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DISTRIBUTION OF FORAMINIFERA ON THE NORTH CAROLINA CONTINENTAL SHELF

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I. Abstract

The quantitative distribution of one hundred and sixty-four species of foraminifera has been studied from eighty-six equal volume samples from the continental shelf of North Carolina. The area is strongly influenced by the Gulf Stream which follows the edge of the continental shelf north to Cape Hatteras from where it flows into the open ocean. A major faunal boundary exists at the latitude of Cape Hatteras, separating faunas which are characteristic for the central and northern Atlantic coasts of the U.S.

[1] Contribution No. 29 from the Ira C. Darling Center.

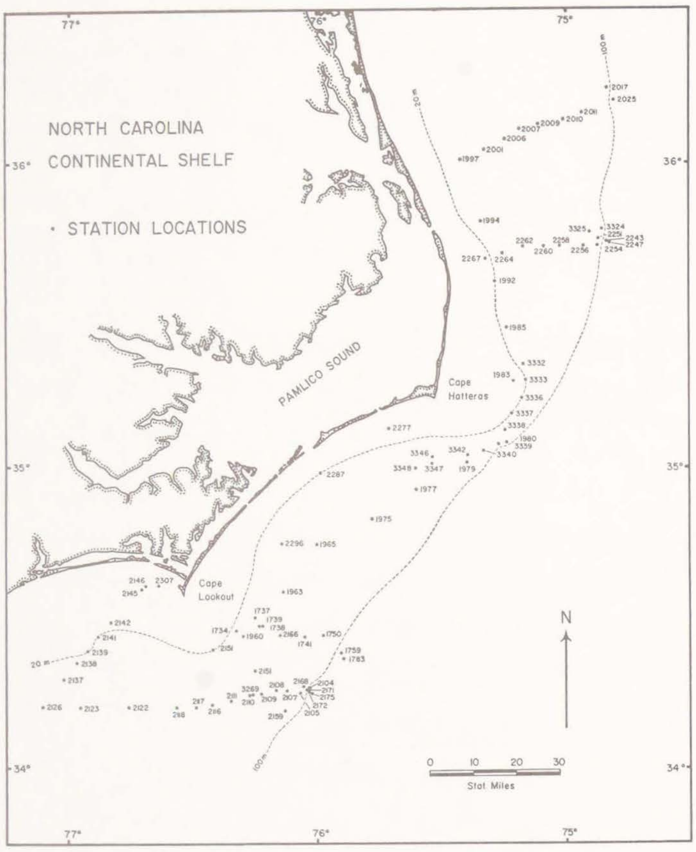

Figure 1. North Carolina Continental Shelf, Index to Sampling Stations

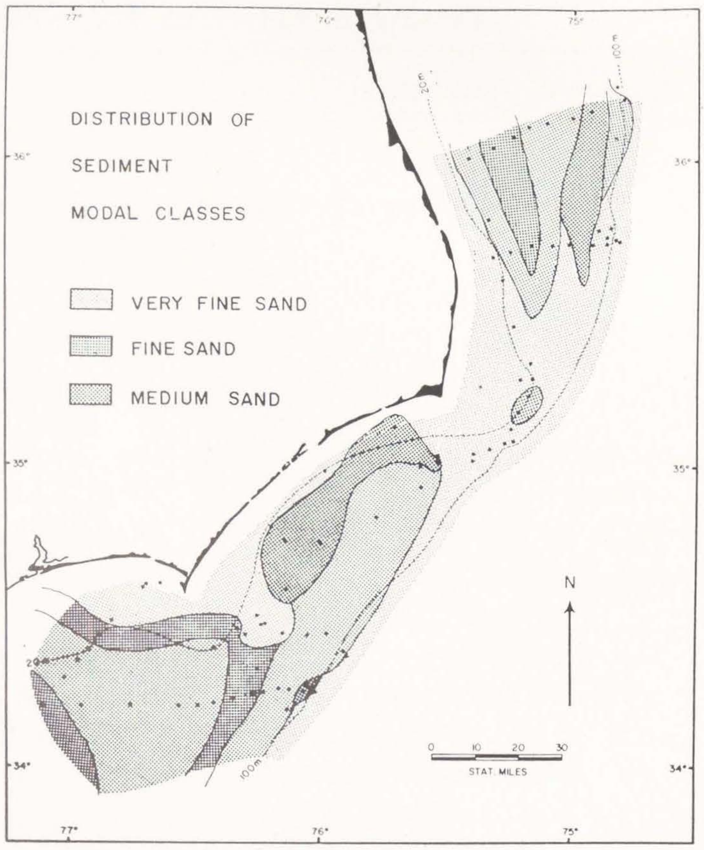

Figure 2. Distribution of sediment modal classes, as determined by the Ingram method (Ingram, 1965)

from faunas which are similar to those from Florida and the Gulf of Mexico. It is possible to distinguish a syn-thanatotope of the central shelf with a lower boundary of about sixty meters and a syn-thanatotope of the shelf edge. The total number of both, benthonic and planktonic specimens, increases with increasing depth. A relict fauna is present on the outer portions of the central shelf and shelf edge which indicates a rise in sea level of about sixty meters since the last Pleistocene glaciation stage. Faunal diversity is higher south of Cape Hatteras which signifies the stabilizing influence of the Gulf Stream in this area.

II. Introduction

The purpose of this study is threefold: first, to inventory the foraminiferal faunas of the continental shelf of North Carolina; second, to determine quantitatively the composition of the foraminiferal populations; and third, to describe the distribution of these populations within the study area.

Interpretation of the faunal data attempts to characterize distinctive habitats and to relate particular distributions to the general oceanography of the area.

Acknowledgments

This project was made possible by the Duke University Marine Laboratory through the use of the R/V *Eastward* in the Cooperative Oceanographic Program. This program is supported through NSF Grant G-17669 to Duke University. Sincere thanks are due Professor Joseph St. Jean, Jr. for his support during the initial phases of this project. The assistance of H. A. Curran and K. McKinney in collecting the samples is greatly appreciated. James Lacey arranged the computer analysis of the faunal data. The writer is greatly indebted to Professor William W. Hay for his guidance and aid which led to the completion of this study. Thanks are also extended to Professors H. R. Wanless, A. V. Carozzi, R. L. Langenheim and E. B. Small for their critical reading of the manuscript. The continued support and encouragement of Julia B. Schnitker is gratefully acknowledged.

III. Area and Methods of Study

The study area is on the continental shelf off North Carolina between approximately 34° N and 36°30′ N Lat., and seaward to approximately the 100 meter contour line (fig. 1). The samples were collected on several cruises of the R/V *Eastward* during the period of June 28 to November 8, 1965, at locations determined by Loran navigation and at depths determined by sonar sounding (Alpine PESR). An initial attempt to obtain bottom samples by a gravity coring device (Phleger, 1951) failed largely because of the compactness of the sandy substrate in most of the study area. Even additional weights and free fall trigger devices did not drive the corer more than 5 cm into the sand. Satisfactory samples were obtained, however, with a modified Van Veen grab. This sampler was provided with four large holes in the upper corners of the sides, so that the water could flow through the jaws when the grab was slowly lowered to the bottom. This minimized the effect of pushing a water mass ahead of the grab, which might sweep light, surficial material away from the grab at the moment of impact. The effectiveness of this modification was shown by capture of shrimp, still resting on the substrate. Further, the bottom-water interface was rarely disturbed, even where sediments were soft. The top of the grab was fitted with a door through which the samples were taken by pushing a short piece of plastic coring tube into the sediment. Thereafter the top centimeter of these sub-samples was cut off and stored in glass jars. For the preservation of live material, formaldehyde, neutralized and buffered with hexamethyleneamine and sodium bicarbonate, was added.

The sub-sampling method was tested by comparing two samples obtained by the gravity corer and the Van Veen grab off the docking facilities of the Duke Marine Laboratory. A chi-square test of the foraminiferal faunas indicated identity at the 95% confidence level.

In the laboratory, Rose Bengal was added to the samples approximately three hours before analysis to stain the protoplasm and

TABLE Ia PERCENTAGE DISTRIBUTION OF TOTAL BENTHONIC POPULATION (North of Cape Hatteras)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2262	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Ammobaculites dilatatus																									x	x				x
Ammodiscus catinus																		x	1		3			x	x		x			
Ammonia beccarii	2				2		5			2	1		1	2	3	1														
Amphistegina lessonii																														
Articulina sagra																														
Astacolus crepidulus																										x				
Asterigerina carinata						6																								
Asterigerinata pulchella					2		2	9	6	5	3	2	5	1	1		3	1	1	3	1	1		x		1	x	1		1
Astrononion stellatum																										x	x		1	
Bolivina alata																									x					x
Bolivina albatrossi																														
Bolivina lanceolata																														
Bolivina lowmani																											x	x	1	
Bolivina pseudoplicata									3		1							x						x	1	1	x	x	1	x
Bolivina spathulata																					1				x	x				x
Bolivina subaen. mexicana																									x	x		x	1	1
Buccella hannai	2	4			2				8		3	2	3	1	2	3	4	2		3	1	1	3	1	1	1	1	1	1	1
Bulimina aculeata							1						2	1				x	5			3	1	2	2	2	2	1	1	2
Bulimina alazanensis																														
Bulimina marginata																	1	2	1	1	1	4		37	8	11	10	10	12	11
Buliminella elegantissima																										x				
Calcituba decorata					4																					1				
Cancris sagra	1																1	2		2	4	5	1	2	2	11	2	2	1	4
Caribeanella polystoma																														
Cassidulina laevigata																										x	x	x	x	x
Cassidulina neocarinata																										x	x	x	2	x
Cassidulinoides bradyi																								x	x	x	x	1	3	x
Chilostomella oolina																														
Cibicides bradyi	2			11						1			1			1	1	2	24	3	4	10	1	4	6	5	6	7	4	5
Cibicides pseudoungerianus					2															2				10	8	5	9	6	9	6
Conicospirillina atlantica																					1									
Cornuloculina inconstans																														
Cyclogyra planorbis																														
Cyclogyra selseyensis																														
Cymbaloporetta atlantica																														
Dentalina communis																								x			x	x	1	x
Discorbinella bertheloti																												x	x	x
Dyocibicides biserialis							x																							
Edentostomina cultrata																														
Eggerella advena							2			8	3	4			2	2		1	1	1	x		1			x		x		
Elphidiella mexicana					4	6	2	3			1		1	1		6		1	5	3	2		1	x	x	3	1	6		4
Elphidium advenum														2		1			4											
Elphidium clavatum	52	70	73	44	32	29	45	41	46	32	53	80	35	36	61	19	29	25	18	17	14	19	44	14	15	9	14	7	7	11
Elphidium incertum	3	2	3		2					1	1			2	1	1	1					1	5			x	x			x
Elphidium subarcticum	4	4	3				1		4	1	8		8	2	5	5		8	10	3	2	4	1	5	5	7	8	8	2	3
Eponides antillarum																		x							x					x

aid recognition of specimens alive at the time of sampling (Walton, 1952).

Each sample, containing about 11.5 cubic centimeters of sediment was split three times, using an Otto microsplit, resulting in a sample of slightly more than one cubic centimeter. The volume of this split was measured as accurately as possible for determination of absolute abundance. The samples were sieved on a 160 mesh screen (0.1 mm average openings), and all foraminifera were picked from the wet residues. Stained and unstained specimens were placed on separate slides and later the number of foraminifera found in each sample was recalculated for a sample volume of exactly one cubic centimeter. Where fewer than 400 specimens were found per split, previously unused fractions of the split were counted out, to procure at least this number of individuals following the suggestions of Wright (1964).

The abundance of each species at any station is expressed in percent of the total benthonic population. All percentage values were rounded off to the nearest 1%.

The sediments were studied and described according to the semiquantitative microscopic inspection technique described by Ingram (1965). This relatively rapid method permits definition of sediment distribution patterns as well as by conventional sieve methods.

IV. Previous Work

The foraminifera of coastal North Carolina have received little attention. In his

TABLE Ia (continued)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2262	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Eponides tumidulus																									x	x			1	x
Eponides repandus																														
Fischerinella dubia																														
Fissurina lacunata																														
Fissurina lucida																		x								x				x
Fissurina stewartii															1											x		x	x	x
Florilus atlanticus	3			22	4		1			1	3		1	1				2	1	1		1	1	1	1	1	1	x	1	1
Florilus auriculus																							1	x		x	x		1	
Fursenkoina fusiformis													1		3		1	x			17			x	2	1			2	
Fursenkoina punctata																										x				x
Glabratella lauriei										2																				
Globobulimina auriculata																											x		x	x
Guttulina caribea		1					2	3		1	1		1	1			1	1									x	x		
Guttulina lactea	2	2	2				4		3	6	2	2	10	3		4		5	4	3		1	2	1	2	1	1	1	1	1
Guttulina pulchella							x			1	1		1			1		1									x		x	
Gyroidina orbicularis																													x	x
Hanzawaia concentrica	12	8	10		11		17	12		14	11		9	9	6	18	21	16	2	7	7	4	6	1	x	x	1	x	1	1
Haplophragmoides canariensis																							1						x	
Höglundina elegans																										x		x		
Islandiella subglobosa																		2	2	1	2		1	12	18	22	18	24	15	19
Lagena acuticosta																														x
Lagena laevis																							1							
Lagena striata																							1		x		x		x	x
Lagena tenuis																		x							x				x	
Lenticulina orbicularis						6																		12	5	6	4	4	10	2
Marginulina advena																														
Marginulina bachei																								2	2	1	1	1	3	x
Marginulina villa																											x			
Melonis pompilioides																									1	1	1		x	1
Miliolinella circularis																														
Miliolinella fichteliana																											x			
Mississippina concentrica																														
Neoconorbina terquemi																					1									
Nodobaculariella atlantica																														
Nodosaria catesbyi																														x
Nonion grateloupi																					1				x	x		x	x	
Nonionella turgida							x				1							x			2				1	x		x	2	x
Oolina melo																										x			x	
Patellina corrugata																														
Peneroplis discoideus																														
Peneroplis proteus																														
Placopsilina confusa					7	12													1											
Planorbulina mediterranensis																	1													
Planulina ariminensis																								x	x	x			x	x
Planulina exorna	1						x				1	4	4	1	1		5	5	2	13	2	1	1	1	1	✓	1	x	1	1
Planulina ornata	7	2	2		7		2	3	22	5	3	2	7	1	1	13	4	6	6	9	4	4	3	5	3	3	5	3	1	4
Pullenia quinqueloba																										x				
Pyrgo denticulata																				1				1	1	x	1		x	x
Pyrgo oblonga																				1	1			1	1	2	x	1	1	2
Pyrgo serrata																										x	x			
Pyrgo subsphaerica																			1					x	x		x			

work on the foraminifera of the Atlantic Ocean, Cushman (1918 to 1931) included material collected in this area. Cushman's contribution, however, was primarily taxonomic, although he discussed general distribution and occurrence of species. In 1936, Hadley briefly discussed recent foraminifera from near Beaufort, N. C. Cushman (1947) described seventeen new species and varieties from the Atlantic Coast between Cape Hatteras and southern Florida. In 1953, Miller investigated the foraminiferal distribution in Mason Inlet, N. C., south of the present study area. Most recently, Wilcoxon (1964) studied foraminiferal distribution off the southern Atlantic Coast between the Florida Straits and Cape Hatteras. He recognized three faunal depth zones on the shelf: Inner shelf, 1–15 meters; middle shelf, 15–61 meters; outer shelf—upper continental slope, 61–183 meters. More detailed papers have been published on the foraminifera from off Portsmouth, N. H. (Phleger, 1952, and Parker, 1952) and from the shelf from the Gulf of Maine to Maryland (Parker, 1948).

V. Description of Area

The continental shelf off North Carolina is the submarine extension of the coastal plain and is underlain by gently eastward dipping Upper Cretaceous and Cenozoic strata. At the coastline it is bordered by a series of long narrow offshore bars which protect extensive lagoons and estuaries. The shelf break to the east occurs generally at depths of 60–80 meters. The shelf is a flat

TABLE Ia (continued)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2262	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Quinqueloculina bicostata																														
Quinqueloculina bosciana																														
Quinqueloculina compta							x				1																			
Quinqueloculina jugosa	4				2		1			1	1				1			1	4	1					1	x		x	1	x
Quinqueloculina lamarckiana												3					1										x	x		
Quinqueloculina poeyana																														
Quinqueloculina polygona																														
Quinqueloculina seminula	2	2			12	18	8	9		3			1	9	4	10	9	10	8	6	3	1		x	1		x		x)	x
Rectobolivina advena																														
Reophax atlantica	1	2	6			20			16	1	3	4		20	7	11	6	1		11	14	17	2	6	2	2	2	2	1	2
Reophax fusiformis																									x	x	x			
Reophax scorpiurus	1		1				1		3		1						1							1		x	x	x	x	
Reussella atlantica					2	6										22								x				x		
Robertinoides normani																														x
Rosalina floridana																							1	x	1	x				1
Rosalina floridensis																			2				1							x
Rosalina globularis		2			2						1					1					1	3	7	1	1	x	x	1	x	1
Rosalina rugosa					2													1		1	4	3	3	4	3	2	5	4	1	3
Sagrina pulchella																														
Scutuloris procera							x				1					1			2	2			1	x					x	x
Sigmoilina antillarum																														
Sigmoilina tenuis																														
Siphonaptera horrida																														
Siphonaptera sabulosa																		x						x			x			
Siphonina pulchra																														
Siphotextularia curta																										x				
Siphotextularia rolshauseni																									x		x			
Sphaeroidina bulloides																							1	x					1	x
Spiroloculina atlantica																														
Spiroloculina depressa																														
Spiroplectammina floridana																														
Stainforthia complanata																														
Stetsoina minuta																					1			1	2	1	1	1	3	2
Stilostomella antillea																														
Textularia candeiana	1																	2						1			x			x
Textularia conica	1																	x		1			1			x	x	x	1	x
Textularia pseudotrochus																														
Textularia truncata						6								1				x		1						x			x	
Textulariella barrettii																														
Trifarina angulosa																					2			2	3	3	3	3	4	4
Trifarina bradyi																								x		x				x
Triloculina tricarinata																														
Triloculina trigonula	1																	1	1		x				x		x	x		x
Trochammina advena																										x				
Trochammina squamata																					1			x						x
Trovhamminula lobata		1											3		1			x		1	2	1	1	x	1	x		x		x
Uvigerina auberiana																							1			x	x	x	x	x
Uvigerina peregrina																									x	x	x			x
Valvulineria laevigata																											x			
Webbinella concava			3			6	5	12		10	1		5	8	3	2	7	2	4	1		9		2			x			
Wiesnerella auriculata																														

plain, 50 to 80 statute miles wide, which narrows to 17 statute miles off Cape Hatteras. The average slope, from the coastline to 70 meters depth ranges from 4.5 to 9.5 feet/mile with the least inclination on the central shelf. Slopes are considerably steeper at the shelf edge.

The water masses overlying the shelf of the study area, the Virginian Coastal water and Carolinian Coastal water of Bumpus & Pierce (1955), are bounded to seaward by the Gulf Stream. The Virginian Coastal water is formed by mixing of slowly southward drifting oceanic water, land runoff and indrafts of slope water (Bigelow and Sears, 1935). The Carolinian Coastal water is formed by Gulf Stream water and land runoff, but runoff contribution is minimal. Gulf Stream water broadly invades the southern shelf frequently. The Virginian and Carolinian Coastal water masses connect around Cape Hatteras only rarely under the influence of northeasterly storms between November to May (Bumpus and Pierce, 1955).

Bottom temperatures north of Cape Hatteras range from less than 9°C near shore to 16°C near the edge of the shelf during the winter. In May, temperature near shore and at the edge of the shelf is 18°C, but is 16°C at the bottom of the central shelf (Bumpus and Pierce, 1955). Maximum surface temperatures during the summer reach 25°–26°C (Fuglister, 1947). South of Cape Hatteras, in Raleigh Bay, winter bottom temperatures may be as cold as to the north, because of an influx of Virginian Coastal water. South of Cape Lookout this influence is no longer present and bottom temperatures in January range from 10°C near shore to 19°C at the shelf edge (Bumpus and Pierce, 1955). Summer surface temperatures reach 27°C (Fuglister, 1947).

Bottom salinities in the Virginian Coastal water range from 31.5‰ near shore to 36‰ near the shelf edge during winter and from 31‰ to 35.5‰ during spring. Carolinian Coastal water is generally more saline, because of mixing with Gulf Stream water and lesser runoff. During the winter, the water in Raleigh Bay may be of reduced salinity because of influx of Virginian Coastal water. Bottom water salinity normally ranges be-

TABLE I b PERCENTAGE DISTRIBUTION OF TOTAL BENTHONIC POPULATION (South of Cape Hatteras)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2138	2110	2127	1734	1965	2116	2118	2122	2123	3348	1977	2117	2156	2111	3269	1960	2296	1963	3346	3347	1737	1738	1739	2109	1741	2166	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25	25	25	26	26	26	28	28	29	29	30	30	30	33	33	33	36	41	42	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Ammobaculites dilatatus																										x			1	4	1	x							1				1				x					x		x
Ammodiscus catinus										x						x		x	x			x							1									1								x	x							
Ammonia beccarii	10	4		8		2	1	3	2		2	7		1		4	1				2	3	1	3	2	4			4	1	x	2	1	6	2	2		6		4		3	x	2	2	4	1	x	2	3		x	1	3
Amphistegina lessonii																									2										1								8	16	2	x	1	3	4	1	1	1	1	1
Articulina sagra							1									x	x									1		2			1	1	1	x	1	1	1	1		1	1	1	x			x					1	1	x	x
Astacolus crepidulus																																																			1	2	x	
Asterigerina carinata			2	x	3		2		2	8	5	10	8	1	12	12	10	7	9		2	10	2	6	2	1	4	3		3	2	2	2	10	6	4	5	8		5	1	6		1	2	3		7	3	3	x	x	2	2
Asterigerinata pulchella																													3			x			1				2		1		2				2	x				x		
Astrononion stellatum																																																				x		
Bolivina alata																																																				x		
Bolivina albatrossi																																																					x	x
Bolivina lanceolata																																																						
Bolivina lowmani	1				1					x						1		x								x						x								x						x	1			1	1	2	x	x
Bolivina pseudoplicata																							1																		x									x		1		
Bolivina spathulata																																																					x	
Bolivina subaen. mexicana																																													x		x				1	1	1	x
Buccella hannai	3	1		1				1	2	x	1			1		1	1	1	x		1	1	1	1		1	2	3	1	1	1	1	1	x	4	2	1		4	2	x		1		2	x	x	x	1	1		x		1
Bulimina aculeata																																									x		1			x	1							x
Bulimina alazanensis																																																x						x
Bulimina marginata												2																													x				x		1	x			x	x	1	x
Buliminella elegantissima	x																																																					
Calcituba decorata			2				7			1			10		4	1	1	1	4						22		1			1				1								1							1					
Caneris sagra																										x		1				1			1					1	1	1			x	1	1	x	1	1	2	2	x	
Caribeanella polystoma			2				6			9	3		7			1	4	1	3		1		10			2	3					1				4		1		1	x		x		7	5	1			x	3	4	1	
Cassidulina laevigata																x	x																												x	x				x	x	1	x	x
Cassidulina neocarinata																																															x		1		1	1	4	4
Cassidulinoides bradyi																															x															x						x		
Chilostomella oolina																																																				x		x
Cibicides bradyi	2						1			3	6	2	2			3	1	1	1			2	2	3		3		1		1	5	3	2	2	4	11		1	2	2	1	1	1	1	2	1	2	1		x	2	1	2	3
Cibicides pseudoungerianus	1										1		x			x	x														1	x	1	x						x	x		2			1	7	6	1	2	1	x	2	2
Conicospirillina atlantica										x									x																							1				x	x				x		x	
Cornuloculina inconstans																	x																																		x			
Cyclogyra planorbis																										x																				x					x	1		
Cyclogyra selseyensis									2							x	x																	x						x		1									x			
Cymbaloporetta atlantica																	x																							x					1	x					1	x	x	
Dentalina communis																																									x		x				x				x	x		
Discorbinella bertheloti										x						x			1													x			1			1		x			x				x	1			1	1	1	1
Dyocibicides biserialis																																x									x						x				x		x	
Edentostomina cultrata																	x											x																							x	x		
Eggerella advena										x						1										x						1		x			1			2	1					x	1			x	x		x	
Elphidiella mexicana	7	2	2		3		1	1		2	7		x			1	1	1	1		1	1		1	2	3		1			3	x	3	1	2	3	3			1	5				4	1	5	x			1		2	1
Elphidium advenum			1	1																										2							1												1					
Elphidium clavatum	27	65	5	35		9	1	10	13	2	x	11	1	7		11	8	1		7	3	9	15	7	14	5	2	1	66	11	2	26	1	21	19	7	3	21	72	12	15	11	25	17	8	6	11	9	11	16		2	1	11
Elphidium incertum				3	1	2				1	x		x		1	1	x		1		1			1		1		1		1	x	x		x			1	1	1	1	3				1	2	3		1		2	3	x	x
Elphidium subarcticum				7												1										3			9	4	2	1	2	x		1	1	1	9	1			2		2	x	2	2			x	x	x	1
Eponides antillarum												1		1		1	x			2	7			2						1	x	1			1	1				1	4	5	5	1	1	1	1	2	3	x	x		x	x

tween 35‰ and 36‰ (Bumpus and Pierce, 1955).

Stetson (1938), Gorsline (1963), Uchupi (1963), and Emery (1966), in the course of large scale surveys of this area have recognized two broad subdivisions within the sediments: a narrow band of modern sediments near the shoreline to a depth of about 20 meters, and relict sediments, which cover the middle and outer portions of the shelf (Emery, 1966).

Figure 2 shows the distribution of the sediment types. The band of very fine grained, near shore sediment is readily apparent. Off Cape Hatteras, however, very fine grained sand has spread across the entire shelf. Off Cape Lookout the very fine grained sand extends far onto the shelf, but does not completely cover it. On the central shelf, fine and medium grained sand dominate. Along the shelf edge very fine grained sand also occurs, and much of it has a bimodal size distribution. Medium or coarse grained sand is present here in amounts of as much as 20%.

Calcium carbonate generally comprises less than 5% of the shelf sediments north of Cape Hatteras. South of the Cape, the amount of calcium carbonate increases markedly. Occurring here in the form of shell fragments and oölites, it may make up from less than 5% of the sediment on the inner shelf to more than 25% on the outer shelf. On the central and outer shelf south of Cape Hatteras and especially south of Cape Lookout, much of the carbonate fraction of the sediment shows signs of alteration in the form of brown and yellow iron staining, glauconitization and phosphatization.

VI. Distribution of Foraminifera

The total abundance of foraminifera per unit sediment has been commonly expressed as the number of specimens per gram of sediment and this has been called the foraminiferal number by Schott (1935). In this

TABLE Ib (continued)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2138	2110	2127	1734	1965	2116	2118	2122	2123	3348	1977	2117	2156	2111	3269	1960	2296	1963	3346	3347	1737	1738	1739	2109	1741	2166	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25	25	25	26	26	26	28	28	29	29	30	30	30	33	33	33	36	41	42	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Eponides tumidulus			1																											1	x	x										x					x	x	1		x	x	1	x
Eponides repandus																				2										1							1						3					x	3					
Fischerinella dubia																										x																									x			
Fissurina lacunata																																																	1					
Fissurina lucida																																																				x	x	
Fissurina stewartii															1	x								1		x																				x					x			
Florilus atlanticus		1		2			1		5	1			1	2	1	3	2	x	1	2		1		2				3	3	2	6	9	4	2	6	5			2	4	2	2	1	2	2	2	3	1		3	1	2	1	3
Florilus auriculus											x				1				1	2	1		1			1			1	1	1	2	1	x						x	x				2	x	x				2	x	x	1
Fursenkoina fusiformis																x																x								x					x		1				x	1		
Fursenkoina punctata																					1					x						x					1			x	x				x	1	x				1	1	x	1
Glabratella lauriei							1	1	2	x	3		1				x							1		x	1					x	2		1	2		2		x							x			1	x			x
Globobulimina auriculata																																																		x	x			
Guttulina caribea			1			2					6		7		1	x	1	3	1			1					2	1				x		x						x	x			1	x	x	x					x		
Guttulina lactea					1					x					1	x	x		x		1			1		x		1	1		x	1			2	2				x	2	1	1			2	1	x			x	x		1
Guttulina pulchella			1	1	1			1		x	x		1			x	1	1		2		1				x					x			x		1	3			x				1		x	x				x	x	x	
Gyroidina orbicularis																																x								x													x	
Hanzawaia concentrica	4	3	2	5	9	15	2	11	20	7	6	4	7	6	18	9	11	3	4	25	17	12	5	10	3	11	13	16		11	12	10	7	11	13	12	19	14	1	11	30	15	10	6	7	9	10	6	6	13	x	1	3	6
Haplophragmoides canariensis																x		2																						x		1		1	x	x					x	x		
Höglindina elegans																																													x								x	
Islandiella subglobosa										x	x					x								1		x		1		1	1	1	1		1	x				1	x				1	1	3	1		1	9	5	15	7
Lagena acuticosta																																																						
Lagena laevis																																									x										1	x		x
Lagena striata																								1																						1					1	1		x
Lagena tenuis																					x																			x	x					x					x	x		
Lenticulina orbicularis																																x									x	1	4	1		x	4	7	1	x	x	2	2	x
Marginulina advena																																				x							3	4		1	1	1	1		x		x	x
Marginulina bachei																																																x						x
Marginulina villa																																														x					1			
Melonis pompilioides																x										x														x			x							x	x	x	1	x
Miliolinella circularis						2									1	x	x		1				1			x						x													1	x					x			
Miliolinella fichteliana																										x		1				x									x											x		x
Mississippina concentrica																																															x		1	1	x	x	1	
Neoconorbina terquemi										1		1	x			x		x	x					2		1	1	2			1			x	1	x				1					2	3	1		1	1	4	4	2	x
Nodobaculariella atlantica										2	x	2	x		1	1	3	x	1		1	3	1	2		1		3			1	2	2	1		3		2		1	1	4		1	1	3	1		1	1	1	1	1	1
Nodosaria catesbyi																										x						x											x				x					x	x	
Nonion grateloupi									2							x	x										1	1						x						x						x					x	1		
Nonionella turgida																					1					x				1	x	x							1	x	1		1				x				1			x
Oolina melo																										x					x												x									x		x
Patellina corrugata																										x										x											x							
Peneroplis discoideus										x		1	x				x				1	1		1				5				x		x		x	2			x		1												
Peneroplis proteus	1		1		4		4	3		10	14	8	8	1	27	7	15	14	9	5	4	18		5		3	3	13		1	4	3	7	2	2	7	21	1		1	1	2		1	1	2	1			1	x	x	x	1
Placopsilina confusa			22			4	39	1		1		5	30		3	1	x	1	27			x	4		25		3			4			1	1				1		1		2	x	5					1					
Planorbulina mediterranensis																x	x					x										x		x						x		1				1	1	x				x		
Planulina ariminensis											x						x	x				x										x			1			1		x	x									x	x		1	1
Planulina exorna	1						1	1		1		1		3		x	1	1	x		2	x	1	1		1					3	3	3	x		x		1		1	1	1	1		2	3	1	2		1	x	1	1	2
Planulina ornata	3	3		7	1		2	1	7	3	3	3	x		2	1	4	1	1		1	2		2		10		5	6	2	7	8	1	2	9	10	1	6	1	4	2	1	5	2	6	4	4	5		7	1	x	4	3
Pullenia quinqueloba																																																			x		x	
Pyrgo denticulata																														1		x			1									1		x	1				1	x	x	x
Pyrgo oblonga																										x					x	x									x					x	1				x		x	x
Pyrgo serrata																															x	1									x		x			1	1		1		x	x	x	
Pyrgo subsphaerica																														2		x									x		1				x	2		x	x	1	x	

study, however, the number of specimens per cubic centimeter of wet sediment is the measure of foraminiferal abundance. Benthonic foraminifera have been shown to live within as well as on the substrate (Boltovskoy, 1966). Drying the sediment, especially if it is rich in clay and/or organic matter, may cause contraction and corresponding weight loss, which distorts the measure of abundance. Foraminiferal numbers from fine-grained sediments will be too high in comparison with those from clean, coarse-grained sediments. Walton (1955) discusses this problem in detail.

The populations of planktonic and benthonic foraminifera are treated separately, so that the total count for each group is considered 100%.

The following discussions pertain to total foraminiferal populations, which, because of the scarcity of living specimens are in effect thanatocoenoses. Analysis of the biocoenoses would have been qualitative at best.

A. Benthonic Foraminifera

The two faunal realms on the North Carolina continental shelf are separated by a major faunal boundary near Cape Hatteras as has already been demonstrated (Bumpus and Pierce, 1955). The distinction is especially marked for mollusks (Abbott, 1954). These northern and southern faunas have been termed Virginian and Carolinian respectively by Johnson (1934). This boundary, however, appears gradational when foraminifera only are considered. Foraminiferal faunas north of Cape Hatteras are similar to those described by Parker (1948) from the coast of Maryland to Cape Cod, and to a lesser degree to those of New Hampshire (Phleger, 1952; Parker, 1952). Foraminiferal faunas south of Cape Lookout closely resemble those listed by Wilcoxon (1964) from the continental shelf of the Southeastern United States, and, to some extent, with faunas of the northeastern Gulf of Mexico (Parker, 1954). The shelf between Cape

TABLE Ib (continued)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2138	2110	2127	1734	1965	2116	2118	2122	2123	3348	1977	2117	2156	2111	3269	1960	2296	1963	3346	3347	1737	1738	1739	2109	1741	2166	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25	25	25	26	26	26	28	28	29	29	30	30	30	33	33	33	36	41	42	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Quinqueloculina bicostata			3		4	2	1			2	3	2	2	3	1	1	2	5	2	2		1		5			5	1		1	1	x	2	2		1				x	x					x			1	1	1	1		1
Quinqueloculina bosciana										1						x	1	x	1					1		1		1				x		x								1				1	1			x	x	1	x	
Quinqueloculina compta	1	1	4	2	10		2	6		5	7	1	x	4	1	2	2	2	1	5	7	2	8	5	2	5	2	2		3	9	6	4	2	1		4	3		2	1	1	1	1		1	x	x		x	x	x	x	x
Quinqueloculina jugosa	4	3	2		2	2	1	7	2	1	1	4		8		1	2	1	1	2	3	3	3	1	2	2	1	1			1	2	1	5		1	2	3		1	1	5	x	1	1	1	x			4	x	1	x	1
Quinqueloculina lamarckiana		6	6	4	8		6	11		8	5		2	2		2	4	6	5		1	4		3		3	1	3			1	2	1	3		2	1	4		4	1	2	1	1	2	3	1	1	2	1		x		x
Quinqueloculina poeyana				2						x				1								x		1		2					1	2	1							1	1					1	x	x		x	1	1	1	1
Quinqueloculina seminula	7	5	18	6	27	31	9	11	9	5	12	30	2	46	10	8	6	23	6	11	9	9	18	14	11	8	7	4		19	9	4	28	14	3	5	9	15		5	13	12	4	19	6	4	5	14	28	19	1	9	5	4
Rectobolivina advena													x				x									x						x		x												1					x	1	x	
Reophax atlantica			2	1			4	13	11	2	3		2			1	2	1		3	7	1	5	2			9		1	2	1	x	2	x		x	1	3	1	x	x	1	2	2	x		x	4	1		1		1	
Reophax fusiformis																																																			2			
Reophax scorpiurus			1		3		1	3		3	2	2	3	1	4	2	2	14	7	16	8	1	1	2	2	1	10	8		10	3	2	7	2	3	1	1	3	1	4	1	4	4	3	2	1	2	2	2	x		x	x	x
Reussella atlantica	3	1							1	1		1			x	1		x							2		1			4	2	2		3	1				1					1	x		x		x	x	x	x	1	1
Robertinoides normani																																																			x	x	x	
Rosalina floridana	1			1	2			1		1	x		1	1		1	x	x			1	1				2	2	1			2	1	1	x		1	1			x					2		x			1	2	1	2	x
Rosalina floridensis						2																x										x								x	x							x			1	1	x	
Rosalina globularis	2		2	1	1	6	1	6	2	2			1			3	2	1	1		2	1	8	2		3	2	3			1	2	1	x	1		2	1	1	3	3		1		5	2	3	1		x	10	7	3	1
Rosalina rugosa																													1																									
Sagrina pulchella										1			x			1								1		x					x	1	1							x	x				x	1				x	x	x		x
Scutuloris procera	1		1			4	1			1						3	2	1	1		3	2	3	1		1		1			1	3	1	x						1	x				3	4	2			1	15	6	4	2
Sigmoilina antillarum													x			x	x	x	x							1						1		x						x	x				x	x					x		x	x
Sigmoilina tenuis																	x																																	x	x	x	x	
Siphonaptera horrida										x	1	1			1	1	1	1				1				x	1	3							1		4				1		1				1	8					x	
Siphonaptera sabulosa	2		8		6		1		4	1	2	1			1	1	1	2	1	2	1	1		1		1	3			1	3	2	2	1	1	1	1			1	x	1	x	1	x	1	x			1			x	1
Siphonina pulchra																																																			x			x
Siphotextularia curta																																																				x	x	
Siphotextularia rolshauseni																																														x					x	x		
Sphaeroidina bulloides																																													x						x	x	1	x
Spiroloculina atlantica							1			x			x					x			1			1							x	1	1	1		x	2			x	x				1	1	x			x	1		x	x
Spiroloculina depressa																x																x									x					1	x				x			
Spiroplectammina floridana																																											x			x	1	3						x
Stainforthia complanata																																x																			x			
Stetsoina minuta																																															1			x	x	x	x	1
Stilostomella antillea																																																			x			
Textularia candeiana	3		7	1	7					1	1	2		2		1	1	2	x	2	2	1	1	4	3			1		2	3	x	1	2	1	x		2		2	2	3	1	1	3	3	x	2	5	2	1	1	2	1
Textularia conica	5		2	4	1	2	1	3		5	2	2	2	3		3	3	1	2		2	4	8	2	6	1	2	3			2	2	1	4	2	2	1	2		4	2	4	1	2	4	5	1	2	3	1	3	3	2	2
Textularia pseudotrochus																																									x		1				1	1	3			1		
Textularia truncata	6	1	1	2	1	2		3		2	1		2	1	1	2	3	3	2	3	2	2	3			x	2			3	x	x	1	1		x		1		1	3	3	1	1	3	1	x	3	2	1	x	2	x	1
Textulariella barrettii																																											x	3				1	3				x	x
Trifarina angulosa				1						1	x			1		2	x	x	1		2		2	2		2	1	1			x	1		x	1	x		1	1	1	1	1			2	2	1	x		x	4	7	4	4
Trifarina bradyi																																																			x	x	x	x
Triloculina tricarinata									2																							x															x							
Triloculina trigonula			1	1		2	1		4					5			1	x						2		1		1	1		3	3	1	1		2		1		x	3	1	2		1	2	3	2			x	1	x	
Trochammina advena		x													x	x										x																				x					x	x	x	
Trochammina squamata			3				1		4	x			1			1											1							x						1	x	1		1		1				1	1	1	x	
Trochamminula lobata			2	1		2		1	4	x	x				1	x			1				2	1		x			1	1		x							1	x	x				2	x	1				1	1	x	
Uvigerina auberiana																																											x		x		x			x	x			1
Uvigerina peregrina																																																			x		x	1
Valvulineria laevigata																																														x					x	x	x	
Webbinella concava	1				2	6	1		2	x			1	1	2	x	x	x	1	2		x			2		2	1		3	x		2	x			2				x	1				x		1	2	1	x			
Wiesnerella auriculata										x			x				x									x						x			1						x					1				x	x	1	x	x

Lookout and Cape Hatteras, however, supports a fauna of mixed character, though southern elements generally dominate. Many species range through the study area and show no marked preference for either realm.

B. Areal and Depth Distribution of Benthonic Foraminifera

Tables I and II present the abundance and distribution of each benthonic species in the samples which are arranged according to depth of occurrence. Table I presents the total benthonic fauna, but table II includes only the living individuals. For the most significant species, distribution maps have been plotted. Species occurrences are conventionally grouped into characteristic thanatotopes, defined by maximum abundance or the upper and lower limits of occurrence of one (= auto-thanatotope) or several (= syn-thanatotope) key species. The following thanatotopes are herein defined for the North Carolina continental shelf:

I a. Near shore—north of Cape Hatteras. This area is essentially an auto-thanatotope, defined by *Elphidium clavatum* abundances of greater than 50% of the total benthonic fauna (figure 3). The landward limit of this area is very poorly defined because few near shore samples were taken.

II. Central shelf—The shelf between about 20 meters and 60 meters depth is here regarded as central shelf from the viewpoint of faunal distribution. It is subdivided into the following syn-thanatotopes:

a. Central shelf, north of Cape Hatteras. The diagnostic species for this syn-thanatotope are *Elphidium clavatum* with frequencies between 50% and 15%, *Hanzawaia concentrica* (fig. 4) with more than 10% and *Reophax atlantica* (fig. 5) with more than 10% of the total benthonic population. *R. atlantica,* however, shows its greatest abundance near the southern portion of the northern area. *Webbinella concava* and *Guttulina lactea* may also be considered diagnostic for

TABLE II a DISTRIBUTION OF LIVING FORAMINIFERA (North of Cape Hatteras)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2265	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Ammobaculites dilatatus																										2				
Ammodiscus catinus																			1		2			1						
Ammonia beccarii							2								1															
Asterigerina carinata																														
Asterigerinata pulchella							2	3		1		1	10				2	3	1	1	1									
Bolivina lowmani																														
Bolivina pseudoplicata																														
Bolivina subaen. mexicana																										1				2
Buccella hannai													4																	
Bulimina aculeata							2							1					1					1	1					
Bulimina marginata																		1		1				3		4	1	3		
Calcituba decorata																														
Cancris sagra																	1	6		1	2	2		4	1	4	1	2		3
Caribeanella polystoma																														
Cassidulina neocarinata																														
Cassidulinoides bradui																										1			1	3
Cibicides bradyi																			1					1				1		
Cibicides pseudoungerianus																								2	1	2			1	
Cymbaloporetta atlantica																														
Dentalina communis																														
Discorbinella bertheloti																														
Eggerella advena							5			1	3	2	1		4	1		2	1	2	5									
Elphidiella mexicana														1		1			1	3	2					1				
Elphidium clavatum	1	1	4				9				2	1		1	2			6	5	5	3									
Elphidium incertum																														
Elphidium subarcticum																			1		3									
Eponides antillarum																														
Eponides repandus																														
Fissurina lucida																										1				
Fissurina stewartii															1															
Florilus atlanticus							1			1	1							2	1	1						3				
Florilus auriculus																										2			1	
Fursenkoina fusiformis															2		1	1			20					2				
Fursenkoina punctata																														
Guttulina caribea																														
Guttulina lactea							2			1		1	11			1		6	2											
Guttulina pulchella													1																	
Hanzawaia concentrica	1				1		13			1	2			1	1	1	1	22		1	1	1								
Haplophragmoides canariensis																														
Höglundina elegans																														

this syn-thanatotope; they attain frequencies of more than 5% in the most northern transect, but their abundance diminishes towards the south.

b. Central shelf, Raleigh Bay. Characteristic for this syn-thanatotope are *Hanzawaia concentrica* with more than 10%, *Reophax atlantica* with more than 10% and *Peneroplis proteus* (fig. 6) with more than 10% of the total benthonic population. Of these, *R. atlantica* is more abundant in the shallower portion of this area. *Quinqueloculina seminula* (10%), *Asterigerina carinata* (fig. 7) (12%), and *Reophax scorpiurus* (5%) have patchy distributions, but where they attain frequencies higher than those indicated, they are also diagnostic and may serve to identify this thanatotope. *Quinqueloculina compta* (fig. 9) is relatively rare, but frequencies of more than 4% are characteristic for this area.

c. Central shelf, south of Cape Lookout. *Peneroplis proteus* with more than 14% and *Placopsilina confusa* (fig. 8) with more than 20%, most persistently characterize this syn-thanatotope, together with the more rare *Quinqueloculina compta* (5%). The following species have patchy distribution, but signify the central shelf where the indicated frequencies are reached: *Quinqueloculina seminula* (20%), and *Reophax scorpiurus* (5%). *Asterigerina carinata* with more than 6%, and *Quinqueloculina lamarckiana* with more than 5% are more typical of the southern portion of this syn-thanatotope.

III. Shelf edge—Upper Continental Slope. The depth limits for this area are approximately 60 meters and 140 meters. Even though the depth range is twice that of the central shelf, the geographic area is considerably smaller because of the greatly in-

TABLE IIa (continued)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2262	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Islandiella subglobosa																		1			1				1	1	2			
Lagena striata																														
Lenticulina orbicularis																								3	1	4		1		1
Miliolinella circularis																														
Mississippina concentrica																														
Neoconorbina terquemi																														
Nodobaculariella atlantica																														
Nonion grateloupi																					1									
Peneroplis proteus																														
Placopsilina confusa						1																								
Planorbulina mediterranensis																														
Planulina exorna																		2			1						1			1
Planulina ornata																				1	1			2	1					
Pyrgo denticulata																														
Pyrgo oblonga																				1						3				1
Pyrgo serrata																														
Quinqueloculina bicostata																														
Quinqueloculina bosciana																														
Quinqueloculina compta											1																			
Quinqueloculina jugosa											1							1	1											
Quinqueloculina lamarckiana																														
Quinqueloculina poeyana																														
Quinqueloculina seminula													1			2	1	12	2	6	1									
Rectobolivina advena																														
Reophax atlantica		3	5						4		1	2		11	7	2	3	3		13	6			11	1	12	1	1		3
Reophax fusiformis																										1				
Reophax scorpiurus	1						2				2						1							3		1				
Reussella atlantica																5														
Rosalina floridana																										1				
Rosalina floridensis																			2											
Rosalina globularis					1											1								1	1	1				
Rosalina rugosa																					3					3				1
Sagrina pulchella																														
Scutuloris procera							1									1			1	3										
Spiroloculina atlantica																														
Stetsoina minuta																					1					2				
Textularia candeiana																														
Textularia conica																														
Textularia truncata																										1				
Trifarina angulosa																										2				1
Triloculina trigonula																		1	1											
Trochammina squamata																								1						1
Trochamminula lobata													7		1					1	2					3		1		2
Webbinella concava							4	1		4			1	1	2		1	1		1		1								
Wiesnerella auriculata																														

creased bottom gradient. Species distribution is more uniform than on the central shelf, but three subdivisions also are recognized.

a. Shelf-edge, north of Cape Hatteras. In this syn-thanatotope *Islandiella subglobosa* (fig. 11) and *Bulimina marginata* (fig. 12) are present with frequencies of more than 10%, *Lenticulina orbicularis* (fig. 13), and *Cibicides pseudoungerianus* with more than 5% and *Trifarina angulosa* with more than 2%. *Eponides punctulatus* occurs with frequencies of about 4%, but is irregularly distributed. *Cibicides bradyi* is characteristic for this syn-thanatotope with frequencies of more than 5%, but south of Cape Hatteras it is no longer diagnostic for this depth as it occurs abundantly in shallow water also.

b. Shelf edge, Raleigh Bay. This thanatotope is not defined precisely because of the availability of only a few samples, of which none were obtained at depths greater than 90 meters. *Lenticulina orbicularis* occurs with frequencies of more than 4%, the abundance of *Amphistegina lessonii* (fig. 14) ranges from 1 to 8%. *Cibicides pseudoungerianus* with frequencies of more than 6% is restricted to this area, but expands its distribution into shallower water south of this area.

c. Shelf edge, south of Cape Lookout. *Islandiella subglobosa* characterizes this area with frequencies of more than 5%, with *Lenticulina orbicularis* reaching more than 2% and *Trifarina angulosa* more than 4%. The abundance of *Amphistegina lessonii* varies between 1 and 16%.

The lower distribution limits of many of these species are undetermined as no sample from a depth of more than 159 meters was taken. The frequency diagrams (figures 20 to 29) indicate, however, that their abundances decline below about 120 meters. Table IV summarizes the composition of the different thanatotopes.

C. Species Dominance

The distribution of the dominant species is represented in Figure 15. The distribution pattern is very simple to the north and just south of Cape Hatteras. Here the entire shelf is characterized by *Elphidium clavatum,* which gives way at the shelf edge to *Islandiella subglobosa.* South of Cape Hatteras the distribution pattern becomes more complex. *Elphidium clavatum* dominates two patches, one just west of Cape Lookout, in the vicinity of Beaufort Inlet, and one south-

TABLE II b DISTRIBUTION OF LIVING FORAMINIFERA (South of Cape Hatteras)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2138	2110	2127	1734	1965	2116	2118	2122
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25
Ammobaculites dilatatus																		
Ammodiscus catinus																		
Ammonia beccarii																		
Asterigerina carinata										3			5			12	5	1
Asterigerinata pulchella																		
Bolivina lowmani																3		1
Bolivina pseudoplicata																		
Bolivina subaen. mexicana																		
Buccella hannai																		
Bulimina aculeata																		
Bulimina marginata																		
Calcituba decorata							1						2				1	
Cancris sagra																		
Caribeanella polystoma			1				6			3			6				2	2
Cassidulina neocarinata																		
Cassidulinoides bradyi																		
Cibicides bradyi												2				8		
Cibicides pseudoungerianus																		
Cymbaloporetta atlantica																	1	
Dentalina communis																		
Discorbinella bertheloti																		
Eggerella advena																6		
Elphidiella mexicana			1					1			2						1	
Elphidium clavatum			1					1	1					1		2		
Elphidium incertum																		
Elphidium subarcticum																		
Eponides antillarum																		
Eponides repandus																		
Fissurina lucida																		
Fissurina stewartii																1		
Florilus atlanticus									1							7	1	
Florilus auriculus															1			
Fursenkoina fusiformis																		
Fursenkoina punctata																		
Guttulina caribea			1			2					1		4					3
Guttulina lactea																1		
Guttulina pulchella													1					
Hanzawaia concentrica			1			1		5	4	1	1		4		2	8	5	3
Haplophragmoides canariensis																		
Höglundina elegans																		

STATION NUMBER	2123	3348	1977	2117	2156	2111	3269	1960	2296	1963	3346	3347	1737	1738	1739	2109	1741	2166
DEPTH IN METERS	25	25	26	26	26	28	28	29	29	30	30	30	33	33	33	36	41	42
Ammobaculites dilatatus																		
Ammodiscus catinus																		
Ammonia beccarii																		
Asterigerina carinata				1					1									
Asterigerinata pulchella																		
Bolivina lowmani																		
Bolivina pseudoplicata					1													
Bolivina subaen. mexicana																		
Buccella hannai				1									1					
Bulimina aculeata																		
Bulimina marginata																		
Calcituba decorata																		
Cancris sagra																		
Caribeanella polystoma	5				8				1									1
Cassidulina neocarinata																		
Cassidulinoides bradyi																		
Cibicides bradyi																		
Cibicides pseudoungerianus																		
Cymbaloporetta atlantica																		
Dentalina communis																		
Discorbinella bertheloti	2																	
Eggerella advena														1				
Elphidiella mexicana								1										
Elphidium clavatum															1	1	2	
Elphidium incertum																		
Elphidium subarcticum								1					1					
Eponides antillarum						1												
Eponides repandus																		
Fissurina lucida																		
Fissurina stewartii																		
Florilus atlanticus											1		1					
Florilus auriculus			1											1				
Fursenkoina fusiformis														1				
Fursenkoina punctata			1															
Guttulina caribea																		
Guttulina lactea														1				
Guttulina pulchella			1															
Hanzawaia concentrica	1	3	1	2	3	3		5	1	2		3	5	1	1	3	1	2
Haplophragmoides canariensis																		
Höglundina elegans																		

STATION NUMBER	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Ammobaculites dilatatus																1		
Ammodiscus catinus																1		
Ammonia beccarii																		
Asterigerina carinata	1			1														
Asterigerinata pulchella																		
Bolivina lowmani																		
Bolivina pseudoplicata																		
Bolivina subaen. mexicana											1				2	2		
Buccella hannai																		1
Bulimina aculeata																		
Bulimina marginata																	1	
Calcituba decorata																		
Cancris sagra				2							3			1	4	2		
Caribeanella polystoma																		
Cassidulina neocarinata													1		3		7	
Cassidulinoides bradyi																		
Cibicides bradyi														1		1		
Cibicides pseudoungerianus					1										1		2	
Cymbaloporetta atlantica																		
Dentalina communis																		
Discorbinella bertheloti																		
Eggerella advena				1							1						1	
Elphidiella mexicana					5													
Elphidium clavatum				1									1					
Elphidium incertum					1													
Elphidium subarcticum																		
Eponides antillarum				3		1					1							
Eponides repandus													1					
Fissurina lucida																		
Fissurina stewartii																		
Florilus atlanticus				6	1													
Florilus auriculus				1														
Fursenkoina fusiformis																		
Fursenkoina punctata															1			
Guttulina caribea																		
Guttulina lactea					1													
Guttulina pulchella	2																	
Hanzawaia concentrica	3			2	6	6				1	4				2			
Haplophragmoides canariensis								1	1									
Höglundina elegans																1		

east of Cape Lookout, on the outer portion of the central shelf and along the shelf edge. *Hanzawaia concentrica* dominates large portions of the central shelf between Cape Hatteras and Cape Lookout (Raleigh Bay). The central portion of the shelf of Raleigh Bay is occupied by *Peneroplis proteus,* which occurs again south of Cape Lookout, but there it is restricted to depths of less than 30 meters. *Quinqueloculina seminula* has a patchy distribution. It occurs just south of Cape Hatteras in very shallow water (18 meters) and is present also southeast of Cape Hatteras on the outer part of the central shelf and shelf edge. Its greatest areal distribution was noted southeast of Cape Lookout in samples from less than 40 meters depth. As along the shelf edge off Cape Hatteras, this species also is dominant in a few shelf edge samples off Cape Lookout where it is bordered on the seaward side by *Islandiella subglobosa. Placopsilina confusa* dominates in a number of samples south of Cape Lookout, but only at depths of less than 30 meters.

It is apparent, that in many cases the dominant species in any particular area is also a member of the diagnostic species group for that area. The notable exception to this generalization is the dominance of *Elphidium clavatum* over the entire northern shelf and over certain portions of the southern area. It is obvious, then, that in certain cases, recognition of a particular environment is based on minor faunal elements, preferably on assemblages whose composition may differ within limits.

D. Total Benthonic Foraminifera

The absolute abundance of benthonic specimens generally increases with depth (or distance from shore) (Fig. 16). This increase is very regular north of the latitude of Cape Lookout. In this area less than 100 specimens per sample are found above depths of 30 to 40 meters. Below this depth the number of specimens per sample increases abruptly to a maximum of 1990 specimens per cubic centimeter at 140 meters

TABLE II b (continued)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2138	2110	2127	1734	1965	2116	2119	2122	2123	3348	1977	2117	2156	2111	3269	1960	2296	1963	3346	3347	1737	1738	1739	2109	1741	2166	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25	25	25	26	26	26	28	28	29	29	30	30	30	33	33	33	36	41	42	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Islandiella subglobosa																																1																			1	1	2	
Lagena striata																																														1								
Lenticulina orbicularis																																															1						1	
Miliolinella circularis																																																						
Mississippina concentrica																																																	1					
Neoconorbina terquemi												1															1																											
Nodobaculariella atlantica																1							1																															
Nonion grateloupi									1																		1																											
Nonionella turgida																					1																				1													
Peneroplis proteus																	1					3															2			3														
Placopsilina confusa			2												1								1																	1														
Planorbulina mediterranensis																																															1							
Planulina exorna														1												1						1																						
Planulina ornata										1					1		1																																					
Pyrgo denticulata																																			1																			
Pyrgo oblonga																																																						
Pyrgo serrata																																									1						1						1	
Quinqueloculina bicostata																	1	1						2			1																											
Quinqueloculina bosciana																2																										1					2							
Quinqueloculina compta	1		1							2				3		2	1				1	2		4							6	1	1	2			1			1		1											1	
Quinqueloculina jugosa								1						1																																							1	
Quinqueloculina lamarckiana								5														2					1															1												
Quinqueloculina poeyana				1																		1																																
Quinqueloculina seminula			1	1				1		2	1					1	1	1					1														1															6	1	
Rectobolivina advena																										1						1																						
Reophax atlantica			1	1			2	3	2		4					2	1			1	1		1				2				2						1	1				2	1				1	1	1		1			
Reophax fusiformis																																																						
Reophax scorpiurus								2		1					1		2	1			1			1			1							1			1	1						1	1									
Reussella atlantica	1																														2	1			1																		2	
Rosalina floridana								1		2			2	1								1					1	1				1					1																1	
Rosalina floridensis						1																										1																				1		
Rosalina globularis			2			2		3	2	3			2			6	6				1	1	7									1		1		1	1	1									1							1
Rosalina rugosa																																																						
Sagrina pulchella																																																						
Scutuloris procera																1																2																						
Spiroloculina atlantica																																					2			1														
Stetsoina minuta																																																						
Textularia candeiana																																														2								
Textularia conica			1					1		3						3	4	1				1	2				2							1						1		1												
Textularia truncata																	5	2					1				1																											
Trifarina angulosa										3						3		1			1		1	2		3	1					1		1	1						1	1			2						1	2	1	
Triloculina trigonula													1			1																									1						1							
Trochammina squamata			2						2	1			3			5																								1				2							4	1	1	
Trochamminula lobata			1	1		1		1	2	2	1				1				1				2	1						1										1					3						1		1	
Webbinella concava						1	1			1						1		1		1					1		2			1							2											2						
Wiesnerella auriculata													1																																									

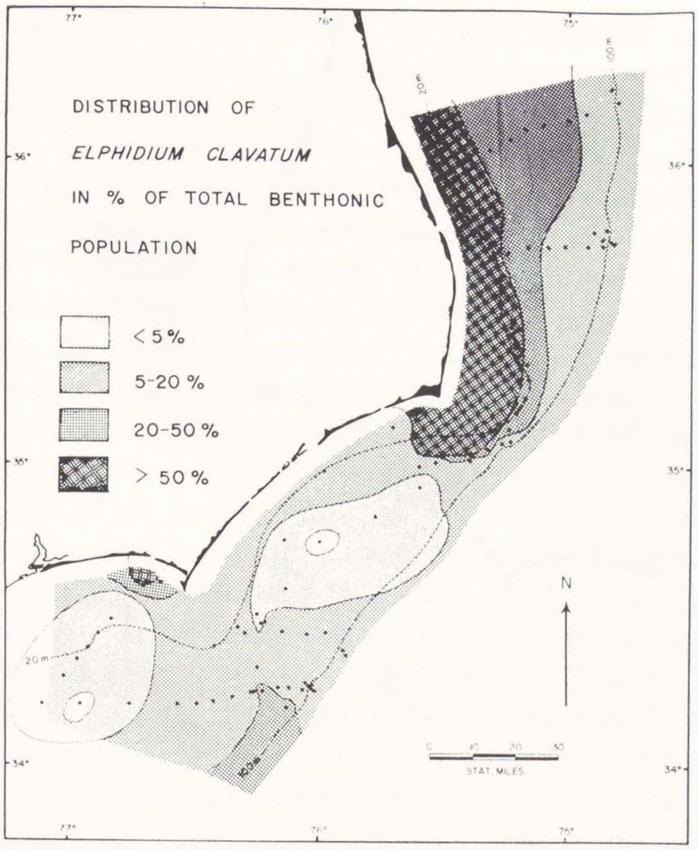

Figure 3

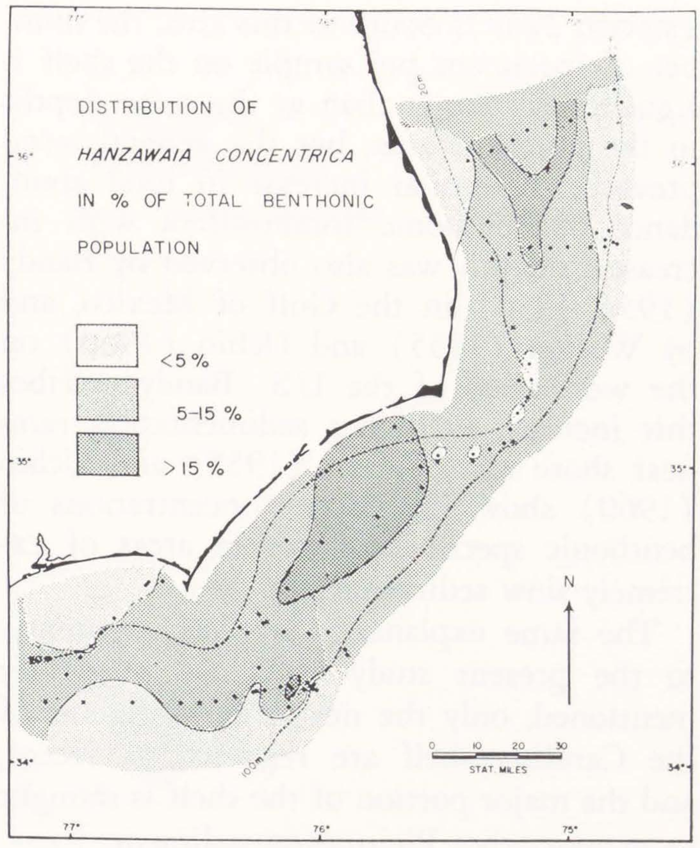

Figure 4

TABLE IIIa PERCENTAGE DISTRIBUTION OF TOTAL PLANKTONIC POPULATION (N of C. H.)

STATION NUMBER	1938	2267	1992	3333	3336	3337	2001	2007	3332	2006	1985	1997	2009	2264	1994	2260	2262	2010	2011	2258	2256	3325	3338	2254	2017	2251	3324	2243	2025	2247
DEPTH IN METERS	19	19	20	20	20	20	22	22	22	23	25	25	26	26	28	32	35	38	38	38	50	50	60	70	80	90	95	110	120	140
Candeiana nitida																													x	
Globigerina bulloides														x				x	x	x	x	x	45	30	37	41	32	45	43	43
Globigerina dutertrei													x						x			x	1	8	14	5	9	6	11	3
Globigerina inflata					x												x	x			x	x	9	21	23	20	20	20	23	19
Globigerina pachyderma																						x		14	3	15	8	13	6	15
Globigerina quinqueloba																					x	x	3	5	3	2	5	4	3	7
Globigerinita glutinata																							6		1	1	x	1		1
Globigerinoides conglobatus																								2					1	
Globigerinoides ruber					x										x		x	x		x	x	x	23	14	12	12	19	8	10	8
Globigerinoides sacculifer																							1		x		x			x
Globigerinoides trilobus	x	x																x				x	4	2	5	1	4	2	2	3
Globorotalia hirsuta																									x	1	x	x	x	x
Globorotalia menardii																							1	4	1	1	1	1	1	x
Globorotalia truncatulinoides																										x	x		x	x
Hastigerina aequilateralis																							1		x	x	x	x	7	x
Hastigerina pelagica																							4							
Orbulina universa																								1	1	1	1			
Pulleniatina obliqueloculata																					x			2	x	x	x	x	1	x

TABLE IIIb PERCENTAGE DISTRIBUTION OF TOTAL PLANKTONIC POPULATION (South of Cape Hatteras)

STATION NUMBER	2145	2146	2142	2307	2141	2277	2139	2151	2287	2137	2183	2110	2127	1734	1965	2116	2118	2122	2123	3348	1977	2117	2156	2111	3269	1960	2296
DEPTH IN METERS	12	12	15	16	17	18	20	20	20	22	22	23	23	24	25	25	25	25	25	25	26	26	26	28	28	29	29
Candeiana nitida																											
Globigerina bulloides				x						x	x		x			x	x	x	x		x			x		x	
Globigerina dutertrei																											
Globigerina inflata																											
Globigerina pachyderma																											
Globigerina quinqueloba																x			x								
Globigerinita glutinata																											
Globigerinoides conglobatus																											
Globigerinoides ruber	x						x	x		x			x	x		x	x	x	x		x	x		x		x	
Globigerinoides sacculifer																			x								
Globigerinoides trilobus								x		x			x						x		x	x				x	
Globorotalia hirsuta																											
Globorotalia menardii																	x		x								
Globorotalia truncatulinoides																					x						
Hastigerina aequilateralis										x							x	x									
Hastigerina pelagica															x												
Orbulina universa														x													
Pulleniatina obliqueloculata																											

STATION NUMBER	1963	3346	3347	1737	1738	1739	2109	1741	2166	1975	2159	3342	2108	1979	2107	3340	2105	2168	1750	1980	3339	2171	1759	2172	2104	2175	1783
DEPTH IN METERS	30	30	30	33	33	33	36	41	42	44	50	50	52	55	57	65	70	75	80	85	90	95	122	125	140	155	159
Candeiana nitida																								x			x
Globigerina bulloides				35	20	x	x	x	x	x		x	36	10		5	x	33	11	8	2	x	16	45	32	3	16
Globigerina dutertrei		x			1				x		x		5	13	x	10	x	10	10	23	28		17	5	7	6	7
Globigerina inflata	x				2			x					2	2				4	x	x	1		4	5	3	4	4
Globigerina pachyderma				2	1				x					1		3			x	1	5		3	1		2	2
Globigerina quinqueloba						x			x		x		7					6		1				1	2	x	x
Globigerinita glutinata														1				10		1			2	1	1	2	1
Globigerinoides conglobatus																3	x				2				1		
Globigerinoides ruber	x	x	x	16	61		x	x	x		x	x	31	41	x	61		10	31	32	55	x	44	25	15	60	59
Globigerinoides sacculifer				x															1	3	2		1	1			1
Globigerinoides trilobus				41	8	x	x	x	x		x		12	12	x	1	x	16	15	14	2	x	11	14	9	8	7
Globorotalia hirsuta								x						1					1	x	1		1	1	1	1	x
Globorotalia menardii				2	5	x			x				3	11		8	x	2	9	5	4		4	3	10	4	4
Globorotalia truncatulinoides				2									2	5		2		2	1	1	1		4	1	4	x	x
Hastigerina aequilateralis				2	1			x			x			2		2			2	1				3		x	1
Hastigerina pelagica																		2	2	x				x	x	x	
Orbulina universa					1									1		2			8	2			1	1	3	x	2
Pulleniatina obliqueloculata													2	2		7	x		2	4	2		2		3	1	2

(station 2247). South of this area, the number of specimens per sample on the shelf is significantly larger than at the same depths in the northern area, but the general trend prevails. A similar increase in total abundance of benthonic foraminifera with increase in depth was also observed by Bandy (1954, 1956) in the Gulf of Mexico, and by Walton (1955) and Uchio (1960) on the west coast of the U.S. Bandy ascribes this increase to higher sedimentation rates near shore and Walton (1955) and Uchio (1960) show that large concentrations of benthonic specimens occur in areas of extremely slow sedimentation.

The same explanation applies apparently to the present study area. As previously mentioned, only the nearshore sediments of the Carolina shelf are regarded as recent, and the major portion of the shelf is thought to expose relict Pleistocene sediment.

Formation of authigenic minerals (glauconite, phosphorite) and strong iron staining are generally considered diagnostic of low sedimentation rates. These minerals occur abundantly on the central and outer portions of the North Carolina shelf. Foraminiferal tests appear highly susceptible to such chemical alteration and figure 17 shows the distribution of altered tests, which have been either glauconitized, phosphatized, iron stained or are covered by a thick crust of secondary glassy calcite. Such specimens are

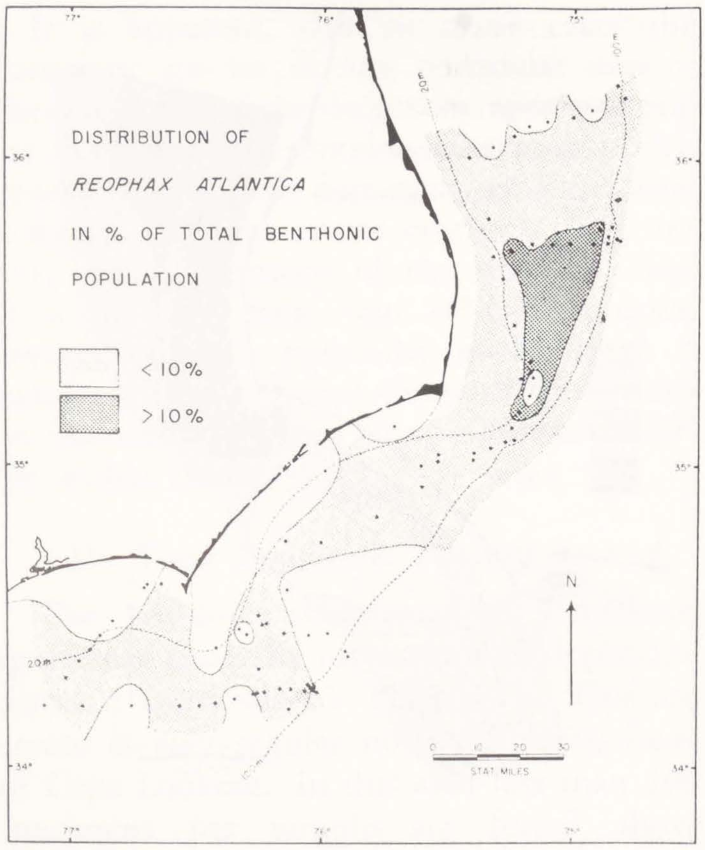

Figure 5

TABLE IV. Thanato-coenosis divisions of the North Carolina Continental Shelf.

		NEAR SHORE		CENTRAL SHELF		SHELF EDGE--UPPER CONT. SLOPE	
VIRGINIAN	I	Elphidium clavatum	50%	Elphidium clavatum	50%-15%	Islandiella subglobosa	10%
				Hanzawaia concentrica	10%	Bulimina marginata	10%
				Reophax atlantica	10%	Lenticulina orbicularia	5%
						Cibicides pseudoungerianus	5%
				Webbinella concava	5%	Trifarina angulosa	2%
				Guttulina lactea	5%	Rosalina rugosa (patchy)	4%
						Cibicides bradyi (shallow in S)	5%
CAROLINIAN	II RALEIGH BAY			Hanzawaia concentrica	15%	Lenticulina orbicularis	4%
				Reophax atlantica	10%	Cibicides pseudoungerianus (shallow in S)	6%
				Peneroplis proteus	10%	Amphistegina lessonii	1%- 8%
				Quinqueloculina seminula	10%		
				Asterigerina carinata	6%-10%		
				Reophax scorpiurus	5%		
				Quinqueloculina compta	4%		
	III ONSLOW BAY			Peneroplis proteus	15%	Islandiella subglobosa	5%
				Placopsilina confusa	20%	Lenticulina orbicularis	2%
				Quinqueloculina seminula	20%	Amphistegina lessonii	1% -16%
				Quinqueloculina lamarckiana	5%	Trifarina angulosa	4%
				Quinqueloculina compta	5%		
				Asterigerina carinata	6%		
				Reophax scorpiurus	5%		

most abundant in the southern portion of the area and their abundance increases with distance from shore. The northern section of the area and the near shore area south of Cape Hatteras is free of altered individuals. Thus it appears that the alteration is caused by Gulf Stream water, either by the Gulf Stream directly along the edge of the shelf or, on the shelf proper, by Carolina Coastal water, derived from Gulf Stream water. The lack of altered specimens on the northern shelf need not imply that those sediments are not relict, but rather that Virginian Coastal water does not induce these chemical changes.

Relative sedimentation rates have also been shown to be indicated by the ratio of living population to total population (Phleger, 1955). This is based on the assumption that the total living population (standing crop) is a measure of test production in any given area. In areas of high sedimentation the abundance of tests in the sediment will be lowered, whereas in areas of low sedimentation rates, the tests will be concentrated. The central shelf is generally the area which carries the highest number of living specimens (fig. 18). If the assumption that the standing crop is a measure of the production of tests is valid, then it appears from figure 19 that the distribution of areas of high, medium, and low relative sedimentation is not what would be expected on the basis of sediment distribution and total benthonic populations. Good agreement with the expected pattern of sedimentation occurs along the outer shelf—shelf edge north of Cape Hatteras, and on the outer portions of the

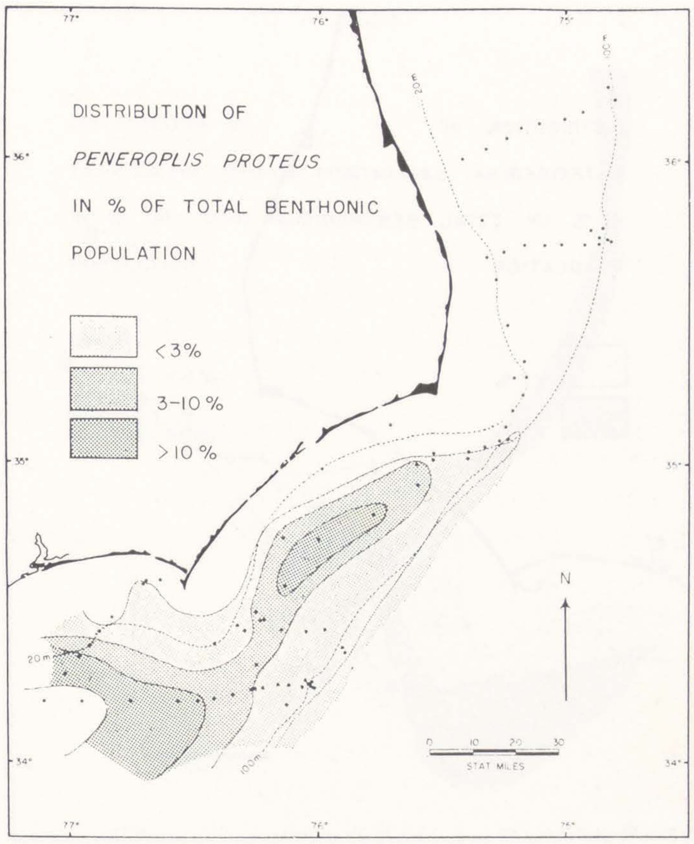

Figure 6

TABLE V
FAUNAL DIVERSITY INDICES

Sample Number	Diversity Index	Sample Number	Diversity Index	Sample Number	Diversity Index	Sample Number	Diversity Index
1734	4.83	2006	5.95	2138	16.39	2261	6.88
1737	19.56	2008	4.84	2139	5.71	2264	5.38
1738	23.14	2004	6.12	2140	12.15	2267	1.98
1739	9.72	2010	7.78	2141	10.12	2277	8.28
1741	16.48	2011	11.58	2145	9.63	2287	13.38
1750	33.39	2017	12.79	2146	2.19	2296	21.39
1759	12.44	2025	15.65	2150	15.68	2308	6.65
1783	24.01	2104	35.58	2156	13.03	3269	7.08
1960	21.74	2105	10.21	2159	10.01	3324	11.55
1963	17.41	2107	13.38	2166	17.14	3325	10.68
1965	7.66	2108	22.35	2168	30.60	3332	3.31
1974	9.07	2109	10.89	2171	8.92	3333	4.50
1977	19.78	2110	8.29	2172	19.22	3336	7.56
1979	15.14	2111	20.69	2175	19.43	3337	8.50
1980	25.24	2116	18.58	2245	10.41	3338	4.34
1983	3.55	2117	12.58	2246	10.75	3339	18.32
1985	3.24	2118	15.19	2251	11.79	3340	11.47
1992	8.85	2122	9.47	2254	13.50	3342	1.88
1994	2.61	2123	9.64	2256	12.98	3346	2.28
1997	1.55	2124	8.08	2257	12.72	3347	14.04
2001	4.19	2137	20.14	2259	9.03	3348	9.22

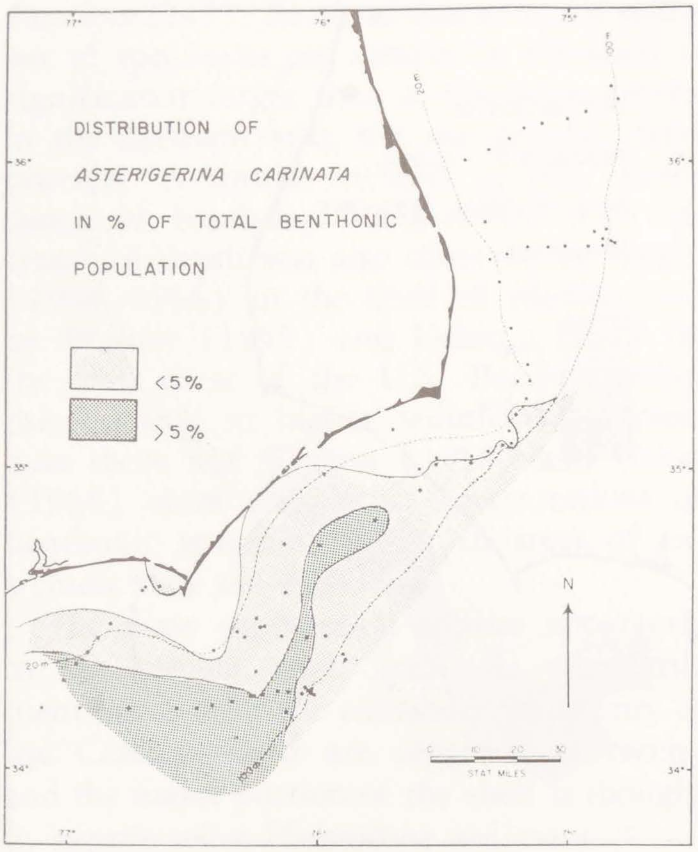

Figure 7

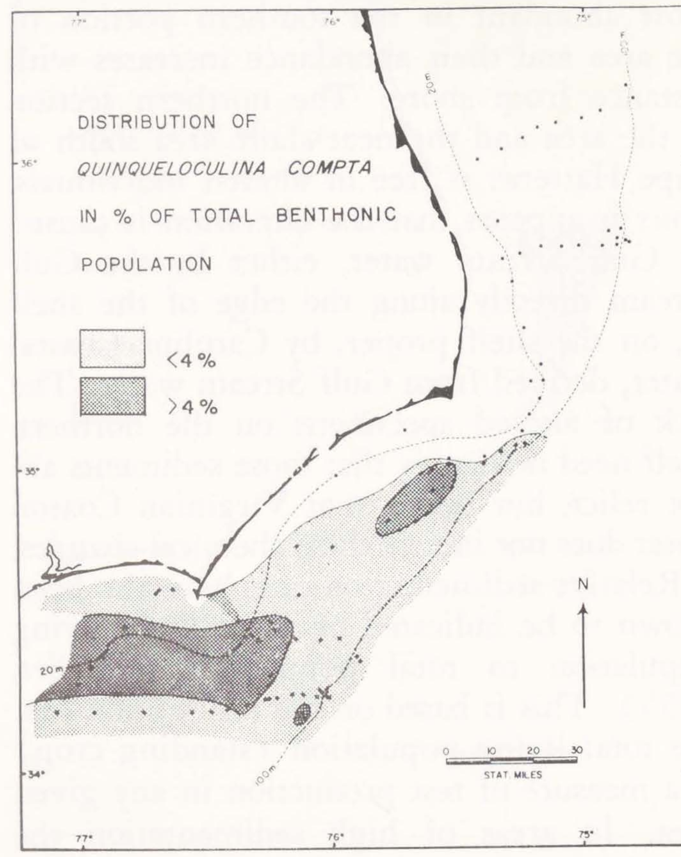

Figure 9

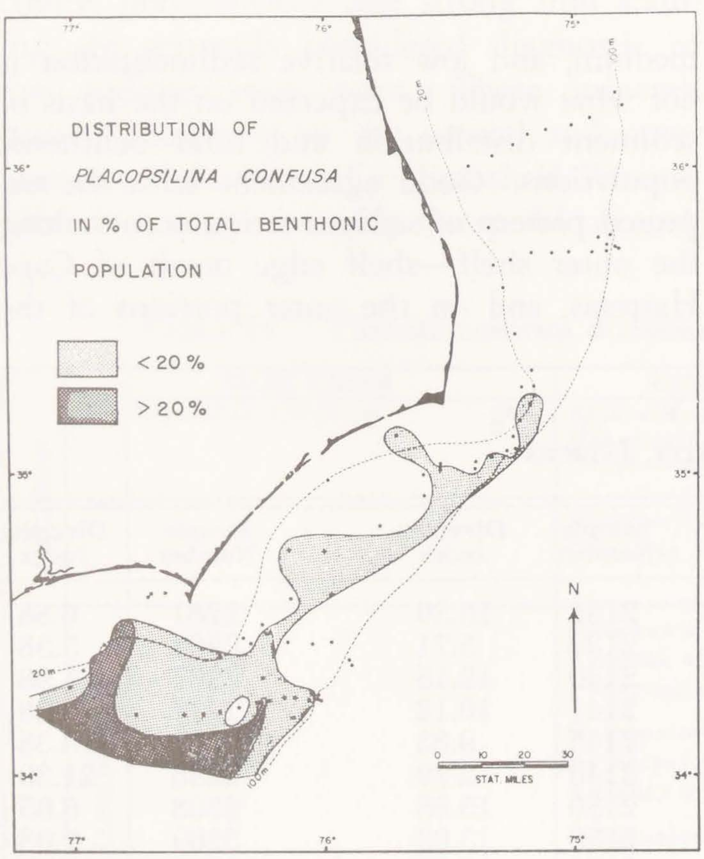

Figure 8

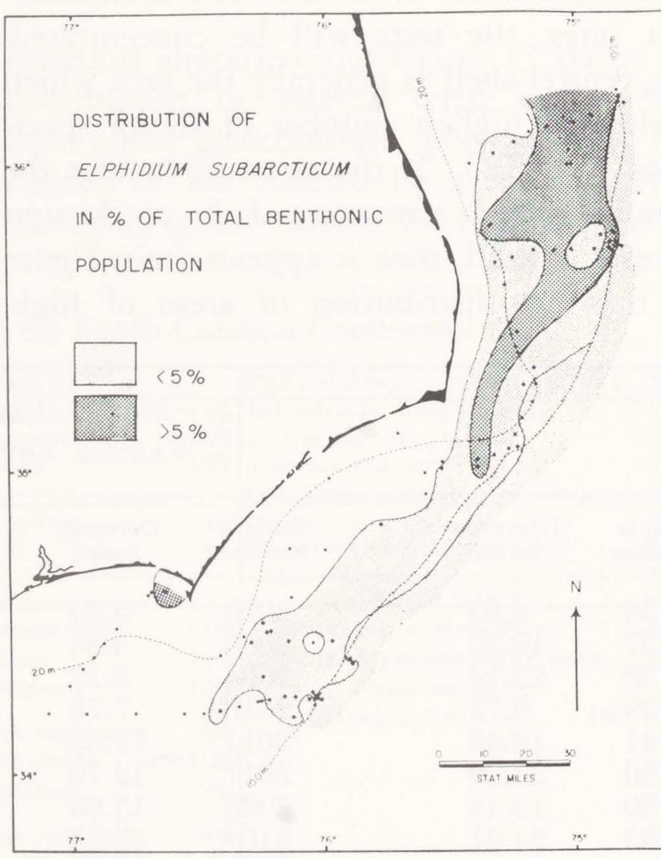

Figure 10

central shelf and the outer shelf south of Cape Hatteras, where very low sedimentation rates are indicated by values of less than 5% of living foraminifera. Also in good agreement is the nearshore area and inner portion of the central shelf between Cape Hatteras and Cape Lookout, where the percentage of living foraminifera decrease with distance from shore. Unexpectedly high percentages are found, however, on the central shelf north of Cape Hatteras and on certain portions of the central shelf south of Cape Lookout. These areas are covered by relatively coarse-grained sediment which is generally assumed to be relict. The most likely explanation for these anomalies may be that

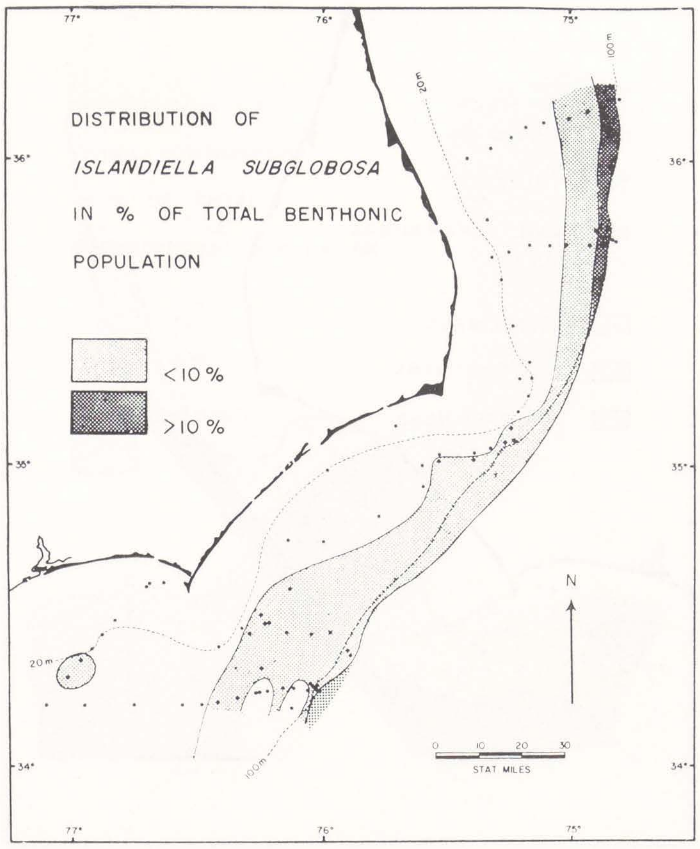

Figure 11

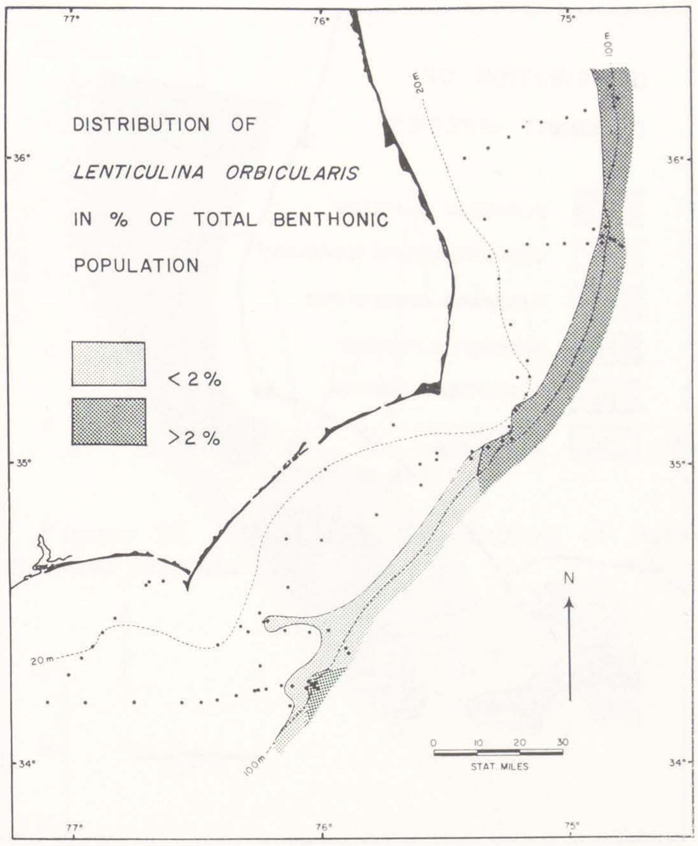

Figure 13

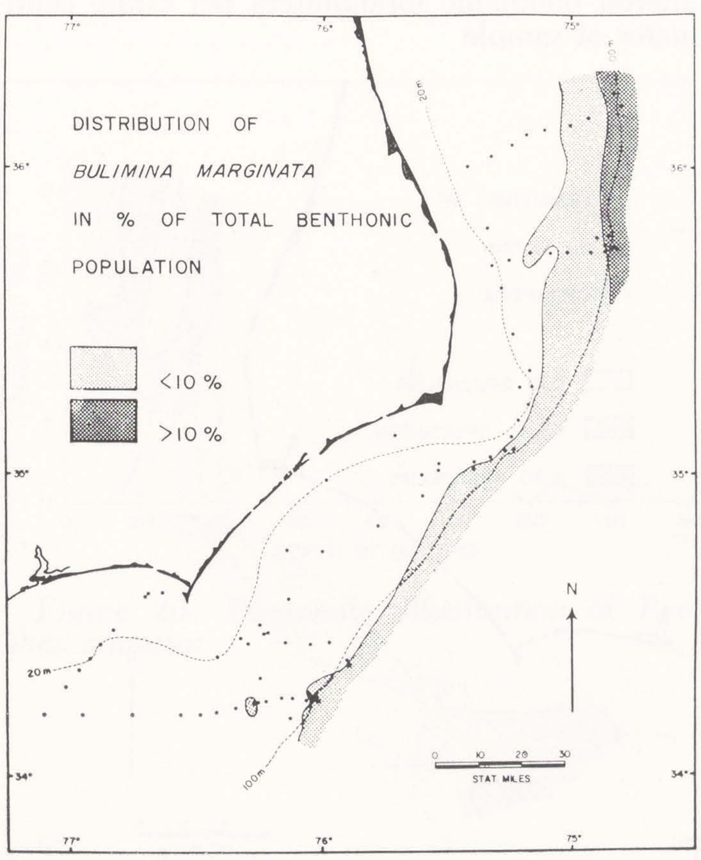

Figure 12

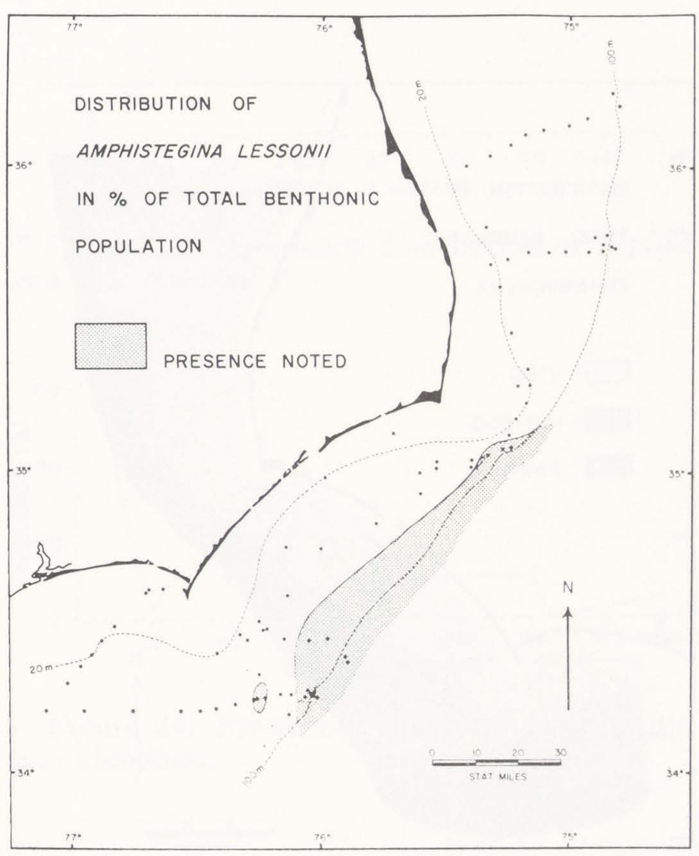

Figure 14

the number of living specimens encountered may not directly reflect the rate of production of empty tests. That is, species living on the central shelf may have longer life cycles, or recognition of living specimens may not have been accurate. As an example, the organic cement of the tests of certain arenaceous species, especially *Reophax atlantica,* is also stained by Rose Bengal and thus empty tests may have been confused with living specimens. *Reophax atlantica* is very abundant on the central shelf (fig. 5).

E. Changes in Sealevel

Comparison of the depth ranges of living and total populations is difficult because

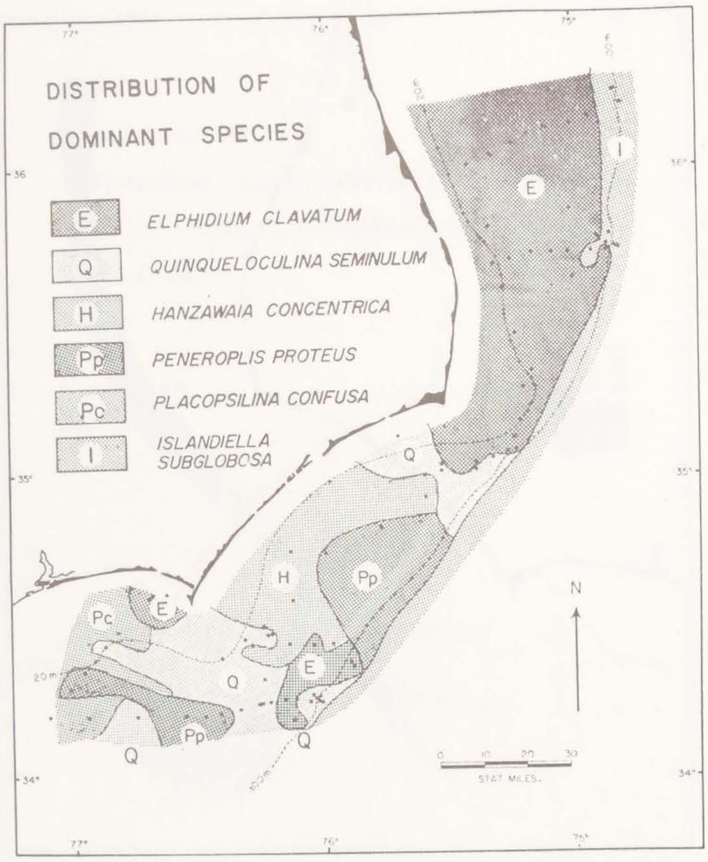

Figure 15

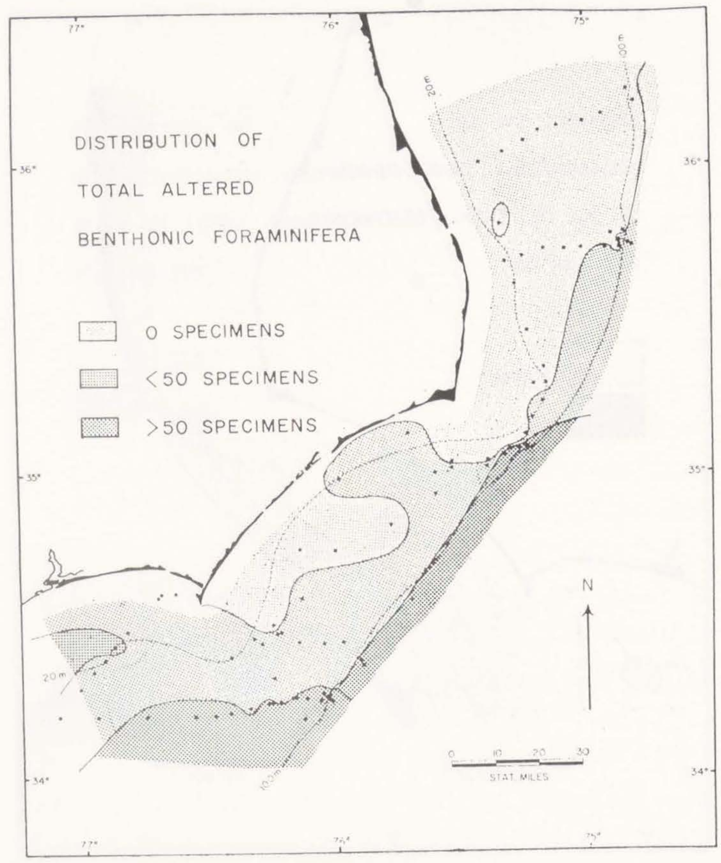

Figure 17. Distribution of total number of altered benthonic foraminifera per cubic centimeter of sample

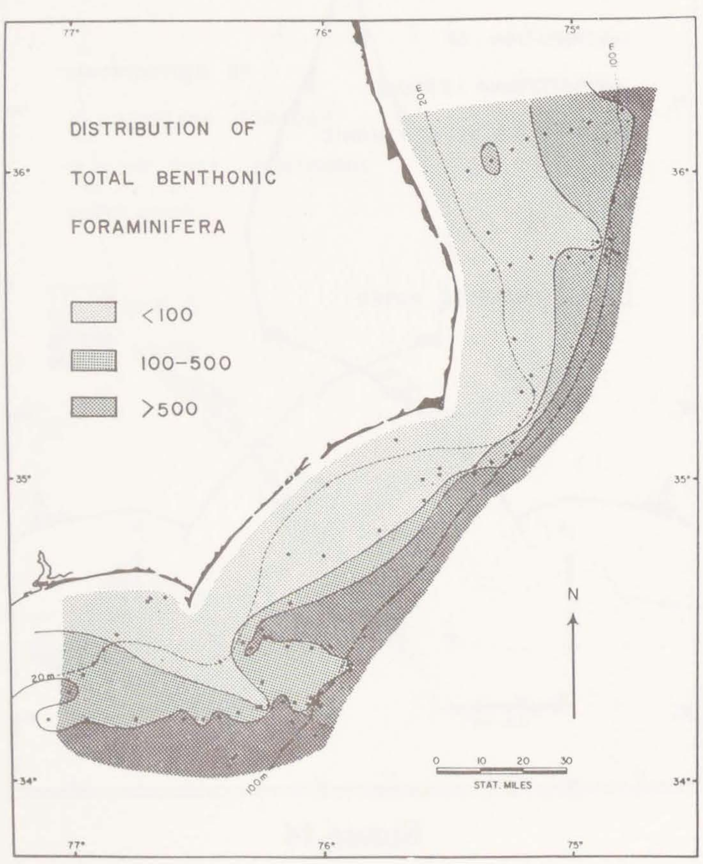

Figure 16. Distribution of total benthonic foraminifera, expressed in number of specimens per cubic centimeter of sample

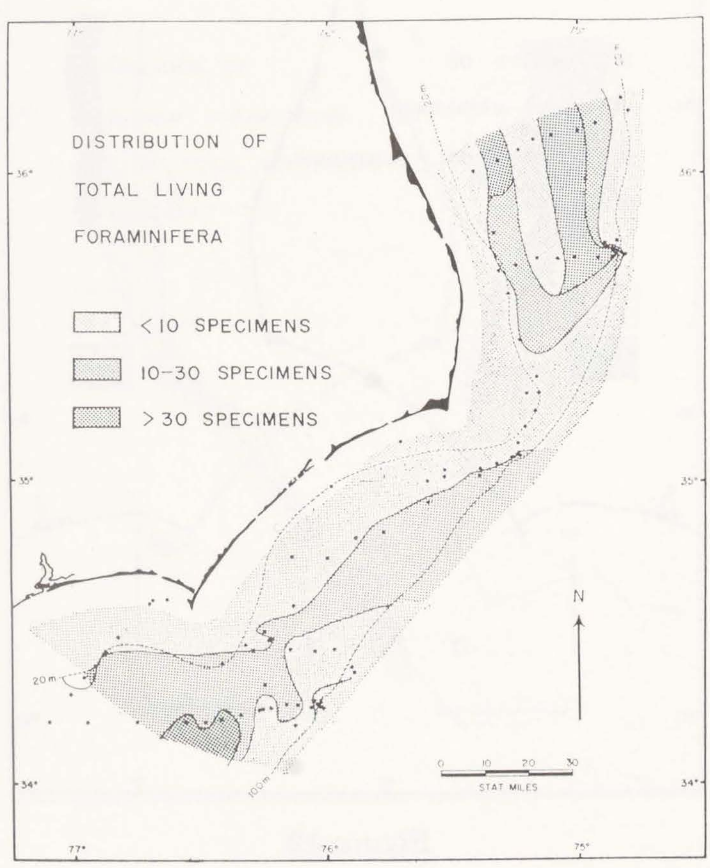

Figure 18. Distribution of total living foraminifera, in specimens per cubic centimeter of sample

very few living specimens were recorded. Thus, especially in the case of less abundant species, the absence of living representatives may result from their scarcity (non-recovery) or from real absence. Comparison can be qualitative only. It has been recognized earlier (Phleger, 1956; Uchio, 1960) that dead individuals frequently occur at greater depths than living populations. This type of distribution may be explained either by

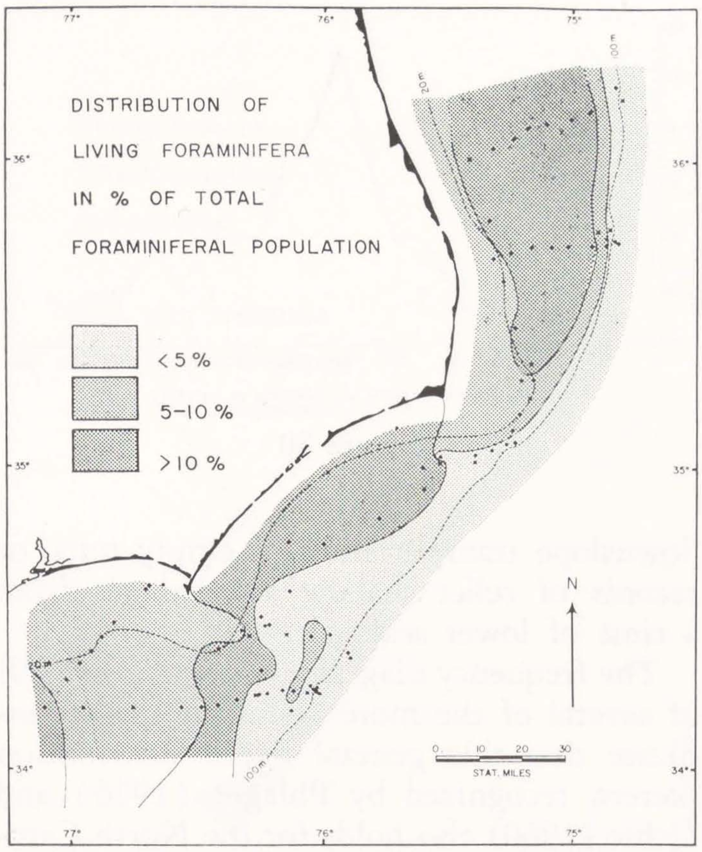

Figure 19

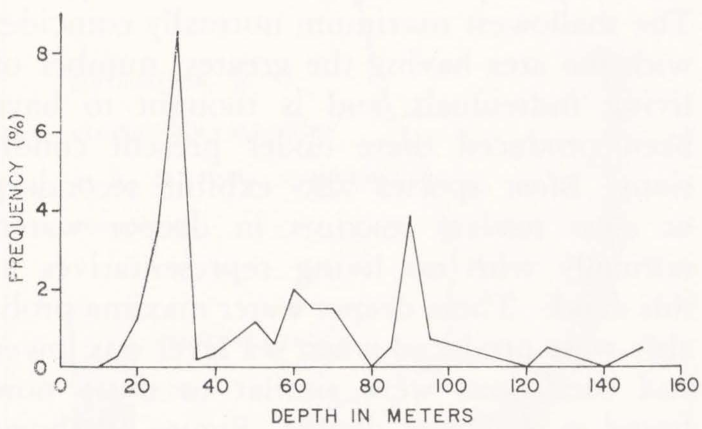

Figure 20. Frequency distribution of *Reophax atlantica.*

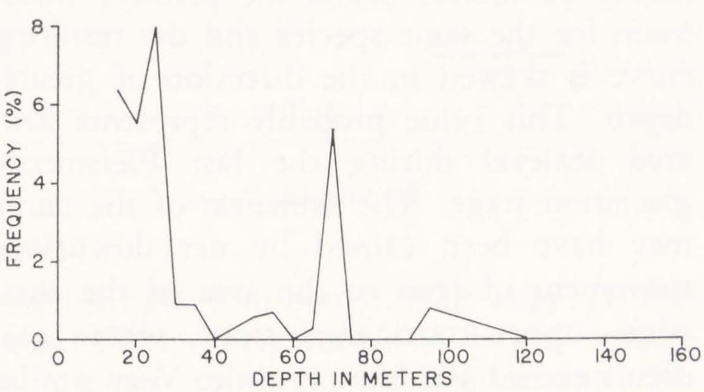

Figure 21. Frequency distribution of *Placopsilina confusa.*

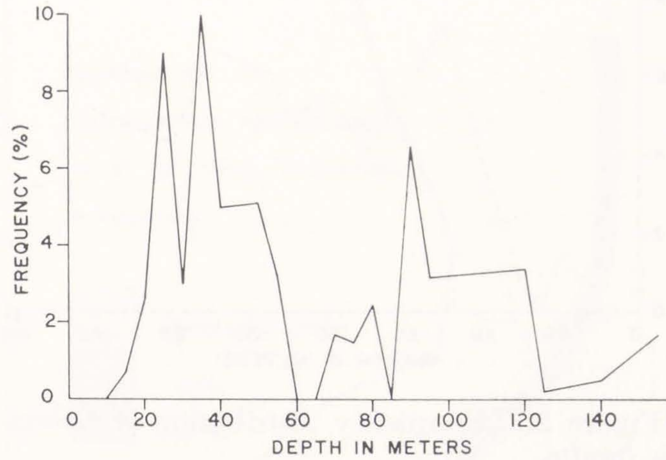

Figure 22. Frequency distribution of *Asterigerina carinata.*

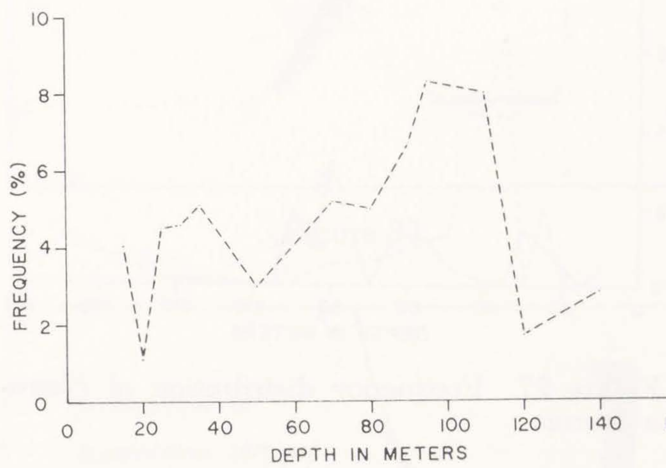

Figure 23. Frequency distribution of *Elphidium subarcticum.*

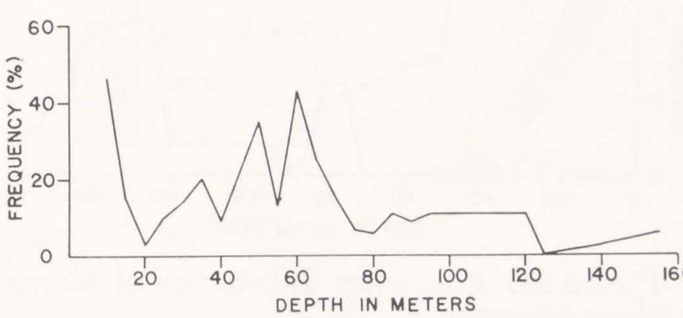

Figure 24. Frequency distribution of *Elphidium clavatum.*

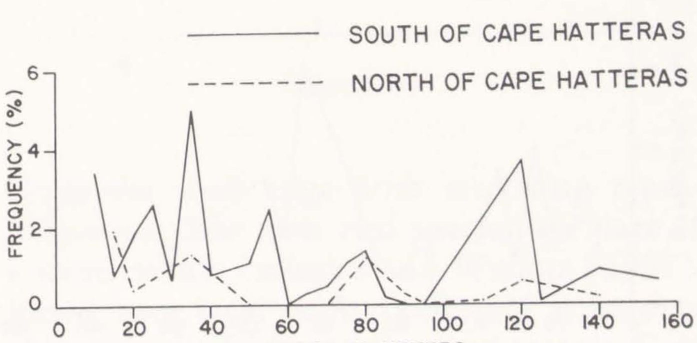

Figure 25. Frequency distribution of *Quinqueloculina jugosa.*

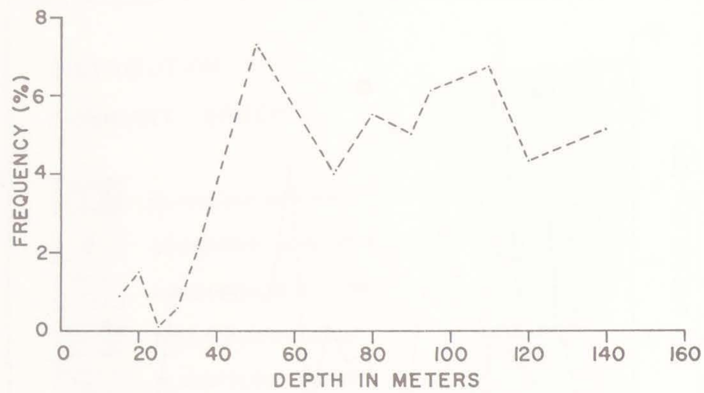

Figure 26. Frequency distribution of *Cibicides bradyi.*

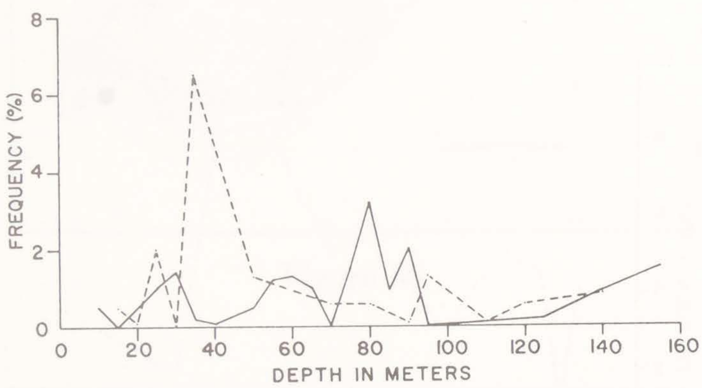

Figure 27. Frequency distribution of *Planulina exorna.*

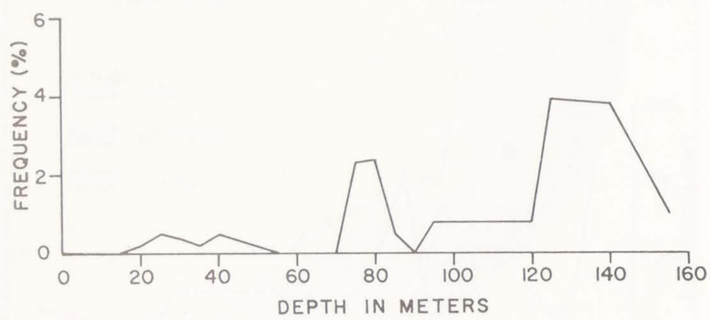

Figure 28. Frequency distribution of *Neoconorbina terquemi.*

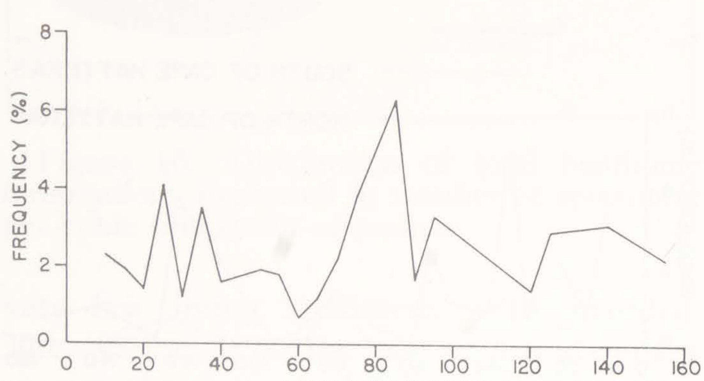

Figure 29. Frequency distribution of *Textularia conica.*

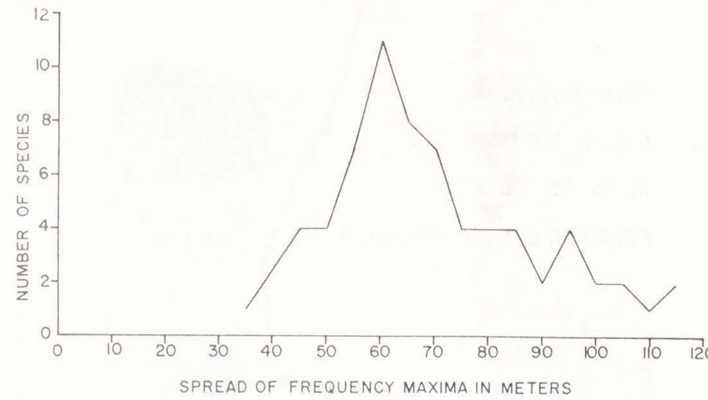

Figure 30

downslope transportation of empty tests, or records of relict shallow assemblages from a time of lower sealevel.

The frequency diagrams (figures 20 to 29) of several of the more abundant species indicate that this general depth distribution pattern recognized by Phleger (1956) and Uchio (1960) also holds for the North Carolina shelf fauna; living specimens are either more abundant or are confined to the shallow portion of the total depth range. Also, very pronounced maxima are apparent in the frequency distribution of the species. The shallowest maximum normally coincides with the area having the greatest number of living individuals, and is thought to have been produced there under present conditions. Most species also exhibit secondary or even tertiary maxima in deeper water, normally with no living representatives at this depth. These deeper water maxima probably were produced when sea level was lower and conditions were similar to those now found at shallower depths. Figure 30 shows the relative positions of the maxima for several species. The shallowest peak of each species is taken as zero and the position of the secondary peaks are recorded accordingly. The greatest number of secondary maxima occurs 60 meters below the primary maximum for the same species and the resulting curve is skewed in the direction of greater depth. This value probably represents lowered sealevel during the last Pleistocene glaciation stage. The skewness of the curve may have been caused by net downslope movement of tests in the area of the shelf edge—upper continental slope, where gradients exceed 100 feet per mile. Very similar values for the lowering sealevel have been reported on the basis of oölite occurrences on

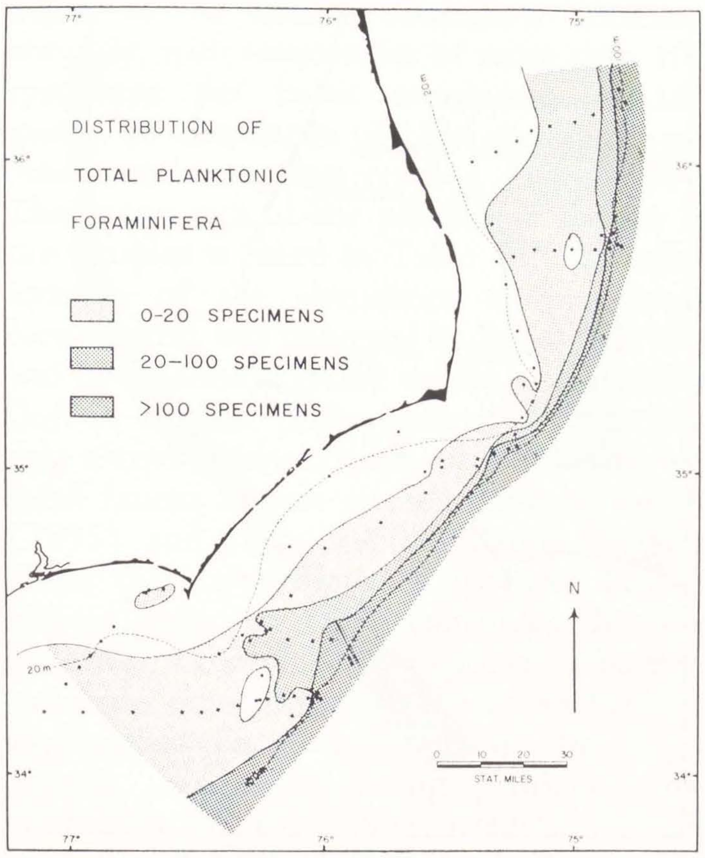

Figure 31. Distribution of total planktonic foraminifera, in specimens per cubic centimeter of sample.

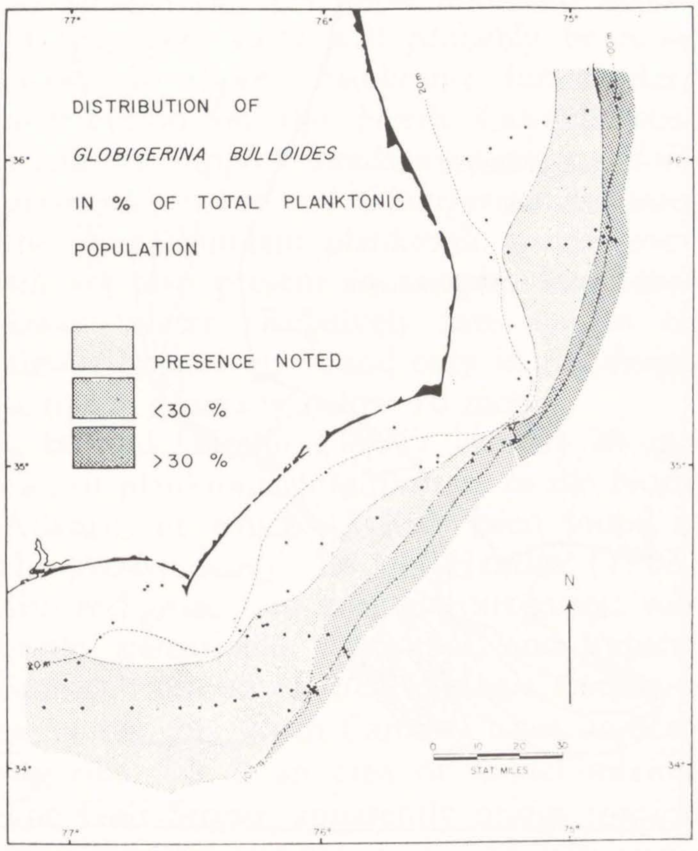

Figure 32

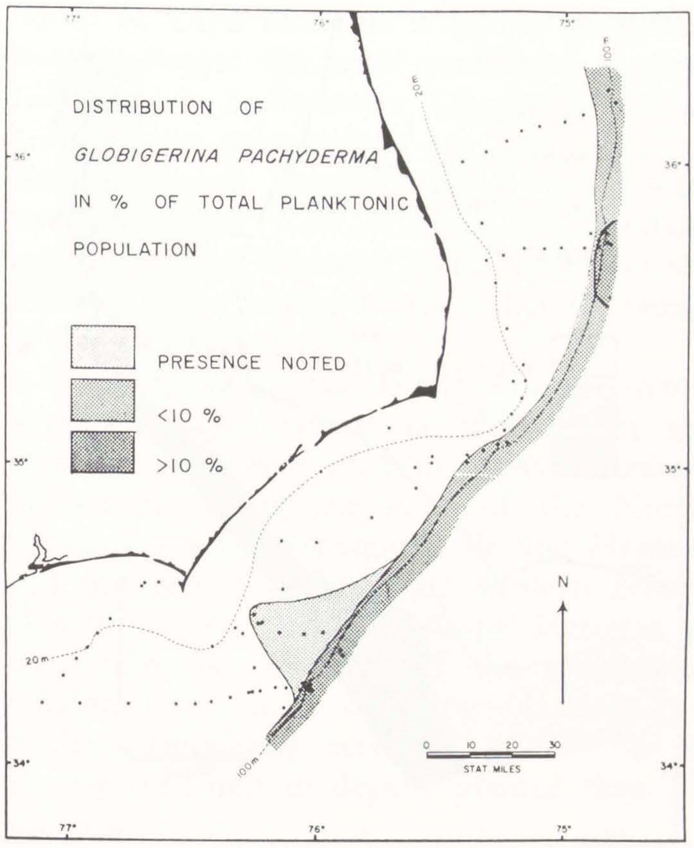

Figure 33

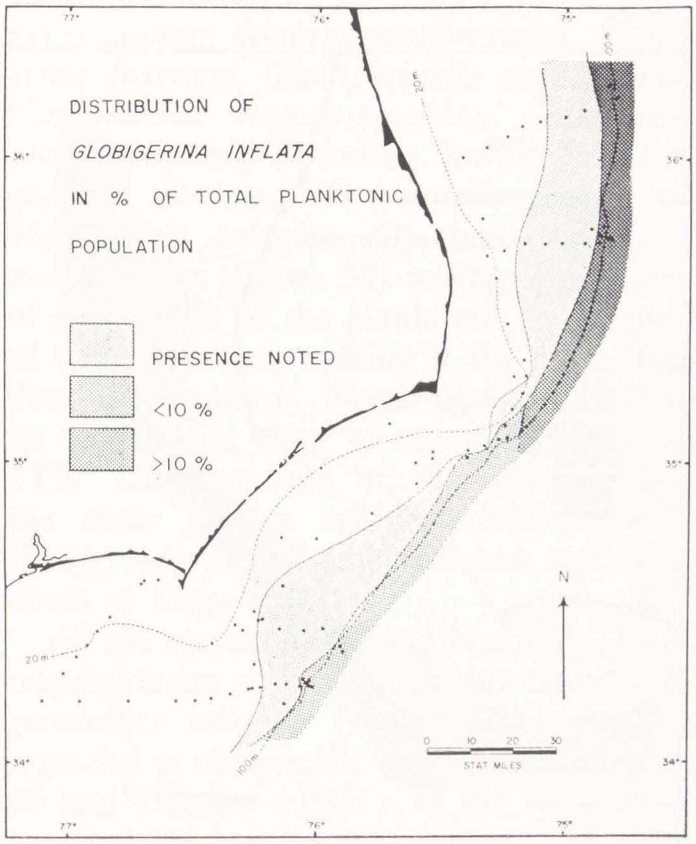

Figure 34

the Georgia continental shelf edge (Pilkey *et al.*, 1966). Occurrences of "larger" foraminifera may corroborate this assumption. *Amphistegina lessonii*, *Textulariella barrettii* and *Textularia pseudotrochus* occur exclusively along the shelf edge with no living representatives. The first two species are part of a fauna which Ludwick and Walton (1957) found associated with dead reef structures along the shelf edge of the northeastern Gulf of Mexico. They concluded that these reefs grew when sealevel was about 60 meters

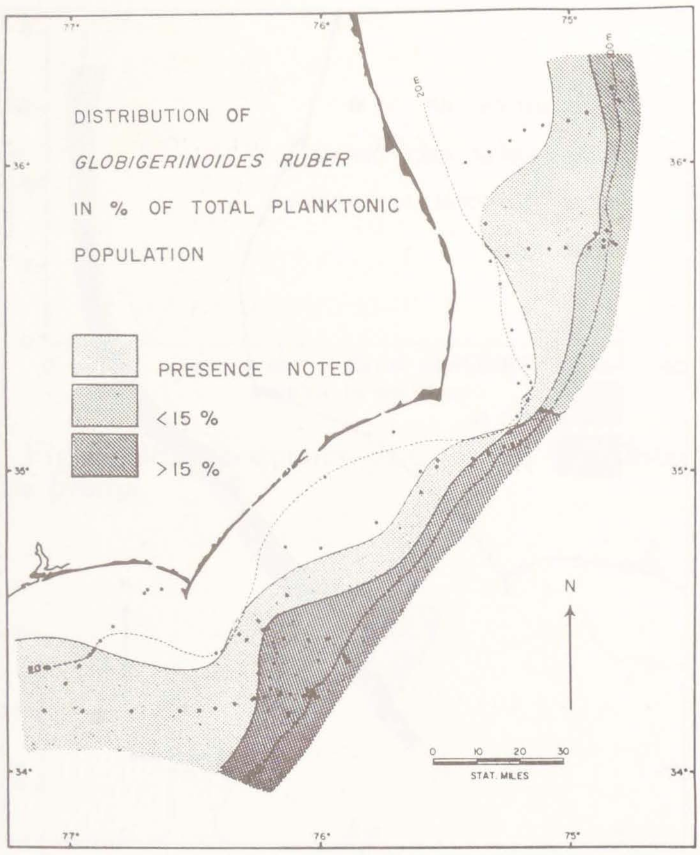

Figure 35

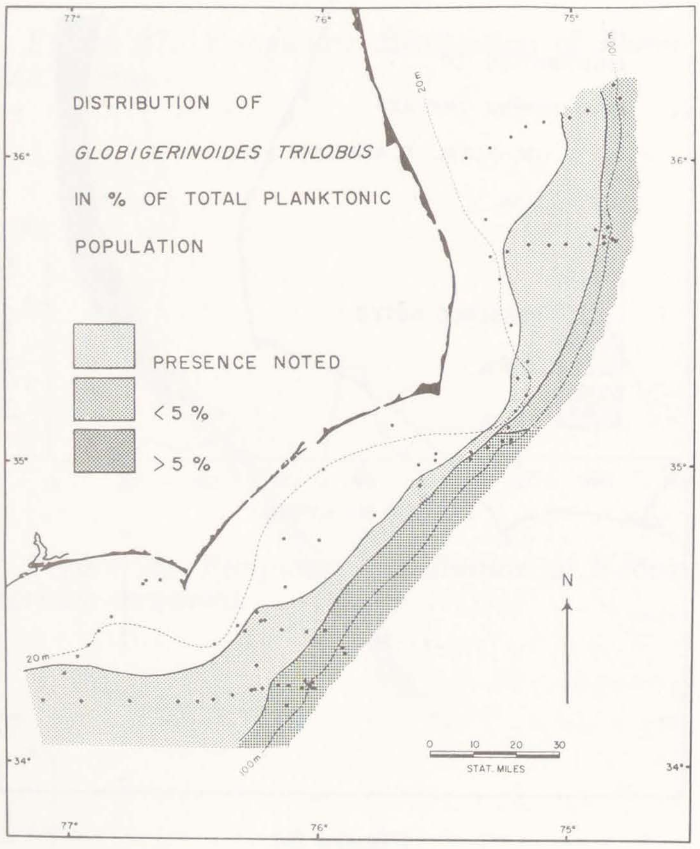

Figure 36

below the present level, probably during the last stage of the Pleistocene glaciation. The dead foraminifera associated with the reef have their living equivalents in the shallow water off the coast of Florida and in the Florida reefs.

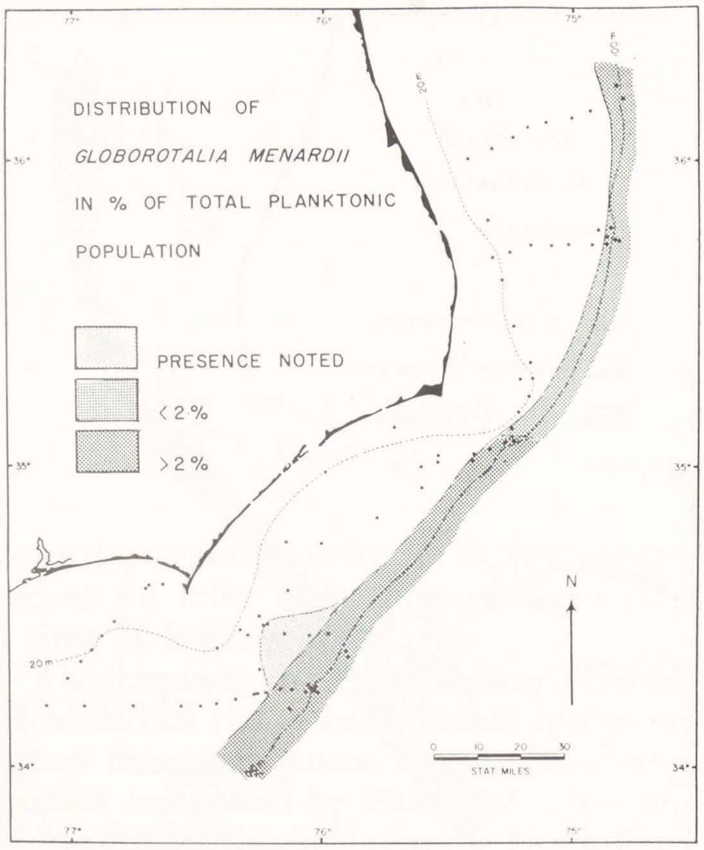

Figure 37

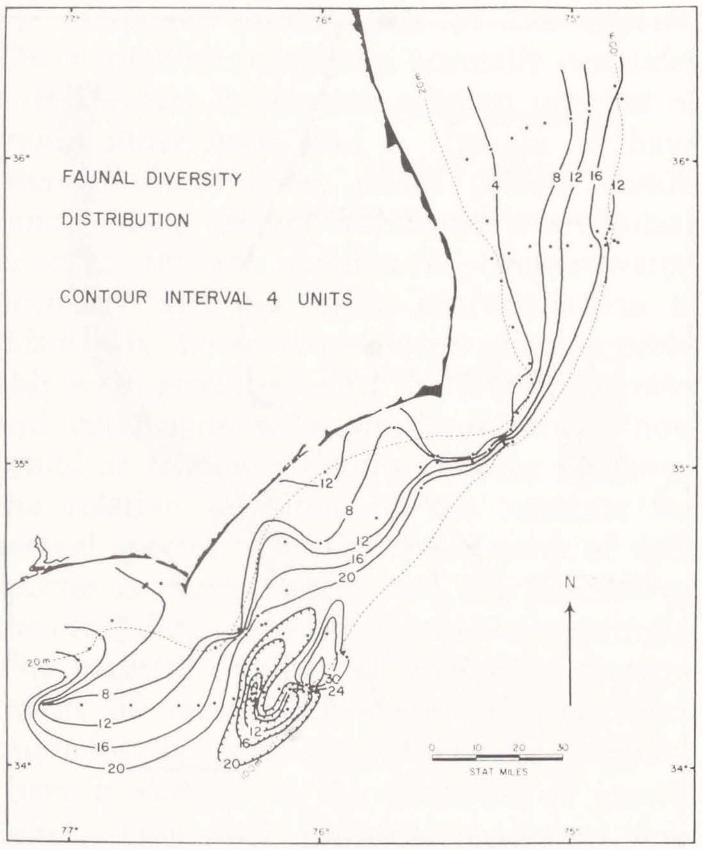

Figure 38

F. Planktonic Foraminifera

The distribution of planktonic foraminiferal tests is very closely correlated with depth. The shallowest specimens appear at depths between 20 and 30 meters. At a depth of 70 meters abundance increases abruptly, with frequencies of more than 100 specimens per cubic centimeter, at 140 meters an abundance of 1834 specimens per cubic centimeter was reached (Figure 31). The occurrence of the planktonic species in the samples is listed in Table III. A similar increase of the abundance of planktonic foraminifera was observed by Bandy (1956) and by Walton (1964) in the northeastern Gulf of Mexico. This regularity of distribution allows reconstruction of bathymetry of fossil faunas as was already done by Smith (1955) and Hay (1960). Bandy (1956) found that certain species appeared farther inshore than others and concluded that the shallowest occurrence of a species in bottom sediments coincided with the upper limit at which the species occurred in the water column. Studies of living planktonic foraminifera (Phleger, 1951; Bradshaw, 1959; and Bé, 1960), however, indicate that Bandy's conclusion was incorrect. Bradshaw (1959) suggests that the depths at which a species occurs in sediment is a function of its abundance. The most abundant species of the open water will probably be found closest to shore. Planktonic foraminiferal distribution on the North Carolina shelf seems to support Bradshaw's view. *Globigerinoides ruber* and *Globigerina bulloides,* the most abundant planktonic species overall, are also present in samples from shallowest water. Relatively rare species are almost exclusively found only in the deeper samples, generally below 70 meters.

Bé and Hamlin (1967) identify 20 species of planktonic foraminifera in the North Atlantic, of which 17 have been found in the present study. Bé and Hamlin (1967) also recognize four ecologic categories: subarctic, transitional, subtropical and tropical. Species from all of these ecologic categories occur off the North Carolina coast, indicating that this is an area of faunal mixing. The Gulf Stream apparently brings tropical species north, and the southward drift seems to introduce subarctic and transitional species.

Globigerina bulloides (figure 32) is the most abundant planktonic species north of Cape Hatteras where it reaches a maximum abundance of 45% and generally constitutes more than 30% of the planktonic fauna. South of Cape Hatteras it is also abundant but no longer the most numerous species. *Globigerina pachyderma* (figure 33) and *Globigerina quinqueloba* are present along the shelf edge, generally below 70 meters, and are about 3 to 4 times as abundant north of Cape Hatteras than to the south. These species belong to the subarctic fauna of Bé and Hamlin (1967).

Globigerina inflata (figure 34), the index species for the transitional faunal zone according to Bé and Hamlin (1967), occurs abundantly along the edge of the North Carolina shelf, even though Bé and Hamlin did not report it from the western North Atlantic coast. North of Cape Hatteras it may comprise 19–23% of the planktonic foraminifera, south of Cape Hatteras the highest frequency recorded is 5%. It is mostly confined to depths greater than 70 meters.

Of the species reported by Bé and Hamlin (1967) as indicators for the subtropical fauna, the following have been found in this investigation: *Globigerinoides ruber, Globigerina dutertrei, Globigerinella aequilateralis, Globorotalia truncatulinoides, Pulleniatina obliqueloculata, Orbulina universa, Globigerinita glutinata, Globorotalia hirsuta* and *Hastigerina pelagica.* Of these, *Globigerinoides ruber* (figure 35) reaches frequencies of up to 60% of the planktonic fauna south of Cape Hatteras, making it the most abundant species there. North of Cape Hatteras its frequencies drop to an average of only 12%. Other species of this group follow the same pattern with the exception of *Hastigerina pelagica,* which does not occur north of Cape Hatteras.

All the species of Bé and Hamlin's (1967) tropical fauna are present in this area. *Globigerinoides trilobus* (figure 36), which is regarded as conspecific with *G. sacculifer* by Bé and Hamlin (1967), is the most abundant, having frequencies of about 10% south of Cape Hatteras, and of about 3–4% north of the Cape. It occurs sporadically only and rarely in samples from less than 60 meters depth. The only other species which occurs in appreciable numbers is *Globorotalia menardii* (figure 37) which reaches frequencies of as much as 11% south of Cape Hatteras and a maximum of only 4% north of the Cape. It is very rare in a few samples from less than 50 meters depth. *Globigerinoides sacculifer, G. conglobatus* and *Candeina nitida* are very rare and occur only along the shelf edge, north and south of Cape Hatteras.

The distribution patterns of these planktonic species make it possible to outline the area of influence of the tropical and subtropical realm (Gulf Stream) and the transitional and subarctic realm. The divide between these two faunal areas is located at the latitude of Cape Hatteras. It appears, however, that regional study is necessary to bring out distribution patterns because faunal overlap and mixing makes it impossible to define faunal boundaries within a small area.

G. Influence of Sediment upon Foraminiferal Distribution

Phleger (1960) summarizes the available information and concludes that, with the exception of specific cases, for example, attached species, there is no causal relationship between sediment and foraminiferal distribution. Species restricted to certain sediment types in one area, are present on different sediments elsewhere. Their occurrence appears to be governed by coincidence of certain topographic and oceanographic features. Furthermore, although Uchio (1960) found the standing crop of foraminifera in the San Diego area to increase with decreasing sediment particle size, the reverse is generally true on the North Carolina continental shelf. Here the largest standing corp is on the central shelf in fine and medium-grained sand which is the coarsest sediment in the area.

A remarkable coincidence of very-fine sand and very high foraminiferal population occurs about 20 miles southeast of Cape Lookout in what is probably a shallow depression. The presence of much organic matter, bits of eelgrass, fecal pellets, and other buoyant material seems to indicate that foraminifera may have been swept into this area from the surrounding higher ground by current action. Inasmuch as the number of living foraminifera is in no way unusually high, the large number of dead foraminifera, 2101 in sample 1738, can only be explained by current transport.

Of all individual species only three correlate closely with sediment type. These three species, *Placopsilina confusa, Calcituba decorata,* and *Webbinella concava,* have in common the habit of attaching their tests to sand grains or shell fragments. *Placopsilina confusa,* which may be as much as 2 mm long, is especially dependent upon a coarse grained substrate.

VII. Faunal Diversity

Recognition of environment is dependent upon identification of the diagnostic coenosis, thanatocoenoesis in this study or in the case of fossil occurrences. The composition of a coenosis, however, is likely to change with localities or time. It is therefore desirable to obtain an abstract measure of coenotic characters which are independent of specific composition. Such an abstraction is the diversity of a faunal assemblage, *i.e.,* the numerical relationship between the number of species in any given fauna and the number of specimens of each species. The usefulness of a faunal diversity measure is based on the observation that, under adverse environmental conditions, individuals of only a few of the species in a faunal assemblage comprise a large number of the population, whereas under normal conditions individuals of the dominant species are less abundant and the greater number of ecologic niches allows for an increase of diversity. Since faunal diversity may be influenced by any combination of environmental factors, a diversity index does not identify any specific factor, but may serve as a means of generalized comparison between diverse communities.

Various statistics have been employed to measure faunal diversity, but few foraminiferal faunas have been analyzed in this respect. Walton (1964) employed the number of ranked species whose cumulative percentage comprises 95% of the total population as a measure of faunal diversity. Gibson (1966) summarizes the biological implications of faunal diversity and demonstrates its use with an example from the Mississippi Sound area. The formula employed by him is from Simpson (1949):

$$\frac{N(N-1)}{\sum_{i=1}^{K} n_i(n_i - 1)}$$

where: N = total number of specimens in sample

n_i = number of specimens in the i^{th} species

K = number of species

This formula, because of its relative insensitivity to the rare species produces a diversity index that is a measure of dominance within a fauna and thus is dependent upon sample size (Sanders, 1968). Figure 38 shows the distribution of faunal diversity on the North Carolina continental shelf, contoured according to this formula in four unit intervals. The calculated values for each sampling station are presented in table V. The North Carolina shelf apparently supports an unusually diverse fauna in contrast to the values obtained by Gibson (1966) and values computed for upper Miocene faunas from North Carolina discussed by Schnitker (1966, unpublished MS). The highest index obtained in the Mississippi Sound area is 8, and 12 is the highest for the upper Miocene fauna, whereas the North Carolina shelf maximum is 35.6. Values greater than 15 are common on the shelf. These differences may result in part from the use of somewhat smaller samples in the Mississippi Sound study and from the more "normal" marine conditions on the North Carolina shelf as compared to the Mississippi Sound area. The latter is not exposed to open ocean and may also be influenced by the influx of less saline water from the Mississippi River. It is more likely, however, that the high faunal diversity on the North Carolina shelf is caused by the superposition of two different faunas: The Pleistocene relict fauna and the indigenous fauna. It was not possible to analyze separately the influence of either fauna.

Generally, faunal diversity increases with distance from shore, indicating an approach to more stable "normal" marine conditions and also, that the size of the relict fauna is larger in deeper water. The diversity indices on the entire shelf to the north of Cape Hatteras are about four units lower on the average than those of the southern shelf. The lower complexity of the Virginian fauna is probably caused by the different composition of the Virginian Coastal water and the greater fluctuations of temperature and salinity. These fluctuations are greater in shallow nearshore water, giving rise to lower diversity. Diversity values of four and less are roughly restricted to the area of recent near-shore sediments on the northern shelf and off Cape Hatteras. The decrease in diversity at the outer edge of the shelf indicates that here modern sedimentation and an abundant indigenous fauna (*Islandiella subglobosa* and *Bulimina marginata*) mask the diversifying effect of the relict fauna. South of Cape Hatteras diversity values are high, probably because of the stabilizing influence of Gulf Stream water.

VIII. Faunal References

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PLATE 1

Figures	
1a, b	*Ammodiscus catinus* Höglund, × 102
2a, b	*Reophax atlantica* (Cushman), × 50
3a, b	*Reophax fusiformis* (Williamson), × 81
4, 5	*Reophax scorpiurus* Montfort, × 23 (fig. 4); × 16 (fig. 5)
6a, b, c	*Haplophragmoides canariensis* (d'Orbigny), × 68
7a, b	*Ammobaculites dilatatus* Cushman and Bronnimann, × 44
8	*Placopsilina confusa* Cushman, × 19
9a, b, c	*Spiroplectammina floridana* (Cushman), × 45
10a, b	*Textularia candeiana* d'Orbigny, × 47
11a, b	*Textularia conica* d'Orbigny, × 83
12a, b	*Textularia truncata* Höglund, × 47
13a, b	*Textularia pseudotrochus* Cushman, × 33
14a, b	*Siphotextularia curta* (Cushman), × 90
15a, b	*Siphotextularia rolshauseni* Phleger and Parker, × 52
16a, b, c	*Trochammina advena* Cushman, × 117
17a, b, c	*Trochammina squamata* Jones and Parker, × 117
18a, b, c	*Trochamminula lobata* (Cushman), × 80
19a, b	*Eggerella advena* (Cushman), × 123
20a, b	*Textulariella barrettii* (Jones and Parker), × 14


PLATE I
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17a
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19b
20b
20a

PLATE 1

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PLATE 2

Figures

1a, b	*Cyclogyra planorbis* (Schultze), × 99
2a, b, c	*Cyclogyra selseyensis* (Heron-Allen and Earland), × 65
3a, b, c	*Fischerinella dubia* (d'Orbigny), × 90
4, 5	*Calcituba decorata* (Heron-Allen and Earland), × 96 (fig. 4); × 31 (fig. 5)
6	*Cornuloculina inconstans* (Brady), × 67
7a, b, c	*Edentostomina cultrata* (Brady), × 52
8a, b	*Nodobaculariella atlantica* Cushman and Hanzawa, × 79
9a, b, c	*Wiesnerella auriculata* (Egger), × 96
10a, b	*Spiroloculina atlantica* Cushman, × 51
11a, b	*Spiroloculina depressa* d'Orbigny, × 70
12a, b, c	*Quinqueloculina bicostata* d'Orbigny, × 40
13a, b, c	*Quinqueloculina bosciana* d'Orbigny, × 58
14a, b, c	*Quinqueloculina compta* Cushman, × 50
15a, b, c	*Quinqueloculina jugosa* Cushman, × 54
16a, b, c	*Quinqueloculina lamarckiana* d'Orbigny, × 85
17a, b, c	*Quinqueloculina poeyana* d'Orbigny, × 108
18a, b, c	*Quinqueloculina polygona* d'Orbigny, × 48

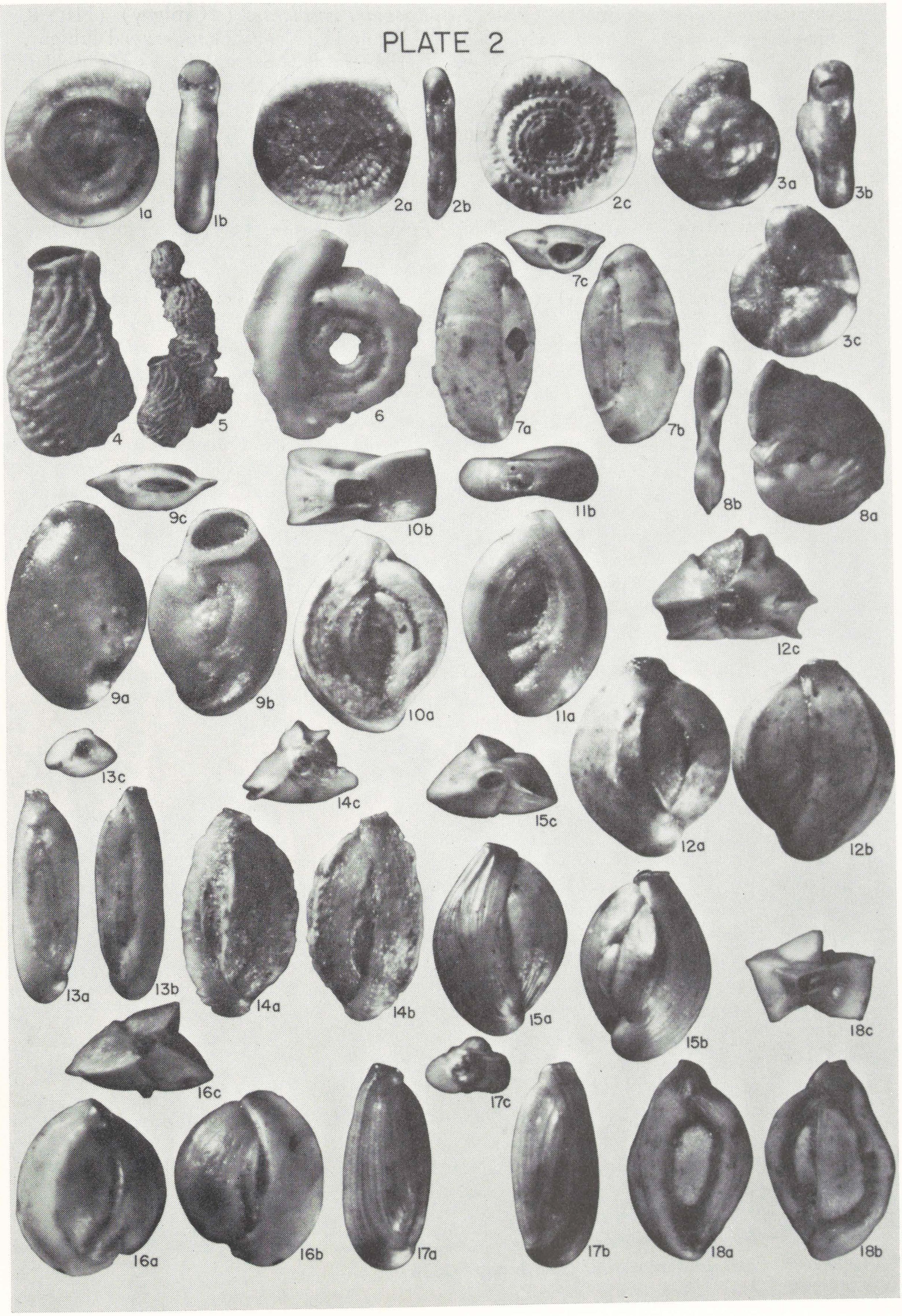
PLATE 2
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PLATE 2

Edentostomina cultrata (Brady) (Plate 2, Figure 7); *Miliolina cultrata* Brady, 1884, Rept. Voy. *Challenger,* Zool., vol. 9, p. 161, pl. 5, figs. 1, 2.

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Elphidium advenum (Cushman) (Plate 7, Figure 2); *Polystomella advena* Cushman, 1922, Carnegie Inst. Washington, Publ. 311, p. 56, pl. 9, figs. 11, 12.

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PLATE 3

Figures	
1a, b, c	*Quinqueloculina seminula* (Linné), × 94
2a, b	*Pyrgo denticulata* (Brady), × 45
3a, b	*Pyrgo oblonga* (d'Orbigny), × 77
4a, b	*Pyrgo serrata* (Bailey), × 49
5a, b	*Pyrgo subsphaerica* (d'Orbigny), × 84
6a, b	*Sigmoilina antillarum* (d'Orbigny), × 68
7a, b	*Sigmoilina tenuis* (Czjzek), × 91
8a, b, c	*Siphonaptera horrida* (Cushman), × 45
9a, b, c	*Siphonaptera sabulosa* (Cushman), × 79
10a, b	*Triloculina tricarinata* d'Orbigny, × 75
11a, b	*Triloculina trigonula* (Lamarck), × 52
12a, b	*Miliolinella circularis* (Bornemann), × 60
13a, b	*Miliolinella fichteliana* (d'Orbigny), × 58
14a, b, c	*Scutuloris* sp., cf. *S. procera* (Göes), × 102
15a, b, c	*Articulina sagra* d'Orbigny, × 108
16	*Peneroplis discoideus* Flint, × 20
17a, b	*Peneroplis proteus* d'Orbigny, × 47
18a, b	*Nodosaria catesbyi* d'Orbigny, × 67
19a, b	*Astacolus crepidulus* (Fichtel and Moll), × 66
20a, b	*Dentalina communis* (d'Orbigny), × 21


PLATE 3
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PLATE 3

Fissurina stewartii (Wright) (Plate 4, Figure 16); *Lagena stewartii* Wright, 1911, Belfast Nat. Field Club, Proc. ser. 2, vol. 6, no. 2, p. 12, pl. 2, fig. 8.

Florilus atlanticus (Cushman) (Plate 10, Figure 8); *Nonionella atlantica* Cushman, 1947, Cushman Lab. Foram. Res., Contr., vol. 23, pt. 4, p. 90, pl. 20, figs. 4, 5.

Florilus auriculus (Heron-Allen & Earland) (Plate 10, Figure 9); *Nonionella auricula* Heron-Allen & Earland, 1930, Roy. Micr. Soc., Jour., vol. 50, p. 192, pl. 5, figs. 68–70.

Fursenkiona fusiformis (Williamson) (Plate 10, Figure 1); *Bulimina pupoides* d'Orbigny var. *fusiformis* Williamson, 1858, Rec. Foram. Gt. Britain, p. 63, pl. 5, figs. 129, 130.

Fursenkoina punctata (d'Orbigny) (Plate 10, Figure 2); *Virgulina punctata* d'Orbigny, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 139, vol. 8, pl. 1, figs. 35, 36.

Glabratella lauriei (Heron-Allen & Earland) (Plate 6, Figure 7); *Discorbina lauriei* Heron-Allen & Earland, 1924, Linn. Soc. London, Jour., Zool., vol. 35, p. 633, pl. 36, figs. 50–52, pl. 37, figs. 53–55.

Globigerina bulloides d'Orbigny (Plate 7, Figure 13); 1826, Ann. Sci. Nat., vol. 7, p. 277; mod. no. 76.

Globigerina dutertrei d'Orbigny (Plate 7, Figure 12); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 84, vol. 8, pl. 8, fig. 4.

Globigerina inflata d'Orbigny (Plate 7, Figure 14); 1839, *in* Barker-Webb & Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 134, pl. 2, figs. 7–9.

Globigerina pachyderma (Ehrenberg) (Plate 8, Figure 2); *Aristerospira pachyderma* Ehrenberg, 1861, Monats. k. preuss. Akad.

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PLATE 4

Figures	
1a, b	*Lagena acuticosta* Reuss, × 140
2a, b	*Lagena laevis* (Montagu), × 85
3a, b	*Lagena striata* (d'Orbigny), × 76
4	*Lagena tenuis* (Bornemann), × 64
5a, b	*Lenticulina orbicularis* (d'Orbigny), × 31
6a, b	*Marginulina advena* (Cushman), × 29
7a, b	*Marginulina bachei* Bailey, × 13.5
8a, b	*Marginulina villa* Cushman, × 61
9a, b	*Guttulina caribaea* d'Orbigny, × 85
10a, b	*Guttulina lactea* (Walker and Jacob), × 98
11a, b	*Guttulina pulchella* d'Orbigny, × 59
12a, b, c	*Webbinella concava* (Williamson), × 106
13a, b	*Oolina melo* d'Orbigny, × 116
14a, b	*Fissurina lacunata* (Burrows and Holland), × 124
15a, b	*Fissurina lucida* (Williamson), × 112
16a, b	*Fissurina stewartii* (Wright), × 182
17a, b	*Buliminella elegantissima* (d'Orbigny), × 121
18	*Sphaeroidina bulloides* d'Orbigny, × 147
19a, b	*Bolivina alata* (Seguenza), × 40
20a, b	*Bolivina albatrossi* Cushman, × 79
21a, b	*Bolivina subaenariensis mexicana* Cushman, × 56
22a, b	*Bolivina lowmani* Phleger and Parker, × 102
23a, b	*Bolivina pseudoplicata* Heron-Allen and Earland, × 92
24a, b	*Bolivina spathulata* (Williamson), × 85
25a, b	*Bolivina lanceolata* Parker, × 74
26a, b	*Rectobolivina advena* (Cushman), × 67

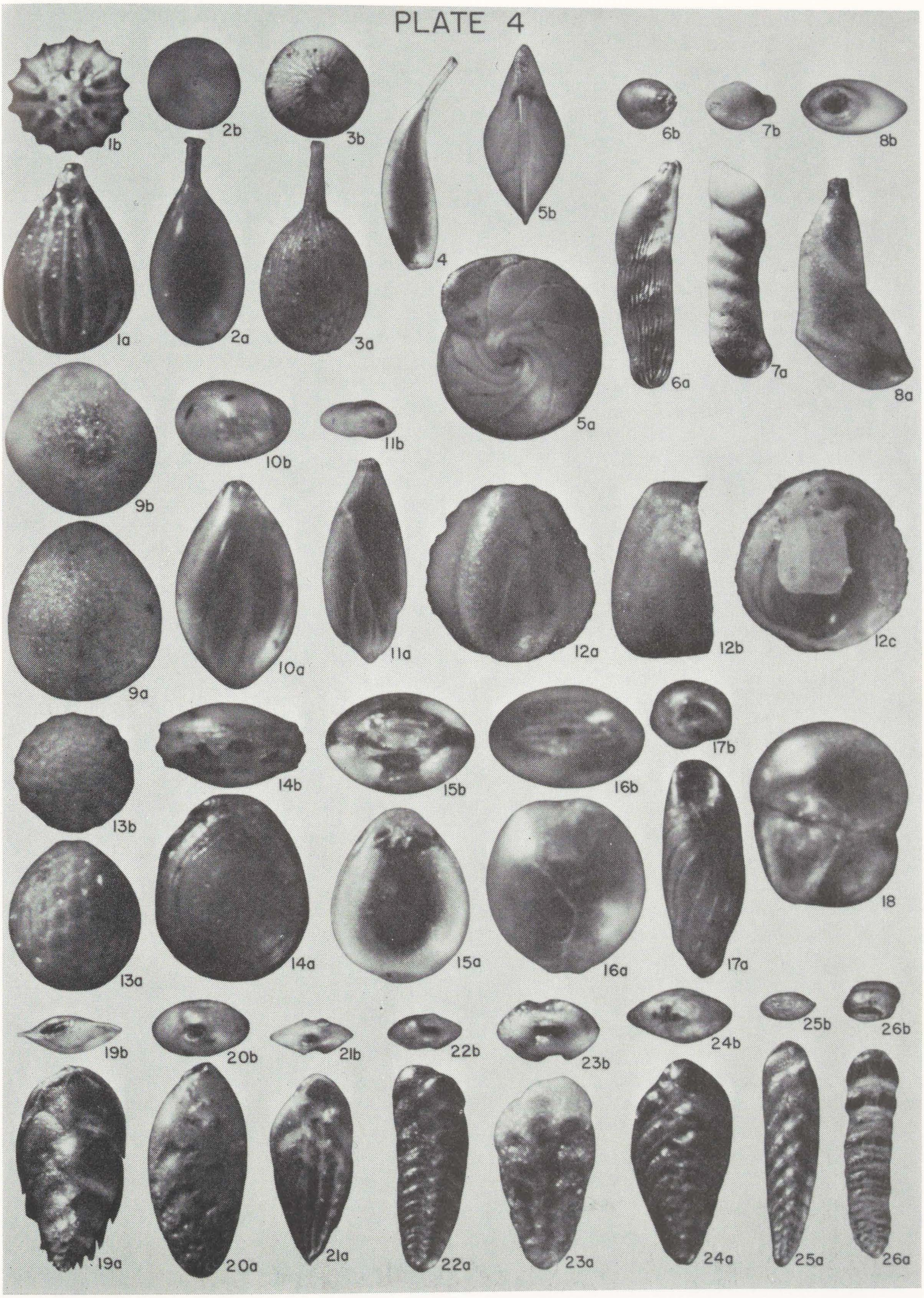
PLATE 4
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PLATE 4

Wiss., Berlin, pp. 276, 277, 303; 1872, (1873), Abhandl. k. Akad. Wiss., Berlin, pl. 1, fig. 4.

Globigerina quinqueloba Natland (Plate 8, Figure 1); 1938, Bull. Scripps Inst. Ocean., Techn. Ser., vol. 4, no. 5, p. 149, pl. 6, fig. 7.

Globigerinita glutinata (Egger) (Plate 8, Figure 8); *Globigerina glutinata* Egger, 1893, Abhandl. k. Akad. Wiss., München, Cl. 2, vol. 18, p. 371, pl. 13, figs. 19–21.

Globigerinoides conglobatus (Brady) (Plate 8, Figure 3); *Globigerina conglobata* Brady, 1884, Rept. Voy. *Challenger,* Zool., vol. 9, p. 603, pl. 80, fig. 5.

Globigerinoides ruber (d'Orbigny) (Plate 8, Figure 5); *Globigerina rubra* d'Orbigny, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 82, vol. 8, pl. 4, figs. 12–14.

Globigerinoides sacculifer (Brady) (Plate 8, Figure 4); *Globigerina sacculifera* Brady, 1877, Geol. Mag., vol. 4, p. 535; 1884, Rept. Voy. *Challenger,* Zool., vol. 9, p. 604, pl. 80, figs. 11–17; pl. 82, fig. 4.

Globigerinoides trilobus (Reuss) (Plate 8, Figure 7); *Globigerina triloba* Reuss, 1850, Denkschr. k. Akad. Wiss., Wien, vol. 1, p. 374, pl. 47, fig. 11.

Globobulimina auriculata (Bailey) (Plate 5, Figure 6); *Bulimina auriculata* Bailey, 1851, Smithsonian Contr., vol. 2, p. 12, pl., figs. 25–27.

Globorotalia hirsuta (d'Orbigny) (Plate 7, Figure 7); *Rotalina hirsuta* d'Orbigny, 1839, *in* Barker-Webb & Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 131, pl. 1, figs. 37–39.

Globorotalia menardii (d'Orbigny) (Plate 7, Figure 10); *Rotalia menardii* d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 273, mod. no. 10.

Globorotalia truncatulinoides (d'Orbigny) (Plate 7, Figure 11); *Rotalina truncatulinoides* d'Orbigny, 1839, *in* Barker-Webb & Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 132, pl. 2, figs. 25–27.

Guttulina caribaea d'Orbigny (Plate 4, Figure 9); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 135, vol. 8, pl. 2, figs. 7, 8.

Guttulina lactea (Walker & Jacob) (Plate 4, Figure 10); *Serpula lactea* Walker & Jacob, 1798, Adam's Essays, ed. 2, p. 634, pl. 24, fig. 4.

Guttulina pulchella d'Orbigny (Plate 4, Figure 11); 1839, *in* de la Sagra, Hist.

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PLATE 5

Figures

1a, b, c	*Islandiella subglobosa* (Brady), × 121
2a, b, c	*Cassidulinoides bradyi* (Norman), × 103
3a, b	*Stilostomella antillea* (Cushman), × 55
4a, b	*Bulimina aculeata* d'Orbigny, × 85
5a, b	*Bulimina marginata* d'Orbigny, × 104
6a, b	*Globobulimina auriculata* (Bailey), × 67
7a, b	*Stainforthia complanata* (Egger), × 77
8a, b	*Reussella atlantica* Cushman, × 94
9a, b	*Bulimina alazanensis* Cushman, × 121
10a, b	*Uvigerina auberiana* d'Orbigny, × 108
11a, b	*Uvigerina peregrina* Cushman, × 84
12a, b	*Sagrina pulchella* d'Orbigny, × 100
13a, b	*Trifarina angulosa* (Williamson), × 84
14a, b	*Trifarina bradyi* Cushman, × 81
15a, b, c	*Buccella hannai* (Phleger and Parker), × 102
16a, b, c	*Neoconorbina terquemi* (Rzehak), × 56
17a, b, c	*Discorbinella bertheloti* (d'Orbigny), × 58
18a, b, c	*Rosalina floridensis* (Cushman), × 101
19a, b, c	*Rosalina floridana* (Cushman), × 105


PLATE 5
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PLATE 5

Phys. Pol. Nat. Cuba, Foraminifères, p. 134, vol. 8, pl. 2, figs. 4–6.

Gyroidina orbicularis d'Orbigny (Plate 9, Figure 9); 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 278.

Hanzawaia concentrica (Cushman) (Plate 10, Figure 13); *Cibicides concentrica* Cushman, 1918, U.S. Geol. Survey, Bull. 676, p. 64, pl. 21, fig. 3; 1931.

Haplophragmoides canariensis (d'Orbigny) (Plate 1, Figure 6); *Nonionina canariensis* d'Orbigny, 1839, *in* Barker-Webb & Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 128, pl. 2, figs. 33, 34.

Hastigerina aequilateralis (Brady) (Plate 7, Figure 8); *Globigerina aequilateralis* Brady, 1884, Rept. Voy. *Challenger,* Zool. vol. 9, p. 605, pl. 80, figs. 18–21.

Hastigerina pelagica (d'Orbigny) (Plate 7, Figure 9); *Nonionina pelagica* d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 27, pl. 3, figs. 13, 14.

Höglundina elegans (d'Orbigny) (Plate 10, Figure 15); *Rotalia (Turbulina) elegans* d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 276.

Islandiella subglobosa (Brady) (Plate 5, Figure 1); *Cassidulina subglobosa* Brady, 1881, Quart. Jour. Micr. Sci., vol. 21, p. 60; Brady, 1884, Rept. Voy. *Challenger,* Zool., vol. 9, p. 430, pl. 54, figs. 17a–c.

Lagena acuticosta Reuss (Plate 4, Figure 1); 1861, Sitz. Akad. Wiss., Wien, vol. 44, pt. 1, p. 305, pl. 1, fig. 4.

Lagena laevis (Montagu) (Plate 4, Figure 2); *Vermiculum laeve* Montagu, 1803, Test. Brit. p. 524. *Lagena laevis* (Montagu). Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 12, pl. 1, figs. 1, 2.

Lagena striata (d'Orbigny) (Plate 4, Figure 3); *Oolina striata* d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, p. 21, pl. 5, fig. 12.

Lagena tenuis (Bornemann) (Plate 4, Figure 4); *Ovulina tenuis* Bornemann, 1855, Deutsche geol. Ges., Zeitschr., vol. 7, pt. 2, p. 317, pl. 12, fig. 3.

Lenticulina orbicularis (d'Orbigny) (Plate 4, Figure 5); *Robulina orbicularis* d'Orbigny, 1826, Tabl. Meth., p. 288, figs. 8, 9.

Marginulina advena (Cushman) (Plate 4, Figure 6); *Vaginulina advena* Cushman, 1923, U. S. Natl. Mus., Bull. 104, pt. 4, p. 134, pl. 39, figs. 1–4.

Marginulina bachei Bailey (Plate 4, Figure 7); 1851, Smithsonian Contr., vol. 2, p. 10, figs. 2–6.

Marginulina villa Cushman (Plate 4, Figure 8); 1947, Cushman Lab. Foram. Res., Contr., vol. 23, pt. 4, p. 89, pl. 19, figs. 7, 8.

Melonis pompilioides (Fichtel & Moll) (Plate 10, Figure 14); *Nautilus pompilioides* Fichtel & Moll, 1798, Test. Micr., p. 31, pl. 2, figs. a–c.

Miliolinella circularis (Bornemann) (Plate 3, Figure 12); *Triloculina circularis* Bornemann, 1855, Zeitschr. deutsch. geol. Ges., vol. 7, pt. 2, p. 349, pl. 19, fig. 4.

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PLATE 6

Figures

1a, b, c	*Rosalina globularis* d'Orbigny, × 103
2a, b, c	*Rosalina rugosa* d'Orbigny, × 58
3a, b, c	*Stetsonia minuta* Parker, × 89
4a, b, c	*Cymbaloporetta atlantica* (Cushman), × 100
5a, b, c	*Cancris sagra* (d'Orbigny), × 103
6a, b, c	*Valvulineria laevigata* Phleger and Parker, × 119
7a, b, c	*Glabratella lauriei* (Heron-Allen and Earland), × 165
8a, b, c	*Siphonina pulchra* Cushman, × 59
9a, b, c	*Asterigerina carinata* d'Orbigny, × 54
10a, b, c	*Asterigerinata pulchella* (Parker), × 110
11a, b, c	*Conicospirillina atlantica* Cushman, × 83
12a, b, c	*Patellina corrugata* Williamson, × 114


PLATE 6
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PLATE 6

Miliolinella fichteliana (d'Orbigny) (Plate 1, Figure 13); *Triloculina fichteliana* d'Orbigny, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 171, vol. 8, pl. 9, figs. 8–10.

Mississippina concentrica (Parker & Jones) (Plate 10, Figure 16); *Pulvinulina concentrica* Parker & Jones, *in* Brady, 1864, Trans. Linn. Soc. Zool., vol. 24, p. 470, pl. 48, fig. 14.

Neoconorbina terquemi (Rzehak) (Plate 5, Figure 16); *Discorbina terquemi* Rzehak, 1888, Geol. Reichsanst., Verh. Wien, no. 11, p. 228.

Nodobaculariella atlantica Cushman & Hanzawa (Plate 2, Figure 8); 1937, Cushman Lab. Foram. Res., Contr., vol. 13, pt. 2, p. 42, pl. 5, figs. 7, 8.

Nodosaria catesbyi d'Orbigny (Plate 3, Figure 18); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 16, vol. 8, pl. 1, figs. 8–10.

Nonion grateloupi (d'Orbigny) (Plate 10, Figure 6); *Nonionina grateloupi* d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 294; 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 46, vol. 8, pl. 6, figs. 6, 7.

Nonionella turgida (Williamson) (Plate 10, Figure 10); *Rotalina turgida* Williamson, 1958, Rec. Foram. Gt. Britain, p. 50, pl. 4, figs. 95–97.

Oolina melo d'Orbigny (Plate 4, Figure 13); 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 20, pl. 5, fig. 9.

Orbulina universa d'Orbigny (Plate 8, Figure 9); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 3, vol. 8, pl. 1, fig. 1.

Patellina corrugata Williamson (Plate 6, Figure 12); 1858, Rec. Foram. Gt. Britain, p. 46, pl. 3, figs. 86–89.

Peneroplis discoideus Flint (Plate 3, Figure 16); *Peneroplis pertusus* (Forskål) var. *discoideus* Flint, 1897, (1899), U. S. Natl. Mus., Rept., p. 304, pl. 49, figs. 1, 2.

Peneroplis proteus d'Orbigny (Plate 3, Figure 17); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 66, vol. 8, p. 8, figs. 4–7.

Placopsilina confusa Cushman (Plate 1, Figure 8); 1920, U. S. Natl. Mus., Bull. 104, p. 71, pl. 14, fig. 6.

Planorbulina mediterranensis d'Orbigny (Plate 9, Figure 11); 1826, Ann. Sci. Nat., vol. 7, p. 280, no. 2, pl. 14, figs. 1–3.

Planulina ariminensis d'Orbigny (Plate 9, Figure 4); 1826, Ann. Sci. Nat., vol. 7, p. 280, pl. 14, figs. 1–3.

Planulina exorna Phleger & Parker (Plate 9, Figure 6); 1951, Geol. Soc. America, Mem. 46, pt. 2, p. 32, pl. 18, figs. 5–8.

Planulina ornata (d'Orbigny) (Plate 9, Figure 5); *Truncatulina ornata* d'Orbigny, 1839, Voy. Amér. Mérid., vol. 5, pt. 5, Foraminifères, p. 40, pl. 6, figs. 7–9.

Pullenia quinqueloba (Reuss) (Plate 10, Figure 11); *Nonionina quinqueloba* Reuss, 1851, Zeitschr. deutsch. Geol. Ges., vol. 3, p. 71, pl. 5, fig. 1.

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PLATE 7

Figures	
1a, b, c	*Ammonia beccarii* (Linné), × 40
2a, b	*Elphidium advenum* (Cushman), × 70
3a, b	*Elphidium subarcticum* Cushman, × 60
4a, b	*Elphidium incertum* (Williamson), × 108
5a, b	*Elphidium clavatum* (Cushman), × 67
6a, b	*Elphidiella mexicanum* (Kornfeld), × 61
7a, b, c	*Globorotalia hirsuta* (d'Orbigny), × 98
8a, b	*Hastigerina aequilateralis* (Brady), × 40
9a, b	*Hastigerina pelagica* (d'Orbigny), × 70
10a, b, c	*Globorotalia menardii* (d'Orbigny), × 35
11a, b, c	*Globorotalia truncatulinoides* (d'Orbigny), × 50
12a, b, c	*Globigerina dutertrei* d'Orbigny, × 58
13a, b, c	*Globigerina bulloides* d'Orbigny, × 77
14a, b, c	*Globigerina inflata* d'Orbigny, × 54

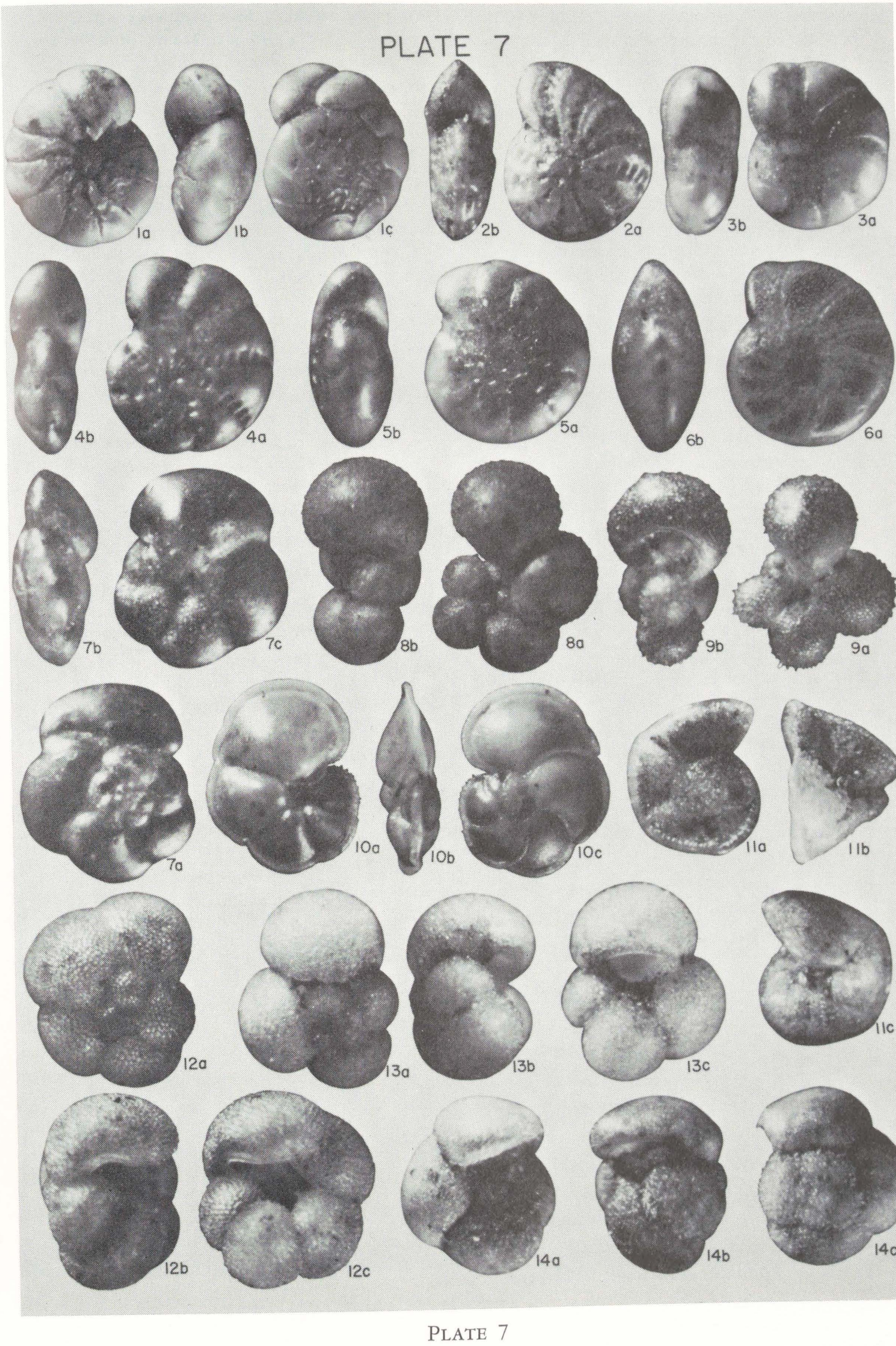
PLATE 7
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PLATE 7

Pulleniatina obliqueloculata (Parker & Jones) (Plate 8, Figure 6); *Pullenia sphaeroides* (d'Orbigny) var. *Obliqueloculata* Parker & Jones, 1865, Philos. Trans. Roy. Soc. London, vol. 155, pp. 365, 368, pl. 19, fig. 4.

Pyrgo denticulata (Brady) (Plate 3, Figure 2); *Biloculina ringens* (Lamarck) var. *denticulata* Brady, 1884, Rept. Voy. *Challenger*, Zool., vol. 9, p. 143, pl. 3, figs. 4, 5.

Pyrgo oblonga (d'Orbigny) (Plate 3, Figure 3); *Biloculina oblonga* d'Orbigny, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 163, vol. 8, pl. 8, figs. 21–23.

Pyrgo serrata (Bailey) (Plate 3, Figure 4); *Biloculina serrata* Bailey, 1861, Boston Jour. Nat. Hist., vol. 7, no. 3, p. 350, pl. 8, fig. E.

Pyrgo subsphaerica (d'Orbigny) (Plate 3, Figure 5); *Biloculina subsphaerica* d'Orbigny, 1839; *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 168, vol. 8, pl. 8, figs. 25–27.

Quinqueloculina bicostata d'Orbigny (Plate 2, Figure 12); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 195, v. 8, pl. 12, figs. 8–10.

Quinqueloculina bosciana d'Orbigny (Plate 2, Figure 13); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 191, v. 8, pl. 11, figs. 22–24.

Quinqueloculina compta Cushman (Plate 2, Figure 14); 1947, Cushman Lab. Foram. Res., Contr., vol. 23, pt. 4, p. 87, pl. 19, fig. 2.

Quinqueloculina jugosa Cushman (Plate 2, Figure 15); *Quinqueloculina seminulum* (Linné) var. *jugosa* Cushman, 1944, Cushman Lab. Foram. Res., Spec. Publ. 12, p. 13, pl. 2, fig. 15.

Quinqueloculina lamarckiana d'Orbigny (Plate 2, Figure 16); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 189, vol. 8, pl. 11, figs. 14, 15.

Quinqueloculina poeyana d'Orbigny (Plate 2, Figure 17); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 191, vol. 8, pl. 11, figs. 25–27.

Quinqueloculina polygona d'Orbigny (Plate 2, Figure 18); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 198, vol. 8, pl. 12, figs. 21–23.

Quinqueloculina seminula (Linné) (Plate 3, Figure 1); *Serpula seminulum* Linné, 1758, Syst. Nat., 10th ed., vol. 1, p. 786, pl. 2, fig. 1a–c.

Rectobolivina advena (Cushman) (Plate 4, Figure 26); *Siphogenerina advena* Cushman, 1922, Carnegie Inst. Washington, Publ. 311, p. 35, pl. 5, fig. 2.

Reophax atlantica (Cushman) (Plate 1, Figure 2); *Proteonina atlantica* Cushman, 1944, Cushman Lab. Foram. Res., Spec. Publ. 12, p. 5, pl. 1, fig. 4.

Reophax fusiformis (Williamson) (Plate 1, Figure 3); *Proteonina fusiformis* Williamson, 1858, Rec. Foram. Gt. Britain, p. 1, pl. 1, fig. 1.

Reophax scorpiurus Montfort (Plate 1, Figures 4, 5); 1808, Conch. Syst., vol. 1, p. 330.

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PLATE 8

Figures	
1a, b, c	*Globigerina quinqueloba* Natland, × 130
2a, b, c	*Globigerina pachyderma* (Ehrenberg), × 69
3a, b, c	*Globigerinoides conglobatus* (Brady), × 46
4a, b, c	*Globigerinoides sacculifer* (Brady), × 32
5a, b, c	*Globigerinoides ruber* (d'Orbigny), × 48
6a, b	*Pulleniatina obliqueloculata* (Parker and Jones), × 50
7a, b, c	*Globigerinoides trilobus* (Reuss), × 33
8a, b, c	*Globigerinita glutinata* (Egger), × 102
9	*Orbulina universa* d'Orbigny, × 53
10a, b	*Candeina nitida* d'Orbigny, × 60
11a, b, c	*Eponides antillarum* (d'Orbigny), × 58

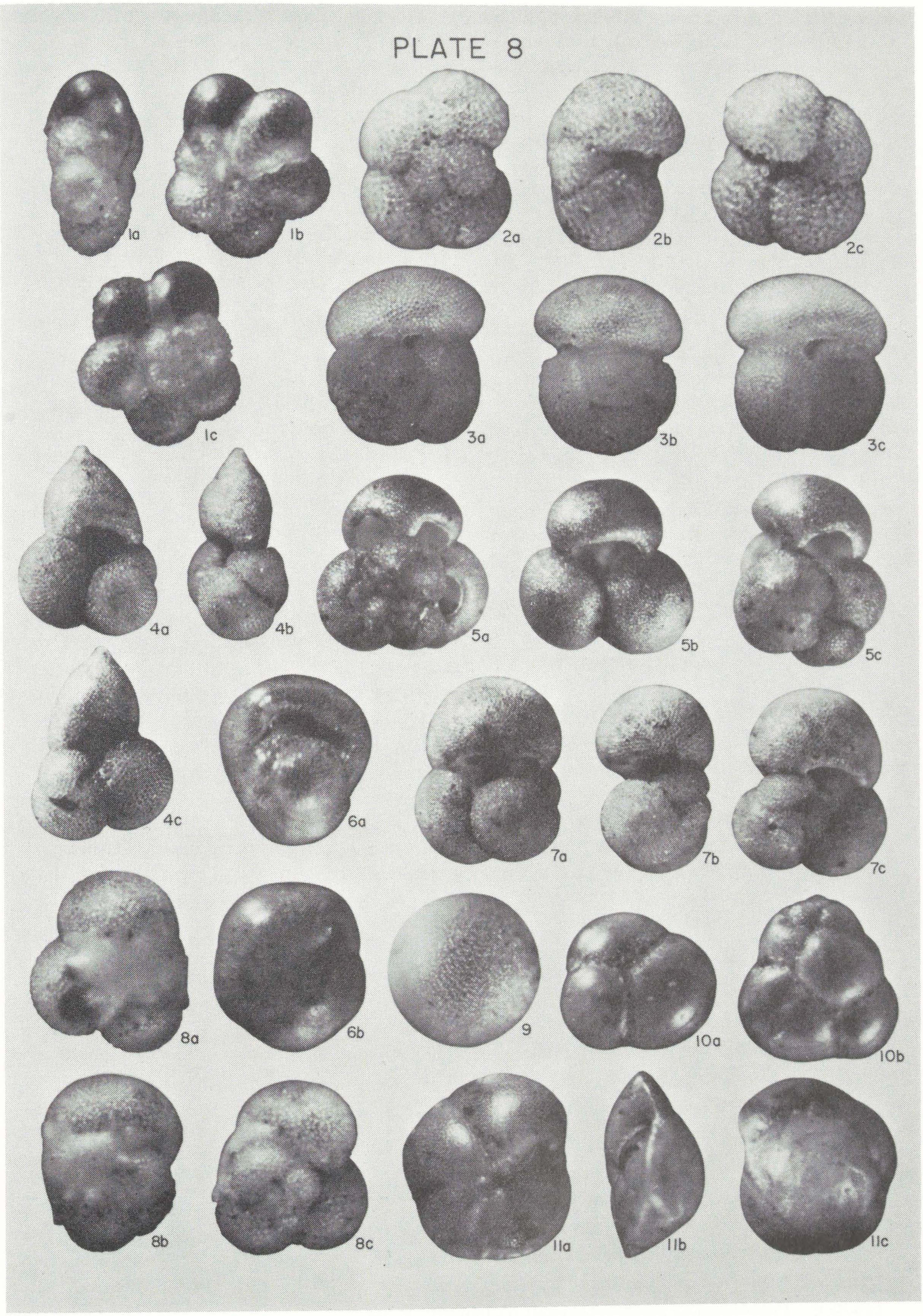
PLATE 8
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PLATE 8

Reussella atlantica Cushman (Plate 5, Figure 8); *Reussella spinulosa* (Reuss) var. *atlantica* Cushman, 1947, Cushman Lab. Foram. Res., Contr., vol. 23, pt. 4, p. 91, pl. 20, figs. 6, 7.

Robertinoides normani (Goës) (Plate 10, Figure 17); *Bulmina normani* Goës, 1894, K. Sv. Vet. Akad. Handl., vol. 25, no. 9, p. 47, pl. 9, figs. 437, 438.

Rosalina floridana (Cushman) (Plate 5, Figure 19); *Discorbis floridanus* Cushman, 1922, Carnegie Inst. Washington, Publ. 311, p. 39, pl. 5, figs. 11, 12.

Rosalina floridensis (Cushman) (Plate 5, Figure 18); *Discorbis floridensis* Cushman, 1931, U. S. Natl. Mus., Bull. 104, pt. 8, p. 17, pl. 3, figs. 3–5.

Rosalina globularis d'Orbigny (Plate 6, Figure 1); 1826, Ann. Sci. Nat., vol. 7, p. 271, pl. 13, figs. 1, 2.

Rosalina rugosa d'Orbigny (Plate 6, Figure 2); 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 42, pl. 2, figs. 12–14.

Sagrina pulchella d'Orbigny (Plate 5, Figure 12); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 150, pl. 1, figs. 23, 24.

Scutuloris sp., cf. *S. procera* (Goës) (Plate 3, Figure 14); *Miliolina procera* Goës, 1896, Harvard Mus. Comp. Zool., Bull. 29, p. 82, pl. 7, figs. 7–9.

Sigmoilina antillarum (d'Orbigny) (Plate 3, Figure 6); *Spiroloculina antillarum* d'Orbigny, 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 166, vol. 8, pl. 9, figs. 3, 4.

Sigmoilina tenuis (Czjzek) (Plate 3, Figure 7); *Quinqueloculina tenuis* Czjzek, 1848, Naturw. Abh., Wien, vol. 2, p. 149, pl. 13, figs. 31–34.

Siphonaptera horrida (Cushman) (Plate 3, Figure 8); *Quinqueloculina horrida* Cushman, 1947, Cushman Lab. Foram. Res., Contr., vol. 23, p. 88, pl. 19, fig. 1.

Siphonaptera sabulosa (Cushman) (Plate 3, Figure 9); *Quinqueloculina sabulosa* Cushman, 1947, Cushman Lab. Foram. Res., Contr., vol. 23, pt. 4, p. 87, pl. 18, fig. 22.

Siphonina pulchra Cushman (Plate 6, Figure 8); 1910, Carnegie Inst. Washington, Publ. 291, p. 42, pl. 14, fig. 7.

Siphotextularia curta (Cushman) (Plate 1, Figure 14); *Textularia flintii* Cushman var. *curta* Cushman, 1922, U. S. Natl. Mus., Bull. 104, pt. 3, p. 14, pl. 2, figs. 2, 3.

Siphotextularia rolshauseni Phleger & Parker (Plate 1, Figure 15); 1951, Geol. Soc. America, Mem. 46, pt. 2, p. 4, pl. 1, figs. 23, 24a, b.

Sphaeroidina bulloides d'Orbigny (Plate 4, Figure 18); 1826, Ann. Sci. Nat., vol. 7, p. 267.

Spiroloculina atlantica Cushman (Plate 2, Figure 10); 1947, Cushman Lab. Foram. Res., Contr., vol. 23, p. 88, pl. 19, figs. 3–5.

Spiroloculina depressa d'Orbigny (Plate 2, Figure 11); 1826, Ann. Sci. Nat., vol. 7, p. 298.

Spiroplectammina floridana (Cushman) (Plate 1, Figure 9); *Textularia floridana*

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PLATE 9

Figures

1a, b, c	*Eponides tumidulus* (Brady), × 144
2a, b, c	*Eponides repandus* (Fichtel and Moll), × 48
3a, b, c	*Amphistegina lessonii* d'Orbigny, × 36
4a, b, c	*Planulina ariminensis* d'Orbigny, × 71
5a, b, c	*Planulina ornata* (d'Orbigny), × 66
6a, b, c	*Planulina exorna* Phleger and Parker, × 53
7a, b, c	*Cibicides pseudoungerianus* (Cushman), × 58
8	*Dyocibicides biserialis* Cushman and Valentine, × 36
9a, b, c	*Gyroidina orbicularis* d'Orbigny, × 100
10a, b, c	*Caribeanella polystoma* Bermudez, × 95
11a, b, c	*Planorbulina mediterranensis* d'Orbigny, × 39

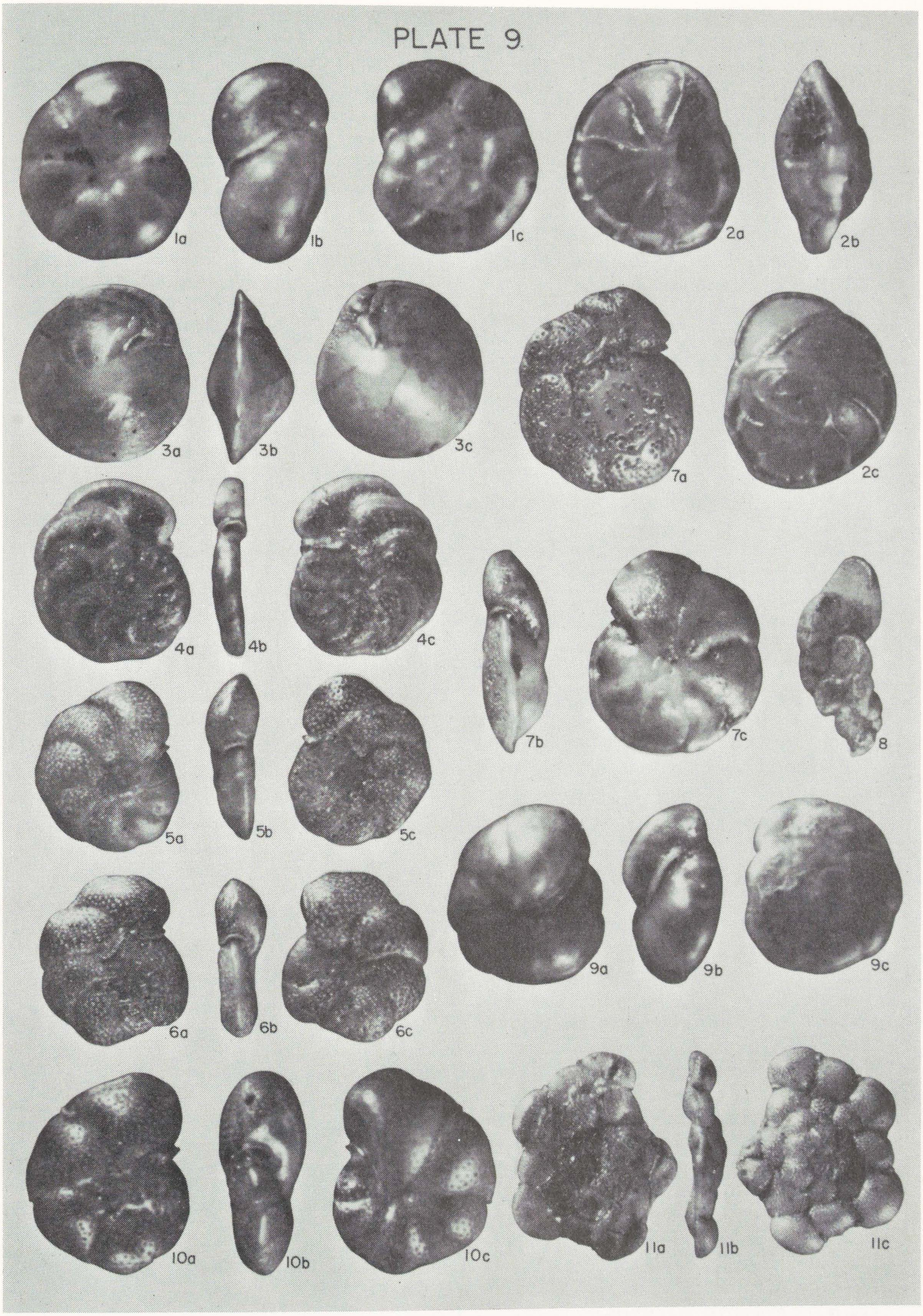
PLATE 9
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PLATE 9

Cushman, 1922, Carnegie Inst. Washington, Publ. 311, v. 17, p. 24, pl. 1, fig. 7.

Stainforthia complanata (Egger) (Plate 5, Figure 7); *Virgulina schreibersiana* Czjzek var. *complanata* Egger, 1893, Abhandl. k. bay. Akad. Wiss. München, vol. 18, pt. 2, p. 292, pl. 8, figs. 91, 92.

Stetsonia minuta Parker (Plate 6, Figure 3); 1954, Harvard Mus. Comp. Zool., Bull. 111, no. 10, p. 534, pl. 10, figs. 27–29.

Stilostomella antillea (Cushman) (Plate 5, Figure 3); *Nodosaria antillea* Cushman, 1923, U. S. Natl. Mus., Bull. 104, pt. 4, p. 91, pl. 14, fig. 9.

Textularia candeiana d'Orbigny (Plate 1, Figure 10); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 143, pl. 1, figs. 19, 20.

Textularia conica d'Orbigny (Plate 1, Figure 11); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 143, pl. 1, figs. 25–27.

Textularia pseudotrochus Cushman (Plate 1, Figure 13); 1922, U. S. Natl. Mus., Bull. 104, p. 21, pl. 5, figs. 1–3.

Textularia truncata Höglund (Plate 1, Figure 12); 1947, Zool. Bidrag Uppsala, Bd. 26, p. 175, pl. 12, figs. 8–9, p. 166, text figs. 147–149.

Textulariella barrettii (Jones & Parker) (Plate 1, Figure 20); *Textularia barrettii* Jones & Parker, 1876, Ann. Soc. Mal. Belg., vol. 11, p. 99, text fig.

Trifarina angulosa (Williamson) (Plate 5, Figure 13); *Uvigerina angulosa* Williamson, 1858, Rec. Foram. Gt. Britain, p. 67, pl. 5, fig. 140.

Trifarina bradyi Cushman (Plate 5, Figure 14); 1923, U. S. Natl. Mus., Bull. 104, pt. 4, p. 99, pl. 22, figs. 3–9.

Triloculina tricarinata d'Orbigny (Plate 3, Figure 10); 1826, Ann. Sci. Nat., vol. 7, p. 299.

Triloculina trigonula (Lamarck) (Plate 3, Figure 11); *Miliolites trigonula* Lamarck, 1804, Paris Mus. Natl. Hist. Nat., Ann., vol. 5, p. 351, vol. 9, pl. 17, fig. 4.

Trochammina advena Cushman (Plate 1, Figure 16); 1922, Carnegie Inst. Washington, Publ. 311, p. 20, pl. 1, figs. 2–4.

Trochammina squamata Jones & Parker (Plate 1, Figure 17); 1860, Quart. Jour. Geol. Soc., vol. 16, p. 304.

Trochamminula lobata (Cushman) (Plate 1, Figure 18); *Trochammina lobata* Cushman, 1944, Cushman Lab. Foram. Res., Spec. Publ. 12, p. 18, pl. 2, fig. 10.

Uvigerina auberiana d'Orbigny (Plate 5, Figure 10); 1839, *in* de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 106, pl. 2, figs. 23, 24.

Uvigerina peregrina Cushman (Plate 5, Figure 11); 1923, U. S. Natl. Mus., Bull. 104, pt. 4, p. 166, pl. 42, figs. 7–10.

Valvulineria laevigata Phleger & Parker (Plate 6, Figure 6); 1951, Geol. Soc.

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PLATE 10

Figures	
1a, b	*Fursenkoina fusiformis* (Williamson), × 107
2a, b	*Fursenkoina punctata* d'Orbigny, × 75
3a, b	*Chilostomella oolina* Schwager, × 78
4a, b	*Cassidulina neocarinata* Thalmann, × 98
5a, b	*Cassidulina laevigata* d'Orbigny, × 99
6a, b	*Nonion grateloupi* (d'Orbigny), × 92
7a, b	*Astrononion stellatum* Cushman and Edwards, × 83
8a, b, c	*Florilus atlanticus* (Cushman), × 55
9a, b, c	*Florilus auriculus* (Heron-Allen and Earland), × 94
10a, b, c	*Nonionella turgida* (Williamson), × 87
11a, b	*Pullenia quinqueloba* (Reuss), × 78
12a, b, c	*Cibicides bradyi* (Trauth), × 102
13a, b, c	*Hanzawaia concentrica* (Cushman), × 56
14a, b	*Melonis pompilioides* (Fichtel and Moll), × 76
15a, b, c	*Höglundina elegans* (d'Orbigny), × 60
16a, b, c	*Mississippina concentrica* (Parker and Jones), × 62
17a, b	*Robertinoides normani* (Goës), × 116

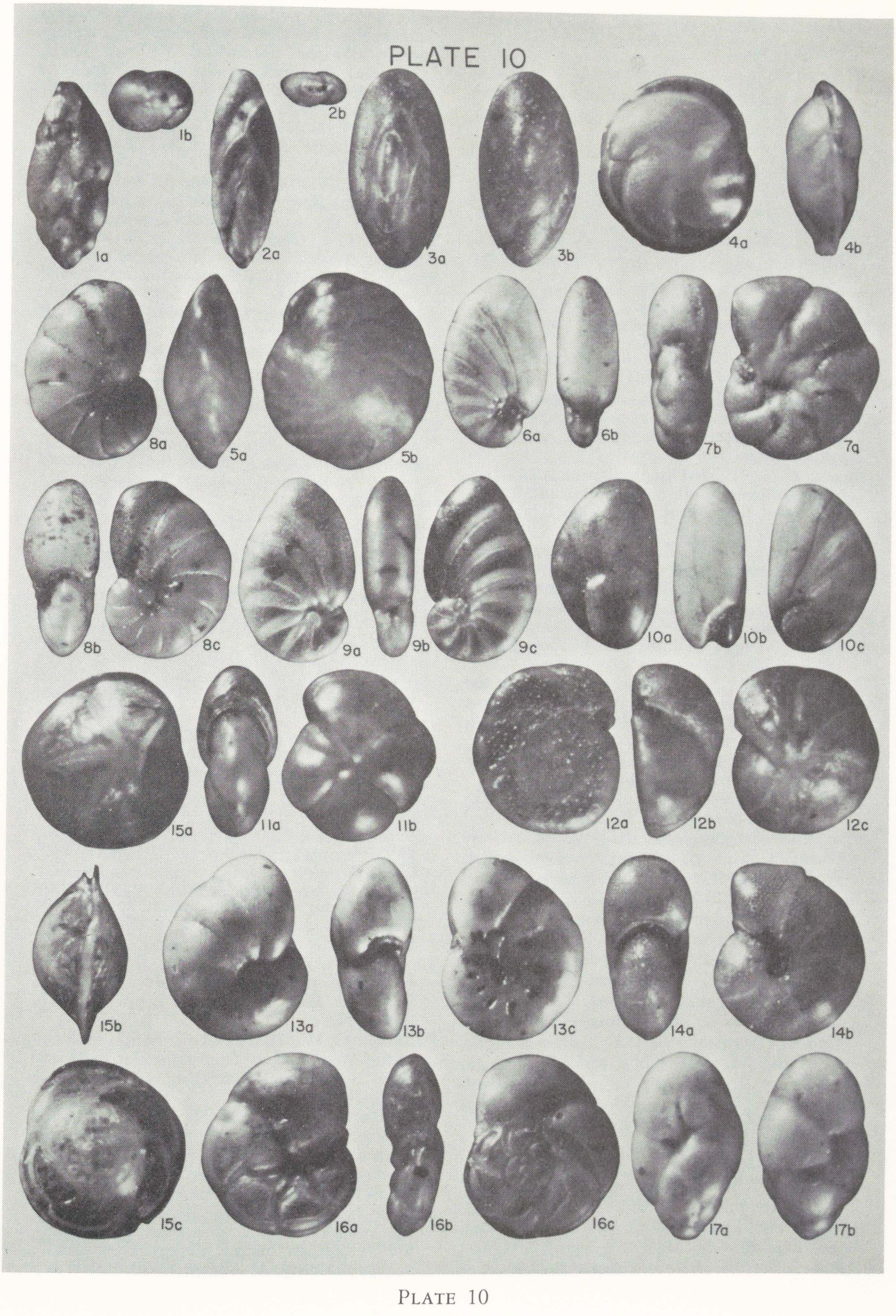
PLATE 10
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PLATE 10

America, Mem. 46, pt. 2, p. 25, pl. 13, figs. 11, 12.

Webbinella concava (Williamson) (Plate 4, Figure 12); *Polymorphina lactea* (Walker & Jakob) var. *concava* Williamson, 1858, Rec. Foram. Gt. Britain, p. 72, pl. 6, figs. 151, 152.

Wiesnerella auriculata (Egger) (Plate 2, Figure 9); *Planispirina auriculata* Egger, 1893, Abhandl. k. bay. Akad. Wiss., München, vol. 18, pt. 2, p. 245, pl. 3, figs. 13–15.

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