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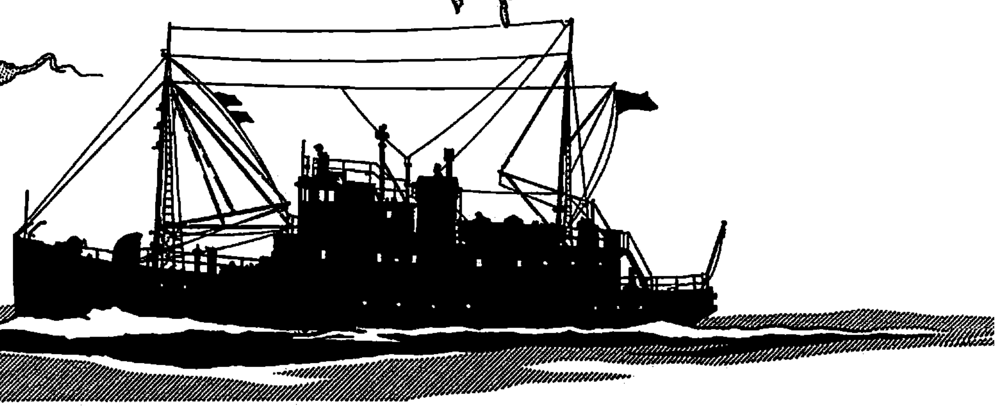

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Technical Report No. 90

DISTRIBUTION OF LIVING PLANKTONIC FORAMINIFERA IN THE NORTHEASTERN PACIFIC, by A. Barrett Smith. Contributions, Cushman Foundation, 14(1):1-15, January 1963.

Technical Report No. 91

A NEW HYPOTHESIS FOR ORIGIN OF GUYOTS AND SEAMOUNT TERRACES, by Y. Rammohanroy Nayudu. Crust of the Pacific Basin, Geophysical Monograph No. 6, pp. 171-180, December 1962.

Technical Report No. 92

PHYSICAL AND SEDIMENTARY ENVIRONMENTS ON A LARGE SPITLIKE SHOAL, by Dean A. McManus and Joe S. Creager. Journal of Geology, 71(4):498-512, July 1963.

Technical Report No. 93

GRAVITY AND THE PROPERTIES OF SEA WATER, by Ricardo M. Pytkowicz. Limnology and Oceanography, 8(2):286-287, April 1963.

Technical Report No. 94

POSTGLACIAL SEDIMENTS IN UNION BAY, LAKE WASHINGTON, SEATTLE, WASHINGTON, by Dean A. McManus. Northwest Science, 37(2):61-73, May 1963.

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RICHARD H. FLEMING
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CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
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257. DISTRIBUTION OF LIVING PLANKTONIC FORAMINIFERA IN THE NORTHEASTERN PACIFIC[1]

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ABSTRACT

The planktonic foraminifera collected in 176 tows in the northeastern Pacific Ocean were studied. Of the eight species identified, the four most common were **Globigerina bulloides, G. pachyderma, Orbulina universa** and **Globigerina eggeri.** Maximum concentrations occurred above the **Globigerina**-rich sediments on the sea floor. No direct correlation between physical variables and the distribution of the foraminiferal population was observed. The possible vertical stratification of several species is discussed.

INTRODUCTION

In the early eighteen hundreds, d'Orbigny (1826) was engaged in a taxonomic study of the planktonic foraminifera. This pioneer work was followed by that of Brady (1884), who studied specimens of the group which had been collected during the Challenger expedition. His samples were obtained from net tows in the surface water as well as from dredgings and soundings in the sediments on the sea floor. The majority of his tows were collected in the upper 91 meters of water and represent the first world-wide study of the group. This work was followed by Murray's (1895, 1897) investigations of the same collections.

After this fine beginning considerable time passed before other valuable contributions were made. Schott (1935) studied low latitude forms taken during the Deutsche Atlantische Expedition and was able to infer climatic changes on the basis of faunal changes in the stratigraphic sequence within the cores. He also had samples of living organisms from tows and found that the largest concentrations were in the upper 100 meters. Phleger (1951) studied planktonic foraminifera from material in net tows and bottom sediments taken from the Gulf of Mexico. Phleger, Parker and Peirson (1953) defined the geographic distribution of planktonic species collected from the Atlantic and considered the limiting factors to be temperature and salinity. As Phleger pointed out, the fauna occurring in bottom samples did not necessarily live in water directly above the sample position and interpretations may be misleading unless the distribution and movements of water masses are taken into account. However, planktonic foraminifera from the sediments have frequently been used in interpreting Recent and paleoenvironments before a true understanding of their ecology has been acquired.

Foraminifera, when entombed in ancient sediments, are frequently used as stratigraphic guides. Such studies have been carried out in the belief that planktonic foraminifera are subject to wide and relatively rapid dispersal by ocean currents. A number of papers based upon such an assumption have been published. In view of this trend of using planktonic foraminifera as tools for paleoecology and stratigraphy, it is alarming to see how little is known concerning the ecology and phylogeny of living forms. The work of Bé (1959, 1960a), Bradshaw (1959) and Parker (1960) are among the first attempts at complete ecologic studies. The approach in this paper is similar; however, the study area is more restricted.

The area in question lies between 39° and 51° N. Lat. and the west coast of North America and 141° W. Long. It is within the scope of this paper to: (1) determine the species of planktonic foraminifera present; (2) delimit their geographical distribution and abundance; (3) consider that distribution in terms of chemical and physical data; and (4) outline the vertical distribution of the organisms.

METHODS

One hundred and seventy-six plankton samples were examined. These were obtained by the University of Washington's Department of Oceanography research ship, the M. V. BROWN BEAR, during seven cruises in the northeast Pacific Ocean from 1956 to 1958. Collections were made with either a Clarke-Bumpus sampler (Clarke and Bumpus, 1950) using a nylon net with 74 meshes per inch and an aperture size of 0.239 mm. or with a half-meter net of the same mesh size. The plankton was preserved in glass jars containing formalin neutralized with borax. During this investigation many of the samples were tested for acidity and found to have a pH of approximately 6. However, most of these contained numerous well preserved foraminifera, and it is believed that few specimens were lost due to dissolution. In a few instances, hardened globular masses of protoplasm resembling *Globigerina* in form were found in the samples. In some cases, broken foraminiferal tests contained these bodies. It is believed that occasionally the test dissolves leaving this evidence of its existence. Generally, these masses were found in samples containing no tests and were seldom found where tests were numerous. Consequently, their presence, noted in seven samples, was taken as an indication of solution.

On BROWN BEAR cruise 144, two Clarke-Bumpus samplers were spaced on the wire so that the lower sampler fished from 400 to 200 meters while the upper one fished from 200 meters to the surface. Both sam-

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plers were lowered closed. At depth they were opened by messenger. After being opened, they were returned while the ship was moving at slow speed. When the upper sampler surfaced, both devices were closed by messenger. Eight single Clarke-Bumpus stations were taken at varying depths and at one station 20 samples were taken from five separate hauls. During each haul, four samplers were lowered so that they fished at 150, 100, 50 meters and the surface.

On the other six cruises both Clarke-Bumpus and half-meter tows were taken. The material was collected from various depths to the surface. All Clarke-Bumpus tows were oblique while the half-meter hauls were vertical, except for surface hauls.

All of the plankton samples were sorted by hand under a binocular microscope. A small portion of the sample was removed from the whole with a syringe and placed in a petri dish. All foraminifera were then removed with a camel's hair brush and placed on microscope slides to be mounted with gum tragacanth. This was repeated until the entire sample had been sorted. Thus, the total number of foraminifera in each sample was recorded. As the Clarke-Bumpus sampler records the approximate volume of water filtered, it was possible to determine the number of organisms present in a cubic meter of water. As there is some controversy concerning whether a half-meter net fishes while being lowered, figures for water filtered by this device are not included.

SYSTEMATICS

The nomenclature of Parker (1958) is followed. The synonomies are not complete, but include the original reference and a few papers of immediate interest. To simplify comparison with the works of others, the author has included some views concerning his concept of those species present. These remarks are not intended to be taken as taxonomic descriptions. Several species are represented by figures of more than one specimen, one considered to be typical, the others common variants. The figured specimens are deposited in the Museum of Paleontology at the University of Washington, Seattle.

Family GLOBIGERINIDAE Carpenter

Globigerina bulloides d'Orbigny

Plate 1, figures 1-4

Globigerina bulloides D'ORBIGNY, 1826, Ann. Sci. Nat., vol. 7, p. 277, no. 1; Modèles, no. 76; and young, no. 17.

Globigerina bulloides d'Orbigny—BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Research, vol. XI, pt. 1, pp. 3-4, pl. 1, figs. 1, 2, 4.

Remarks.—The typical *G. bulloides* has 4 chambers in the final whorl with a large umbilical aperture opening into all chambers (pl. 1, figs. 1-2). Occasionally a specimen with five chambers is found (pl. 1, fig. 3). Rather compressed forms are not uncommon. In these, the aperture opens into the final chamber and becomes crescent shaped. The shape of the entire test becomes more triangular than the typical form and the chambers are less globular (pl. 1, fig. 4).

Globigerina bradyi Wiesner

Plate 2, figures 24-25

Globigerina sp., BRADY, 1884, Rept. Voy. *Challenger*, Zool., vol. 9, p. 603, pl. 82, figs. 8-9.

Globigerina bradyi WIESNER, 1931, "Die Foraminiferen der deutschen Sudpolar-Expedition 1901-1903" (*in* Drygalski "Deutsche Sud-Polar Expedition 1901-1903") de Gruyter, Berlin u. Leipzig, Bd. 20 (Zool. Bd. 12), p. 133, (no figure).

Globigerinoides minuta NATLAND, 1938, Bull. Scripps Inst. Oceanography, Tech. Ser. vol. 4, no. 5, p. 150, pl. 7, figs. 2-3.

Globigerina bradyi Wiesner—BOLLI, 1957, U. S. Natl. Mus., Bull. 215, pp. 110-111, pl. 23, figs. 5 a-c.

Globigerina bradyi Wiesner—BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Research, vol. XI, pt. 1, pp. 5-6, pl. 3, figs. 1-2.

Remarks.—The specimens found during this study agree, with little variation, with the description of the lectotype designated by Banner and Blow. The only difference being that those from the northeastern Pacific are slightly shorter than that figured for the lectotype.

Globigerina eggeri Rhumbler

Plate 1, figures 8-11

Globigerina dubia Egger—BRADY, 1879, Quart. Jour. Micr. Sci., vol. 19, (n.s.) p. 285.

Globigerina eggeri Rhumbler, 1901, *in* BRANDT, Nordisches Plankton, Lief. 1, Nr. 14, pp. 19-20, text-figs. 20 a-c.

Globigerina eggeri Rhumbler—BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Research, Vol. XI, pt. 1, pp. 11-12, pl. 2, fig. 4.

Remarks.—This is a high-spired form usually with five chambers in the final whorl. Infrequently this whorl has six chambers. The aperture is wide and leads from the final chamber into the umbilicus. Frequently, the interior of the earlier chambers may be seen. The test is nearly circular in outline. The surface shows a rough texture with large pores. The chambers, which taper axially, closely resemble the segments of a peeled orange.

Globigerina pachyderma (Ehrenberg)

Plate 2, figures 15-18

Aristerospira pachyderma EHRENBERG, 1861, Monats. k. preuss. Ak. Wiss. Berlin, p. 303; 1872 (1873), Abhandl. Ak. k. Wiss. Berlin, pl. 1, fig. 4.

Globigerina pachyderma (Ehrenberg)—PARKER, 1958, Repts. Swedish Deep-Sea Exped., vol. VIII, no. 4, p. 278, pl. 5, fig. 9.

Globigerina pachyderma (Ehrenberg)—BÉ, 1960, Contr. Cushman Found. Foram. Research, vol. XI, pt. 2, pp. 64-68, text-fig. 1.

Remarks.—The test is typically square in outline, very low spired with four chambers in the final whorl. The walls are thick and crystalline. The aperture is a narrow slit which runs from the umbilicus toward the periphery of the test, parallel to the suture separating the first and final chambers in the last whorl, (figs. 16-17). Generally, a well-defined lip is present. Often a fifth chamber will be seen in various stages of development, (figs. 15 and 18). This appears to be derived from the lip and often takes the appearance of a porch over the umbilical area. Commonly a rather triangular form is found that closely resembles the compressed variety of *G. bulloides.* A prominent lip, a smaller aperture which is more slit-like, and less globular chambers distinguish it from that species.

Globigerina quinqueloba Natland
Plate 1, figures 5-7

Globigerina quinqueloba NATLAND, 1938, Bull. Scripps Inst. Oceanography, Tech. Ser. vol. 4, no. 5, pp. 149-150, pl. 6, fig. 7a-c.

Remarks.—The only variation from the type described by Natland is that frequently the lip over the aperture is absent, having been either broken or not developed. Young animals are difficult to separate from young *G. eggeri.*

Globigerinita glutinata (Egger)
Plate 2, figures 26-28

Globigerina glutinata EGGER, 1893, Abhandl. K. bay. Akad. Wiss. München, Cl. 11, vol. 18, p. 317, pl. 13, figs. 19-21.—RHUMBLER, 1911, Ergeb. Plankton-Exped. Humboldt Stift., vol. 3, p. 148, pl. 29, figs. 14-26; pl. 33, fig. 20; pl. 34, fig. 1.

Globigerinita glutinata (Egger)—PHLEGER, PARKER and PEIRSON, 1953, Repts. Swedish Deep-Sea Exped., vol. VII, no. 1, p. 16, pl. 2, figs. 12-15.

Remarks.—There are generally four spherical chambers in the final whorl. These enlarge rapidly with a final chamber that is much larger than the others. Frequently there will be but three chambers in the last whorl. In the material studied, few specimens had supplementary apertures. The primary aperture is a crescentic slit adjoining the umbilicus. Some forms closely resemble the more compressed form of *Globigerina bulloides* but may be distinguished from that species by the more rapidly expanding chambers, an aperture that is restricted to the final chamber, and a much smoother texture.

Orbulina universa d'Orbigny
Plate 2, figures 19-20

Orbulina universa d'Orbigny, 1839, *in* DE LA SAGRA, Hist. Phys. Pol. Nat. Cuba, "Foraminifères," p. 3, pl. 1, fig. 1.

Orbulina universa d'Orbigny—BLOW, 1956, Micropaleontology, vol. 2, no. 1, pp. 57-70, text-figs. 1-4.

Orbulina universa d'Orbigny—PARKER, 1958, Repts. Swedish Deep-Sea Exped., vol. VIII, no. 4, p. 280, pl. 6, fig. 13.

Remarks.—Generally, single-chambered forms were found. However, several multilobate forms were collected (fig. 20). The author follows Parker (1958) in referring both forms to a single species.

Family GLOBOROTALIIDAE

Globorotalia scitula (Brady)
Plate 2, figures 22-23

Pulvinulina scitula BRADY, 1882, Proc. Roy. Soc. Edinburgh, vol. 11, p. 716.

Pulvinulina patagonica BRADY, 1884 (not *Rotalina patagonica* d'Orbigny, 1839), Rept. Voy. *Challenger, Zool.*, vol. 9, p. 693, pl. 103, fig. 7.

Globorotalia scitula (Brady)—CUSHMAN, 1927, Bull. Scripps Inst. Oceanography, Tech. Ser., vol. 1, no. 10, p. 175.

Globorotalia scitula (Brady)—CUSHMAN, 1931, Bull. U. S. Natl. Mus. 104, pt. 8, pp. 100-101, pl. 17, figs. 5 a-c.

Remarks.—The few specimens of this, the only species of *Globorotalia* found, agree closely with the original description.

JUVENILE AND MORPHOLOGIC INTERGRADES OF *GLOBIGERINA*

As Bé (1959, p. 83) has pointed out, "(1) there is an overlapping range of morphologic variation in adult individuals of some closely related species (infra- or interspecific variation), which results in intergradation between forms that have been established as separate species, (2) there is morphologic similarity among juveniles of many different species, (3) there is lack of agreement as to the relative significance of observable characters."

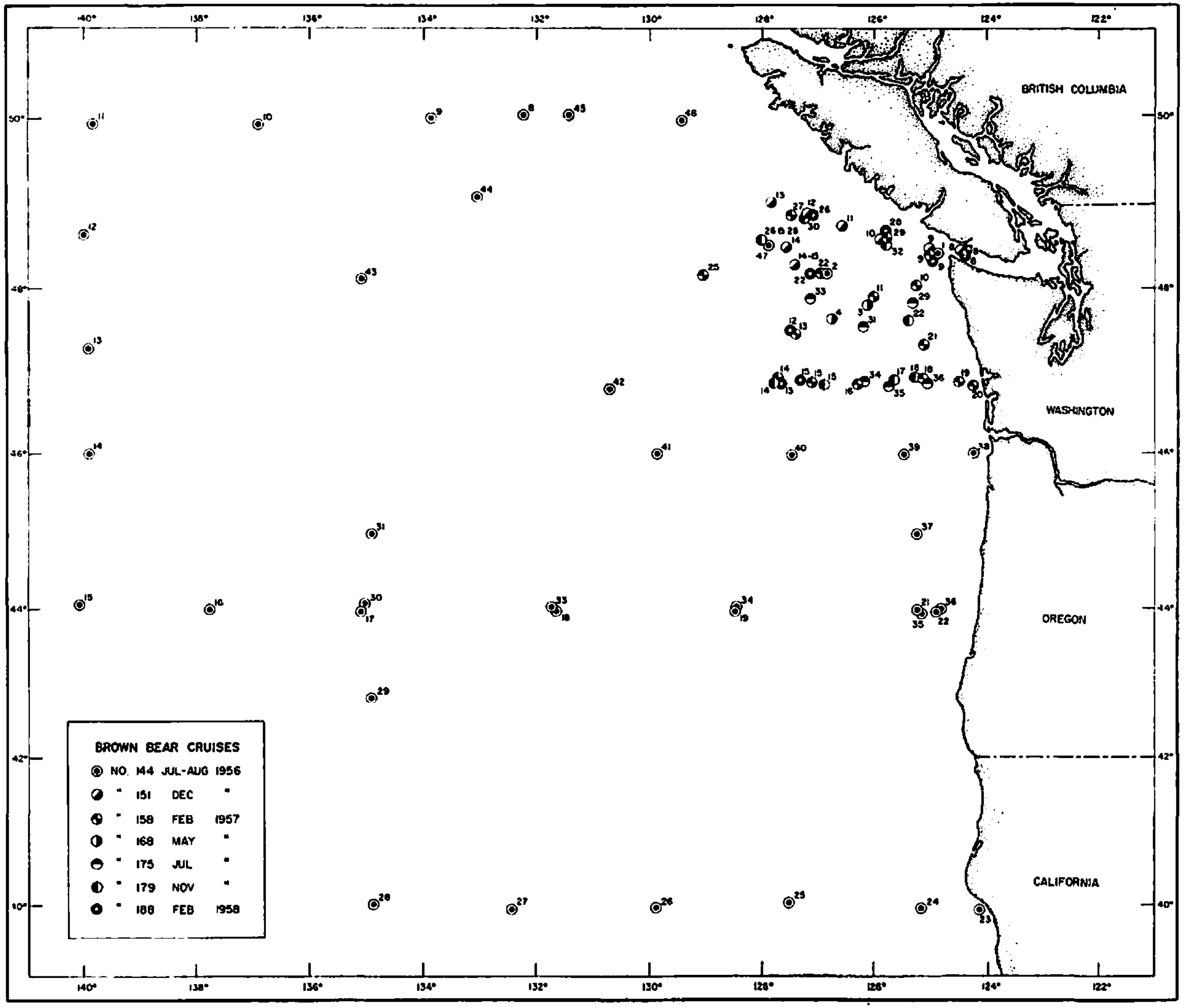
In the case of juveniles, this author has found it impossible to differentiate forms which are smaller than about 50 microns. Some of those that closely resemble one another, when juvenile, are: *Globigerina bulloides* and *Globigerinita glutinata,* compressed *Globigerina bulloides* and *G. pachyderma,* larger *G. pachyderma* and *G. eggeri,* smaller *G. eggeri* and *G. quinqueloba.*

The similarity between the forms of *G. pachyderma* which have a long slit aperture and more distinct sutures than the typical forms and young stages of *G. eggeri* which have not developed the final chambers in the last whorl make separation difficult. These are grouped together as the morphologic intergrade *Globigerina pachyderma-eggeri* and are figured (pl. 1, figs. 12-14, pl. 2, fig. 21).

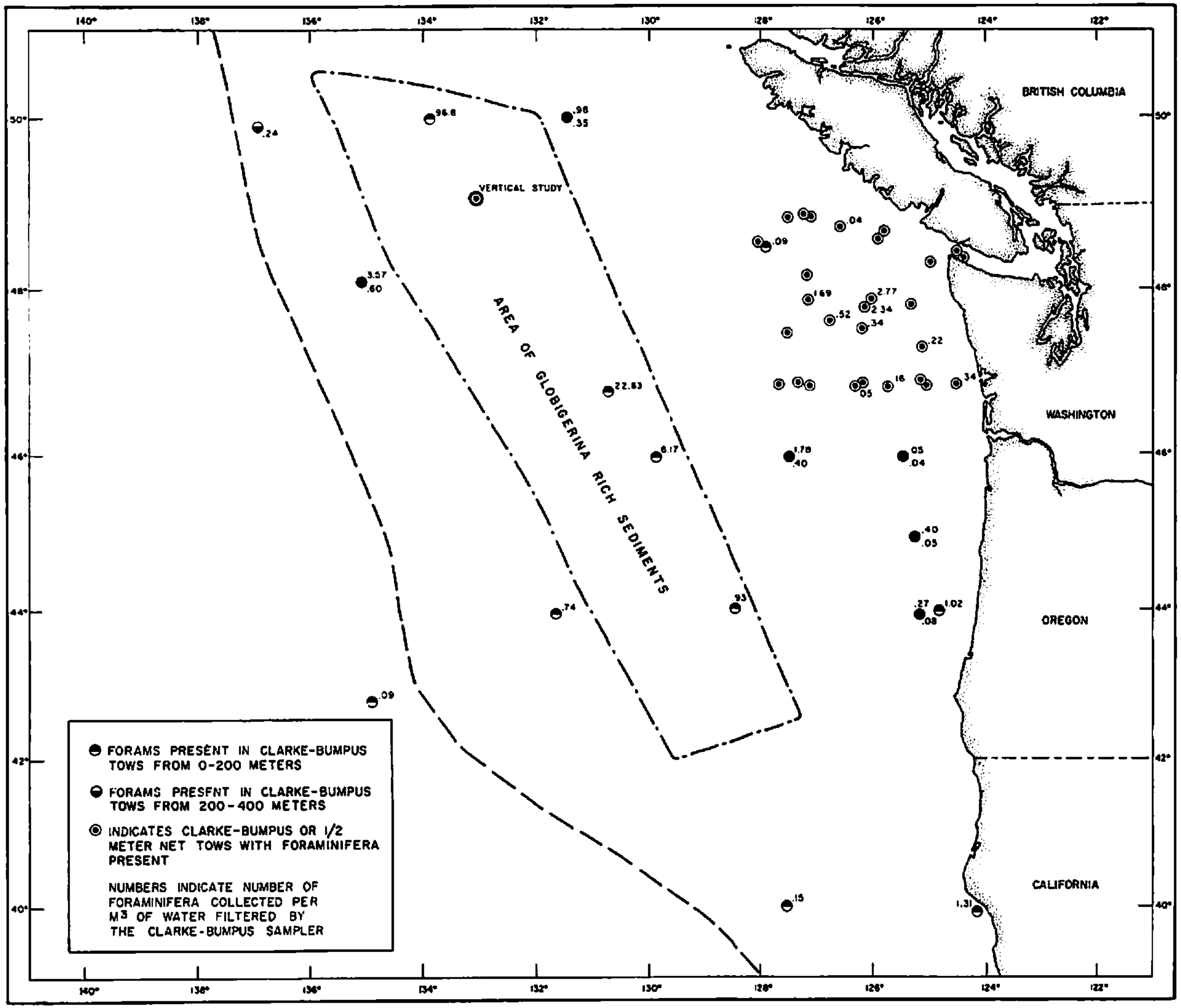
It is doubtful that problems concerning morphologic intergradation in the Globigerinidae can be accurately studied until living animals are collected and observed through various stages of development.

AREAL DISTRIBUTION

One hundred and fifty-six of the one hundred and seventy-six samples were considered for the study of geographical distribution. The remaining 20 are discussed under vertical distribution. Thirty-three of the former were taken from 400 to 200 meters. The others



TEXT FIGURE 1
Locations of all plankton stations.



TEXT FIGURE 2

Locations of all tows capturing foraminifera (only 1 tow seaward of dashed line contained any specimens).

were taken from various depths, generally near 200 meters, to the surface. Text figure 1 shows the locations of all stations.

The patchiness of the plankton has been mentioned repeatedly by earlier workers (Phleger, 1951, King and Demond, 1953). The latter, in their study of the zooplankton of the central Pacific, found an extremely erratic distribution of planktonic foraminifera. These organisms were found to constitute as much as 60 percent of the total plankton at one station while at others, they were absent. In the current study, foraminifera were collected in only 65 of the 156 samples. Such extreme fluctuations between stations makes it difficult to define the geographical boundaries of these organisms. A great many samples are necessary before one can have any confidence that the sampling is not selective.

The close agreement between the area where foraminifera are found in the surface waters and the *Globigerina*-rich sediments described by Nayudu [1959] may be seen in text figure 2. The three tows having the greatest number of foraminifera per cubic meter of water filtered are directly above this zone. However, it should be noted that two stations within this area did not yield foraminifera. The lack of foraminifera seaward of the area of maximum numbers may be a reflection of the patchiness of the plankton rather than a definite geographical restriction of the organisms. This agreement between the area of maximum numbers in the plankton and the *Globigerina*-rich sediments is to some degree surprising. The fact that planktonic foraminifera are subject to wide dispersal by surface currents would seem to require that living populations be offset from the zone of occurrence on the bottom since they would be subject to transport after death. However, Murray (1897) and Schott (1935) found evidence that transport was slight after death and that the animals were deposited close to where they lived. This appears to be true in this case. However, future sampling seaward of the area of maximum numbers might reveal large populations of planktonic foraminifera which could be carried coastward.

Coastward of the *Globigerina*-rich sediments, moderate sized populations of foraminifera were collected in the plankton. Here, planktonic foraminifera constituted a small proportion of the sediment. This apparent discrepancy with the material collected from the sediment may be explained quite simply. Near the coast, terrigenous sediments comprise a large percentage of the surface sediments while seaward of the slope their presence is negligible. For a sediment to be considered *Globigerina*-rich, foraminifera must make up 30 percent or more of the volume. Nearshore the foraminiferal population is masked by the terrigenous components.

Many workers studying the sediments in other areas have noted that the percentage of planktonic foraminifera increases seaward (Bandy, 1961). No evidence of a similar trend in the living plankton could be found during this investigation. Other than above the *Globigerina*-rich sediments, the location of larger populations seems to be random. Enbysk [1960] in her study of the foraminifera from the sediments in the same area was unable to find any seaward trends that were not related to topography or other factors of sedimentation.

Temperature, salinity, dissolved oxygen, and inorganic phosphate concentrations were determined at a depth of 50 meters in an attempt to correlate the occurrence of planktonic foraminifera with these variables. This depth was selected for three reasons. The vertical study showed that foraminifera were most abundant at this depth. Secondly, the physical environment at depth is more stable than at the surface and thus provides a better index for correlation. Finally, a preliminary study indicated a closer correlation with the organisms and the physical environment at 50 meters. The physical data were obtained from samples taken at the time the plankton samples were collected. Charts for the average temperature, salinity, dissolved oxygen and inorganic phosphate concentrations at 50 meters, compiled by the editors of the NORPAC Atlas (1960), are shown (text figs. 3-6).

Temperature and Salinity

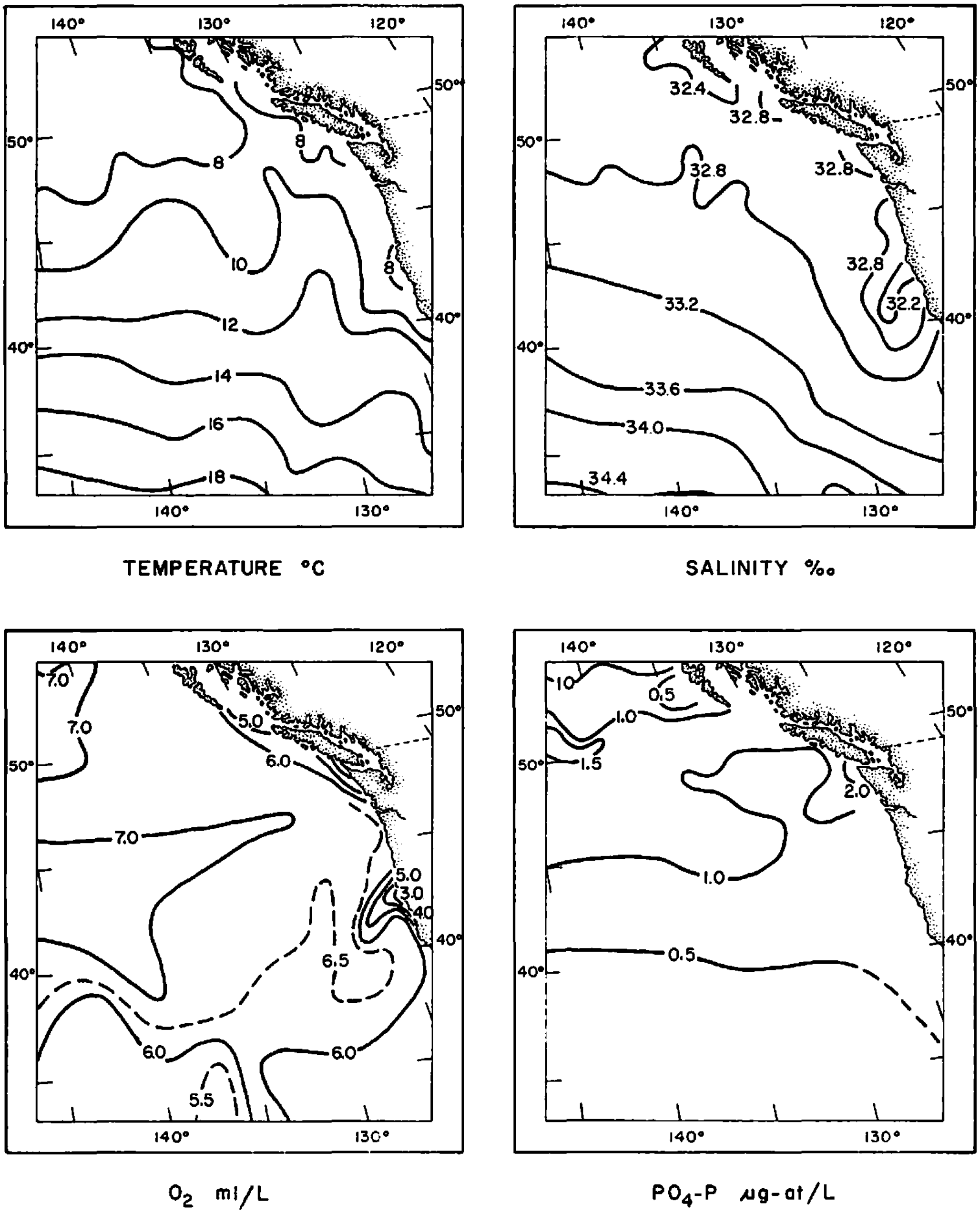
Temperatures within the area studied varied between about 6° and 16°C. at 50 meters. The majority of readings were between 7° and 10.5°C. Salinity ranged from 31.11 to 33.75 parts per thousand, the majority being between 32.20 and 33.20 parts per thousand.

Text figure 7 shows the temperature and salinity at all stations where these data were collected. The tows were divided into two groups, those containing fewer than five foraminifera and those capturing more than five. The relationship between these two groups and temperature and salinity is similar. Thus, it may be seen that no correlation between these factors and the distribution of foraminifera is evident.

Dissolved Oxygen and Inorganic Phosphate

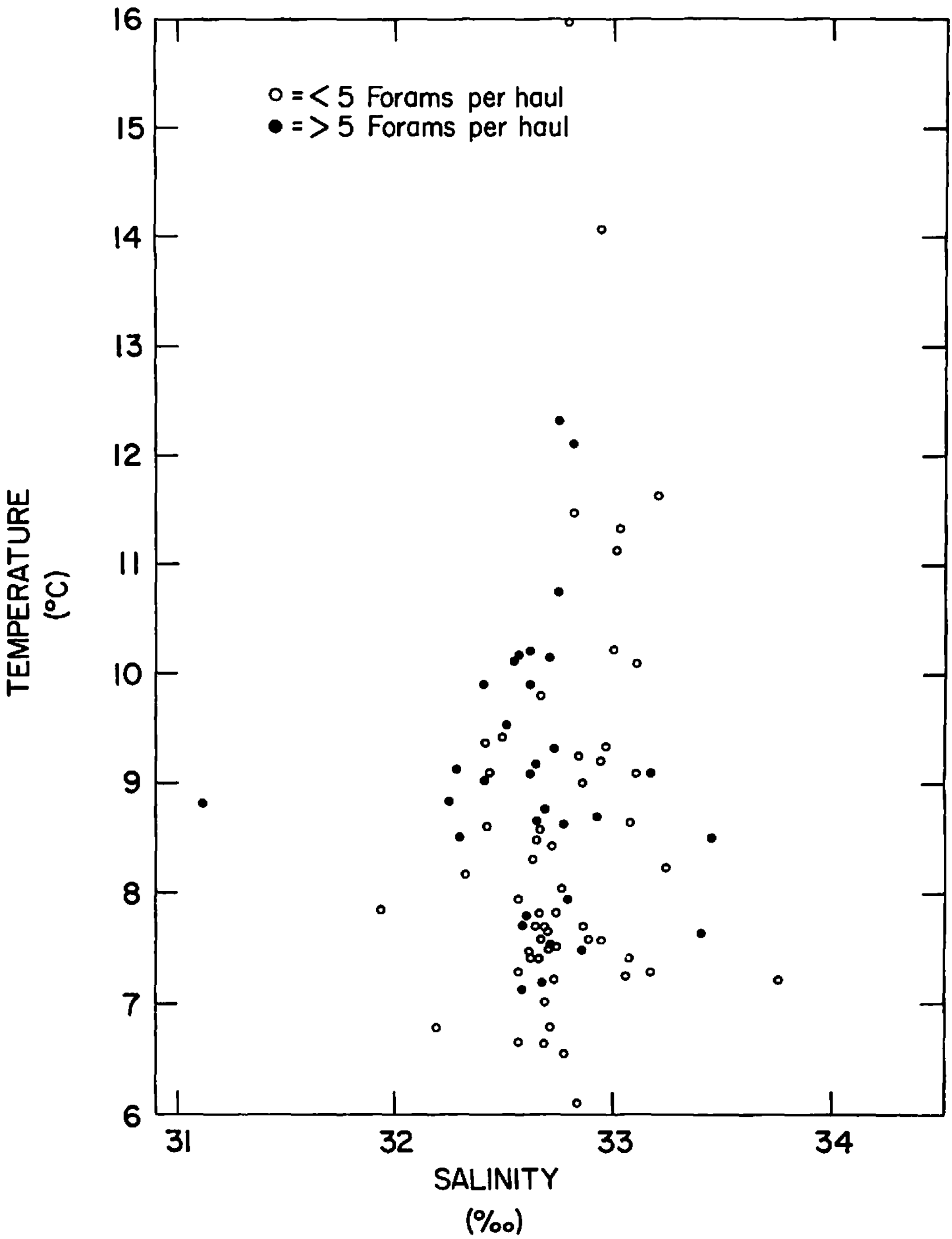
The range in dissolved oxygen concentrations is between 0.117 and 0.652 mg-at/l. However, the majority of samples showed concentrations of 0.400 to 0.650 mg-at/l. All but four stations where foraminifera were collected in numbers greater than five organisms per haul showed a dissolved oxygen concentration that was greater than 0.500. Text figure 8 shows the relationship between the two groups of tows and dissolved oxygen and inorganic phosphate concentrations at 50 meters.

Inorganic phosphate concentrations range between about 0.50 and 2.70 µg-at/l. The majority were from 0.50 to about 1.70 µg-at/l. Foraminifera were found in waters with concentrations greater than 1.30 at five stations; none were found in waters where the concentrations were less than 0.67 µg-at/l.

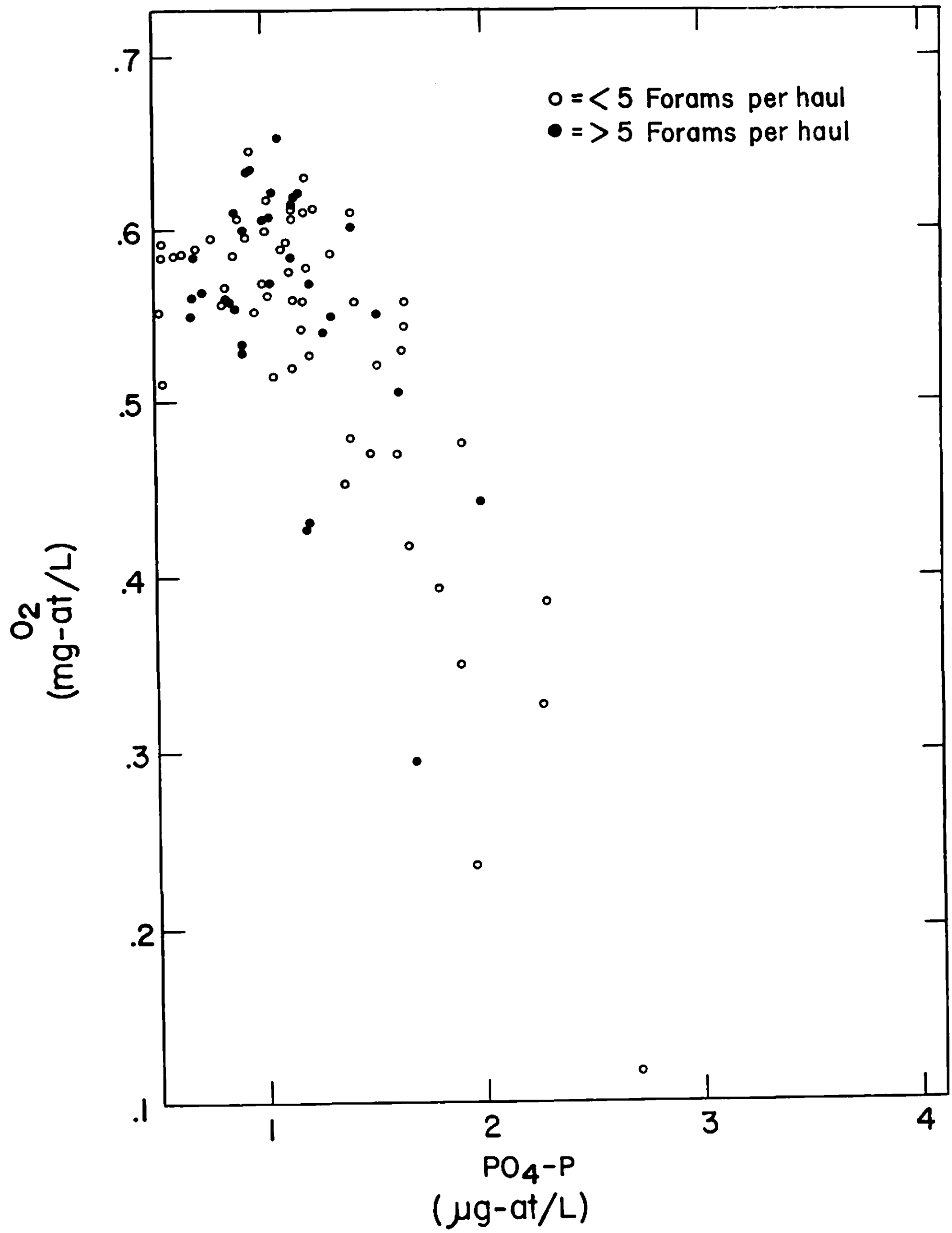


TEXT FIGURES 3-6

Sea temperatures, salinities, dissolved oxygen, and inorganic phosphate concentrations at 50 meters (after NORPAC Atlas, 1960).

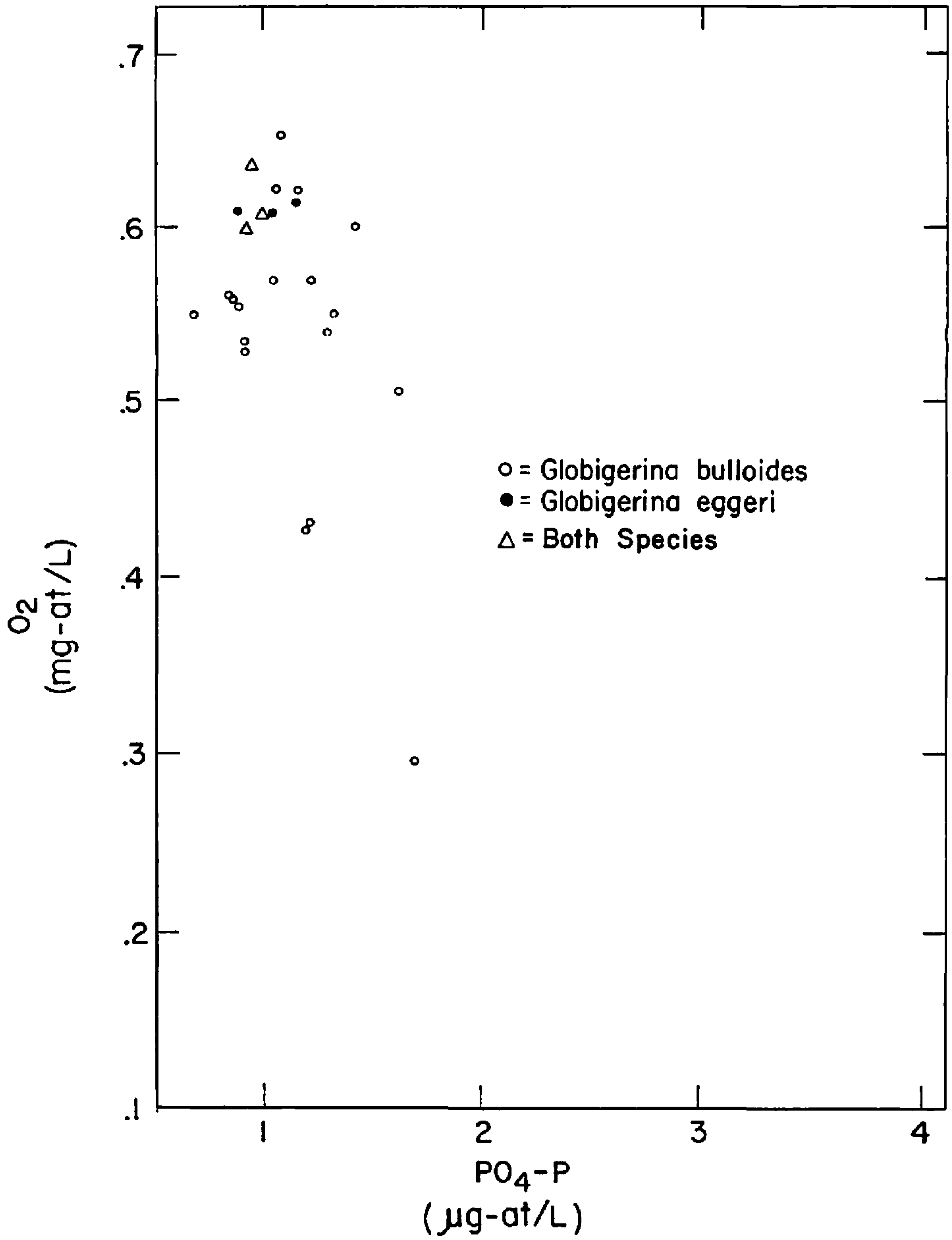


TEXT FIGURE 7
Abundance of planktonic foraminifera as related to temperature and salinity at 50 meters.



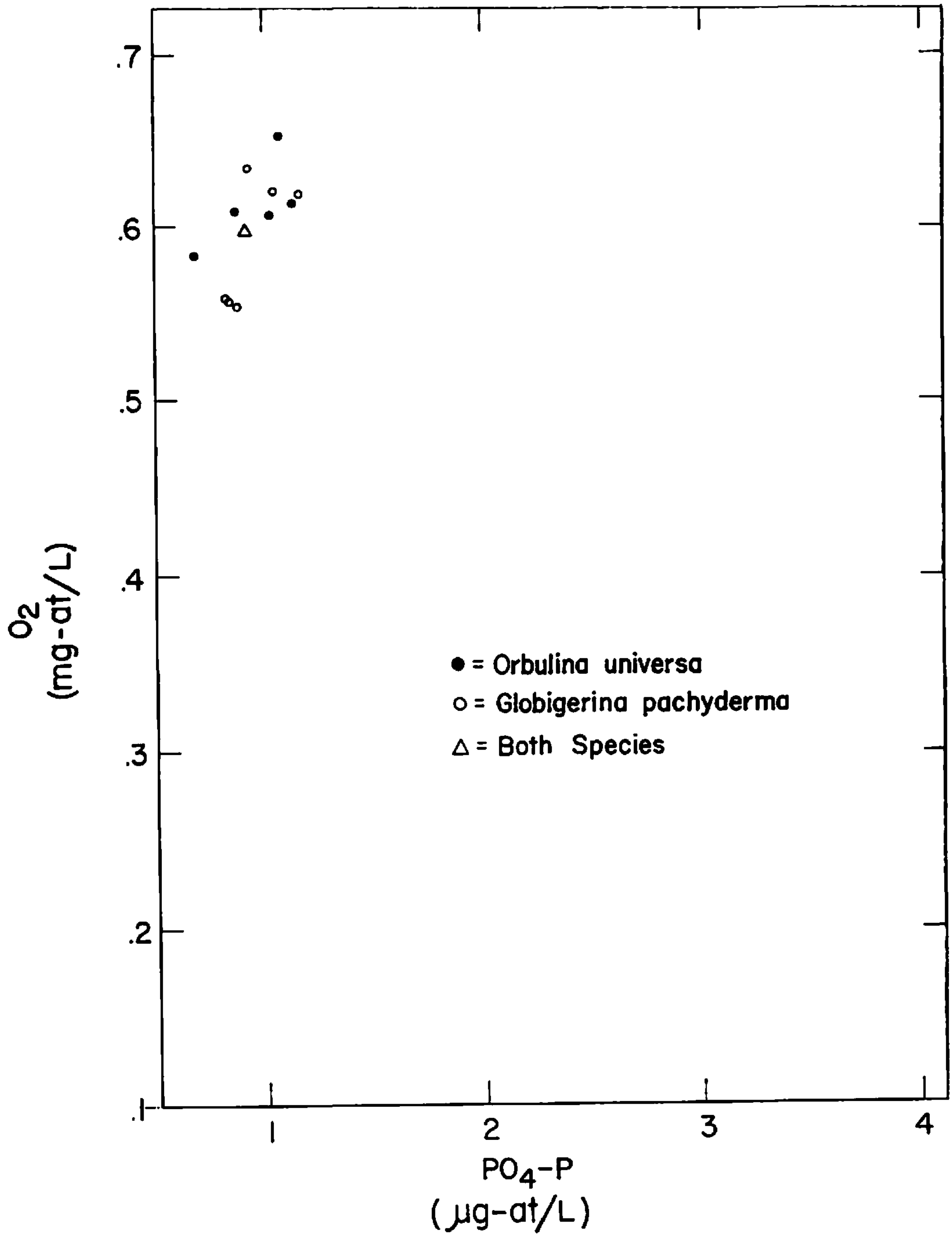
TEXT FIGURE 8

Abundance of planktonic foraminifera as related to dissolved oxygen and inorganic phosphate concentrations at 50 meters.



TEXT FIGURE 9

Distributions of *Globigerina eggeri* and *G. bulloides* as related to dissolved oxygen and inorganic phosphate concentrations at 50 meters.



TEXT FIGURE 10

Distribution of *Globigerina pachyderma* and *Orbulina universa* as related to dissolved oxygen and inorganic phosphate concentrations at 50 meters.

SPECIES DISTRIBUTION

The areal distributions of the eight species, *Globigerina bulloides, G. bradyi, G. eggeri, G. pachyderma, G. quinqueloba, Globigerinita glutinata, Orbulina universa*, and *Globorotalia scitula* are basically similar. *Globigerina bulloides* exhibits the most widespread distribution, being found throughout the area where the organisms were present. *Globigerinita glutinata* shows the most restricted distribution, being found only in a narrow band extending from the northern edge of the area of maximum numbers to the coast. The most abundant species are *Globigerina bulloides, G. pachyderma, Orbulina universa*, and *Globigerina eggeri*, in that order.

The fact that the area under study is small and the physical factors restricted in range makes it difficult to determine which conditions limit the distribution of the planktonic foraminifera. Text figure 9 represents the distribution of *G. eggeri* and that of *G. bulloides* in relation to dissolved oxygen and inorganic phosphate concentrations. The values for these variables at 50 meters, for all stations where these species were present in numbers greater than five, are plotted. *G. bulloides* showed no restriction as regards these variables other than those mentioned for the entire foraminiferal population. However, *G. eggeri* was found only in waters where dissolved oxygen concentrations were greater than 0.590 mg-at/l and where inorganic phosphate concentrations ranged from 0.85 to 1.15 µg-at/l. This is by no means sufficient evidence to infer that *G. eggeri* is restricted to such an environment but it does suggest an area for further study. *G. pachyderma* and *Orbulina universa* (text fig. 10), show a restriction as regards dissolved oxygen and inorganic phosphate concentration but not to the degree of *G. eggeri*. The other species did not occur in sufficient numbers to warrant plotting. None of the species show distribution patterns that can be correlated directly with temperature and salinity.

Vertical Distribution

Only seven of 33 samples taken from 400 to 200 meters contained planktonic foraminifera. In these, concentrations were never greater than 0.6 organisms per cubic meter of water filtered. Of the eight species identified from the area of study, only *Globigerina bradyi* and *Globigerinita glutinata* were absent from the deeper tows. Fifty-eight of the 127 tows taken above 200 meters contained foraminifera.

The 20 samples collected during the special vertical station were taken in an effort to determine possible vertical stratification in the upper 150 meters of water. The procedure was explained earlier. Casts were taken at two-hour intervals commencing at midnight and continuing until 8:00 a.m. In the three night tows, animals were collected in all samples except the two earliest ones at 50 meters. The midnight sample at 150 meters was discarded due to a malfunction of the sampling device. Table 1 shows the physical data collected from the surface to 200 meters for this station. These were collected about two hours before the first haul.

TABLE 1
Physical data for 144-44 vertical station

Depth	Temperature °C	Salinity o/oo	Dissolved Oxygen mg-at/l	Inorganic Phosphate µg-at/l
0	16.10	32.73	0.529	0.62
10	16.08	32.72	0.528	0.67
20	16.06	32.72	0.530	0.57
30	14.90	32.74	0.554	0.58
50	10.74	32.78	0.599	0.91
75	6.74	32.79	0.605	1.09
100	6.42	32.81	0.583	1.20
150	5.56	33.16	0.535	1.62
200	5.89	33.80	0.360	2.06

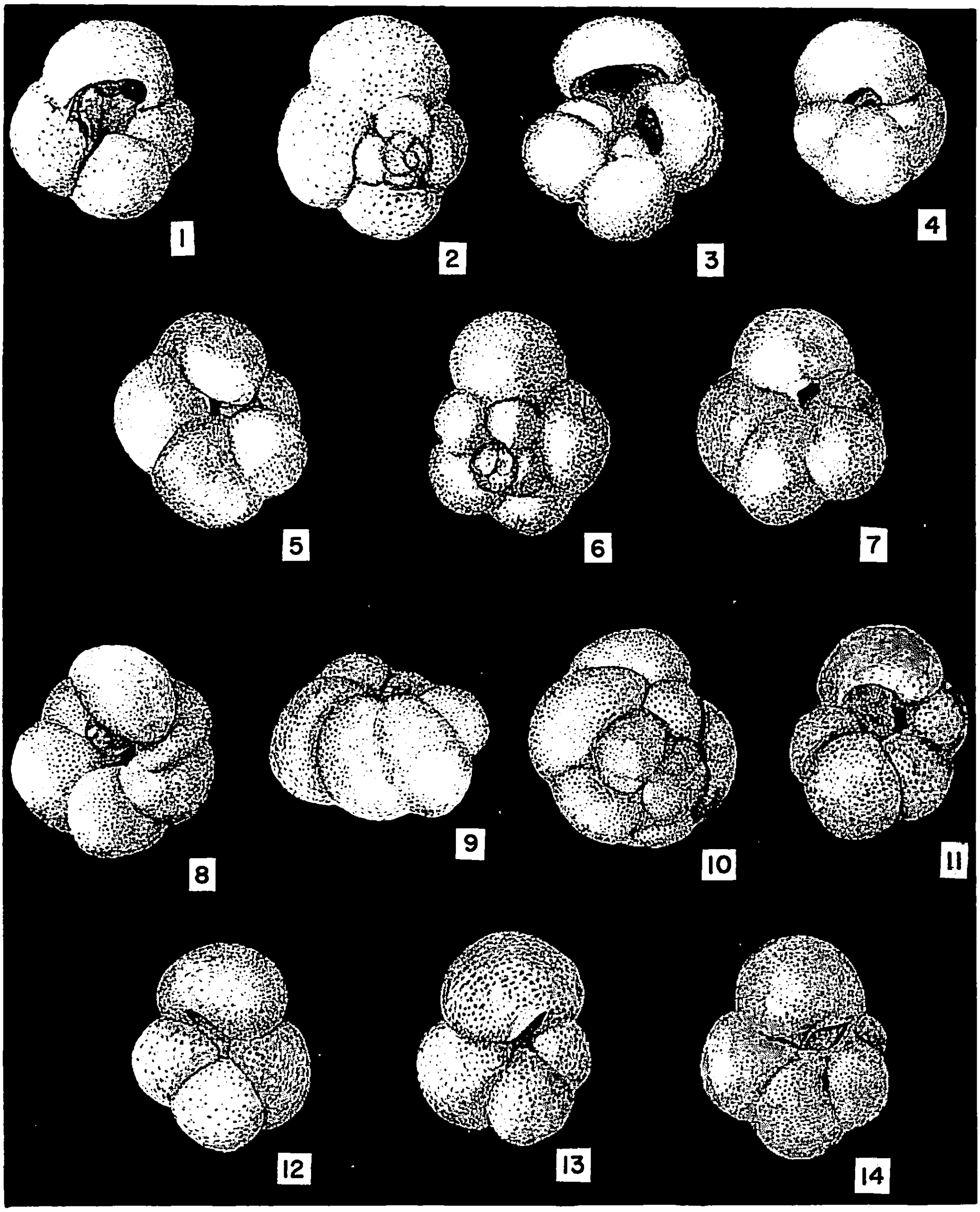
Only the 50-meter samples of the daylight tows contained foraminifera. Over one hundred organisms were collected at 0600, while 569 organisms were collected at 0800. This suggests a vertical migration from the surface to about 50 meters with the coming of light. A secondary migration from deeper waters upwards may also take place. The data obtained from the 20 samples (table 2) show that, on the average, concentrations at 50 meters were 1.3 times those at the surface, 3.5 times those at 100 meters, and 12.5 times greater than those from 150 meters. These averages disregard the time of day during which the material was collected.

Globigerina bradyi and *G. quinqueloba* were not collected below 50 meters. *Globigerinita glutinata* was rare at 100 meters and absent from the 150-meter samples, but at 50 meters it comprised 17.3, 26.6 and 27.1 percent of the total samples and was present in four surface tows. Thus, these three species appear to be restricted, with minor exceptions, to the upper 50 meters.

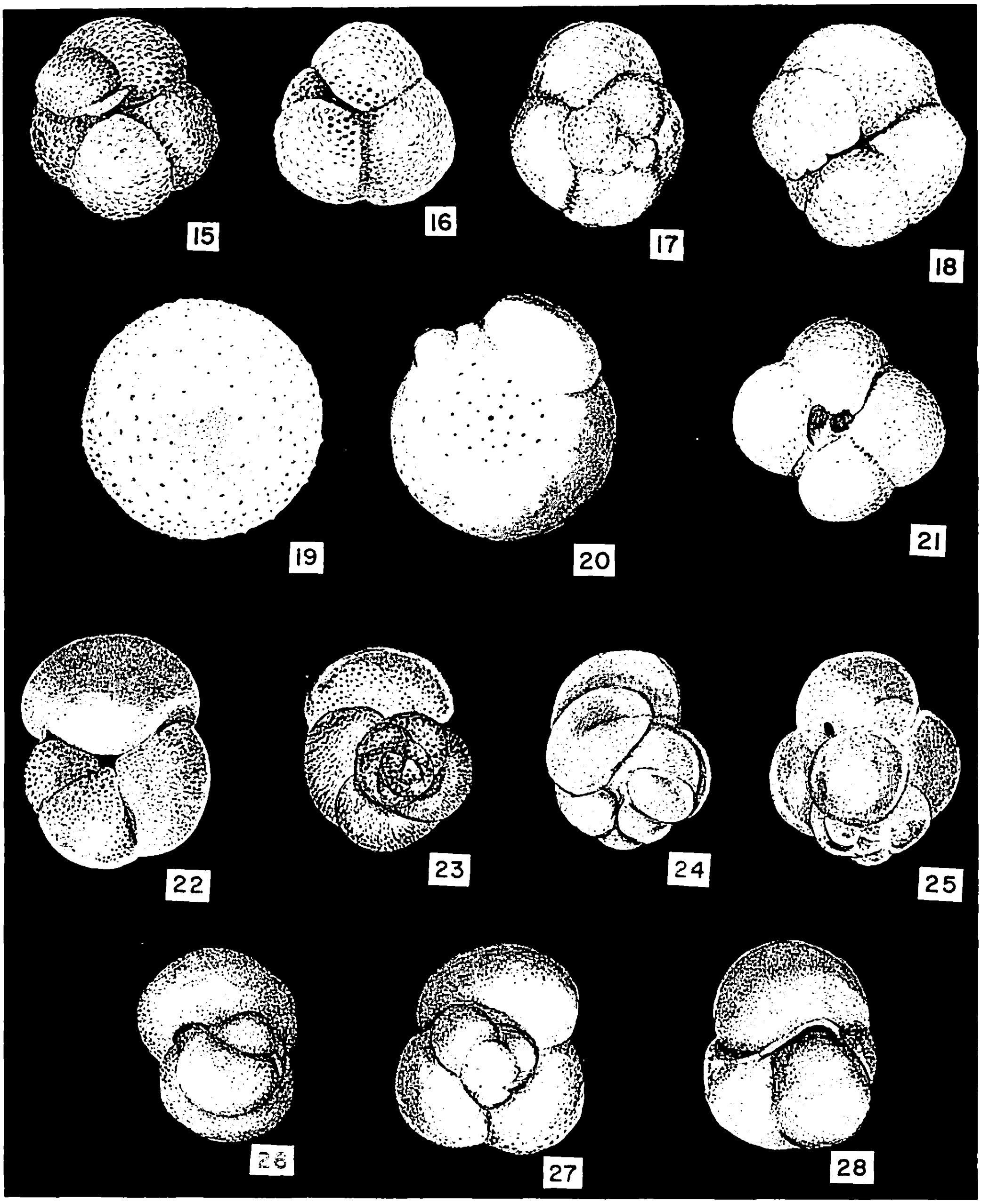
The morphologic intergrade *Globigerina pachyderma-eggeri* was most abundant at the surface, making up over 47 percent of the total in all but one sample. It was present, in smaller numbers, throughout the 150

EXPLANATION OF PLATE 1

FIGS.		PAGE
1-4.	*Globigerina bulloides* d'Orbigny. 1, × 56; 2, × 62; 3, × 54; 4, × 64.	2
5-7.	*Globigerina quinqueloba* Natland. 5, × 87; 6, × 106; 7, × 152.	2
8-11.	*Globigerina eggeri* Rhumbler. 8, × 55; 9, × 58; 10, × 52; 11, × 62.	2
12-14.	Morphologic intergrade *Globigerina pachyderma-eggeri*. 12, × 74; 13, × 122; 14, × 125.	3



Smith: Living planktonic Foraminifera, northeast Pacific



Smith: Living planktonic Foraminifera, northeast Pacific meters. *G. pachyderma* was never abundant. The largest numbers (7 and 8) were from 150-meter samples. Single specimens were found on two occasions at the surface. Bé (1960b, p. 67) pointed out that *G. pachyderma*, in arctic waters, does appear in near surface waters but is significantly different morphologically from the typical form which is found on the bottom. At the surface this species closely resembles small *G. bulloides* and/or *G. eggeri*. This is probably the case in the northeastern Pacific. Many specimens of the morphologic intergrade *G. pachyderma-eggeri* may in reality be early stages of *G. pachyderma* and typical forms of this species may exist only in deeper waters. However, since *G. bulloides* and *G. eggeri* are present in abundance at the surface, it is impossible to differentiate between young specimens of these species and early stages of *G. pachyderma*.

Globigerina bulloides and *G. eggeri* occurred throughout the 150 meters, however few of either were collected below 100 meters. *G. eggeri*, by far the most abundant species in this vertical study, was present in the greatest numbers at 50 meters, making up over 60 percent of the total sample on three occasions. *G. bulloides* was most abundant at the surface but never made up more than 27.7 percent of the total sample.

Orbulina universa was found in one surface sample. Single specimens were found in two samples at 50 meters. At 100 meters this species was present in three samples in an abundance greater than 50 percent, and at 150 meters it composed 64.8 and 37.5 percent of the two samples at this depth in which foraminifera were found. A possible explanation for this vertical stratification may be found in the work of Le Calvez (1936). He found that *Globigerina*-like chambers inside the spherical test of *O. universa* dissolve during the formation of gametes. A study of the vertical distribution of specimens taken from plankton tows indicated a strong correlation between the amount of destruction and depth. At 50 meters the *Globigerina*-like bodies are displaced from the central position which they occupy while at the surface. At 100 meters they are nearly dissolved and only yellow protoplasm remains in the test. At 300 meters the test is completely empty.

Fifty specimens were broken open during this investigation. Those collected above 50 meters contained poorly preserved *Globigerina*-like bodies. Those from 100 and 150 meters contained only hardened protoplasm. It is likely that a population which was in the process of producing gametes was sampled and that the organisms were in that stage of development where they were concentrated between 100 and 150 meters.

SUMMARY

The distribution of planktonic foraminifera in this area of the northeastern Pacific is extremely patchy; concentrations ranged from nil to 96.8 organisms per cubic meter of water filtered. The area of maximum concentration is directly above the area of *Globigerina*-rich sediments about 350 miles off the coast of Washington and Oregon. No foraminifera were collected seaward of 137° W. Long.

No direct correlation between temperature, salinity, dissolved oxygen, or inorganic phosphate concentrations and the distribution of the foraminiferal population was observed.

Globigerina eggeri showed the closest correlation with the physical factors, being limited to an area where the inorganic phosphate concentrations were between 0.85 and 1.15 µg-at/l and dissolved oxygen concentrations were between 0.590 and 0.650 mg-at/l.

Foraminifera were rare below 200 meters and most abundant within the upper 100 meters.

Globigerinita glutinata, *Globigerina bradyi* and *G. quinqueloba* appear to be restricted to the upper 50 meters.

G. pachyderma was most abundant at 150 meters. However, the morphologic intergrade *G. pachyderma-eggeri* was most abundant at the surface. It is believed that juvenile forms of *G. pachyderma* are present at the surface but are indistinguishable from small *G. bulloides* and *G. eggeri*.

The vertical stratification of *Orbulina universa* at 100 and 150 meters is, possibly, related to the production of gametes.

With the coming of light, diurnal vertical migration from the surface to about 50 meters was observed.

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EXPLANATION OF PLATE 2

FIGS.		PAGE
15-18.	*Globigerina pachyderma* (Ehrenberg). 15, × 82; 16, × 78; 17, × 85; 18, × 102.	2
19, 20.	*Orbulina universa* d'Orbigny. 19, × 49; 20, × 58.	3
21.	Morphologic intergrade *Globigerina pachyderma-eggeri*. 21, × 62.	3
22, 23.	*Globorotalia scitula* (Brady). 22, × 74; 23, × 64.	3
24, 25.	*Globigerina bradyi* Wiesner. 24, × 160; 25, × 174.	2
26-28.	*Globigerinita glutinata* (Egger). 26, × 85; 27, × 98; 28, × 86.	3

TABLE 2

Data from the vertical hauls where five casts using four Clarke-Bumpus samplers simultaneously were made, showing the vertical distribution of the species collected (p-e = morphologic intergrade *Globigerina pachyderma - eggeri. G. = Globigerina*)

Station 144-44

Time	0020 to 0042		0214 to 0238		0434 to 0455		0614 to 0635		0815 to 0835		
Haul	1		2		3		4		5		
Depth	15.571		17.883		13.926		14.380		16.039		m^3 Water Filtered
(m)	155		166		219		0		16*		Total Population
	No.	%	No.	%	No.	%	No.	%	No.	%	
	84	54.1	100	60.2	103	47.0	0	0	0	0	*Globigerina p-e*
	43	27.7	42	25.3	29	13.2	0	0	0	0	*G. bulloides*
	6	3.8	13	7.8	56	25.5	0	0	0	0	*G. eggeri*
0	2	1.2	0	0	0	0	0	0	0	0	*Orbulina universa*
	1	.6	0	0	1	.4	0	0	0	0	*Globigerina pachyderma*
	12	7.7	7	4.2	13	5.9	0	0	1	6.2	*Globigerinita glutinata*
	3	1.9	4	2.4	11	5.0	0	0	0	0	*Globigerina bradyi*
	4	2.5	0	0	4	1.8	0	0	0	0	*G. quinqueloba*
Depth	11.555		14.091		14.302		11.068		10.104		m^3 Water Filtered
(m)	0*		0		75		114		569		Total Population
	No.	%	No.	%	No.	%	No.	%	No.	%	
	0	0	0	0	2	2.6	0	0	70	12.3	*G. p-e*
	0	0	0	0	2	2.6	0	0	18	3.1	*G. bulloides*
	0	0	0	0	47	62.6	81	71.0	344	60.4	*G. eggeri*
50	0	0	0	0	0	0	1	.8	1	.1	*Orbulina universa*
	0	0	0	0	20	26.6	31	27.1	99	17.3	*Globigerinita glutinata*
	0	0	0	0	1	1.3	0	0	3	.5	*Globigerina bradyi*
	0	0	0	0	3	4.0	0	0	34	5.9	*G. quinqueloba*
Depth	17.640		19.697		17.270		13.097		16.438		m^3 Water Filtered
(m)	54		124		36		0		0*		Total Population
	No.	%	No.	%	No.	%	No.	%	No.	%	
	0	0	12	9.6	0	0	0	0	0	0	*G. p-e*
	1	1.8	26	20.9	5	13.8	0	0	0	0	*G. bulloides*
100	20	37.0	19	15.3	7	19.4	0	0	0	0	*G. eggeri*
	27	50.0	65	52.4	24	66.6	0	0	0	0	*Orbulina universa*
	3	5.5	2	1.6	0	0	0	0	0	0	*Globigerinita glutinata*
Depth	.058		18.394		18.769		11.862		13.612		m^3 Water Filtered
(m)	0		37		24		0		0		Total Population
	No.	%	No.	%	No.	%	No.	%	No.	%	
	0	0	1	2.7	1	4.1	0	0	0	0	*Globigerina p-e*
	0	0	4	10.8	1	4.1	0	0	0	0	*G. bulloides*
150	0	0	0	0	5	20.8	0	0	0	0	*G. eggeri*
	0	0	24	64.8	9	37.5	0	0	0	0	*Orbulina universa*
	0	0	7	18.9	8	33.3	0	0	0	0	*Globigerina pachyderma*

* Possible Solution

LITERATURE CITED

BANDY, O. L., 1961, Distribution of foraminifera, Radiolaria and diatoms in sediments of the Gulf of California: Micropaleontology, vol. 7, no. 1, pp. 1-26, pls. 1-5.

BÉ, A. W. H., 1959, Ecology of recent planktonic foraminifera; Part 1 - Areal distribution in the western North Atlantic: Micropaleontology, vol. 5, no. 1, pp. 77-100, pls. 1-2, text-figs. 1-52, tables 1-2.

———, 1960a, Ecology of recent planktonic foraminifera; Part 2 - Bathymetric and seasonal distributions in the Sargasso Sea off Bermuda: Micropaleontology, vol. 6, no. 4, pp. 373-392, text-figs. 1-19, tables 1-6.

———, 1960b, Some observations on arctic planktonic foraminifera: Cushman Found. Foram. Research Contr., vol. 11, pt. 2, pp. 64-68, fig. 1, table 1.

BRADSHAW, J. S., 1959, Ecology of living planktonic foraminifera in the north and equatorial Pacific Ocean: Cushman Found. Foram. Research, Contr., vol. 10, pt. 2, pp. 25-64, text-figs. 1-43, pls. 6-8, table 1.

BRADY, H. B., 1884, Report on the foraminifera dredged by the H. M. S. "Challenger" during the years 1873-1876: Rept. Voy. *Challenger*, Zool., vol 9, 814 pp., 115 pls.

CLARKE, G. L., and BUMPUS, D. F., 1950, The plankton sampler, an instrument for quantitative plankton investigations: Amer. Soc. Limnology and Oceanography, Special Pub. 5, pp. 2-8, 4 figs.

ENBYSK, BETTY J., (1960), Distribution of foraminifera in the northeast Pacific: (Univ. of Washington, doct. diss., 1960.) 226 pp., 21 pls., 23 text-figs., 11 tables.

KING, J. E. and DEMOND, J., 1953, Zooplankton abundance in the central Pacific: U. S. Fish and Wildlife Serv., Fish Bull. 82, pp. 111-144, figs. 1-11, 18 tables.

LE CALVEZ, J., 1936, Modification du test des foraminifères pélagiques en rapport avec la reproduction: *Orbulina universa* et *Tretomphalus bulloides* d'Orb.: Ann. Protistol, vol. 5, pp. 125-133.

MURRAY, J., 1895, Summary of the scientific results obtained at the sounding, dredging and trawling stations of H. M. S. "Challenger": *Challenger* Repts., Summary, pts. 1 and 2, pp. 1-1608.

———, 1897, On the distribution of pelagic foraminifera at the surface and on the floor of the ocean: Nat. Sci., vol. 11, pp. 17-27. (Ecology).

NAYUDU, Y. R., (1959), Recent sediments of the northeast Pacific: (Univ. of Washington, doct. diss., 1959.) 217 pp., 14 figs.

NORPAC COMMITTEE, 1960, Oceanic observations of the Pacific: 1955, The NORPAC Atlas: Univ. Calif. Press & Univ. Tokyo Press, Berkeley & Tokyo.

ORBIGNY, A. D', 1826, Tableau méthodique de la classe des céphalopodes: Ann. Sci. Nat., vol. 7, pp. 245-314, pls. 10-17.

PARKER, F. L., 1958, Eastern Mediterranean foraminifera: Repts. Swedish Deep-Sea Exped., vol. 8, no. 4, pp. 219-283.

———, 1960, Living planktonic foraminifera from the equatorial and southeast Pacific: Science Repts. Tohoku Univ., Sendai, Japan, 2nd Sec. (Geol.), Spec. vol., no. 4, pp. 71-82, 20 figs.

PHLEGER, F. B, 1951, Ecology of foraminifera, northwest Gulf of Mexico; Part 1 - Foraminifera distribution: Geol. Soc. America Mem. 46, pp. 1-88.

———, PARKER, F. L., and PEIRSON, J. F., 1953, North Atlantic foraminifera: Repts. Swedish Deep-Sea Exped., vol. 7, fasc. 1, pp. 3-122.

SCHOTT, W., 1935, Die Foraminiferen in dem äquatorialen Teil des Atlantischen Ozeans: Wiss. Ergeb. deutsch: Atlantische Exped. "Meteor" 1925-1927, Bd. 3, pt. 3, Sec. B, pp. 43-134.