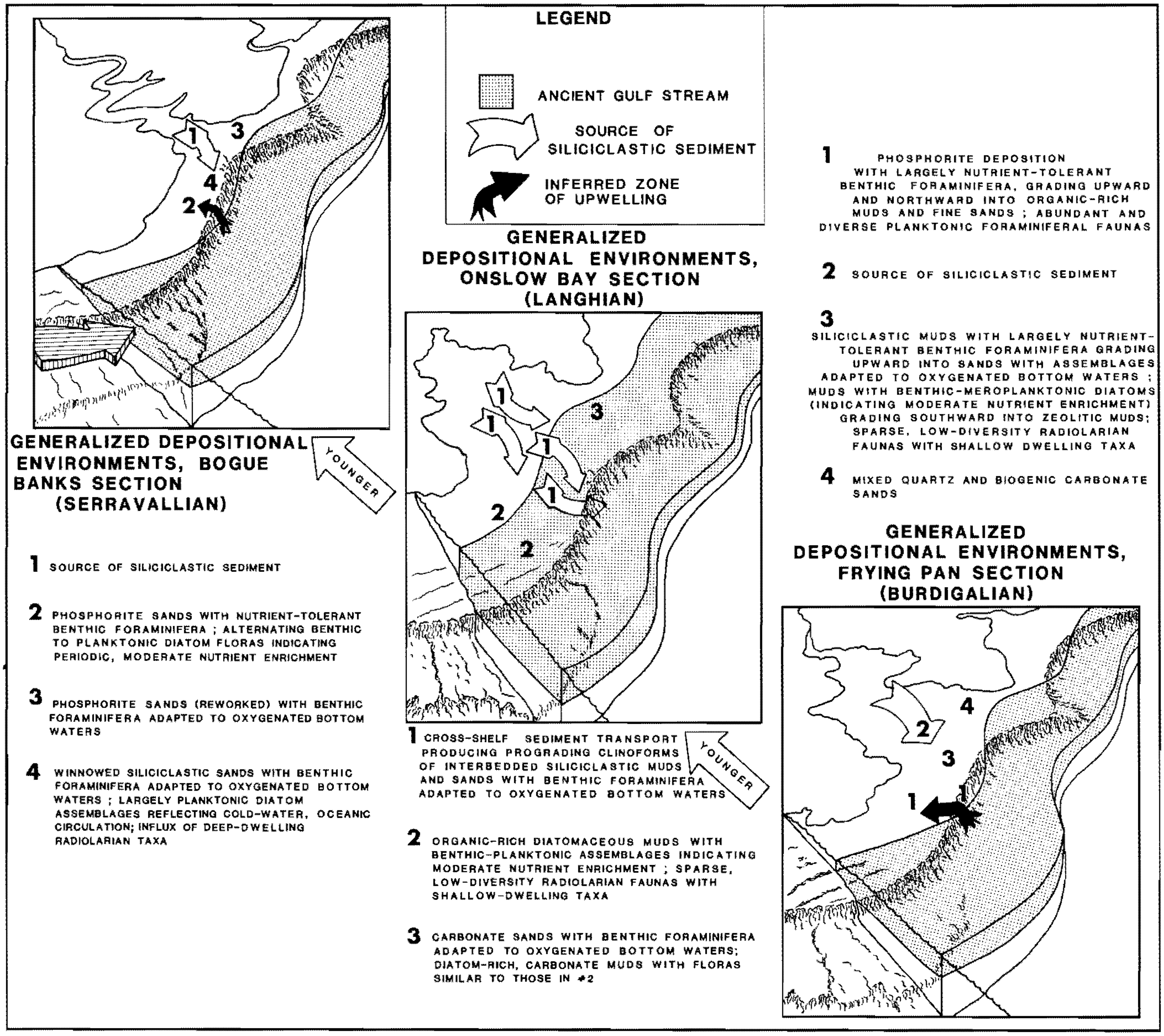

FIGURE 4. Graphic summarization of generalized paleo-environmental setting within the three sections that approximate third-order coastal onlap events. Graphic design and positions of Gulf Stream and shoreline adapted from Riggs (1984).

crofossils are generally absent, but the source of silica for zeolitic muds may have been, at least in part, biogenic. Perhaps a rich and diverse association of diatoms and radiolarians was initially present but was not preserved. Stratigraphically higher fourth-order sequences have less phosphate. Deposition of the Frying Pan Section in this portion of the bay culminated with a channel-fill sequence of foraminiferal quartz sands (FPS-6). Increased clastic and reduced authigenic sedimentation was accompanied by changes in the benthic foraminiferal fauna that reflect reduced nutrient and increased oxygen levels in bottom and interstitial waters.

Central Onslow Bay was the site of primarily clastic sediment deposition. Planktonic foraminifera are generally scarce and benthic assemblages are composed predominantly of taxa known to thrive in well-oxygenated bottom waters. Diatoms in the lower Frying Pan Section are largely sublittoral benthic forms, but an upward increase in meroplanktonic taxa suggests minor influence from oceanic waters. Floras with species composition similar to modern assemblages adjoining upwelling centers grade southward into zeolitic muds. Sparse, rather low-diversity radiolarian faunas are predominantly shallow-dwelling forms. The presence of low-latitude radiolarian taxa (absent from equivalent deposits in the Salisbury Embayment) reflects the proximity of the Gulf Stream.

Sediments from the Frying Pan Section in northern Onslow Bay were not extensively sampled. They are a mix of quartz and biogenic carbonate sands with some siliciclastic muds. Microfossil assemblages are absent or poorly preserved and paleoenvironmental interpretation is equivocal.

ONSLOW BAY SECTION

Samples from the Onslow Bay Section in southern Onslow Bay come from undifferentiated outliers that cannot be confidently assigned to one of the four numbered fourth-order sequences. Microfossils are predominantly siliceous. Diatom floras differ from those of the underlying Frying Pan Section in having, 1) a slightly higher percentage of planktonic taxa, some known to be associated with modern upwelling systems; 2) a greater percentage of meroplanktonic taxa; and 3) a greater abundance of benthic taxa (e.g., *Delphineis* spp.) adapted to nutrient-enriched conditions. These floral characteristics combine to suggest a shelf environment with moderately elevated concentrations of nutrients. Radiolarians, although present, are sparse and have rather low-diversity. Taxa are largely shallow-dwelling types.

Sediments in central Onslow Bay are composed of interbedded siliciclastic sands and muds which formed seaward-prograding clinoforms. These sediments are often barren of microfossils. Siliceous remains are absent, and benthic foraminifera, when present, are largely taxa adapted to moderately high-energy, well-oxygenated bottom conditions. Planktonic foraminifera are rare and benthic species composition suggests a middle to lower sublittoral depositional setting.

Northern Onslow Bay is characterized by carbonate-rich sands containing abundant foraminifera, and by carbonate muds which are occasionally rich in diatoms and radiolarians. Benthic foraminifera indicate that the sands were deposited in well-oxygenated bottom waters, while diatoms from associated muds contain up to 15% planktonic taxa considered to be reliable indicators of upwelling. They indicate a depositional setting similar to that described for OBS outliers in southern Onslow Bay. Radiolarians are predominantly shallow-dwelling types.

BOGUE BANKS SECTION

In contrast to the limitations on biostratigraphic analyses of the Bogue Banks Section (data from BBS-1 through only BBS-5), paleoenvironmental interpretations apply to the entire section (BBS-1 through BBS-8). The outcrop/shallow subcrop pattern of the Bogue Banks Section is confined to central and northern Onslow Bay.

Except for one small region characterized by phosphatic sands, Bogue Banks sediments in central Onslow Bay are composed of winnowed siliciclastic sands with minor amounts of mud. The phosphatic sands contain a benthic foraminiferal fauna predominated by taxa tolerant of organic enrichment and low levels of dissolved oxygen. Elsewhere, siliciclastic sands contain benthic assemblages numerically dominated by taxa adapted to well-oxygenated bottom conditions. Immediately to the north of the phosphorites, siliceous microfossil assemblages indicate the influx of cooler, more nutrient-enriched waters derived from an open oceanic source. Radiolarian assemblages, although sparse, are characterized by the presence of deep-dwelling forms. Diatom assemblages are composed of 50% benthic taxa but contain 35 to 40% planktonic species which indicate cold water and probable upwelling. Upwelling of deeper water into central Onslow Bay at this time is the most plausible explanation for this curious mix of shelf and oceanic taxa. Upwelling also helps to explain the presence of phosphate deposits and the composition of their associated benthic foraminiferal assemblages.

In northern Onslow Bay, Bogue Banks sediments are composed of mixed phosphorite and siliciclastic muddy sands. Radiolarians are absent, but siliceous remains are present in the form of diatoms. Floras are marked by high abundances of planktonic and meroplanktonic species typical of cold, often nutrient-enriched waters. Evidence of high primary productivity is corroborated by the common occurrence of benthic taxa which also suggest elevated nutrient levels. Curiously, benthic foraminiferal species composition does not reflect nutrient or organic enrichment. Taxa are largely types associated with less productive, highly oxygenated bottom conditions. Sedimentologically, phosphate grains appear to be reworked, rather than *in situ* (Mallette, 1986). Perhaps the influx of colder water in northern Onslow Bay near the end of the

Bogue Banks depositional episode reflects the influence of the cold, southward-flowing Labrador Current rather than an upwelling event. Seismic evidence (Stephen W. Snyder, 1982) suggests that the Cape Lookout High was by this time no longer an effective barrier against circulation of northerly waters into Onslow Embayment.

CONCLUDING REMARKS

Depositional patterns related to sea-level cyclicity (Haq and others, 1987) adequately explain some aspects of the Miocene stratigraphic record in Onslow Bay. The Pungo River Formation was deposited during the TB2 supercycle, and bounding unconformities correlate with those noted in other widely distributed sections of the Atlantic margin (Poag and Ward, 1987). The three distinct stratigraphic sections within the formation (Frying Pan, Onslow Bay, Bogue Banks) conform less precisely to specific third-order coastal onlap events. Also, all third-order coastal onlap events of the Haq and others (1987) curve are not represented by known deposits in Onslow Bay. Factors other than third-order eustatic sea-level fluctuations must have influenced the depositional record. However, each of the three preserved stratigraphic sections does encompass the maximum landward "peak" of only one third-order coastal onlap event, indicating that the cycle chart of Haq and others (1987) explains, at least in part, the parasequence framework in this region.

Several recent papers illustrate the complexity of factors that may have affected the Miocene continental margin in the region of modern Onslow Bay. Popenoe and others (1987) demonstrated that the Gulf Trough, a major subsurface low extending from the Florida panhandle to Cape Hatteras, N.C., marks a seaway swept by strong currents from middle Eocene through late Oligocene. This trough was the site of nondeposition and erosion during the Eocene and Oligocene, when the erosional trend across the Cape Fear Arch (=Mid-Carolina Platform High) was an ancient analogue to erosion by the modern Gulf Stream tract across the Charleston Bump on the northern Blake Plateau. By the end of the Oligocene, terrigenous sediments began infilling the Gulf Trough (Riggs, 1984). Filling of this erosional trough with Miocene to Holocene sediments records a major change in the geologic history of the southeastern Atlantic continental margin, a change that had profound influence on the Onslow Bay region.

Mullins and others (1987) documented the initiation of the Loop Current in the northeastern Gulf of Mexico some 12 to 15 Ma. They attributed initiation of this current to tectonically induced impedance of through-going ocean currents in the Isthmus of Panama, not to eustatic oscillations. Establishment of the Loop Current, which accounts for one-third of the total volume of the modern Gulf Stream, must have increased both volume and flow rate of the Miocene Gulf Stream. The potential to alter depositional processes in the Onslow Bay region is obvious.

Pinet and Popenoe (1985) and Popenoe (1985) showed that the stratigraphic succession on Blake Plateau was influenced by lateral migration of the Gulf Stream in step with eustatic sea-level change. The Miocene Gulf Stream, strengthened by closure of the Gulf Trough and initiation of the Loop Current, may have caused erosion as it impinged upon the shelf in Onslow Embayment during marine transgressions. It is not yet clear why one eustatic highstand would leave a depositional record whereas another would result in erosion.

Miller and Katz (1987) provided an excellent discussion of Miocene paleoceanography in the North Atlantic, in which they used sediment and foraminiferal accumulation rates, dissolution indices, carbon isotopic comparisons and seismic stratigraphic evidence to reconstruct abyssal circulation. They concluded that the greatest changes in bottom water conditions occurred in the late early to early middle Miocene (20 to 10 Ma), and that the principal cause of concomitant benthic foraminiferal faunal changes was increased primary productivity. Changes in Atlantic deep water may reflect oceanographic changes which also affected marginal areas such as Onslow Embayment. Increased productivity in the Atlantic, coupled with intensified Gulf Stream circulation, could have triggered the upwelling of deeper, nutrient-rich waters. Paleoclimatic trends, such as steepening of global temperature gradients and increased oceanic circulation (Kennett, 1982) may also have played a part.

Finally, and perhaps most importantly, the depositional record which one might expect to document third-order cyclicity may have been complexly altered, both by erosion and deposition associated with shorter, fourth-order sea-level cyclicity (18 such cycles being recognized in Onslow Bay). On a passive continental margin characterized by minimal subsidence and sporadic sediment supply, deposits representing some third-order cycles may not have been preserved. Even where portions of them were preserved, stratigraphic complexities superimposed by fourth-order cycles likely obscured relationships between sediment patterns and third-order cyclicity.

Clearly, the Miocene depositional record in Onslow Bay may have been influenced by a combination of regional events, global oceanographic changes, and varying scales of sea-level cyclicity. It is not surprising that the resulting stratigraphic package does not correspond exactly with the cycles recognized by Haq and others (1987).

To better understand Miocene sedimentary sequences along the central Atlantic continental margin, two steps must be accomplished: 1) significant progress in correlating offshore and coastal plain stratigraphic data bases, with particular emphasis on seismic interpretations; 2) continuous coring through the thicker, down-dip portions of the Miocene section.

ACKNOWLEDGMENTS

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