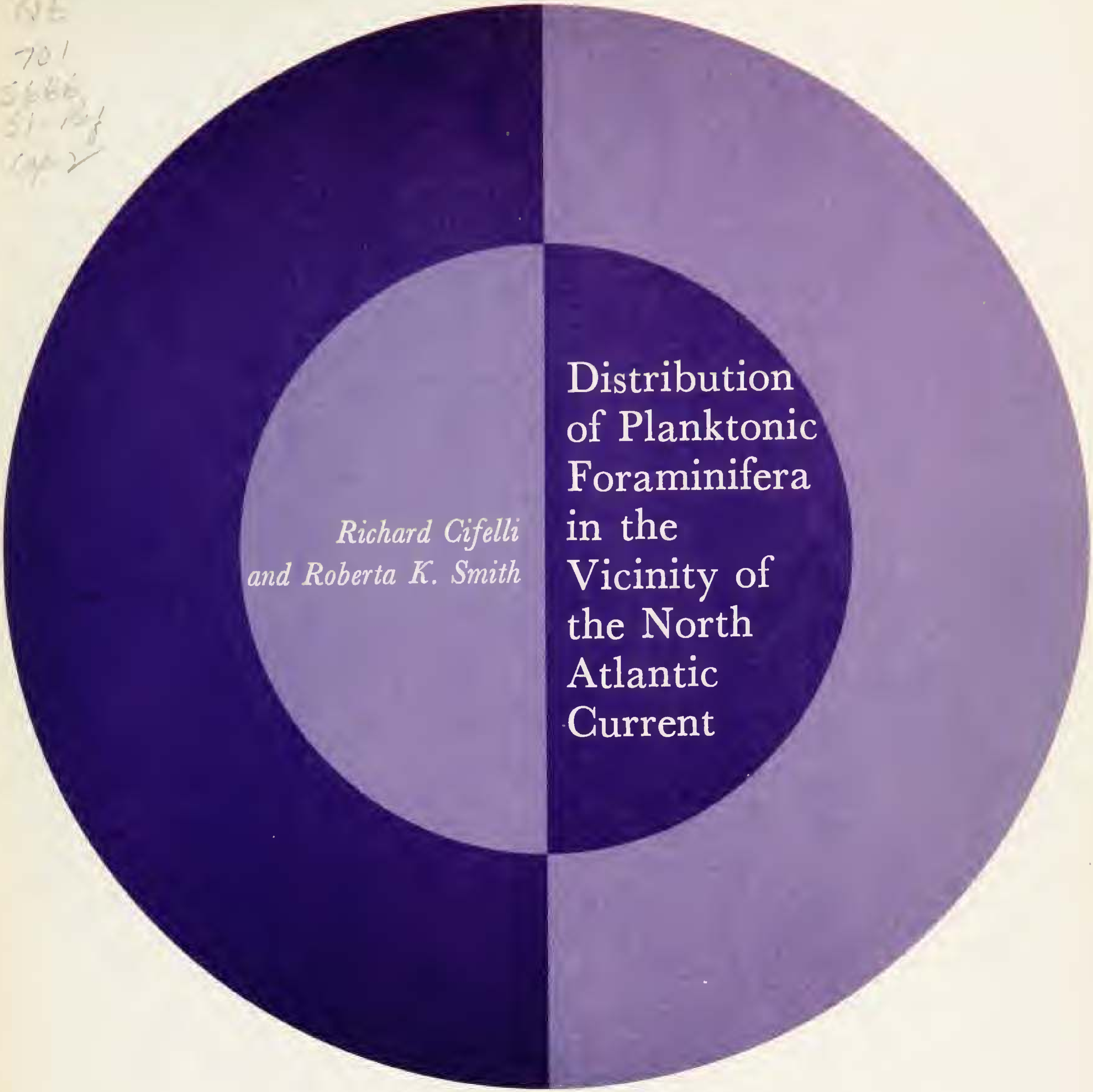

Richard Cifelli
and Roberta K. Smith

Distribution of Planktonic Foraminifera in the Vicinity of the North Atlantic Current

SMITHSONIAN CONTRIBUTIONS TO PALEOBIOLOGY • 1970 NUMBER 4

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ABSTRACT

Cifelli, Richard, and Roberta K. Smith. Distribution of Planktonic Foraminifera in the Vicinity of the North Atlantic Current. *Smithsonian Contributions to Paleobiology,* 4:1–52. 1970.—Planktonic Foraminifera collected from the vicinity of the North Atlantic Current and the Gulf Stream during late winter-early spring and fall of 1964 are described and their distributions are recorded. Variations in faunal composition seem to be related largely to water regime dynamics and seasonal cycle. Among the fall collections, three distinctive assemblages can be recognized: a western group in the vicinity of the Gulf Stream, containing predominantly Sargasso Sea-Gulf Stream species dominated by *Globigerinoides ruber;* a northern group, dominated by *Globigerina quinqueloba egelida,* new subspecies, reflecting the influence of cold, northern waters adjacent to the North Atlantic Current; and an eastern group, dominated by *Globigerina incompta,* apparently developed within the limits of the North Atlantic Current. The last group seemingly represents an anomaly, as North Atlantic Current surface temperatures were relatively high at the time of collection, and dominance of a warm-water form, such as *Globigerinoides ruber,* might have been expected. The anomaly suggests that the North Atlantic Current is a partially closed gyre, fed by both slope waters and Gulf Stream. Temperatures are considered to be close to threshold for both cold and warm-water species.

Distributional patterns displayed by the late winter-early spring collections are compatible with the proposed model. Also, these collections, taken over a period of almost three months, reflect marked seasonal changes in faunal composition, particularly in Sargasso Sea-Gulf Stream elements.

Twenty-five species and subspecies are described. One species, *Globigerina atlantisae,* and one subspecies, *Globigerina quinqueloba egelida,* are new.

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Contents

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Introduction

The North Atlantic Current is that part of the North Atlantic gyre formed south and east of the Grand Banks. Although the North Atlantic Current represents, in part at least, a northern continuation of the Gulf Stream, it manifests a distinct hydrographic setting. In this paper, planktonic Foraminifera from the vicinity of this current system are described and their distributions recorded. In addition, we have attempted to discern distributional patterns and explain them.

This study is based on plankton collections obtained from two cruises of the Woods Hole Oceanographic vessel R/V *Atlantis II* in 1964. The first cruise, *Atlantis II*–9, occupied plankton stations during winter–early spring between 1 February and 29 April in the region generally south and east of the Grand Banks. The second cruise, *Atlantis II*–13, occupied stations in the same general region in fall, between 2 and 21 September. In addition, stations were occupied during *Atlantis II*–13 west of the Grand Banks, along the Gulf Stream's mean path. Figures 1 and 2 show station locations from both cruises with respect to the major circulatory features of the North Atlantic.

As our studies of North Atlantic planktonic Foraminifera progress, we become increasingly impressed with the complex dynamics of the distribution of planktonic organisms. Owing to the environment's mobility, planktonic organisms are constant, involuntary travelers (if we may be permitted an anthropomorphic metaphor) that, during their lifetimes, may find themselves in places they do not care to be. Therefore, it is difficult to attach spatial limits to species distributions or to relate these directly to specific-physiochemical factors, such as temperature. Attempts have been made to do this (e.g., Bé, 1968; Boltovskoy, 1968), but these schemes, in our view, both oversimplify the realities of nature and fail to distinguish among spatial, temporal, and physiochemical aspects of the environment.

Information is still insufficient to attempt a general synthesis of planktonic foraminiferal distribution in the North Atlantic. Therefore, we have, in this study, limited our interpretations to particular distributional situations. Because the two cruises offer distinctly different distributional data, we describe *Atlantis II*–9 and *Atlantis II*–13 separately. We develop our distributional concepts along with the descriptions.

Acknowledgments

The plankton samples described were collected on cruises 9 and 13 of R/V *Atlantis II* of the Woods Hole Oceanographic Institution; it is a pleasure to thank the scientific parties, officers, and crews during these cruises for their assistance. Financial support of the work at sea was variously by the Office of Naval Research (contract Nonr–2196(00)), the Atomic Energy Commission (contract AT(30–1)–2174), and the National Science Foundation (grant GP 861) at the Woods Hole Oceanographic Institution; processing and distribution of the samples were supported by

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A.E.C. under the contract named. We thank each of these agencies for its consideration.

V. T. Bowen of the Woods Hole Oceanographic Institution has read the manuscript, as have F. L. Parker and W. Berger of the Scripps Institution of Oceanography; we thank them. Rudolpf S. Sheltema of the Woods Hole Oceanographic Institution provided useful information on circulation patterns of the North Atlantic and distributional patterns of pelagic larvae. Brenda Williams assisted in preparation of samples. Marsha Jessup drew the plates of Foraminifera and L. B. Isham prepared the figures. To these and those other people who have given assistance, we are most grateful.

This is contribution number 2370 of the Woods Hole Oceanographic Institution.

Methodology

Samples mainly were obtained in oblique tows from between 200 and 300 meters with a number 10 plankton net (0.158 mm aperture) having a ¾-meter openmouth diameter. The ship's towing speed was between one and two knots. A few samples were obtained from between zero and 5 meters depth while the ship drifted on station. Figure 4 shows location, time, and depth of collections. Samples were preserved in 5 percent formalin, buffered with hexamethylenamine.

After arrival at the laboratory, samples were prepared and concentrated by the ignition method (Sachs, Cifelli, and Bowen, 1964; Sachs, 1965; Smith, 1967). Briefly, (1) formalin is washed out of samples, (2) samples are digested in sodium hypochlorite or hydrogen peroxide, (3) the digesting agent is washed out and the samples dried, (4) samples are ignited at 500°C in a muffle furnace for approximately 1 to 2 hours, (5) the ashy residue is washed out of ignited samples, and (6) dried samples are stored in pyrex petri dishes for subsequent study.

A random specimen count is needed, both to determine specimen number per given volume of sea water and to be sure a taxonomically and numerically representative sample is seen and/or picked. Therefore, we follow a standard procedure. First, if the prepared sample is so large that it overcrowds the picking dish—either making specimens more than one layer thick or so dense that it is difficult to count specimens in a given area of the dish—we split the sample to an appropriate size with a microsplitter.

We use a rectangular metal picking dish with a grid of 100 divisions (Smith, 1967). If the sample contains less than 500 specimens, all are examined, counted, picked, and identified. If more are present, we select a random sample by using a table of random numbers to indicate the particular numbered rectangles in the picking dish in which specimens are to be counted. Thus, by obtaining a continuing mean as specimens from different randomly selected rectangles are counted, examination of 10 to 20 rectangles usually suffices to determine the total specimen number in the sample or per given volume of sea water. We usually pick and identify between 300 and 400 specimens (every specimen in the randomly designated rectangles). Occasionally, it is necessary to pick more. Care should be exercised to spread the sample as evenly as possible in the picking dish so as to reduce the number of rectangles necessary for consideration to reach a nearly constant mean.

Subsequent to picking, all specimens are arranged according to species in an assemblage slide. Numbers of individuals of each species or taxon are then counted. From these numbers, absolute and relative abundances are calculated by comparing with the total number in the slide and sample.

Hydrography

In Figures 1 and 2 the *Atlantis II*–13 and –9 stations are plotted on Sheltema's (1968, unpublished data, W.H.O.I.) North Atlantic circulation scheme. This compilation appears a reasonable compromise of previously proposed circulatory systems (Stommel, 1958; Worthington, 1962; Mann, 1967). It shows North Atlantic circulation as essentially a single, clockwise, asymmetrical gyre, with the Gulf Stream swinging southeast at about longitude 50° W and the North Atlantic Current forming a more or less separate eddy of restricted dimensions.

Stommel (1965) gives a thorough account of the western North Atlantic hydrography, particularly regarding boundary conditions. The principal circulatory feature is the Gulf Stream, which originates in the Straits of Florida and flows clockwise and northeasterly between the Sargasso Sea east and south, and the slope waters west and north. It does not move in a straight course, but flows in meanders which sometimes develop into detached eddies, and the position varies appreciably throughout the year. The Gulf

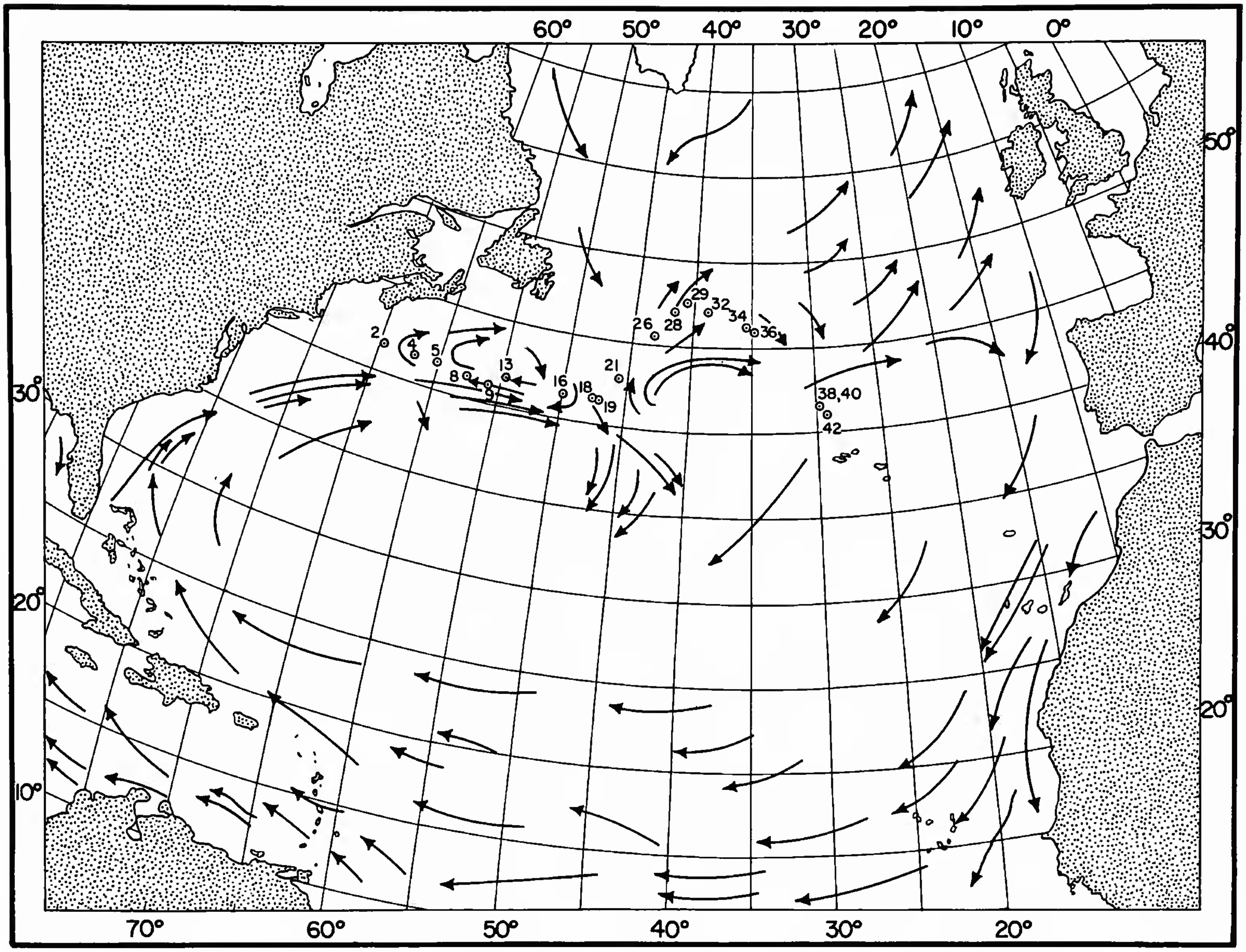


FIGURE 1.—*Atlantis II*–13 stations plotted with respect to surface circulation (after Scheltema, unpublished data, Woods Hole Oceanographic Institution).

Stream, therefore, is a dynamic but effective boundary between the distinctive cold slope waters and warm Sargasso Sea. It shows a strong temperature gradient at the surface and in subsurface. Stommel (1958, p. 173) states, "The Gulf Stream is not a river of hot water flowing through the ocean, but a narrow ribbon of high-velocity water acting as a boundary that prevents the warm water on the Sargasso Sea (right-hand) side from overflowing the colder, denser waters on the inshore (left-hand) side." The concept of the Gulf Stream as a boundary rather than a river of water has important bearing on interpretation of distribution of planktonic organisms in the North Atlantic.

The Gulf Stream can be traced about as far as longitude 50°W where it passes southeast of the Grand Banks. From there on the continuation appears to consist of several distinct currents, but the nature of these currents still is obscure. Apparently, the Gulf Stream splits into two main branches (Sverdrup, Johnson, and Fleming, 1942, fig. 187; Stommel, 1965). The stronger branch is diverted north as the North Atlantic Current. The southern branch moves diffusedly clockwise southeast and blends with the Canaries Current east of the Azores. According to this view, the North Atlantic comprises a single gyre with no sharp eastern boundary of the Sargasso Sea.

Worthington (1962) proposes a different scheme for eastern North Atlantic circulation, whereby the Gulf Stream turns entirely southeast after passing the Grand Banks, completing a western Atlantic gyre. Northeast of this gyre is another, separated from the first by a low pressure trough over the southeastern

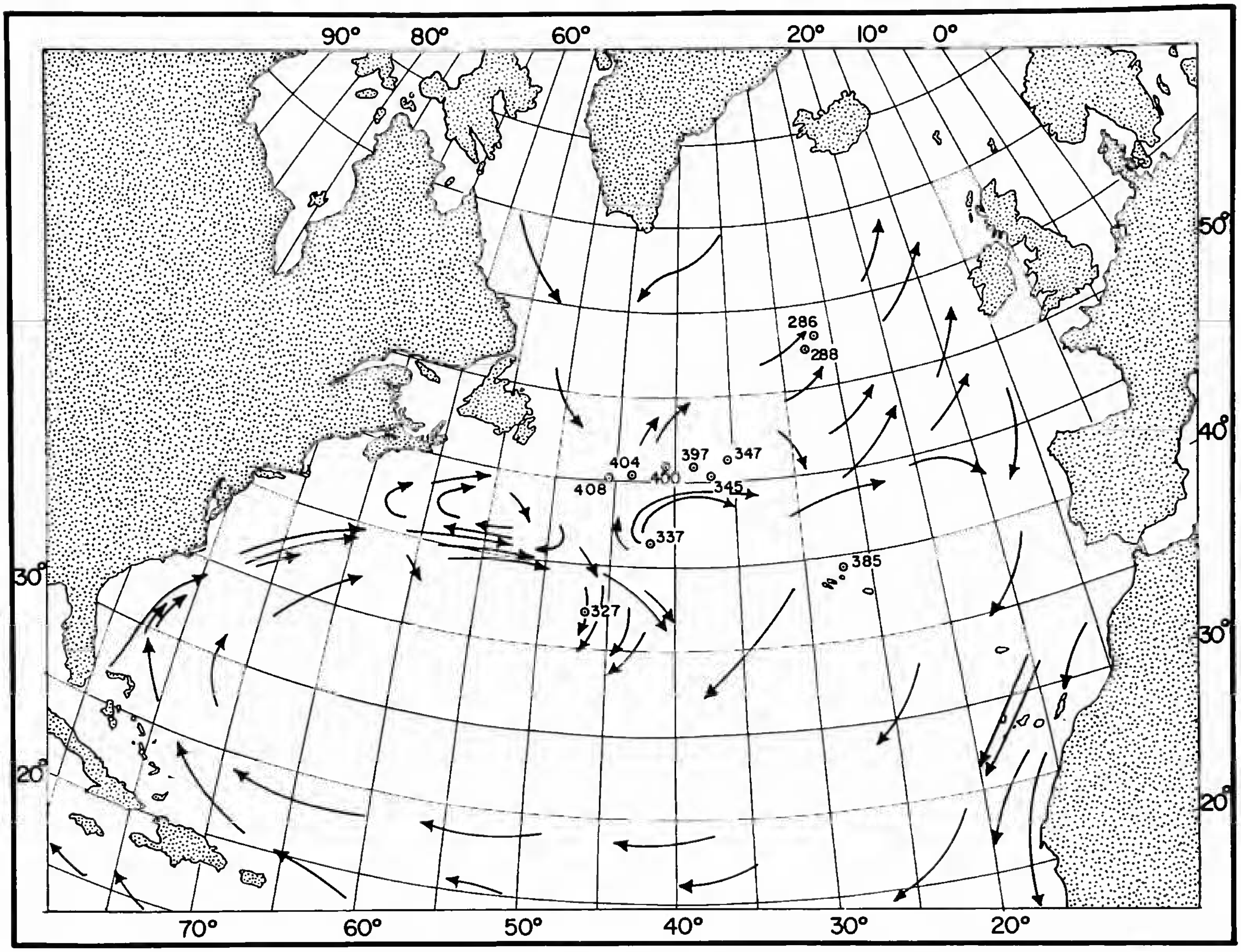


FIGURE 2.—*Atlantis II*–9 stations plotted with respect to surface circulation (after Scheltema, unpublished data, Woods Hole Oceanographic Institution).

Newfoundland Ridge. This trough is considered permanent, so that two separate gyres maintaining two more-or-less distinct water regimes compose North Atlantic circulation.

Mann (1967) proposes a scheme that, in some ways, is a compromise of the previous ones. Accordingly, the Gulf Stream does swing south at about latitude 50°W, as suggested by Worthington. Mann, however, rejects the North Atlantic Current as part of a separate gyre. He proposes, instead, that both slope water and a northern branch of the Gulf Stream, flowing north and east, feed the North Atlantic Current. It is true, however, that Gulf Stream and northern-water sources of the North Atlantic Current are still poorly known.

Mann also suggests that the Gulf Stream swings sharply south at about latitude 35°N and longitude 40°W. Unfortunately, Mann's data do not extend east of longitude 40°W, and thus do not pertain to the eastern *Atlantis II*–13 and –9 stations. His scheme, however, does suggest that the North Atlantic Current forms a partially closed eddy northeast of the main gyre. As both Gulf Stream and slope waters feed the eddy, a water regime results with planktonic populations displaying unique dynamic relationships, as discussed later.

The North Atlantic Current forms a devious path of the North Atlantic gyre that eventually blends with the Canaries Current to the east and the Sargasso Sea to the south, at about latitude 35°N. Therefore, the essential continuity of North Atlantic circulation as a single clockwise gyre is maintained, and the North Atlantic Current behaves as an extension of the Gulf

Stream as a transport medium. The continuity of Gulf Stream–North Atlantic Current circulation is evidenced by drift bottles released from eastern North America and recovered in the Azores and the transoceanic occurrences of numerous pelagic larvae of tropical shallow-water benthonic invertebrates (Sheltema, personal communication). Many pelagic larvae have been recovered along the general course of the North Atlantic Current. At the same time, however, the North Atlantic Current is distinct from the Gulf Stream. A significant feature of the Gulf Stream is that it borders the Sargasso Sea. No part of the North Atlantic Current eddy is comparable to the Sargasso Sea as the 18° water, a distinctive feature of the Sargasso Sea (Worthington, 1959) is lacking there (Sverdrup, Johnson, and Fleming, 1942, fig. 186).

Distributional Data

Before summarizing the *Atlantis II*–13 and –9 data and the distributional patterns implied by them, we will review some previous North Atlantic distributional data. While these data are few and mostly limited to the Western North Atlantic, they serve as a useful framework for interpreting the *Atlantis II*–13 and –9 faunas.

A study of four seasonal traverses across the Gulf Stream (Cifelli, 1962) strongly suggests that the western North Atlantic could be viewed as containing two distinct endemic faunas. One consists essentially of *Globigerina* species and is found in the slope waters north of the Gulf Stream. The other consists of a diverse group of species belonging to several genera, but with numerically few representatives of *Globigerina*. This fauna occurs in the Sargasso Sea and Gulf Stream. The Gulf Stream also must contain elements carried from the Caribbean Sea, but thus far distinctly diagnostic Caribbean elements have not been recognized. The Gulf Stream fauna conforms with the concept that the Gulf Stream forms the western border of the Sargasso Sea (Stommel, 1965).

In slope waters adjacent to the Gulf Stream, *Globigerina* species are found with Sargasso Sea and Gulf Stream species. This is the boundary fauna and generally, the frequency of *Globigerina* species increases with distance north of the Gulf Stream's mean path. The boundary between the Gulf Stream and slope waters, however, cannot be defined rigidly because its extent and position vary considerably throughout the year. Seasonal faunal boundary variations most likely result from changes in position and extent of the Gulf Stream.

According to the concept of two endemic western North Atlantic faunas, assemblages in the slope-water boundary are regarded as faunal mixtures rather than faunal transitions. Although the two western North Atlantic faunas appear to maintain their identity throughout the year, significant seasonal variations in species frequency-relationships occur (Bé, 1960b; Cifelli, 1962, 1965). Although these variations are not fully understood, particularly those occurring north of the Gulf Stream, some known aspects bear on the interpretation of the *Atlantis II* traverses.

In the Sargasso Sea–Gulf Stream fauna, a spectacular change in species dominance occurs between summer and winter. In summer and fall, *Globigerinoides ruber* is dominant, but after the fall turnover it strongly declines, along with other *Globigerinoides* species. In winter, *G. ruber* appears mostly in negligible percentages, while *Globorotalia truncatulinoides* is dominant. During late winter, *G. truncatulinoides* declines and *G. hirsuta* achieves dominance. In spring, *Globigerinoides ruber* again becomes dominant, but *Globigerinella aequilateralis* also occurs in high frequencies.

The extent of slope-water fauna seasonal change is much less clear than in the Sargasso Sea–Gulf Stream fauna. Partly, the obscurity results from the slope-water fauna's greater degree of local lateral variation, which, in turn, may result from the slope-water environment's greater variability than the Sargasso Sea. Yet, past work (Cifelli, 1965, pp. 5–8) reveals some spatial and temporal frequency changes of *Globigerina* species which might help explain some *Atlantis II*–13 and –9 frequency relationships.

In previous traverses across western slope waters, maximum concentrations of *Globigerina inflata* were found during fall in inner slope waters, relatively close to the Gulf Stream (Cifelli, 1965, p. 6). Bé and Hamlin (1967, p. 102) also found *G. inflata* in high concentrations during summer in inner slope waters and considered it an indicator of "transitional waters." They also found it considerably less common in the eastern Atlantic in summer.

Globigerina quinqueloba egelida, new subspecies, exhibited peak development in western slope waters during winter (Cifelli, 1965, p. 7) and was relatively scarce during summer. Bé and Hamlin (1967) found *G. quinqueloba egelida* maxima during summer in the subarctic region. *G. incompta* has exhibited maxima in western slope waters during summer and fall, with frequencies being generally higher farther north of the Gulf Stream than those of *G. inflata.*

From the above data it is clear that the slope-water and Sargasso Sea–Gulf Stream faunas each undergo significant changes in species frequencies during the year. In comparing faunas, one should take into account these seasonal changes.

The *Atlantis II*–13 and –9 collections were made when North Atlantic waters were, respectively, warmest and coldest. These collections provide some information on seasonal faunal changes in the vicinity of the North Atlantic Current which is needed for meaningful comparison of this part of the North Atlantic water regime with that farther west. Because of the marked difference in seasonal setting of the *Atlantis II*–13 and –9 cruises, they will be treated separately in the sections that follow. The check list (Figure 4) gives data on the occurrence and numerical abundance of all species from both cruises.

Atlantis II–13 Distributional Patterns

The *Atlantis II*–13 traverse covers much of the breadth of the North Atlantic, transecting a region of complex circulation. Changes in faunal associations are complex and difficult of interpretation because of the complexities of the planktonic environment and circulation in the region of the traverse; however, the tendency toward mutual exclusivity of *Globigerinoides ruber, Globigerina incompta,* and *G. quinqueloba egelida,* new subspecies, reveals some pattern. Figure 5 shows this, where the frequency of each is shown as a percent of the total of the three, not the total foraminiferal populations. Three more-or-less distinct populations are suggested, with only stations 4 and 29 appearing transitional. Moreover, these station groupings by frequency are spatially compatible (Figure 1). Therefore, stations are grouped spatially and evaluated in light of the three distributional patterns suggested by the frequency relationships. As the stations were occupied in September, the summer (Cifelli, 1965; Bé and Hamlin, 1967) and fall (Cifelli, 1965) seasonal data are used as references.

Numerical Abundances and Diversity

Numerical abundances vary from about 200 to 80,000 specimens per 1,000 cubic meters of sea water. Most values compare favorably with those found previously in western Atlantic slope waters (Cifelli and Sachs, 1966). The western part of the traverse (stations 2, 4, 5, 8), however, shows counts less than 6,000 per 1,000 cubic meters, compared to previous counts

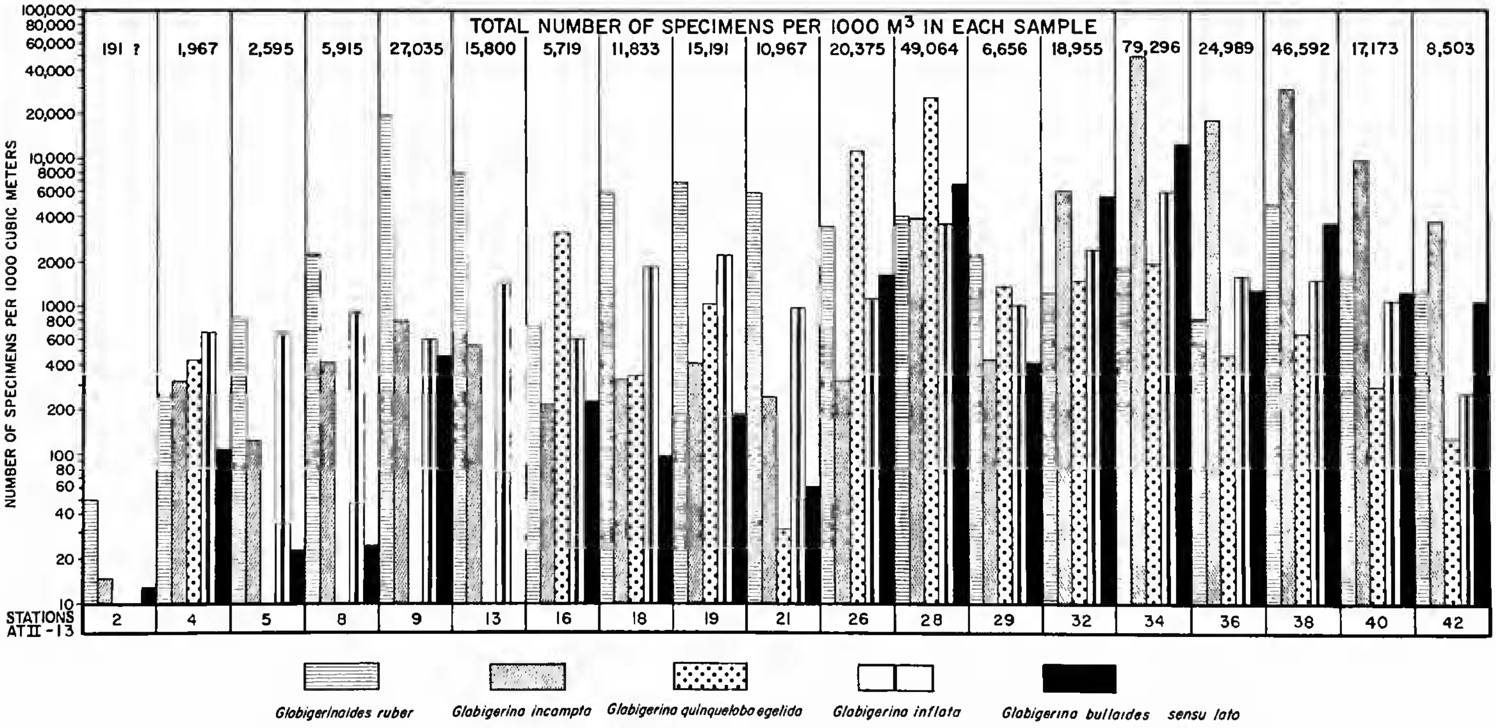


Figure 3.—Numerical abundance relationships among *Globigerinoides ruber, Globigerina incompta, G. quinqueloba egelida,* new subspecies, *G. inflata,* and *G. bulloides,* sensu lato from *Atlantis II*–13 stations.

LAT. N LONG. W	41°33' 64°37'	41°34' 62°00'	41°30' 60°13'	41°15' 57°30'	41°23' 55°52'	41°38' 54°44'	41°30' 50°00'	41°30' 47°30'	41°29' 47°04'	42°49' 45°52'	45°29' 43°06'	47°10' 41°42'	47°28' 40°46'	47°09' 38°50'	46°17' 35°32'	45°58' 34°53'	41°33' 29°43'	41°33' 29°43'	41°04' 29°12'	52°55' 26°45'	52°09' 27°51'	37°12' 46°45'	41°15' 42°00'	45°24' 36°58'	46°13' 35°33'	39°11' 27°23'	45°55' 38°22'	45°52' 41°00'	45°23' 43°39'	45°10' 45°39'
SPECIES STATIONS	2	4	5	8	9	13	16	18	19	21	26	28	29	32	34	36	38	40	← AII13 42	AII9 → 286	288	327	337	345	347	385	397	400	404	408
Globigerina atlantisae	0	0	1	1	0	<1	0	<1	<1	2	0	0	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	<1	0	0	0
G. bulloides bulloides			<1			0		<1			8	14	6		16		8	8	13							9				62
G. bulloides falconensis	7	5		<1	2	0	4		1	<1				29		5				2	6	18	54	64	53		24	16	3	
G. dutertrei	3	1	<1	4	6	3	2	1	3	3	1	<1	<1	<1	0	<1	<1	2	0	0	0	0	0	0	0	3	5	2	0	<1
G incompta	8	16	5	7	4	3	4	3	3	2	2	8	7	32	64	72	62	55	44	0	1	0	1	2	3	14	21	16	15	6
G. inflata	35	35	26	16	2	9	11	16	15	9	5	7	15	13	7	6	3	6	3	38	75	21	11	22	20	24	18	50	69	5
G. megastoma	0	0	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G. aff. *G. pachyderma*	<1	<1	5	2	<1	0	<1	2	<1	0	3	1	2	4	6	4	3	5	3	0	0	0	0	0	<1	0	0	0	0	0
G. quinqueloba egelida	3	22	<1	0	0	0	55	3	7	<1	55	53	21	8	2	2	1	2	2	5	0	0	0	0	1	6	20	2	<1	15
G. rubescens	<1	<1	<1	<1	<1	<1	<1	<1	0	<1	<1	<1	<1	<1	<1	<1	<1	0	<1	0	0	0	0	0	<1	0	0	0	0	0
Glabigerina sp(p).	0	0	0	0	0	0	<1	0	<1	0	0	0	0	<1	<1	<1	<1	0	1	0	0	<1	<1	0	0	2	0	0	0	0
G. (?) sp(p).	0	0	<1	<1	0	0	0	<1	0	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Globigerinella aequilateralis	9	4	23	18	4	16	2	8	4	6	<1	<1	8	2	<1	2	4	5	5	0	0	2	1	0	0	1	0	<1	0	0
Globigerinita glutinata	2	2	<1	5	2	7	6	5	7	6	5	4	1	<1	<1	2	2	2	5	0	2	12	3	0	8	36	11	11	7	11
G. humilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	<1	0	0	0	0	0	0
Globigerinaides conglabatus	1	<1	<1	1	<1	1	<1	2	2	3	0	<1	<1	<1	<1	0	3	5	4	0	0	0	<1?	0	0	0	0	0	0	0
G. elongatus	0	0	0	0	0	0	0	5	4	0	<1	<1	<1	<1	0	0	2	<1	2	0	0	0	0	0	0	0	0	0	0	0
G. ruber	27	13	31	38	71	49	13	51	45	55	17	8	33	7	2	3	9	9	15	0	0	12	3	<1	0	2	0	1	0	0
G. trilobus trilobus	3	<1	0	3	5	7	<1	1	5	9	<1	<1	0	<1	<1	<1	1	0	<1	0	0	0	0	0	0	1?	0	0	0	0
Glabarotalia hirsuta	0	0	0	0	0	0	0	<1	<1	0	0	0	0	0	0	<1	0	<1	<1	0	2	29	24	8	10	1	0	<1	6	<1
G. menardii	0	<1	<1	<1	0	<1	<1	<1	1	3	1	<1	0	<1	<1	0	<1	0	0	0	0	0	0	0	0	0	0	0	0	0
G. punctulata	0	0	1	<1	0	<1	0	<1	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G. scitula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	1	<1	<1	0
G. truncatulinaides	0	0	<1	0	0	0	0	0	0	0	0	0	<1	0	0	0	<1	0	0	2	11	4	2	<1	3	0	0	<1	<1	0
Hastigerina pelagica	0	0	1	<1	0	2	0	<1	0	<1	0	0	2	0	0	<1	<1	<1	2	0	<1	1	0	0	<1	0	0	<1	0	0
Orbulina universa	<1	<1	2	1	<1	<1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0	0	0	0	0	0	0	0	0	0	0
Planarbulina mediterranensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
Tretamphalus atlanticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
unidentified Foraminifera	0	<1	0	0	<1	0	0	<1	0	0	0	0	0	0	<1	0	0	0	<1	2	0	<1	0	0	0	0	0	0	0	0
Surface temperature in degrees C.	18.6	18.8	21.2	23.1	23.8	21.6	16.1	21.7	22.3	22.1	15.3	13.5	17.0	16.6	16.7	17.8	20.6	20.6	20.7	10.22	9.99	17.37	14.15	12.84	11.45	15.32	12.31	13.53	13.87	10.37
Volume sampled in cubic meters	?	858	1048	550	940	373	456	418	241	659	512	233	649	626	304	526	267	284	529	1751	2796	2052	791					661	568	
Number of Foraminifera per 1000 M^3	191 ?	1,967	2,595	5,915	27,035	15,800	5,719	11,833	15,191	10,967	20,375	49,064	6,656	18,955	79,296	24,989	46,592	17,173	8,503	66	239	3,446	10,151					6,464	14,485	
Depth in meters (tows oblique unless marked H for horizontal)	125	SURFACE	230	250	SURFACE	250	250	252	238	249	251	252	250	251	254	252	254	254	253	200H	200H	200	100	SURFACE	270	SURFACE	SURFACE	150	150	150
Date	9-2-64	9-3-64	9-4-64	9-5-64	9-5-64	9-6-64	9-7-64	9-7-64	9-7-64	9-10-64	9-11-64	9-12-64	9-13-64	9-15-64	9-17-64	9-18-64	9-19-64	9-20-64	9-21-64	2-1-64	2-2-64	3-16-64	3-19-64	3-21-64	3-22-64	4-22-64	4-26-64	4-26-64	4-27-64	4-29-64
Time (local) (Most tows are about one half hour)	2340	1050	0005	0100	1300	2335	0115	1755	2339	0043	2350	2335	2336	2107	1919	0112	2355	0554	0006	0700	0230	0300	0320	0130–0330	0100	0200	0100	1800	2400	0200

FIGURE 4.—Check list of planktonic Formaminifera, *Atlantis II*–13 and *Atlantis II*–9 stations.

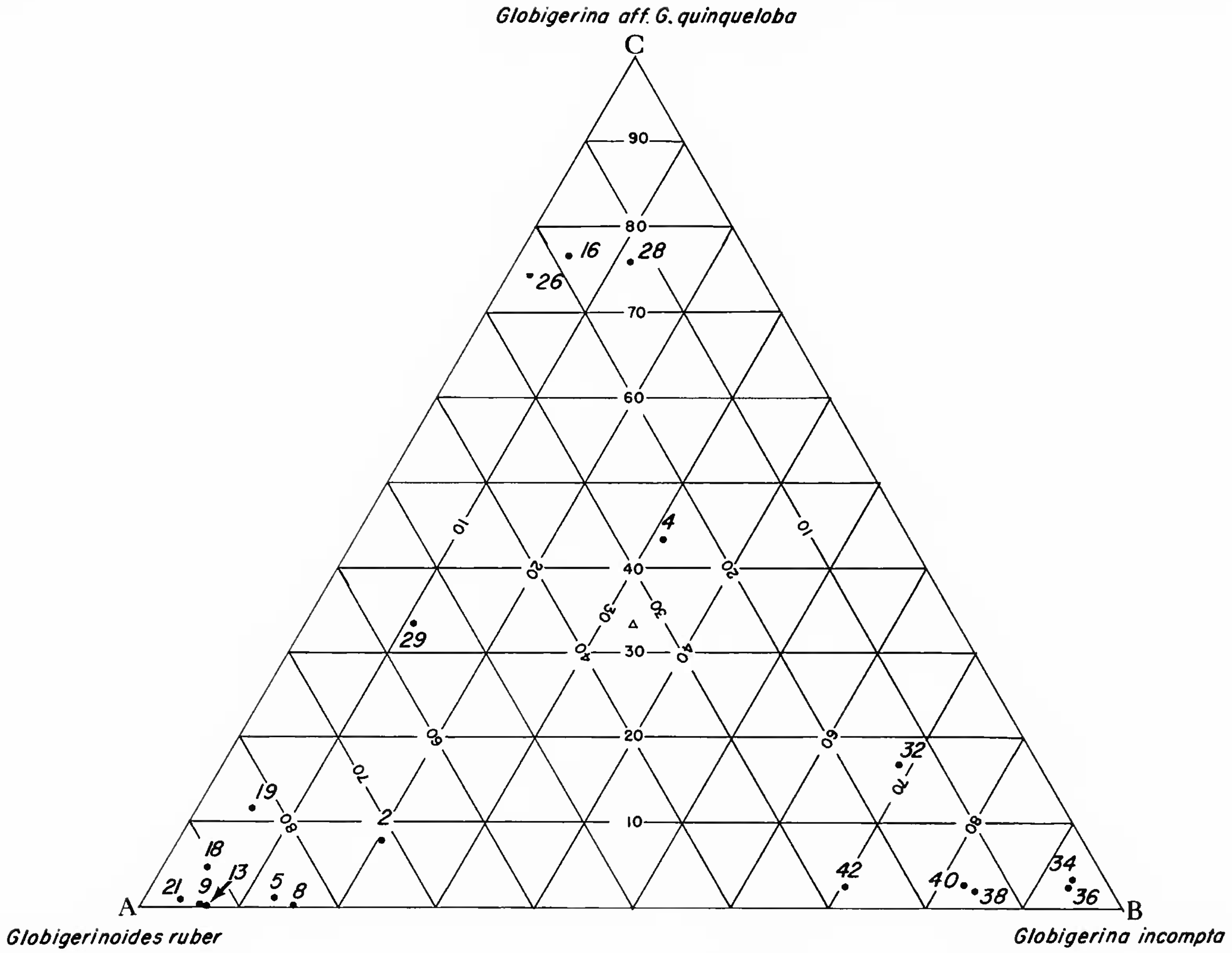


FIGURE 5.—Frequency relationships among *Globigerina incompta, G. quinqueloba egelida,* new subspecies, and *Globigerinoides ruber* from *Atlantis II*–13 stations.

of over 15,000. Highest abundances come from the eastern part of the traverse, with the maximum of 80,000 from station 34.

Diversity is relatively high throughout the traverse, ranging between 12 and 21 per station and with no significant correlation between dominant species and diversity apparent. Stations and their diversities are, respectively: 2—12; 4—14; 5—18; 8—17; 9—13; 13—14; 16—14; 18—21; 19—17; 21—16; 26—14; 28—15; 29—17; 32—18; 34—15; 36—15; 38—18; 40—14; 42—17.

Many species are ubiquitous, but only six represent 10 or more percent of total populations. These are *Globigerinoides ruber, Globigerina incompta, G. quinqueloba egelida,* new subspecies, *G. inflata, G. bulloides,* sensu lato, and *Globigerinella aequilateralis.* Figure 3 shows the number of specimens of these species per 1,000 cubic meters of sea water at each station. *G. aequilateralis* is excluded because it is only fairly well developed at three stations (Figure 4). These species' maximum-development areas, percentages, and numerical abundances may be summarized as follows.

Globigerinoides ruber is maximally developed in the western area, parallel to or in the path of the Gulf Stream, at stations 5, 8, 9, 13, 18, 19, and 21; it reaches a maximum percent of the fauna of 55 at station 21 and a maximum abundance per 1,000 cubic meters of 20,000 at station 9. *Globigerina incompta* is maximally developed in the eastern area at stations 32, 34, 36, 38, 40, and 42; it reaches a maximum percent of 72 at station 36 and a maximum abundance of 70,000 per 1,000 cubic meters at station 34. *Globigerina quinqueloba egelida,* new subspecies, is maximally developed at northern stations 16, 26, and 28, reaches 55 percent at stations 16 and 26, and shows a maximum abundance of 25,000 per 1,000 cubic meters at station 28. *Globigerina inflata* is maximally developed at far western stations 2, 4, and 5, reaches 35 percent at station 4, and shows a maximum abundance of 5,500 per 1,000 cubic meters at station 5. *Globigerina bulloides,* sensu latio, is maximally developed at eastern stations 32 and 34, reaches 29 percent at station 32 and a numerical abundance of 15,000 per 1,000 cubic meters at station 34. *Globigerinella aequilateralis* is best developed at western stations 5, 8, and 13, reaches 23 percent at station 5 and a numerical abundance of 2,500 per 1,000 cubic meters at station 13.

STATIONS 2–13, 18, 19, 21

Stations of the western part of the traverse share a common distributional pattern. Stations 2–13 are close to the Gulf Stream's mean path or its meanders. Stations 18, 19, and 21, located beyond the Gulf Stream path, are still within the influence of its southern branch. Except for station 4, all show high relative frequencies of the dominant warm-water form, *Globigerinoides ruber,* with respect to *Globigerina incompta* and *G. quinqueloba egelida,* new subspecies (Figure 3). Frequencies of *Globigerinoides ruber* and other species indicate a boundary fauna occurring adjacent to the Gulf Stream. *G. ruber* strongly dominates at stations 18, 19, and 21, and 9 and 13, decreasing westerly. This decrease is not unexpected, as the Gulf Stream mean path, swinging from the southwest, does not reach the latitudes of *Atlantis II*–13 stations until about 55°W longitude, closest to stations 9 and 13.

Gulf Stream meandering could account for the variability in species frequency relationships at stations 2–8. Good overall agreement exists in faunal composition between these stations and those previously occupied during fall in the slope waters close to, but at varying distances from, the Gulf Stream (Cifelli, 1965, p. 6). The principal *Globigerina* species is *G. inflata,* previously seen best developed in western slope waters during fall and closer to the Gulf Stream than other *Globigerina* species.

The fairly numerous globigerinas and relatively few *Globigerinoides ruber* at stations 2 and 4 (Figure 4) suggest their farthest removal from the Gulf Stream. Station 4 being farthest removed from the Gulf Stream can explain what we previously (Cifelli and Smith, 1969) thought an instance of patchiness. Although station 4 is no farther from the mean Gulf Stream path than 2 and 5, meandering may have placed 2 and 5 closer to Gulf Stream water. Patchiness in that region might be due to mixing of slope and Gulf Stream waters.

The general identity of the western faunal pattern continues east and north of the Grand Banks at stations 18, 19, and 21. *Globigerinoides ruber* dominates and has frequencies from 45 to 55 percent. *Globigerina* frequencies are low, but with *G. inflata* still the principal slope-water representative. The high frequencies of *Globigerinoides ruber* correlate with high surface temperatures at those stations (Figures 5 and 6). Thus, faunal patterns of the western North Atlantic may extend east and north of the Grand Banks, at least to longitude 46°W. Yet, stations 18, 19, and 21 waters may be isolated eddies or a continuation of part of the Gulf Stream. Bathythermographs from this area reveal unusually rapid lateral changes in surface and subsurface temperatures.

STATIONS 16, 26, 28, 29

Stations 16, 26, and 28 reveal a distinct distributional pattern, reflecting their low surface temperatures (13.5°C to 16.1°C). *Globigerina quinqueloba egelida,* new subspecies, dominates and has frequencies between 51 and 55 percent, more comparable to past records of winter rather than fall distribution in the slope waters (Cifelli, 1965, p. 7). Likewise, the relatively low frequencies of *G. inflata* (5–11 percent) resemble winter more than fall distribution in slope waters. Moreover, during summer, *G. quinqueloba egelida* maxima were found in the subarctic region (Bé and Hamlin, 1967, pp. 90, 96). Distinct populations, then, appear between stations 16, 26, and 28 and those of western slope waters. These populations probably were stocked mostly from cold Labrador waters.

Frequencies of *Globigerinoides ruber* (8–16 percent) and occurrences of other Sargasso Sea–Gulf Stream species suggest some southern mixture. Yet, mixing appears relatively minor considering proximity to warm-water stations. In particular, station 16 is very close to a boundary found between relatively cold and warm bodies of water. As revealed by bathythermographs, a strong thermal gradient marked the front, apparently isolating the water bodies and allowing only minimal faunal mixing. (Note that we speak of the time of

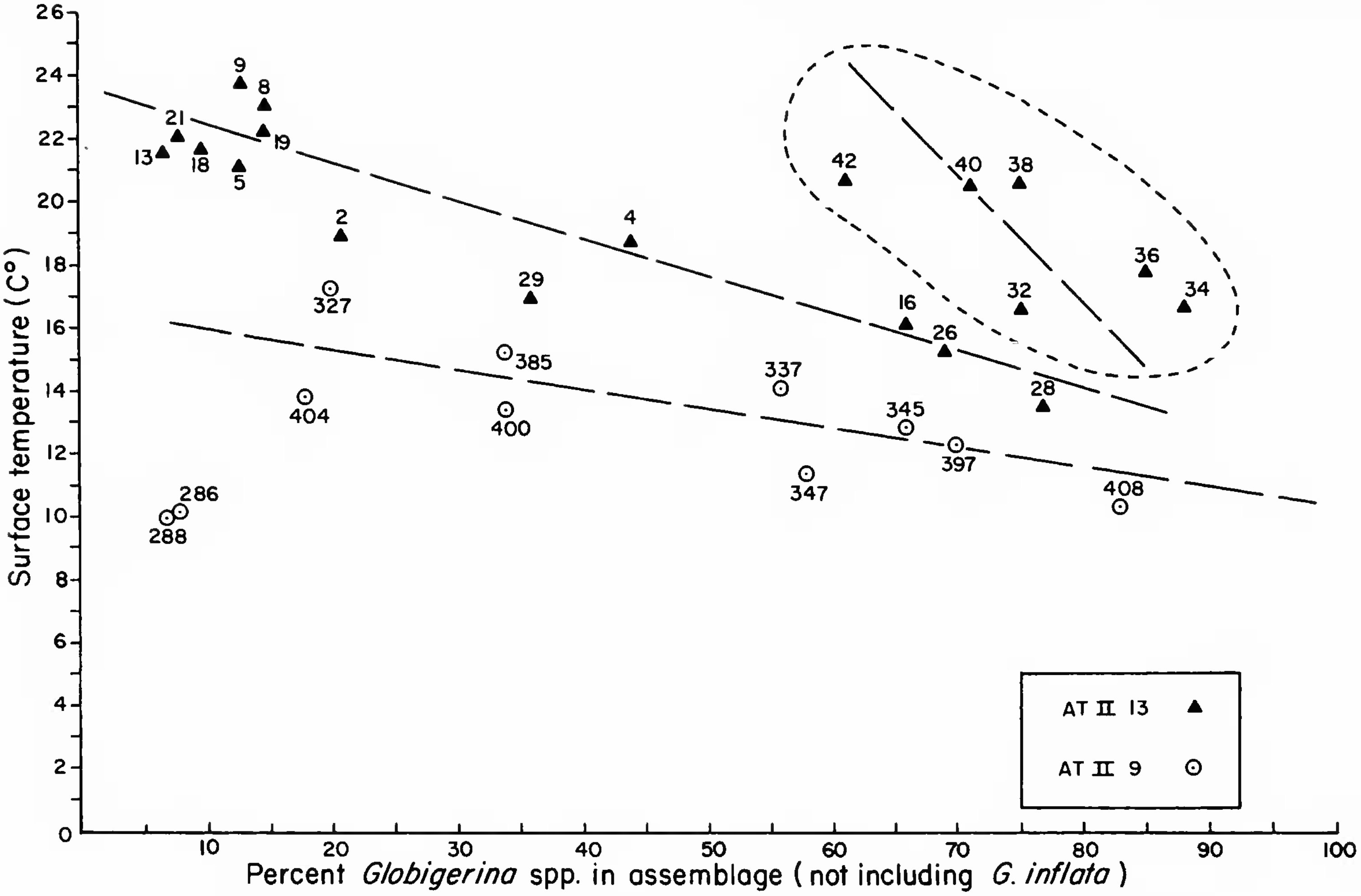


FIGURE 6.—Relationship between percentage of combined species of *Globigerina* (exclusive of *G. inflata*) and surface temperature from *Atlantis II*–13 stations.

collection of the *Atlantis II*–13 stations, as the local hydrography varies within limits seasonally and probably also over greater time spans. Thus, conditions at particular geographic points are subject to change.)

The traverse's northernmost station, 29, appears to represent an area of effective mixing. The frequency relationships of *Globigerinoides ruber* and *Globigerina quinqueloba egelida,* and also *G. inflata,* indicate a transitional fauna (Figures 3, 4). The 17.1°C surface temperature is intermediate between cold-water *G. quinqueloba egelida* stations and those at previously discussed warmer-water stations. Further, bathythermographs reveal no steep thermal gradients nor marked cold fronts in the vicinity of station 29.

STATIONS 32–42

Stations 32–42, from east of longitude 40°W, reveal a third distributional pattern. Like the previous group of stations, slope-water elements make up the bulk of the populations, but *Globigerina incompta* rather than *G. quinqueloba egelida,* new subspecies, dominates. Numerous Sargasso Sea–Gulf Stream species occur, but their frequencies are consistently low. Of the latter, *Globigerinoides ruber* is the chief representative, as at the previous stations. *Globigerina bulloides,* sensu lato is more abundant than elsewhere. *G. inflata* appears in relatively low percentages. Overall, stations 32–42 compare best with outer slope stations during fall (Cifelli, 1965, p. 6). The great spatial separation, however, with the distinct faunal pattern of stations 16, 18, and 19, and 29 in between, rules out a direct relationship between the water bodies represented by these groups of stations. The stations 32–42 faunal pattern strongly suggests a water regime distinct from those to the west.

Figure 6 shows the frequency relationship between combined *Globigerina* species and surface temperature. It further indicates the distributional pattern's uniqueness in the eastern waters. (*G. inflata* is here excluded because of its uncertain generic placement (Cifelli, 1965, p. 14).) The *Globigerina* frequency-surface temperature correlation allows projection of a line through stations 2–29 showing a remarkably good general inverse relationship (Figure 6). Stations 32–42, however, cluster above the line; *Globigerina* frequencies are significantly higher than expected from the relatively high surface temperatures, using the western stations (2–29) as a reference. Interestingly, though, stations 32–42 tend to cluster such that a line showing an inverse relationship in the North Atlantic Current can be drawn through them also. The relationship differs, however, not only in showing higher temperatures but also in showing more variation among the eastern stations. Further, deviation from western-stations relationships appears to increase with distance from western stations.

Further to the south, stations 2 and 3 of *Chain* cruise 21, about 12° due south of *Atlantis II*–13 station 42 (Figure 1) had yielded typical Sargasso Sea assemblages (Cifelli, 1967, p. 122). These contrast sharply with those from stations 32–42. Although these *Chain* stations were occupied in December, assemblages contained one or less percent *Globigerina*, with *Globigerinella aequilateralis* and *Globigerinoides ruber* dominant.

The anomaly shown by stations 32–42 has important implications. Slope-water species of *Globigerina*, particularly *G. incompta*, thrive in the North Atlantic Current at surface temperatures favoring flourishment of *Globigerinoides ruber* or other Sargasso Sea—Gulf Stream forms in the western North Atlantic. This implies the existence of a peculiar dynamic structure in the North Atlantic Current that strongly influences the composition of plankton populations. Therefore, in the fossil record, an increase in "cold-water" forms (such as slope-water species of *Globigerina*) need not necessarily imply a decrease in temperature of surface waters. A hypothetical explanation of the *Globigerina* anomaly will be given in the following section.

Summary of *Atlantis II*–13 Distributional Patterns and North Atlantic Circulation

WESTERN STATIONS

West of 50°W, where circulation is best known, distributional patterns relate closely to the broad aspects of the circulation. Planktonic foraminiferal assemblages from stations 2–13 show frequency relationships characteristic of inner slope waters relatively close to the Gulf Stream during fall. Allowances for distances from the mean position of the Gulf Stream and its meanderings can account for variations in species frequency relationships among these stations. Stations 18, 19, and 21, near the North Atlantic Current, show similar faunal patterns. These stations are southeast of the Grand Banks, near where the North Atlantic Current is formed, suggesting a dynamic continuity with the waters farther west. Slope-water assemblages characterize stations 16, 26, and 28 and the dominance of *Globigerina quinqueloba egelida*, new subspecies, indicates the influence of cold Labrador water. Roughly equal frequencies of slope-water and Sargasso Sea–Gulf Stream elements at station 29 indicate water mixture there.

EASTERN STATIONS

East of 50°W a marked change in distributional pattern occurs and we believe this change is associated with the dynamics of the circulation. Stations 32–42 are at the edge of and within the eddy formed by the North Atlantic Current (Figure 1). While the Gulf Stream partly feeds the North Atlantic Current, the water regime is distinct because the North Atlantic Current is not a border of the Sargasso Sea as is the Gulf Stream. Bathythermographs reveal that the waters around stations 32–42 lack the homogenous layer of 18°C water that characterizes the Sargasso Sea (Worthington, 1959). The North Atlantic Current is fed by both slope water and the Gulf Stream. No dramatic boundary exists between two major hydrographic provinces with different endemic faunas as is seen crossing the Gulf Stream. Under these circumstances, one might expect a distinct communal structure in the waters associated with the North Atlantic Current. The high frequencies of *Globigerina* species at stations 32–42, therefore, probably indicate the individuality of North Atlantic Current communal structures, where the water regime cannot be directly compared with those to the west.

The North Atlantic Current, however, is not a closed system. It forms a devious path of the North Atlantic gyre that eventually blends with the Canaries Current to the east and the Sargasso Sea to the south, at about latitude 35°N. Therefore, the continuity of a single clockwise gyre is maintained, and the North Atlantic Current is a Gulf Stream extension as a transport medium. The circulation continuity is evidenced by drift bottles released from eastern North America and recovered in the Azores and the transoceanic occurrences of numerous pelagic larvae of tropical shallow-water benthonic invertebrates (Scheltema, personal communication). Many pelagic larvae have been recovered along the general course of the North Atlantic Current.

Before attempting to explain the peculiar communal structures of the North Atlantic Current, we believe it necessary to consider some aspects of plankton population dynamics. Actually, little is known about this subject and we approach it in broad, hypothetical terms.

Dynamics of Plankton Populations

Because the open ocean continually is in motion, its dwellers are constant travelers who, during their lifetimes, may occupy a considerable range of habitat. In general, one can recognize three categories of open-ocean dwellers, each bearing distinctive dynamic relationships to the environment. One group comprises the free swimmers, as fishes, which live entirely in the open sea. Being locomotive, they are somewhat independent of the water motion and can, within limits, choose environments most favorable to productivity and flourishment. The other two groups are free floaters, negligibly locomotive, and thus involuntarily transported by ocean currents. The free floaters include (1) pelagic larvae of benthonic organisms and (2) truly planktonic organisms, such as the Foraminifera. Dynamically, the major distinction is that the former do not achieve maturity during their travels while the latter live and reproduce entirely in the open sea. However, the itineraries and destinies of all free floaters are determined by water movements.

The first free-floater group constitutes excellent indicators of water movement since no productivity occurs during travel, leaving population structure unchanged except for downstream numerical and diversity decreases from mortalities. One can also determine points at which larvae are "seeded" into the environment. Scheltema (personal communication) views North Atlantic circulation as a giant carrousel along which the larvae are riders that may jump off at any time. Truly planktonic organisms also ride this carrousel but where they get on or jump off is not obvious.

A Distributional Model for the North Atlantic Current

North Atlantic Current stations 32–42 are characterized by high standing crops. Numerical values are particularly high compared to adjacent stations 18, 19, and 21, located southwestward, where the Gulf Stream begins its swing northeast as part of the North Atlantic Current. We believe the high standing corps at stations 32–42 reflect increased productivity, resulting from convergence of slope waters and Gulf Stream (forming the North Atlantic Current); however, slope-water species dominate; Sargasso Sea–Gulf Stream species show fairly high diversity, but occur in consistently low frequencies.

Globigerina incompta shows the highest numerical abundance, which accounts for its strong dominance. Also, with stations 32–42, an inverse relationship may exist between standing crop of total population and frequency of *G. incompta*. Stations 34, 36, and 38 have the highest standing crops and lower frequencies of *G. incompta* than 32, 40, and 42 (Figure 3). Perhaps significantly, stations 40 and 42 are farthest south in the North Atlantic Current. This suggests a gradient, along which *G. incompta* achieves a maximum through productivity and then declines to the south. Further, south of station 42, at *Chain* 21 stations 2 and 3 (Figure 1; see Cifelli, 1967, Text-fig. 1) *Globigerina* species are scarce or absent.

Figure 7 illustrates the hypothetical model for our explanation. The North Atlantic Current forms a partially closed eddy with a dynamic setting different from that to the west. No conspicuous boundaries exist and conditions are potentially favorable to productivity. Importantly, we assume that the North Atlantic Current temperatures remain close to threshold. They are both close to tolerance maxima of *Globigerina* slope-water species and to minima, at least for reproduction,

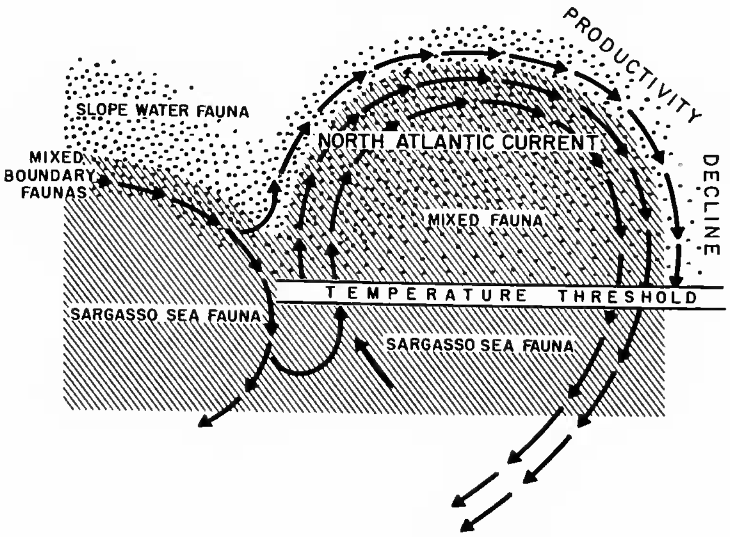


Figure 7.—Schematic model of faunal relationships in the general area of the North Atlantic Current.

of Sargasso Sea species. As populations sweep along the North Atlantic Current, they arrive at the productively favorable area within temperature tolerances of *Globigerina incompta* and other *Globigerina* species. The particular circumstances favoring preferential productivity of *G. incompta* are unknown, but unique, in terms of our past experience, is a species flourishing where temperatures must be close to its tolerance maximum. Yet, perhaps this should not be too surprising, as poikilitic animals often show optimum development at temperatures closer to the maximum than the minium of their range. At the same time, temperatures may be below reproductive minima of *Globigerinoides ruber* and other Sargasso Sea forms.

As populations continue clockwise movement south, conditions favorable to *Globigerina incompta* productivity diminish and it decreases both in numerical abundance and relative frequency. Eventually, the populations pass a temperature threshold, where *G. incompta* and other *Globigerina* species severely decline, finally being completely removed. Then population compositions are that of the Sargasso Sea. *Chain* 21 stations 2 and 3 from the southern North Atlantic Current (Cifelli, 1967) have typical Sargasso Sea type populations.

The explanation for foraminiferal distribution that we propose is hypothetical, but we believe it can be tested by detailed sampling and hydrographic surveying across the North Atlantic Current.

Atlantis II–9 Distributional Patterns

The *Atlantis II*–9 stations, distributed over a wide region east of longitude 50°W, were occupied between 2 February and 29 April 1964. Since surface-water warming begins about the end of March, temperatures were close to minimum, whereas *Atlantis II*–13 temperatures were close to maximum. Stations were located in or close to the North Atlantic Current eddy, with some exceptions (Figure 2). Stations 286 and 288 were distantly removed from the others; station 327 was near the southern branch of the Gulf Stream; and station 408 was close to the North Atlantic Current's western boundary.

Since the *Atlantis II*–9 stations were collected over a period of almost three months, one cannot view distributional patterns quasisynoptically, as with the *Atlantis II*–13 stations. The *Atlantis II*–9 traverse actually represents three transects, with time lapses of about (1) one and (2) one and a half months. These time lapses introduce seasonal change in interpreting distribution; seasonal change seems evidenced in the Sargasso Sea components. For this reason, we treat the *Atlantis II*–9 stations as three transects, according to collection time.

NUMERICAL ABUNDANCES AND DIVERSITY

Standing crops at *Atlantis II*–9 stations are relatively low, from less than 100 to about 14,000 specimens per 1,000 cubic meters of sea water at those stations having current-meter readings. Diversities also are low, with only 4 to 12 species per station. Species frequencies differ considerably from the *Atlantis II*–13 traverse. *Globigerina inflata, G. bulloides,* sensu lato, *Globorotalia hirsuta* and, to a lesser degree, *G. truncatulinoides* more or less replace the *Atlantis II*–13 dominants *Globigerina incompta, G. quinqueloba egelida,* new subspecies, and *Globigerinoides ruber*.

The *Atlantis II*–9 stations display a generally inverse correlation between frequency of combined *Globigerina* species (exclusive of *G. inflata*) and surface temperature, similar to *Atlantis II*–13 stations. Figure 6 compares these correlations. Stations 286 and 288 appear anomalous.

The inverse *Globigerina*-temperature correlations of the two *Atlantis II* traverses nearly parallel, with no station-group overlaps. The relative *Globigerina* species-increase with lower temperatures is less with *Atlantis II*–9 than *Atlantis II*–13 stations. This parallel relationship is not entirely clear, but supports surface temperature not directly affecting development of slope-water species of *Globigerina*. As stated before, we think the *Globigerina* species frequency-surface temperature relationship largely reflects interaction of water regimes and population dynamics.

STATIONS 286, 288

These two stations were the first collected (1 and 2 February) and are considerably northeast of the others. Fifty percent of the station 286 assemblage is the nonplanktonic species *Planorbulina mediterranensis* and *Tretomphalus atlanticus,* the latter lacking float chambers, indicating a benthonic habitat. We cannot explain the open-ocean concentration of benthonic forms. Perhaps they attached to sea-grass, or, possibly, station 286 is over a shallow, uncharted seamount. Nearby station 288, nor any other station, reveal no benthonic forms.

Planktonic populations of stations 286 and 288 are very similar. Both show unusually low standing crops (66 and 239 specimens per 1,000 cubic meters, respectively). *Globigerina inflata* strongly dominates, with about 75 percent (discounting station 286 benthonics). Virtually the only Sargasso Sea species is *Globorotalia truncatulinoides,* achieving 11 percent at station 288. It indicates Gulf Stream influence in these northeastern waters. It strongly dominates in the northern Sargasso Sea during January (Bé, 1960b; Cifelli, 1962); thus it is the most likely Gulf Stream contribution at stations 286 and 288 collecting time. Probably *G. truncatulinoides* does not produce in these cold, northeastern waters; low standing crops at stations 286 and 288 indicate a general productivity lack and largely dormant populations.

Strong dominance of *Globigerina inflata* largely accounts for the anomalously low frequencies of other slope-water *Globigerina* species at these stations with the traverse's minimum surface temperatures (10.0° and 10.2°C). Yet, the anomaly remains striking. Frequencies of *G. inflata* at stations 286 and 288 are the highest observed for this species. Moreover, in the western North Atlantic, *G. inflata* normally is a "warmer-water" *Globigerina,* favoring inner slope waters near the Gulf Stream and with maximum development in fall (Cifelli, 1965; Bé and Hamlin, 1967). Dominance of *G. inflata* in waters distant from western Atlantic slope waters well illustrates that species frequency relationships may vary with water regime as well as season.

Stations 327, 337, 345, 347

These stations, collected between 16 and 22 March, extend northeast from near the southern Gulf Stream branch on into the North Atlantic Current eddy (Figure 2). Station 327, nearest the Gulf Stream branch, reveals a boundary assemblage with nearly equal slope-water *Globigerina* and Sargasso Sea forms. The principal species, at 29 percent, is the Sargasso Sea form *Globorotalia hirsuta.* Winter changes in the northern Sargasso Sea are reflected in *G. hirsuta* replacing *G. truncatulinoides* as dominant. *Chain* cruise 25 reveals *G. hirsuta* as similarly dominant in the northern Sargasso Sea during early April (Cifelli and Smith, 1969).

Station 337 begins to show a frequency decline of *G. hirsuta* and a large relative increase of *Globigerina.* Those (345, 347) to the north, in the North Atlantic Current have this relationship well developed. The principal *Globigerina* species is *G. bulloides,* sensu lato, with 64 percent at station 345. Frequency relationship changes among stations 327, 337, 345, and 347 are the kind expected from the positions relative to the southern branch of the Gulf Stream (Figures 2, 4).

Stations 385–408

These stations, collected between 26 and 29 April, extend northwest and west across the North Atlantic Current eddy (Figure 2). The North Atlantic Current western boundary probably falls between stations 404 and 408. The surface temperature change suggests this, decreasing from 13.9°C at station 404 to 10.4°C at station 408. Further, a significant faunal change occurs between station 408 and the adjacent easterly stations.

The *Atlantis II*–9 station 408 assemblage (45°10′ N, 45°39′ W) indicates Labrador Current waters. This assemblage closely resembles one collected in the western Labrador Current in early April during *Chain* cruise 25, station 462 (42°00′ N, 65°00′ W). The two assemblages are compared in Table 1.

TABLE 1.—*Species frequency relationships between* Chain *25, station 462 and* Atlantis II–*9, station 408*

Species	*Station 462* *3 April* *1962* (percent)	*Station 408* *29 April* *1964* (percent)
Globigerina bulloides, sensu lato	66	62
G. incompta	18	6
G. inflata	2	5
G. quinqueloba egelida	10	15
Globigerinita glutinata	2	11
Globorotalia hirsuta	0	>1
Orbulina universa	2	0

Probably most significant is the frequency relationship between *Globigerina bulloides,* sensu lato, and *G. inflata.* At both stations, *G. bulloides,* sensu lato, strongly dominates, with low percentages of *G. inflata.* At *Atlantis II*–9 station 404 the relationship is reversed; *G. inflata* strongly dominates (69 percent), with few *G. bulloides* (3 percent). Nearby station 400 shows nearly identical frequency relationships, although with some increase of *G. bulloides,* sensu lato.

Frequency relationships within the North Atlantic Current are not homogeneous, however. Station 397 shows almost equal percentages of *G. bulloides,* sensu lato, and *G. inflata,* and no species exhibits strong dominance. Station 385, at the southern end of the North Atlantic Current, reveals only 9 percent *G. bulloides,* sensu lato, and shows dominance of *Globigerinita glutinata* (36 percent). This variation's significance is not clear.

Curiously, stations 385–408 are impoverished in Sargasso Sea forms. *Globigerinita glutinata,* a ubiquitous form, is the only species not of *Globigerina* that occurs in frequencies of over 10 percent. The Sargasso Sea form *Globorotalia hirsuta* composes 6 percent of the station 404 assemblage. At all other stations, combined Sargasso Sea forms account for 3 or less percent.

Since we have no quasisynoptic data from the Sargasso Sea, we can only speculate on the cause of this impoverishment. Conceivably, however, April is a critical time in North Altantic planktonic population dynamics. Previous April data indicate that *Globorotalia hirsuta* frequency declines rather sharply and forms such as *Globigerinoides ruber* and *Globigerinella aequilateralis* achieve dominance; however, April temperatures in the North Atlantic Current are still relatively low. Perhaps *Globigerinoïdes ruber* and *Globigerinella aequilateralis* lack as low a temperature tolerance as *Globorotalia hirsuta;* the former species develop maximally in the northern Sargasso Sea between spring and fall and are virtually absent there in winter. Accordingly, in the context of the dynamic model proposed for *Atlantis II*–13 distribution (page 28), we suggest that temperatures are generally below threshold in the North Atlantic Current for Sargasso Sea forms and they mainly are unable to survive the journey around the eddy.

Measurement of Chambers and Test Volution

Among planktonic foraminiferal taxa, particularly of *Globigerina* species, differences often are subtle and occasional morphologic overlap occurs. Because of this, we add to some species descriptions data on test size and number of chambers relative to test volution. (The species are *Globigerina atlantisae,* new species, *G. bulloides bulloides, G. dutertrei, G. incompta, G.* aff. *G. pachyderma,* and *G. quinqueloba egelida,* new species.) Such data point up resemblances and differences among species and assist in establishing population maturity and geographic variation. We hope these data will allow comparisons in future studies.

In descriptions of coiled Foraminifera, one customarily includes maximum diameter, total number of chambers (if determinable) and number of chambers occupying the periphery. Only rarely is the relationship between (1) size and/or number of chambers and (2) coil or degrees of volution examined throughout the test. Probably for this reason, the chambers occupying the periphery are defined as the "final whorl" and those surrounding the proloculus as the "initial whorl."

One obtains this "final whorl" by rotating the test 'backward' 360°, with the final chamber as starting point (Figure 8). These chambers occupy the periphery of the test. (Usually, however, the 360° line falls across the whorl's innermost chamber, giving a whorl

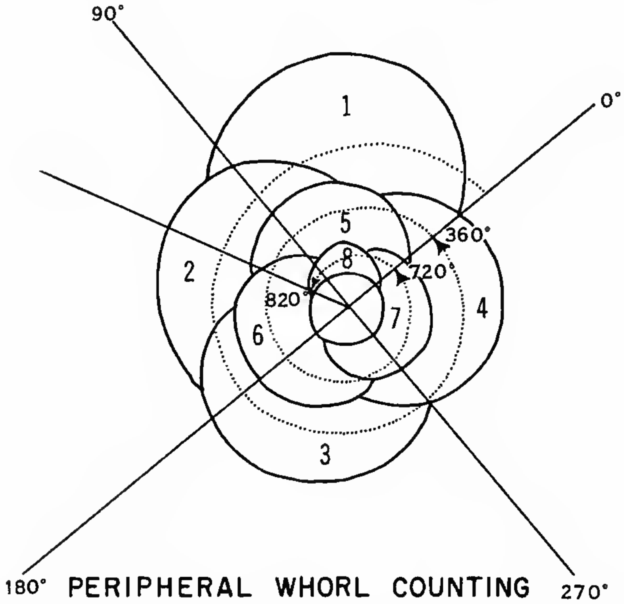


FIGURE 8.—Peripheral whorl counting. The cross hairs of the goniometer microscope eyepiece are represented by the 0°–180° and 90°–270° lines. They are centered in the proloculus, with the 0°–180° line extending through the center of the proloculus and the outermost basal edge of the final chamber. Measurement starts at the intersection of the line with that basal edge and gives degrees of whorl occupied by each chamber, with a total of 820°. Chambers are numbered progressively inward, with the final chamber as 1. Each whorl occupies 360°. Therefore, in this case the peripheral whorl is occupied by chambers 1, 2, 3, and most of 4; the pre-peripheral whorl by part of 4, 5, 6, and most of 7; and 720° to 820° by part of 7 and 8. By this method, the peripheral whorl is complete and it is the chambers immediately "younger" than the proloculus which do not complete a whorl.

containing a number of complete chambers plus a fraction of a chamber.) One obtains the "initial whorl" by rotating the test 'forward' from the proloculus (Figure 9). Continuation of this 'forward' measurement usually results in the last complete whorl (360°) extending onto the periphery and thus overlapping the "final whorl." ('Backward' measurement usually gives an "initial whorl" short of 360°.)

Although opposite to the direction of growth (see Cifelli, 1961), practical reasons exist for inward measurement of chambers with respect to volution. Peripheral chambers are most clearly visible, becoming progressively less so inward and often barely or not visible in the prolocular whorl. The number and size of chambers occupying the periphery are useful, easily obtained diagnostic criteria. By rotating specimens reverse to growth, one can determine the relationship between chamber number and degrees of whorl throughout much of the test ontogeny, with a fixed point of reference, even though early chambers may be obscure. Therefore, we use this method here. To maintain consistency and avoid ambiguity, however, we propose the term "peripheral whorl" for the sum of chambers that occupy the periphery and comprise a 360° volution when the last-formed chamber is used as starting point. Peripheral whorl is intended to replace "final whorl" of common usage.

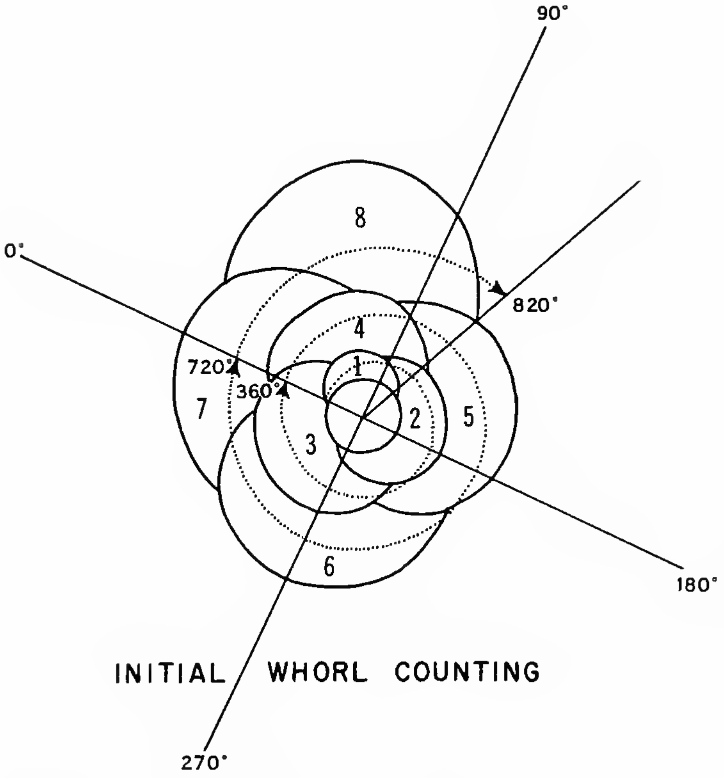


Figure 9.—Initial whorl counting. The cross hairs of the goniometer microscope eyepiece are represented by the 0°–180° and 90°–270° lines. They are centered in the proloculus, with the 0°–180° line extending through the center of the proloculus and its intersection with the beginning of the first chamber beyond it. Measurement starts at that intersection and gives degrees of whorl occupied by each chamber, with a total of 820°. Chambers are numbered progressively outward from the proloculus. Each whorl occupies 360°. Therefore, in this case, the first whorl is occupied by chambers 1, 2, and most of 3; the second by part of 3, 4, 5, 6, and part of 7; and the third by part of 7 and 8. By this method, the third whorl finishes *before* completing 360° and the chambers around the periphery are *not all* included in the third whorl.

Our procedure for counting and measuring chambers per whorl follows. The specimen is oriented spiral side upward on a mechanical stage of a binocular microscope having a goniometer eyepiece. The goniometer crosshairs next are rotated until the north-south line intersects the suture between the ultimate and penultimate chambers, and the degrees of rotation are recorded. This process continues so far as chambers are visible enough to measure. The size (maximum diameter) of each volution (360° of rotation) also is measured and recorded.

The choice of intersection point of the north-south line with the final chamber's forward edge and with the previous chamber's sutures offers minor problems. With the final chamber, the point can be at the chamber base, where it last touches or lies directly above the earlier-formed whorl, or it can be at the chamber's forwardmost projection. With sutures between previous chambers, the point can be either at their bases or outermost visible extremities. Once these choices have been made, they should be adhered to consistently.

We have compiled graphs showing the relationship between chamber addition and degrees of volution for specimens of the species mentioned above. The graphs are arranged "backwards," so to speak, as final chambers are the 0° points, and the curves run opposite to growth direction. This procedure is necessary to keep the curves open-ended for those specimens whose early chambers are not clearly visible. Further, this method avoids the problem of beginning (and comparing) plots of specimens with their most uncertain measurements, of chambers immediately surrounding proloculi; even when these chambers can be seen, their measurements may be rather inexact because of their very small sizes.

Systematic Descriptions

Family GLOBIGERINIDAE Carpenter, Parker, and Jones, 1862

Genus *Globigerina* d'Orbigny, 1826

Globigerina atlantisae, new species

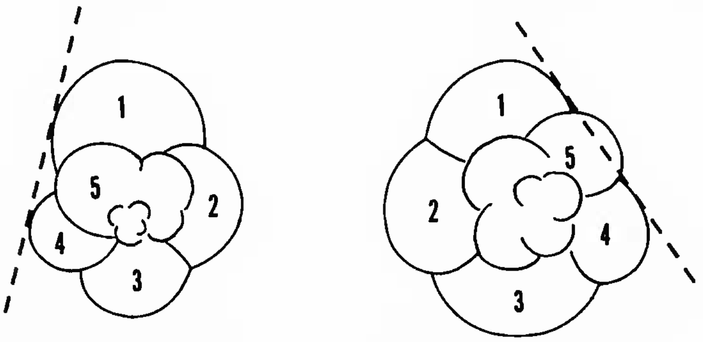
Plate 1: FIGURES 1, 2, 3

Globigerina radians Egger.—Parker, 1958, p. 278, pl. 5: fig. 10.

Test compressed, trochospiral, with a rounded, lobate periphery and a rather elliptical outline; chambers rapidly enlarging as added, usually between two and three whorls in the adult with between four and five chambers in the peripheral whorl and from four to five in the pre-peripheral whorl; number of chambers ranging from 8 to 14 in the entire test, usually 10 or 11; chamber shape appearing elongated along the axis of coiling on the spiral side, and perpendicularly to the periphery on the umbilical side, vertically compressed, especially in the peripheral whorl; sutures distinct, depressed, narrow, slightly curved to radial on the spiral side, more curved on the umbilical side, with the spiral suture following around the bases of the chambers of the peripheral whorl and meeting the radial sutures sometimes in a substellate pattern, otherwise lobate; spiral side of test either almost flat or with early whorls raised as a plane above the peripheral whorl (Plate 1: figure 2); aperture interiomarginal, umbilical-extraumbilical, a slit reaching close to the periphery, almost covered by the extended final chamber and small flap attached to the base of that chamber; wall finely perforate, finely hispid, thin; coiling direction both left and right, with left slightly predominant; maximum diameters of primary types 0.23–0.26 mm.

Parker (1958) synonymized her form with *Globigerina radians* Egger on the basis of figures for this species given by Rhumbler (1909). The original figure is enigmatic, through it resembles *Globigerinella aequilateralis* superficially. Rhumbler (1909, p. 11) stated that the form figured by him as *G. radians* was obtained from Egger. Inspection of these figures reveals, however, that the chambers are not so elongate in the direction of coiling on the spiral side as are those of the present form or Parker's specimens, but instead are distinctly more lobulate. In this regard, they more closely resemble those of some *Globigerinita iota* Parker. The nature of the figures, although revealing a form similar to both *G. iota* and *Globigerina atlantisae,* new species, does not permit truly detailed comparison.

Globigerina atlantisae, new species, most closely resembles *G. quinqueloba egelida,* new subspecies. It differs from the latter in its slightly greater curvature of the sutures. This difference is particularly apparent on the umbilical side. The chambers of *G. atlantisae* are more elongate along the axis of coiling on the spiral side of the test and less spherical (or subspherical) than those of *G. quinqueloba egelida. Globigerina atlantisae* also has fewer chambers (generally 10 to 11 in the adult test compared to 13 or 14 in *G. quinqueloba egelida*). In the peripheral whorl there are between four and five chambers instead of the four and a half to five found in *G. quinqueloba egelida.* Related to this is that there is a consistent difference in the peripheral outline between the two, with an indentation below and adjacent to the final chamber of *G. atlantisae* which is not present with *G. quinqueloba egelida* (Figure 10). The aperture of *G. atlantisae* usually is obscured by the final chamber's flap-like extension, while *G. quinqueloba egelida* shows this feature less commonly. Further, the aperture of *G. atlantisae* extends closer to the periphery. Both species are compressed, but *G. atlantisae* is generally more so, and also generally has a flatter spiral surface. With *G. atlantisae* specimens, chambers tend to occupy more nearly the same number of degrees of whorl (compared with other



Globigerina atlantisae

Globigerina quinqueloba egelida

FIGURE 10.—Comparison of outlines of *Globigerina altantisae,* new species, and *Globigerina quinqueloba egelida,* new subspecies. Chambers of *G. atlantisae* are more elongate in the direction of coiling on the spiral side. Further, the plan of growth produces a consistant indentation in the outline of specimens, adjacent to the last chamber, whereas *G. quinqueloba egelida* shows no such indentation; that is, a line drawn tangent to chambers 1 and 4 will not touch chamber 5 in *G. atlantisae,* whereas it will intersect chamber 5 in *G. quinqueloba egelida.*

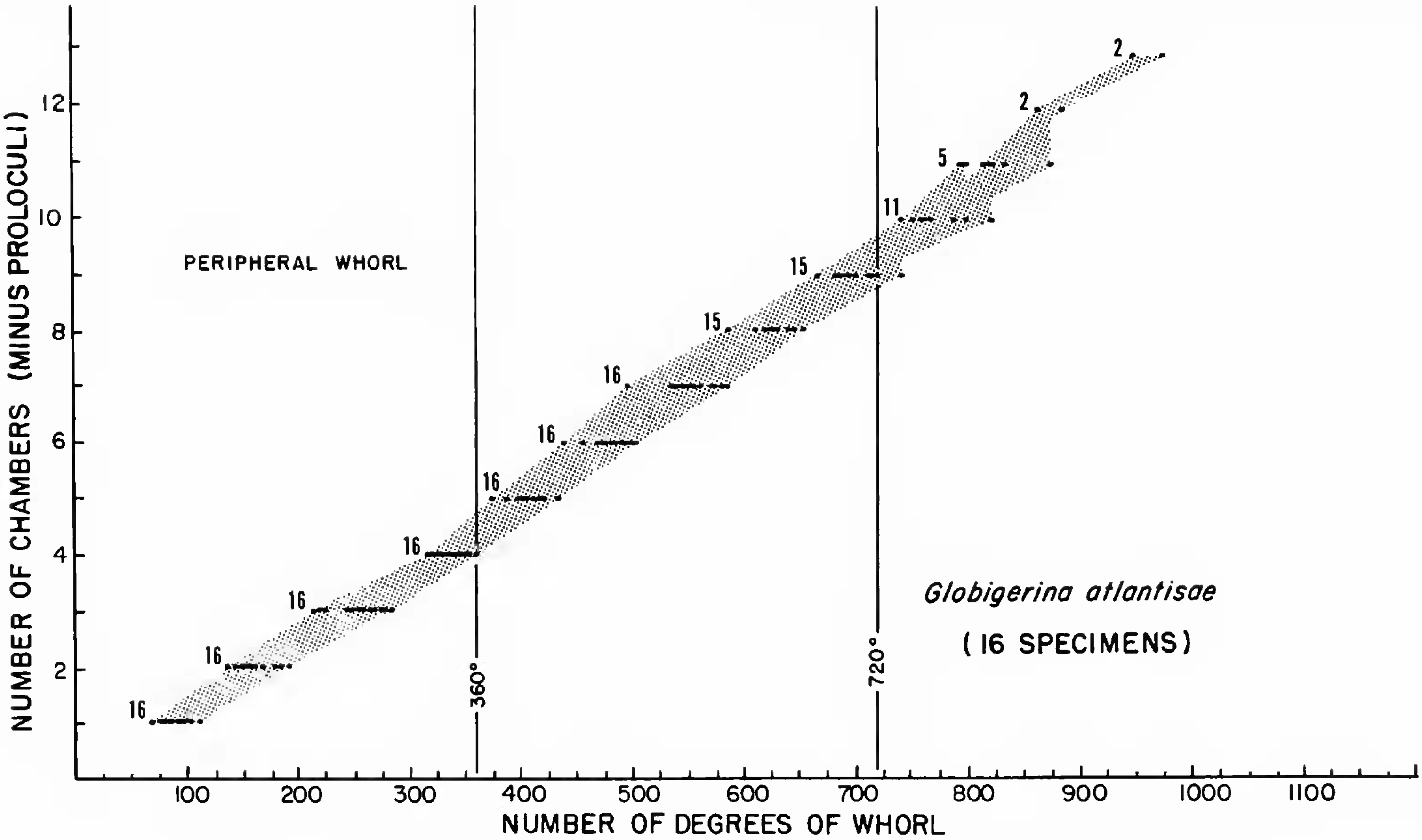


FIGURE 11.—*Globigerina atlantisae*, new species. A growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for 16 specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

chambers of the same and other specimens) than is the case with *G. quinqueloba egelida* (Figure 11).

MEASUREMENTS.—Sixteen specimens were selected to determine the relationship between chamber number and degrees of test volution in *Globigerina atlantisae*, new species (Figure 11). The maximum number of chambers recorded is 14, but most specimens contain 12 or fewer chambers. In all but four specimens the chambers occupy more than two but less than three full whorls. The four specimens consisting of less than two full whorls probably represent immature forms. Good consistency exists among specimens in growth pattern and they plot close to a straight line with a relatively small spread of points. The peripheral whorl contains between four and five chambers, which represents a slight decrease in rate of chamber addition from the previous 360° of volution (pre-peripheral whorl).

TABLE 2.—*Sizes and chamber numbers of 16 specimens of* Globigerina atlantisae, *new species*

	Range	*Mean*
Maximum diameter (mm) through peripheral whorl	0. 16–0. 28	0. 22
Maximum diameter (mm) less peripheral whorl	0. 05–0. 13	0. 09
Ratio of diameters of peripheral whorl and rest of test	3. 2–2. 2	2. 4
Total number of chambers	8–14	11(11. 31)
Number of chambers in peripheral whorl	4. 2–4. 8	4. 44
Number of chambers in preperipheral whorl (for those 12 specimens continuing beyond this whorl)	4. 4–5. 4	4. 98

DISTRIBUTION.—*Globigerina atlantisae*, new species, is not common in *Atlantis II* material. It occurs at seven *Atlantis II*–13 stations and one *Atlantis II*–9. It reaches a peak of 2 percent at station 21.

Globigerina bulloides bulloides d'Orbigny

PLATE 1: FIGURES 5, 6

Globigerina bulloides d'Orbigny, 1826, p. 277, nos. 17, 76.—Brady, 1884, p. 593, pl. 79: fig. 7.—Phleger, Parker, and

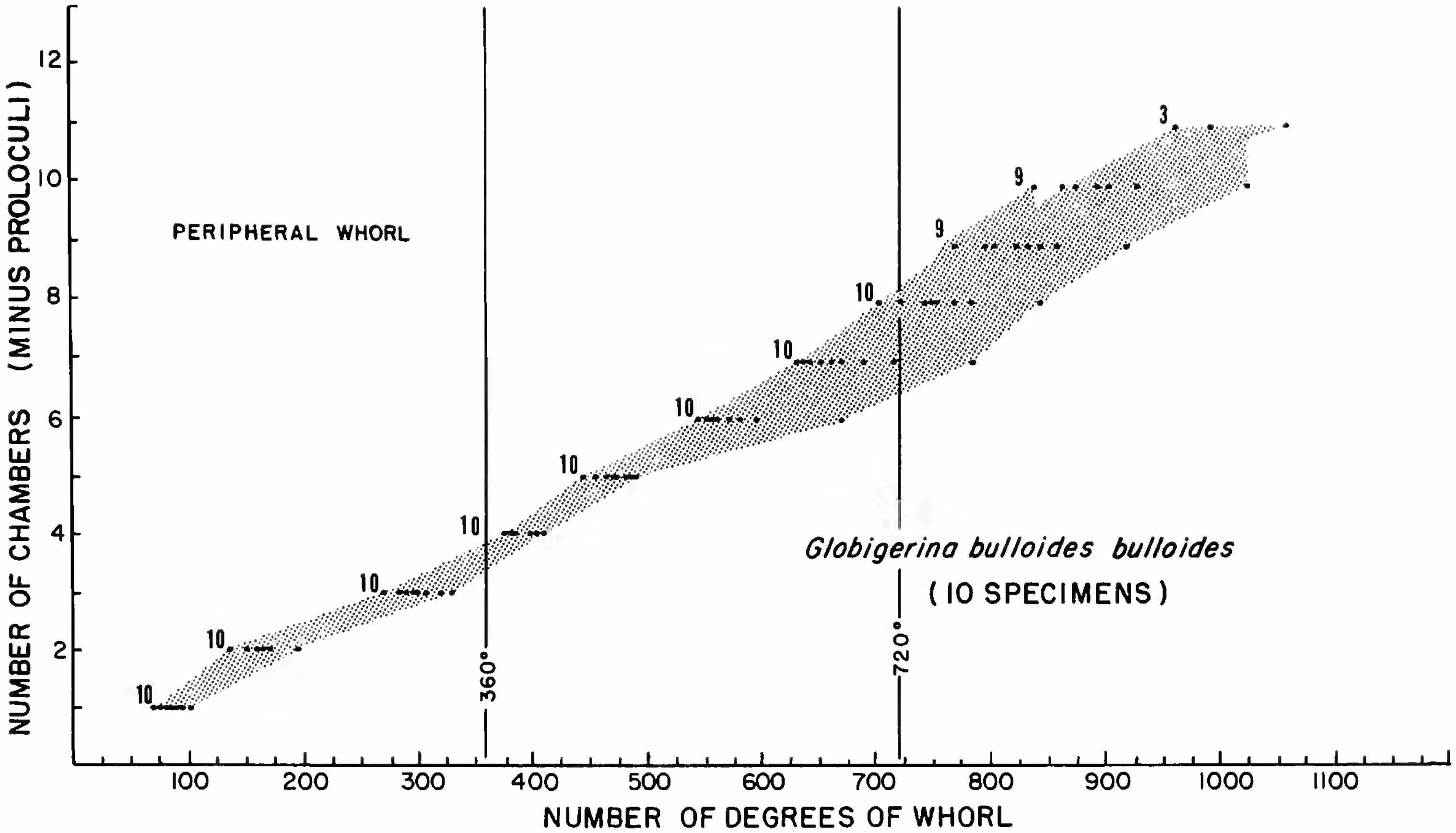


FIGURE 12.—*Globigerina bulloides bulloides.* A growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for 10 specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

Pierson, 1953, p. 11, pl. 1: figs. 3, 4, 7, 8.—Parker, 1958, p. 276, pl. 5; figs. 1–4.—1962, p. 221, pl. 1, figs. 1–8.—Bé, 1959, pl. 1, figs. 15–17.—Bradshaw, 1959, p. 33, pl. 6, figs. 1–4;—Banner and Blow, 1960a, p. 3; pl. 1, figs. 1, 4.—Cifelli, 1965, p. 11, pl. 1, figs. 1–3, 5.

Populations of *Globigerina bulloides bulloides* in the *Atlantis II* material mainly are easily distinguishable from other groups. Occasional difficulty is encountered in separation from some forms of *Globigerinella aequilateralis* in which the growth plan remains essentially trochospiral. Distinction is made primarily on the apertural position, which in *G. aequilateralis* is extra-umbilical and tends to extend into the equatorial region. The growth plan of quite immature forms of *Globigerinoides conglobatus* is almost identical with that of *Globigerina bulloides bulloides,* but the former species is usually easily distinguishable by its coarsely hispid wall and the occurrence of suppementary apertures. A serious problem of differentiation exists between *G. bulloides bulloides* and *G. bulloides falconensis*; this is discussed under the latter taxon. One of the few specimens of *G. bulloides bulloides* with a supplementary aperture is figured (Plate 1; figure 5) because it is unique.

MEASUREMENTS.—Ten specimens were selected to show the relationship between number of chambers and test volution in *Globigerina bulloides bulloides* (Figure 12). *G. bulloides bulloides* exhibits a rather distinctive growth pattern among planktonic species, averaging slightly fewer (11) total number of chambers and having fewer (between three and four)

TABLE 3.—*Sizes and chamber numbers of ten specimens of* Globigerina bulloides bulloides

	Range	*Mean*
Maximum diameter (mm) through peripheral whorl	0. 25–0. 40	0. 32
Maximum diameter (mm) less peripheral whorl	0. 09–0. 19	0. 13
Ratio of diameters of peripheral whorl and rest of test	2. 8–2. 1	2. 5
Total number of chambers	9–12	11. 10
Number of chambers in peripheral whorl	3. 5–3. 9	3. 8
Number of chambers in preperipheral whorl	2. 9–4. 7	3. 9

chambers in the peripheral whorl than do many species. All chambers are contained in within two to three test volutions. In the early volutions there is high variability in chamber addition with respect to test volution, but the variability decreases markedly in the pre-peripheral whorl.

DISTRIBUTION.—*Globigerina bulloides,* sensu lato is represented in all *Atlantis II*–13 samples, but seldom in large numbers. Its maximum development is in cold water, especially sample 32, where 29 percent of the assemblage was referred to *G. bulloides falconensis.* No obvious different distribution pattern exists between the two subspecies, *G. bulloides bulloides* and *G. bulloides falconensis.* In *Atlantis II*–9 samples, *G. bulloides,* sensu lato dominated at five of the eleven stations.

Globigerina bulloides falconensis Blow

PLATE 1: FIGURE 4

Globigerina falconensis Blow, 1959, p. 177, pl. 9: figs. 40, 41.—Parker, 1962, p. 224, pl. 1: figs. 14, 16–19.

This subspecies tends to be smaller than the subspecies *bulloides* and has a constricted aperture. Of the reduced final chamber and more lobulate periphery, considered characteristic by Parker (1962, p. 224) in differentiating *Globigerina falconensis* from *G. bulloides,* the latter character appears too variable among the present specimens to be taxonomically significant, and neither seems characteristic of North Atlantic populations here referred to this taxon. Populations from the Pacific referred to *G. falconensis* by F. L. Parker and kindly showed to the junior author by her, differ from those here referred to *G. bulloides falconensis,* however. Their chambers do not increase so rapidly in size in the peripheral whorl and thus their outline differs. Two taxa may be represented.

Among the present specimens, there are usually between three and four chambers in the peripheral whorl. The earliest peripheral whorl chamber is much smaller than the other three. In the *Atlantis II* material the subspecies *falconensis* is completely gradational to the subspecies *bulloides.* Specimens with three chambers almost completely occupying the peripheral whorl closely resemble some immature *Globigerinoides trilobus* in growth plan.

Insofar as we are able to determine from examination of type-specimens, the relatively small forms with relatively constricted apertures associated with and previously included in *Globigerina bulloides* (see Cifelli, 1965, p. 11, pl. 1: fig. 2) are identical with *G. bulloides falconensis* of this report. As in our material these forms intergrade, we propose to treat *G. falconensis* as a subspecies of *G. bulloides.*

Perhaps it should be emphasized at this point that subspecies as used here refer to *populations* not to *forms* or specimens. Most of our populations show considerable variation and include mixtures of *bulloides* and *falconensis,* although one or the other usually clearly dominates. We assign populations according to which form is the most abundant. Thus, *Globigerina bulloides falconensis* includes those populations where over half of the individuals are recognizable as *falconensis.*

In the present material, a major differentiation problem exists between *Globigerina bulloides falconensis* and *Globigerinita glutinata,* and it is possible that some workers would include many of our specimens in *G. glutinata.* A gradation occurs between shiny, smooth-surfaced forms with extraumbilical silt-like apertures and three chambers in the peripheral whorl (morphologically like mature *Globigerinoides trilobus trilobus* but smaller and smoother) and forms with rather opaque, finely hispid walls and with umbilical apertures which, while not as rounded as those characteristic of *Globigerina bulloides* are less silt-like than usual for *Globigerinita glutinata.* With assemblages from some stations only an almost arbitrary separation is possible between *G. glutinata* and *Globigerina bulloides falconensis.* In these assemblages characteristic *Globigerinita glutinata* is poorly developed, although some specimens appear to belong to that taxon. It is interesting, however, that where *G. glutinata* is well developed, as at stations 8 and 13, few forms referrable to *Globigerina bulloides falconensis* occur and the two groups are fairly distinct.

Occasionally, differentiating *G. bulloides falconensis* and *Globigerinita glutinata* from relatively smooth or shiny immature specimens of *Globigerinoides ruber* and *G. trilobus* poses problems. For further discussion of the *G. glutinata* problem, see page 35. *Globigerina rubescens,* rare in the present assemblages, has more spherical chambers than *G. bulloides falconensis* and chambers which in the peripheral whorl, tend to be of approximately the same size instead of increasing markedly in size. The aperture of *G. rubescens* also is more arched and the average size less than that of characteristic *G. bulloides falconensis.*

Globigerina dutertrei d'Orbigny

PLATE 2: FIGURES 1, 2

Globigerina dutertrei d'Orbigny, 1839a, p. 84, pl. 4: figs. 19–21.—? Brady, 1884, p. 601, pl. 81: fig. 1.—Banner and Blow, 1960a, p. 11, pl. 2: fig. 1.—Cifelli, 1965, p. 12, pl. 2: figs. 1, 2.

Globigerina dubia Egger.—Brady, 1884, p. 595, pl. 79: fig. 17.

Globigerina eggeri Rhumbler, 1901, p. 19, fig. 20.—Phleger, Parker, and Pierson, 1953, p. 12, pl. 1: figs. 11, 12.—Parker, 1958, p. 277, pl. 5: figs. 5, 7.—Bé, 1959, pl. 2: figs. 1–3.—Bradshaw, 1959 [part], p. 35, pl. 6: figs. 5, 10 [not 8, 9].

Globoquadrina dutertrei (d'Orbigny).—Parker, 1962, p. 242, pl. 7: figs. 1–13, pl. 8: figs. 1–4.

Fully developed specimens are distinctive and easily recognizable. They have a large, open umbilical aperture, with some development of umbilical teeth and greater number of chambers and degrees of volution than is usual among globigerinids. (The open umbilicus is found much more frequently among water-column than bottom-sediment specimens.) *Globigerina dutertrei,* however, is highly variable and less fully developed forms may closely resemble both *G. incompta* and forms here referred to as *G.* aff. *G. pachyderma.* The relationship of *G. dutertrei* with the latter two species still remains obscure and considerable differences in opinion exist among workers as to synonomies and morphologic limits.

Questioned are how many taxa are actually represented by the *G. dutertrei–G. incompta–G. pachyderma* (or *G.* aff. *G. pachyderma*) complex and whether *G. incompta* is a life stage of either of the other two. From our study of the *Atlantis II*–13 and –9 material, we believe that *G. dutertrei, G. incompta,* and *G.* aff. *G. pachyderma* represent three separate taxa. We will present most of our arguments here, under discussion of *G. dutertrei.* (Bottom-sediment speciments present similar and possibly more complex problems, but they are not discussed per se here.)

Largely, we base our conclusions on differences in development, treated under ontogenies and measurements. Because the problem is intricate, some redundancy is inevitable, but perhaps will emphasize the reasons for our treatment of these forms. We will start with general remarks on problems and resemblances and differences among these forms.

Both Parker (1962, p. 224) and Bé and Hamlin (1967, p. 96) consider *G. incompta* fully synonomous with *G. pachyderma.* Bé and Hamlin regard *G. incompta* as immature *G. pachyderma,* while Parker considers the differences between the latter two forms and *G. dutertrei* sufficient to place them in separate genera and subfamilies. (Parker, 1968 personal communication, presently is inclined to view *G. incompta* as more closely related to *G. dutertrei* and possibly a form of that species.) Yet, considerable similarity exists between *G. incompta* and *G. dutertrei.* When *G. incompta* was first described, it was compared mainly with *G. dutertrei* (Cifelli, 1961). A number of forms in the literature identified as *G. dutertrei* compare favorably or are identical with *G. incompta.*

According to Parker (1962, p. 242), one of the more distinctive features of *G. dutertrei* (*Globoquadrina dutertrei* of Parker) is the "pitted" wall surface. We have noted this "pitted" surface. The "pits" are rather angular and appear to represent open spaces above pores and to be surrounded by discontinuous ridges that look like small papillae joined together. Among the small, ridge-like papillae are a few higher, angular, spinose-appearing projections. For the most part, the ridge-like papillae are continuous around the pore area, but on a single specimen they may range from complete continuity, forming a joined network, to a discontinuous ridge, to isolated, discrete papillae. In *Globigerina incompta* the papillae tend to be more discrete, and in some cases spines protrude from the angular projections. Some tendency, however, exists for papillae to fuse around the pore area, resulting in a surface texture very similar to that of *G. dutertrei.* Therefore, distinction between the two species cannot always be made based on surface texture.

The wall of *G.* aff. *G. pachyderma* is coarser, with a sugary texture, especially in the early stages, and it tends to greatly obscure the earlier chambers. Basically, however, it seems of the same texture, except that the papillae are thicker, more angular, and less regularly arranged. Actually, the fine details of the wall of all species are difficut to ascertain under the light microscope. Textural appearance varies with lighting and state of preservation of specimens. Detailed examination with an electron scanning microscope will be necessary to determine the nature of these fine structures.

Smaller individuals of *G. dutertrei* with fewer than average chambers and relatively large final chambers closely resemble, and are sometimes difficult to distinguish from, *G. incompta* (Cifelli, 1961). We base our separation mainly on the aperture, which tends to be more centrally located and larger in *G. dutertrei* (from the water column). In *G. dutertrei* the arrangement of chambers is less regular and the outline more elliptical. Therefore, we do not believe that *G. incompta* is an immature stage of *G. dutertrei*. In the *Atlantis II*–13 samples *G. incompta* was found in large numbers and associated with but few typical forms of *G. dutertrei;* we believe this supports our contention of two distinct forms.

Smaller forms of *G. dutertrei* also closely resemble fully developed *G.* aff. *G. pachyderma.* The latter taxon, however, has a much more constricted aperture that lacks umbilical teeth. The coarse, sugary wall texture and nature of the reduced final chamber, when it is present, also serve to distinguish *G.* aff. *G. pachyderma. G. dutertrei* from the water column may also have reduced final chambers but they do not tend to be bulla-like as do those of *G.* aff. *G. pachyderma.* The difference in wall texture between (1) *G.* aff. *G. pachyderma* and (2) *G. dutertrei* and *G. incompta* is particularly evident in the early stages, as is the difference in amount of depression of sutures, with *G.* aff. *G. pachyderma* showing relatively little depression.

Ontogenies.—Specimens we believe to represent ontogenetic stages of *G. dutertrei, G. incompta,* and *G.* aff. *G. pachyderma* are illustrated in Figures 13, 14, and 15, respectively. Unfortunately, line drawings cannot reveal adequately ontogenetic differences in wall texture, a feature considered a clue to separation of this complex of species; however, the illustrated specimens are in the National Museum of Natural History collections and are available for examination.

Early stages of *G. dutertrei* have thin, mostly smooth, shiny walls with small, discrete papillae. During growth, the wall becomes thicker and coarser. The papillae appear to coalesce, forming the partially continuous ridges encircling the depressions containing the pores. Though degree of coalescence varies, it is not complete, even in the adult. Occassional fully developed specimens exhibit a final chamber with a thin, smooth, discretely papillate wall like those of earlier stages of ontogeny.

In *G. incompta,* the very early stages show a wall that is thicker and has larger and more discrete papillae than are usually seen in equally immature *G. dutertrei.* During growth, the wall of *G. incompta* tends to follow a similar pattern of coalescence of papillae as occurs in *G. dutertrei,* except that the coalescence begins earlier in the ontogeny and is less well developed in *G. incompta,* leaving many more discrete papillae in the adult form. Thus, the textural pattern of pits and ridges characterizes both *G. dutertrei* and *G. incompta,* though it is less pronounced in the latter, and some morphologic overlap occurs.

In *G.* aff. *G. pachyderma* the ontogenetic textural trend appears just the reverse of that of the two other species. In early stages the wall is extremely thick and coarse, with a sugary texture. The surface is irregular and some spinose and angular papillae can be seen, but for the most part structural details of the texture are difficult to determine. Late in the ontogeny, usually in the last three or four chambers, the wall becomes thinner and the surface more regular. Papillae become more distinct and a pattern of partially coalescent ridges surrounding depressed pore areas can be seen. This pattern bears close resemblance to that of *G. incompta* and also some forms of *G. dutertrei* in which the papillae are less typically coalesced. The *G.* aff. *G. pachyderma* wall, however, remains coarser than that of *G. incompta,* with less regularly shaped papillae that also tend to be more spinose. Thus, while the adult wall of *G.* aff. *G. pachyderma* closely resembles that of *G. incompta* and some forms of *G. dutertrei,* a distinct difference exists in the early stages and some differences can be seen in the mature forms.

The aperture of *G. dutertrei* closely resembles that of *G. incompta* in the early stages. Both apertures are at the base of the final chamber and are umbilical-extraumbilical or extraumbilical but do not reach the periphery. In *G.* aff. *G. pachyderma,* the aperture is relatively small and consistently umbilical-extraumbilical, with the maximum dimension always confined to the umbilical region.

During ontogeny, the aperture of *G. incompta* remains constant in both position and relative size. In *G. dutertrei* (from the water column) the aperture becomes more consistently umbilical and relatively larger and more open early in the ontogeny. This change towards an open umbilical aperture in *G. dutertrei* relates to ontogenetic coiling change and the relatively small size increase of later chambers, which tend to encircle and maximally disclose the umbilicus. In *G.* aff. *G. pachyderma* the aperture remains essentially constant during ontogeny except that it becomes more incised because of increased lobulation of the later chambers.

Thin apertural lips occur throughout the ontogenies of both *G. dutertrei* and *G. incompta.* During growth of *G. dutertrei,* however, some lips develop single, tooth-like lobes (Figures 13*d, e, f*). In *G.* aff. *G. pachy-*

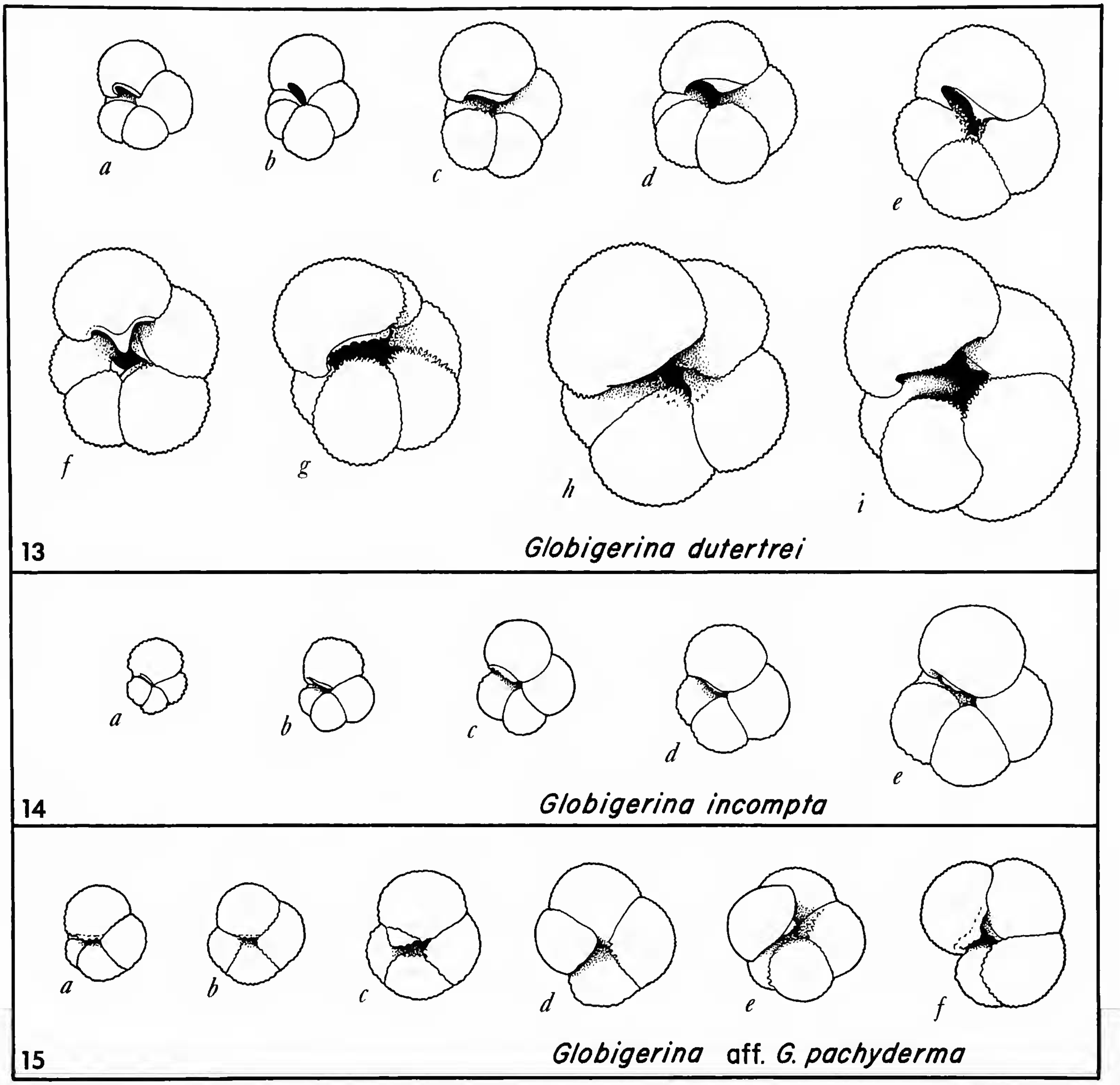


FIGURE 13–15. Comparison of the growth patterns and general morphology of three taxa: 13, *Globigerina dutertrei;* 14, *G. incompta;* 15, *G.* aff. *G. pachyderma.*

derma thin lips are not present in early stages but sometimes appear in later stages. The edge of the aperture may be jagged because of the coarse, sugary, irregular texture of the wall. Also, in both early and late stages there may appear partially or completely developed bullae, ranging to reduced final chambers. The wall texture of these bullae or reduced final chambers corresponds with that of the particular ontogenetic stage at which they occur, in most cases, with a few in the fully developed stage being thinner than the rest of the peripheral whorl chambers.

Both *G. dutertrei* and *G. incompta* begin as flat, compressed coiled forms. *G. incompta,* in the very early stages, is particularly flattened on the spiral side and is globorotalid in appearance (Figure 14*a*). Coiling becomes more conical during growth in both species, but change is more noticeable in *G. dutertrei,* where the later chambers encircle the large, open umbilicus (Figure 13). This encircling and apertural size also relates to the fact that many, though far from all, specimens of *G. dutertrei* show little chamber size increase between the final two or three chambers. In *G.* aff. *G. pachyderma* early stage coils are flattened, although not nearly as compressed as in the other two taxa. The later stages show a slight tendency to become conically coiled, but this tendency is considerably less than in *G. dutertrei.* Related to coiling, though probably in different ways for the different taxa, is that both *G. dutertrei* and *G.* aff. *G. pachyderma* show the exact same number of chambers in the peripheral whorl on both spiral and umbilical sides, while *G. incompta* tends to show slightly fewer on the umbilical than spiral side.

Throughout the ontogeny of *G. dutertrei* and *G. incompta,* the lobulation of the periphery and indentation of sutures remain relatively constant. By contrast, the early stages of *G.* aff. *G. pachyderma* exhibit relatively little indentation of sutures. In later stages lobation and indentation increases markedly and adults thus closely resemble *G. incompta* (Figures 14, 15).

MEASUREMENTS.—The relationship between number of chambers and degrees of volution in *G. dutertrei* is shown in Figure 16. Among all the globigerinids, this species shows the greatest range both in total number of chambers and degrees of whorl. The maximum number of chambers recorded is 19 and the minimum 10. These chambers are contained in between 650° and 1300° of whorl. Four of the 25 specimens measured (see Figure 16) reach more than 1080° (three full whorls) and have 17 or more chambers. Over half the

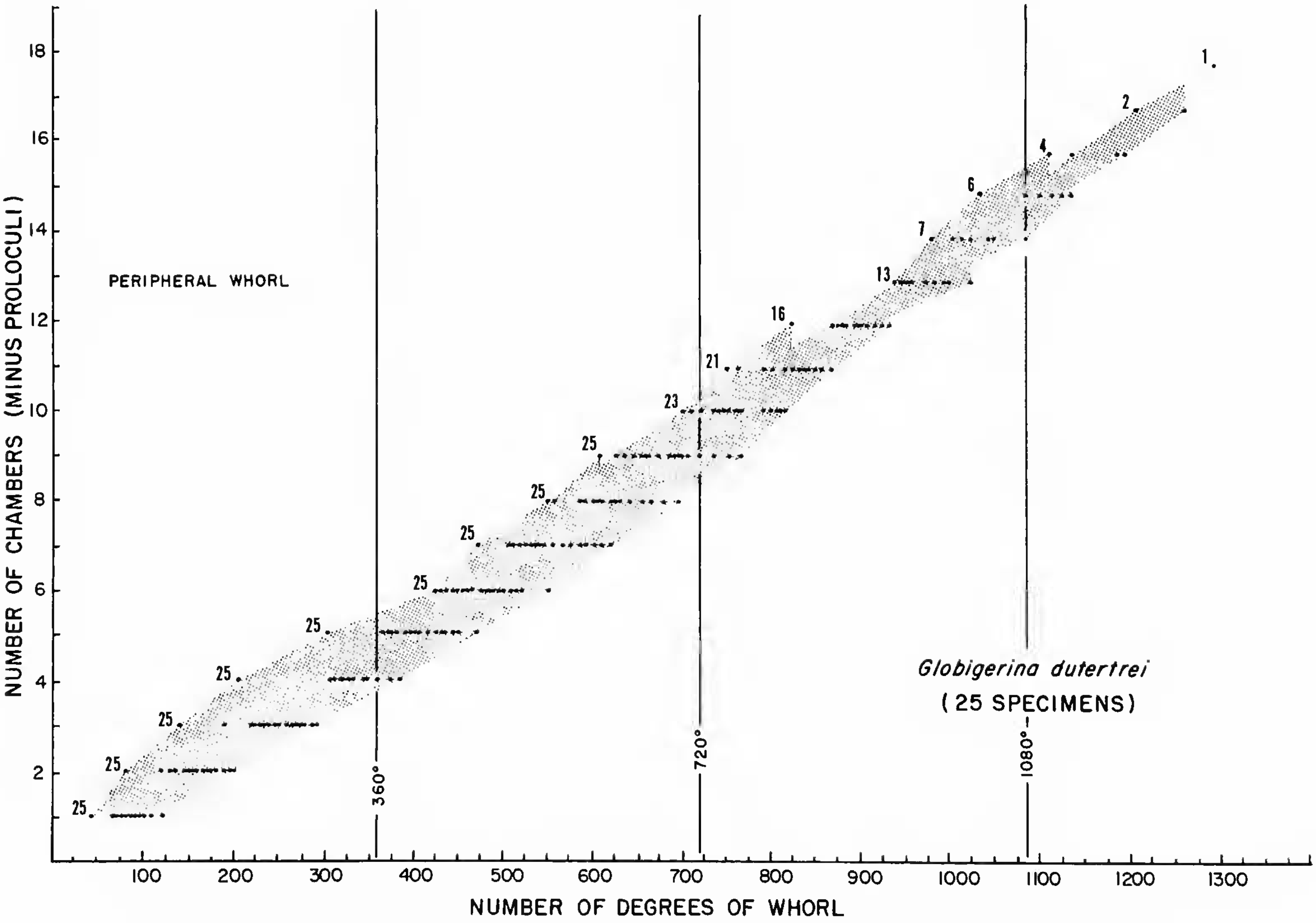


FIGURE 16.—*Globigerina dutertrei.* Growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for 25 specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

specimens reach two and a half full whorls with 13 or more chambers.

The number of chambers in the peripheral whorl of *G. dutertrei* varies and ranges from approximately three and a half to five and a half, with an average of approximately four and a half. In the volution between 360° and 720° (preperipheral whorl) there are slightly more chambers, ranging from approximately four and a half to six, with an average of approximately five. This tendency towards slight decrease in rate of chamber addition with respect to volution in the peripheral whorl seems to characterize most globigerinids.

If the specimens measured may be considered representative of populations as a whole, some differences can be seen between *G. dutertrei, G. incompta,* and *G.* aff. *G. pachyderma* (Figures 16, 17, and 19). First, *G. dutertrei* shows a greater tendency toward both a greater total number of chambers and degrees of whorl. As the average *G. dutertrei* is larger, this is not unexpected, but is not a necessary correlate with size. In the peripheral whorl the number of chambers varies from between three and four to between five and six. *G. incompta* and *G.* aff. *G. pachyderma* peripheral whorl chamber-numbers are more constant, between four and five.

A notable difference between *G. dutertrei* and *G. incompta* exists in the variability in rate of chamber addition. In *G. dutertrei* this variation is relatively constant throughout ontogeny. In *G. incompta,* however, high variability occurs among specimens in the earlier volutions and decreases rather suddenly toward the end of the pre-peripheral whorl; in the peripheral whorl the rate of chamber addition is remarkably constant. For example, at chamber 12 of *G. incompta* (Figure 17) the spread in amount of whorl is about 225°, while at chamber one it is only about 25°. In *G.* aff. *G. pachyderma* the pattern of variability in rate of chamber addition is relatively constant, as in *G. dutertrei.* While, however, the rate of chamber addition among specimens is relatively constant, it varies considerably in the ontogeny of individual specimens. Unfortunately, this is not shown in the chamber addition figures as it is not possible to portray individual ontogenies by connecting points with lines without obscuring the general pattern of the figures.

These figures illustrate that *G. dutertrei* tends to have a larger number of chambers, although the mean falls within the range of both *G. incompta* and *G.* aff. *G. pachyderma.* The maximum numbers of chambers of *G.* aff. *G. pachyderma* cannot be determined with certainty in most cases as the early chambers are mostly obscured. The data suggest, however, that *G.* aff. *G. pachyderma* tends to average at least one more chamber than *G. incompta.*

TABLE 4.—*Suites of specimens selected to determine differences in numbers of chambers among* G. dutertrei, G. incompta, *and* G. *aff.* G. pachyderma

	G. dutertrei	*G. incompta*		*G.* aff. *G. pachyderma*
Atlantis II-13 station	9	34	36	36
Number of specimens	35	19	25	8
Number of chambers				
Range	10–19	9–15	10–15	12–15
Mean	13.91	11.89	12.16	12.75
Number of chambers in peripheral whorl				
Range	3.8–5.5	4.0–5.0	4.0–4.5	4.0–5.0
Mean	4.4	4.48	4.34	
Number of chambers in preperipheral whorl				
Range	4.4–6.1	4.0–7.0	4.5–6.5	4.5–6.7
Mean	5.1	5.07	5.34	

TABLE 5.—*Suites of specimens selected randomly for a comparison of maximum diameters of* Globigerina dutertrei, G. incompta, *and* G. *aff*. G. pachyderma

	G. dutertrei	*G. incompta*		*G.* aff. *G. pachyderma*
Atlantis II–13 Station	9	34	36	36
Number of specimens	36	43	40	37
Range of maximum diameters (mm)	0. 20–0. 58	0. 16–0. 36	0. 18–0. 35	0. 20–0. 35
Mean maximum diameters (mm)	0. 3725	0. 2665	0. 25475	0. 2670
Variance	0. 01365	0. 00250	0. 00242	0. 00118

Globigerina dutertrei has the greatest range and largest mean of maximum diameters. The ranges of the other two taxa fall virtually within and at the low-size end of *G. dutertrei*. Mean sizes of *G. incompta* and *G.* aff. *G. pachyderma* are virtually identical. The variance of *G. dutertrei* is the greatest and that of *G.* aff. *G. pachyderma* least. The variances of the two populations of *G. incompta* are very similar.

The F test (see Natrella, 1963) at the 95-percent level was used to determine whether any significant differences between the variances of the taxa exist. The tests showed that there are significant differences between the variances of the three taxa. Further, no significant difference exists between the two populations of *G. incompta*.

All specimens of *G. dutertrei* observed are right coiled.

DISTRIBUTION.—Specimens of *G. dutertrei* occur in almost every sample of the *Atlantis II*–13 traverse and in four from the *Atlantis II*–9 traverse, but in small numbers. The maximum frequency of this species is 6 percent, found at station 9. At *Atlantis II*–13 stations, when *G. incompta* is 8 percent or less, *G. dutertrei* is less than 5 percent (except at station 9). It is, however, more abundant than where *G. incompta* exceeds 8 percent. There *G. dutertrei* usually is 1 percent or less, although totally absent at only two stations (34, 42). At *Atlantis II*–9 stations, on the other hand, *G. dutertrei* is present only where *G. incompta* is relatively abundant (four stations).

Globigerina incompta Cifelli

PLATE 2: FIGURE 3

Globigerina eggeri Rhumbler.—Bradshaw, 1959 [part], p. 35, pl. 6: figs. 8, 9 [not 5, 10].

Globigerina incompta Cifelli, 1961, p. 84, pl. 4: figs. 1–7.

Globigerina pachyderma incompta Cifelli.—Cifelli, 1965 [part], p. 11 [not pl. 1: figs. 4, 6].

The ways in which this species may be distinguished from *Globigerina dutertrei* and *G.* aff. *G. pachyderma* are discussed under *G. dutertrei*. In a previous paper (Cifelli, 1965, p. 11), *G. incompta* was treated tentatively as a subspecies of *G. pachyderma*. This was done because Parker (1962, p. 224) reported that the forms are gradational in Pacific bottom sediments, and some gradation appeared to exist in North Atlantic slope waters. From detailed studies of *Atlantis II*–13 and –9 and other North Atlantic plankton tows, however, it now seems unlikely that such a gradation exists—at least not in the temperate North Atlantic surface waters. Our studies indicate that the close resemblance between adult *G. incompta* and *G.* aff. *G. pachyderma* of this study is the result of ontogenetic convergence (see p. 22 under G. *dutertrei*). In the material we have studied, *G. incompta* and *G.* aff. *G. pachyderma* are distinct, although sometimes difficult to distinguish, particularly when *G. incompta* has a reduced final chamber.

The closest affinities of *G. incompta* seem to be with *G. dutertrei*. While fully developed forms of *G. dutertrei*, with large, open umbilical apertures and relatively numerous chambers are easily distinguished, earlier stages of this species are less distinctive and some morphologic overlap with *G. incompta* occurs. The overlap is slight, however, and we have found no trouble in assigning the majority of our specimens to one or the other species. In spite of this overlap, we would hesitate at this time to treat them as conspecific subspecies. The relations of the *G. dutertrei*–*G.*

imcompta–G. pachyderma complex are still obscure and it is possible that these forms exhibit different morphologic development in areas outside of the temperate North Atlantic.

Very early stages of *G. incompta* have a distinctly globorotalid aspect, being flat on the spiral side, with a low trochospiral coil and have an aperture located extraumbilically, along the base of the final chamber. These small forms resemble some young stages of *G. inflata* which are coarsely hispid, a character more prominent, however, in very early stages of *G. incompta*. We have encountered no difficulty separating *G. incompta* from *G. quinqueloba egelida*, new subspecies, in the present material. Among the seemingly intergrading populations of taxa from the Labrador Sea and Arctic plankton we have examined, however, forms referable to both *G. incompta* and *G. quinqueloba egelida*, as well as other taxa, occur and separations among taxa can be most difficult.

MEASUREMENTS.—Ten specimens of *G. incompta* were selected to determine the relationship between chamber number and degrees of volution (Figure 17). For these 10, the maximum chamber number is 15 and the minimum 10, but the majority have 12. In all but one specimen, the chambers occupy between two and three full volutions, with a maximum of 1050° of whorl. In the peripheral whorl, the number of chambers ranges between slightly less than four to five. In the previous whorl the number of chambers ranges from between four and five to between six and seven.

Chamber addition with respect to degrees of volution is consistent among specimens in the peripheral whorl, but in the earlier volutions considerable variability and a wide spread of points exist (as mentioned previously). In this respect, *G. incompta* resembles *G. bulloides bulloides* (Figures 12 and 17). Within the peripheral whorl consistency, a common tendency for the third chamber measured to occupy more degrees of whorl than the second or fourth may be noted.

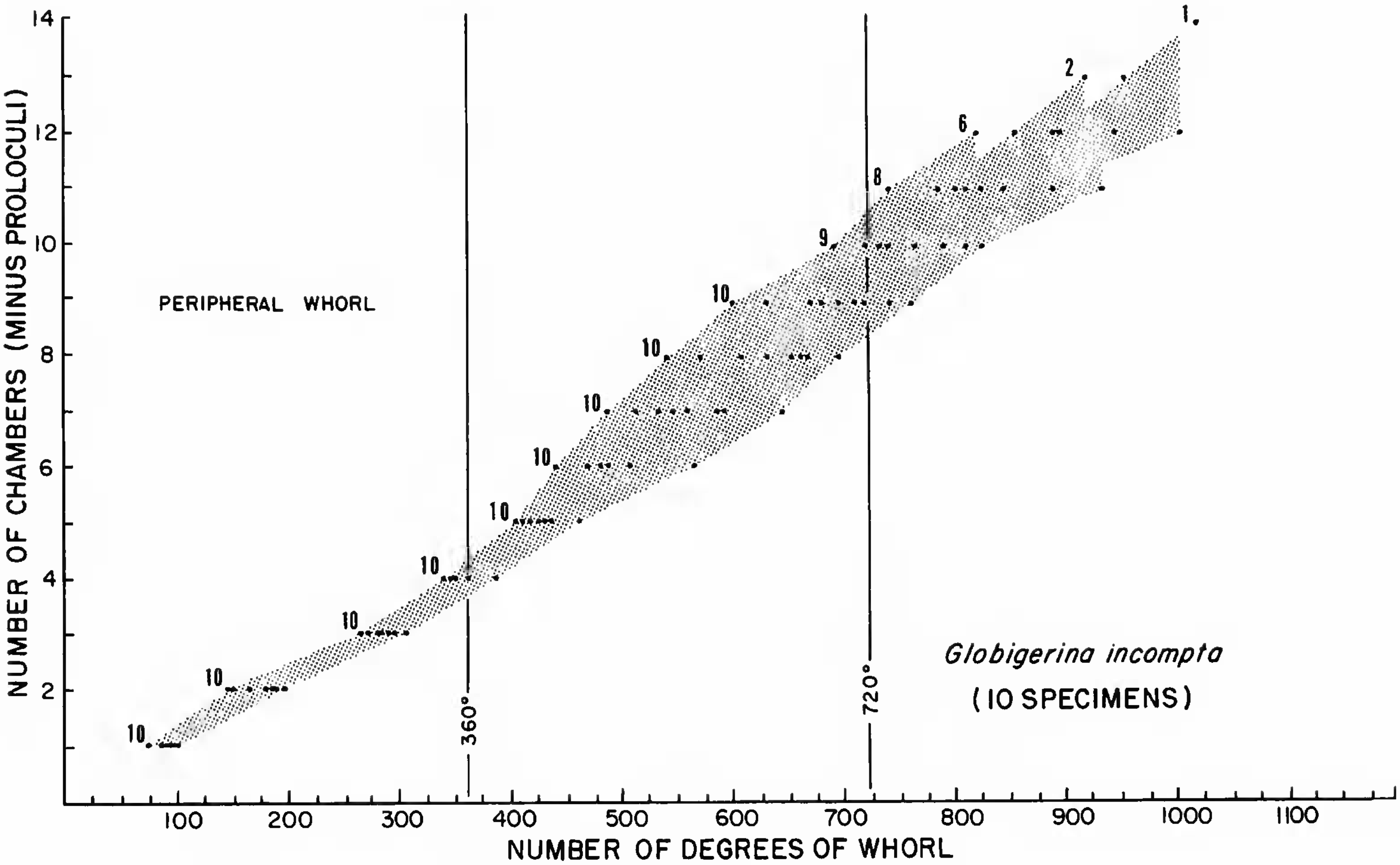


FIGURE 17.—*Globigerina incompta.* Growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for 10 specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

TABLE 6.—*Sizes of the ten specimens of* Globigerina incompta *shown in Figure 17*

	Range	*Mean*
Maximum diameter (mm) through peripheral whorl	0. 18–0. 33	0. 26
Maximum diameter (mm) less peripheral whorl	0. 06–0. 14	0. 095
Ratio of diameters of peripheral whorl and rest of test	3. 0–2. 4	2. 7

Maximum diameters and chamber numbers of an additional number of specimens from two stations were measured and compared with those of *G. dutertrei* and *G.* aff. *G. pachyderma* (Tables 4, 5). All specimens observed are right-coiling.

DISTRIBUTION.—*Globigerina incompta* is present in almost every assemblage studied. It constitutes less than 10 percent of the assemblages in many samples of the *Atlantis II*–13 traverse but reaches 16 percent in sample 4, 32 percent in sample 32, and 64 percent, 72 percent, 62 percent, 55 percent, and 44 percent in samples 34, 36, 38, 40, and 42, respectively. In the *Atlantis II*–9 samples, *G. incompta* constitutes more than 10 percent of four assemblages, 6 of one, and less than 5 percent of four.

Globigerina inflata d'Orbigny

PLATE 2: FIGURES 4, 5

Globigerina inflata d'Orbigny, 1839b, p. 134, pl. 2: figs. 7–9.—Phleger, Parker, and Pierson, 1953, p. 13, pl. 1: figs. 15, 16.—Parker, 1958, p. 277, pl. 6: fig. 3.—Bé, 1959, pl. 1: figs. 12–14.—Bradshaw, 1959, p. 36, pl. 6: figs. 16–18.—Cifelli, 1965, p. 14, pl. 4: figs. 1–3.

Globorotalia inflata (d'Orbigny).—Parker, 1962, p. 236, pl. 5: figs. 6–9.

This species varies considerably in chamber inflation and apertural character. Normally there are four chambers in the peripheral whorl, but some individuals, particularly among small immature ones, contain three or five. Large inflated forms often strongly tend towards peripheral rounding and streptospiral coiling in the final whorl. Rarely the final chamber is reduced. The aperture usually is umbilical-extraumbilical but may be extraumbilical or, more rarely, umbilical, and varies considerably in height. Where the last chamber is streptospirally arranged, as proves to be the case with most specimens upon close inspection, the aperture is oblique to the suture between the first two chambers of the peripheral whorl. Some specimens of this type closely approach *Pulleniatina* in their coiling. In fully trochospiral specimens with four chambers in the peripheral whorl, the aperture is approximately perpendicular to the suture between the two earliest chambers of the peripheral whorl. Normally, high, large apertures are associated with forms with inflated chambers; lower more restricted (although still large) apertures characterize forms with acute peripheries.

As previously noted (Cifelli, 1965, p. 14), the closest morphologic affinities of this species appear to be with *Globorotalia punctulata* (of Cifelli, 1965), the difference being chiefly in the degree of chamber inflation and concomitant peripheral sharpness and in the apertural height. (See Cifelli, 1965 for discussion of the generic placement of *Globigerina inflata* and related problems.) Although the characters are variable, we have not observed a complete transition between the forms. Complete certainty of identity, however, is not always possible with some small, immature individuals. These tend to have relatively acute peripheries; many also have low, restricted umbilical-extraumbilical apertures, although some have rather rounded umbilical apertures. A marked bend in the ventral sutures characterizes some of these small specimens. The numbers of these small problematic specimens usually are significantly smaller than those of more characteristic *Globigerina inflata,* but in sample 13 they occur almost as abundantly. A comparison of the variational patterns between *Globigerina inflata* and *Globorotalia punctulata* is shown in Figure 18.

DISTRIBUTION.—*Globigerina inflata* is well represented in the *Atlantis II*–13 traverse assemblages, being present at every station, ranging in relative abundances from 2 to 34 percent. The small forms which morphologically also approach *Globorotalia punctulata* but are taxonomically referred to *Globigerina inflata* are present in most samples in abundances of from less than 1 to 4 percent. In the *Atlantis II*–9 samples *Globigerina inflata* (including the small form) is very abundant. It is present in all samples, constituting more than 10 percent of every assemblage but one, and 20 percent or greater in all but three, reaching a maximum of 75 percent in sample 288.

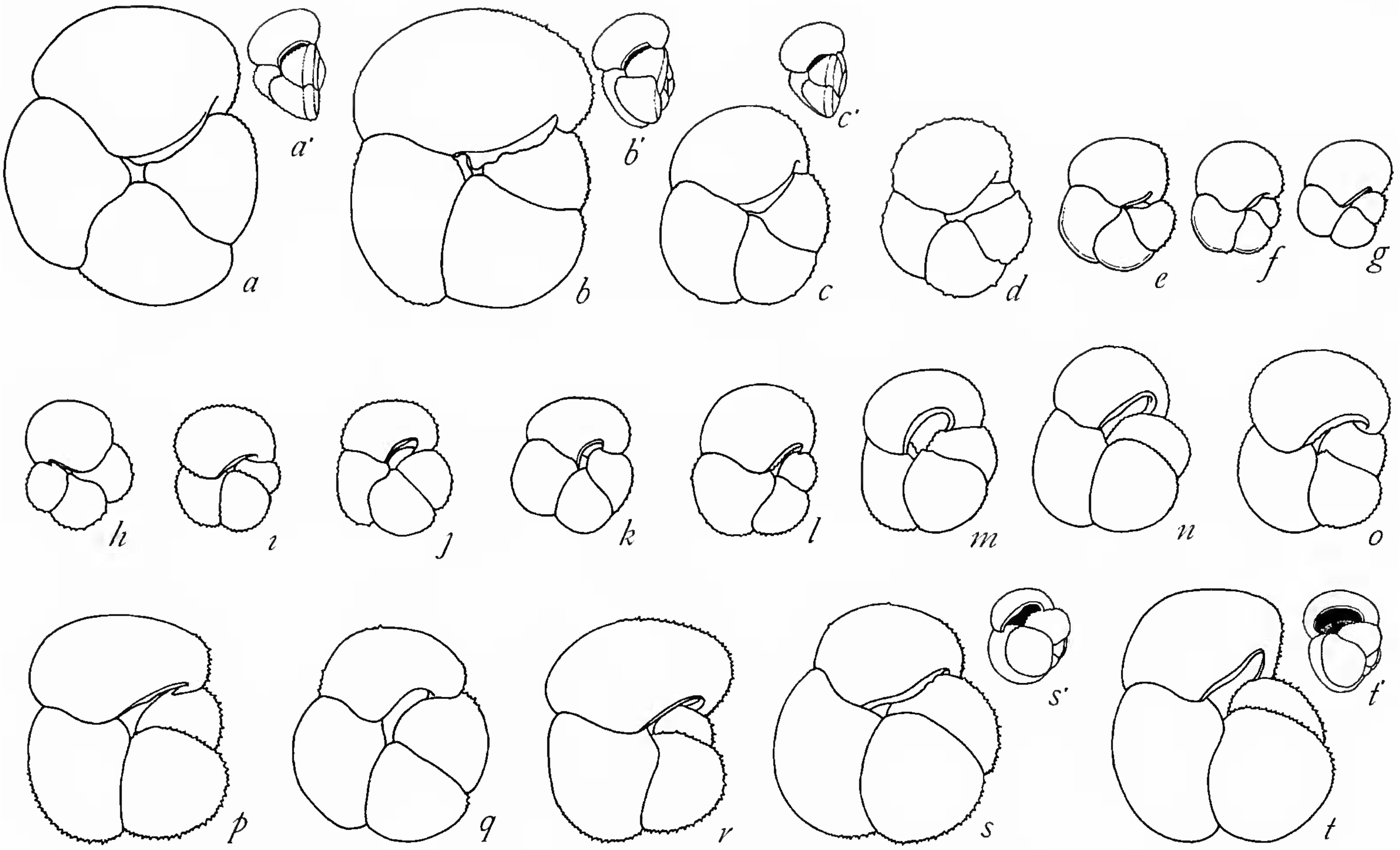


FIGURE 18.—Comparison between and growth series of (*g–a*) *Globorotalia punctulata* and (*h–t*) *Globigerina inflata.* Note similarity between species of some immature individuals.

Globigerina megastoma Earland

PLATE 3: FIGURE 1

Globigerina megastoma Earland, 1934 (1935), p. 177, pl. 8: figs. 9–12.

Two specimens apparently referable to this species were found in the sample from station 5. They are quite distinct from any other forms found in the *Atlantis II* assemblages. Although not as large (0.34 mm maximum diameter as compared with 0.60 mm given by Earland) as Earland's form from the South Atlantic, these two specimens compare well in having a very thin, fairly smooth wall, a highly trochoid spiral test, chambers greatly inflated and rapidly increasing in size with slightly more than four but not five complete chambers in the peripheral whorl, and quite depressed sutures. The nature of the aperture of the present two specimens may differ somewhat from that described by Earland but precise comparison is difficult on the basis of the figures. Earland (1934, p. 177) states that the aperature, "situated on the inner edge of the final chamber is large and semicircular, with a reverted lip." The apertures of the present specimens extend from the umbilical area outward around the periphery to the spiral side of the test. They are large but not semicircular, being rendered rather subrectangular in outline by their position and the presence of an outward-protruding lip across their upper margin, which actually compares favorably with Earland's figures.

To our knowledge this is the first record of this species in the plankton. It may have been overlooked in the past because of the test's frangibleness. The specimens' appearance, especially the aperture, also suggests that they could be immature individuals of some other planktonic taxon, but none occurring in our material.

Globigerina aff. *G. pachyderma* (Ehrenberg)

PLATE 3: FIGURES 2, 3

Globigerina pachyderma incompta Cifelli.—Cifelli, 1965 [part], p. 11, pl. 1.: figs. 4, 6.

Test trochospirally low, rounded to lobate; chambers subangular to subcircular, numbering approximately

12–13 in test, but so obscured in early volution as to be indeterminate on most specimens, with four to five chambers in peripheral whorl, exact number depending on final chamber size; chambers in peripheral whorl of almost equal size except final chamber which may be reduced; aperture small, umbilical-extraumbilical but mostly umbilical with slit-like extension towards periphery, often partially overlapped by reduced final chamber or bulla; wall thick, coarse with surgary texture, hispid, ridged, and pitted; sutures radial, flush in early part to depressed in peripheral whorl, mostly obscure on early chambers; coiling to the right.

The specimens included here bear the most resemblance to *Globigerina pachyderma* of any we have observed in North Atlantic plankton. The resemblance is closest among the small, not fully developed individuals. These are characterized by extremely compact tests with thick walls, which obscure early chambers, by silt-like apertures whose maximum dimensions are centrally located, and by four chambers in the peripheral whorl. Except for the fact that they are on the average smaller, they compare favorably with *G. pachyderma* observed in bottom sediments from the Arctic and Antarctic regions. The larger, more fully developed specimens, however, become less compact, with the aperture umbilical-extraumbilical and more open, though partly obscured by the downward extension of the final chamber. They also usually have a less coarsely surfaced, although still sugary-appearing wall in the latter part of the test. There are between four and five chambers in the peripheral whorl. Where a full fifth chamber appears in the peripheral whorl, it is much reduced in size, and sometimes bulla-like. Adult specimens closely resemble and can be confused with *G. incompta,* as was done by Cifelli (1965, p. 11, pl. 1: figs. 4, 6) with the two specimens he figured as variants of *G. incompta.* They are distinguishable, however, from *G. incompta* and *G. dutertrei,* which they also resemble, mainly on their ontogenetic development which is discussed under *G. dutertrei* (p. 22).

In contrast, a suite of specimens from Pacific bottom sediments kindly sent us by F. L. Parker includes forms comparable to mature *Globigerina* aff. *G. pachyderma* and to mature *G. dutertrei.* Further, specimens from Atlantic bottom sediments show transition between forms referable to *G. dutertrei* and *G.* aff. *G. pachyderma,* although these forms are not identical to our water-column specimens. No clear division between either the Pacific or Atlantic bottom sediment forms could be made. They seemingly represent transitional series and it might therefore appear that *G.* aff. *G. pachyderma* of this report is an immature form of *G. dutertrei.* Further, the junior author has seen a few specimens at Scripps Institution of Oceanography that were collected from the water column in the Pacific. These specimens are definitely referable to "typical" *G. pachyderma* and they occur in association with *G. dutertrei.* We have no explanation for the apparent differences in relationships of these two water-column groups between the Atlantic and Pacific, nor for the differences between the transitional series from the two oceans. Possibly, *G. pachyderma* and *G. dutertrei* are polyphyletic groups. On the basis of the Atlantic water-column material that we have examined, however, the taxa are discrete and we prefer to retain them until relationships are clarified.

Perhaps the chief problem with *Globigerina pachyderma* is that while it dominates bottom planktonic faunas in the Arctic and Antarctic regions, comparable assemblages mainly are of doubtful occurrence or absent in the plankton. It is possible that they live mainly in water deeper than normally sampled. According to Bé (1960a) forms with *G. pachyderma* morphology do not occur in Arctic surface waters. In *G.* aff. *G. pachyderma* of this report, the forms most comparable with *G. pachyderma,* forma typica, constitute but small percentages of the populations.

To account for the apparent absence of *Globigerina pachyderma,* forma typica, in surface waters, Bé concluded that the *G. pachyderma* morphology is achieved after the individuals sink below 200 meters, where additional calcite and a reduced final chamber are added. We cannot reconcile our observations with this conclusion. First, the forms from *Atlantis II*–13 and –9 that are comparable with *G. pachyderma* come from waters 200 meters or less deep. It may eventually prove biogeographically significant that these waters are temperate, not Arctic. Second, our ontogenetic interpretation is opposite to Bé's. We infer that the *G. pachyderma* found is an early, rather than late, developmental stage. Finally, Arctic plankton assemblages we have observed are composed of a variety of forms of difficult taxonomic placement. We find it hard to see how many of them could assume the *G. pachyderma* morphology by Bé's mechanism.

Another interpretation of the *G. pachyderma* problem, one that deserves serious consideration, is that of Uchio (1960). Uchio suggested that the *G. pachyderma* on the Antarctic bottom were deposited sometime before the present and that sedimentation there is slow. Dating of the tests by C_{14} gave 5,490 (±370) years ago.

According to D. J. Stanley (personal communication), the bottom in the region around Nova Scotia, particularly on the slope, and perhaps around the Arctic region as a whole, receives little sediment and the Pleistocene crops out near the surface. There are also indications that the Holocene sediment exposed may be mixed with Pleistocene. Another possibility is that the Arctic and Antarctic cold waters act to dissolve tests of species with relatively thin walls at depths considerably less than normal calcium carbonate compensation depth. Kennett (1966) and Berger (1968), among others, have shown that Arctic and Antarctic bottom waters act particularly aggressively in attacking calcium carbonate. Most of the forms we have observed in Arctic plankton have relatively thin walls, so perhaps most dissolve before, or shortly after reaching the bottom. In summary, it is worth considering that assemblages of *G. pachyderma,* sensu stricto, observed on the bottom are extinct or near extinct, and that *G.* aff. *G. pachyderma* is a descendant subspecies.

Measurements.—The relationship between chamber number and test volution of six specimens of *Globigerina* aff. *G. pachyderma* is shown in Figure 19. The coarse wall surface obscures chambers in early volutions and the exact total number clearly shows on only two of the six specimens. For this reason, queries are placed at the initial volutions in Figure 19. The recorded maximum number of chambers on any specimen is 14, but probably the actual maximum is not much greater, since the wall totally obscures only a minute portion of the test.

Chamber addition in this species appears relatively consistent throughout the observable part of the

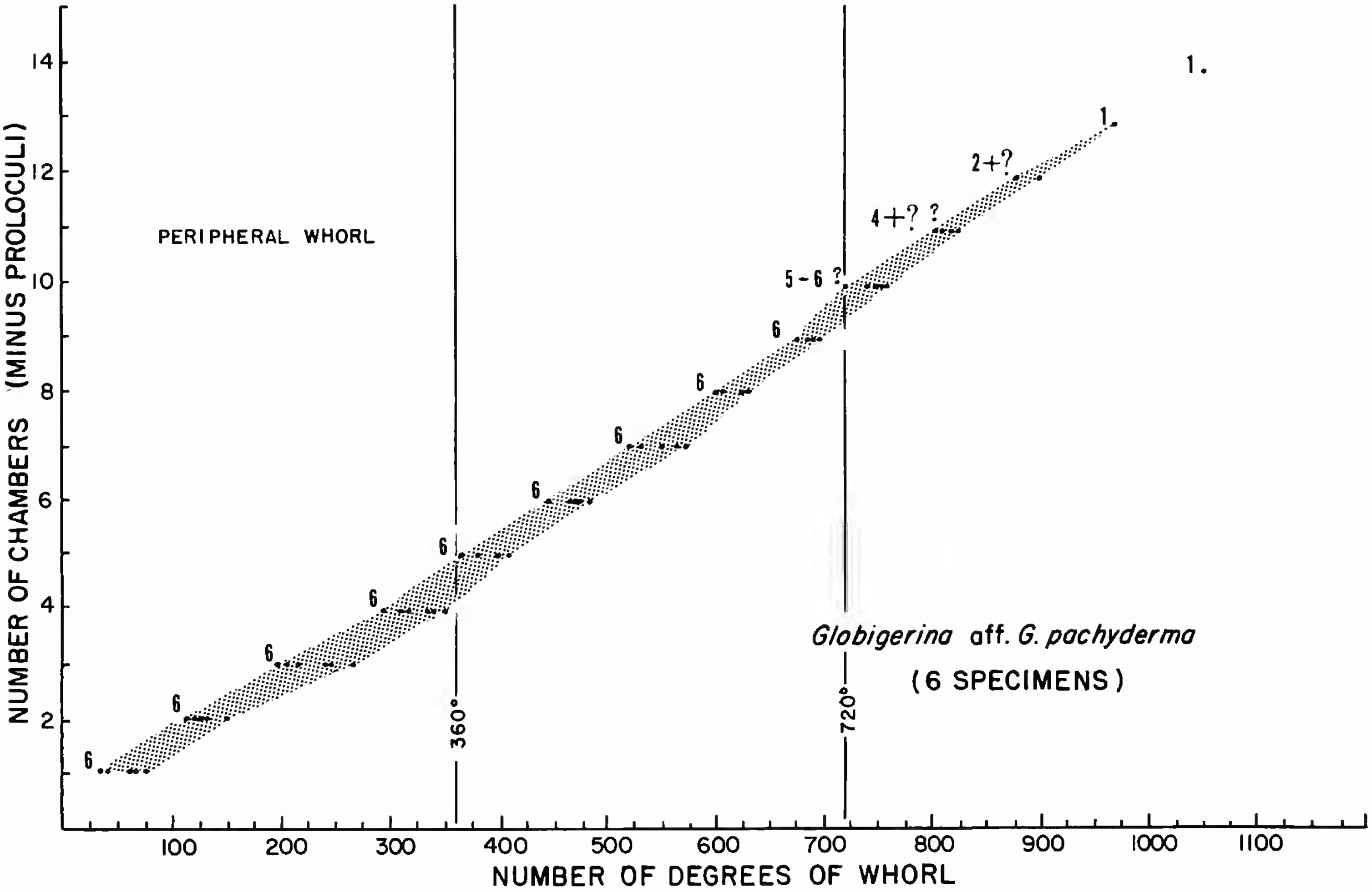


Figure 19.—*Globigerina* aff. *G. pachyderma.* Growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for six specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

ontogeny, more comparable, in this respect, with *G. dutertrei* than with *G. incompta* (Figures 16, 17).

The relationship or ratio between chambers and degrees of whorl does not vary particularly among individuals, except as affected by the amount of reduction of the final chamber. In this respect, *G.* aff. *G. pachyderma* is much more consistent than either *G. dutertrei* or *G. incompta,* although both *G.* aff. *G. pachyderma* and *G. incompta* are quite consistent in the peripheral whorl. Each chamber of the peripheral whorl occupies about the same number of degrees with *G.* aff. *G. pachyderma* (except reduced final chambers) while this is not the case with *G. incompta.* As with *G. incompta,* most specimens of *G.* aff. *G. pachyderma* extend into but do not complete a third whorl. All specimens of *G.* aff. *G. pachyderma* measured fully completed their fourth chambers in the peripheral whorl, which is not so for *G. incompta* or *G. dutertrei.* In all specimens there are between four and five chambers in the peripheral whorl and a slightly greater number (about half a chamber in the measured specimens) in the pre-peripheral whorl. The recorded maximum number of degrees of volution in *G.* aff. *G. pachyderma* is about 1040°; and the actual number probably is about the same as in *G. incompta.*

TABLE 7.—*Sizes of the six specimens of* Globigerina *aff.* G. pachyderma *shown in Figure 19*

	Range	*Mean*
Maximum diameter (mm) through peripheral whorl	0.28–0.35	0.31
Maximum diameter (mm) less peripheral whorl	0.12–0.17	0.13
Ratio of diameters of peripheral whorl and rest of test	2.3–2.1	1.8

These maximum diameters are slightly greater than those of the suite chosen for comparison with *G. dutertrei* and *G. incompta* (see p. 26). Probably this is because of some bias towards larger specimens in the present suite, in order to reveal maximum ontogenetic development.

DISTRIBUTION.—*Globigerina* aff. *G. pachyderma* occurs in small numbers in almost all *Atlantis II*–13 samples, reaching a peak of 6 percent of the assemblage at station 34. It represents less than 1 percent and 2 percent, respectively, in two *Atlantic II*–9 assemblages.

Globigerina quinqueloba egelida, new subspecies

PLATE 3: FIGURES 4, 5, 6, 7

Globigerina cf. *quinqueloba* Natland.—Todd and Bronnimann, 1957, p. 40, pl. 12: figs. 2, 3.—Bé, 1959, pl. 1: figs. 21, 22.

Globigerina aff. *G. quinqueloba* Natland.—Cifelli, 1965, p. 13, pl. 2: figs. 3, 4.

Test trochospirally low with a rounded, lobate periphery, and with up to three and occasionally part of four whorls; chambers subspherical, enlarging fairly rapidly and at an even rate, usually with four and a half to five in the peripheral whorl, which are visible on both sides of the test, and averaging a total of 13 or 14 in the adult test, forming a low, conical spire on most specimens but almost planar in others, final chamber often itself extended or with a thin lip or flap extending downward to partially cover the aperture, occasionally a reduced final chamber or a bulla covering the aperture; aperture interiomarginal, umbilical to umbilical-extraumbilical, subrounded; sutures distinct, narrow, depressed, radial on both sides; wall finely perforate, thin, finely hispid or spinose but with occasional specimens having a few coarser spines around the peripheral parts of the chambers, sometimes in combination with a reduced final chamber; direction of coiling about equally divided between left and right. Maximum diameters of holotype and paratypes 0.15–0.24 mm.

According to F. L. Parker (personal communication) paratypes of *Globigerina quinqueloba* Natland presumably deposited at the Scripps Institution of Oceanography are not there, so that the holotype, deposited at the National Museum of Natural History is the only available primary type. The holotype of *Globigerina quinqueloba* Natland resembles *G. quinqueloba egelida,* but does not fall within the range of variation of the North Atlantic assemblages included within this new subspecies. The chief differences are that the test of the holotype is thicker walled, more compact, with less depressed sutures and a less lobulate

TABLE 8.—*Sizes and chamber numbers of forty specimens of* G. quinqueloba egelida, *new subspecies* (*ten plotted on Figure 20, ten from* Atlantis II–*13 sample 26, and 20 from sample 18*)

	Range		*Mean*	
Station (*Atlantis II*–13)	26	18	26	18
Maximum diameter (mm) through peripheral whorl	0. 11–0. 26	0. 10–0. 19	0. 20	0. 14
Maximum diameter (mm) less peripheral whorl	0. 06–0. 10	–	0. 08	–
Ratio of diameters of peripheral whorl and rest of test	1. 8–2. 6	–	2. 5	–
Total number of chambers	11–16	12–14	14 (13. 79)	13 (12. 95)
Number of chambers in peripheral whorl	4. 5–5. 0	4. 6–5. 0	4. 69	4. 78
Number of chambers in pre-peripheral whorl	4. 5–5. 0	4. 2–6. 0	4. 74	4. 86

periphery. Of these differences, the only one possibly a result of the holotype being a bottom-sediment specimen is the thicker wall. Moreover, the holotype is thicker with respect to its maximum diameter than *G. quinqueloba egelida* and also appreciably larger in maximum diameter. In *G. quinqueloba egelida,* the aperture is small and either open and semicircular, often with a thin lip, or modified and partially covered by the final chamber which may form a flap that obscures, but does not completely close over the aperture (bullae are seldom seen). State of preservation of the holotype prevents determination of whether there may be a thin lip at the base of the flap. In contrast to *G. quinqueloba egelida,* however, the flap of the holotype is a gross feature that extends across the aperture, attaching to the chamber below, almost completely closing over the apertural area. Most adult specimens of *G. quinqueloba egelida* have a total of 13 chambers with between four and half and five in the peripheral whorl, which is the same as the holotype of *G. quinqueloba.*

Comparison between *Globigerina quinqueloba egelida,* new subspecies, and *G. quinqueloba,* sensu stricto, has been made from a suite of specimens from the approximate type-locality, kindly furnished us by F. L. Parker. This suite of specimens appears to show a gradation between the holotype of *G. quinqueloba* and *G. quinqueloba egelida.* As a group, the specimens are closer to the holotype in the thicker, more coarsely hispid and perforate wall, compactness and thickness of test, relatively slight depression of sutures and the pronounced apertural coverings and flaps. The majority of specimens, however, are not as thick or as compact as the holotype, and the holotype, therefore, appears an end member of the populations of the species that we have seen.

All assemblages of *Globigerina quinqueloba* that we have observed in North Atlantic plankton tows are referable to *G. quinqueloba egelida,* new subspecies. Thus we include in our synonymy those figured as *G.* cf. *quinqueloba* by Bé (1969) and *G.* aff. *G. quinqueloba* by Cifelli (1965). The assemblages from bottom sediments in the Gulf of Paria figured by Todd and Bronniman (1957) as *G.* cf. *quinqueloba* are referable to the new subspecies, as are the specimens from North Atlantic bottom sediments figured as *G. quinqueloba* by Phleger, Parker, and Pierson (1953).

The specimen figured by Bradshaw (1959) as *G. quinqueloba* from Pacific plankton appears to belong to *G. quinqueloba,* sensu stricto.

A close similarity exists between *G. quinqueloba egelida,* new subspecies, and the subarctic planktonic form with five chambers in the peripheral whorl referred by many to *G. pachyderma.* Characteristically, however, that form is larger and thicker than the present specimens, has a more umbilical and more open aperture, and a heavier wall. The relationship between these two forms needs further investigation.

A form with a few coarser spines and reduced, rather peculiarly shaped final chambers might repre-

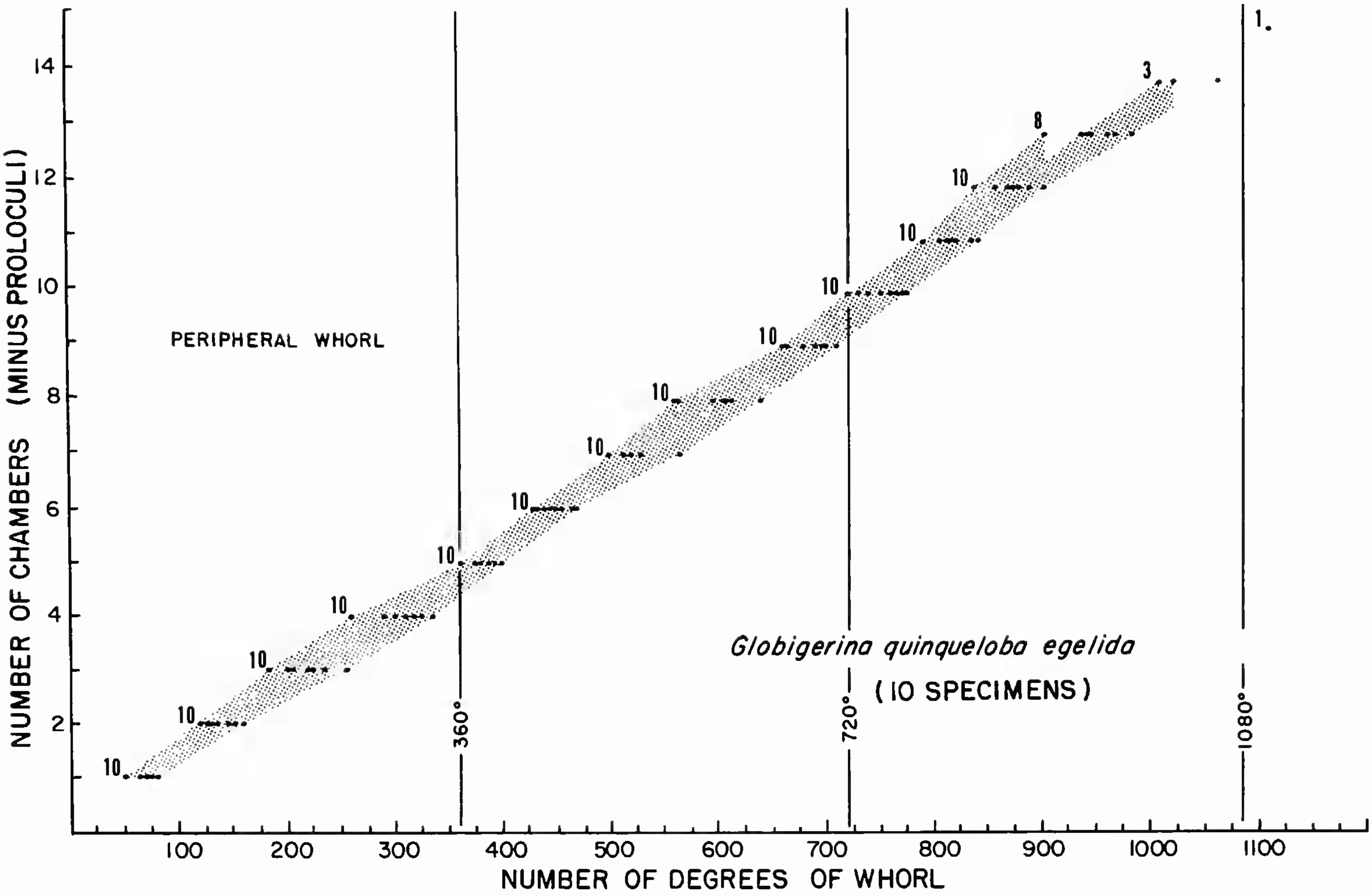


FIGURE 20.—*Globigerina quinqueloba egelida,* new subspecies. Growth pattern expressed as the relationship between number of chambers and number of degrees of whorl for 10 specimens. The measurement increase on both axes goes from the final chamber inward, not from proloculus outward.

sent a distinct group, but specimens of this sort are only occasionally seen and the relationship is difficult to determine.

Comparison between *G. quinqueloba egelida,* new subspecies, and *G. atlantisae,* new species is made under *G. atlantisae* (p. 17).

MEASUREMENTS.—The relationship between chamber number and test volution in ten specimens of *Globigerina quinqueloba egelida* is shown in Figure 20. Chamber addition in this species is relatively consistent through ontogeny, probably most closely comparable with *G. atlantisae,* new species (Figure 11). Spread of points is relatively low through whorls, and the decrease in chamber number with respect to test volution in the periphereal whorl is negligible. The minimum number of chambers recorded was 11 and the maximum 16, contained in 1110°, or slightly more than three full whorls. In the majority of specimens there were 13 to 14 chambers, contained in 800° to 1000°; or between two and three whorls; all specimens completed more than two whorls. The number of chambers in the peripheral whorl was four to five. In the pre-peripheral whorl the chamber number is about the same. The number of chambers in the peripheral whorl of *G. quinqueloba egelida* tends to be slightly greater than in *G. atlantisae* and even slightly more so than in *G. incompta* (Figures 11, 20).

DISTRIBUTION.—*Globigerina quinqueloba egelida,* new subspecies, occurs in most of the samples examined. They account for less than 10 of the assemblage in eleven *Atlantis II*–13 and six *Atlantis II*–9 samples, 15 and 20 percent in two *Atlantis II*–9 samples, and 21, 22, 53, and 55 percent in five *Atlantis II*–13 samples (stations 29, 4, 28, 16, and 26, respectively).

Globigerina rubescens Hofker

PLATE 4: FIGURE 1

Globigerina rubescens Hofker, 1956, p. 234, pl. 35: figs. 18–21.—Parker, 1962, p. 226, pl. 2: figs. 17, 18.

Hofker (1956) remarks on the similarity of this species to *Globigerinoides ruber;* however, no difficulty occurs in separating the two except when small immature specimens of *G. ruber* with four chambers in the final whorl are present (see p. 38). These two forms are separable on the basis of the juvenile specimens of *G. ruber* having a much more rapid increase in chamber size with the result that the final chamber occupies most of the area above the previous three chambers, giving a somewhat rectangular outline to the test, as opposed to the almost diamond-shaped outline of *Globigerina rubescens.* The aperture of *G. rubescens* also tends to be more restricted than that of juvenile *Globigerinoides ruber,* the wall more finely hispid, and the chambers slightly more spherical.

Globigerina rubescens closely resembles some variants of *G. bulloides falconensis.* In this case the distinguishing differences are the more rapid increase of chamber size and the less spherical shape of the chambers of *G. bulloides falconensis. G. rubescens* has a more diamond-shaped outline. A few specimens of *Globigerinita glutinata* with relatively coarse walls are quite similar but have more restricted apertures, in the present populations at least.

DISTRIBUTION.—*Globigerina rubescens* occurs in 17 assemblages from *Atlantis II*–13 and one from *Atlantis II*–9 collections, but never exceeds a frequency of 1 percent.

Genus *Globigerinella* Cushman, 1927

Globigerinella aequilateralis (Brady)

PLATE 4: FIGURES 2, 3, 4

Globigerina aequilateralis Brady, 1884, p. 605, pl. 80: figs. 18–21.

Globigerinella aequilateralis (H. B. Brady).—Phleger, Parker, and Pierson, 1953, p. 16, pl. 2, fig. 8.

Globigerinella aequilateralis (Brady).—Parker, 1958, p. 278, pl. 6: figs. 5, 6.—Bé, 1959, pl. 1: figs. 19, 20, 27.—Bradshaw, 1959, p. 38, pl. 7: figs. 1, 2.—Cifelli, 1965, p. 22, pl. 7: figs. 3–5.

Globigerinella siphonifera (d'Orbigny).—Parker, 1962, p. 228, pl. 2: figs. 22–28.

Globigerinella aequilateralis is a distinctive but variable species. Contrary to the original description, it is trochospiral instead of planispiral, at least in the earlier stages. The position of the aperture is somewhat variable but mainly is spiro-umbilical, forming a long slit around the base of the final chamber, with a longer extension occurring on the umbilical side. Some specimens exhibit uncoiling. Chambers vary in thickness, and the final chamber may or may not be significantly larger than the previous. Sutures are always depressed and radial but the degree of depression and compactness of the test varies considerably. The wall is finely and densely perforate and spinose.

Some immature specimens are very similar to *Globigerina bulloides* and in some cases separation between the two groups becomes almost arbitrary. Distinction is based on the position of the aperture, which in *G. bulloides* never reaches the periphery.

DISTRIBUTION.—*Globigerinella aequilateralis* occurs commonly in the *Atlantis II*–13 material and rarely in the *Atlantis II*–9. Present in every sample of the former, it ranges from less than 1 to 23 percent. In the latter, it constitutes less than 1 percent in two assemblages and 2 percent in another.

Genus *Globigerinita* Bronnimann, 1951

Globigerinita glutinata (Egger)

PLATE 4: FIGURE 5

Globigerina glutinata Egger, 1893, p. 371, pl. 13: figs. 19–21.

Globigerinita glutinata (Egger).—Phleger, Parker, and Pierson, 1953, p. 16, pl. 2: figs. 12–15.—Bé, 1959, pl. 1: figs. 25, 26.—Bradshaw, 1959, p. 40, pl. 7: figs. 7, 8.—Cifelli, 1965, p. 16, pl. 3: figs. 2, 4, 5.

Parker (1962, p. 247) has reviewed the history and discussed the complexities of this species and the genus *Globigerinita.* Thus far we have no adequate criteria for establishing morphologic limits to *Globigerinita glutinata.* In particular, its relationships with *Globigerina bulloides falconensis* of this study are obscure. It would seem that a gradational series may exist between the two forms although usually in assemblages where one is abundant and of characteristic morphology, the other is not.

In the absence of the specifically characteristic bulla and secondary aperture, rarely seen in North Atlantic populations, the one seemingly distinguishing feature of *Globigerinita glutinata* is the wall surface. In its typical form, the wall surface appears smooth, white, and shiny. Yet, if the wall surface is treated as an invariant character, the species limits become narrowly defined and exclude many specimens with otherwise identical morphologic characters. Moreover, wall surface cannot always be unequivocally interpreted, at least under the binocular microscope. The surface is covered by numerous closely, irregularly spaced, short spinose projections. These projections are small but vary in size from specimen to specimen and in some cases they coalesce. The size of these projections often decreases on later chambers, sometimes not being present on the final chamber or apertural bulla.

It is, of course, possible that the ultrastructure of *G. glutinata* eventually may prove unique. Under the binocular microscope, however, close inspection shows that the size, density, and regularity of spacing of the spinose projections and their relationship to the pores seems to determine the surface appearance. Where a high density of small spinose projections of uniform height and spacing occurs, the apparently smooth, shiny wall of the typical *G. glutinata* results. Increase in size and irregularity in the height and spacing of the projections results in the wall looking spinose, as in *Globigerina bulloides falconensis.* A translucent, glassy appearing wall results when the projections and pores are widely spaced or absent. This glassy wall is similar in appearance to that of *Hastigerina pelagica.* In the present material those *Globigerinita glutinata* with the most glassy wall mainly have the chamber arrangement of adult *Globigerinoides trilobus trilobus,* with three fairly compactly arranged chambers in the peripheral whorl, a relatively large final chamber and a slit-like extraumbilical or peripheral aperture.

In view of the apparently variant character of the wall surface, we here interpret *Globigerinita* quite broadly and include a varied suite of specimens in *Globigerinita glutinata.* Included in the group referred to *Globigerinita glutinata* are (1) those specimens with a compact chamber arrangement with three to four rapidly enlarging chambers in the peripheral whorl, mainly fairly smooth-surfaced and shiny, though having small spinose projections and usually with a reduced to slit-like extraumbilical to peripheral aperture with a phialine lip; (2) glassy-walled forms, with relatively few, widely spaced small spinose projections, four chambers in the peripheral whorl which are less compactly arranged and less rapidly enlarging than the above, with the final chamber only slightly if at all larger than the penultimate, and with the aperture centrally located in the umbilicus, but still reduced and with a phialine lip; (3) specimens with some but not all of the above characters which appear to grade into *Globigerina bulloides falconensis* but generally with the aperture more reduced or extraumbilical and with a phialine lip and a wall that is smoother and more shiny than that of characteristic *G. bulloides falconensis.* Separation from *G. bulloides falconensis* has been arbitrary in some cases. No secondary apertures and only one bulla were seen on the specimens from the *Atlantis II* traverses. Occasionally, unusually glassy-appearing juveniles of *Globigerinoides ruber* and especially *G. trilobus,* with its more-reduced aperture, superficially resemble *Globigerinita glutinata,* but usually can be distinguished on such features as plan of growth and differences in the wall texture.

Distribution.—*Globigerinita glutinata* is present in all of the samples of the *Atlantis II*–13 traverse, but usually in relatively low frequencies. Its maximum is 9 percent at station 19. It reaches 5 percent or more in only six other samples. This species is much more abundant in the *Atlantis II*–9 samples, being present at nine of the eleven stations and representing approximately 10 percent of the assemblage at four stations and 36 percent at another.

Globigerinita humilis (Brady)

Plate 5: figure 1

Truncatulina humilis Brady, 1884, p. 665, pl. 94: fig. 7.—Banner and Blow, 1960a, p. 36, pl. 8: fig. 1.

Globigerinita humilis (Brady).—Parker, 1962, p. 249, pl. 10: figs. 1–25.

A few specimens from the samples of the *Atlantis II*–9 traverse are referable to this species, not previously recorded from the plankton, to our knowledge. They are small (averaging approximately 0.20 mm in greatest diameter), with six to seven chambers in the peripheral whorl and about 16 in the entire test, distributed in about two and a half whorls. The wall is finely and densely hispid. The chambers are inflated and separated by narrow, depressed sutures, resulting in a lobate periphery. Our specimens, however, lack the modified, extended, final chamber which characterizes the type of the species. In other respects they appear identical with the specimens of *Globigerinita humilis* (Brady) figured by Parker (1962), except in having a slightly more lobate periphery and somewhat more coarsely hispid wall.

Genus *Globigerinoides* Cushman, 1927

Globigerinoides conglobatus (Brady)

PLATE 5: FIGURES 2, 3, 4, 5

Globigerina conglobata Brady, 1884, p. 603, pl. 80: figs. 1–5, pl. 82: fig. 5.—Banner and Blow, 1960a, p. 6, pl. 4: fig. 4.
Globigerinoides conglobata (H. B. Brady).—Phleger, Parker, and Pierson, 1953, p. 15, pl. 2: figs. 1–3.
Globigerinoides conglobata (Brady).—Parker, 1958, p. 279, pl. 6: fig. 17.—Bradshaw, 1959, p. 40, pl. 7: figs. 5, 6.
Globigerinoides conglobatus (H. B. Brady).—Bé, 1959, pl. 2: figs. 7–12.
Globigerinoides conglobatus (Brady).—Parker, 1962, p. 229, pl. 3: figs. 1–5.—Cifelli, 1965, p. 28, pl. 8: figs. 2, 3.
Globigerinoides sp. Bradshaw, 1959, p. 42, pl. 7: figs. 16, 17.

Juvenile specimens of this species closely resemble *Globigerina bulloides,* but are distinguished by their more coarsely hispid wall and the presence of at least one secondary aperture, appearing when the specimens are still relatively small. In nearly or fully developed specimens of *Globigerinoides conglobatus,* two supplementary apertures are clearly visible in later chambers. In the early stages, the primary aperture, although similar to that of characteristic *Globigerina bulloides,* tends to be slightly extraumbilical and slightly less regular in shape. The chambers normally increase in size slightly more rapidly than do those of *G. bulloides.*

It is not unusual for immature specimens of this species to totally represent or outnumber the mature forms and, since marked changes occur during ontogeny, it is possible to assume two taxa are represented. Some of the incompletely developed forms with thin walls and open umbilical apertures are almost as large as mature "typical" *Globigerinoides conglobatus.* It seems probable that some individuals retain this form throughout their ontogeny, although changing in chamber shape and arrangement somewhat, while others develop "typical" morphology.

The fully developed mature individual is very distinct, with the final chamber sometimes capping the apertural area of the previous part of the test and with a very thick, honeycomblike wall and sutures which, while not greatly depressed in the usual sense, often are deeply incised between the extended edges of the chambers. Apparently this wall structure and the consequent incision of the sutures arises out of additional deposition of calcite around the entire exposed surface of the test, which causes spines to coalesce around the pores and grow outward, eventually forming a pronounced honeycomblike structure. Some of the spines protrude markedly further than the general extended surface of the test, and long, discrete spines are often prominent in the primary aperture. When specimens are dissected, the early chambers can be seen to have small pores on those parts which have not been overgrown by later deposition of calcite. The large adult chambers, however, show larger pores at the immediate chamber surface; this can be seen both on the inner and outer surfaces of chambers lacking in secondary shell growth and on the inner surfaces of chambers where the basic outer surface is concealed by the later overgrowth. The sutures are simply depressed but not slotlike where the honeycomb surface is absent. Sutures become less depressed during the ontogeny.

DISTRIBUTION.—Together, the two forms of *Globigerinoides conglobatus* were found in all but two samples from the *Atlantis II*–13 traverse. Their combined abundances never exceed 5 percent of an assemblage and both forms occur together in eight samples. The mature form was found in one sample not containing the incompletely developed, or simpler form, but constituted less than 1 percent of the assemblage. In eight other samples, the "juvenile" only was found. It constituted less than 1 percent of the assemblage in five of those, and in three samples it constituted 3 percent, 4 percent, and 5 percent of the assemblages, 5 percent being the greatest representation of *G. conglobatus* found in this traverse. From the *Atlantis II*–9 assemblages, only one specimen is referred to *G. conglobatus,* and that questionably.

Globigerinoides elongatus (d'Orbigny)

Globigerina elongata d'Orbigny, 1826, p. 277, list no. 4.—Banner and Blow, 1960a, p. 12, pl. 3: fig. 10.
Globigerinoides elongatus (d'Orbigny).—Cifelli, 1965, p. 26, pl. 9: fig. 5.

Globigerinoides elongatus closely resembles and possibly is a variant form of *G. ruber.* It differs from the latter in having a flattened and usually a relatively small final chamber. It's distributional pattern is similar to, but more restricted than, that of *G. ruber,* although *G. elongatus* occurs only in small numbers in the *Atlantis II*–13 traverse. Many *G. ruber* populations are found with no *G. elongatus* associated.

Globigerinoides ruber (d'Orbigny)

PLATE 5: FIGURE 6

Globigerina rubra d'Orbigny, 1839a, p. 82, pl. 4: figs. 12–14.—Banner and Blow, 1960a, p. 19, pl. 3: fig. 8.
Globigerinoides rubra (d'Orbigny).—Phleger, Parker, and Pierson, 1953, p. 15, pl. 2: figs. 4, 7.—Parker, 1958, p. 279, pl. 6: fig. 12.—Bradshaw, 1959, p. 42, pl. 7: figs. 12, 13.
Globigerinoides ruber (d'Orbigny).—Bé, 1959, pl. 2: figs. 16, 17.—Parker, 1962, p. 230, pl. 3: figs. 11–13.—Cifelli, 1965, p. 25, pl. 8: figs. 1, 4.

Large, well developed *Globigerinoides ruber* show an extreme streptospiral coil (Cifelli, 1965, p. 25). They have three chambers in the peripheral whorl, with the large, semicircular primary aperture of the final chamber situated symmetrically above the suture between the two preceding chambers. Two supplementary apertures are usually clearly visible at the base of the last chamber. With large specimens, other supplementary apertures in earlier chambers also are visible. Supplementary apertures develop late in the ontogeny, however, and are seldom seen in small specimens. Also, there is some variation in the coiling of the smaller forms. Many individuals are identical in chamber arrangement with the mature forms, but a gradation exists between such forms and others that are less streptospiral and include a form with four chambers in the peripheral whorl. In the latter form, which occurs rather commonly in our populations, the aperture is umbilical and this form closely resembles a *Globigerina,* since supplementary apertures are rarely present at this stage of development. The variation in coiling and developmental stages of immature *Globigerinoides ruber* are illustrated in Figure 21. *G. trilobus* shows similar variation in coiling, and separation between juveniles of the two species sometimes is difficult and, with minute specimens, sometimes arbitrary, being based on the tendency of *G. ruber* to have a larger aperture.

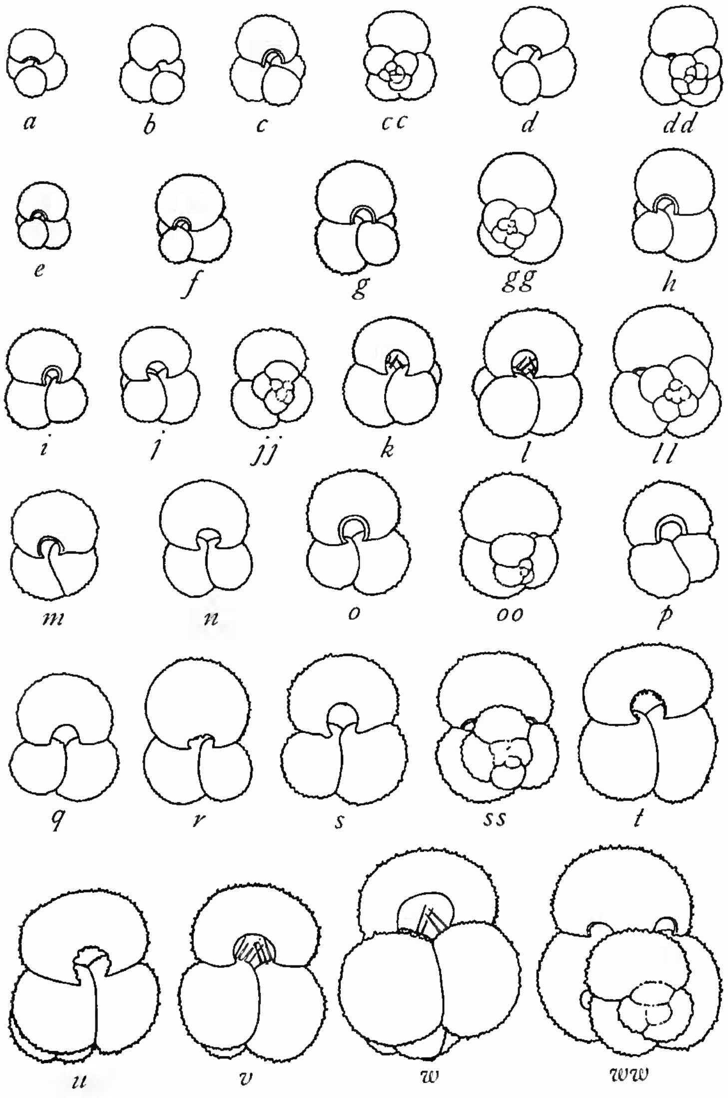


FIGURE 21.—*Globigerinoides ruber.* A growth series beginning with immature individuals showing most or part of four chambers in the peripheral whorl rather than the characteristic three chambers found in adults and most immature individuals.

DISTRIBUTION.—*Globigerinoides ruber* is present in every sample of the *Atlantis II*–13 traverse, ranging from 2 to 71 percent of particular assemblages. No pattern of significant difference appears to exist from sample to sample in the relative percentages of mature and immature specimens of both forms. In most assemblages, the mature forms outnumber the immature forms and commonly the more characteristic immature form outnumbers the other immature form. To illustrate the exception, in the material from station 42 mature forms account for 7 percent of the assemblage and immature forms of the four chamber peripheral-whorled type also account for 7 percent of the assemblage, while the more characteristic immature forms represent less than 1. With the *Atlantis II*–9 traverse, *G. ruber* was not commonly found, accounting for less than 5 percent of four assemblages and 12 percent of another.

Globigerinoides trilobus trilobus (Reuss)

PLATE 6: FIGURE 1

Globigerina triloba Reuss, 1850, p. 374, pl. 47: fig. 11.
Globigerinoides sacculifera (Brady).—Parker, 1958, p. 280, pl. 6: fig. 4 [top two specimens].—Bradshaw, 1959 [part], p. 42, pl. 7: figs. 15, 18 [not fig. 14].

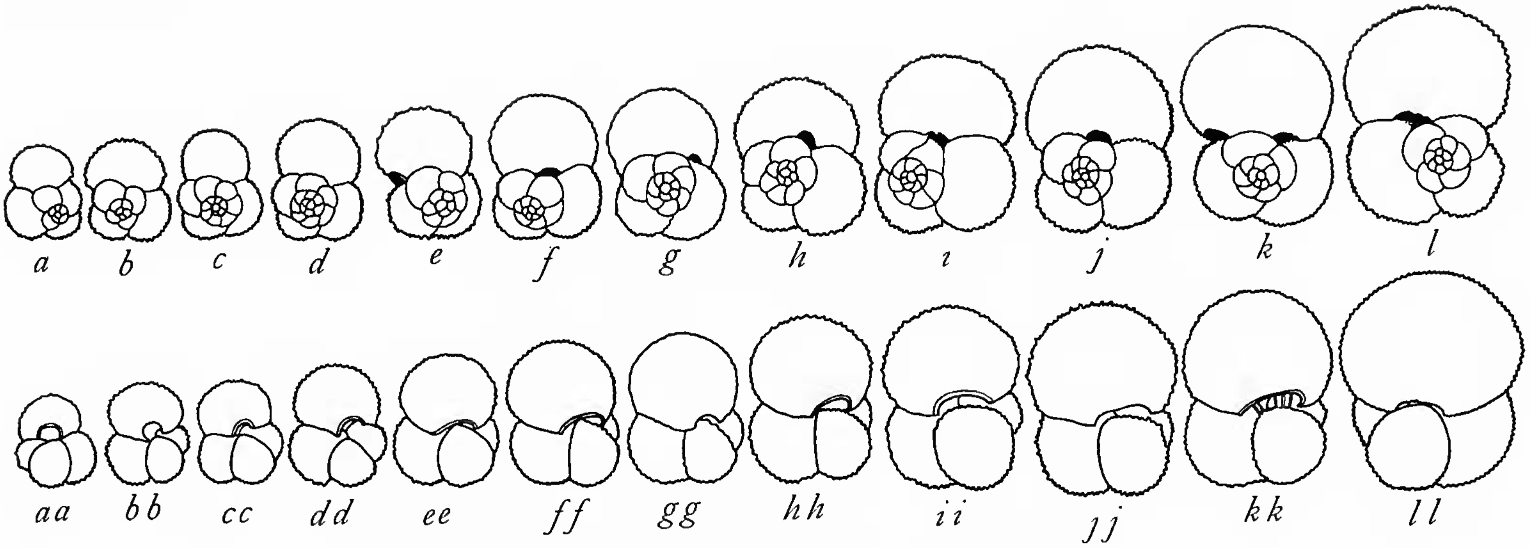


FIGURE 22.—*Globigerinoides trilobus trilobus.* A growth series beginning with immature individuals showing four chambers in the peripheral whorl rather than the characteristic three chambers found in adults and most immature individuals.

Globigerinoides sacculifer (H. B. Brady).—Bé, 1959 [part], pl. 2: figs. 13, 14 [not fig. 15].

Globigerinoides trilobus trilobus (Reuss).—Cifelli, 1965 [part], p. 26, pl. 9: figs. 1, 4 [not figs. 2, 3].

Included here is the form *sacculifer* which has a asc-like final chamber. This form, however, is very poorly developed and rare in the *Atlantis II* material. It was observed in only three samples.

As discussed previously, immature stages of *Globigerinoides trilobus trilobus* are sometimes difficult to separate from immature *G. ruber.* Small specimens of both species vary in coiling of chambers and include a form with four chambers in the peripheral whorl. In the latter form the main distinction from *G. ruber* is that the aperture of *G. trilobus trilobus* tends to be more slit-like and restricted. Changes in coiling and developmental stages of *G. trilobus* are shown in Figure 22. This series does not, however, include the smallest specimens of *G. trilobus.* These specimens go beyond the four-chamber-peripheral-whorl stage, having five or even six chambers in what is the peripheral whorl at that early stage of development. *G. ruber* on the other hand, apparently does not have as large a number of chambers in the very early whorls.

Some variation occurs among immature forms in density of spines. Where spines are widely spaced, the test has a smooth appearance and in a few cases closely resembles *Globigerinita glutinata.*

DISTRIBUTION.—*Globigerinoides trilobus* occurs in most of the *Atlantis II*–13 assemblages (15 out of 19) but in low frequencies. It constitutes 1 percent or less in 9 assemblages and reaches peaks of 8 and 9 percent at stations 13 and 21, respectively. Only one specimen was referred to *G. trilobus* from the *Atlantis II*–9 traverse, and that questionably.

Family GLOBORTALIIDAE Cushman, 1927

Genus *Globorotalia* Cushman, 1927

Globoratalia hirsuta (d'Orbigny)

PLATE 6: FIGURE 2

Rotalina hirsuta d'Orbigny, 1839b, p. 131, pl. 1: figs. 37–39.

Pulvinulina canariensis d'Orbigny.—Brady, 1884, p. 692, pl. 103: figs. 8–10.

Globorotalia hirsuta (d'Orbigny).—Phleger, Parker, and Pierson, 1953, p. 19, pl. 4: figs. 1–7.—Bé, 1959, pl. 1: figs. 4, 8.—Bradshaw, 1959, p. 44, pl. 8: figs. 1, 2.—Parker, 1962, p. 236, pl. 5: figs. 10–15.—Cifelli, 1965, p. 19, pl. 5: figs. 2, 3.

In the *Atlantis II* samples no problems were encountered in recognition of *Globorotalia hirsuta* nor with its separation from other taxa, although in other samples we have seen, this is not always the case. This species is similar to but easily distinguishable from *Globorotalia punctulata.* As in the latter, there are four chambers in the peripheral whorl. Also, there is a similarity between the two species in the shape and relative increase in size of chambers. The chambers, however, are less inflated in *G. hirsuta* and the periphery is consequently more acute. There is some lobulation of the periphery in *G. hirsuta* and a distinct keel bounds each of the chambers on most specimens, although on rare occasions it is not present on all chambers of a given specimen. The keel often forms an even, unbroken slope with the wall of the chamber and it is not always readily apparent, especially on the spiral side. The wall is quite thick, a fact apparent particularly from seeing the pores passing through the wall.

Perhaps the most distinctive features of *Globorotalia hirsuta* are the convexity of the spiral side and the papillate surface of the test. There is considerable range in the convexity among the specimens from the *Atlantis II* traverses but in no instance was a spiral side found to be flat. The umbilical side is normally flat but among the larger specimens it is sometimes concave. Papillae vary in size and density among specimens. Fine papillae sometimes continue onto the keel.

The sutures in *G. hirsuta* are flush to depressed on the spiral side and depressed on the umbilical side. On the spiral side the sutures sometimes appear limbate, owing to the juxtaposition of the keels of the chambers with previous chambers. On some specimens chambers are added at such an angle to one another that the edge of a previous chamber is much higher than the beginning of the next. A calcite thickening often occurs on the spiral side, obscuring the earlier chambers and making the early chambers, those inside the peripheral whorl, resemble an unbonal boss.

In a population of 50 individuals from *Atlantis II*–9 station 327, specimens range in maximum diameters from 0.22 mm up to 0.89 mm, with a mean of 0.43.

DISTRIBUTION:—*Globorotalia hirsuta* is well represented from the *Atlantis II*–9 traverse but very sparsely from the *Atlantis II*–13. It occurs in abundances of less than 1 to 29 percent in nine of the eleven stations of the former and less than 1 percent in five of the nineteen stations of the latter.

Globorotalia menardii (d'Orbigny)

Rotalia menardii d'Orbigny, 1826, p. 273, no. 26, Modèles, no. 10.

Pulvinulina menardii (d'Orbigny).—Brady, 1884, p. 690, pl. 103: figs. 1, 2.

Globorotalia menardii (d'Orbigny).—Phleger, Parker, and Pierson, 1953, p. 19, pl. 3: figs. 1, 2, 4, 5.—Bé, 1959, pl. 1: figs. 1–3.—Bradshaw, 1959, p. 44, pl. 8: figs. 3, 4.—Cifelli, 1965, p. 19, pl. 6: figs. 3, 4.

This species occurs sparingly in the *Atlantis II* traverses. The maximum size of specimens is 0.90 mm but the average is between 0.40 and 0.50 mm. There are about 15 chambers in the test and the chambers increase rapidly in size in the peripheral whorl. The test mainly is thin, almost translucent, and has a rather thin, uniformly developed keel which extends around the chambers as they develop, forming limbate sutures and increasing the lobulation of the test in its later part.

DISTRIBUTION.—*Globorotalia menardii* was found in frequencies of less than 1 to 3 percent at 13 of the 19 *Atlantis II*–13 stations, being less than 1 percent in all but two. It was not recorded from the *Atlantis II*–9 traverse.

Globorotalia punctulata (d'Orbigny)

PLATE 6: FIGURE 3

Globigerina punctulata d'Orbigny, 1826, p. 277, Modèles, no. 8.—Fornasini, 1898, p. 210, fig. 5.

Pulvinulina crassa (d'Orbigny).—Brady, 1884, p. 694, pl. 103: figs. 11, 12.

Globorotalia punctulata (d'Orbigny).—Phleger, Parker, and Pierson, 1953, p. 20, pl. 4: figs. 8–12.—Parker, 1958, p. 281.—Bé, 1959, p. 83, pl. 1: figs. 9–11.—Cifelli, 1965, p. 18, pl. 4: fig. 4, pl. 5: fig. 1.

Globorotalia crassaformis (Galloway and Wissler).—Parker, 1962, p. 235, pl. 4: figs. 17, 18, 20, 21.

The possible affinities of this species with *Globigerina inflata* have been discussed (see p. 28). In *Globorotalia punctulata,* the periphery is distinctly angular, although not particularly acute, except in the smaller specimens. The aperture is umbilical-extraumbilical, narrow, and with a distinct lip.

There are four chambers in the peripheral whorl and, in plan view, the periphery is subrounded to subrectangular. Sutures are narrow and slightly depressed. The umbilicus is relatively shallow and narrow, but distinct, and increases in dimensions with maturity of specimens. For the most part a keel is not developed in this species; however, on the larger specimens there is sometimes a trace of an apparently imperforate rim on the later chambers.

Papillae or spinose projections of variable size and spacing cover both sides of the test. On the average, these projections are larger than the spinose projections seen on *Globigerina inflata* and smaller than those papillae on *Globorotalia hirsuta.* Papillae are best developed on the larger specimens.

DISTRIBUTION.—*Globorotalia punctulata* was found in frequencies of 2 percent or less at eight of the nineteen *Atlantis II*–13 stations. It was not found in samples from the *Atlantis II*–9 traverse.

Globorotalia scitula (Brady)

PLATE 6: FIGURE 4

Pulvinulina scitula Brady, 1882, p. 716.—Banner and Blow, 1960a, p. 27, pl. 5: fig. 5.
Pulvinulina patagonica d'Orbigny sp.—Brady, 1884, p. 693, pl. 103: fig. 7.
Globorotalia scitula (H. B. Brady).—Phleger, Parker, and Pierson, 1953, p. 21, pl. 4: figs. 13, 14.
Globorotalia scitula (Brady).—Parker, 1958, p. 281; 1962, p. 238, pl. 6: figs. 2, 3.—Bradshaw, 1959, p. 44, pl. 8: figs. 5, 6.

This species is meagerly represented in the two *Atlantis II* traverses of this study. The few specimens present are small (average maximum diameter 0.23 mm), compressed, but slightly convex on both sides with a rather sharp although not carinate periphery. Approximately 15 chambers occupy the test in between two and three whorls, with five to six chambers in the peripheral whorl. The wall surface is mainly smooth and shiny with very small pores, but some specimens have irregularly distributed, small, short spinose projections marking the surface. The spinose projections appear more concentrated at the outer edges of chambers. The sutures are narrow to slightly limbate and are slightly depressed on both sides of the test. They are curved, becoming strongly so between later chambers. The aperture is umbilical-extraumbilical with a small simple lip in the umbilical area. No difficulty occurred in identifying *Globorotalia scitula* in the *Atlantis II* samples. In other material, however, *G. scitula* sometimes presents taxonomic problems.

DISTRIBUTION.—*Globorotalia scitula* does not occur in the *Atlantis II*–13 assemblages. It accounts for from less than 1 to 2 percent of six of the 11 *Atlantis II*–9 assemblages.

Globorotalia truncatulinoides (d'Orbigny)

Rotalina truncatulinoides d'Orbigny, 1839b, p. 132, pl. 2: figs. 25–27.
Pulvinulina michelineana d'Orbigny.—Brady, 1884, p. 694, pl. 104: figs. 1, 2.
Globorotalia truncatulinoides (d'Orbigny).—Phleger, Parker, and Pierson, 1953, p. 22, pl. 4: figs. 17, 18.—Parker, 1958, p. 281; 1962, p. 239, pl. 6: fig. 7.—Bé, 1959, pl. 1: figs. 5–7.—Bradshaw, 1959, p. 44, pl. 8: figs. 7, 8.—Cifelli, 1965, p. 20, text-fig. 3, pl. 6: figs. 1, 2.

Although not abuntantly represented, *Globorotalia truncatulinoides* from the the *Atlantis II* traverses includes well-developed forms with a mean maximum diameter of 0.48 mm (based on the specimens from three samples). This compares well with the maximum size of specimens from Pacific bottom sediments reported by Parker (1962, p. 239). The total number of chambers cannot be ascertained from the present specimens because papillae cover the wall and obscure the early chambers. There are five chambers in the peripheral whorl and this number is constant. A well-developed but not particularly thick keel bounds the periphery of the test. The wall is of moderate thickness and is covered with papillae on both the spiral and umbilical sides. The papillae are smaller and less dense on the chambers of the peripheral whorl on the spiral side as a rule, and considerable variation may exist in their denseness among chambers of a single specimen and among specimens of a population. Papillae occur on small, immature specimens as well as fully developed ones. They continue onto the keel. The umbilicus is relatively narrow, although very deep, especially on the large subconical specimens. Apertural lips are poorly developed or absent. In plan view, the peripheral outline is subrounded to subangular overall but usually with a pronounced projection formed by the final chamber. The sutures are slightly curved, narrow, and slightly depressed on the umbilical side. On the spiral side they are slightly curved, very slightly depressed, and tend to be slightly limbate, reflecting the presence of the keel; the keel also causes the spiral suture to be limbate. Over 90 percent of the specimens examined are left coiled.

DISTRIBUTION.—*Globorotalia truncatulinoides* is not abundant but is fairly well represented in some of the *Atlantis II*–9 samples, but is rare in the *Atlantis II*–13 assemblages. In the former, it ranges in frequency from less than 1 to 11 percent in eight of the eleven samples. In the latter traverse, *G. truncatulinoides* is present but accounts for less than 1 percent of three assemblages.

Genus *Hastigerina* Thomson, 1876

Hastigerina pelagica (d'Orbigny)

Nonionina pelagica d'Orbigny, 1839c, p. 27, pl. 3: figs. 13, 14.
Hastigerina murrayi Thomson, 1876, p. 534, pls. 22, 23.
Hastigerina pelagica (d'Orbigny).—Brady, 1884, p. 613, pl. 83; figs. 1–18.—Parker, 1958, p. 280, pl. 6: fig. 15; 1962, p. 228.—Bé, 1959, pl. 2; figs. 21, 22.—Bradshaw, 1959, p. 47, pl. 8: figs. 14, 15.—Banner and Blow, 1960b, p. 20, fig. 1.—Cifelli, 1965, p. 23, pl. 7: figs. 1, 2.

This distinctive species, which is rare but present in most of the *Atlantis II* samples, has a very fragile test. Its thin and transparent wall is smooth and glassy but finely and densely perforate with a few long, prominent spines, which may pass through the wall from one whorl to another. It is planispiral to slightly trochospiral, with a broad, low but open aperture crossing the base of the final chamber from one side of the test to the other. The sutures are narrow and deeply incised, resulting in a very lobate test outline. The chambers increase rapidly in size, with five usually present in the peripheral whorl. *Hastigerina pelagica* is similar to *Globigerinella aequilateralis* but the nature of the wall and the more planispiral coiling easily distinguish it.

DISTRIBUTION.—Specimens of *Hastigerina pelagica* were found in small numbers in ten samples (2 percent or less of assemblages) from the *Atlantis II*–13 traverse and four samples from the *Atlantis II*–9 traverse.

Genus *Orbulina* d'Orbigny, 1839

Orbulina universa d'Orbigny

PLATE 6: FIGURE 5

Orbulina universa d'Orbigny, 1839a, p. 3, pl. 1: fig. 1.—Brady, 1884, p. 608, pl. 81: figs. 8–26, pl. 82: figs. 1–3.—Phleger, Parker, and Pierson, 1953, p. 17, pl. 2: fig. 8.—Parker, 1958, p. 280, pl. 6: fig. 13.—Bé, 1959, pl. 2: fig. 18.—Bradshaw, 1959, p. 49, pl. 8: figs. 17, 18.—Cifelli, 1965, p. 17, pl. 3: figs. 6, 7.

Orbulina universa is present in most *Atlantis II*–13 samples, but in very small numbers. Some specimens contain internal chambers. Most of the internal chamber arrangements found are rather incomplete, but rare forms were found which look similar to *Globigerina bulloides* as well as the juvenile form of *Globigerinoides conglobatus.*

Four specimens included here appear identical with *Orbulina suturalis.* They have a minute initial coiled end with poorly defined sutures and well-developed pores at the junction of the initial end with the final large bulbous chamber (Plate 6: figure 5).

DISTRIBUTION.—*Orbulina universa* was found in very small numbers at 18 of the 19 *Atlantis II*–13 stations. It is not recorded from the smaller samples of the *Atlantis II*–9 traverse.

Family DISCORBIDAE Ehrenberg, 1838

Genus *Tretomphalus* Moebius, 1880

Tretomphalus atlanticus Cushman

Tretomphalus atlanticus Cushman, 1934, p. 86, pl. 11: fig. 3, pl. 12: fig. 7.—Phleger, Parker and Pierson, 1953, p. 43, pl. 9: figs. 30, 31.

Most of the small number of *Tretomphalus atlanticus* collected appear to be juvenile forms, with relatively few chambers and a deep and wide slot-shaped opening almost bisecting the concave ventral surface. No specimens with "float chambers" were found. The small specimens begin with a round proloculus followed by approximately a whorl of four to six chambers which are subrounded to elongate (in the direction of coiling) and have sutures at first radial then curved and oblique. In the large specimens the elongate chambers are succeeded by rather irregular whorls of chambers of variable shape and number.

DISTRIBUTION.—This species occurs solely in sample 286 from the *Atlantis II*–9 traverse. In this small assemblage, *Tretomphalus atlanticus* accounts for 20 percent of the specimens.

Family PLANORBULINIDAE Schwager, 1877

Genus *Planorbulina* d'Orbigny, 1826

Planorbulina mediterranensis d'Orbigny

Planorbulina mediterranensis d'Orbigny, 1826, p. 280, no. 2, pl. 14: figs. 4–6, bis; Modèles, no. 79.—Phleger, Parker and Pierson, 1953, p. 50, pl. 11, figs. 20, 21.

These few individuals consist of large numbers of irregularly shaped, but tending toward hemispherical to hemielliptical, chambers arranged in bent, irregular subplanispiral coils. On some specimens, the early chambers are regularly arranged, as in *Cibicides.* The surface is coarsely punctate. The dorsal surface is quite rough, whereas the ventral surface is smooth, allowing early whorls to be seen more clearly. The aperture forms a slit at the base of the final chamber; the apertures of many earlier chambers can be seen also, because of the irregular nature of the addition of chambers.

DISTRIBUTION.—Members of this genus constitute 30 percent of the small assemblage from station 286 of the *Atlantis II*–9 traverse.

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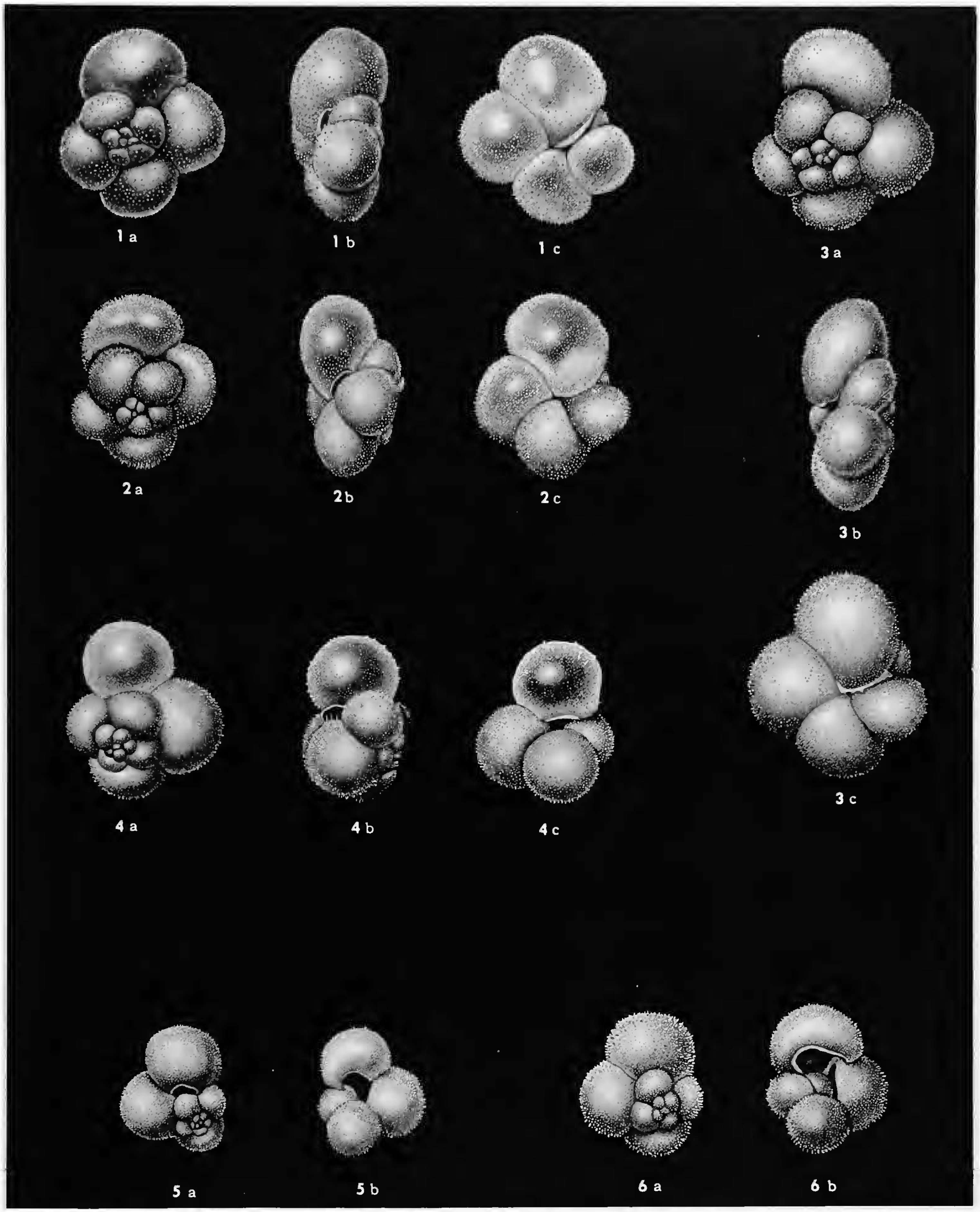

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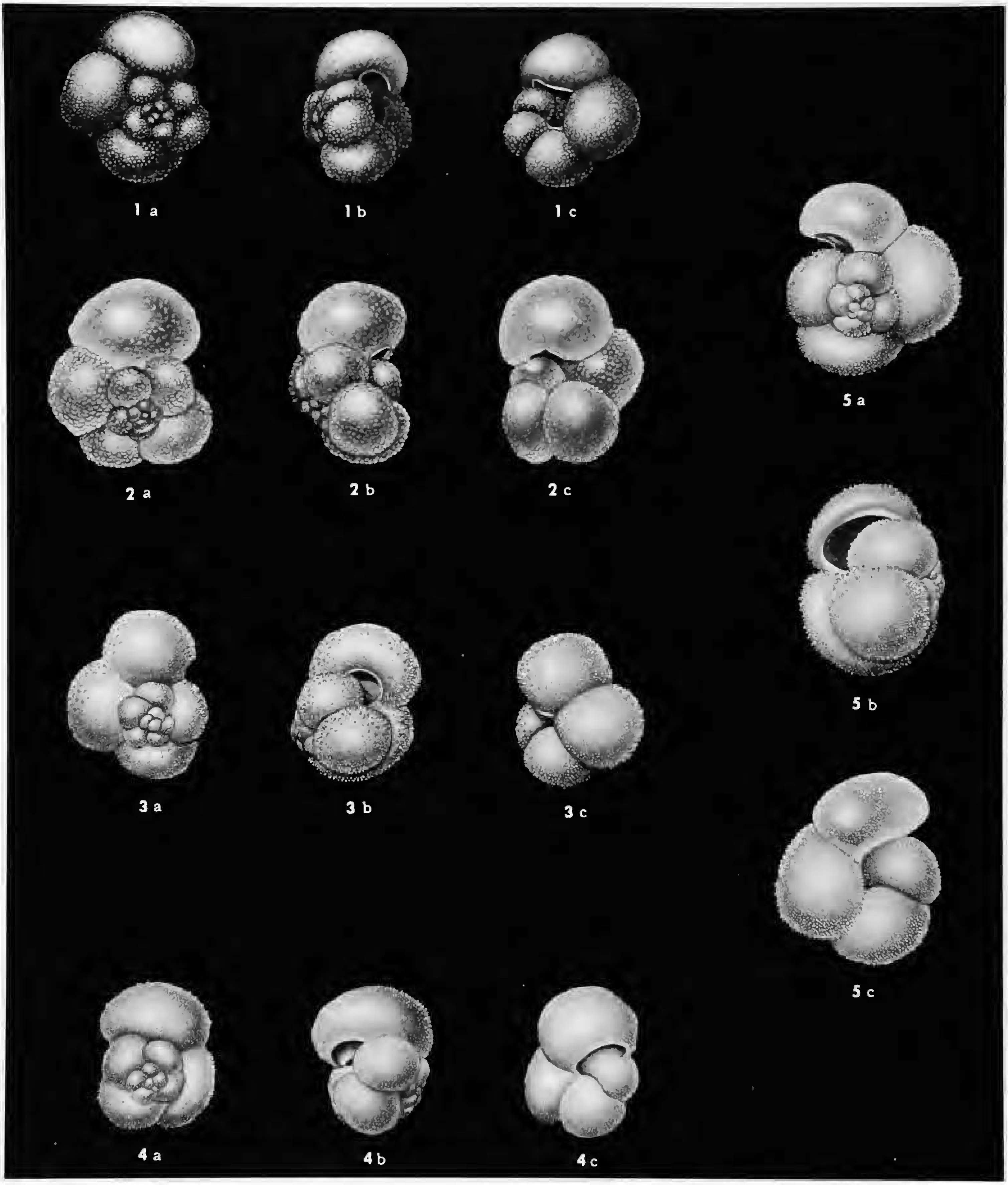

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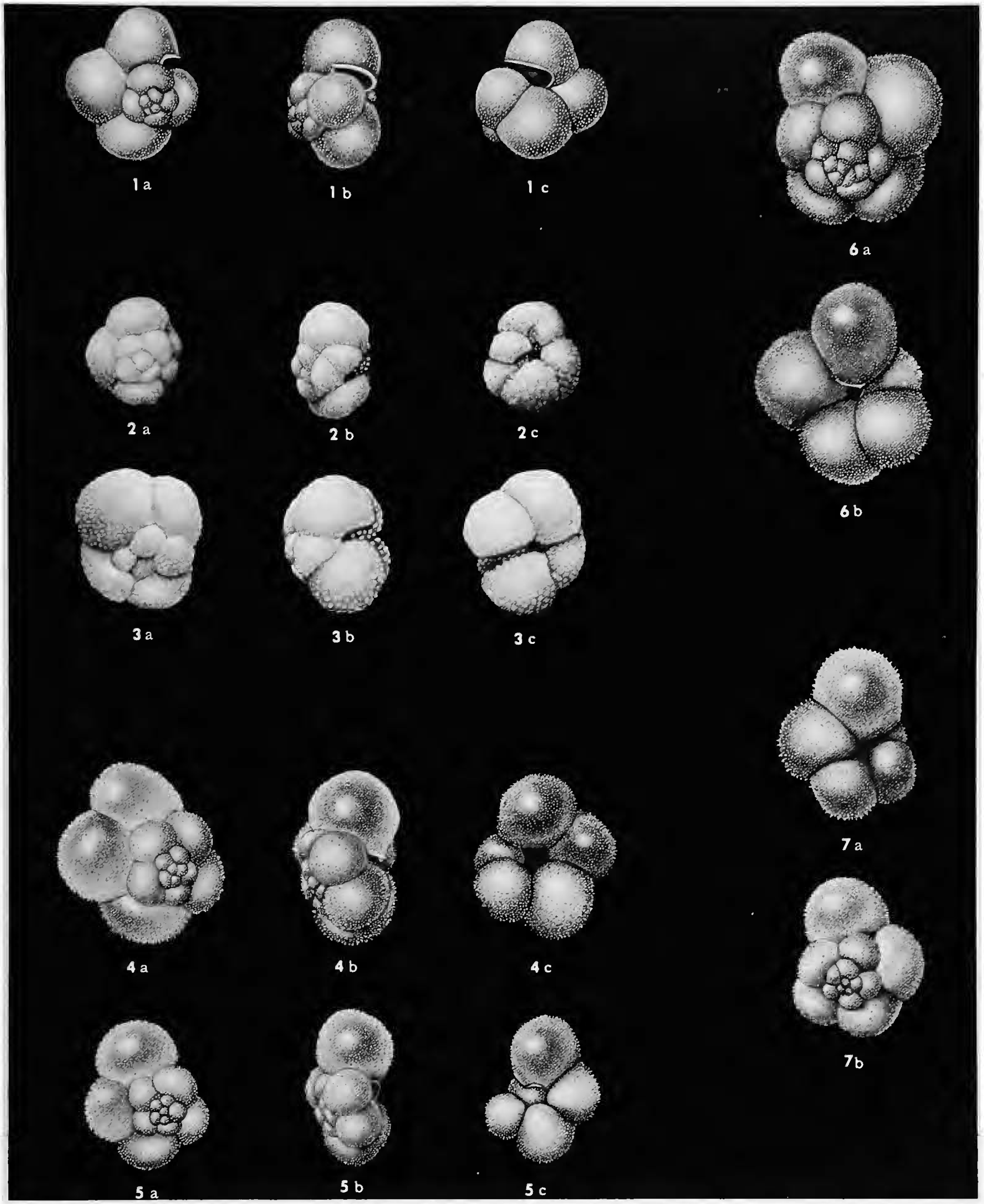

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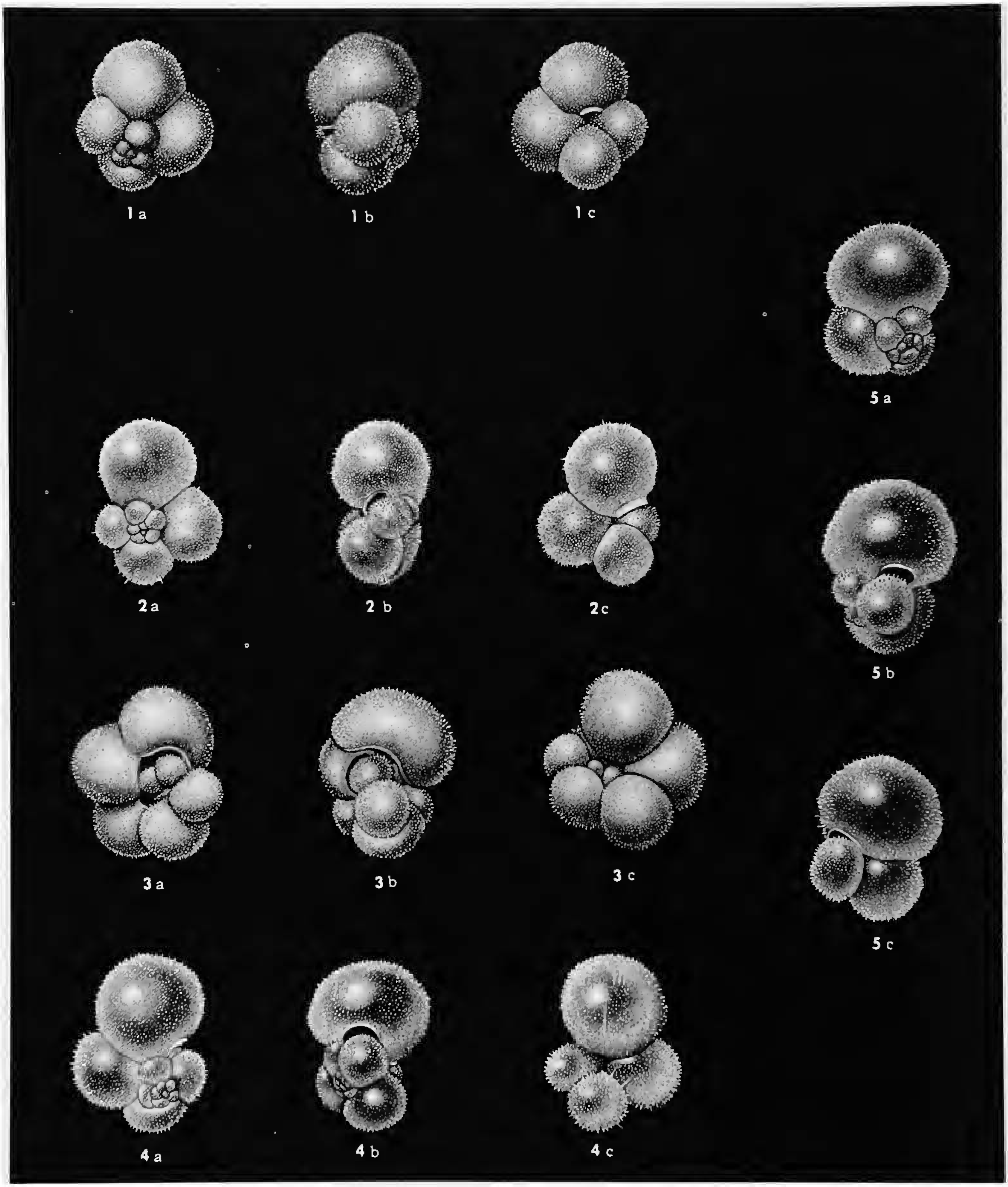

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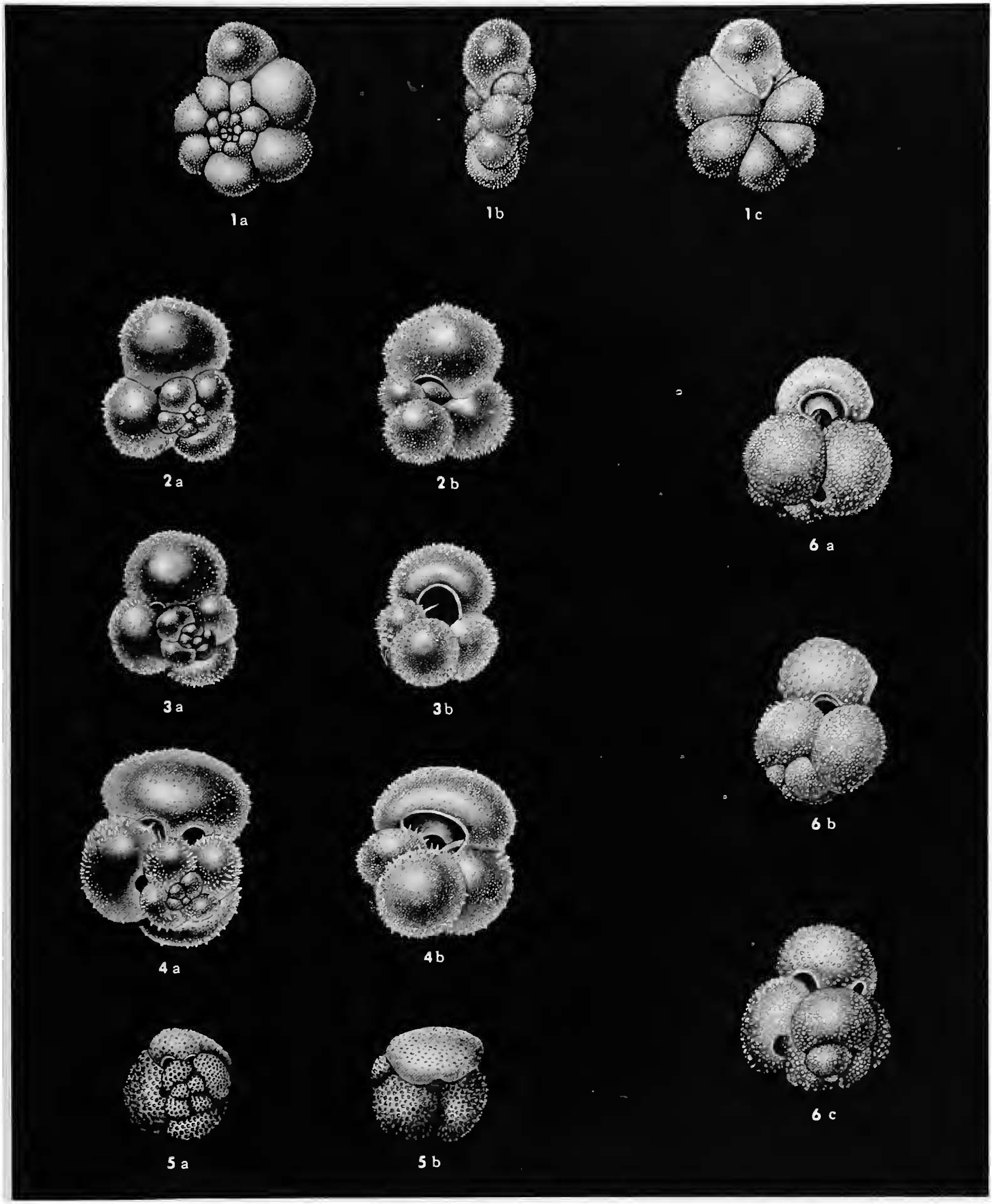

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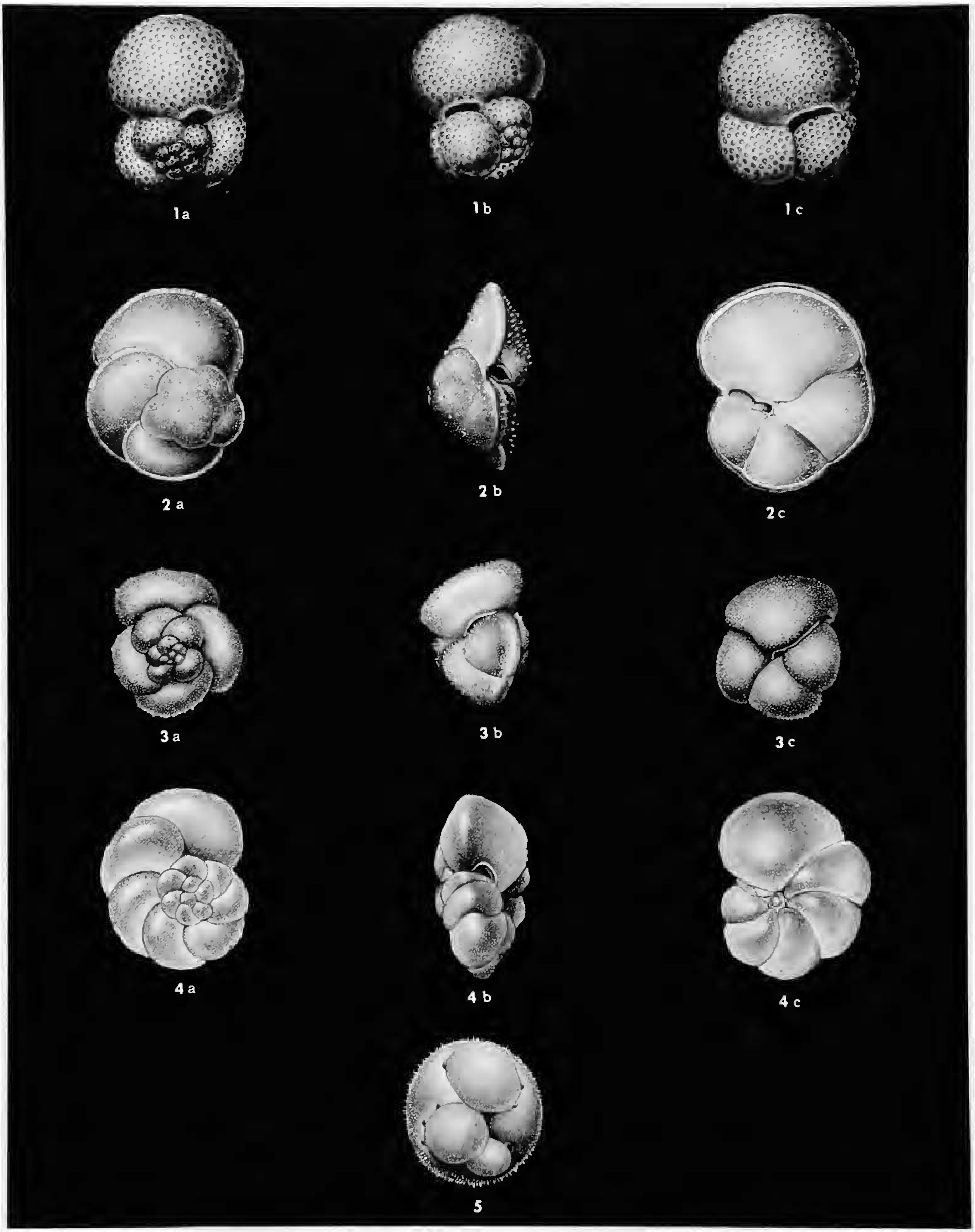

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