VERTICAL DISTRIBUTION OF PELAGIC FORAMINIFERA.*

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ABSTRACT. The importance of additional knowledge of the ecology of pelagic Foraminifera is stressed. Methods for quantitative collections and study of pelagic Foraminifera are discussed. Study of five serial plankton tows indicates that living Foraminifera are present in significant quantities down to a depth of at least 1,000 meters.

STUDY of submarine cores has shown the necessity of more accurate knowledge of the ecology of Foraminifera. The most fundamental problem is the question of where the animals live during all or part of their existence. It is known that certain species are pelagic, because they have been collected in plankton tows, and it is assumed that all others are benthonic.

Most geologists have subconsciously assumed that all pelagic Foraminifera live at the surface of the sea. This does not appear logical since other elements of the plankton live throughout the water column. It is true, however, that the greatest abundance of plankton occurs in the surface water layers. In addition, certain distributions of benthonic Foraminifera in submarine cores are difficult to explain if we assume that they are strictly benthonic.

There are other aspects of the problem of distribution of pelagic species. Do the shells in marine bottom samples represent an assemblage which lived in the water directly above the position of the sample? How far are the shells transported by currents before deposition? In interpreting past marine environments by faunas in submarine cores, it is essential to know what water layers are being interpreted. Most of the work done on submarine cores has been a study of the different marine environments represented by the deposits at different levels in many cores. The recognition of environmental differences in the sediments which occur in the cores is based almost entirely on different occurrences of Foraminifera at different stratigraphic levels. Most of the differences between faunas occurring at different core levels can be interpreted as due to

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water temperature or climatic variations. Many of the Foraminifera used for these relative temperature determinations are pelagic.

If all the pelagic forms normally live at or near the surface of the sea, the problem of interpretation is a simple one, but the greater the vertical distribution of the pelagic Foraminifera, the more complex the problem. In ocean water of warm tem-

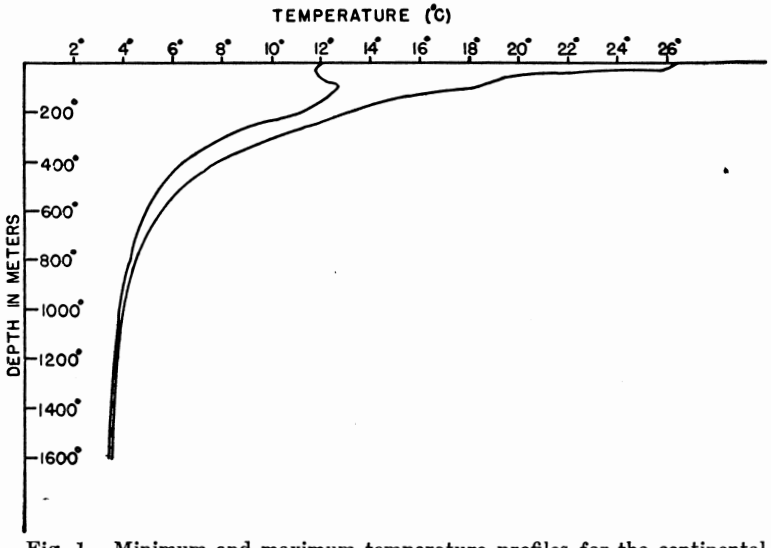

Fig. 1. Minimum and maximum temperature profiles for the continental slope water off eastern North American. (Modified after Iselin.)

perate regions there is a decrease in temperature with depth. Moreover, the layers of water above about 100 meters depth have a much greater annual range of temperature than deeper water. This is shown graphically in Fig. 1, which contains generalized minimum and maximum temperature curves for the water of the continental slope off eastern North America. Any foraminifer which lives at 500 meters depth must have a different temperature tolerance (8-10° C.) than one which is restricted to the surface (12-26° C.) (See Fig. 1).

This paper is in the nature of a report on methods which have been developed for attacking the problem of bathymetric distribution of Foraminifera. The data obtained from the plankton tows made by the writer are inadequate, but they illustrate the procedure and may be indicative of the type of results to be expected in future investigations.

Any study of the distribution of pelagic Foraminifera should

be made from tows taken at known water depths and should be quantitative if it is to be of any value in solving the problems relative to ecology and paleoecology. Most records of tows are purely qualitative and are from surface water zones. One of the recent exceptions is the work done aboard the *Meteor* in equatorial Atlantic waters, reported by Schott (1935).[1] A series of traverses were made between the African coast and Brazil. In the report of the Meteor Expedition, Schott lists plankton tow records for Foraminifera from 93 stations. The tows were made with a Nansen closing net, and the water was sampled at various depths down to 1000 meters. The tows were of uniform time duration and the total number of specimens of Foraminifera in each sample were counted, with percentage ratios of the species also listed. In this region the greatest frequency of pelagic Foraminifera is in water depths of 0 to 100 meters, although significant numbers occur at all depths sampled. The following is an analysis of Schott's data by the writer, and it clearly shows this.

Depth in Meters	No. of Tows	Mean No. of Specimens per Tow
0–100	71	489
100–200	7	8
200–400	13	24
400–600	19	10
600–800	12	11
800–1000	19	28

Globigerinoides sacculifera is the most abundant species in the Atlantic equatorial region. *Globigerina bulloides* and G. *inflata* are found in abundance only in the colder surface waters of this equatorial region or in the colder water at considerable depth.

The quantitative results of these tows are only partially reliable, as Schott realized. The reliability of the results showing the mean numbers of specimens occurring at different depths is directly proportional to the number of tows. A difficulty inherent in the Nansen closing net is that the volume of water strained is unknown. Great variation in volume strained is common, as illustrated by quantitative plankton samplers now in use. No attempt was made to discover which specimens were alive when collected and which were simply empty shells. The empty shells represent specimens which are sinking to the bottom and are of no significance in solving problems of habitat.

During a short cruise of the *Atlantis* in the summer of 1941, the writer made serial plankton tows at known depths to 1000

meters. These were made with the quantitative sampler developed by Dr. George L. Clarke and Mr. Dean F. Bumpus (1940)[2] of the Woods Hole Oceanographic Institution. This device may be opened and closed at known depths, and in addition, the volume of water strained is measured by the revolutions of a propeller. The plankton was preserved successfully in neutral formalin; adequate neutral formalin may be made by addition of sodium carbonate to the solution. Formalin which is not neutralized will, in many cases, dissolve the tests of Foraminifera. The use of alcohol as a preservative is not recommended since it makes a white gelatinous precipitate with sea water, and it is difficult to see and to disengage Foraminifera from the other plankton.

In operating these plankton nets for pelagic Foraminifera, certain precautions must be observed, since the small size and relative abundance of the specimens may cause inadvertent contamination from material on board ship or in water layers not being sampled. The nets must be kept in a clean container or hanging, and contact with other things on board avoided. When the nets are recovered after a tow has been made, they should be thoroughly washed on the outside with fresh water or filtered sea water. After recovering the plankton from the net, which is done by repeated washing into a bottle fastened to the end, the net should be cleaned with a stiff spray of water for several minutes.

In order to study the Foraminifera it is necessary to separate them from the remainder of the plankton, of which they may constitute only a fraction of one per cent. This may be done by extracting each specimen with a pipette, and this procedure avoids injury to delicate specimens. Each plankton sample must be thoroughly examined several times, since small specimens tend to be obscured by other plankton materials.

One of the difficulties has been to distinguish living specimens from empty tests. This involves recognition of protoplasm in the specimen and is very difficult without staining. Certain biological stains can be applied, but decalcification of the specimens is advisable and in most cases necessary. This procedure destroys the test which is most valuable for a paleontologist and upon which the recognition of the species is based. At the suggestion of Dr. George P. Child of the Amherst College Biology Department, a successful technique for recognizing protoplasm without dissolving the test was developed by Mr.

Garrish Metcalf, a student at Amherst College. This is the Biuret test for protein in which the protein-containing substance such as any protoplasm is colored purple.

The procedure in making the Biuret test on this material is as follows: Foraminifera in formalin solution are placed in a shallow glass evaporating dish and to this a few drops of a 10 per cent solution of sodium hydroxide are added. The sodium hydroxide breaks down the proteins in the protoplasm to form compounds related to urea. After several minutes (in the experience of the writer approximately 30 to 40 minutes) a few drops of a very dilute solution (.05 per cent) of copper sulphate is added. In a short time the protoplasm is colored purple and this coloration can be seen clearly through the test against a white background with a properly adjusted light source. If the specimens are to be stored for future reference, it is necessary to wash them several times before storing, since the sodium hydroxide eventually will destroy the tests. The entire technique is simple, speedy, and the shells can be preserved for future reference.

This method can be used to great advantage in studying benthonic populations. Any marine bottom sample probably contains more empty tests than live Foraminifera. It is necessary to know which specimens were living at the time the sample was taken to determine: 1.) which species actually live in that environment and were therefore not transported there, and 2.) the productivity of the area and therefore the probable rate of accumulation of the tests. Also, there is some evidence that certain pelagic species may live a part of their life cycle at or near the bottom. Many empty tests of Foraminifera become filled with clayey substances on marine bottoms. These materials have an appearance not unlike protoplasm after being placed in a preserving solution. Ordinary biological stains affect this substance in almost the same way as they do protoplasm, and so cannot be used to differentiate living from dead specimens. The Biuret test is a successful method for distinguishing those individuals filled with protoplasm.

The greatest concentration of pelagic specimens is in water over the continental slope and ocean basins, according to occurrences in bottom samples. The 1941 *Atlantis* tows came from the basin of the North Atlantic, south of Georges Bank, where the depth of water varies from about 3000 to 5000 meters. The tows were made primarily to discover if the

FIGURE 2. Distribution of Foraminifera in Plankton Tows.

	Station 1 Lat. 40° 05′ N Long. 68° 21′ W			Station 2 Lat. 39° 50′ N Long. 67° 11′ W			Station 3 Lat. 40° 58′ N Long. 66° 39′ W		Station 4 Lat. 40° 43′ N Long. 69° 50′ W			Station 6 Lat. 39° 55′ N Long. 68° 48′ W		
	Sample 1 Depth 700 m. Vol. 26.04 cu. m.	Sample 2 Depth 350 M. Vol. 12.53 cu. m.	Sample 3 Depth 70 m. Vol. 6.13 cu. m.	Sample 1 Depth 1000 m. Vol. 5.14 cu. m.	Sample 2 Depth 650 m. Vol. 11.92 cu. m.	Sample 3 Depth 400 m. Vol. 4.91 cu. m.	Sample 1 Depth 700 m. Vol. 35.44 cu. m.	Sample 2 Depth 325 m. Vol. 20.6 cu. m.	Sample 1 Depth 975 m. Vol. 17.73 cu. m.	Sample 2 Depth 475 m. Vol. 17.61 cu. m.	Sample 3 Depth 75 m. Vol. 17.51 cu. m.	Sample 1 Depth 1000 m. Vol. 28.36 cu. m.	Sample 2 Depth 500 m. Vol. 18.4 cu. m.	Sample 3 Depth 100 m. Vol. 19.84 cu. m.
Globigerina *bulloides*	1(*5*)	(*1*)	(*10*)	2(*2*)	(*11*)	9(*18*)	58(*70*)	(*8*)	72(*56*)	2	16(*13*)	12(*34*)	(*1*)	6(*1*)
G. inflata				(*2*)		(*3*)	1							
G. pachyderma									2					
Globigerinoides *rubra*	1(*3*)		5(*9*)	4(*4*)	(*11*)	4(*9*)	5(*8*)		8(8)		2	1(*7*)		1
G. truncatulinoides				(*1*)	(*1*)		(*1*)							
Globigerinella *aequilateris*				(*2*)	(*1*)									
Unidentified Globigerinidae							8							
Globorotalia *scitula*						(*1*)		(*1*)						
G. hirsuta						(*2*)								
Orbulina universa							1							

The numbers in light type indicate living specimens and the numbers in italics and in parentheses indicate empty tests.

quantitative samplers could be operated successfully at great depths and whether Foraminifera occurred at depths in this region and could be collected. An equally important purpose was to use the material for experiments in the technique of preservation and study.

Since only six serial tows were made (and the material in one tow was destroyed in the process of experimentation) the results have no quantitative significance. It is possible, however, to make several interesting and important observations on the data obtained. The most significant fact is that specimens of Foraminifera were present in every sample collected at several depths from 75 m. to 1000 m. The number of living specimens found at 1000 m. varied from 1.5 specimens to 4.6 specimens per cu. m. of water. At station 4, approximately four and one-half times the number of living specimens per unit volume of water were found at 975 m. as were found at 75 m. It is true that most of the specimens found in most of the deep tows were empty tests, presumably those settling from the upper layer of water. The data suggest a larger population of living Foraminifera at about 1000 m. than at about 100 m. at some localities.

Nearly all the specimens in the tows are very small and without exception very thin shelled. This may have been due to the season of year at which collecting was done (August). In bottom samples from the same region a large percentage of the specimens are large and heavy-shelled. By far the greatest number of living and dead specimens were of *Globigerina bulloides* with *Globigerinoides rubra* occurring in significant numbers.

This is preliminary to a more extensive program of towing for pelagic Foraminifera which, it is hoped, can be undertaken as soon as conditions permit. It is further hoped that other individuals and organizations will undertake similar studies, either in the North Atlantic or elsewhere, and that similar studies will be made on benthonic populations.

REFERENCES.

1. Schott: 1935, Die Foraminiferen in den aquatorialen Teil des Atlantischen Ozeans, Deutsche Sudpolar Exped., 11, Heft. 6, 411-616.
2. Clark, G. L., and Bumpus, D. F.: 1940, The Plankton Sampler—an Instrument for Quantitative Plankton Investigations. Spec. Pub. No. 5, Limnological Society of America.

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