Some Dynamic Aspects of the Distribution of Planktonic Foraminifera in the Western North Atlantic

Richard Cifelli[1,2]

U. S. National Museum
Washington, D. C.

ABSTRACT

Studies of Foraminifera from plankton tows taken during the four seasons of the year at stations in shelf water, slope water, the Gulf Stream, and Sargasso Sea between Cape Cod and Bermuda in the western North Atlantic have shown that the slope waters generally yielded the highest concentrations of Foraminifera at all seasons, with spring and fall being the most productive seasons. The transition between the temperate fauna, composed almost entirely of *Globigerina* species, and the diverse subtropical fauna varied in position throughout the year but always occurred on the northern or slope side of the Gulf Stream, suggesting appreciable mixing of surface waters there. The southern foraminiferal fauna showed considerable changes in frequencies of species during the year, but the percentage of the temperate *Globigerina* species was consistently low in all seasons. Descriptive and distributional details of all Foraminifera taken will be reported upon later.

Introduction. The waters of the North Atlantic between Cape Cod and Bermuda are of unusual interest for faunal studies because of the presence of the Gulf Stream and the consequent wide range of hydrographic conditions encountered within a relatively short distance. In these waters there occurs a marked faunal change as the temperate species of the North Atlantic shelf-slope waters are replaced to the south by the subtropical assemblages of the Gulf Stream-Sargasso Seas, a change that may well represent one of the most distinct boundaries of faunas in the North Atlantic. This paper summarizes (1) the more important aspects of the foraminiferal distribution with respect to the major hydrographic features of this area of the western North Atlantic and (2) the changes in distribution that were observed there during 1960–1961.

Methods. The traverses and the stations at which the plankton hauls were made are shown in Fig. 1. The four seasonal cruises, by the Woods Hole Oceanographic Institution vessels CHAIN and CRAWFORD in 1960 and 1961,

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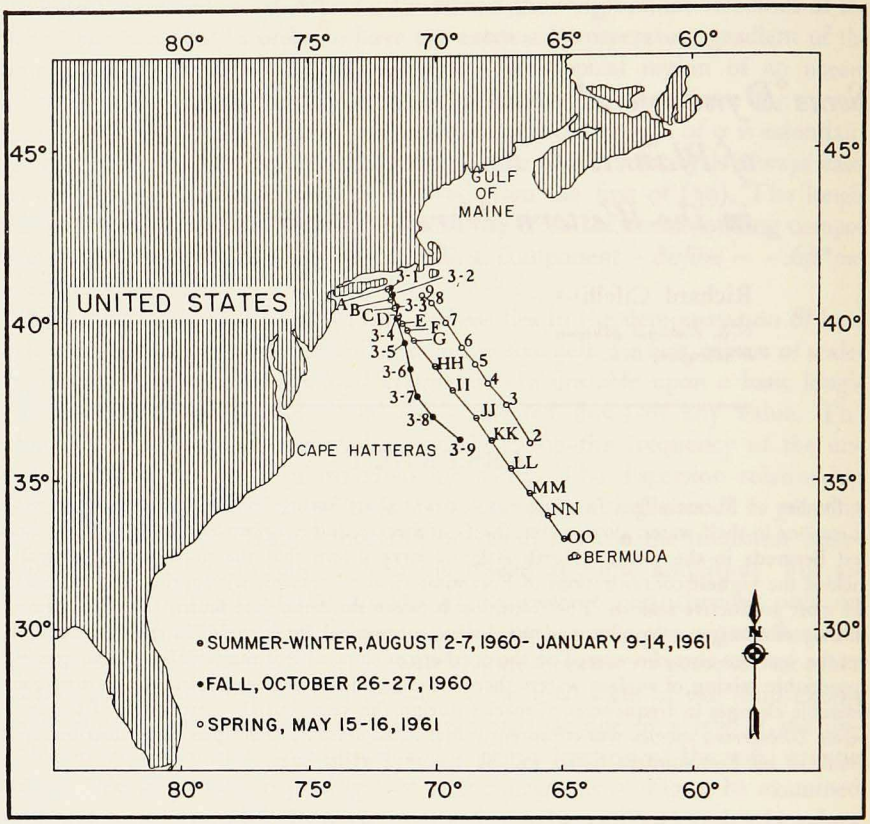

Figure 1. Location of stations.

traversed shelf waters, slope waters, the Gulf Stream, and Sargasso Sea. The stations occupied during the summer and winter are almost the same, except that (1) NN and OO were not occupied in the summer and (2) the position of the Gulf Stream (st. 2) was ascertained by BT; also, sts. HH′ and HH″, in the slope waters near the Gulf Stream but located northeast of the regular traverse, were occupied in the summer (Fig. 2, inset) on the return trip of that cruise.

The collections were obtained in oblique tows with a No. 10 plankton net having a 3/4 meter open mouth diameter. At shallow stations on the shelf the net was lowered as close as possible to the bottom, and beyond the shelf it was lowered to 200 m. The ship's speed during towing was approximately two knots. The samples were preserved in 5% formalin, buffered with hexamethylenamine.

Abundance. A flow meter was not available at most of the stations, and for them reliable estimates of the amount of water filtered could not be obtained. Therefore the numerical abundance of Foraminifera, shown in the upper halves of Figs. 2, 4, 5, 7, is expressed in numbers of specimens per half hour tow. This, clearly, is an inexact expression of standing crop, for a sizable error is introduced by assuming that the relationship between time of towing and amount of water filtered is constant. The error is probably highest for the shelf stations, where the great abundance of salps, jellyfish and other large zooplankters quickly clogs and reduces the filtering capacity of the net when being towed; this clogging may account in part for the generally poor yields of Foraminifera on the shelf; for example, the highest concentrations of Foraminifera were obtained there during the winter, a time when the mean displacement volume of zooplankton is greatly reduced (Grice and Hart, 1961: 7). On the other hand, however, it was noted that samples barren or impoverished in Foraminifera often contained appreciable numbers of pteropods and diatoms, comparable in size to Foraminifera. Thus, it would appear that Foraminifera are, in fact, normally scarce and irregularly distributed on the inner part of the shelf.

At every season the highest concentrations of Foraminifera were obtained at the slope stations. Except for the summer traverse, however, the numerical abundance showed considerable variation on the slope, and the differences in number of specimens per half hour tow at stations near each other, sometimes amounting to several orders of magnitude, were too large to have been caused by differences in the filtering capacity of the net. This unevenness in distribution is considered here to be real and to reflect that complex and poorly understood set of phenomena known as patchiness. Hardy (1955) has stressed the importance of patchiness in ecologic interpretations of plankton.

The Gulf Stream and Sargasso stations were generally impoverished as compared with those on the slope. However, in the winter traverse, slope sts. F and HH yielded fewer Foraminifera per half hour tow than did the Gulf Stream or most of the Sargasso stations. The distribution in numbers of specimens is considerably more uniform in the Sargasso Sea than in the slope waters.

Seasonally, the richest concentrations of Foraminifera were obtained in the spring and fall, while the poorest concentrations were encountered in the summer.

Faunal Composition and Distribution. A total of 20 species was recognized from the traverses studied, as follows: *Candeina nitida* d'Orbigny, *Globigerina bulloides* d'Origny, *G. dutertrei* d'Orbigny, *G. incompta* Cifelli, *G. inflata* d'Orbigny, *G.* aff. *G. quinqueloba* Natland, *Globigerina* sp., *Globigerinella aequilateralis* (Brady), *Globigerinita glutinata* (Egger), *Globigerinoides conglobatus* (Brady), *Gl. elongatus* (d'Orbigny), *Gl. ruber* (d'Orbigny), *Gl. trilobus trilobus* (Reuss), *Globorotalia hirsuta* (d'Orbigny), *Gl. menardii* (d'Orbigny),

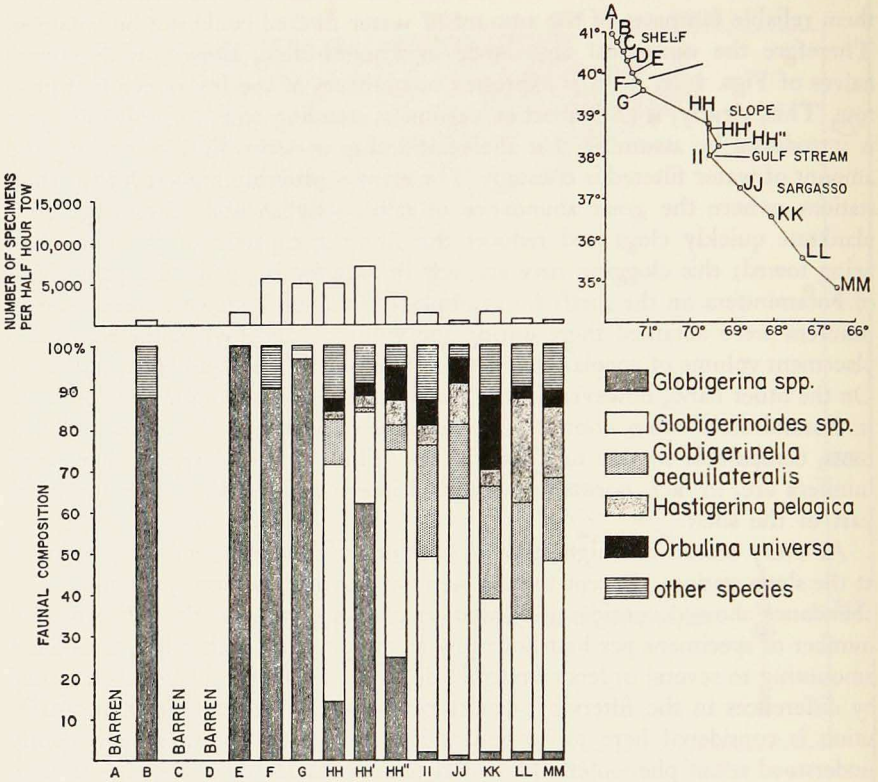

Figure 2. Composition and abundance of planktonic Foraminifera taken at summer stations.

Gl. punctulata (d'Orbigny), *Gl. truncatulinoides* (d'Orbigny), *Hastigerina pelagicia* (d'Orbigny), *Orbulina universa* (d'Orbigny), *Pulleniatina obliquiloculata* (Parker and Jones).

The foraminiferal compositions in frequencies of occurrence at the various stations are shown in the lower halves of Figs. 2, 4, 5, 7, which have been prepared so as to emphasize the major changes. Hence, those species which were found in low frequencies have been grouped together under OTHER SPECIES, and the species of *Globigerina* and *Globigerinoides* have been included together under their respective genera.

With the exception of *Globigerinita glutinata*, all of the OTHER SPECIES are primarily Sargasso forms. *G. glutinata* is sporadic in its distribution, showing equally high frequencies in the shelf-slope and Sargasso waters. Details of the distribution, as well as descriptions, of all species of Foraminifera will be given in a forthcoming paper.

Summer (Fig. 2). In the northern part of the traverse on the shelf and inner part of the slope (sts. A through G), the foraminiferal fauna was overwhelmingly characterized by species of *Globigerina* which were recorded in frequencies of 80–100% of the total foraminiferal population. Of these *G. bulloides* was dominant, but *G. incompta* was almost equally as common. *G. inflata* occurred in low to moderately high frequencies while *G.* aff. *quinqueloba* and *G. dutertrei* were scarce. The only species not belonging to *Globigerina* which occurred in frequencies higher than 2% at sts. A through G was *Globigerinita glutinata* which reached 12% at st. B and 9% at st. F.

Beyond st. G there was a marked change characterized by a large decrease in the percentage of *Globigerina* and an increase in numbers of species characteristic of the southern part of the traverse. This diverse subtropical fauna was dominated by species of *Globigerinoides* which achieved a frequency of up to 62%. *Globigerinella aequilateralis*, *Hastigerina pelagica*, and *Orbulina universa* are other species that were recorded in high frequencies, as shown in Fig. 2. Of the *Globigerinoides* species, *G. ruber* was the dominant form and *G. trilobus trilobus* was second in importance. The majority of *G. ruber* specimens ranged in color from pink to bright red. *G. conglobatus* and *G. elongatus* were mostly rare, but at st. KK, *G. conglobatus* was recorded at a frequency of 15% and was the most common species of *Globigerinoides* at that station.

Note that this change occurred to the northward, or on the slope side of the Gulf Stream. Between sts. G and HH the percentage of *Globigerina* decreased from 97 to 14%. The composition in the Gulf Stream with only 2% *Globigerina* and no endemic elements was identical with that in the Sargasso Sea.

Intermediate percentages of *Globigerina* were recorded at HH′ and HH″. However, these latter stations, although south of st. HH, were northeast of the regular traverse and were occupied several days after st. HH, on the return run of the cruise. It is quite possible, and indeed probable, that sts. HH′ and HH″ were as far removed from the Gulf Stream as st. HH, or even farther removed.

Mixing between the slope waters and Gulf Stream-Sargasso waters is reflected in both intermediate faunal character and subsurface temperatures of the stations between G and II. The subsurface temperatures at the summer stations are shown in Fig. 3. The relationship between the frequency of *Globigerina* species and subsurface temperature, as indicated by the depth of the 18.5°C isotherm, is as follows:

	Frequency of *Globigerina* spp. (%)	Depth of 18.5°C isotherm (m)		Frequency of *Globigerina* spp. (%)	Depth of 18.5°C isotherm (m)
St. G	97	18	St. HH	14	55
St. HH′	62	40	St. II	2	245
St. HH″	25	52			

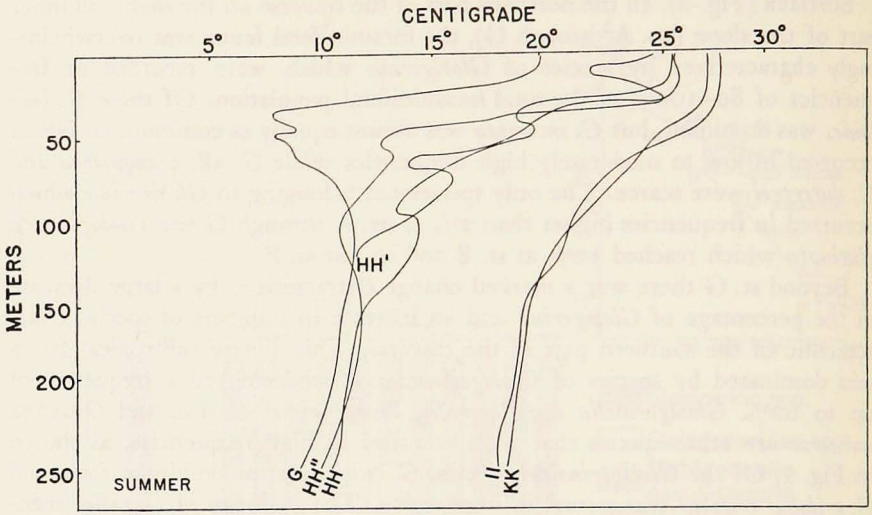

Figure 3. Subsurface temperatures at selected summer stations.

Fall (Fig. 4). A BT was not available for the fall cruise, and since no subsurface temperatures were recorded, the precise position of the Gulf Stream along the fall traverse in uncertain.

During this cruise the distributional pattern was again characterized almost entirely by *Globigerina* on the northern side and by a diverse subtropical fauna on the sourthern side of the traverse. In between, the foraminferal fauna was intermediate in composition. A marked change occurred between st. 4 at the edge of the shelf and at st. 5 on the slope, a distance of about 45 miles; there the frequency of *Globigerina* dropped from 96 to 59%. However, the frequency of *Globigerina* remained relatively high through the presumed position of the Gulf Stream, st. 7, where species of this genus were recorded at 42%. To the south of st. 7, *Globigerina* dropped to 5% at st. 8, and to 2% at st. 9.

The change in Foraminifera in the fall occurred closer inshore than during any of the other seasons. On the other hand, relatively high percentages of *Globigerina* persisted through st. 7 so that at this season there was a broad band of slope water of intermediate faunal character. This seems to suggest relatively large scale mixing between the slope and Gulf Stream-Sargasso waters. It is unfortunate that subsurface temperatures were not available for this traverse.

Among the *Globigerina*, *G. bulloides* showed a marked decrease from the summer; in the fall the dominant species were *G. incompta* and *G. inflata*, whereas *G. dutertrei* and *G.* aff. *quinqueloba* appeared in moderately high frequencies.

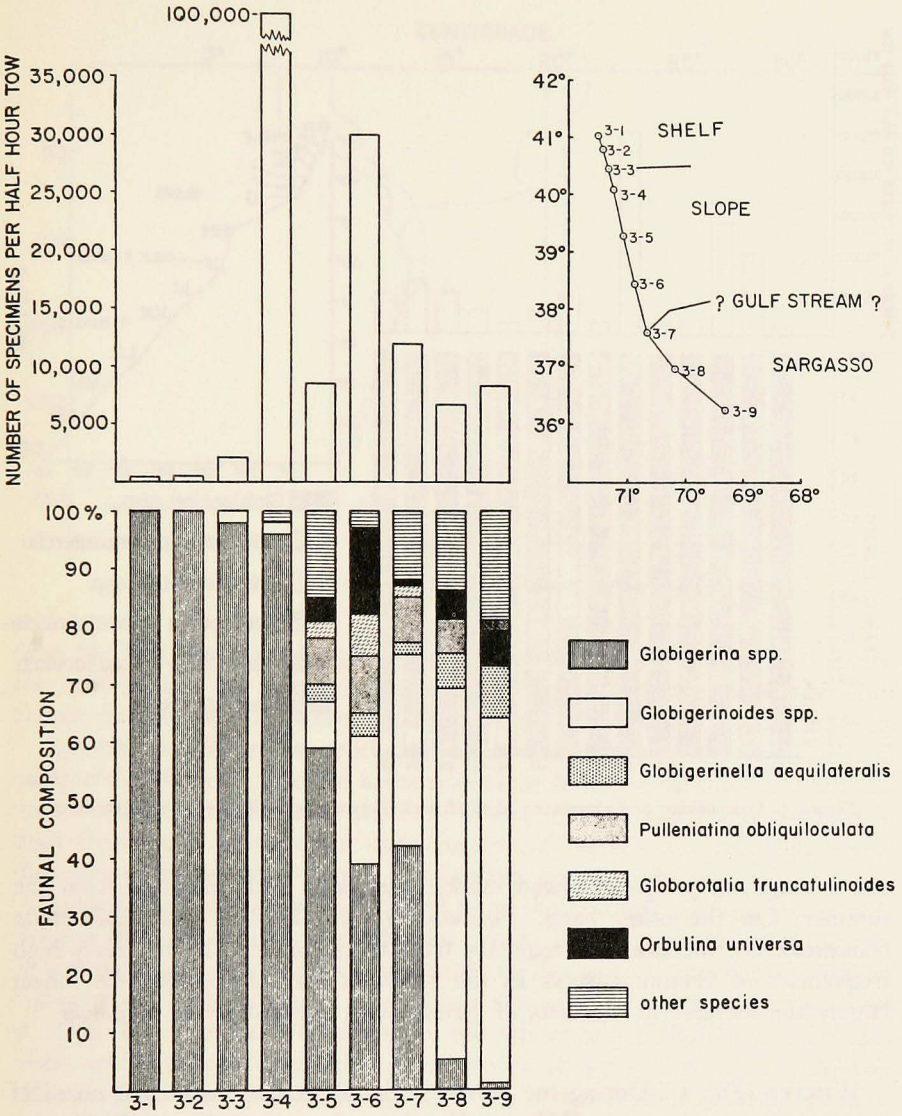

Figure 4. Composition and abundance of planktonic Foraminifera taken at fall stations.

The diverse Foraminifera in the southern part of the traverse was again dominated by species of *Globigerinoides*; in fact, this genus reached its highest frequency in the fall; the most common species was again *G. ruber*, but *G. trilobus* was almost as important. The ratio of pink-red to white specimens of *G. ruber* was less in the fall than in the summer. *Globigerinella aequilateralis*

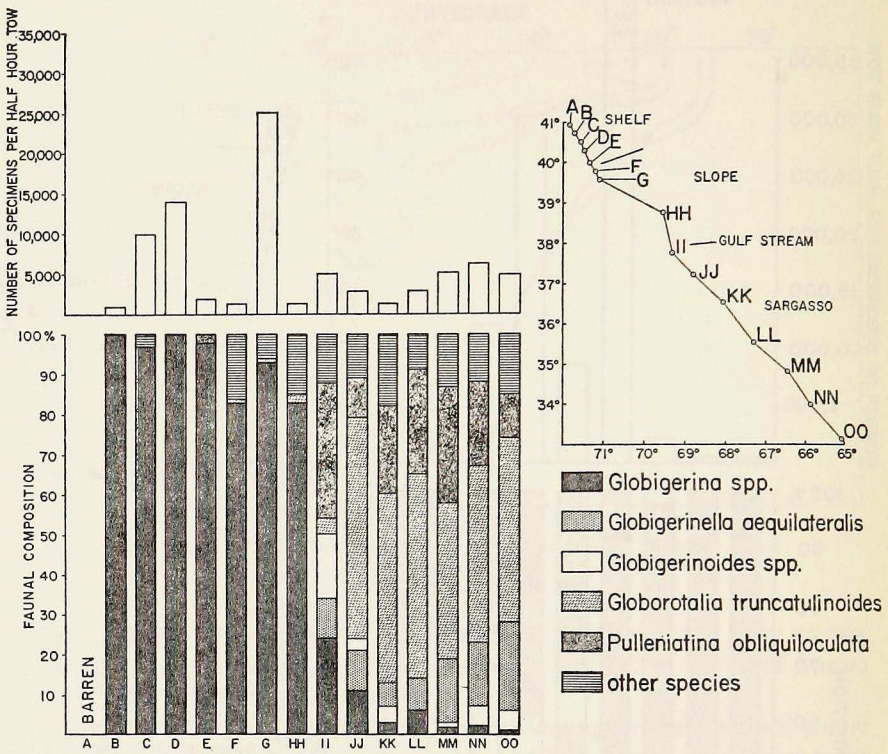

Figure 5. Composition and abundance of planktonic Foraminifera taken at winter stations.

and *Hastigerina pelagica* showed marked decreases in frequencies from the summer. On the other hand, *Pulleniatina obliquiloculata* and *Globorotalia truncatulinoides* increased in frequency from the summer. The relatively high frequencies of OTHER SPECIES in the southern part of the traverse reflect largely the increase in numbers of *Globorotalia*, particularly *G. menardii*.

WINTER (Fig. 5). During the winter cruise the change occurred north of the Gulf Stream between HH and II where the percentage of *Globigerina* species dropped from 83 to 24%. At st. JJ, *Globigerina* were still fairly numerous at 11%, but these species diminished to 6% or less at the remaining southern stations.

At this season there is the maximum difference in surface temperatures bebween the shelf-slope waters and the Gulf Stream-Sargasso Sea, since the former waters cool to a much greater extent than the latter. Between slope st. HH and Gulf Stream st. II the temperature increased from 11° to 22°C

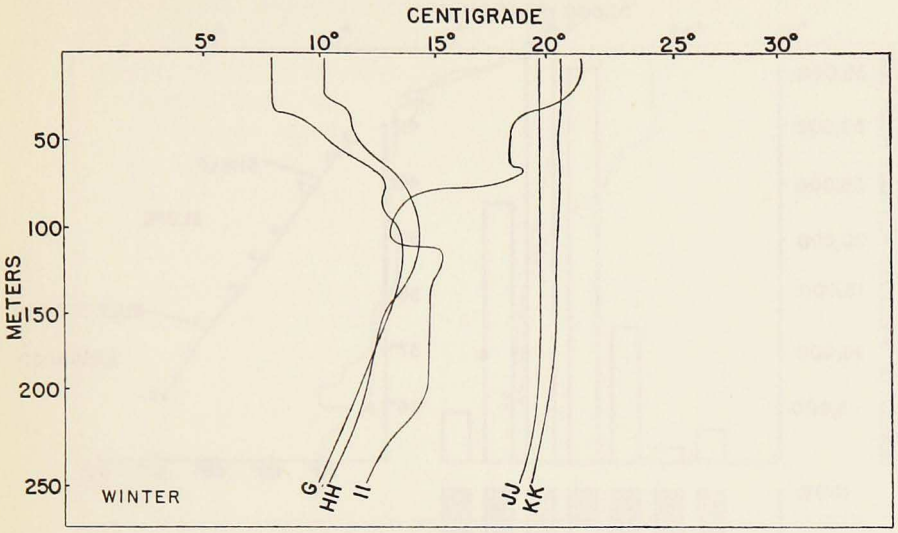

Figure 6. Subsurface temperatures at selected winter stations.

(Fig. 6). The winter cooling, however, mostly affects only the surficial layers, for below 60 m the temperature relationships between the slope and Gulf Stream-Sargasso stations were much the same in the winter as in the summer.

Among the *Globigerina* species *G. bulloides* was dominant over-all. *G.* aff. *quinqueloba*, however, showed a sharp increase from the summer and fall and even surpassed *G. bulloides* at shelf sts. D and E. *G. incompta* was recorded in high frequencies only at the slope stations. *G. inflata* was relatively scarce throughout the winter stations; *G. dutertrei* was not observed at all.

Among the Foraminifera characteristic of the southern stations, remarkable changes from the summer and fall were noted. The formerly dominant species of *Globigerinoides* showed a sharp decline in the winter; this genus achieved a moderately high frequency at only one station (II), where it was recorded at 16%. The dominant form during the winter was *Globorotalia truncatulinoides* which reached a maximum frequency of 55% at st. II. *Pulleniatina obliquiloculata* was also common, achieving a maximum frequency of 34% at st. II. Both of these species were very scarce in the summer, but showed some increase in the fall. *Globigerinella aequilateralis* was found in moderately high percentages and showed a sizable increase from the fall.

Spring (Fig. 7). The spring traverse showed the same preponderance of *Globigerina* on the shelf and slope as the winter traverse as well as a faunal change marked by a replacement of *Globigerina* species with a diverse foraminiferal fauna in the Gulf Stream and Sargasso Sea. As in winter, the change

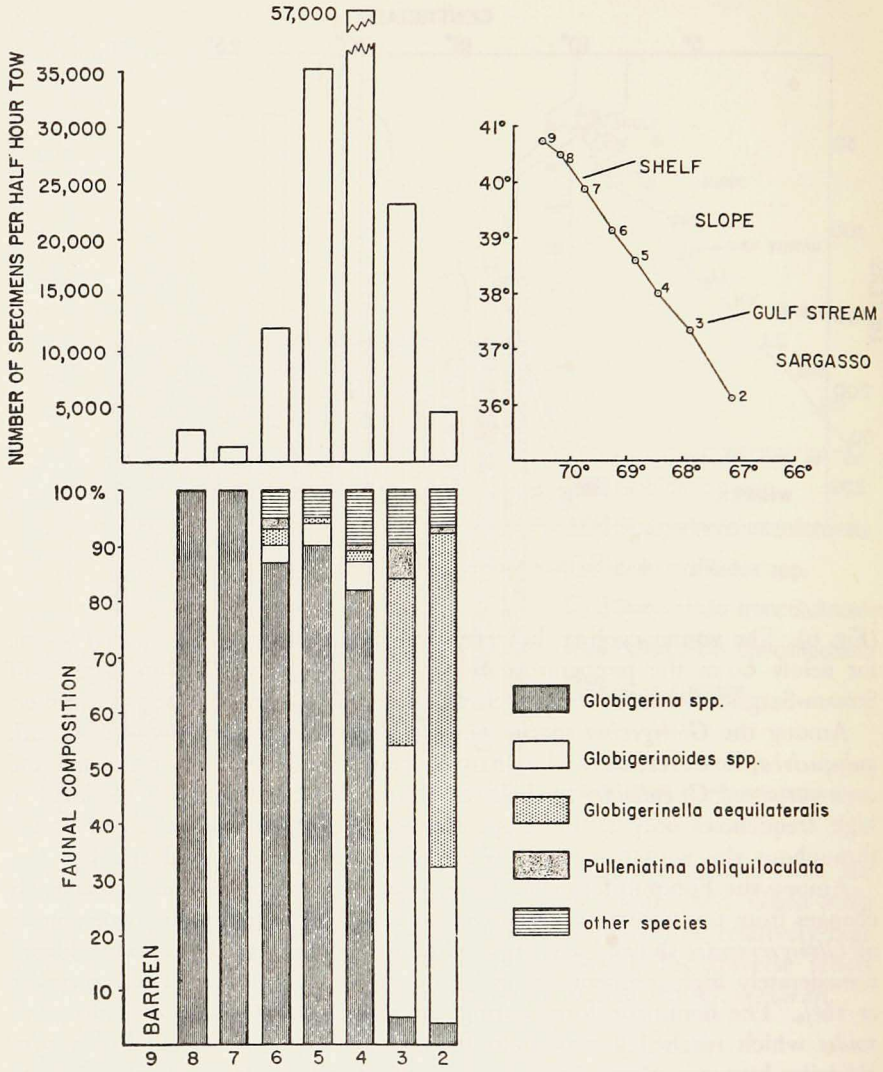

Figure 7. Composition and abundance of planktonic Foraminifera taken at spring stations.

occurred near the Gulf Stream, but this change was even more marked in the spring. Between slope st. 4 and Gulf Straem st. 3, the percentage of *Globigerina* dropped from 82 to 5%. At Sargasso st. 2 the *Globigerina* species were recorded at 4%.

Between the southernmost slope stations and the Gulf Stream station there was a marked difference in subsurface temperatures (Fig. 8). The surface

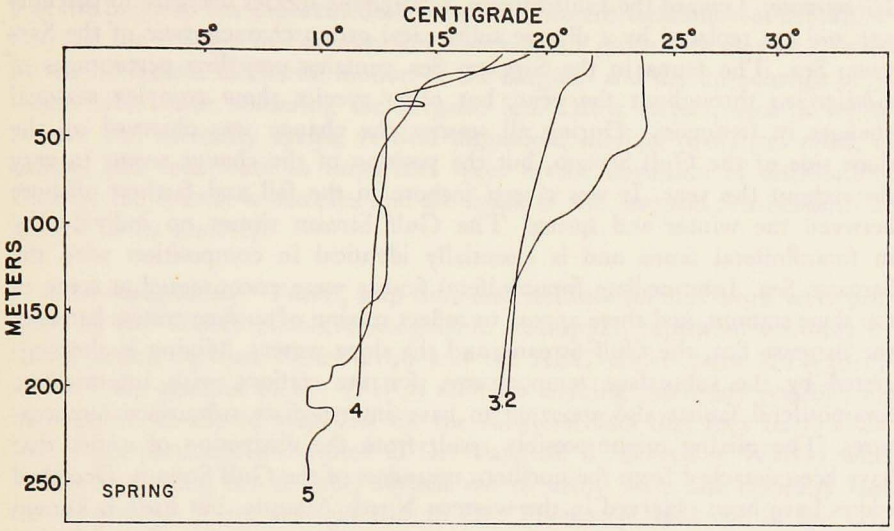

Figure 8. Subsurface temperatures at selected spring stations.

water of the slope showed the surperficial effect of spring warming (19°C at st. 4), but there was a sharp thermocline immediately below the surface with the temperature dropping to 15°C at 15 m. At st. S in the Gulf Stream, a band of water of about 24°C persisted to a depth of almost 60 m, below which there was a weak thermocline; but the temperature remained higher there than in the slope water throughout the depth recorded on the BT graph. Sargasso st. 2 showed the development of a seasonal thermocline at about 15 m.

Among the *Globigerina*, *G. bulloides*, *G. incompta*, and *G. inflata* were all recorded in high frequencies; *G.* aff. *quinqueloba* was fairly common, and *G. dutertrei* was scarce.

The Foraminifera in the southern part of the traverse again changed in composition from the previous season. *Globorotalia truncatulinoides*, the dominant winter species, was recorded at less than 2% at all of the spring stations. *Pulleniatina obliquiloculata* also declined sharply from the winter and reached a maximum frequency of only 6% in the spring. The *Globigerinoides* species showed a large increase from the winter and reached a maximum of 48%. *Globigerinella aequilateralis* attained its highest frequency and was recorded at 60% at st. 2.

Summary and Discussion of the Distribution. In the surface waters between Cape Cod and Bermuda the change from a temperate to a subtropical planktonic foraminiferal fauna is clearly observed. On the shelf and on part of the slope this fauna, during all seasons, is composed almost entirely of species of

Globigerina. Toward the Gulf Stream, *Globigerina* species decrease in percentage and are replaced by a diverse subtropical group characteristic of the Sargasso Sea. The fauna in the Sargasso Sea contains very low percentages of *Globigerina* throughout the year, but other species show complex seasonal changes in frequency. During all seasons the change was observed on the slope side of the Gulf Stream, but the position of the change seems to vary throughout the year. It was closest inshore in the fall and farthest offshore between the winter and spring. The Gulf Stream shows no individuality in foraminiferal fauna and is essentially identical in composition with the Sargasso Sea. Intermediate foraminiferal faunas were encountered at some of the slope stations, and these appear to reflect mixing of surface waters between the Sargasso Sea, the Gulf Stream, and the slope waters. Mixing is also suggested by the subsurface temperatures, for the stations with intermediate foraminiferal faunas also appeared to have intermediate subsurface temperatures. The mixing might possibly result from the dissipation of eddies that have been detached from the northern meanders of the Gulf Stream. Detached eddies have been observed in the western North Atlantic, but little is known about their frequency of occurrence or importance as a means of transferring water across the Gulf Stream (Stommel, 1958: 63). The data here are meager, and more detailed studies are needed. In this respect, BT's provide a rapid and easy source of important hydrographic information, and it is recommended that, wherever possible, BT's be taken with all plankton tows.

The faunal changes occurring during the year in the Sargasso Sea correspond in a general way with the seasonal fluctuations in species observed by Bé (1960) at stations near Bermuda. However, comparison also reveals some differences in frequencies of species at particular times of the year, indicating that there is not a clear-cut relationship between faunal changes and seasonal hydrographic fluctuations in the Sargasso Sea. For example, Bé recorded high percentages of *Globigerina* species during the winter; at the Sargasso stations studied here, *Globigerina* occurred in low frequencies throughout the year, suggesting that the Gulf Stream, in this part of the Atlantic, is an effective barrier in preventing appreciable numbers of *Globigerina* from penetrating the Sargasso Sea from the slope waters. It is probable, however, that effective penetrations of *Globigerina* from the slope waters to the Sargasso Sea occur in other parts of the North Atlantic, as for example, east of the Grand Banks where the Gulf Stream becomes erratic, diffuse, and probably ineffective as a barrier. In addition, Bé recorded *Globorotalia hirsuta* as a temperate species with high frequencies in January through May; that species was scarce or absent at all of the stations of the traverses studied here.

At various times of the year, differences in frequencies of other species could also be observed, but it would serve no useful purpose to consider all of these details here as the areas studied are very limited and the foraminiferal fauna in the greater part of the Sargasso Sea is still poorly known. It is possible

that the Sargasso Sea simultaneously supports different foraminiferal communities, and the changes in Foraminifera observed in a given area may be effected by the horizontal clockwise motion of the Sargasso and the interchange of its waters with those bordering the Sargasso Sea. Other factors, such as reproductive and mortality cycles, vertical migration, survival tolerances must, of course, also contribute in important ways to the dynamics of distribution. Clearly, the system is complex and the fauna of the Sargasso Sea needs to be studied in its entirety.

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REFERENCES

Bé, A. W. H.
1960. Ecology of Recent planktonic Foraminifera: Part 2 – Bathymetric and seasonal distributions in the Sargasso Sea off Bermuda. Micropaleontology, 6: 373–392.

Grice, G. D. and A. D. Hart
1961. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. Woods Hole Oceanog. Inst. Unpubl. ms., Ref. No. 62-4.

Hardy, A. C.
1955. A further example of the patchiness of plankton distribution. Deep Sea Res., 3, (Suppl.): 7–11.

Stommel, Henry
1958. The Gulf Stream, a physical and dynamical description. Univ. California Press, Berkeley and Los Angeles. 202 pp.