CONTRIBUTIONS
FROM THE
CUSHMAN FOUNDATION
FOR
FORAMINIFERAL RESEARCH

Volume XXI (1970)

Editor
DON L. EICHER

1970

CUSHMAN FOUNDATION FOR FORAMINIFERAL RESEARCH, INC.

1970

PATRONS

Arthur N. Dusenbury, Jr., 19 Sherman Ave., White Plains, New York
Waldo L. Schmitt, U. S. National Museum, Washington, D. C.
Sun Oil Company, Dallas, Texas

FELLOWS

Harold V. Andersen, Louisiana State University, Baton Rouge, Louisiana
Richard E. Anderson, Anderson & Nicholeris, Ventura, California
Harry W. Anisgard, Humble Oil & Refining Co., New Orleans, Louisiana
Zach M. Arnold, Univ. California, Berkeley, California
Orville L. Bandy, Univ. Southern California, Los Angeles, California
C. Lothrop Bartlett, 842 East Drive, Beaumont, Texas
R. Stanley Beck, 621 Truxtun, Bakersfield, California
Leroy E. Becker, R. D. 1, Spencer, Indiana
James Bush, Box 2936, Palm Beach, Florida
Chevron Oil Field Research Co., La Habra, California
Richard Cifelli, U. S. National Museum, Washington, D. C.
Dana K. Clark, Shell Development Co., Houston, Texas
W. Storrs Cole, 310 Fall Creek Drive, Ithaca, New York
G. Arthur Cooper, U. S. National Museum, Washington, D. C.
James H. Dorman, Tenneco Oil Co., Lafayette, Louisiana
Raymond C. Douglass, U. S. National Museum, Washington, D. C.
John B. Dunlap, 167 O.K. Ave., New Orleans, Louisiana
Robert L. Ellison, Univ. Virginia, Charlottesville, Virginia
Esso Production Research Co., Houston, Texas
Roberta K. Smith Evernden, U. S. National Museum, Washington, D. C.
M. A. Furrer, Creole Petroleum Corp., Caracas, Venezuela
J. B. Garrett, Jr., Pan American Petroleum Corp., Houston, Texas
J. L. Gevirtz, State University New York, New Paltz, New York
Geologisch-Palaontologisches Inst., Univ. Kiel, Kiel, Germany
George L. Harrington, 850 Webster St., Palo Alto, California
Hollis D. Hedberg, 118 Library Place, Princeton, New Jersey
Lloyd G. Henbest, U. S. Geological Survey, Washington, D. C.
Ismail Kafescioglu, American Univ. of Beirut, Beirut, Lebanon
Mrs. F. H. Kierstead, Old Goshen Road, Goshen, Massachusetts
Robert M. Kleinpell, Univ. California, Berkeley, California
H. G. Kugler, Natural History Museum, Basel, Switzerland
Doris L. Low, U. S. Geological Survey, Washington, D. C.
George W. Lynts, Duke University, Durham, North Carolina
Donald A. Myers, Federal Center, Denver, Colorado
Enrico F. DiNapoli, Via G. A. Guttani 14, Rome, Italy

INDEX TO VOLUME XXI, 1970

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 1, JANUARY, 1970

379. ESTUARINE FORAMINIFERA FROM THE RAPPAHANNOCK RIVER, VIRGINIA[1]

ROBERT L. ELLISON
University of Virginia, Charlottesville, Virginia
and
MAYNARD M. NICHOLS
Virginia Institute of Marine Science, Gloucester Point, Virginia

ABSTRACT

Populations of benthonic foraminifera were studied from 263 samples obtained in 5 collections from the estuary, its tributaries and bordering marshes. Of the 20 species identified, 2 constitute more than 80 percent of the fauna.

Two biofacies are recognized in the estuary:

- a. A basin biofacies of **Elphidium clavatum** Cushman in the lower part of the estuary, and
- b. A shoal biofacies of **Ammobaculites crassus** Warren in upper reaches, shoals, and tributaries.

The biofacies are broadly related to different estuarine layers which fluctuate with river inflow and estuarine mixing. They are separable along a relatively sharp boundary where salinity is 15 ppt.

Two principal biofacies are recognized in the marshes:

- a. An outer biofacies of **Miliammina fusca** Brady in relatively salty water, and
- b. An inner biofacies of **Ammoastuta salsa** Cushman in freshened reaches.

These biofacies intergrade with distance across the gradient zone of the upper estuary.

Total populations increase upstream to a peak in the upper part of the estuary where tidal and seasonal variations of salinity are great. In general, the distribution of total populations (largely dead) throughout the estuary corresponds to that of the living population, except locally where tests are effectively redistributed.

Distributional features and distinctive species of foraminifera provide a basis for recognizing ancient estuarine deposits.

INTRODUCTION

The Rappahannock River estuary of Chesapeake Bay is well suited for an ecological study of foraminifera. Environmental conditions range widely and are better known than in most other estuaries. As an environment with two-way flow and unstable salinity, the estuary supports a benthic microfauna that must either adapt to or shift with environmental changes.

The purpose of this paper is to report the distribution and abundance of benthic foraminifera in the estuary and to assess their relationship with known environmental factors. An attempt is made to formulate characteristics of an estuarine fauna useful in interpreting fossil distributions.

ACKNOWLEDGMENTS

This study was largely supported by grants from the National Science Foundation Research Participation programs (NSF-G20443 and GE-471). Field sampling was done from research vessels and small craft of the Virginia Institute of Marine Science. Several students contributed to the study: John Hughes studied marsh foraminifera with support of NSF Undergraduate Research Participation funds (NSF-GI-5724) in 1962; Warren Norton studied populations at the estuary head in 1965; and Allan Hartwell traced foraminiferal variations in marsh deposits with support of NSF Undergraduate Research Participation funds (NSF-GE-6558 and GY-916).

The authors thank R. Cifelli and M. Buzas of the U. S. National Museum and James D. McLean, Jr. for helpful suggestions and for making their facilities and specimens available. The foraminifera were illustrated by Jane Davis of the Virginia Institute of Marine Science, and the figured specimens are deposited in the U. S. National Museum.

PREVIOUS WORK

Although foraminiferal faunas are rather well known from many shallow-water environments, only a few data have been published on faunas in river estuaries and estuarine marshes; for example, Parker (1952), Todd and Brönnimann (1957), Boltovskoy (1957), Behm and Grekulinski (1958), van Voorthuysen (1960), Fowler *et al.* (1966), and Bartlett (1966). Occurrences of specimens from the Rappahannock in 1962, analyzed as part of this study, are listed in Ellison *et al.* (1965). Certain aspects of the distributions are reported in Nichols and Ellison (1967).

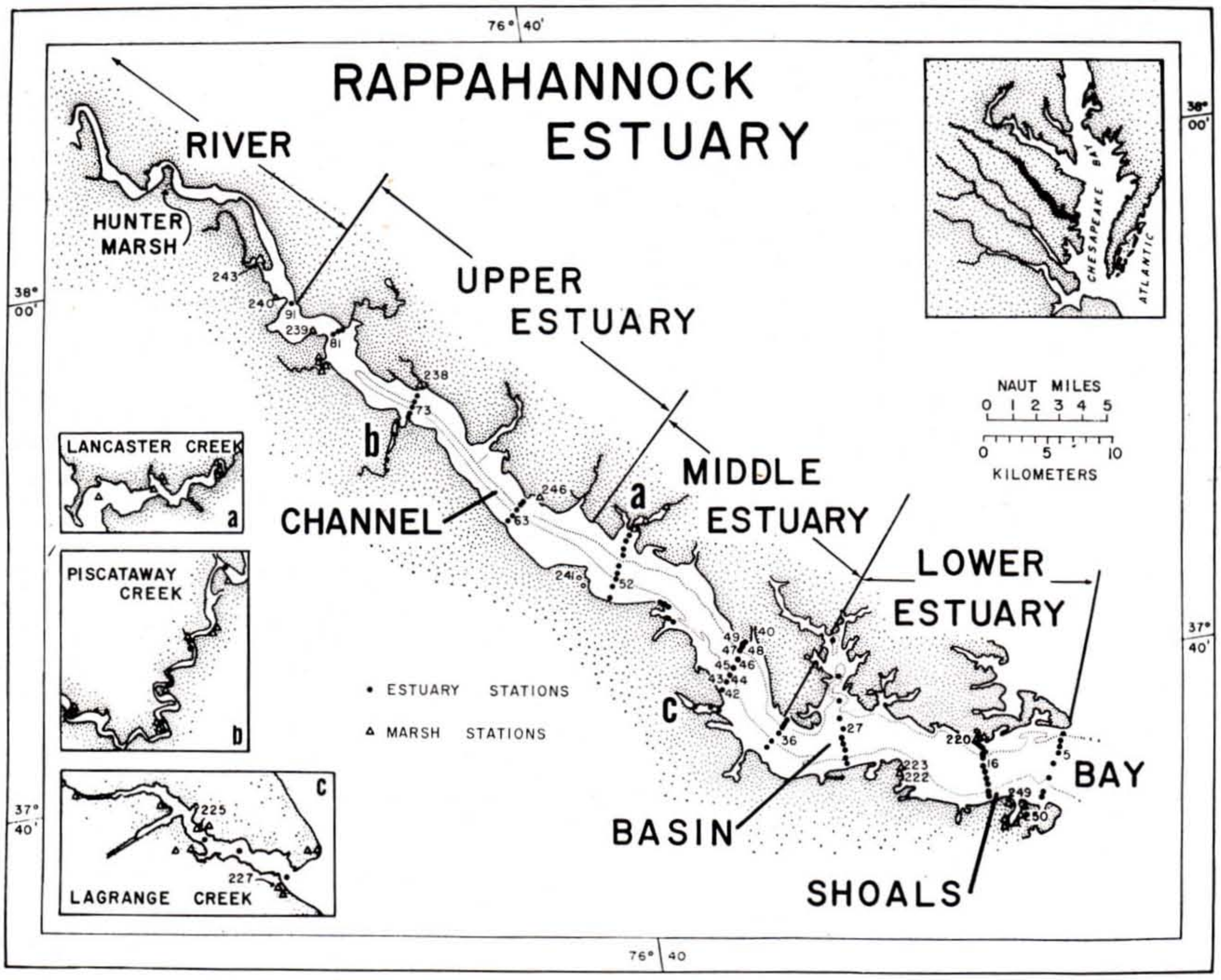
METHODS

Field Sampling

Samples were collected throughout the estuary during each of five periods: (1) June and July, 1962; (2) June and July, 1963; (3) January, 1964; (4) March and May, 1965; and (5) June through December, 1965. Salinity and other environmental variables differed from period to period. For example, during the first collection, salinity was relatively low and the water partly mixed, whereas in the following summer of 1963 salinity was high and the water relatively well mixed. Hydrographic data obtained during each collection period are given in Ellison *et al.* (1965) and Ellison (in press).

---

[1] This paper is contribution No. 244 of the Virginia Institute of Marine Science.



TEXT FIGURE 1

Location of Rappahannock estuary, inset, upper right (black), reaches, creeks, general bathymetry, and location of stations. Numbers for all stations are given in Ellison *et al.* (1965) and Ellison (in press).

Stations were established on transects through a range of salinity and varying water depths in the estuary and up tributary creeks as shown in text fig. 1. In marsh areas, stations were located across different zones of intertidal vegetation. Additional stations were made during each collecting period in local areas of abundant eelgrass and in areas requiring closer study.

Most samples consist of two 20 ml. portions of the top 0.39 inch (1 cm.) of wet sediment. They were collected with either a light-weight gravity corer (Nichols and Ellison, 1966) or a hand corer equipped with 2-inch (5 cm.) diameter plastic tubing that cuts a 3.1 sq. in. (20 sq. cm.) area of sediment. To obtain sufficient material in the marshes and to integrate variations typical of marsh microhabitats, three cored portions were collected at each station. Samples were preserved with neutralized formalin and stored wet.

Laboratory Procedures

Samples were washed over a sieve having 62-micron apertures and stained with rose Bengal to identify living specimens. A solution of no less than 1.0 gm. rose Bengal plus 5 ml. of phenol per 100 ml. of distilled water gave the most effective stain. Most samples were examined wet under a binocular microscope. The percentage frequency of each species was determined and the total number of foraminifera, living and dead, per 20 ml. was calculated. Procedural details are given in Ellison *et al.* (1965) and Ellison (in press).

THE ESTUARY

Like other estuaries in the Chesapeake Bay region, the Rappahannock follows the course of a former river valley cut into coastal plain sediments. Submergence of the valley during the postglacial rise of sea level formed the estuary and gave it a distinctive configuration. The 50-mile (80 km.) long estuary is narrow and funnel-shaped, varying from 4 miles wide at its mouth to 1 mile near its saline head (text fig. 1). Bluffs of Miocene sediments form a margin occasionally broken and indented by tributary creeks. Except for the large Corrotoman River entering the lower estuary, the creeks reach inland less than 3 miles. The estuary floor is molded into a narrow channel flanked by wide submerged shoals. The channel meanders gently through the upper part of the estuary with depths from 16 to 33 feet, but in the middle estuary it deepens seaward into a narrow basin 60 to 80 feet deep. A submerged sill at the mouth partly impedes upstream movement of near-bottom water, whereas near-surface water drains freely into Chesapeake Bay.

Sedimentation

The river plays a prominent role in transporting sediments to the estuary. River-borne sediments accumulate at varying rates on different parts of the estuary floor. Silty clay is the most widespread type of substratum, but in the lower estuary sand is the principal sediment of the shoals. Also, scour leaves some sand as lag deposits on bars and in deep holes of the channel floor. An account of the chemical and mineralogical properties of bottom sediments typical of substrate conditions for microfauna was given by Nelson (1960, 1961, 1962).

Vegetation

Low-lying banks along the creeks and around meander bends of the upper estuary are colonized by intertidal salt-marsh vegetation for a width of about 0.25-0.75 mile (0.32-1.20 km.). Two groups of marshes are recognized along the estuary, and within each group are two zones. The outer marsh, bathed by relatively salty water of the middle and lower estuary, is divided into a lower *Spartina alterniflora* zone which is frequently submerged and a higher *Spartina patens* zone. The inner marsh in freshened reaches of the upper estuary and the river is characterized by a narrow lower *Scirpus americana* and *Sagittaria subulata* zone and a higher widespread *Spartina cynosuroides-Typha angustifolia* zone. Submerged shoals less than 8 feet deep, in the middle and lower estuary, are irregularly covered in summer with luxuriant growths of aquatic eelgrass (*Zostera marina*) which support a variety of organisms.

Water Characteristics

From a large number of hydrographic observations by the Chesapeake Bay Institute extending over more than 20 years (Stroup and Lynn, 1963; Hires *et al.*, 1963; Stroup and Wood, 1966), the U. S. Coast and Geodetic Survey (Haight *et al.*, 1930; Nichols and Poor, 1967), and unpublished data of numerous oyster and trawl surveys of the Virginia Institute of Marine Science, the range of certain environmental parameters is known and the general hydrographic climate bearing on foraminiferal distributions can be described. During the present study the estuary was largely unpolluted and free of human influence except for oyster harvesting. For purposes of discussion, the estuary is divided into four parts: the river, and the upper, middle and lower estuary (text fig. 1).

Tide.—The tide generates the chief movement of water in the estuary and, in turn, produces short-term fluctuations in salinity and turbidity. The mean tidal range varies from 1.1 feet near the mouth to 2.6 feet at the head near Tappahannock. This headward increase results in an increase in maximum current velocity from 1.7 ft./sec. near the mouth to 3.4 ft./sec. at the head. In the upper estuary, tidal movement favors relatively free exchange between tributary creeks and the main estuary.

Temperature.—Water temperature is remarkably uniform throughout the Rappahannock at any one time. However, water temperature varies seasonally with air temperature from a monthly mean of 4°C in winter to 28°C in summer, with occasional extremes for short periods.

Turbidity.—Total concentrations of suspended sediment decrease downstream progressively from about 150 mg./1 in the river to 2 mg./1 at the estuary mouth. In the middle and upper estuary, concentrations also increase toward the bottom and vertical gradients are relatively high. Occasional wave agitation of bottom sediment on the shoals also contributes to the turbidity. The influence of turbidity on benthic microfauna is relatively unknown.

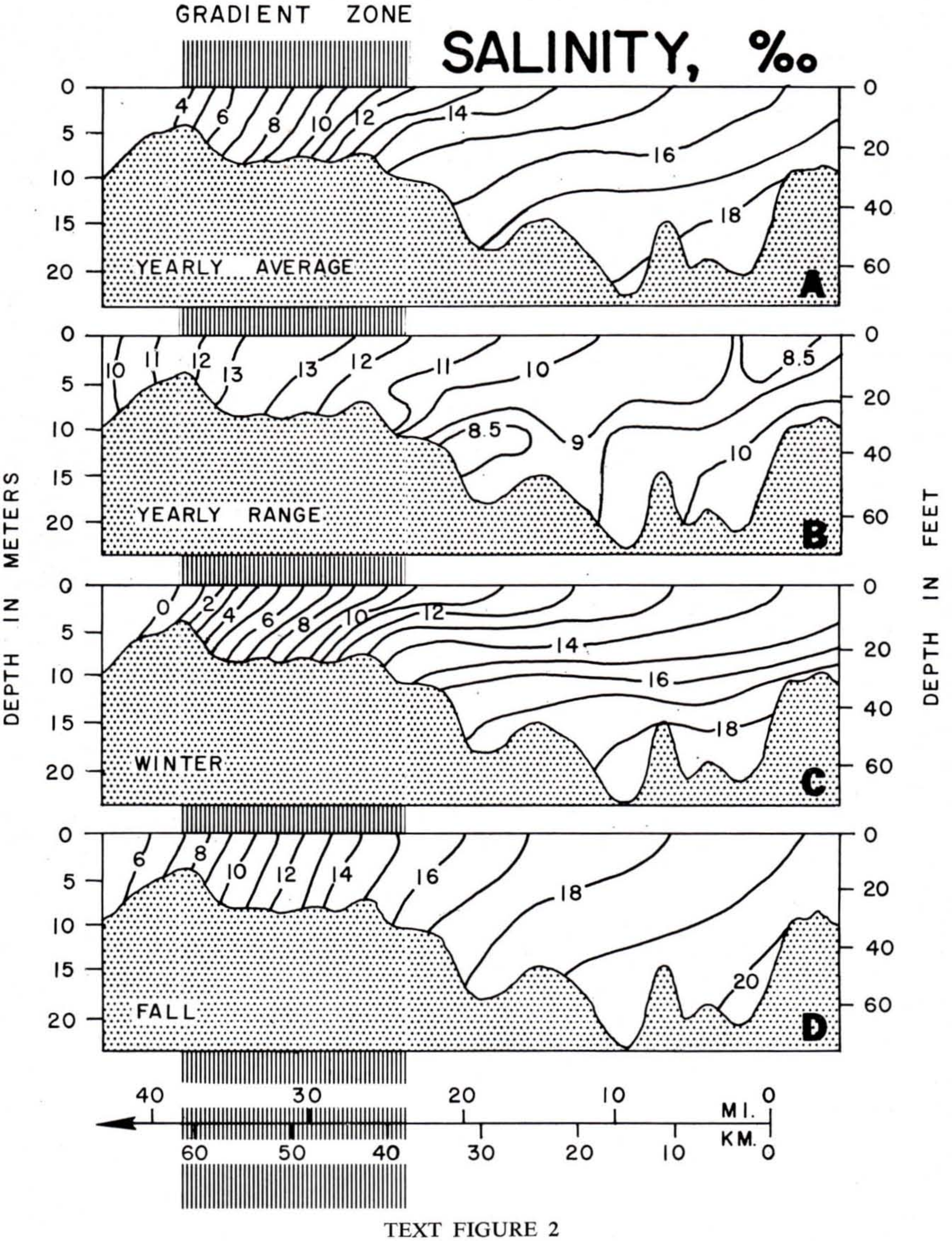
Oxygen.—During most of the year, water and near-surface sediments are well aerated by tidal mixing and atmospheric exchange. However, during late summer when the prevailing temperature is high, oxygen in deeper parts of the basin and in restricted tributary creeks is frequently depleted, owing to rapid decomposition of organic matter combined with insufficient mixing. This condition often kills fish and benthic fauna (McHugh, 1967).

Nutrients.—Total phosphate, including particulate plus soluble unreactive forms, generally increases headward most of the year. Concentrations range from about 0.6 μg at/1 at the mouth to 2.2 μg at/1 near the head and in spring occasionally reach 4.5 μg at/1.

Chlorophyll "a."—In summer and fall, concentrations generally increase headward from about 4.0 μg at/1 in the estuary proper to more than 30.0 μg at/1 at the head, but in winter and spring concentrations are relatively low (< 18 μg at/1) throughout the estuary and slightly decrease with distance headward (Brehmer, personal communication).

Hydrogen ion concentration.—The pH typically diminishes with distance up the estuary, ranging from about 8.2 near the mouth to 7.1 near the head. Often in spring and summer slightly acid conditions (with pH 6.6) occur locally in near-bottom water of the upper estuary.

Salinity.—The salinity of estuary water increases seaward from nearly 0‰ at the head to an annual



TEXT FIGURE 2

Salinity distribution along the estuary length showing the zone of relatively high salinity gradient. A. - yearly average; B. - yearly range; C. - winter average; D. - fall average.

average of 16.5‰ at the mouth (text fig. 2A). This is part of a longer gradient extending 45 miles (72 km.) to the mouth of Chesapeake Bay, where the salinity is about 31‰. The seaward increase is greatest in the middle and upper estuary; in this gradient zone stratification is most pronounced and salinity fluctuates up to 5‰ daily and 13‰ annually (text fig. 2B). With seasonal fluctuations of river inflow, the vertical structure of estuarine water alternates from partly mixed to relatively well mixed.

TABLE 1

Summary of the occurrences of tests of foraminiferal species in the Rappahannock estuary, tributary creeks, and marshes

Species	Estuary and Creeks, 1962		Marshes, 1962		Estuary and Creeks, 1963	
	*Frequency	†Abundance	Frequency	Abundance	Frequency	Abundance
Ammoastuta salsa	32	2.23	71	19.66	19	0.40
Ammobaculites crassus	97	68.68	73	9.33	100	68.50
Ammobaculites cf. *A. dilatatus*	17	0.08	17	0.21	32	0.49
Ammobaculites cf. *A. exiguus*	7	0.03	17	0.22	32	0.24
Ammonia beccarii var. A	15	0.11	0	0	30	3.41
Ammonia beccarii tepida	70	3.79	97	0.07	79	7.46
Arenoparrella mexicana	19	0.22	71	8.23	4	0.03
Astrammina rara	3	0.02	49	1.75	1	0.01
Elphidium clavatum var. A	42	14.19	24	0.01	81	7.01
Elphidium clavatum var. B	35	4.69	0	0	40	3.81
Elphidium clavatum var. D	0	0	0	0	47	4.31
Elphidium galvestonense	0	0	0	0	1	0.04
Haplophragmoides hancocki	15	0.21	80	3.53	5	0.04
Haplophragmoides manilaensis	10	0.08	73	2.04	1	0.01
Haplophragmoides wilberti	17	0.14	59	1.39	6	0.02
Miliammina earlandi	16	0.18	75	7.39	8	0.05
Miliammina fusca	83	4.39	88	23.79	68	2.89
Protelphidium tisburyense	13	0.20	0	0	7	0.10
Reophax nana	49	0.93	17	0.25	53	0.99
Tiphotrocha comprimata	15	0.21	56	11.22	9	0.13
Trochammina inflata	25	0.36	75	3.64	21	0.29
Trochammina macrescens	15	0.13	66	1.72	8	0.09
Trochammina squamata	10	0.32	0	0	4	0.07

*Percentage of samples in which each species was found.

†Average percentage of each species.

When river inflow is high, usually in late winter, freshening reduces surface salinity at the mouth to 14‰ and limits salty water to the lower 38 miles (61 km.) of the estuary (text fig. 2C). Like other Chesapeake estuaries, it is to be expected that mean salinity is slightly higher on the north than on the south side of the estuary owing to the influence of the Coriolis force (Pritchard, 1952).

Circulation.—An internal net circulation generated by vertical mixing of waters of different salinities is superimposed on the back and forth movement of the tide over many tidal cycles. Near-surface water flows seaward, whereas near-bottom water flows headward. Net velocities are small, less than 0.03 ft./sec. (0.9 cm./sec.) (Nichols and Poor, 1967), but in time they may disperse foraminifer tests either upstream in the channel or downstream over the shoals.

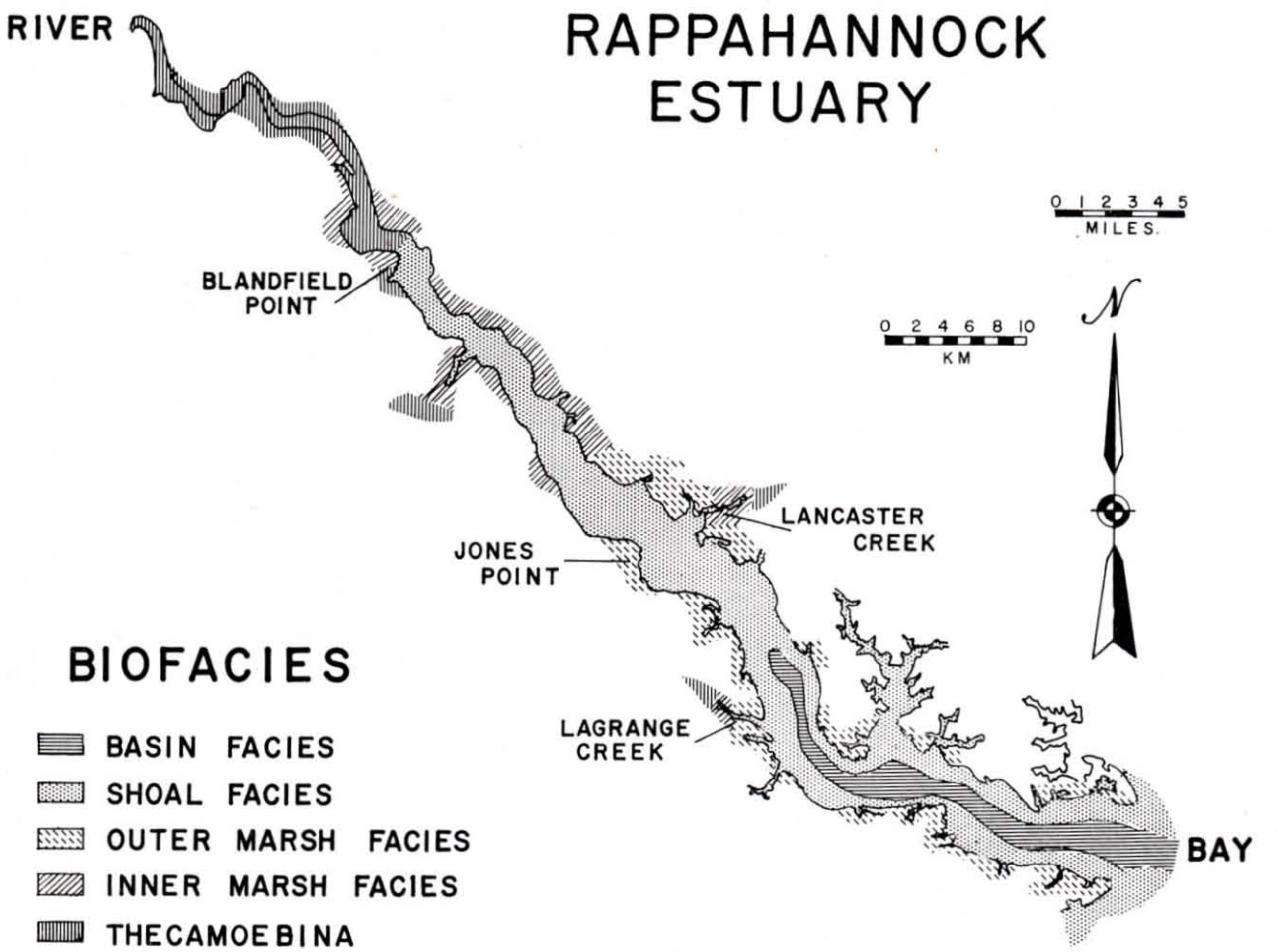
Water types.—From the circulation pattern and the distribution of salinity, two types of water are recognized in the Rappahannock estuary: (1) a low salinity, near-surface layer with a net flow down the estuary, and (2) a saline, lower layer in the basin and channel with a net flow up the estuary. Other characteristics are associated with these water types. For example, the lower layer is less turbulent than the upper layer, oxygen is occasionally depleted, and the temperature range is less than in the near-surface layer. These water types, though dynamic, generally reflect changing qualities of the water, depending on the rate of river inflow and degree of mixing between fresh and salt water.

DISTRIBUTION OF FORAMINIFERA

General Features of the Populations

The fauna comprises 19 species; two species, *Elphidium clavatum* Cushman variants and *Ammobaculites crassus* Warren, make up more than 80% of the estuary population. Samples from the upper estuary contain vast numbers of one species, *Ammobaculites crassus.* Of lesser abundance throughout the estuary are *Miliammina fusca* Brady and *Ammonia beccarii tepida* (Cushman), which together make up less than 10% of the population. Of the remaining 15 species, most average less than 1%. Faunal diversity, expressed in species per sample or in species per 300 individuals, is relatively high in the middle estuary basin and near mouths of tributary creeks and low in the upper estuary. Five species per sample is average for the estuary, nine for the marshes. Species abundance and frequency for the 1962 and 1963 collections are summarized in Table 1. Species of foraminifera are listed in the faunal reference list and illustrated in Plates 1 and 2, and text fig. 9. Species of thecamoebinids were not identified.

Total populations (*i.e.,* living plus dead) in the estuary vary from about 3 specimens to more than 10,164 per 20 ml. sample. In general, the average number of specimens per sample increases upstream



TEXT FIGURE 3

Distribution of biofacies in the estuary (basin and shoal facies) and marshes at average salinity conditions, June, 1962.

from less than 100 near the mouth to more than 2,000 per 20 ml. in the upper estuary (text fig. 4C). On the other hand, living populations are relatively small, averaging fewer than 42 specimens per 20 ml. Substantial standing crops occur along the basin shoulder at depths of 15 to 25 feet, and large living populations, reaching an estimated 500 specimens per 20 ml. sample, occur in the upper estuary, an area where total populations are also large.

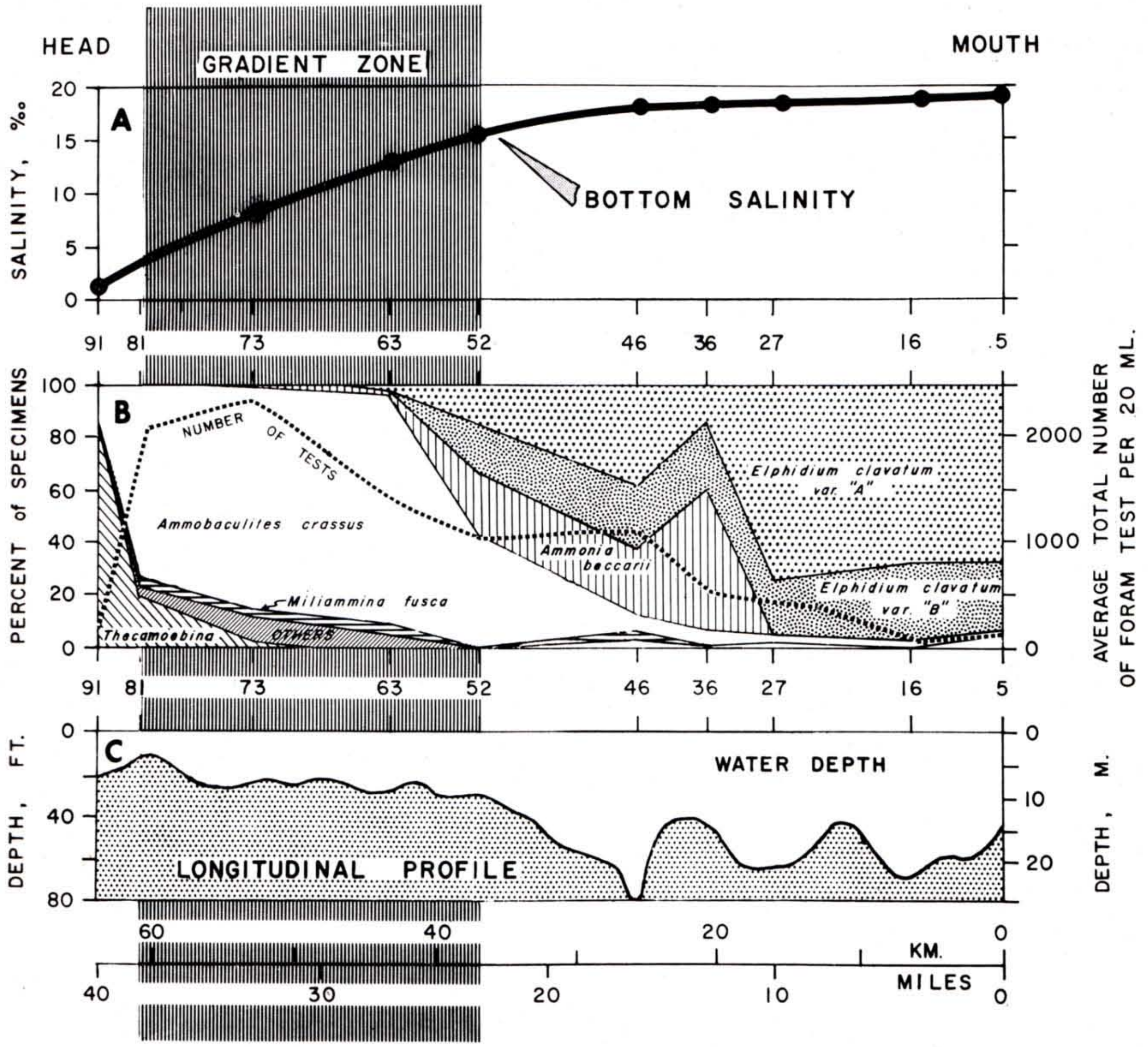
Biofacies and Faunal Composition

The distribution of the most abundant species of foraminifera permits recognition of four well-defined assemblages or biofacies: (1) basin, (2) shoal, (3) outer marsh, and (4) inner marsh. Thecamoebinids are present in the river and adjacent freshwater marshes. The disposition of biofacies is shown in text fig. 3.

The basin biofacies in deeper parts of the lower and middle estuary consists mainly of *Elphidium clavatum* variants. This facies extends headward from Chesapeake Bay to about 20 miles (32 km.) above the estuary mouth. Farther upstream, and laterally on both sides of the basin, in depths less than about 22 feet (6.7 m.), the basin facies passes into the shoal facies.

The shoal biofacies occurs on shoals throughout the estuary as well as in tributary creeks and in the channel of the upper estuary. It consists almost entirely of arenaceous species, chiefly *A. crassus,* and a few specimens of *M. fusca, Ammoastuta salsa,* and *Trochammina inflata,* which are also common in the marshes. This facies extends landward to bordering marshes and upstream to the river, about 45 miles (72 km.) above the mouth. At the fresh-salt transition, where salinity is 0.5‰ foraminifera are replaced by thecamoebinids. The change in faunal composition at selected stations across the estuary and along its length is shown in composite frequency diagrams (text figs. 4B, 5).

Salt marshes are characterized by several foraminiferal species that define "outer" and "inner" marshes along the estuary and, to some extent, "low" and "high" subfacies relative to the elevation of the marsh. The facies distribution generally corresponds with zones of marsh vegetation. The distribution of principal foraminiferal species along the estuary is shown in text fig. 6, and the relative abundance of marsh species in each biofacies is summarized in text fig. 7. As shown in text fig. 7, many species are widely distributed throughout the estuary. Therefore, the facies are established on



TEXT FIGURE 4

A. Distribution of bottom salinity with distance seaward, June-July, 1962.

B. Variation in species composition and total number of foram tests at channel and basin stations along the estuary length, June-July, 1962.

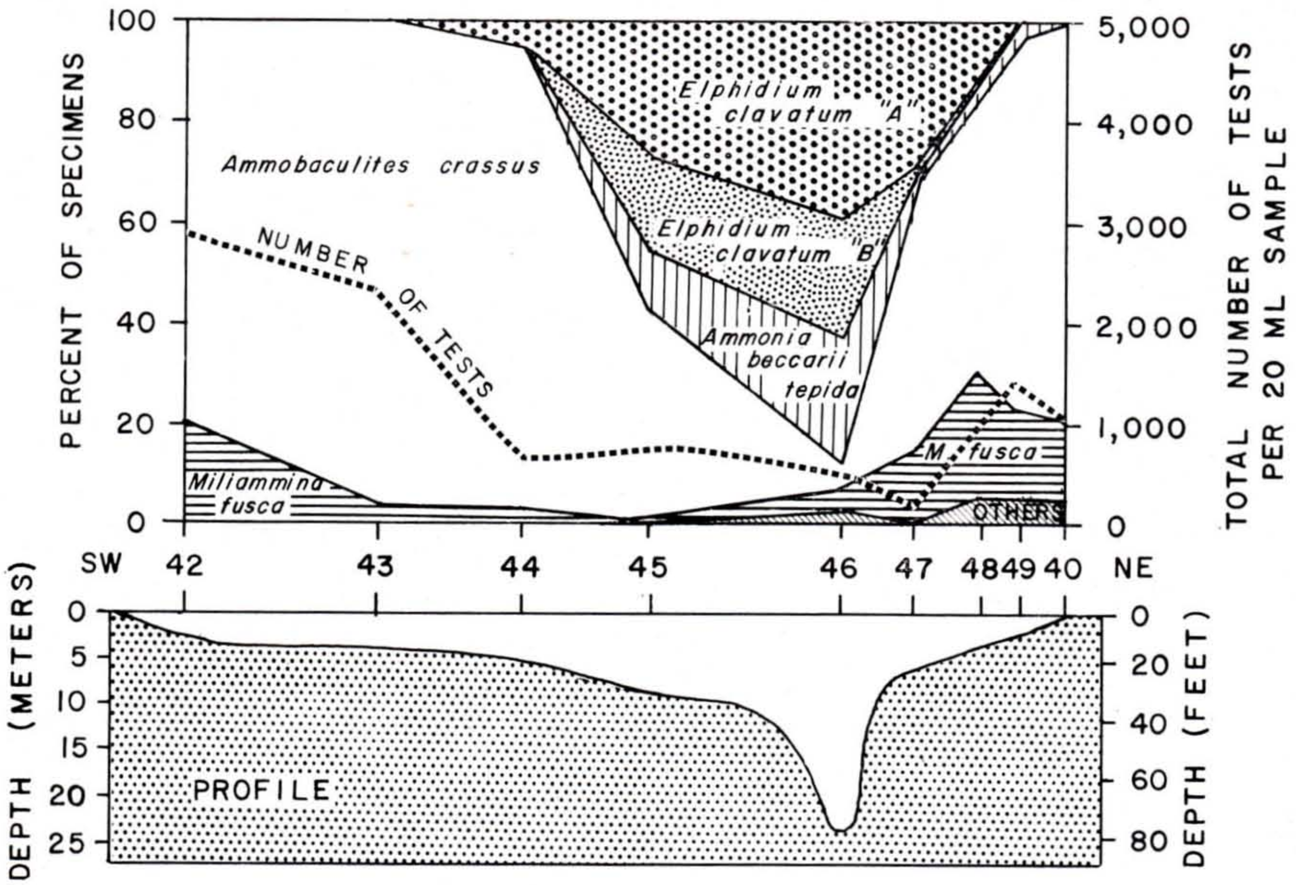
C. Corresponding longitudinal profile and water depth.

relative number of various species rather than on the unique association of a particular species with a particular habitat.

The fauna of the outer marsh biofacies along the lower and middle estuary consists of abundant *Miliammina fusca,* plus a few *Ammonia beccarii tepida* and *Trochammina inflata.* Higher parts of these marshes have fewer *M. fusca* and more *Haplophragmoides* spp. and *T. inflata* than lower parts. The fauna of the inner marsh biofacies along the upper estuary and innermost reaches of tributary creeks (text fig. 3) consists of abundant *Ammoastuta salsa* and some *Astrammina rara.* Also present are low percentages of *M. fusca, Arenoparrella mexicana* and *Trochammina inflata.* One species, *Tiphotrocha comprimata,* is widely distributed throughout all marshes and reaches greatest abundance in marshes along the middle estuary. In freshwater marshes, as in the estuary, thecamoebinids replace foraminifera.

Biofacies Boundaries

The transition between biofacies depends on estuarine mixing and bottom topography. Near the head of the basin, where the depth changes gradually along the estuary axis, the shoal and basin facies intergrade along a 10-mile (16 km.) reach of the estuary. Laterally, with a rapid change in depth, the facies boundary is abrupt. Although a few shoal species are scattered throughout the deeper areas, basin species are rarely found on the shoals, except in the middle estuary where waters are relatively well mixed. Species found in inner and outer marshes also are in part indigenous to the shoals, so that the faunal boundary between these two bio-



TEXT FIGURE 5

Lateral variation in species composition and total number of tests across the estuary, stations 40-42-49, June-July, 1962 (upper) in relation to the bottom profile (lower).

facies is gradational. Similarly, outer and inner marsh facies are gradational, except in middle-estuary tributary creeks where the marsh faunal change is sharper than in marshes of the main estuary. High and low marsh subfacies are indistinctly differentiated, though more detailed study, may, in future, show a marked distinction in association with plant zonation.

Population Variation

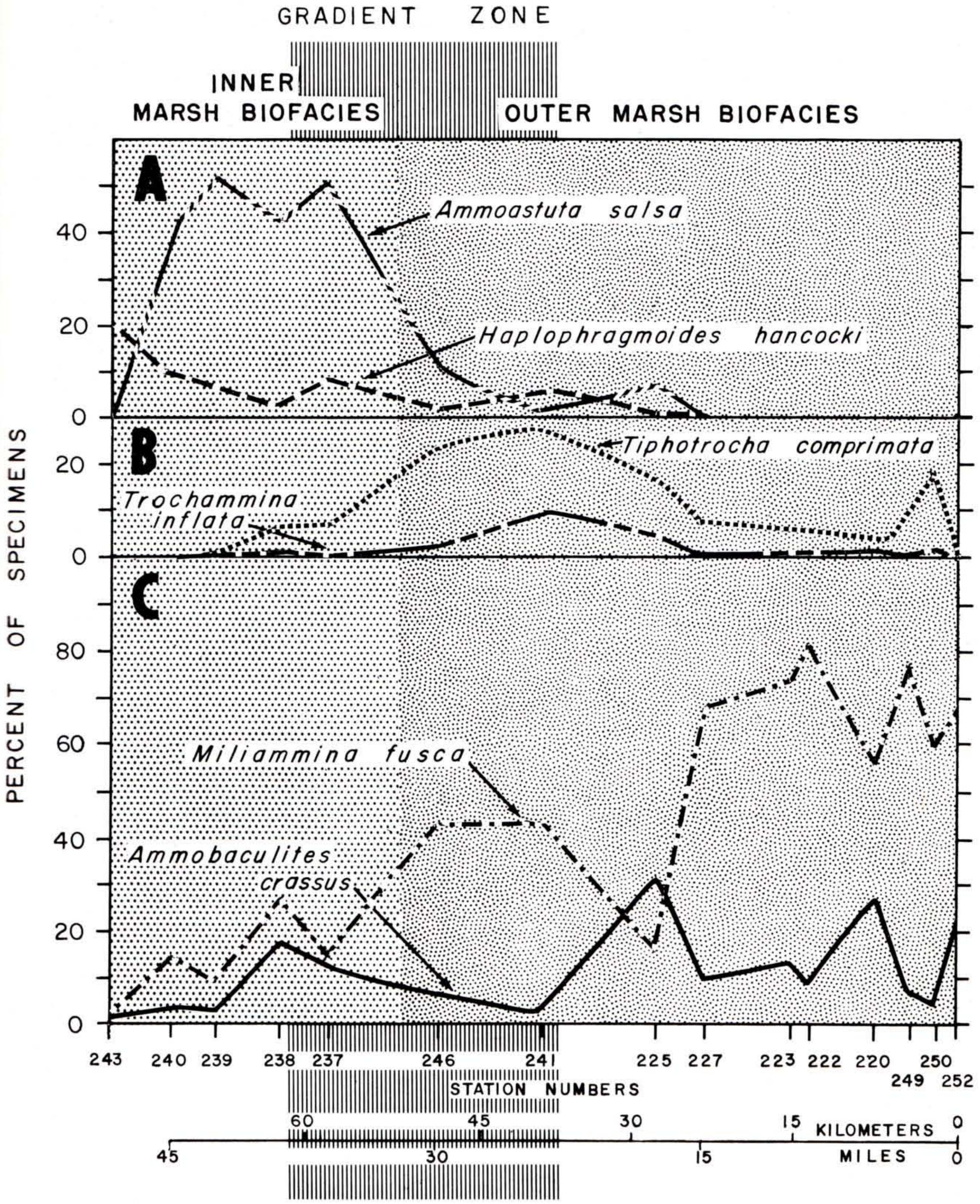
To evaluate sources of spatial variations in the populations, we collected three cores from each of several stations in the middle estuary, and these samples were counted twice. Results of the counts, reported in Ellison (in press), show that, although the percentages of tests of the common species vary only slightly, the percentages of the rarer species as well as the total numbers of tests per sample vary widely between duplicate counts and between the three samples taken at each of the stations. Therefore, the foraminiferal data, especially total numbers of tests, include some natural variations due to the non-uniform distribution of foraminifera, as well as a certain amount of experimental error. In this study we have attempted to reduce the natural variability by analyzing two combined samples for each station. Moreover, analytical errors were reduced by discounting broken specimens, improving the rose Bengal stain, and by counting up to 1000 specimens in some samples. An account of the analysis of local variation is reported by Ellison (1966).

Seasonal Variations

To study changes in the distributions from time to time, we analyzed populations of foraminifera from the estuary at four different times of the year. (Collection dates are given in the section on methods.) The distribution of total populations in each period exhibited the two principal biofacies, shoal and basin, found in the summer of 1962, but the patterns differed and the facies boundaries were located in different places (text fig. 8).

When salinity was relatively low and estuarine water moderately stratified in spring (1965), a time of high river inflow, the shoal-basin facies boundary, drawn where the percentage of *Ammobaculites* equals *Elphidium,* was in the lower estuary (text fig. 8A). Specimens of *A. crassus* were found in relatively high percentages on the shoals of the middle estuary, particularly along the southwestern side. For example, in text fig. 8A the seaward edge of the 90 percent *Ammobaculites* pattern trends diagonally across the middle estuary. Living populations, although small and variable, generally fall within the boundaries delineated by total populations.

When salinity was relatively high and water well-

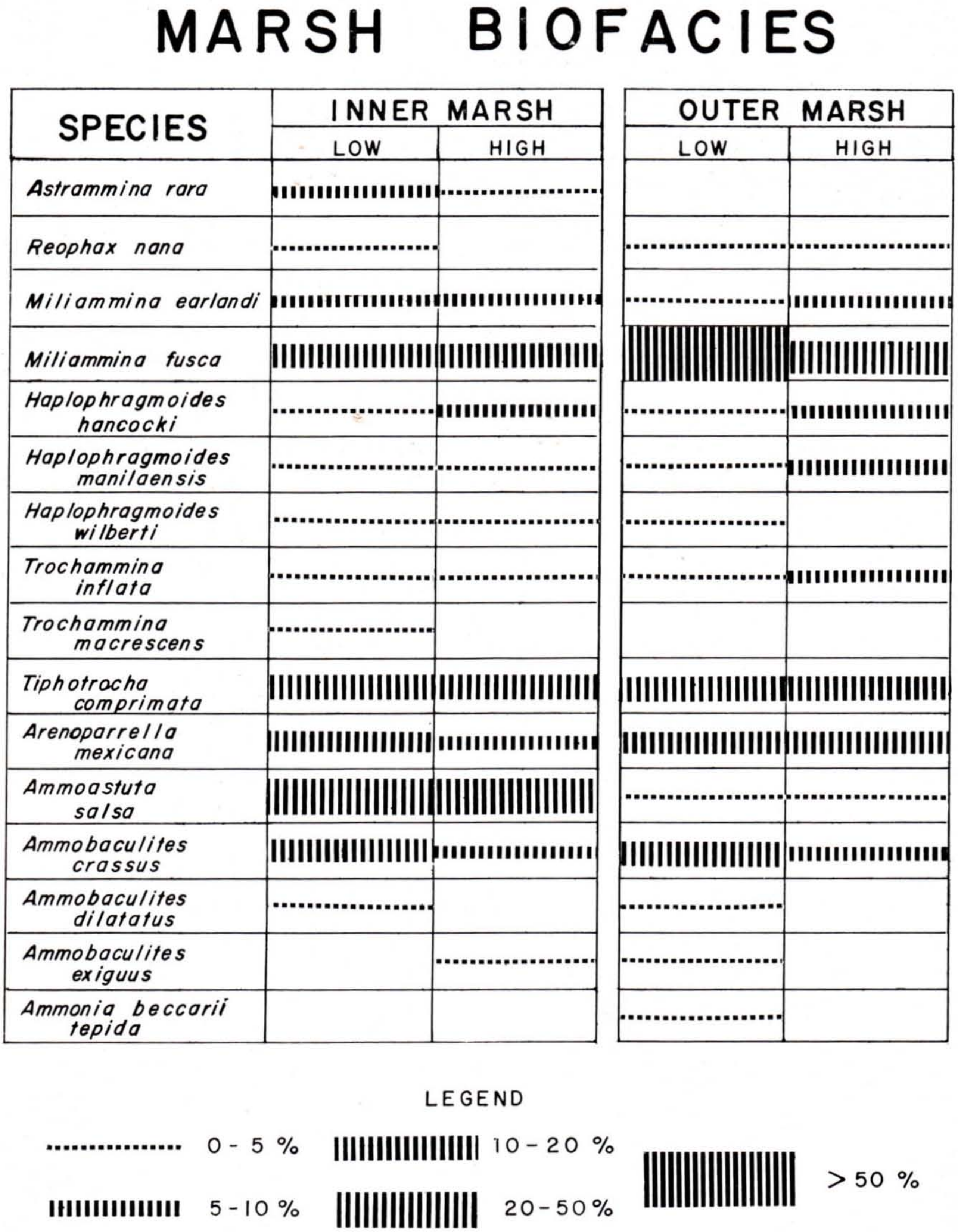


TEXT FIGURE 6

Variation in species composition of foraminifera from marsh stations (both "low" and "high") along the estuary length, June-July, 1962.

mixed in the summer of 1963, a time of low river inflow, the shoal-basin facies boundary reached the middle estuary. *Elphidium* was found in higher percentages on the basinward parts of the shoals and farther upstream than in the summer of 1962. Corresponding peaks for the average living and total population shifted upstream 4 to 6 miles (6.4-9.6 km.).

The species composition of total populations sampled in summer 1962, a time of average salinity, was compared with samples from corresponding stations in summer 1963, a time of relatively high

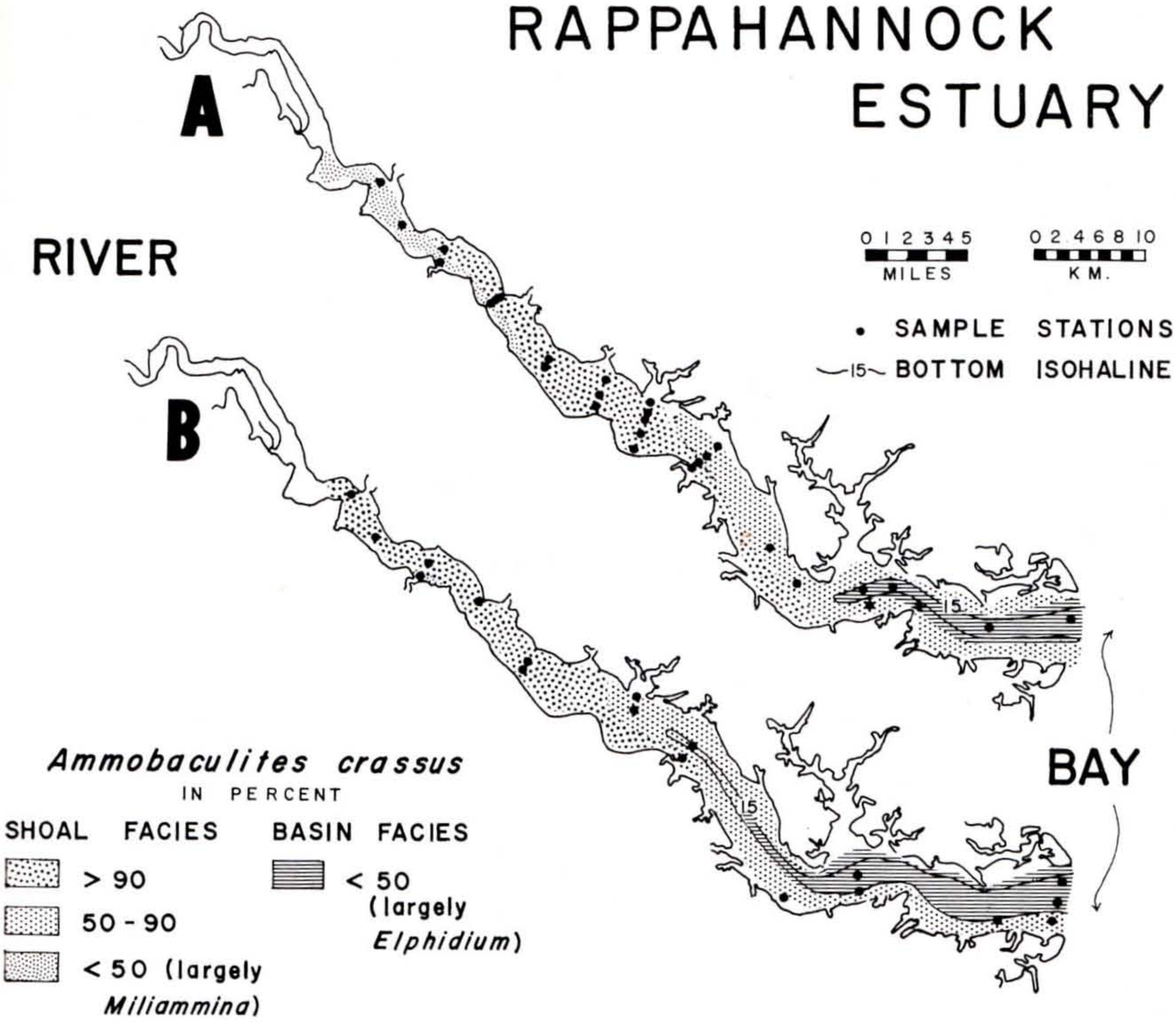


SPECIES	INNER MARSH		OUTER MARSH	
	LOW	HIGH	LOW	HIGH
Astrammina rara	5-10 %	0-5 %		
Reophax nana	0-5 %		0-5 %	0-5 %
Miliammina earlandi	5-10 %	5-10 %	0-5 %	5-10 %
Miliammina fusca	10-20 %	10-20 %	> 50 %	20-50 %
Haplophragmoides hancocki	0-5 %	5-10 %	0-5 %	5-10 %
Haplophragmoides manilaensis	0-5 %	0-5 %	0-5 %	5-10 %
Haplophragmoides wilberti	0-5 %	0-5 %	0-5 %	
Trochammina inflata	0-5 %	0-5 %	0-5 %	5-10 %
Trochammina macrescens	0-5 %			
Tiphotrocha comprimata	10-20 %	10-20 %	10-20 %	10-20 %
Arenoparrella mexicana	10-20 %	5-10 %	10-20 %	10-20 %
Ammoastuta salsa	20-50 %	20-50 %	0-5 %	0-5 %
Ammobaculites crassus	10-20 %	5-10 %	10-20 %	5-10 %
Ammobaculites dilatatus	0-5 %		0-5 %	
Ammobaculites exiguus		0-5 %	0-5 %	
Ammonia beccarii tepida			0-5 %	

TEXT FIGURE 7

Relative abundance of marsh species in different biofacies, "inner" and "outer" and in subfacies "low" and "high" marsh.

salinity. This was done by summing the smallest percentages (1962 vs. 1963) for all of the species at each station. If the two years were very similar, the cumulative percentage for any single station would approach 100. On the other hand, values of less than 50 indicate major changes in the species composition at that station from one year to the next. Results presented in Table 2 indicate that differences in species composition were most pronounced in the basin of the lower estuary. These



TEXT FIGURE 8
Seasonal variations in the distribution of total *Ammobaculites crassus* in relation to bottom isohaline (‰); A. - spring, March-May, 1965; B. - winter, January, 1964.

may reflect real faunal changes, but most values were no greater than would be expected from variation inherent in benthic populations.

Using the same method of analysis, we found that adjacent stations were more alike in 1963 than in 1962 (Table 3). This greater uniformity of the distributions in 1963 accompanied higher salinity and less stratification than in 1962.

During a period of intense drought, from June through December 1965, monthly sets of samples were collected across the river-shoal facies boundary. The general increase in living foraminiferal numbers and decrease in thecamoebinids are reflected in the upstream migration of the facies boundary as a function of increasing salinity with time.

DISCUSSION

Relationship between Distribution and Environment

The two biofacies in the estuary are related to different water types. An *Elphidium* fauna inhabits the salty, lower layer in deeper parts of the lower and middle estuary, an *Ammobaculites* fauna largely occupies marginal shoals bathed by the relatively unstable and freshened upper layer, and a thecamoebinid fauna lives in the river. The facies patterns, therefore, generally parallel the depth and the boundary between water types. Furthermore, the elongate facies pattern and the water-type boundary are slightly skewed seaward on the south side of the estuary in a way that suggests the influence of the Coriolis force. Both the facies and the water types are separated by distinct boundaries.

The lateral transition between facies is very sharp. There are no physical barriers in the estuary, and tidal currents freely sweep the estuary floor and continually mix sediments and water. The abruptness of the faunal change may reflect stratification, but the causal relations are not understood. Transport of tests, particularly juveniles, in opposing upstream and downstream flows may redistribute foraminifera into areas bathed by the two estuarine

TABLE 2

Sums of least percentages for samples collected at stations in both 1962 and 1963. Percentages are those based on total tests. For station locations, see Ellison, *et al.*, 1965.

LOWER ESTUARY		MIDDLE ESTUARY		UPPER ESTUARY	
Station	Sums of least percentages	Station	Sums of least percentages	Station	Sums of least percentages
4	65.7	40	87.3	61	87.8
5	53.5*	42	77.4	63	92.4
16	29.2†	43	77.8	71	94.4
17	70.7	46	84.3	73	95.7
18	89.8	49	73.7	81	93.7
20	90.5	51	80.4	82	96.9
23	53.2*	55	93.0	101	98.0
24	49.6*	56	68.5	230	91.1
25	49.5*	57	40.7†	233	98.6
28	41.5†				
33	96.5				
36	71.4				
37	67.5				

*Questionable correspondence between members of yearly pairs.

†Significantly low degree of correspondence between members of yearly pairs.

layers, which have narrow transitions. Passive transport of barnacles and oyster larvae to sites suitable for growth has been demonstrated by Bousfield (1955) and Carriker (1951).

The position of the shoal-basin facies boundary approximately coincides with that of the 15‰ bottom isohaline (text fig. 8) at most levels of salinity studied. A similar relation was observed in the James estuary (Nichols and Norton, in press). The relationship to salinity is further strengthened by observations in tributary creeks, where the salinity gradient is sharp and the bottom shallow and smooth. As in the estuary proper, the fauna changes abruptly at about 15‰ salinity. The upstream "migration" of living foraminifera (chiefly *Ammobaculites crassus*) into reaches of the river with penetration of the salt water lends further support to the importance of salinity in controlling the distributions.

Salinity *per se* is not necessarily a causal factor affecting the distribution of all species, but it may serve as an index of dilution or mixing by river inflow that influences other conservative factors besides salinity. A number of species have a limited range along the estuary length. For example, *Ammonia beccarii tepida* ranges headward to the upper estuary where salinity averages 6‰, but it is most abundant where salinity is about 14‰. In laboratory cultures this foraminiferan ceases growing in salinities less than 7‰ and reproduces only in salinities above 13‰ (Bradshaw, 1957). Low salinity may effectively confine *Elphidium* to the middle and lower part of the estuary. *Ammobaculites crassus,* on the other hand, extends from the mouth to the head, through a salinity range from 0.5 to more than 16‰.

Although marsh foraminifera are grouped into biofacies more or less paralleling zones of vegetation, there is no sharp floral or faunal change with increasing elevation landward across the marsh or with distance along the estuary length. Instead the marsh distributions form a broad continuum along which different species appear or disappear. For example, *Ammoastuta salsa* is largely confined to the upper estuary, where salinities range from 0.5 to 12‰. Distribution of marsh foraminifera along tributary creeks is similar to that along the estuary proper at corresponding levels of salinity. The distribution of marsh species, therefore, appears to be partly controlled by salinity.

Both living and total populations increase to a peak in the upper estuary, suggesting that (1) empty tests are not redistributed on a large scale throughout the estuary after death, and (2) the large populations may be due to high production. Large stand-

TABLE 3

Sums of least percentages for pairs of adjacent stations for 1962 and 1963. (Percentages based on total tests).

	Station pairs	Sums for 1962	Sums for 1963
LOWER	4-5	36.1†	85.6
	16-17	17.3†	78.3
	17-18	79.2	58.8
	23-24	35.8†	66.9
	24-25	27.0†	72.5
	36-37	39.3†	86.0
MIDDLE	40-49	76.9	88.9
	42-49	81.4	93.2
	55-56	97.2	72.7
	56-57	94.6	42.5†
UPPER	81-82	93.7	97.4
	230-233	79.4	83.9

†Significantly low degree of correspondence between members of pairs.

ing crops of benthic foraminifera observed near the Mississippi River and Guadalupe River entrances have been related to high organic production (Lankford, 1959). In the Rappahannock, large populations are attributed to river-borne nutrients or food materials conducive to production. Monthly distributions of chlorophyll "a" and nutrients such as nitrogen and phosphate in near-surface water show these constituents increasing upstream most of the year, with highest concentrations in the marsh-fringed reaches of the river (Brehmer, personal communication). Although maximum populations do not coincide with the highest nutrient concentrations, it is possible that nutrients or food materials, or both, are significant in increasing foraminiferal production up to a point. Farther upstream, low salinity may limit foraminiferal growth or reproduction. Before these factors can be correlated, much remains to be learned about feeding habits of foraminifera and about primary productivity in benthic substrata.

PALEOECOLOGICAL IMPLICATIONS

Studies of foraminiferal distribution in estuaries such as the Rappahannock enable one to recognize and better interpret ancient estuarine deposits. Most of the species now living in the estuary range back to the middle Tertiary of the Atlantic and Gulf coasts (Bandy, 1956). These species should be valuable paleoecological guides, if one can assume that their environmental preferences have not changed, and that the distribution of fossil tests faithfully parallels that of the once-living foraminifer. Paleoecological interpretation is facilitated by combining other faunal and sedimentary characteristics with features of the foraminiferal distribution.

Like foraminiferal faunas in bays, lagoons, and around deltas, estuarine faunas have few species, with one or two dominants. There are more species near the ocean than near the river of an estuary. Although populations vary widely in size, they are commonly largest in the gradient zone of inner reaches where the salinity range is great. The faunal composition changes seaward from one that is all thecamoebinids in fresh water, to arenaceous foraminifera in the 0.5 to 15‰ salinity range, and to chiefly calcareous foraminifera at a salinity greater than 15‰.

Estuarine faunas that live in an environment of unstable salinity and opposing currents develop certain features that differ from those of other nearshore environments. An estuarine fauna is distinguished by a distinct distributional pattern. In plan view this pattern is elongate, generally paralleling the depth, but slightly asymmetrical.

The change of facies is marked, especially across the estuary. A calcareous *Elphidium* fauna extends headward in a narrow zone of the medial basin or channel. With greater stratification of estuarine water, facies boundaries become more asymmetrical and sharp.

Estuarine faunas are subject to modifications arising from addition or removal of certain species. A few specimens of marsh species may be found in the estuarine deposits, particularly along marsh-fringed reaches and at mouths of tributary creeks. Locally, fossil specimens, derived from exposures along the estuary shore or on the channel floor, are mixed into the estuarine fauna. On the other hand, the number of calcareous foraminifera may be greatly reduced or completely eliminated by post-depositional solution of tests. The resulting fossil fauna may be barren except for arenaceous specimens.

In a stratigraphic section, estuarine faunas may be expected to show marked vertical changes in abundance and composition. With long-term sedimentary aggradation, salt water intrusion will be limited, stratification reduced, and the more marine *Elphidium* fauna will be less widespread in younger than in older sediments. The facies boundary along the longitudinal axis would shift seaward as one proceeds stratigraphically up the section, and the sequence would have the general appearance of a marine regression.

REFERENCES

BANDY, O. L., 1956, Ecology of foraminifera in northeastern Gulf of Mexico: U. S. Geol. Survey, Prof. Paper, no. 274-G, pp. 179-204.

BARTLETT, G. A., 1966, Distribution and abundance of foraminifera and thecamoebina in Miramichi River and Bay: Bedford Inst. Oceanography Rept., no. 66-2, pp. 1-107, unpublished.

BEHM, H. J., and GREKULINSKI, E. F., 1958, The ecology of foraminifera of Main and Richmond Creeks, Staten Island, N. Y.: Proc. Staten Island Inst. Arts and Sci., Vol. 20, pp. 53-66.

BOLTOVSKOY, E., 1957, Los foraminiferos del estuario del Rio de la Plata y su zona de influencia: Inst. Nac. de Invest. de las Cienc. Nat., Mus. Argentino de Cienc. Nat., Cienc. Geol., tomo 6, 77 p.

BOUSFIELD, E. L., 1955, Ecological control of the occurrence of barnacles on the Miramichi Estuary: Bull. Nat. Mus. Canada, No. 137.

BRADSHAW, J. S., 1957, Laboratory studies on the rate of growth of the foraminifer *Streblus beccarii* (Linne) var. *tepida* Cushman: Jour. Paleontology, Vol. 31, pp. 1138-1147.

BUZAS, M. A., 1966, The discrimination of morphological groups of *Elphidium* (Foraminifer) in Long Island Sound through canonical analysis and invariant characters: Jour. Paleontology, Vol. 40, No. 3, pp. 585-594.

CARRICKER, M. R., 1951, Ecological observations on the distribution of oyster larvae in New Jersey estuaries: Ecol. Monographs, Vol. 21, No. 1, pp. 19-38.

ELLISON, R. L., 1966, Contagious distribution of foraminifera: Geol. Soc. America Proc. Annual Meetings, p. 62.

ELLISON, R. L., Data for Rappahannock estuary Foraminifera, 1963-1965: Va. Inst. Marine Science, Data Rept. (in press).

ELLISON, R. L., M. NICHOLS, and J. HUGHES, 1965, Distribution of Recent Foraminifera in the Rappahannock River estuary, Va.: Va. Inst. Marine Science, Special Sci. Rept., no. 47, pp. 1-35.

FOWLER, G. A., A. A. HUNGER, and C. MANSKE, 1966, Foraminiferal trends in marginal marine environments of Oregon: Geol. Soc. America Proc. Annual Meetings, p. 72.

HAIGHT, F. J., H. E. FINNEGAN, and G. L. ANDERSON, 1930, Tides and currents in Chesapeake Bay and tributaries: U. S. Coast and Geodetic Survey, Special Pub. 162, 145 p.

HIRES, R. I., STROUP, E. D., and SEITZ, R. C., 1963, Atlas of the distribution of dissolved oxygen and pH in Chesapeake Bay 1949-1961: Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Md., Graphical Summary Rept. 3, pp. 1-412.

LANKFORD, R. R., 1959, Distribution and ecology of foraminifera from east Mississippi Delta margin: Bull. Am. Assoc. Petrol. Geologists, Vol. 43, pp. 2065-2099.

MCHUGH, J. L., 1967, Estuarine nekton: *in* Estuaries, G. H. Lauff (Ed.), Am. Assoc. Adv. Sci., Washington, D. C., 83:581-620.

NELSON, B., 1960, Clay mineralogy of the bottom sediments, Rappahannock River, Virginia: 7th National Conf. Clays and Clay Minerals, pp. 135-147.

NELSON, B., 1961, Dispersal of clay sediment in the Rappahannock River: Am. Assoc. Petroleum Geologists, Proc. annual meeting, p. 97.

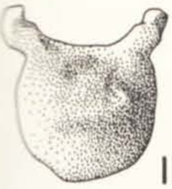
NELSON, B., 1962, Important aspects of estuarine sediment chemistry for benthic ecology: *in* Symposium on the environmental chemistry of marine sediments, edited by N. Marshall, Narragansett Marine Lab., Univ. of Rhode Island, Kingston, R. I., Occ. Publ. no. 1, pp. 27-41.

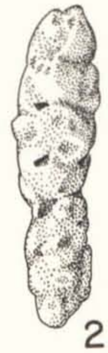
NICHOLS, M., and ELLISON, R. L., 1966, Lightweight bottom samplers for shallow water: Chesapeake Sci., Vol. 7, no. 4, pp. 217-218.

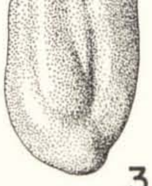
NICHOLS, M., and ELLISON, R. L., 1967, Sedimentary patterns of microfauna in a coastal plain estuary: *in* Estuaries, G. H. Lauff (Ed.), Am. Assoc. Adv. Sci., Washington, D.C., 83:283-288.

EXPLANATION OF PLATE 1

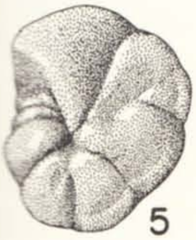
FIGS.		PAGE
1.	*Astrammina rara* Rhumbler. Marsh station No. 200. Specimen showing the two well-developed horns typical for the species.	15
2.	*Reophax nana* Rhumbler. Estuary station No. 49. Specimen showing moderately well-defined sutures and chambers.	16
3.	*Miliammina earlandi* Loeblich and Tappan. Marsh station No. 200. Specimen showing the lustrous surface and the elongate character of the test.	16
4.	*Miliammina fusca* (Brady). Marsh station No. 200. Specimen showing the somewhat irregular quality of the shell surface, and the broad form of the test.	16
5.	*Haplophragmoides hancocki* Cushman and McCulloch. Marsh station No. 201.	16
6.	*Haplophragmoides manilaensis* Andersen. Marsh station No. 201. Specimen showing apertural lip, inflated chambers, and resultant lobulate periphery.	16
7.	*Haplophragmoides wilberti* Andersen. Marsh station No. 201. Specimen showing apertural lip and flattened character of the test.	16
8, 9.	*Trochammina inflata* (Montagu). Marsh station No. 201. 8. Dorsal view of large right-handed specimen with inflated chambers and well-defined sutures. 9. Ventral view of slightly smaller, left-handed specimen showing slit-like aperture along base of apertural face.	16
10, 11.	*Trochammina macrescens* (Brady). 10. Marsh station No. 202: dorsal view of right-handed specimen with collapsed chambers, and showing the dark color of the first 3 chambers. 11. Marsh station No. 200: ventral view of left-handed specimen, showing sigmoidal sutures.	16
12, 13.	*Trochammina squamata* Parker and Jones. 12. Chesapeake Bay station No. E6. Ventral view of left-handed specimen showing collapsed chambers, and margins of chambers standing up in relief. 13. Estuary station No. 4. Dorsal view of right-handed specimen showing poorly defined sutures and chambers.	16
14, 15.	*Tiphotrocha comprimata* (Cushman and Brönnimann). Marsh station No. 201. 14. Ventral view of left-handed specimen with slightly concave surface and showing lappets extending into the umbilicus, and the undercut nature of the sutures. 15. Dorsal view of left-handed specimen showing subtle character of chambers and their crescentic outline.	16

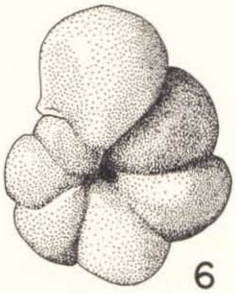

1


2

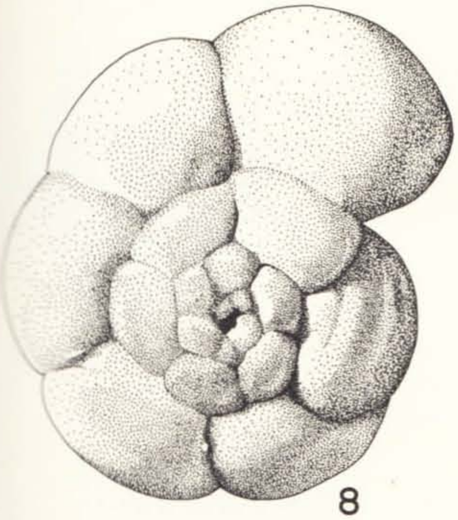

3

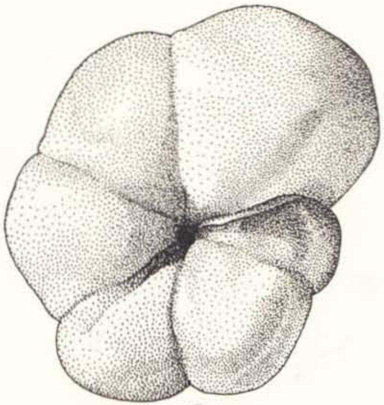

4

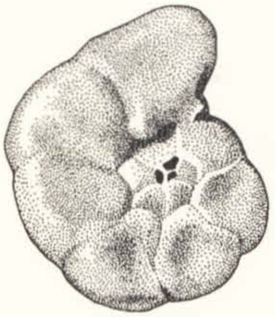

5


6

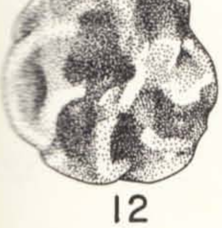

7

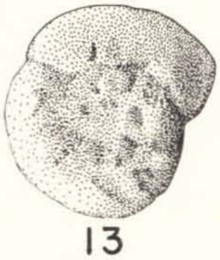

8

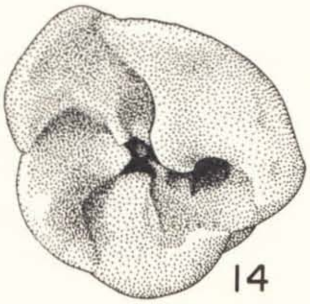

9


10


11


12

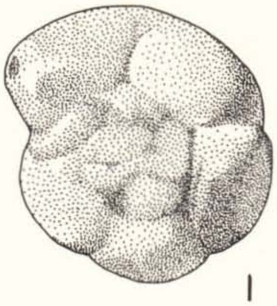

13

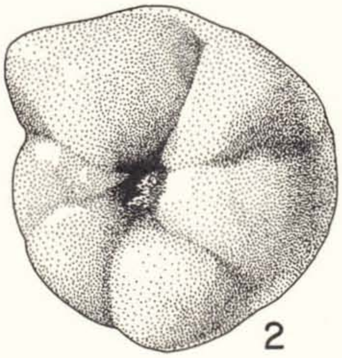

14


15

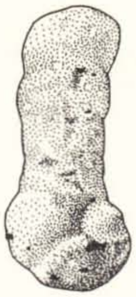
1 mm.

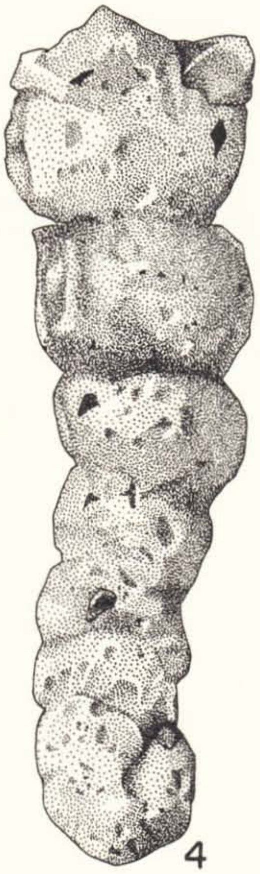
Ellison and Nichols: Estuarine Foraminifera from Virginia

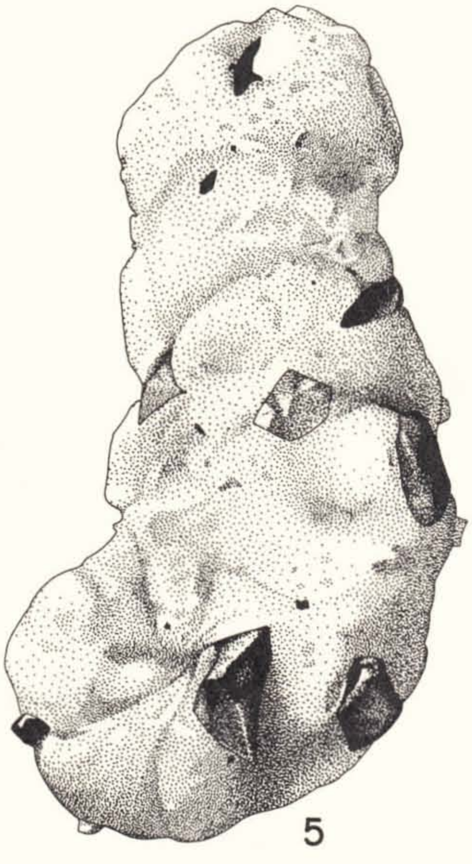

1

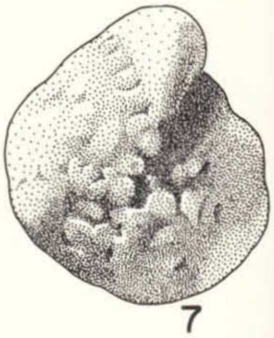

2

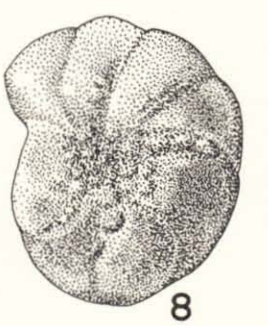

3

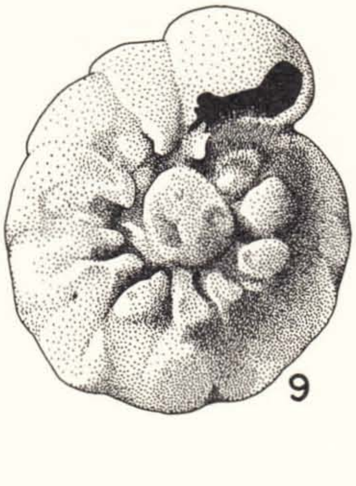

6

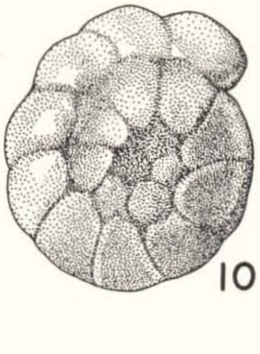

4


5


7


8


9


10


11


12

1 mm.

Ellison and Nichols: Estuarine Foraminifera from Virginia

NICHOLS, M., and NORTON, W., Foraminiferal populations in a coastal plain estuary (in press).

NICHOLS, M., and POOR, G., 1967, Sediment transport in a coastal plain estuary: Jour. Waterways and Harbors, Am. Soc. Civil Engr., Vol. 93, no. WW4, paper 5571, pp. 83-95.

PARKER, F. L., 1952, Foraminiferal distribution in the Long Island Sound-Buzzards Bay area: Bull. Mus. Comp. Zool., Vol. 106, no. 10, pp. 427-473.

PRITCHARD, D. W., 1952, Salinity distribution and circulation in the Chesapeake Bay estuarine system: Jour. Mar. Res., Vol. 13, pp. 133-144.

STROUP, E. D., and LYNN, R. J., 1963, Atlas of salinity and temperature distributions in Chesapeake Bay 1952-1961 and seasonal averages 1949-1961: Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Md., Graphical Summary Rept. 2, pp. 1-410.

STROUP, E. D., and WOOD, J. H., 1966, Atlas of turbidity, phosphate and chlorophyll in Chesapeake Bay 1949-1951: Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Md., Graphical Summary Rept. 2, pp. 1-410.

TODD, R., and BRÖNNIMANN, P., 1957, Recent Foraminifera and Thecamoebina from the eastern Gulf of Paria: Cushman Found. Foram. Res. Spec. Pub., no. 3, pp. 1-43.

VAN VOORTHUYSEN, J. H., 1960, Die Foraminiferen des Dollart-Ems-Estuarium: Verhandel. koninkl. Ned. Geol. Mijnbouwk. Genoot., Geol. Ser. Vol. 9, pp. 237-269.

FAUNAL REFERENCE LIST

References to the original descriptions are listed below and species are illustrated in Plates 1 and 2 and text fig. 9.

Ammoastuta salsa Cushman and Brönnimann, 1948. *Cushman Lab. Foram. Research Contr.*, 24:17, pl. 3, figs. 14-16.

Ammobaculites crassus Warren, 1957. *Cushman Found. Foram. Res. Contr.*, 8:32, pl. 3, figs. 5-7.

Ammobaculites cf. *A. dilatatus* Cushman and Brönnimann, 1948. *Cushman Lab. Foram. Research Contr.*, 24:39, pl. 7, figs. 10, 11.

Ammobaculites cf. *A. exiguus* Cushman and Brönnimann, 1948. *Cushman Lab. Foram. Research Contr.*, 24:38, pl. 7, figs. 7, 8.

Ammonia beccarii (Linnaeus) var. A* = variety of *Nautilus beccarii* Linnaeus, 1758. *Systema naturae,* 10 ed., Holmiae, 1:710, pl. 1, figs. 1a-c.

Ammonia beccarii tepida (Cushman) = *Rotalia beccarii* var. *tepida* Cushman, 1926. *Carnegie Inst. Wash.*, Pub. 344:79, pl. 1.

Arenoparrella mexicana (Kornfeld), emend. Andersen = *Trochammina inflata* (Montagu) var. *mexicana* Kornfeld, 1931. *Stanford Univ. Dept. Geol. Contr.,* 1:86, pl. 13, figs. 5a-c.

Astrammina rara Rhumbler, 1931. In: Drygalski, E. von, *Deutsche Sübpolar Expedition 1901-1903,* W. de Gruyter, Berlin, 20:78, pl. 2, figs. 19a, b.

EXPLANATION OF PLATE 2

FIGS.		PAGE
1, 2.	*Arenoparrella mexicana* (Kornfeld). Marsh station No. 200. 1. Dorsal view of left-handed specimen showing typically subtle sutures and blocky chambers. 2. Ventral view of right-handed specimen showing radially directed sutures and excavated umbilicus.	15
3.	*Ammoastuta salsa* Cushman and Brönnimann. Marsh station No. 200. Lateral view of 10-chambered specimen.	15
4.	*Ammobaculites crassus* Warren. Estuary station No. 30. Large specimen showing trochispiral initial portion of test with vaguely visible sutures, and increasingly larger and more inflated chambers toward the aperture.	15
5.	*Ammobaculites* cf. *A. dilatatus* Cushman and Brönnimann. Estuary station No. 301. Specimen showing compressed character of test, and vaguely visible sutures that are markedly convex toward the aperture.	15
6.	*Ammobaculites* cf. *A. exiguus* Cushman and Brönnimann. Marsh station No. 220. Specimen showing subequant initial, planispiral portion of test, and uniserial portion with low chambers separated by nearly horizontal, subparallel sutures.	15
7, 8.	*Elphidium clavatum* Cushman. Estuary station No. 3. 7. Variant A; specimen showing slit-like pits marking septal bridges along the sutures, and the irregular bosses and pits in the umbilical area. 8. Variant B; specimen showing slightly arcuate, beaded sutures, and beaded umbilical area.	16
9, 10.	*Ammonia beccarii* Linnaeus variety A. Estuary station No. 23. 9. Ventral view of left-handed specimen (last chamber broken), showing thickened lappets extending toward large umbilical boss, and radially directed sutures. 10. Dorsal view of right-handed specimen showing slightly limbate, arcuate sutures.	15
11, 12.	*Ammonia beccarii tepida* (Cushman). Estuary station No. 46. 11. Dorsal view of right-handed specimen showing lobulate periphery and arcuate sutures. 12. Ventral view of right-handed specimen showing excavated umbilicus and radial sutures.	15

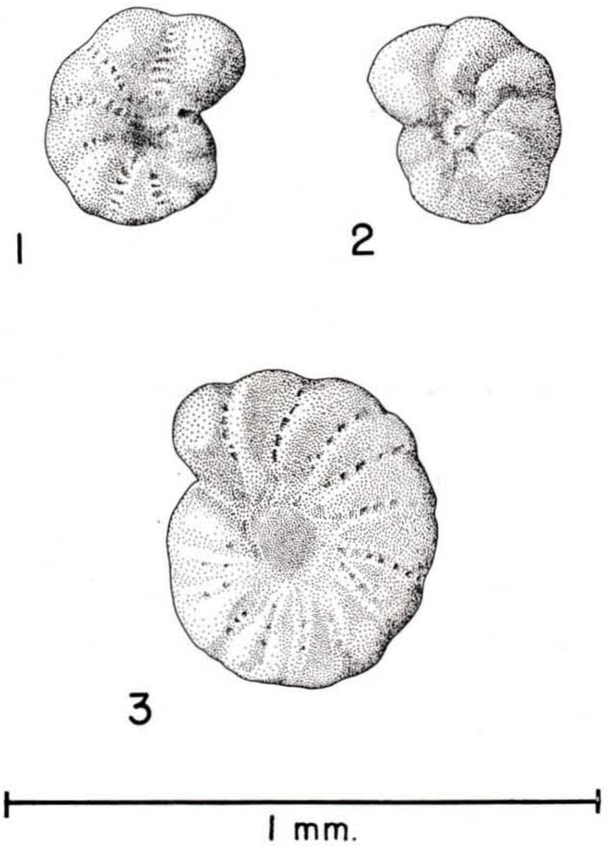
Elphidium clavatum Cushman vars. A, B, and D† = *Elphidium incertum* (Williamson) Cushman, 1930. *U. S. Nat. Mus. Bull.,* 104:18-19, pl. 7, figs. 8a, 8b, 9a, 9b = *Elphidium incertum* var. *clavatum* Cushman, 1930. *U. S. Nat. Mus. Bull.,* 104:18-19, pl. 7, figs. 10a, b.

Elphidium galvestonense Kornfeld = *Elphidium gunteri* Cole var. *galvestonensis* Kornfeld (part), 1931. *Stanford Univ. Dept. Geol. Contr.,* 1:86, pl. 15, figs. 1-3.

Haplophragmoides hancocki Cushman and McCulloch, 1939. *Allan Hancock Pacific Expeditions,* 6:79, pl. 6, figs. 5, 6.

Haplophragmoides manilaensis Andersen, 1952. *Cushman Found. Foram. Res. Contr.,* 4:22, pl. 4, figs. 8a, b.

Haplophragmoides wilberti Andersen, 1952. *Cushman Found. Foram. Res. Contr.,* 4:21, pl. 1, figs. 7a, b.



TEXT FIGURE 9

Top, left: *Elphidium clavatum* Cushman variant D. Estuary station No. 313. Specimen showing depressed sutures with small, unevenly spaced retral processes, and the excavated umbilical region.

Top, right: *Protelphidium tisburyense* (Butcher). Estuary station No. 313. Specimen showing recurved sutures that lack retral processes.

Bottom: *Elphidium galvestonense* Kornfeld. Estuary station No. 313. Large specimen showing somewhat flattened character of the test, and the numerous (15) chambers per whorl.

Miliammina earlandi Loeblich and Tappan, 1955. *Smithsonian Misc. Coll.,* 121:12, pl. 1, figs. 15, 16.

Miliammina fusca (Brady) = *Quinqueloculina fusca* Brady, 1870. *Ann. Mag. Nat. Hist.,* Ser. 4, 6:286, pl. 11, figs. 2, 3.

Protelphidium tisburyense (Butcher) = *Nonion tisburyensis* Butcher, 1948. *Cushman Lab. Foram. Res. Contr.,* 24:22, text figs. 1-3.

Reophax nana Rhumbler, 1911. *Plankton-Exped. Humboldt-Stiftung, Ergeb.,* 3:182, pl. 8, figs. 6-12.

Tiphotrocha comprimata (Cushman and Brönnimann, 1948. *Cushman Lab. Foram. Research Contr.,* 24:41, pl. 8, figs. 1-3.

Trochammina inflata (Montagu) = *Nautilus inflata* Montagu, 1808. *Testacea Brittanica,* Suppl. S. Woolmer, Exeter, Eng., p. 81, pl. 18, fig. 3.

Trochammina macrescens (Brady) = *Trochammina inflata* (Montagu) var. *macrescens* Brady, 1870. *Ann. Mag. Nat. Hist.,* Ser. 4, 6:51, pl. 11, figs. 5a-c.

Trochammina squamata Parker and Jones, 1860. Jones and Parker, 1860. *Quart. Jour. Geol. Soc. London,* 16:407, pl. 15, figs. 30, 30a-c.

**Remarks.*—Samples collected from stands of eelgrass in late summer of 1963 yielded abundant living specimens of *Ammonia beccarii* var. A. In addition, the associated sediment was sampled to determine whether the foraminifera were selectively inhabiting the grass. Most ratios for the eelgrass exceed those for the sediment. Nearly all high values result from large numbers of living *A. beccarii* var. A. In the summer this is an important epiphytic form in the Rappahannock.

†*Remarks.*—*Elphidium clavatum* exhibits considerable morphological variation. Specimens of this species in our collection are identical with material identified as *E. incertum* from Buzzards Bay (USNM 40941-40944). Other specimens are the same as those identified as *E. incertum* var *clavatum* from Buzzards Bay (USNM 41123, 41125, 41126). The shell wall of *Elphidium incertum* (Williamson) is microgranular, whereas the wall structure of our specimens is radial. Despite certain morphological divergences of our specimens from typical *Elphidium clavatum,* we regard them as belonging to that species.

In the Rappahannock River estuary, at least three morphological variants can be recognized with some confidence. These are referred to as *Elphidium clavatum* A, B, and D. Variants A and B are ubiquitous and commonly occur together, whereas D was found after 1962, and chiefly in the middle estuary.

The morphological differences of these three variants can be seen most clearly on adult specimens. Generally, variant A is opaque, with well-defined retral processes or interrupted slits along the sutures, and with the umbilical regions irregularly filled with one or more bosses. Variant B is transparent, and the sutures and umbilical regions bear glassy, bead-like processes. Measurements of several morphological characters (Buzas, 1966) showed no significant difference between these two variants. Variant D resembles imperfect specimens of *E. poeyanum* and can be recognized by its depressed sutures with retral processes that are subuniformly spaced and by its excavated umbilical regions. The test is coarsely perforate and superficially resembles the finely agglutinate shell of *Miliammina earlandi* or *Trochammina*.

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 1, JANUARY, 1970

380. PLANKTONIC FORAMINIFERA DESCRIBED FROM THE UPPER CRETACEOUS OF CALIFORNIA[1]

ROBERT G. DOUGLAS
Case Western Reserve University, Cleveland, Ohio 44106

ABSTRACT

Twenty-four species of Cretaceous planktonic foraminifera have been described from California in the last four decades. An examination of the taxonomic status of these taxa reveals that ten of the twenty-four are valid, although three require a change in generic designation. The valid species include **Hedbergella kingi** (Trujillo), **H. beegumensis** Marianos and Zingula, **H. murphyi** Marianos and Zingula, **Praeglobotruncana roddai** (Marianos and Zingula), **Globotruncana churchi** Martin, **G. goudkoffi** Martin, **G. cachensis** Douglas, **Planoglobulina ornatissima** (Cushman and Church) and **Bifarina douglasi** Sliter. A distinct California variant, previously described as **G. putahensis** Takayanagi, is assigned as a subspecies of **Globotruncana stuartiformis** Dalbiez. The remaining taxa, with the exception of two recently described forms, are synonyms or probable synonyms of species erected outside California.

INTRODUCTION

Marine sedimentary rocks of Cretaceous age crop out over large areas of California, but thick sections of these strata, particularly in the central and northern parts of the state, contain a very sparse megafauna. For this reason, foraminifera have played a major role in the zonation and stratigraphic correlation of Cretaceous strata. In the last decade or so planktonic foraminiferal species, because of their important correlative value, have received increasing attention, and several recent papers either emphasize or are devoted to a discussion of the systematics and stratigraphic distribution of the planktonic microfauna. These include reports by Küpper (1956a, b), Takayanagi (1965), Douglas and Sliter (1966), Marianos and Zingula (1966), and Douglas (1969a, b) on the faunas from the western Sacramento Valley; Trujillo's (1960) descriptive work on the species from the Redding area; the foraminiferal analysis, including both the benthonic and planktonic species of the western San Joaquin Valley, by Martin (1964) and Graham and Clark (1961); and the description and discussion of the planktonic taxa present in southern California by Bandy (1951), Douglas and Sliter (1966) and Sliter (1968). In addition, planktonic foraminiferal taxa are listed or mentioned in a large number of papers issued since 1929, when planktonic species were first specifically identified from deposits of Cretaceous age in California (Cushman and Church, 1929). These papers have been reviewed and annotated by Graham (1961, 1962).

Most of the 70 or so taxa listed or reported from the California Cretaceous are identified as belonging to taxa originally described from other parts of America or Europe. Naturally not all of these identifications have proven to be correct (and, undoubtedly, future mistakes will occur). Nevertheless, the reported faunas establish that the majority of species and all of the genera occurring in California are common to contemporaneous assemblages found over large areas of the globe. The cosmopolitan aspect of planktonic foraminiferal species, in contrast to the strong provincialism of molluscan fossils, has permitted detailed correlation of the California Cretaceous with classical sections in the Gulf Coast and Europe (Martin, 1964; Sliter, 1968; Douglas, 1969a). In addition to the cosmopolites, several workers have recognized species which were different or apparently different from any then known in the literature. These forms, described as new or indicated by the various workers as probably new, presently number two dozen. For one reason or another, the majority of these microfossils have not become well known: many have not been cited in the literature since their initial description and most, apparently, are not known outside California. The exceptions, such as *Rugoglobigerina kingi* Trujillo and *R. praehelvetica* Trujillo, which are reported in Europe (Scheiberova, 1963; Samuel and Salaj, 1966), are few. Also, since the creation of several of the California species, considerable progress has occurred in the study of planktonic foraminifera, including the elucidation of poorly known species described in the 19th century. Redescription and taxonomic redefinition of these older taxa, particularly the European ones, has made it apparent that some of them are senior synonyms of California species. Thus it seems appropriate to re-examine the species described from California Cretaceous deposits in the light of the many nomenclatural changes and classificatory revisions at the generic level (Loeblich and Tappan, 1964; Pessagno, 1967) that have occurred in recent years. It is the intent of this paper to review briefly the current taxonomic status of the 24 taxa described in California over the last 40 years. For purposes of discussion, the species will be divided into three categories and will be treated in the following order: recently described species, synonymous species and endemic forms. A

---

[1] Contribution No. 51, Department of Geology, Case Western Reserve University, Cleveland, Ohio 44106.

TABLE 1

Index to species of Upper Cretaceous planktonic foraminifera described in California. Entries arranged by author(s). Those starred are discussed in text.

ORIGINAL DESIGNATION	VALID DESIGNATION
1. *Praeglobotruncana hansbolli* Trujillo	1. *Globigerinelloides caseyi* Bolli, Loeblich and Tappan
2. *Rugoglobigerina kingi* Trujillo	2. *Whiteinella kingi* (Trujillo)*
3. *R. praehelvetica* Trujillo	3. *Praeglobotruncana helvetica* (Bolli)*
4. *Globotruncana renzi primitiva* Küpper	4. *Praeglobotruncana stephani* (Gandolfi)*
5. *Praeglobotruncana caryi* Martin	5. *Hedbergella crassa* Bolli
6. *Globotruncana fresnoensis* Martin	6 *G. marginata* (Reuss)
7. *G. churchi* Martin	7. same*
8. *G. goudkoffi* Martin	8. same*
9. *G.* sp. A. Marianos and Zingula	9. *G. marianosi* Douglas*
10. *G.* sp. B. Marianos and Zingula	10. *G. pseudolinneiana* (Pessagno)
11. *G.* sp. C. Marianos and Zingula	11. *Praeglobotruncana loeblichae* Douglas*
12. *G. roddai* Marianos and Zingula	12. *Praeglobotruncana roddai* (Marianos and Zingula)*
13. *Rotalipora tehamaensis* Marianos and Zingula	13. *R. greenhornensis* (Morrow)*
14. *Hedbergella quadrata* Marianos and Zingula	14. *H. portsdownensis* (Mitchell-Williams)
15. *H. beegumensis* Marianos and Zingula	15. Probably the same; insufficient material available for judgment*
16. *H. murphyi* Marianos and Zingula	16. same*
17. *Globotruncana putahensis* Takayanagi	17. *G. stuartiformis putahensis* Takayanagi*
18. *G. cachensis* Douglas	18. same*
19. *Bifarina douglasi* Sliter	19. same*
20. *Globigerina almadenensis* Cushman and Todd	20. *Hedbergella trochoidea* (Gandolfi)
21. *Globorotalia californica* Cushman and Todd	21. *Praeglobotruncana stephani* (Gandolfi)
22. *G. decorata* Cushman and Todd	22. *Rotalipora greenhornensis* (Morrow)
23. *G. almadenensis* Cushman and Todd	23. *R. evoluta* (Sigal)
24. *Ventilabrella ornatissima* Cushman and Church	24. *Planoglobulina ornatissima* (Cushman and Church)

planktonic foraminifer which has not been previously reported from the West Coast is also discussed.

ACKNOWLEDGMENTS

The writer is indebted to A. W. Marianos, Humble Oil and Refining Company, and W. V. Sliter, ESSO Production Research Company, for stimulating discussions concerning California Cretaceous planktonic foraminifera and for reading the manuscript, and to E. A. Pessagno, Jr., Southwest Center for Advanced Studies, for numerous helpful comments regarding Gulf Coast taxa.

METHODS AND MATERIALS

Determining the morphologic limits of a species and the range of variation that is acceptable for membership within a group is difficult because there are few guidelines for establishing these boundaries in micropaleontology. When a group displays a wide range of intraspecific variation, as many planktonic foraminifera do, taxonomic judgements are difficult, often controversial. Therefore it seems worthwhile to state that the writer views the microfossils discussed herein, and in general, as biological populations (or as close to these as they can be conceived to be in the fossil state) which originally were composed of arrays of individuals exhibiting variation on a common theme. Small-scale morphologic variation which occurs in a clinal or consistent manner is viewed primarily as intraspecific (*e.g.* ecologic or geographic) rather than interspecific. In this context type specimens are viewed in the sense of Simpson (1961) as name bearers and not as archeotypes. Workers using planktonic foraminifera primarily as stratigraphic indices will find disagreement with this approach.

The primary types and large suites of individuals, many from the type area, of the California species discussed herein have been examined. In addition, California assemblages have been compared to contemporaneous assemblages from the Gulf Coast and Western Interior of North America and to selected faunas from North Africa and Europe.

Type specimens of the recently described species are deposited in the Helen Tappan Loeblich Collection, Department of Geology, University of California, Los Angeles. Additional types are on deposit in the Hyde Paleontological Collection, Department of Geology, Case Western Reserve University.

Localities referred to in the text have been described by Douglas (1966) and the pertinent samples are on file in the type collections, Department of Geology, University of California, Los Angeles.

SYSTEMATIC DISCUSSION

Recently described species

Globotruncana marianosi Douglas

Plate 3, figure 1

Globotruncana sp. A Marianos and Zingula, 1966, Jour. Paleont., vol. 40, no. 2, p. 341, pl. 39, fig. 1.

Globotruncana marianosi Douglas, 1969, Micropaleontology, vol. 15, p. 182, pl. 2, fig. 3, text-fig. 5.

Test free, large, low trochospiral, flat to slightly depressed spiral side, biconvex, becoming umbilicoconvex in adult, equatorial periphery nearly circular, slightly lobate, axial periphery angular rhomboid becoming angular conical in last whorl, with single keel. Chambers petaloid, subcircular on spiral side, subtriangular, inflated on umbilical side, increasing rapidly in size, 6 to 8 in final whorl. Sutures curved, raised, beaded on spiral side, depressed, radial on umbilical side. Wall calcareous, perforate, surface smooth to very finely spinose on umbilical side. Umbilicus wide and deep. Aperture interiomarginal, umbilical-extra-umbilical, extending only to the margin, with small apertural flaps extending into the umbilical cavity.

specimen	max. diameter	max. thickness
holotype (CWRU H013) (unfig.)	0.74 mm	0.25 mm
paratype (CWRU P124) (unfig.)	0.87 mm	0.31 mm
paratype (CWRU P125) (unfig.)	0.70 mm	0.25 mm
paratype (UCLA 47027) (unfig.)	0.68 mm	0.26 mm
topotype (CWRU T133) (fig.)	0.92 mm	0.41 mm

Remarks.—This species resembles *Globotruncana sigali* Mornod in general appearance; however, *G. marianosi* may be distinguished by (1) its umbilically inflated chambers which give the test a distinct umbilicoconvex shape, (2) the rapid increase in chamber size, and (3) the tendency to develop a slightly depressed spiral size. Small, juvenile specimens of the two species are most easily separated by the shape of the chambers.

Occurrence.—The holotype (CWRU-H013) and unfigured paratypes are from unnamed Turonian strata, San Miguel Island, Santa Barbara County. Paratype (UCLA 47027) and unfigured specimens in the writer's collection are from the lower portion of the Venado Formation, Cache Creek, Colusa County. The species has been recovered from Middle to Upper Turonian strata in the Sacramento Valley and other localities in central and northern California. At the lower end of its stratigraphic range it occurs with *Globotruncana sigali, Praeglobotruncana helvetica* and *Globotruncana pseudolinneiana*; its last occurrence is associated with *G. imbricata* and *G. cachensis.* It is confined to the upper part of the *Praeglobotruncana helvetica* Zone (*Globotruncana imbricata* Subzone) (Douglas, in press).

Praeglobotruncana loeblichae Douglas

Plate 3, figures 3, 4

Hedbergella sp. 1 Douglas and Sliter, 1966, Tulane Stud. Geol., vol. 4, no. 3, p. 105, pl. 4, fig. 10.

Globotruncana sp. C Marianos and Zingula, 1966, Jour. Paleont., vol. 40, no. 2, p. 341, pl. 39, fig. 4.

Praeglobotruncana loeblichae Douglas, 1969, Micropaleontology, vol. 15, p. 170, pl. 5, figs. 6, 7.

Test free, medium size, low trochospiral, gently convex on spiral side, umbilical side nearly flat, equatorial periphery lobate, axial periphery rounded to broadly truncate, covered with large spines. Chambers petaloid, initially globular becoming compressed, subcircular to subrectangular, 5 to 6 in final whorl, increasing gradually in size. Sutures radial and depressed, slightly curved on spiral side, sometimes beaded with rims; depressed, radial on umbilical side. Wall calcareous, perforate, margins pierced with occasional pore, surface spiny to rugose on spiral side, surface on umbilical side spiny on initial chambers, later chambers smooth. Umbilicus wide and shallow. Aperture a low, interiomarginal, umbilical arch extending from umbilicus nearly to margin, bordered by a narrow, thickened margin. All specimens examined were sinistrally coiled.

specimen	max. diameter	max. thickness
holotype (UCLA 47040) (unfig.)	0.63 mm	0.19 mm
paratype (CWRU P031)	0.44 mm	0.18 mm
paratype (CWRU P032)	0.46 mm	0.15 mm

Remarks.—Most species of Cretaceous planktonic foraminifera exhibit a strong preference for one direction of coiling; the majority appear to be dextrally coiled. This form is unusual in that all the specimens examined (about 300) are sinistrally coiled. Two other distinctive features are the coarsely spinose or rugose spiral and umbilical surface, except for the last formed chamber, and the blunt to slightly rounded margin of the test. Species of *Praeglobotruncana* are usually either finely spinose or smooth, and typical forms, *e.g. P. stephani,* have acute peripheral margins. Rounded chamber margins are common among *Hedbergella,* but since the species has an imperforate periphery it cannot be placed in this genus.

This taxon was first described and figured by Marianos and Zingula (1966; pl. 39, fig. 4) as

Globotruncana sp. C. Their description notes a beaded double keel on early chambers of the last whorl but lacking on later ones. The vast majority of the tests examined by the writer possess broad, truncate peripheral margins with only slight keel-like thickenings at the edge of the margin. In most forms keel-like structures are absent (Plate 3, fig. 4) or they are developed as rims on the leading edge of spiral chambers (Plate 3, fig. 3). Rarely, when the margin is thickened on the umbilical edge of the margin, tests are found with the indication of two keels. However, it should be pointed out that even in specimens where "keels" are present, they are not comparable in development or extent to the keeled margins of species of *Globotruncana, e.g. G. pseudolinneiana* (Pessagno).

Occurrences.—Figured specimen (CWRU 031) is from outcrops of gray clay shale exposed on Old Benicia Road (loc. B3) Benicia, Solano Co.; specimen CWRU 032 was collected from the lower Sites Formation, Funks Creek, Colusa Co. Unfigured specimens in the writer's collection are from Marsh Creek Formation, Marsh Creek, Contra Costa Co., Yolo and Sites Formations, Colusa and Yolo Counties and the Matunaska Formation, Matunaska Valley, Alaska.

Despite its widespread distribution, the species is presently known only from a narrow stratigraphic interval dated by other microfossils and ammonites as Upper Turonian and Lower Coniacian.

Globotruncana sp.

Plate 5, figure 2

Globotruncana augusticarinata Gandolfi. Takayanagi, 1965, Tohoku Univ. Sci. Rept. 2nd Ser. (Geol.), vol. 36, no. 2, p. 208, pl. 22, figs. 4a-c, 5 (non Gandolfi).

Globotruncana mariei Banner and Blow. Douglas and Sliter, 1966, Tulane Stud. Geol., vol. 4, p. 112, pl. 3, fig. 8 (NOT pl. 2, fig. 8).

Description.—Test free, low trochospiral biconvex, axial periphery initially acute, later angular truncate, with two keels, carinal band sloping toward umbilicus on early chambers of final whorl. Chambers increase gradually in size, 6 to 7 in final whorl, subpetaloid to crescentic on spiral side, subrectangular on umbilical side. Sutures curved, raised, beaded on spiral side, raised, curved on umbilical side. Wall calcareous, perforate, surface smooth. Umbilicus narrow and deep. Primary aperture interiomarginal, umbilical. Specimens examined lack tegilla or apertural modifications.

Greatest diameter of figured specimen 0.39 mm., thickness 0.18 mm.

Remarks.—This species is separated from *G. goudkoffi* Martin by the crescentic chamber of the spiral side and the wide carinal band on the last chambers of the final whorl.

Most of the examined specimens possess thickened ridges on the umbilical side running from the outer chamber margins along the sutural line between the keels. They may be extensions of the beaded sutures or remnants of large flanges or coalesced pustules. At present material is limited to two localities in northern California and is insufficient for an adequate evaluation of its morphologic variation. Designation as a new taxon will be made pending the discovery of additional specimens.

Occurrence.—Figured specimen from Salt Creek, Rumsey Hills (loc. 197), Colusa Co. The species appears restricted to the lower part of the Forbes Formation in Colusa and Yolo Counties.

Globotruncana stuartiformis putahensis Takayanagi

Plate 5, figure 1

Globotruncana putahensis Takayanagi, 1965, Tohoku Univ., Sci. Rept., 2nd Ser. (Geol.), vol. 36, no. 2, p. 221, pl. 27, fig. 2.

Globotruncana concavata (Brotzen). Takayanagi, 1965, *ibid.*, p. 211, pl. 23, fig. 3 (non Brotzen).

Remarks.—*Globotruncana putahensis* was described as a new species from the Forbes Formation of the Sacramento Valley. Takayanagi separated the species from the "elevata stuartiformis" lineage, which he stated it closely resembles because it possesses two keels. However, examination of the holotype specimen (Stanford Univ. Paleo. Coll. no. 9799) fails to reveal the presence of a second keel. For this reason and because axial thin section of specimens from Upper Campanian deposits in several parts of California fail to substantiate the presence of a second keel, Douglas and Sliter (1966) and Sliter (1968) concluded that *G. putahensis* was a junior synonym of *G. stuartiformis.* Further examination of the planktonic foraminiferal faunas from the Forbes Formation has documented the presence of a species which matches the original diagnosis of *G. putahensis, i.e.,* a taxon which closely resembles *G. stuartiformis,* has narrow, crescentic chambers and possesses two closely spaced keels; a well-developed spiral keel and a weak or incipient umbilical keel. To this taxon, for example, belongs the spirally crushed specimen incorrectly assigned to *G. concavata* by Takayanagi (1965). The species first appears near the base of the Forbes Formation and can be traced vertically upwards several thousand feet stratigraphically (locally to the top of the Cretaceous). Within this interval the species undergoes a morphologic change, and the incipient second keel becomes weaker, is reduced to a row of pustules along the umbilical edge of the carinal band, and then finally disappears completely. This evolutionary transition from the two-keeled *"putahensis"* type to the characteristic single-keeled *"stuartiformis"* form occurs in a narrow stratigraphic interval that, based upon associated megafossils, is confined to the Lower Campanian. The type specimen of *G. putahensis* comes from near the top of the Forbes Formation in strata of middle Upper Campanian age and represents the last phase of the transition when only a thin row of pustules is evidence of the second keel. Many specimens from this horizon even lack the pustules. The taxon described by Takayanagi represents the earlier phase in the evolutionary development of *Globotruncana stuartiformis*, however, a phase that may easily be recognized morphologically; it appears also to have potential stratigraphic significance. This form is of sufficient importance to warrant recognition, but the slight difference in keel structure between *G. putahensis* and *G. stuartiformis* does not warrant separate specific status. Instead, the writer suggests that the lower Campanian evolutionary phase of the two species, with two discernible keels, be designated a geographic subspecies of *G. stuartiformis,* as it is known only from the north Pacific region.

Occurrence.—The figured specimen of *G. stuartiformis putahensis* (CWRU 050) is from the lower portion of the Forbes Formation in its type area, Rumsey Hills, Colusa County, California. The stratigraphic range of the subspecies in California is Lower to Middle Campanian.

Some species requiring taxonomic revision

Whiteinella kingi (Trujillo)

Rugoglobigerina kingi TRUJILLO, 1960, Jour. Paleon., vol. 34, no. 2, p. 339, pl. 49, fig. 5.

Remarks.—The species is placed in the genus *Whiteinella,* following the generic revisions of Pessagno (1967).

The general similarity and wide range of intraspecific variation exhibited by many species of Late Cenomanian and Turonian *Hedbergella* has made difficult their subdivision into meaningful taxonomic units. Several species exist in the literature which have nearly identical geologic ranges and morphology. One group is composed of *Hedbergella kingi* (Trujillo) and *Praeglobotruncana gigantea* Lehmann (= *Hedbergella gigantea*). The descriptions and illustration of these two forms are quite similar, and North African hedbergellid assemblages in the writer's collection do contain a species essentially identical to *H. kingi.* Without comparative type specimens of *Praeglobotruncana gigantea,* it is hazardous to conclude that the two forms are synonymous, but the circumstantial evidence is strong that they are. A group which overlaps *H. kingi - P. gigantea* morphologically and stratigraphically is composed of *Globigerina paradubia* Sigal, *Hedbergella brittonensis* Loeblich and Tappan, *H. quadrata* Marianos and Zingula, and *Globigerina portsdownensis* Mitchell-Williams. The last three species form a single intergrading population of medium to low spired forms with five to six chambers in the final whorl, and a small, deep umbilicus. *Hedbergella paradubia* is probably conspecific, although greater detail on its umbilical features is desired for a more definite judgment. The major morphological difference between the species typified by *H. portsdownensis* and *H. kingi* is in the development of an umbilicus and apertural flaps. The California species has a large, wide umbilical cavity (see e.g., Marianos and Zingula, 1966, pl. 38, figs. 6, 7, 8 for comparison) and apertural portici which are lacking in the other species group. These two features are the basis of a broad morphologic dichotomy in late Cenomanian-Coniacian hedbergellid populations (Pessagno, 1967).

Praeglobotruncana helvetica (Bolli)

Rugoglobigerina praehelvetica TRUJILLO, 1960, Jour. Paleont., vol. 34, no. 2, p. 340, pl. 49, fig. 6.

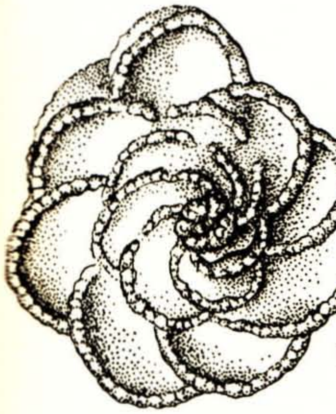
Remarks.—Trujillo described this taxon from shallow-water Turonian shales on the east side of the Sacramento Valley, near Redding. In recent years it has been identified in other parts of California (Marianos and Zingula, 1966) and outside North America (*e.g.,* Samuel, 1962). The diagnostic features which led Trujillo to erect a separate species were the flattened spiral side and rapidly expanding chambers. These are also important features of *Praeglobotruncana helvetica* (Bolli), to

---

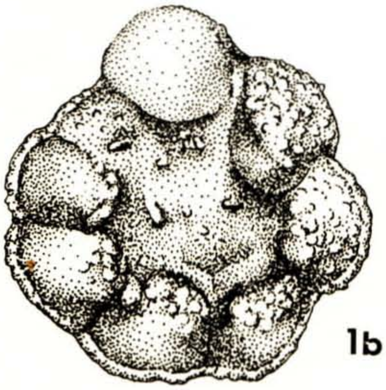
EXPLANATION OF PLATE 3

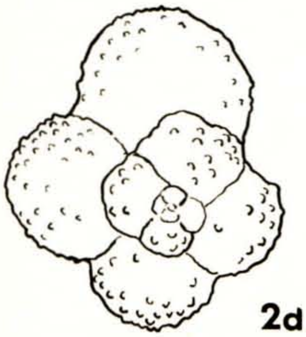
a = spiral view; b = umbilical view; c = side view

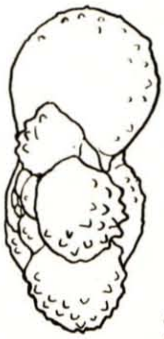
FIGS.		PAGE
1.	*Globotruncana marianosi* Douglas ×46, topotype, unnamed Turonian deposit, San Miguel Island, Santa Barbara County, (CWRU T133).	20
2.	*Whiteinella archaeocretacea* (Pessagno) ×98, typical adult specimen, Sites Formation, Funks Creek, Colusa County (CWRU 045).	25
3, 4.	*Praeglobotruncana loeblichae* Douglas 3, ×89, paratype, morphovariant with blunt margin and well developed rim on spiral chambers, unnamed unit, near Benicia, Solano County (CWRU 031). 4, ×89, paratype, morphovariant with more spinose surface, rounder margin and poorly developed rims on spiral chambers, Sites Formation, Funks Creek, Colusa County (CWRU 032).	20

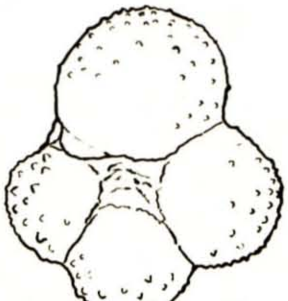

1a

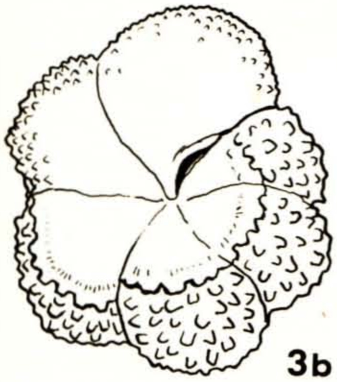

1c


1b


2d

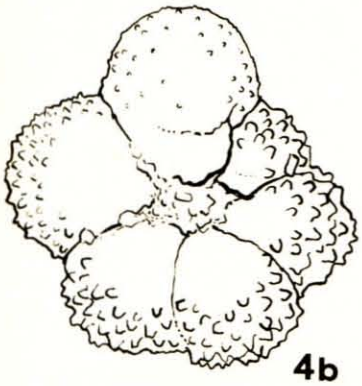

2c

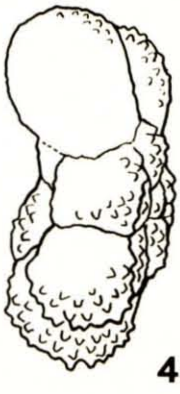

2b

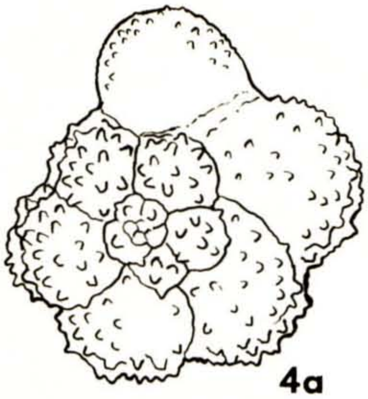

3b


3c

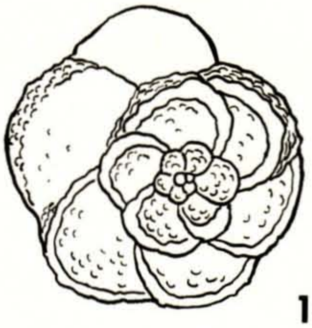

3a


4b

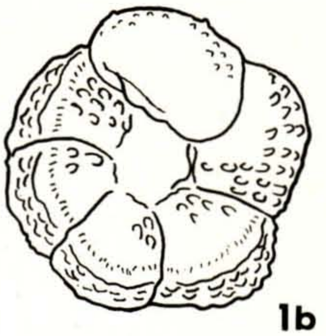

4c

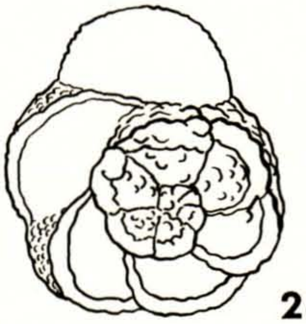

4a

Douglas: California Cretaceous Planktonts

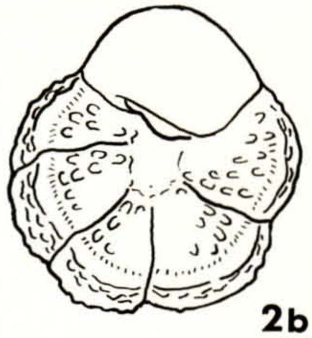

1a

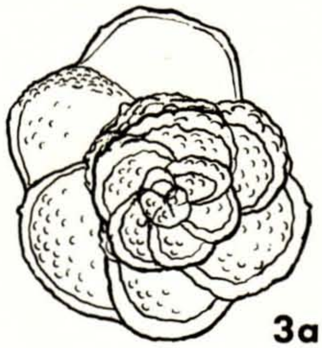

1c

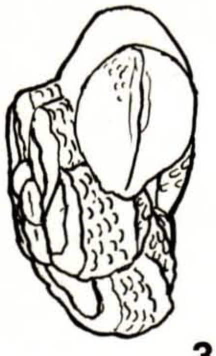

1b

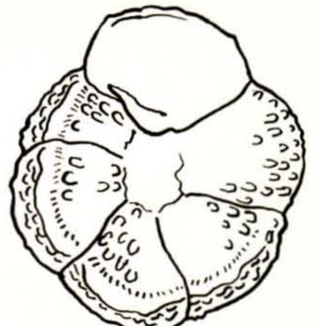

2a

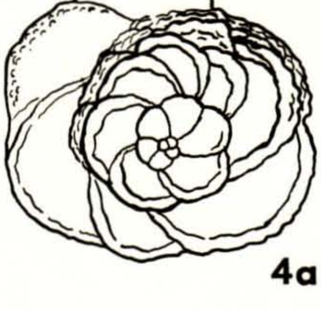

2c


2b

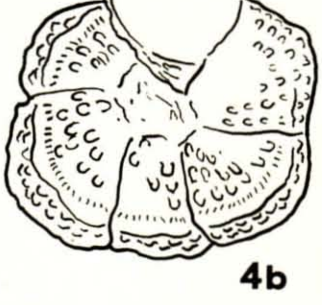

3a


3c


3b


4a


4c


4b

Douglas: California Cretaceous Planktonts

which Trujillo likened his taxon, but the two species were stated to be distinguishable by the lack of a "typical keel" in *R. praehelvetica* and by the fact that "each individual whorl is rounded in section as opposed to the flattened nature of those of *G. helvetica* (= *P. helvetica*) as shown by the cross section of the original types" (Trujillo, 1960). Further examination of *H. praehelvetica* from northern California indicates that the two species broadly overlap morphologically. The cross-sectional profile of early whorls of *P. helvetica* is rounded and the test becomes flattened and hemispherical concomitant with keel development on the last-formed chambers. As demonstrated by axial sections, *Rugoglobigerina praehelvetica* develops the same profile sequence, with the exception that the last-formed chambers, with their hemispherical shape, lack the projecting keel. The profile sequence is not a diagnostic criterion, however, so this leaves the development of a keel as the principal distinguishing character between the two forms. The keel structure in *P. helvetica,* when best developed, is a narrow rim of poreless shell material deposited along the spiral margin of the test and projecting slightly above the surface of the whorl. It is most apparent in larger adult individuals. Smaller tests with essentially globular chambers have porous margins, but as the chambers become hemispherical and the consequent right-angle bend is formed in the shell, the pores first become widely separated at the bend (spiral edge) and, then, the margin becomes imperforate and a keel is formed. However, keels are not always the end product of this development, and a proportion of the population is left with semi-porous, non-carinate spiral margins, this the *R. praehelvetica* form. A very similar set of observations on keel growth in *P. helvetica* has been made by Pessagno (1967, pl. 99, fig. 4; pl. 100, fig. 4). Pessagno suggested that *R. praehelvetica* represented a transitional form linking *P. helvetica* and *Whiteinella archaeocretacea* Pessagno. The present writer believes, however, after examination of populations of the two forms in California, that *P. helvetica* and *R. praehelvetica* are morphologic end members of one specific type. This conclusion is suggested by: (1) the actual association of the two types in nature; (2) their identical morphology, except for degree of keel development, and (3) their identical geologic range. It is possible that they are homeomorphic species, but this cannot be determined from the fossil record. The geographic distribution of the two forms, though incomplete, suggests different ecologic preferences. The keeled form is more numerous in shallow-water, near-shore deposits in southern California and the eastern Sacramento Valley, while *R. praehelvetica* dominates the deeper-water facies of the western Sacramento Valley and is the sole representative in Turonian deposits of Alaska. The intimate spatial association of the two forms, which argues against subspecies, points to the forms as dimorphic phases of one species, or, accounting for their apparent environmental preference, perhaps ecophenotypic variants. Following this interpretation, the two "species," which are currently placed in separate genera, should be united under a single name. In this case, *Praeglobotruncana helvetica* (Bolli) has priority.

Praeglobotruncana roddai (Marianos and Zingula)

Globotruncana roddai MARIANOS and ZINGULA, 1966, Jour. Paleont., vol. 40, no. 2, p. 340, pl. 39 fig. 5.

Globotruncana kuepperi Thalmann. MARIANOS and ZINGULA, 1966, Jour. Paleont., vol. 40, no. 2, p. 340, pl. 39, fig. 6.

Praeglobotruncana algeriana CARON, 1966, Rev. Micropaléont., vol. 9, no. 2, p. 74, pl. 2, fig. 5.

Remarks.—*Praeglobotruncana roddai* (Marianos and Zingula) was described for a Lower Turonian species exhibiting two closely spaced keels which become weaker and more closely spaced on the last chamber. Samples containing the species also contain forms which differ only in having the keels merge into a broad single keel on the last one or two chambers. This form was identified as *Globotruncana kuepperi* Thalmann (Marianos and Zingula, 1966). The two-keel types, rather than different species, are end members of an intergrading morphologic series. Also, the holotype of *G. kuepperi* Thalmann, based upon *G. renzi* subsp. *primitiva* Küpper (1956), is conspecific with *P. stephani* (Gandolfi) (see Loeblich and Tappan, 1961) and different from the species identified by Marianos and Zingula.

Several Lower Turonian species have been described in recent years which appear closely related to or synonymous with *P. roddai.* These include *P. algeriana* Caron, *P. turonica* (Samuel and Salaj), *P. biconvexa* (Samuel and Salaj), *Globotruncana*

EXPLANATION OF PLATE 4

a = spiral view; b = umbilical view; c = side view

FIGS.		PAGE
1-4.	*Globotruncana cachensis* Douglas .... All specimens ×98, Yolo Formation, Salt Canyon, Colusa County (CWRU 046, 047, 048, 049, respectively). Morphologic series illustrating continuous variation in height of spire and accompanying chamber modification.	25

difformis Gandolfi, and, possibly, *Marginotruncana bouldinensis* Pessagno. Unfortunately, type specimens of the Czech species (*P. turonica* and *P. biconvexa*) were not available to the writer; reassignment based solely on the literature is unwise. However, specimens of *P. algeriana* Caron from the type area and numerous examples of *M. bouldenensis* and *G. difformis* from the Gulf Coast Cretaceous have been examined. Based upon these comparisons, *P. algeriana* and *P. roddai* are judged to be the same. Both have about the same number of chambers per whorl, two closely spaced keels, distinct radial, depressed umbilical suture and the same geologic range. The American species (*G. difformis* and *M. bouldenensis*) are distinct from each other and both can be distinguished from *P. roddai* by the number of chambers per whorl and the degree of spiroconvexity of the test. All three have, however, evolved along similar morphological lines and have certain basic features in common. Foremost of these features are the closely spaced double keels which sometimes merge to form one keel on the last one or two chambers, the radially depressed umbilical sutures, and simple apertural flaps. These common characters suggest that the species, and probably *P. biconvexa* and *P. turonica* which also possess them, are part of an evolving plexus that originated from a *P. stephani*-like ancestor in the late Cenomanian.

Praeglobotruncana stephani (Gandolfi)

Globotruncana (*Praeglobotruncana*) *renzi* subsp. *primitiva* KÜPPER, 1956, Cushman Found. Foram. Res., Contr., vol. 7, pl. 2, p. 43, pl. 8, fig. 1.

Globotruncana kuepperi THALMANN, 1959, Cushman Found. Foram. Res., Contr., vol. 10, p. 130.

Remarks.—After examining the holotype of *G.* (*Praeglobotruncana*) *renzi* subsp. *primitiva* Küpper, the writer is in agreement with Loeblich and Tappan (1961) that it is a crushed specimen of *P. stephani* (Gandolfi). Thus the nominal species, *Globotruncana kuepperi* Thalmann, erected to replace the homonymic combination *G. primitiva,* becomes a junior synonym and is invalid. The species described as *G. kuepperi* by Marianos and Zingula should be referred to *Praeglobotruncana roddai* Marianos and Zingula (see discussion under *P. roddai.*

Rotalipora greenhornensis (Morrow)

Rotalipora tehamaensis MARIANOS and ZINGULA, 1966, Jour. Paleont., vol. 40, p. 339, pl. 38, fig. 4.

Remarks.—Marianos and Zingula erected *R. tehamaensis* for a nearly circular, biconvex rotaliporid with 6 to 8 chambers in the final whorl, and radial umbilical sutures, depressed near the outer edge of the test but becoming raised and thickened near the umbilicus. The species is widespread in Cenomanian deposits in California. Earlier, Loeblich and Tappan (1961) had assigned this species to *R. greenhornensis* (Morrow), but Marianos and Zingula disagreed with this because "none of the specimens figured by Loeblich and Tappan as *R. greenhornensis* agrees with the holotype of that species . . ." (p. 339). It is true that the California species differs slightly from the holotype. However, comparison of the California species with large suites of topotypes of *R. greenhornensis* indicates that it falls well within the range of variation of the topotypic population. The umbilical sutures of *greenhornensis* vary from slightly curved or nearly straight, radial depressions to being flush with the surface, particularly between the early chambers of the last whorl. This writer agrees with the earlier statements of Loeblich and Tappan that the California species is conspecific with *R. greenhornensis* (Morrow).

Globotruncana goudkoffi Martin

Globotruncana goudkoffi MARTIN, 1964, Jb. Geol. Bundesanst., Sonderbd. 9, p. 80, pl. 10, fig. 1. DOUGLAS, 1969, Micropaleontology, vol. 15, no. 2, p. 179, pl. 8, fig. 3.

Globotruncana stephensoni PESSAGNO, 1967, Palaeont. Amer., vol. 5, no. 37, p. 354, pl. 69, fig. 1-7; pl. 96, fig. 5, 6.

Globotruncana mariei Banner and Blow. SLITER, 1968, Kan. Paleont. Contr., vol. 49, art. 7, p. 105, pl. 17, fig. 7-8.

Remarks.—In a recent monograph on the planktonic foraminifera from the Gulf Coast Upper Cretaceous, Pessagno (1967) described the species *Globotruncana stephensoni.* It is a somewhat compressed biconvex form with a sharply angled periphery containing two narrowly spaced keels. The keels tend to form a single keel on the last chamber. Pessagno stated that it resembled higher spired forms of *G. stuarti* (d'Lapparent) and externally was similar to *G. conica* White. These are also the basic characteristics of *G. goudkoffi* Martin, described from the Moreno Gulch area, western San Joaquin Valley. Comparison of the type specimens of the two species fails to reveal any significant difference between them. For this reason, *G. stephensoni* is here considered a junior synonym of *G. goudkoffi.*

Some confusion exists concerning the species *Globotruncana mariei* Banner and Blow and *G. goudkoffi* Martin. The former name was proposed as a replacement for *G. cretacea* Cushman when it was established that *Globigerina cretacea* d'Orbigny was a *Globotruncana.* Later restudy of the type of *G. cretacea* Cushman reveals (Pessagno, 1967), that it is a small immature form of *G. rosetta*

(Carsey). Therefore *G. mariei* is synonymous with the older name *G. rosetta*. Specimens identified as *G. mariei* by Douglas and Sliter (1966) and Sliter (1967) should be assigned to *G. goudkoffi* Martin.

Endemic species

The following species are so far known only from the west coast of North America or the North Pacific region:

- *Hedbergella murphyi* Marianos and Zingula (Turonian)
- *Praeglobotruncana loeblichae* Douglas (Turonian-Lower Coniacian)
- *Globotruncana cachensis* Douglas (Turonian to Lower Santonian)
- *G. churchi Martin* (Campanian to Lower Maastrichtian)
- *G. marianosi* Douglas (Upper Turonian)
- *G.* sp. (Lower Campanian)
- *G. stuartiformis putahensis* Takayanagi (Campanian)
- *Heterohelix* sp. (Lower Campanian)
- *Planoglobulina ornatissima* (Cushman and Church) (Upper Campanian-Lower Maastrichtian)
- *Bifarina douglasi* Sliter (Upper Campanian to Lower Maastrichtian)

The more recently described species will require further verification of their apparent endemic distribution, as they may elsewhere be differently identified or as yet unrecognized. However, *Planoglobulina ornatissima* has been known for 40 years and the species is not known outside the North Pacific. Douglas (1969) noted that specimens identified as *P. ornatissima* from Cuba (Brönnimann and Rigassi, 1963) and Czechoslovakia (Samuel and Salaj, 1967) should be assigned to *Gublerina cuvillieri* Kikione.

One interesting aspect of the endemics is that they are not randomly distributed in time but are concentrated at two distinct stratigraphic horizons, the Upper Turonian to Coniacian and the Upper Campanian. These seem to be times of provincialism in California planktonic foraminiferal faunas as compared to the distribution patterns of other North American assemblages (Douglas and Sliter, 1966). The fact that the Campanian species *P. ornatissima* and *G. churchi* occur in Japan, Alaska, and California suggests they have a Pacific distribution which is the equivalent of the European Boreal.

Species previously unreported in California

Whiteinella archaeocretacea Pessagno

Plate 3, figure 2; Plate 5, figures 4, 5

Whiteinella archaeocretacea PESSAGNO, 1967, p. 298, pl. 51, figs. 2-4; pl. 54, figs. 19-21, 22-24; pl. 100, fig. 8.

Remarks.—The genus *Whiteinella*, with *W. archaeocretacea* Pessagno as type species, was recently described from the Gulf Coast Cretaceous. The basis for separating this taxon from *Hedbergella* is the more umbilical position of the primary aperture and large apertural flaps. Members of this genus are most easily recognized by the wide, open umbilical cavity and the apertural portici which project into it.

The California species possesses two features which are not mentioned in the original species diagnosis. In some adults there is a tendency for the last chamber to become greatly inflated and extend into the umbilical region (Plate 5, fig. 4). The position and shape of the aperture is usually distorted when this occurs. Normal chamber development is illustrated in Plate 3, fig. 2.

There is noticeable difference in size between California specimens studied and those described from the Gulf Coast. Individuals from the Eagle Ford and Chispa Summit Formations, Texas, as reported by Pessagno, range up to 0.60 mm. in maximum diameter, while the largest individual from the Sacramento Valley is about one half this size. The reason for this difference, apparently indicative of different growth or development, is unknown.

Occurrence.—The stratigraphic range of the species in Texas is Eaglefordian to Lower Austanian (approximately basal Turonian to Lower Santonian). It occurs rarely in the upper part of the "Fiske Creek" Formation in western Sacramento Valley, horizons identified as latest Cenomanian or earliest Turonian in age, but frequent occurrences are restricted to the upper part of the Yolo and portions of the Sites Formations. These strata are uppermost Turonian and Coniacian in age and fall within the *Globotruncana cachensis* Zone (Douglas, in press). At present the species has not been identified in Santonian deposits (*G. coronata* Zone) in Northern California.

BIBLIOGRAPHY

BANDY, O. L., 1951, Upper Cretaceous foraminifera from the Carlsbad area, San Diego County, California: Jour. Paleont., vol. 25, no. 4, pp. 488-513, pls. 72-75.

BRÖNNIMANN, P., and RIGASSI, D., 1963, Contributions to the Geology and Paleontology of the area of the City of La Habana, Cuba, and its surroundings: Ecolgae Geol. Helv., vol. 56, no. 1, pp. 193-480, pls. 1-26.

BUTT, A. A., 1966, Foraminifera of the type Turonian: Micropaleontology, vol. 12, no. 2, pp. 168-182, pls. 1-4.

CARON, MICHELE, 1966, Globotruncanidae du Crétacé supérieur du synclinal de la Gruyère (Prealpes médianes-Suisse): Rev. Micropaléont., vol. 9, no. 2, pp. 68-93, pls. 1-6, figs. 1-2.

CUSHMAN, J. A., and CHURCH, C. C., 1929, Some Upper Cretaceous Foraminifera from near Coalinga, California: Proc. Calif. Acad. Sci., vol. 4, pt. 18, pp. 497-540, pls. 36-41.

DOUGLAS, R. G., 1966, Upper Cretaceous planktonic foraminiferal biostratigraphy of the western Sacramento Valley, California: Univ. Calif., Los Angeles, Ph.D. dissertation.

———, 1969a, Upper Cretaceous Biostratigraphy in Northern California: Archives des Sciences (Genève). Spec. Publ., vol. 2, pp. 126-152.

———, 1969b, Upper Cretaceous planktonic foraminifera in Northern California; Part I - Systematic Descriptions: Micropaleontology. vol. 15, pp. 151-209, pls. 1-11.

———, in press, Upper Cretaceous planktonic foraminifera in Northern California; Part II - Stratigraphic Distributions. Micropaleontology.

———, and SLITER, W. V., 1966, Regional Distribution of some Cretaceous Rotaliporidae and Globotruncanidae (Foraminiferida) within North America: Tulane Stud. Geol., vol. 4, no. 3, pp. 89-131, pls. 1-5.

GRAHAM, J. J., 1961, An annotated bibliography of California Cretaceous microfossils, including a brief history of the literature: Calif. Div. Min., Spec. Rept. 66, pp. 1-43, 2 illus.

———, 1962, A review of the planktonic foraminifera from the Upper Cretaceous of California: Cushman Found. Foram. Res., Contr., vol. 13, pt. 3, pp. 100-109, pls. 19, 20, 1 table.

———, and CLARK, D. K., 1961, New Evidence for the age of the "G-1 Zone" in the Upper Cretaceous of California: Cushman Found. Foram. Res., Contr., vol. 12, pp. 112, pl. 5, figs. 9a-c.

HAGN, H., and ZEIL, W., 1954, Globotruncana aus dem Ober-Cenoman und Unter-Turon der Bayerischen Alpen: Eclogae Geol. Helv., vol. 47, no. 1, pp. 1-60, pls. 1-7.

KÜPPER, KLAUS, 1955, Upper Cretaceous Foraminifera from the "Franciscan Series," New Almaden District, California: Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, pp. 112-118, 123, pl. 18.

———, 1956, Upper Cretaceous pelagic Foraminifera from the "Antelope Shale," Glenn and Colusa Counties, California: Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, pp. 40-47, pl. 8, 1 text-fig.

LOEBLICH, A. R., JR., and TAPPAN, H., 1961, Cretaceous planktonic foraminifera: Part I - Cenomanian: Micropaleontology, vol. 7, no. 3, pp. 257-304, pls. 1-8.

———, and ———, 1964, Treatise on Invertebrate Paleontology Part C, Protista 2, Chiefly Thecamoebians and Foraminifera (ed. R. C. Moore), 2 vols., pp. 1-900, figs. 1-653.

MARIANOS, A. W., and ZINGULA, R. P., 1966, Cretaceous planktonic foraminifers from Dry Creek, Tehama County, California: Jour. Paleont., vol. 40, p. 328-342, pls. 37-39, text-figs. 1-3.

MARTIN, L., 1964, Upper Cretaceous and Lower Tertiary Foraminifera from Fresno County, California: Jb. Geol. Bundesanst., Sonderbd. 9, pp. 1-128, pls. 1-16, text-figs. A-D, figs. 1-5.

PESSAGNO, E. A., 1967, Upper Cretaceous planktonic Foraminifera from the western Gulf Coastal Plain: Paleontogr. Americana, vol. 5, no. 37, pp. 245-387, pls. 48-100, text-figs. 1-63, tables 1-2.

SAMUEL, O., 1962, Microbiostratigraphic situation in Cretaceous sediments of Klippes-zone in vicinity of Benatina: Geol. Práce, Zpravy 24, pp. 153-197.

———, and SALAJ, J., 1966, Foraminifera der

EXPLANATION OF PLATE 5

a = spiral view; b = umbilical view; c = side view

FIGS. PAGE

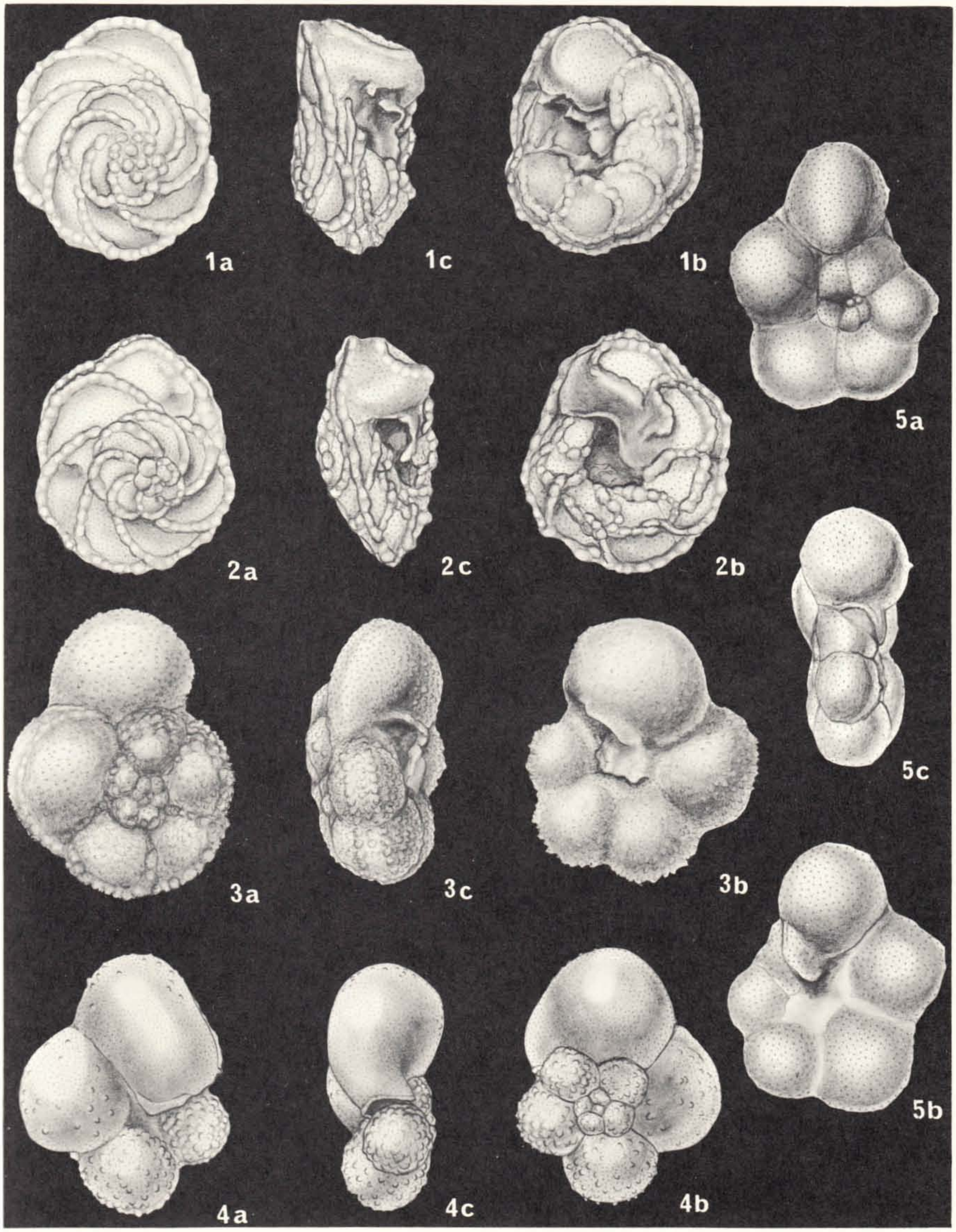
1. *Globotruncana stuartiformis putahensis* Takayanagi 21
×66, Forbes Formation, Rumsey Hills, Colusa County (CWRU 050). Subspecies of *Globotruncana stuartiformis* Dalbiez occurring in the Lower Campanian of California in which an incipient second keel is developed.

2. *Globotruncana* sp. 21
×98, Forbes Formation, Rumsey Hills, Colusa County (CWRU 051).

3. *Globotruncana cachensis* Douglas 25
×98, Yolo Formation, Cache Creek, Colusa County (CWRU 052).

4. *Whiteinella archaeocretacea* (Pessagno) 25
×98, Sites Formation, Funks Creek, Colusa County (CWRU 045). Morphovariant with greatly inflated last chamber.

5. *Whiteinella* cf. *archaeocretacea* (Pessagno) 25
×128, Sites Formation, Funks Creek, Colusa County (CWRU 053).



Douglas: California Cretaceous Planktonts

Westkarpaten-Kreide (Slowakei): Geol. Ustav Dion. Stura, Bratislava, pp. 1-291, pls. 1-48.

SCHEIBNEROVA, VIERA, 1963, Some new foraminifera from the Middle Turonian of the Klippen Belt of the west. Carpathians in Slovakia: Geol. Sbornik., vol. 14, no. 1, pp. 139-143.

SIMPSON, G. G., Principles of Animal Taxonomy: Columbia Univ. Press, New York, 247 pp.

SLITER, W. V., 1968, Upper Cretaceous foraminifera from southern California and northwestern Baja California, Mexico: Univ. Kansas Paleo. Contr., Ser. no. 49, Art. 7, pp. 1-141, figs. 1-9, pls. 1-24, tables 1-15.

TAKAYANAGI, T., 1965, Upper Cretaceous Planktonic Foraminifera from the Putah Creek subsurface section along the Yolo-Solano County line, California: Tohoku Univ., Sci. Rept., 2nd Ser. (Geol.), vol. 36, no. 2, pp. 161-237, pls. 20-29, text-figs. 1-9.

THALMANN, H., 1959, New names for foraminiferal homonyms IV: Cushman Found. Foram. Res., Contr., vol. 10, pt. 4, pp. 130-131.

TRUJILLO, E. F., 1960, Upper Cretaceous Foraminifera from near Redding, Shasta Co., California: Jour. Paleont., vol. 34, pp. 290-346, pls. 43-50, text-figs. 1-3.

VASSILENKO, V. P., 1961, Foraminifery Verkhnego mela poluostrova Mangyshlaka (Opisanie, Skhemy filogenii nekotorykh grupp istratigrafischeskii analiz) Trudy Vses. Neft. Nauch-Issled. Geol.-Razved. Inst. (VNIGRI) no. 171, pp. 1-487, 20 figs., 14 b., pls. 1-41.

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 1, JANUARY, 1970

381. UPPER EOCENE PLANKTONIC FORAMINIFERA FROM THE KOPILI FORMATION, MIKIR HILLS, ASSAM, INDIA

BIMAL K. SAMANTA
Department of Geology, University College of Wales, Aberystwyth, U.K.

ABSTRACT

Twenty-five species and subspecies of planktonic foraminifera, occurring in association with abundant larger foraminifera, have been identified from the Upper Eocene of Mikir Hills, Assam, India. The stratigraphical distribution of these planktonic foraminifera in the sequence permits recognition of the three zones reported earlier by Blow and Banner from the Upper Eocene of Tanganyika, East Africa. This is the first record of a complete sequence of the Upper Eocene planktonic foraminiferal zones from Eastern India.

INTRODUCTION

The presence of a well developed marine Upper Eocene outcrop along the southern foothills of the Garo, Khasi-Jaintia and Mikir Hills in Assam and its importance in the biostratigraphic investigation of the Upper Eocene of the Indian region have been pointed out by the writer (Samanta, 1968). These Upper Eocene sediments are highly fossiliferous and contain abundant foraminifera and mollusks. They are conformable upon equally fossiliferous Middle Eocene rocks.

A systematic investigation of the marine Eocene sequence developed in the Garo Hills has earlier been carried out by the writer. At first, attention was given to the larger foraminifera which constitute the dominant element in the fauna. Later an attempt was made to record the planktonic foraminifera to aid in the classification and long range correlation of these sediments. However, in the Garo Hills only a small number of samples bearing planktonic foraminifera was available and in the Upper Eocene part of the sequence only one planktonic foraminiferal assemblage (equivalent to that of the *Globorotalia cerro-azulensis* zone of Bolli) was recorded (Samanta, 1969).

To gather more information on the Eocene biostratigraphy of this region the investigation was extended to the Mikir Hills, where the Eocene succession was found to be similar to that developed in the Garo Hills. In the Mikir Hills the Eocene rocks lie directly on the Pre-Cambrian complex and are made up of the Mikir formation, the Garampani Limestone and the Kopili formation in ascending order. The sequence is apparently conformable. The Mikir formation is dominantly arenaceous and consists of sandstone, siltstone, shale and coal. This formation is devoid of foraminifera. The Garampani Limestone is dominantly calcareous and is made up chiefly of fossiliferous limestone with some marls and shales. It is richly fossiliferous and contains abundant foraminifera. On the basis of the foraminifera, a Middle Eocene age is assigned to the Garampani Limestone. The overlying Kopili formation is made up of fossiliferous argillaceous limestone, shale and sandstone. The limestones and shales contain abundant foraminifera which indicate an Upper Eocene age for the formation.

Material for the present study was derived from a borehole passing through the Kopili formation and the Garampani Limestone. The borehole is located east of the Shillong-Haflong road, at a distance of about 5 Km. from Garampani village (92°38′E., 25°30′N.). An examination of these core samples has revealed the presence of Upper Eocene planktonic foraminifera in association with larger foraminifera in the Kopili formation. In the present paper a systematic account of these planktonic foraminifera is provided and the recognition in the present sequence of the three zones reported by Blow and Banner (1962) from the Upper Eocene of Tanganyika, East Africa, is discussed.

ACKNOWLEDGEMENTS

The writer is indebted to the Chief Engineer, State Electricity Board, Assam, for the material on which this study is based, to Professor Alan Wood for providing facilities in the Department, and to Dr. J. R. Haynes for valuable discussions and critical perusal of the manuscript. Sincere thanks are due to Messrs. S. Ganguli and A. Basu for their help in the field, to Dr. C. G. Adams for access to collections in the Protozoa Section, British Museum (Natural History), and to Professor H. M. Bolli for helpful discussions and for allowing the writer to examine the material in his collections. The illustrations are camera lucida drawings by the writer.

PLANKTONIC FORAMINIFERA

In the present study, nine core samples of the Kopili formation were examined for smaller foraminifera, but only seven were found to contain planktonic foraminifera. They occur associated with abundant larger foraminifera. The preservation of the material is not good. Delicate features of the test, such as the spines of the hantkeninids and the bullae of the globigerinids, are usually not completely preserved. Often the apertural region is covered with matrix which obscures the details of the aperture. However, the taxonomically significant morphological features are in most cases suffi-

TABLE 1

Stratigraphic distribution of the planktonic foraminifera in the Upper Eocene Kopili formation, Mikir Hills, Assam, India

Zones	Globigerapsis semi-involuta				Cribrohantkenina inflata	Globigerina gortanii	
Species Sample Nos.			46	45	44	43	42
**Chiloguembelina tenuis* (Todd)	×					×	
C. sp.						×	
Globigerapsis tropicalis Blow and Banner				×			
Globigerina ampliapertura Bolli						×	×
**G. angustiumbilicata* Bolli				×	×	×	
G. corpulenta Subbotina	×	×		×	×	×	×
**G. eocaena* Gümbel		×		×	×	×	×
G. gortanii (Borsetti)	×	×		×	×	×	×
**G. linaperta* Finlay		×		×			
**G. officinalis* Subbotina			×	×	×	×	
**G. praebulloides occlusa* Blow and Banner		×		×			×
G. senilis Bandy				×		×	
**G. tripartita tripartita* Koch						×	×
**G. yeguaensis* Weinzierl and Applin	×		×	×	×	×	×
Globigerinatheka sp. cf. *G. barri* Brönnimann				×			
Globigerinita dissimilis (Cushman and Bermúdez)				×			
**G. unicava* (Bolli, Loeblich and Tappan)		×	×	×	×		×
**Globorotalia centralis* Cushman and Bermúdez	×		×	×	×		
**G. cerro-azulensis* (Cole)	×	×	×	×	×		
**G. gemma* Jenkins						×	×
G. increbescens (Bandy)						×	
**G. opima nana* Bolli	×	×		×	×	×	×
G. permicra Blow and Banner						×	
**Hantkenina alabamensis* Cushman				×	×		
**Pseudohastigerina micra* (Cole)	×			×	×	×	

ciently well-preserved to permit satisfactory identification of the forms present in the material.

Twenty-five species and subspecies of planktonic foraminifera, belonging to eight genera, are recorded here from the Kopili formation (Table 1). In both number of individuals and of species *Globigerina* is the most abundant genus in the fauna. The eleven species and subspecies of *Globigerina* recorded here represent all the common groups of forms of the genus known to occur in the Upper Eocene of tropical-subtropical regions. Of the several groups present here, the one comprising the closely related forms *Globigerina corpulenta* Subbotina, *G. eocaena* Gümbel and *G. gortanii* (Borsetti) is most abundantly represented. Because of their much larger size in comparison to the rest of the planktonic fauna, members of the *G. gortanii* group constitute the most conspicuous element of the planktonic foraminiferal fauna in the Kopili formation. *G. gortanii* is the largest of the planktonic foraminiferal species recorded here. *Globorotalia,* represented by six species, is next in abundance. All the common forms of the genus reported from the Upper Eocene of the tropical-subtropical regions are represented here. *G. cerro-azulensis* (Cole) is the most distinctive form of the genus in the fauna; it attains the largest size among the representatives of *Globorotalia* found here. These two genera—*Globigerina* and *Globorotalia*—constitute about 90% of the planktonic fauna. Of the remaining six genera *Chiloguembelina* and *Globigerinita* are each represented by two species, while *Globigerapsis, Globigerinatheka, Hantkenina* and *Pseudohastigerina* are each represented by one. The representatives of *Globigerinita* and *Pseudohastigerina* occur frequently, but those of the other four genera are rare in the material.

The stratigraphic distribution of the planktonic foraminifera shown in Table 1 permits recognition of the three zones reported by Blow and Banner (1962) from the Upper Eocene of Tanganyika, East Africa. In the lower zone occur nineteen species and subspecies of planktonic foraminifera, belonging to eight genera. The *Globigerina gortanii* group dominates the assemblage. Among the *Globorotalias, G. cerro-azulensis* (Cole) is the most distinctive and abundant form. Four species—*Globigerapsis tropicalis* Blow and Banner, *Globigerina linaperta* Finlay, *Globigerinatheka* cf. *barri* Brönnimann and *Globigerinita dissimilis* (Cushman and

Bermúdez)—do not range above this zone. The assemblage in this zone is characterized by the common occurrence of *Globigerina gortanii* (Borsetti), *Globorotalia cerro-azulensis* (Cole), and *Hantkenina alabamensis* Cushman, in association with representatives of the genera *Globigerapsis* and *Globigerinatheka*. Coarsely ornamented species of *Globorotalia* and representatives of the genus *Truncorotaloides* are typically absent. This is the only horizon in the sequence having species of *Globigerapsis and Globigerinatheka*. Although *Globigerapsis semi-involuta* (Keijzer), the zonal marker, is not present, the joint occurrence of *Globorotalia cerro-azulensis* and *Hantkenina alabamensis* with *Globigerapsis tropicalis* and *Globigerinatheka* cf. *barri* is sufficient for satisfactory correlation of the present assemblage with that of the *Globigerapsis semi-involuta* zone of Bolli.

Twelve species and subspecies, belonging to five genera, occur in the middle zone. All of them range upward from the underlying zone. In the composition of the two common genera *Globigerina* and *Globorotalia* there is no significant difference between the assemblages of the lower and the middle zones. The present assemblage is distinguished from that of the underlying zone by the absence of species referable to the genera *Globigerapsis* and *Globigerinatheka*. *Globorotalia centralis* Cushman and Bermúdez, *G. cerro-azulensis* (Cole), and *Hantkenina alabamensis* Cushman do not range above this zone. The fauna in this zone is much impoverished in comparison to those in the underlying and overlying ones. Here also, as in the lower zone, the zonal marker *Cribrohantkenina inflata* (Howe)—a senior synonym of *Cribrohantkenina danvillensis* (Howe and Wallace)—is not present. However, this characteristic Upper Eocene form has been recorded by the writer (Samanta, 1969) from an equivalent horizon in the Garo Hills. The presence of *Globorotalia cerro-azulensis* and *Hantkenina alabamensis* and the absence of species of *Globigerapsis* and *Globigerinatheka* permit correlation of this zone with the *Cribrohantkenina inflata* zone of Blow and Banner.

Eighteen species and subspecies, belonging to five genera, occur in the upper zone. Twelve of these range upward from the underlying zones while six appear here for the first time. In this horizon significant changes take place in the composition of the genera *Globigerina* and *Globorotalia*. *Globorotalia centralis* and *G. cerro-azulensis,* the two common forms of the genus in the underlying zones, are absent, while *G. gemma* Jenkins, *G. increbescens* (Bandy) and *G. permicra* Blow and Banner appear for the first time. *G. gemma* is the most common form of the genus in this zone. As in the underlying two zones, the *Globigerina gortanii* group dominates the fauna, but the appearance of *Globigerina ampliapertura* Bolli makes the present assemblage distinct from the lower ones. The fauna of this zone is characterized by the presence of *Globigerina ampliapertura, Globorotalia increbescens,* and *G. permicra* and the absence of *Globorotalia centralis, G. cerro-azulensis,* and *Hantkenina alabamensis.* It is essentially the same as that recorded by Blow and Banner in their *Globigerina gortanii* zone. As in Tanganyika, the samples of this zone contain abundant specimens of the Paleocene-Eocene larger foraminiferal genus *Discocyclina.*

Previously, only a fauna of the *Cribrohantkenina inflata* zone had been recorded from the Upper Eocene of the Garo Hills, so the recognition of this sequence of three planktonic foraminiferal zones in the Upper Eocene of Mikir Hills is of considerable significance. This is the first record of the fauna from the *Globigerina gortanii* zone in the Indian region. It proves that the uppermost Eocene was not the period of marine regression in Eastern India it was earlier thought to be by the writer (Samanta, 1968).

SYSTEMATIC PALEONTOLOGY

The classification followed here is based on that proposed by Bolli, Loeblich and Tappan (1957), with modifications and additions from classifications presented by later workers. It has been discussed earlier by the writer (Samanta, 1969).

The synonymy has been restricted to the original description and to references providing important information on the taxonomy and distribution of the forms. The forms marked with an asterisk in table 1 have been recorded from the Upper Eocene of the Garo Hills in an earlier publication wherein detailed discussions and synonymy lists of these forms will be found. Of these, six less significant species, well illustrated by material from the Garo Hills, are not figured here.

Family CHILOGUEMBELINIDAE Reiss, 1963

Genus **Chiloguembelina** Loeblich and Tappan, 1956

Chiloguembelina tenuis (Todd)

Plate 6, figure 18

Gümbelina tenuis TODD, 1957, p. 303, pl. 65, figs. 31a-b.

Chiloguembelina tenuis Todd, SAMANTA, 1969, p. 329, pl. 1, figs. 8a-b.

Remarks.—With their elongate, compressed test, 6 to 7 pairs of chambers between depressed, oblique sutures, and elongate aperture, the present specimens compare closely with the type description and illustration of *C. tenuis.* The aperture in the present specimens is less elongate than that in those reported from the Garo Hills by the writer.

Occurrence.—Previously it has been recorded from the Upper Eocene of Saipan and the Garo

Hills, Assam. It occurs in the *Globigerapsis semiinvoluta* and *Globigerina gortanii* zones in the present area.

Chiloguembelina sp.

Plate 6, figures 13, 14

Description.—Test short, thick, subtriangular; periphery rounded, lobate; chambers biserial, inflated, rapidly increasing in size in the later part of the test; sutures oblique, depressed; wall smooth; aperture large, semicircular with faint lip.

Remarks.—Although the present form with short, triangular test, inflated, rapidly increasing chambers in the later part of the test and large, semi-circular aperture is distinct from the described Upper Eocene representatives of the genus, it is not described as new, because only two specimens were found. It bears some resemblance to *Chiloguembelina wilcoxensis* (Cushman and Ponton), which is restricted to the Paleocene-Lower Eocene.

Occurrence.—It is restricted to the *Globigerina gortanii* zone.

Family GLOBIGERINIDAE Carpenter, Parker and Jones, 1862

Genus **Globigerina** d'Orbigny, 1826

Globigerina ampliapertura Bolli

Plate 6, figures 9, 10; Plate 7, figures 1, 2

Globigerina ampliapertura BOLLI, 1957a, p. 108, pl. 22, figs. 4a-7b; BERMÚDEZ, 1961, p. 1.155, pl. 3, figs. 8a-c; WADE, 1964, pl. 1, figs. 13-14, 18, ?15, 17; REISS and GVIRTZMANN, 1966, pl. 88, figs. 6a-8c; TODD, 1966, p. I 33, pl. 8, fig. 7.

Globigerina ampliapertura ampliapertura Bolli, BLOW and BANNER, 1962, pp. 83-84, pl. 11, figs. A-D, pl. 17, fig. C, text-fig. 12b.

Remarks.—It is a form well represented in this material. Three specimens are figured here to show its range of variation in the assemblage. They are regarded to be well within the range of variation of *G. ampliapertura* described and illustrated by Bolli (1957a).

While describing *G. ampliapertura,* Bolli (1957a, p. 108) compared it with *Globigerina venezuelana* Hedberg and *G. apertura* Cushman and distinguished his new species mainly on the character of the aperture. Later, in the course of reporting *G. ampliapertura* from the Upper Eocene San Fernando formation, Bolli (1957b, p. 164) remarked: "*Globigerina ampliapertura,* which appears in the uppermost Eocene and continues into the basal Oligocene, seems to be genetically related to *Globorotalia centralis* Cushman and Bermúdez... The species might represent a gerontic stage of the *G. centralis-G. cocoaensis* strain, reverting before its extinction to a globigerinid form and also to random coiling." He (op. cit., p. 169) continued this discussion under remarks on *Globorotalia centralis* Cushman and Bermúdez from Trinidad and added: "... specimens transitional between *G. centralis* and *Globigerina ampliapertura* Bolli are found in the *Globorotalia cocoaensis* zone, San Fernando formation. Further studies on the *Globorotalia centralis* group and related species will have to be carried out before it will be possible to establish definitely the genetic relationships. It may then be possible to erect a number of subspecies of stratigraphic value."

Because of its stratigraphic significance, *G. ampliapertura* has been subjected to critical studies by later workers who differ considerably in their definition of Bolli's form. One group of workers, led by Blow and Banner, have postulated a more restricted definition of *G. ampliapertura* and have erected some new species and subspecies for forms originally assigned by Bolli to *G. ampliapertura.* On the other hand, several other workers, including Wade (1964) and Hornaday (1965), have considerably enlarged the definition of the species to include forms quite different from those originally assigned to it. This tends to reduce considerably the stratigraphic significance of the species. A more consistent definition, based on detailed taxonomic and stratigraphic studies of *G. ampliapertura* and related forms, is needed before they can be satisfactorily used in detailed biostratigraphic studies.

Occurrence.—Originally described from Trinidad where, according to Bolli, it ranges from his *Globorotalia cerro-azulensis* zone (San Fernando formation) to *Globigerina ampliapertura* zone (Cipero formation). Later, Blow and Banner (1962), in the course of their investigation on the Mid-Tertiary *Globigerinaceae* from East Africa, assigned material from the *Globorotalia cerro-azulensis* zone of Trinidad identified by Bolli as *G. ampliapertura* to their new species *Globigerina pseudo-ampliapertura* and postulated that *G. ampliapertura* does not occur in the *Globorotalia cerro-azulensis* zone of Trinidad and in equivalent horizons elsewhere. According to them, *G. ampliapertura* evolved from *Globorotalia increbescens* (Bandy) in their uppermost Eocene *Globigerina gortanii* zone. Other workers have reported *G. ampliapertura* from beds ranging in age from the base of the Upper Eocene to basal Miocene. It is restricted to the *Globigerina gortanii* zones in the present material.

Globigerina angustiumbilicata Bolli

Plate 6, figure 3

Globigerina ciperoensis angustiumbilicata BOLLI, 1957a, p. 109, pl. 22, figs. 12a-13c; BOLLI, 1957b, p. 164, pl. 36, figs. 6a-b; JENKINS, 1966b, p. 4, pl. 1, figs. 7a-c.

Globigerina angustiumbilicata Bolli, BLOW, 1959, p. 172, pl. 7, figs. 33a-c, 34; JENKINS, 1960, p. 350, pl. 1, figs. 2a-c; BLOW and BANNER, 1962,

p. 85, pl. 9, figs. X-Z, text-figs. 9 (iv), 16 (vi, vii); WADE, 1964, pl. 1, figs. 11a-c; REISS and GVIRTZMANN, 1966, pl. 88, figs. 14a-15c; SAMANTA, 1969, p. 330, pl. 1, figs. 1a-c.

Remarks.—The present specimens, with their small, low, trochoid test, 5 globular, gradually-enlarging chambers in the last whorl, small umbilicus, and low arched aperture, agree closely with the type description of *G. angustiumbilicata* Bolli. An apertural lip, considered by some workers (Jenkins, 1966b, p. 4) to be a diagnostic feature of *G. angustiumbilicata,* is not clearly discernible in the specimen figured here. Bolli (1957a, p. 109) has, however, indicated that in the type population of *G. angustiumbilicata* the apertural lip is not always present. Only a faintly developed lip is noticeable in the illustration of the holotype of *G. angustiumbilicata,* while no apertural lip is distinctly discernible in the specimen illustrated by Bolli (1957b, pl. 36, figs. 6a-b) from the Upper Eocene of Trinidad. Thus, the presence of an apertural lip does not seem to be a constant feature in *G. angustiumbilicata.*

Occurrence.—The reported stratigraphic range of *G. angustiumbilicata* is Upper Eocene to Lower Miocene. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present material.

Globigerina corpulenta Subbotina

Plate 7, figures 9, 10

Globigerina corpulenta SUBBOTINA, 1953, p. 75, pl. 9, figs. 5-7, ?pl. 10, figs. 1-4; ECKERT, 1964, p. 1057, pl. 3, figs. 5a-6e; HAGN and LINDENBERG, 1966, text-fig. 4b.

Remarks.—The present specimens agree closely with the original description of the species. They are characterized by a large test, moderately raised dorsal spire, 4 inflated, gradually-enlarging chambers in the last whorl, well-developed umbilicus and low, arched aperture. The species is abundantly represented in the present material and shows variation in the height of the spire. Specimens with a bulla-like last chamber are not common. *G. corpulenta* is discussed and demonstrated by Hagn and Lindenberg (1966) to be transitional between *G. eocaena* Gümbel and *G. gortanii* (Borsetti).

The assignment of the present form to the genus *Globigerinita* by Blow and Banner (1962, p. 113) is not accepted. The three related species *G. eocaena, G. corpulenta* and *G. gortanii,* characterized by large, high-spired tests, occur abundantly in the present material. Although representatives of these three forms occasionally possess bulla-like final chambers, they seem to be unrelated to known species of *Globigerinita* and are, at present, retained in the genus *Globigerina.*

Occurrence.—*G. corpulenta* was originally described from the Upper Eocene of Russia. It has been reported from the Upper Eocene of Egypt and Syria. In the Alps it is reported to range from Upper Eocene to Oligocene. It ranges from *Globigerapsis semi-involuta* zone to *Globigerina gortanii* zone in the area under discussion.

Bandy (1964, p. 7) has referred specimens from the Upper Eocene of Alabama, previously identified by him as *Globigerina dutertrei* d'Orbigny, to *Globigerina gortanii* (Borsetti). Judging from the description and illustration provided by Bandy (1949), the Alabama specimens seem to be more closely comparable to *G. corpulenta* than to *G. gortanii.*

Globigerina eocaena Gümbel

Globigerina eocaena GÜMBEL, 1868, p. 662, pl. 2, figs. 109a-b; SAMANTA, 1969, p. 330, text-fig. 1a-c.

Globigerina (Subbotina) eocaena Gümbel, HAGN and LINDENBERG, 1966, pp. 349-353, pl. 1, figs. 1-6, text-figs. 3-4a.

Remarks.—It is a common form in the material. Specimens comparable to the neotype of *G. eocaena* illustrated by Hagn and Lindenberg (1966) are present. The size of the test and the height of the spire show variation in my material. Individuals with traces of a bulla-like last chamber are present. Frequently the umbilical region of the test is covered with matrix and the apertural characters are not clearly discernible.

Occurrence.—According to Hagn and Lindenberg (1966), who carried out a revision of Gümbel's form on the basis of the material from the Eocene of the foothills of the Bavarian Alps, *G. eocaena* ranges from the Lower Eocene to the Lower Oligocene. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present area.

Globigerina gortanii (Borsetti)

Plate 7, figures 11, 12

Catapsydrax gortanii BORSETTI, 1959, pp. 205-207, pl. 1, figs. 1a-d.

Globigerina turritilina turritilina BLOW and BANNER, 1962, pp. 98-99, pl. 13, figs. D-G.

Globigerina turritilina praeturritilina BLOW and BANNER, 1962, p. 99, pl. 13, figs. A-C.

Globigerina gortanii (Borsetti), BLOW and BANNER, 1962, p. 146; HAGN and LINDENBERG, 1966, text-fig. 4c; TODD, 1966, p. I 33, pl. 2, figs. 3a-b, ?pl. 10, figs. 6-8.

Remarks.—With its large test and rapidly enlarging, inflated chambers arranged in a high trochospire, *G. gortanii* is the most distinctive planktonic foraminifer in the material. It attains the largest size of all the planktonic foraminifera recorded here. It is abundantly represented and shows noticeable variation in the height of the spire and in the degree of development of the umbilicus. Specimens with a small bulla-like last chamber are present.

While describing the new species *Catapsydrax gortanii,* Borsetti (1959) compared it with the five species of the genus known at that time, *e.g., C. dissimilis* (Cushman and Bermúdez), *C. stainforthi* Bolli, Loeblich and Tappan, *C. parvulus* Bolli, Loeblich and Tappan, *C. unicavus* Bolli, Loeblich and Tappan and *C. echinatus* Bolli. Blow and Banner (1962, p. 98), on the other hand, remarked that the only known members of the Globigerinidae which grossly resemble their new species *Globigerina turritilina* (a junior synonym of Borsetti's species) are *Globigerina helicina* d'Orbigny and *Globigerinoides mitrus* Todd. Later, Hagn and Lindenberg (1966), in the course of their revision of *Globigerina eocaena* Gümbel from the Eocene of the Bavarian Alps, examined abundant material of the present species and pointed out the close relationship of *G. gortanii* with *Globigerina corpulenta* Subbotina and *G. eocaena* Gümbel. They reported all stages of transition between these three species. The present study of abundant material of these three species supports the observations of Hagn and Lindenberg.

Occurrence.—Originally described from the Lower Oligocene of Italy, it was later recorded from Tanganyika, East Africa, where it ranges from the *Globigerapsis semi-involuta* zone (Upper Eocene) to the *Globigerina selli* zone (Oligocene). Other reliable occurrences include the Lower Oligocene of the Bavarian Alps and the Upper Eocene-Oligocene of Guam. Blow and Banner (1962) have mentioned its occurrence in the Oligocene of Sarawak, Malaysia. The specimen from the Jackson formation of Alabama (Bandy, 1949, pl. 22, figs. 4a-c), referred by Bandy (1964, p. 7) to *G. gortanii,* seems to be closely comparable to *G. corpulenta* Subbotina. *G. gortanii* ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present area.

Globigerina linaperta Finlay

Plate 6, figures 19, 20

Globigerina linaperta FINLAY, 1939, p. 125, pl. 23, figs. 54-57; BOLLI, 1957b, p. 163, pl. 36, figs. 5a-b; HORNIBROOK, 1958, pp. 33-34, pl. 1, figs. 19-21 (holotype redrawn); REISS and GVIRTZMANN, 1966, pl. 88, figs. 4a-c; SAMANTA, 1969, p. 331, pl. 3, figs. 5a-c.

Remarks.—The figured specimen differs from the holotype of *G. linaperta* in having a large last chamber, constituting about one half of the test, and a periphery that is less strongly lobed. They are closely comparable otherwise. The preservation of the specimens is not completely satisfactory, and in some specimens the low aperture is covered with matrix.

Occurrence.—The reported stratigraphic range of *G. linaperta* is from Paleocene to Uppermost Eocene. It occurs in the *Globigerapsis semi-involuta* zone in the present area.

Globigerina officinalis Subbotina

Plate 6, figure 2

Globigerina officinalis SUBBOTINA, 1953 (part), p. 78, pl. 11, figs. 1a-2c, 6a-7c, ? figs. 5a-c (not figs. 3a-4b); BLOW and BANNER, 1962, p. 88, pl. 9, figs. A-C, text-fig. 16; REISS and GVIRTZMANN, 1966, pl. 88, figs. 9a-12; FERRER, 1967, pl. 3, figs. 6a-c; SAMANTA, 1969, p. 331, pl. 1, figs. 2a-c.

Globigerina parva BOLLI, 1957a, p. 108, pl. 22, figs. 14a-c; JENKINS, 1960, p. 352, pl. 1, figs. 12a-c.

Remarks.—It is a common form in the material. In diagnostic features the figured specimen agrees closely with the holotype of *G. officinalis.* A specimen similar to the holotype of *Globigerina parva* Bolli also occurs in the material.

Occurrence.—The reported stratigraphic range of *G. officinalis* is from Upper Middle Eocene to basal Miocene. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present area.

Globigerina praebulloides occlusa
Blow and Banner

Plate 6, figures 6-8

Globigerina praebulloides occlusa BLOW and BANNER, 1962, pp. 93-94, pl. 9, figs. U-W, text-figs. 14 (i-ii); ECKERT, 1964, p. 1058, pl. 4, figs. 2a-d; SAMANTA, 1969, p. 331, pl. 1, figs. 5a-c.

Remarks.—The present specimens are characterized by a low trochoidal test, prominently lobed periphery, 4 subglobular, rapidly enlarging chambers in the last whorl, distinctly developed umbilicus and arched umbilical aperture. They fall well within the range of variation of *G. praebulloides occlusa* discussed by its authors. The specimen illustrated here as figures 7, 8 in plate 6 compare closely with the specimen from the Upper Eocene of Trinidad first identified by Bolli (1957b, pl. 36, figs. 3a-b) as *Globigerina* cf. *trilocularis* d'Orbigny and later included in the synonymy of *G. praebulloides occlusa* by Blow and Banner (1962).

Occurrence.—The reported stratigraphic range of the subspecies is Middle Eocene-Lower Miocene. It occurs in the *Globigerapsis semi-involuta* and the *Globigerina gortanii* zones in the present area.

Globigerina senilis Bandy

Plate 7, figures 3-5

Globigerina ouachitaensis Howe and Wallace, var. *senilis* BANDY, 1949, p. 121, pl. 22, figs. 5a-c.

Globigerina senilis Bandy, BLOW and BANNER, 1962, pp. 95-96, pl. 11, figs. R-U.

Remarks.—Originally Bandy (1949) described it as a variety of *Globigerina ouachitaensis* Howe and Wallace. Later, Blow and Banner, (1962), in the course of their investigation on planktonic foraminifera from Tanganyika, considered Bandy's variety to be specifically distinct from *G. ouachitaensis* Howe and Wallace and raised it to specific rank. This is accepted here.

The Assam specimens agree closely with the type description and illustration of *G. senilis*. They are characterized by a slightly convex dorsal side, 4 inflated chambers in the last whorl (the last one being smaller than the penultimate), lobed periphery, distinctly developed quadrate umbilicus, and low, arched umbilical aperture.

Occurrence.—It was described from the Upper Eocene-Oligocene of the Little Stave Creek section in Alabama. It ranges through the same interval in Tanganyika, East Africa. It occurs in the *Globigerapsis semi-involuta* zone and *Globigerina gortanii* zones in the present material.

Globigerina tripartita tripartita Koch

Globigerina bulloides d'Orbigny var. *tripartita* KOCH, 1926, p. 746, text-figs. 21a-b.

Globigerina tripartita tripartita Koch, BLOW and BANNER, 1962, pp. 96-97, pl. 10, figs. A-F, text-fig. 18; ECKERT, 1964, p. 1059, pl. 4, figs. 3a-c; REISS and GVIRTZMANN, 1966, pl. 90, figs. 1a-4c; SAMANTA, 1969, p. 332, pl. 3, figs. 6a-c.

Globoquadrina tripartita tripartita (Koch), BANDY, 1964, p. 7, text-fig. 5 (9).

Remarks.—In their diagnostic features the present specimens are closely comparable to those recorded from the Upper Eocene of the Garo Hills by the writer (Samanta, 1969). In comparison to the Garo Hills specimens they are smaller in size and possess a less flattened final chamber.

Occurrence.—The reported stratigraphic range of *G. tripartita tripartita* is from the upper part of the Middle Eocene to the basal Miocene (Blow and Banner, 1962, p. 97). It is restricted to the *Globigerina gortanii* zone in the present material.

Globigerina yeguaensis Weinzierl and Applin

Globigerina yeguaensis WEINZIERL and APPLIN, 1929, p. 408, pl. 43, figs. 1a-b; BOLLI, 1957b, p. 163, pl. 35, figs. 15a-c; REISS and GVIRTZMANN, 1966, pl. 88, figs. 1a-2, ?3; FERRER, 1967, pl. 3, figs. 9a-c; SAMANTA, 1969, p. 332, pl. 3, figs. 7a-c.

Globigerina yeguaensis yeguaensis Weinzierl and Applin, BLOW and BANNER, 1962, pp. 99-100, pl. 13, figs. H-M; ECKERT, 1964, p. 1060, pl. 4, figs. 4a-5c.

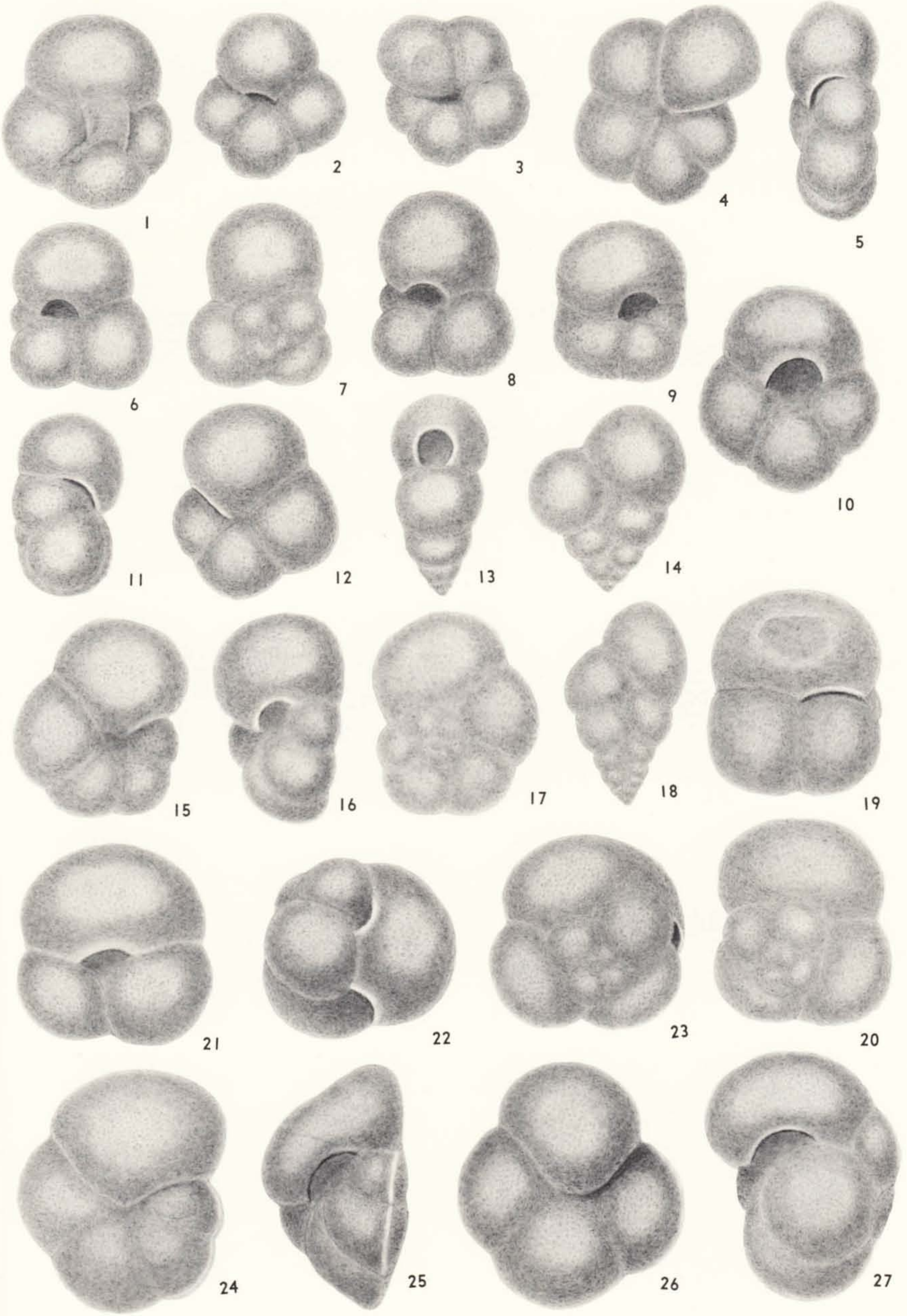
Remarks.—It is a common form in my material. The present specimens are smaller than those recorded from the Eocene succession of the Garo Hills (Samanta, 1969), but otherwise they are similar.

Occurrence.—According to most authors it is a Middle Eocene-Oligocene species. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present material.

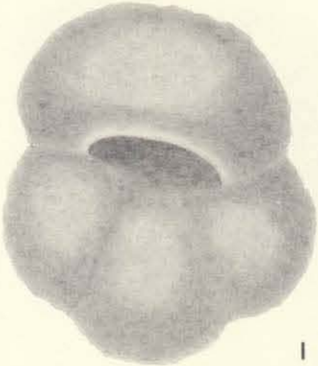
EXPLANATION OF PLATE 6

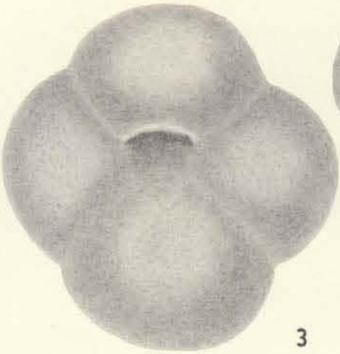
All figures approximately ×120, except 13-18, which are approximately ×180.

FIGS.		PAGE
1.	*Globigerinita dissimilis* (Cushman and Bermúdez). Ventral view. From sample 45.	35
2.	*Globigerina officinalis* Subbotina. Ventral view. From sample 43.	33
3.	*Globigerina angustiumbilicata* Bolli. Ventral view. From sample 43.	31
4, 5.	*Globorotalia gemma* Jenkins 4, ventral view. 5, peripheral view. From sample 43.	36
6-8.	*Globigerina praebulloides occlusa* Blow and Banner. 6, 8, ventral views. 7, dorsal view. From sample 47.	33
9, 10.	*Globigerina ampliapertura* Bolli. Ventral views. From sample 43.	31
11, 12.	*Globorotalia opima nana* Bolli. 11, peripheral view. 12, ventral view. From sample 43.	37
13, 14.	*Chiloguembelina* sp. 13, peripheral view. 14, side view. From sample 43.	31
15-17.	*Globorotalia permicra* Blow and Banner. 15, ventral view. 16, peripheral view. 17, dorsal view. From sample 43.	37
18.	*Chiloguembelina tenuis* (Todd). Side view. From sample 43.	30
19, 20.	*Globigerina linaperta* Finlay. 19, ventral view. 20, dorsal view. From sample 45.	33
21-23.	*Globigerapsis tropicalis* Blow and Banner. 21, ventral view. 22, peripheral view. 23, dorsal view. From sample 45.	35
24, 25.	*Globorotalia cerro-azulensis* (Cole). 24, ventral view. 25, peripheral view. From sample 45.	36
26, 27.	*Globorotalia increbescens* (Bandy). 26, ventral view. 27, peripheral view. From sample 43.	36

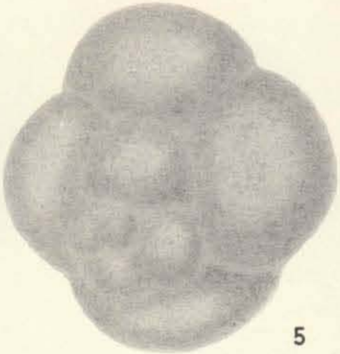


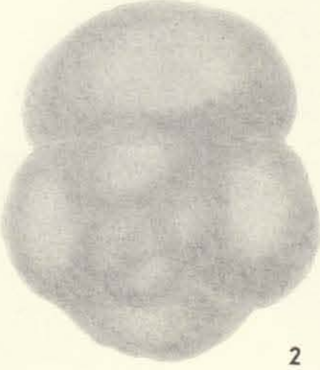
Samanta: Upper Eocene Foraminifera from India

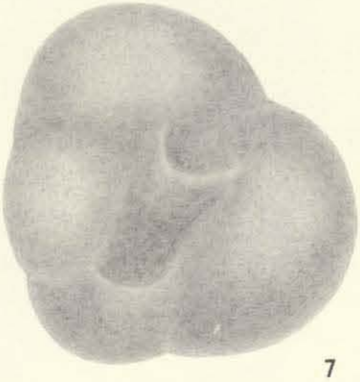

1

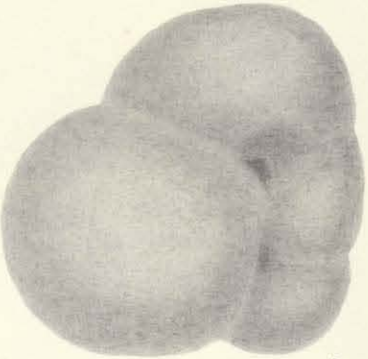

3

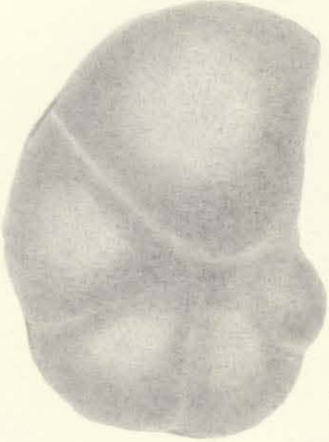

4

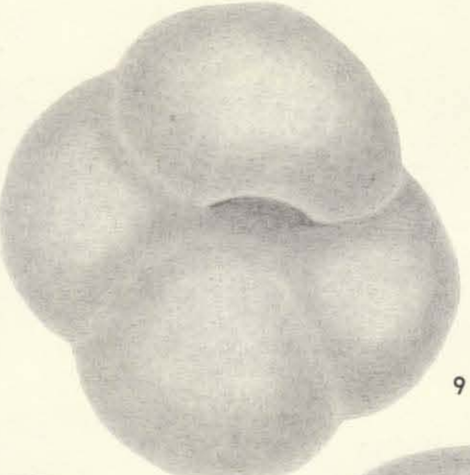

5

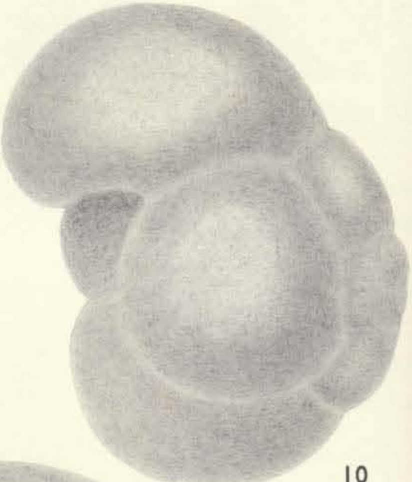

2

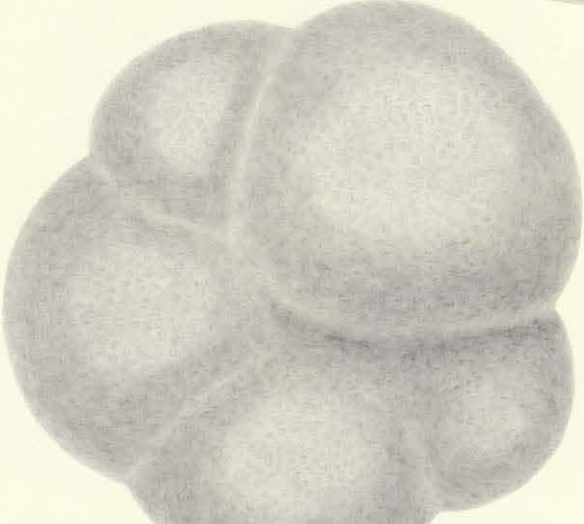

7

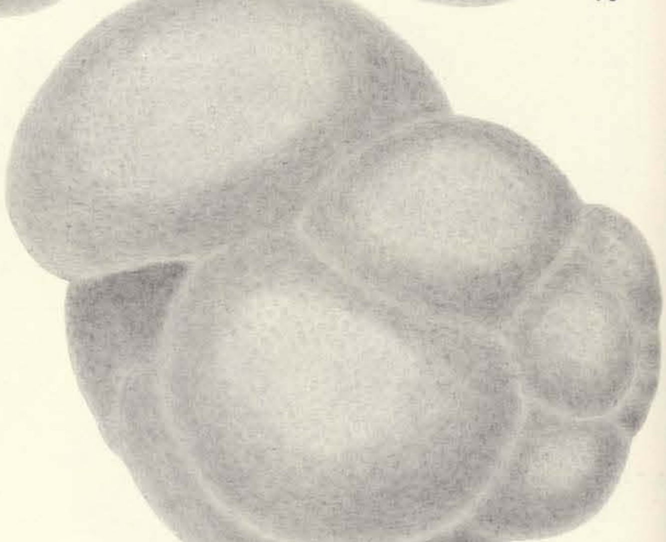

6


8


9


10


11


12

Samanta: Upper Eocene Foraminifera from India

Genus **Globigerinita** Brönnimann, 1951, emend. Blow and Banner, 1962

Globigerinita dissimilis (Cushman and Bermúdez)

Plate 6, figure 1

Globigerina dissimilis CUSHMAN and BERMÚDEZ, 1937, pp. 25-26, pl. 3, figs. 4-6; BERMÚDEZ, 1949, p. 279, pl. 21, fig. 47; BECKMANN, 1954, pp. 391-392, pl. 25, fig. 10, text-fig. 16.

Catapsydrax dissimilis (Cushman and Bermúdez), BOLLI, LOEBLICH and TAPPAN, 1957, p. 36, pl. 7, figs. 6-8.

Globigerinita dissimilis (Cushman and Bermúdez), BERMÚDEZ, 1961, pp. 1.262-1.263, pl. 7, figs. 4-5.

Globigerina (*Globigerinita*) *dissimilis* Cushman and Bermúdez, MCTAVISH, 1966, p. 9, pl. 2, figs. 15-17, 27-28, 30.

Remarks.—The figured specimen, with low trochoidal test, 4 inflated, fairly rapidly enlarging chambers in the last whorl, lobed periphery and quadrate bulla extending from the last chamber across to the antepenultimate chamber with two arched openings, agree closely with the original description and illustration of the species. The preservation of the material does not reveal the presence of lips over the openings in the bulla. The subspecific differentiation of *G. dissimilis* proposed by Blow and Banner (1962) is not recognised in the present study. It is a rare form in my material.

Occurrence.—*G. dissimilis* was originally described from the Eocene of Cuba. The reported stratigraphic range of the species is from the upper part of the Middle Eocene to the Lower Miocene. It is a widely distributed representative of the genus. It is restricted to the *Globigerapsis semi-involuta* zone in the present area.

Globigerinita unicava (Bolli, Loeblich and Tappan)

Catapsydrax unicavus BOLLI, LOEBLICH and TAPPAN, 1957, p. 37, pl. 7, figs. 9a-c; BOLLI, 1957b, p. 166, pl. 37, figs. 7a-b; JENKINS, 1960, p. 356, pl. 3, figs. 7a-c.

Globigerinita unicava (Bolli, Loeblich and Tappan), ECKERT, 1964, p. 1062, pl. 5, figs. 2a-c, 3; SAMANTA, 1969, p. 332, pl. 1, figs. 4a, c.

Globigerina (*Globigerinita*) *unicava* (Bolli, Loeblich and Tappan), MCTAVISH, 1966, p. 9, pl. 2, figs. 19, 22-23.

Remarks.—It is a common form of the genus here. The present specimens agree closely with those of *G. unicava* recorded from the Eocene succession of the Garo Hills (Samanta, 1969).

Occurrence.—This Middle Eocene-Lower Miocene form has been reported from widely separated localities. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone here.

Genus **Globigerapsis** Bolli, Loeblich and Tappan, 1957

Globigerapsis tropicalis Blow and Banner

Plate 6, figures 21-23

Globigerapsis tropicalis BLOW and BANNER, 1962, pp. 124-125, pl. 15, figs. D-F; ECKERT, 1964, p. 1063, pl. 7, figs. 5a-c; FERRER, 1967, pl. 4, figs. 2-5.

Remarks.—In the original description of *G. tropicalis,* Blow and Banner stated that the adult test of their form possesses 3 to 4 apertural openings. Later, Eckert (1964) and Ferrer (1967) recorded *G. tropicalis* from the European Upper Eocene as possessing only 2 to 3 apertural openings. The specimen figured here, the only well-preserved specimen of *G. tropicalis* in my material, with its 2 apertural openings resembles more closely the European specimens than the holotype of the species.

The difference between *Globigerapsis tropicalis* and the closely related *G. semi-involuta* (Keijzer) has been discussed in detail by Blow and Banner (1962) and Eckert (1964). According to its authors *G. tropicalis* is probably ancestral to Keijzer's form.

Occurrence.—*G. tropicalis* was described from Tanganyika, East Africa, where it ranges from Middle Eocene to the lower part of the Upper Eocene. According to its authors it also occurs in the Middle-Upper Eocene of the Caucasus and Trinidad. It has been recorded from the lower part of the Upper Eocene in Switzerland and Spain and its occurrence has been reported from the Upper Eocene of Syria. It is restricted to the *Globigerapsis semi-involuta* zone in the present area.

EXPLANATION OF PLATE 7

All figures approximately ×120.

FIGS.		PAGE
1, 2.	*Globigerina ampliapertura* Bolli. 1, ventral view. 2, dorsal view. From sample 43.	31
3-5.	*Globigerina senilis* Bandy. 3, ventral view. 4, peripheral view. 5, dorsal view. From sample 45.	34
6, 7.	*Globigerinatheka* sp. cf. *G. barri* Brönnimann. Peripheral views. From sample 45.	36
8.	*Hantkenina alabamensis* Cushman. Side view. From sample 44.	37
9, 10.	*Globigerina corpulenta* Subbotina. 9, ventral view. 10, peripheral view. From sample 45.	32
11, 12.	*Globigerina gortanii* (Borsetti). 11, ventral view. 12, peripheral view. From sample 45.	32

Genus **Globigerinatheka** Brönnimann, 1952

Globigerinatheka sp. cf. **G. barri** Brönnimann

Plate 7, figures 6, 7

Cf. *Globigerinatheka barri* BRÖNNIMANN, 1952 (part), pp. 27-28, text-figs. 3a-c.

Remarks.—Only one badly preserved specimen is recorded here. It is characterized by the large, inflated last chamber covering the umbilicus and provided with four apertural openings, two of which are covered by bullae. The bullae over the other two openings are not preserved. Although the specimen appears to be specifically indistinguishable from *Globigerinatheka barri* Brönnimann, it is here only tentatively identified, because of its rarity and poor preservation.

Occurrence.—It occurs in the *Globigerapsis semi-involuta* zone.

Family GLOBOROTALIIDAE Cushman, 1927

Genus **Globorotalia** Cushman, 1927

Globorotalia centralis Cushman and Bermúdez

Globorotalia centralis CUSHMAN and BERMÚDEZ, 1937, p. 26, pl. 2, figs. 62-65; BOLLI, LOEBLICH and TAPPAN, 1957, p. 41, pl. 10, figs. 4a-c; BOLLI, 1957b, p. 169, pl. 39, figs. 1-4; SAMANTA, 1969, p. 333, pl. 2, figs. 2a-c (synonymy).

Occurrence.—This widely distributed, easily recognisable Middle-Upper Eocene species occurs in the *Globigerapsis semi-involuta* and *Cribrohantkenina inflata* zones in the present area. It is less common here than in the material from the Garo Hills.

Globorotalia cerro-azulensis (Cole)

Plate 6, figures 24, 25

Globigerina cerro-azulensis COLE, 1928, p. 217, pl. 1, figs. 11-13.

Globorotalia cocoaensis CUSHMAN, 1928, p. 75, pl. 10, figs. 3a-c.

Globorotalia cerro-azulensis (Cole), BERMÚDEZ, 1949, p. 285, pl. 22, figs. 27-29; SAMANTA, 1969, p. 333, pl. 2, figs. 1a-c (synonymy).

Remarks.—It is a common distinctive species of *Globorotalia* in the material. The specimens show variation in the convexity of the ventral side of the test, the size of the last chamber, and the acuteness of the periphery. It attains the largest size among the representatives of the genus in the material.

Occurrence.—Previously *G. cerro-azulensis* was regarded as ranging to the top of the Upper Eocene. Later, Blow and Banner (1962) in the course of their detail investigation on Mid-Tertiary planktonic foraminifera from Tanganyika, East Africa, found *G. cerro-azulensis* in their uppermost Eocene planktonic foraminiferal zone. Reiss and Gvirtzmann (1966) have recorded a similar range for *G. cerro-azulensis* in Israel. In the present area also it occurs only in the *Globigerapsis semi-involuta* and *Cribrohantkenina inflata* zones and is typically absent in the *Globigerina gortanii* zone.

Globorotalia gemma Jenkins

Plate 6, figures 4, 5

Globorotalia gemma JENKINS, 1966a, pp. 1115-1118, fig. 11, nos. 97-103; SAMANTA, 1969, p. 334, pl. 2, figs. 3a-c (synonymy).

Remarks.—With their small, very low trochoidal test, lobed periphery, 4½ to 6 globular, gradually enlarging chambers in the last whorl, small umbilicus and very low, arched aperture furnished with a lip, the present specimens agree closely with the type description and illustrations of *G. gemma*. In comparison to specimens recorded from the Garo Hills, the present ones resemble the holotype of *G. gemma* more closely in having a flat dorsal side and lower aperture. The present assemblage shows a similar range of variation to that observed in the New Zealand populations of *G. gemma* by Jenkins (1966a).

Occurrence.—The reported stratigraphic range of *G. gemma* is Upper Eocene-Oligocene. In the present area it is restricted to the *Globigerina gortanii* zone, where it is the most abundant representative of the genus.

Globorotalia increbescens (Bandy)

Plate 6, figures 26, 27

Globigerina increbescens BANDY, 1949, pp. 120-121, pl. 23, figs. 3a-c; TODD, 1966, p. I 33, pl. 11, fig. 1.

Globorotalia (*Turborotalia*) *increbescens* (Bandy), BLOW and BANNER, 1962, pp. 118-119, pl. 13, figs. T-V, pl. 17, figs. D, K, text-figs. 9 (xiii-xv).

Globorotalia increbescens increbescens (Bandy), BANDY, 1964, p. 7, text-fig. 5 (7).

Remarks.—The figured specimen, with gently convex dorsal side and strongly convex ventral side, 4 inflated, slowly enlarging chambers in the last whorl, broadly rounded periphery, small, shallow umbilicus and arched aperture extending from umbilical region to near the periphery, agrees closely with the original description and illustration of *G. increbescens*. It also resembles very closely the specimen of *G. increbescens* illustrated by Todd (1966) from Guam.

Originally described as a *Globigerina*, it was later transferred to the genus *Globorotalia* because of its umbilical-extraumbilical aperture. In general features *G. increbescens* shows some resemblance to *G. centralis* Cushman and Bermúdez, from which it can easily be distinguished by the shape of the test and the character of the aperture. The close relationship of the species to *Globorotalia opima* *nana* Bolli has been discussed by Blow and Banner (1962), who have suggested the evolution of *G. increbescens* from Bolli's form.

Occurrence.—Originally described from the Little Stave Creek section in Alabama, where it was shown to range from the Tallahatta formation (Middle Eocene) to the Mariana Limestone (Oligocene). Later, Blow and Banner (1962) found it to range from the Upper Eocene to the Oligocene in East Africa and postulated its evolution from *Globorotalia opima nana* Bolli during the Upper Eocene. It is restricted to the *Globigerina gortanii* zone in the present area.

Globorotalia opima nana Bolli

Plate 6, figures 11, 12

Globorotalia opima nana Bolli, 1957a, p. 118, pl. 28, figs. 3a-c; Samanta, 1969, p. 334, pl. 3, figs. 4a-c (synonymy).

Remarks.—Bolli (1957a) described *G. opima nana* from the Cipero formation of Trinidad and compared it with *Globorotalia mayeri* Cushman and Ellisor and *G. opima opima* Bolli, both occurring in the Cipero formation. Later, several workers have doubted the validity of Bolli's form. Jenkins (1960, p. 366) considered it to be a juvenile form, while Bermúdez (1961, p. 1.322) included it in the synonymy of *Globorotalia increbescens* (Bandy). Although it is accepted that *G. opima nana* and *G. increbescens* resemble each other, they are here treated as distinct species.

It is a common form of *Globorotalia* in the present material. Here, *G. opima nana* can readily be distinguished from *G. increbescens* by its flatter dorsal side, more restricted umbilicus and much lower aperture. The stratigraphic ranges of the two forms are also different in the present area.

Occurrence.—The reported stratigraphic range of *G. opima nana* is Middle Eocene to basal Miocene. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present material. It is the only representative of *Globorotalia* that occurs in all three zones here.

Globorotalia permicra Blow and Banner

Plate 6, figures 15-17

Globorotalia (Turborotalia) permicra Blow and Banner, 1962, p. 120, pl. 12, figs. N-P.

Remarks.—With its minute plano-convex test, about 5 inflated, gradually enlarging chambers in the last whorl, rounded periphery and arched aperture furnished with a narrow lip, *Globorotalia permicra* Blow and Banner is a distinct form of the genus in the material. The specimen figured here agrees closely with the illustration of the holotype of *G. permicra*. The smallest species of *Globorotalia* here, it is rare in my material.

Although Blow and Banner (1962, p. 120) compared their new species with *Globorotalia minutissima* Bolli, characterized by very low trochospiral, almost equally convex, umbilicate test, the two species seem to be completely unrelated and belong to two different groups of forms.

Occurrence.—*G. permicra* was described from Tanganyika, East Africa, where it ranges from the *Globigerina gortanii* zone, uppermost Eocene, to the *G. selli* zone, Oligocene. Its occurrence in the Cipero formation of Trinidad, Rupelian of Germany and lower Aquitanian of France has been mentioned by Blow and Banner. *G. permicra* was later reported from the Oligocene of Syria. It is restricted to the *Globigerina gortanii* zone in the present material.

Family HANTKENINIDAE Cushman, 1927

Genus **Hantkenina** Cushman, 1925

Hantkenina alabamensis Cushman

Plate 7, figure 8

Hantkenina alabamensis Cushman, 1925, pp. 3-4, pl. 1, figs. 1-6, pl. 2, fig. 5, text-fig. 1; Samanta, 1969, p. 338, pl. 3, figs. 3a-b (synonymy).

Remarks.—Although it is represented by only a few badly preserved specimens, this distinctive species is easily recognized in the material. The present specimens compare well with those of *H. alabamensis* recorded from the Garo Hills (Samanta, 1969), where the species is represented by abundant well preserved specimens.

Occurrence.—This is a widely distributed Middle (Upper part) to Upper Eocene species. According to Blow and Banner (1962), it does not range to the uppermost Eocene. In the present material it ranges from the *Globigerapsis semi-involuta* to the *Cribrohantkenina inflata* zone.

Genus **Pseudohastigerina** Banner and Blow, 1959

Pseudohastigerina micra (Cole)

Nonion micrus Cole, 1927, p. 22, pl. 5, fig. 12.

Pseudohastigerina micra (Cole), Banner and Blow, 1959, pp. 19-20, text-figs. 4g-i; Samanta, 1969, p. 342, pl. 1, figs. 6a-b (synonymy).

Remarks.—Well preserved specimens, closely comparable to those recorded from the Garo Hills (Samanta, 1969), are present in the material. The number of chambers in the last whorl and the compression of the chambers vary in the present specimens.

Occurrence.—This is a common planktonic foraminifer of Middle Eocene-Middle Oligocene age. It ranges from the *Globigerapsis semi-involuta* to the *Globigerina gortanii* zone in the present material.

REFERENCES

Bandy, O. L., 1949, Eocene and Oligocene foraminifera from Little Stave Creek, Clarke County, Alabama: Bull. Am. Paleontology, v. 32, no. 131, pp. 1-211, pls. 1-27.

———, 1964, Cenozoic planktonic foraminiferal zonation: Micropaleontology, v. 10, no. 1, pp. 1-17, text figs. 1-6.

Banner, F. T., and Blow, W. H., 1959, The classification and stratigraphical distribution of the Globigerinaceae: Palaeontology, v. 2, pt. 1, pp. 1-27, pls. 1-3, text figs. 1-5.

Beckmann, J. P., 1954, Die Foraminiferen der Oceanic Formation (Eocaen-Oligocaen) von Barbados, Kl. Antillen: Eclog. Geol. Helvetiae, v. 46, no. 2, (1953), pp. 301-412, pls. 26-30, text figs. 1-29.

Bermúdez, P. J., 1949, Tertiary smaller Foraminifera of the Dominican Republic: Special Pub. no. 25, Cushman Lab. Foram. Research, pp. 1-322, pls. 1-26.

———, 1961, Contribución al estudio de las Globigerinidea de la región Caribe-Antillana (Paleocene-Reciente): Congreso Geol. Venezolano, 3rd, Mem., v. 3 (Bol. Geol., Publ. Espec. no. 3), pp. 1.119-1.393, pls. 1-20.

Blow, W. H., 1959, Age, correlation, and biostratigraphy of the Upper Tocuyo (San Lorenzo) and Pozan Formations, eastern Falcon, Venezuela: Bull. Am. Paleontology, v. 39, no. 178, pp. 59-251, pls. 6-19, text figs. 1-5.

———, and Banner, F. T., 1962, The mid-Tertiary (Upper Eocene-Aquitanian) Globigerinaceae: *in* Eames, F. E., *et al.*, Fundamentals of mid-Tertiary stratigraphical correlation: Cambridge University Press, pp. 61-151, pls. 8-17, text figs. 6-20.

Bolli, H. M., 1957a, Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, B.W.I.: U. S. Natl. Mus., Bull. 215, pp. 97-124, pls. 22-29, text figs. 17-21.

———, 1957b, Planktonic foraminifera from the Eocene Navet and San Fernando formations of Trinidad, B.W.I.: *Ibid.*, pp. 155-172, pls. 35-39, text figs. 25-26.

———, Loeblich, A. R., Jr., and Tappan, H., 1957, Planktonic foraminiferal families Hantkeninidae, Orbulinidae, Globorotaliidae and Globotruncanidae: *Ibid.*, pp. 3-50, pls. 1-11, text figs. 1-9.

Borsetti, A. M., 1959, Tre nuovi foraminiferi planctonici dell'Oligocene Piacentino: Ann. Mus. Geol. Bologna, Giorn. Geol., Ser. 2, v. 27, pp. 205-212, pl. 1.

Brönnimann, P., 1952, *Globigerinoita* and *Globigerinatheka*, new genera from the Tertiary of Trinidad, B.W.I.: Contr. Cushman Found. Foram. Research, v. 3, pt. 1, pp. 25-28, text figs. 1-3.

Cole, W. S., 1927, A foraminiferal fauna from the Guayabal formation in Mexico: Bull. Am. Paleontology, v. 14, no. 51, pp. 1-46, pls. 1-5.

———, 1928, A foraminiferal fauna from the Chapapote formation in Mexico: *Ibid.*, v. 14, no. 53, p. 200-232, pls. 1-5.

Cushman, J. A., 1925, A new genus of Eocene Foraminifera: U. S. Natl. Mus., Proc., v. 66, (1924), no. 2567, art. 30, pp. 1-4, pls. 1-2.

———, 1928, Additional foraminifera from the Upper Eocene of Alabama: Contr. Cushman Lab. Foram. Research, v. 4, pt. 3, pp. 73-79, pl. 10.

———, and Bermúdez, P. J., 1937, Further new species of foraminifera from the Eocene of Cuba: *Ibid.*, v. 13, pt. 1, pp. 1-29, pls. 1-2.

Eckert, H. R., 1964, Die Obereozänen Globigerinen-Schiefer (Stad-und Schimbergschiefer) zwischen Pilatus und Schrattenfluh: Eclog. Geol. Helvetiae, v. 56 (1963), no. 2, pp. 1001-1072, pls. 1-7.

Ellis, B. F., and Messina, A. R., 1940, *et seq.*, Catalogue of Foraminifera: New York: Am. Mus. Natl. Hist., Spec. Publ., 30 vols. and supplements, illus.

Ferrer, J., 1967, Le Paléocène et l'Éocène des Cordillères côtières de la Catalogne (Espagne): Eclog. Geol. Helvetiae, v. 60, no. 2, pp. 567-575, pls. 1-4.

Finlay, H. J., 1939, New Zealand foraminifera: Key species in stratigraphy - No. 2: Roy. Soc. New Zealand, Trans. Proc., v. 69, pt. 1, pp. 89-128, pl. 23, figs. 54-57.

Gümbel, C. W., 1868, Beiträge zur Foraminiferenfauna der nordalpinen Eocängebilde: K. Bayer Akad. Wiss. München. Math. - Physik. Cl., Abh. v. 10, pt. 2, pp. 580-730, pls. 1-4.

Hagn, H., and Lindenberg, H. G., 1966, Revision of *Globigerina* (*Subbotina*) *eocaena* Gümbel from the Eocene of the Bavarian foothills of the Alps: [Russian]. Voprosy. Mikropal., Akad. Nauk. U.S.S.R., v. 10, pp. 342-358, pl. 1, text figs. 1-4.

Hornaday, G. R., 1965, An Eocene foraminiferal faunule from the northwestern Santa Ynez mountains, California: Contr. Cushman Found. Foram. Research, v. 16, pt. 1, pp. 29-39, pls. 3-4.

Hornibrook, N. de B., 1958, New Zealand Upper Cretaceous and Tertiary foraminiferal zones and some overseas correlations: Micropaleontology, v. 4, no. 1, pp. 25-38, pl. 1.

JENKINS, D. G., 1960, Planktonic foraminifera from the Lakes Entrance oil shaft, Victoria, Australia: Micropaleontology, v. 6, no. 4, pp. 345-371, pls. 1-5, text figs. 1-10.

———, 1966a, Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand: New Zealand Jour. Geol. Geophys., v. 8 (1965), no. 6, pp. 1088-1126, figs. 1-15.

———, 1966b, Planktonic foraminifera from the type Aquitanian-Burdigalian of France: Contr. Cushman Found. Foram. Research, v. 17, pt. 1, pp. 1-15, pls. 1-3.

KOCH, R., 1926, Mittletertiäre Foraminiferen aus Bulongan, Öst-Borneo: Eclog. Geol. Helvetiae, v. 19, pp. 722-751, 26 text figs.

MCTAVISH, R. A., 1966, Planktonic foraminifera from the Malaita Group, British Solomon Islands: Micropaleontology, v. 12, no. 1, pp. 1-36, pls. 1-7.

REISS, Z., and GVIRTZMAN, G., 1966, Subsurface Neogene stratigraphy of Israel: *in*: Proceedings of the Third Session in Berne (8-13 June, 1964). Leiden, Netherlands: E. J. Brill, Internat. Union Geol. Sci., Comm. Medit. Neogene Stratig., pp. 312-346, pls. 88-99.

SAMANTA, B. K., 1968, The Eocene succession of Garo Hills, Assam, India: Geol. Mag., v. 105, no. 2, p. 124-135.

———, 1969, Eocene planktonic foraminifera from Garo Hills, Assam, India: Micropaleontology, v. 15, no. 3, pp. 325-350, pls. 1-3, text figs. 1-2.

SUBBOTINA, N. N., 1953, Fossil Foraminifera from the U.S.S.R., Globigerinidae, Hantkeninidae and Globorotaliidae: Trudy Vses. Neft. Nauko-Issledov. Geol. Razved. Inst., n. ser., no. 76, pp. 1-296, pls. 1-41.

TODD, R., 1957, Smaller foraminifera: *in* Geology of Saipan, Mariana Islands: Part 3 - Paleontology: U. S. Geol. Survey Prof. Paper 280-H, pp. 265-320, pls. 64-93.

———, 1966, Smaller foraminifera from Guam: *Ibid.*, 403-I, pp. I1-I41, pls. 1-19.

WADE, M., 1964, Application of the lineage concept to biostratigraphic zoning based on planktonic foraminifera: Micropaleontology, v. 10, no. 3, pp. 273-290, pls. 1-2.

WEINZIERL, L. L., and APPLIN, E. R., 1929, The Claiborne formation on the Coastal Domes: Jour. Paleontology, v. 3, pp. 384-410, pls. 42-44.

CONTRIBUTIONS FROM THE CUSHMAN FOUNDATION
FOR FORAMINIFERAL RESEARCH
VOLUME XXI, PART 1, JANUARY, 1970

RECENT LITERATURE ON THE FORAMINIFERA

Below are given some of the more recent works on the Foraminifera that have come to hand.

ARNAUD-VANNEAU, ANNIE. Quelques précisions concernant l'appareil embryonnaire du genre *Palorbitolina* Schroeder.—Revue de Micropaléontologie, v. 12, No. 1, June 1969, p. 16-20, pl. 1, text figs. 1-3 (diagrams).

AYALA-CASTAÑARES, AGUSTIN, and SEGURA, LUIS R. Ecologia y distribucion de los Foraminiferos Recientes de la Laguna Madre, Tamaulipas, Mexico.—Univ. Nac. Auto. Mexico, Instit. Geol., Bol. No. 87, 1968, p. 1-89, pls. 1-8, text figs. 1-29 (maps), tables 1-10.—Thirty-four identified species, none new, in this hypersaline coastal lagoon in its final evolutionary stages.

AZEMA, JACQUES, FERNEX, FRANCOIS, HOTTINGER, LUCAS, MAGNÉ, JEAN, and PAQUET, JACQUES. *Borelis melo* (Fichtel et Moll) dans le Miocène de la partie orientale des Cordillères bétiques (Espagne).—Bull. Soc. Géol. France, ser. 7, v. 10, No. 4, 1968 (July 1969), p. 444-448, pl. 28, text fig. 1 (map).

BANDY, ORVILLE L., BUTLER, E. ANN, and WRIGHT, RAMIL C. Alaskan upper Miocene marine glacial deposits and the *Turborotalia pachyderma* datum plane.—Science, v. 166, No. 3905, Oct. 31, 1969, p. 607-609, text figs. 1, 2 (map, stratigraphic sections, stereoscan photos). —Abrupt appearance of left-coiling *T. pachyderma*, evolving from *T. continuosa*, at boundary between middle and upper Miocene, accompanied by decrease of 10°C, indicates polar glaciation.

BANDY, ORVILLE L., and CASEY, RICHARD E. Major Late Cenozoic planktonic datum planes, Antarctic to the Tropics.—Antarctic Jour. of U.S., v. 4, No. 5, Sept.-Oct. 1969, p. 170-171, text fig. 1 (range chart).

BANDY, O. L., MORIN, R. W., and WRIGHT, R. C. Definition of the *Catapsydrax stainforthi* Zone in the Saucesian Stage, California.—Nature, v. 222, No. 5192, May 3, 1969, p. 468-469, text figs. 1, 2 (range chart, stereoscan photos).

BANDY, ORVILLE L., VINCENT, EDITH, and WRIGHT, RAMIL C. Chronologic relationships of orbulines to the *Globorotalia fohsi* lineage.—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 131-145, pls. 1, 2, text figs. 1-3 (range charts).—A polyphyletic origin of orbulines is supported by the later appearance of orbulines in some areas than in the tropics, by the development of different species inside orbuline chambers, and by differences in wall structure.

BANERJEE, D., and KINDRA, G. S. Microforaminifera from Paleogene subcrops of India.—Quart. Jour. Geol., Mining Metall. Soc. India, v. 40, No. 2, June 1968, p. 89-91, 1 pl.—Resistant to HCl.

BAUMANN, PAUL, and ROTH, PETER H. Zonierung des Obereozäns und Oligozäns des Monte Cagnero (Zentralapennin) mit planktonischen Foraminiferen und Nannoplankton.—Eclogae Geol. Helvetiae, v. 62, No. 1, July 31, 1969, p. 303-323, text figs. 1, 2 (map, range chart). —Correlation between planktonic Foraminifera zones and nannoplankton zones.

BELYAEVA, N. V. Thanatocoenoses of planktonic foraminifers on the Pacific floor (in Russian). —Akad. Nauk SSSR, Okean. Komiss., Okeanologija, tom 9, vyp. 3, 1969, p. 500-504, text fig. 1 (map).

BIGNOT, G., and LARSONNEUR, C. Étude du Crétacé Supérieur au large du Cotentin et remarques sur les *Planorbulina* du Crétacé Supérieur et du Paléocène.—Revue de Micropaléontologie, v. 12, No. 1, June 1969, p. 25-39, pls. 1-3, text figs. 1-7 (drawings), table 1 (check list), map.—Study based on 250 submarine samples from off Cotentin of Senonian and Maestrichtian age.

BOLLI, HANS M. Zonacion de sedimentos marinos del Cretaceo hasta el Plioceno basada en Foraminiferos planctonicos.—Instit. Mexicano del Petroleo, Publ. No. 69 AE/047, 1969, p. 1-36, tables 1-4.

BOLTOVSKOY, ESTEBAN. Tanatocenosis de Foraminiferos planctonicos en el estrecho de Mozambique.—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 117-129, pls. 1-3.—Thirty-two species.

BRÖNNIMANN, PAUL, and CONRAD, MARC A. Remarks on the morphology and occurrence of *Pseudotextulariella*? *scarsellai* (De Castro) in the Lower Cretaceous of the Geneva region.—Geologica Romana, v. 7, 1968, p. 95-105, pls. 1, 2, text figs. 1-4 (drawings).

BROUWER, J. Foraminiferal assemblages from the Lias of north-western Europe.—Verhandl. Kon. Nederl. Akad. Wetenschappen, Afd. Natuurkunde, Eerste Reeks, Deel 25, No. 4, 1969, p. 1-64, pls. 1-8, text figs. 1-4 (map, tables, graphs), tables 1-4.—Occurrence in numerous areas from beds ranging from Hettangian to Toarcian is recorded for 100 species. Many names are included in synonymy.

Buzas, Martin A. Foraminiferal species densities and environmental variables in an estuary.—Limnology and Oceanography, v. 14, No. 3, May 1969, p. 411-422, text figs. 1-10 (map, graphs), tables 1-6.—Quantitative study of relationships between species densities of *Elphidium clavatum, Ammobaculites exiguus,* and *Ammonia beccarii* and environmental variables in the Choptank River. Three stations were sampled monthly for temperature, salinity, oxygen, and chlorophyll a, b, and c. Density of *E. clavatum* decreased upstream; density of the others varied little.

Camacho, Horacio H. Paleontografia Bonaerense, fasc. III. Invertebrados.—Prov. Buenos Aires, Com. Invest. Cien., La Plata, 1966, 159 p., 19 pls.—Catalog includes Foraminifera (p. 3-35, pls. 1-3).

Chang, Li-Sho. A biostratigraphic study of the Tertiary in the Coastal Range, eastern Taiwan, based on smaller Foraminifera (III: middle part).—Proc. Geol. Soc. China, No. 12, April 1969, p. 89-101, pls. 1-6, text figs. 1, 2 (map, outcrop photo), tables 1-8 (check lists, correl. chart).—Upper Miocene Foraminifera (about 300 species) illustrated and their occurrence and abundance plotted on check lists.

Cita, Maria Bianca, and Premoli Silva, Isabella. Sui Foraminiferi incontrati in un pozzo perforato nella Laguna di Venezia.—Mem. Biogeografia Adriatica, v. 7, 199-67, p. 29-51, pls. 1, 2, text figs. 1-9 (map, columnar section, drawings, graphs).—Fauna from well boring in Venetian lagoon is dominated by *Ammonia beccarii.*

Closs, Darcy, and Madeira, Marly Lopes. Seasonal variations of brackish Foraminifera in the Patos Lagoon, southern Brazil.—Univ. Federal Rio Grande do Sul, Escola Geol., Publ. Espec. No. 15, 1968, p. 1-51, pls. 1-5, text figs. 1-14 (map, graphs), tables 1, 2 (charts of occurrence and abundance).—Quantitative study based on 2 stations, collected seasonally; 46 species are recorded. Variations in salinity and temperature are recorded. Total, living, and dead populations are determined.

Conrad, Marc A. Les calcaires urgoniens dans la région entourant Genève.—Eclogae Geol. Helvetiae, v. 62, No. 1, July 31, 1969, p. 1-79, pls. 1-7, text figs. 1-25 (diagrams, map, classification chart, drawings, range chart), table 1.—Barremian and lower Aptian Foraminifera on an epicontinental shelf; 5 zones are recognized.

Cuvillier, Jean, Foury, Geneviève, and Pignatti Morano, Alessandro. Foraminifères nouveaux du Jurassique Supérieur du Val Cellina (Frioul Occidental, Italie).—Geologica Romana, v. 7, 1968, p. 141-156, pls. 1-3, text figs. 1-3 (stratigraphic section, drawings).—Two new subgenera of the orbitolinid genus *Urgonia,* and 2 new species.

Dabagian, N. V., and Kulchizky, J. O. Planctonic foraminifers of a new facies variety from the Cretaceous of the Rahov Zone (the Ukrainian Carpathians) (in Russian with English summary).—Izdat. L'vov. Univ., Paleont. Sbornik, No. 5, vyp. 1, 1968, p. 10-17, pls. 1, 2.—Seven species, 1 new.

Dallan Nardi, Laura. I Microforaminiferi del "Macigno" di Calafuria (Monti Livornesi).—Boll. Soc. Geol. Ital., v. 87, fasc. 4, 1968, p. 611-621.—Foraminifera indicate Paleogene-Aquitanian age.

Dasgupta, Amal. On the occurrence of *Discocyclina omphalus* (Fritsch) from middle Eocene of Cutch, western India.—Geol. Soc. India Bull., v. 6, No. 2, April 1969, p. 54-57, text figs. 1-3 (photomicrographs).

Deloffre, R., and Hamaoui, M. Biostratigraphie des "Breches de Soumoulou" et description de *Pseudobroeckinella soumoulouensis* n. gen., n. sp., Foraminifère du Crétacé Supérieur d'Aquitaine.—Bull. Centre Recherches de Pau, v. 3, No. 1, May 31, 1969, p. 5-31, pls. 1-8, text figs. 1-3 (diagrams).—A large imperforate foraminifer belonging in the Soritidae.

Dhillon, D. S. Notes on the foraminiferal sediments from the Lupar and Labuk estuaries, East Malaysia.—Geol. Survey Borneo Region, Malaysia, Bull. 9, Geol. Papers 1967, 1968, p. 56-73, pl. 1, text figs. 1-3 (maps, graphs), tables 1-3.—Fauna of Lupar estuary is predominantly calcareous, that of Labuk is predominantly arenaceous. Quantitative analyses are included.

Djanelidze, O. The intraspecific variability of some foraminifers of the middle Miocene of Georgia (English abstract of Russian text).—Akad. Nauk Gruzin. SSR, Instit. Paleobiol., 1968, p. 53-62, pls. 1-3.

Douglas, Robert G., and Rankin, Clay. Cretaceous planktonic Foraminifera from Bornholm and their zoogeographic significance.—Lethaia, v. 2, Sept. 15, 1969, p. 185-217, text figs. 1-18 (maps, range chart, drawings, graph), tables 1, 2.—Two assemblages, middle to early upper Cenomanian and lower Senonian. Two species are new.

Dulub, V. G. Foraminifera of the genus *Vaginulina* from the Lower Cretaceous beds of Volyno-Podolian borderland of the Russian platform and Forecarpathian depression (in Russian with English summary).—Izdat. L'vov. Univ., Paleont. Sbornik, No. 5, vyp. 1, 1968, p. 3-9, 1 pl.—Five species, 1 new.

Fisher, M. J., Funnell, B. M., and West, R. G. Foraminifera and pollen from a marine interglacial deposit in the western North Sea.—Proc. Yorkshire Geol. Soc., v. 37, pt. 3, No. 14, Aug. 14, 1969, p. 311-320, text fig. 1 (map), tables 1, 2.—Species listed indicating middle Pleistocene.

Frerichs, William E. Recent arenaceous foraminifers from Gulf of Mexico.—Univ. Kansas Paleont. Contr., Paper 46, Oct. 1, 1969, p. 1, 2, pls. 1, 2.—Three new species from deep water. *Ammoglobigerinoides* n. gen. (type species *A. dehiscens* n. sp.) and *Pseudotrochammina* n. gen. (type species *P. triloba* n. sp.) in the Trochamminidae.

Gagic, Nadezda. La microfaune Tortonienne et Sarmatienne inférieure des environs plus larges de Koceljevo (Serbie Occidentale) (French résumé of text).—Instit. Recherches Geol. Geophys., Vesnik (Geol.), ser. A, v. 26, 1968, p. 229-242, pls. 1-5, text figs. 1-3 (stratig. column, map, graph), table 1 (check list).—Illustrations of Foraminifera.

Gonzalez-Donoso, J. M. Données nouvelles sur la texture et la structure du test de quelques Foraminifères du bassin de Grenade (Espagne).—Revue de Micropaléontologie, v. 12, No. 1, June 1969, p. 3-8, pls. 1, 2.—Photomicrographs of thin sections.

Greiner, Gary O. G. Recent benthonic Foraminifera: Environmental factors controlling their distribution.—Nature, v. 223, No. 5202, July 12, 1969, p. 168-170, text fig. 1 (map).—Type of wall may be limited by amount of available $CaCO_3$.

Gudina, V. I., and Saidova, Kh. M. Biostratigraficheskaja Zona *Miliolinella pyriformis* v Chetvertichnykh Otlozhenijakh Arktiki.—Doklady Akad. Nauk SSSR, Tom 185, No. 5, 1969, p. 1109-1111, text figs. 1, 2 (drawings).—*Tappanella* gen. nov. (type species *Glandulina laevigata* of Gudina 1966).

Haynes, John, and Dobson, Max. Physiography, Foraminifera and sedimentation in the Dovey estuary (Wales).—Geological Jour., Liverpool, v. 6, pt. 2, 1969, p. 217-256, pls. 17-20 (photos), text figs. 1-17 (maps, graphs, profiles, diagrams), tables 1, 2.—Areal distribution of Foraminifera is used in interpreting the vertical sequence found in boreholes.

Hazel, Joseph E. Faunal evidence for an unconformity between the Paleocene Brightseat and Aquia Formations (Maryland and Virginia).—U. S. Geol. Survey Prof. Paper 650-C, 1969, p. 58-65, text figs. 1-5 (map, strat. section, range charts, correl. diagram), table 1 (check list).—A disconformity equivalent to two planktonic zones separates the Brightseat from the Aquia.

Hiltermann, Heinrich. Stratigraphy and microfauna in the Miocene of the Ukrainian Subcarpathians.—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 181-194, pl. 1, text figs. 1, 2 (map, range chart).—Based on well drillings. Subdivided into four bionomical units.

Hornibrook, N. de B. Foraminiferal biostratigraphy, *in* Geology of the Clifden section.—New Zealand Geol. Survey Bull., n. ser., No. 79, 1969, p. 98-110, table 11 (check list and range chart), text figs. 43-46 (drawings).—Illustrations of bioseries in the Miocene.

Hottinger, Lucas. Foraminifères benthoniques du Bassin Cotier de Tarfaya. 1. Foraminifères flabelliformes du Crétacé Supérieur.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 181-201, pls. 1-4, text figs. 1-8 (drawings, graphs).—Three species, 2 new, and 2 subspecies, both new, from the Santonian and Coniacian.

Foraminifères benthoniques du Bassin Cotier de Tarfaya. 2. Quelques Foraminifères benthoniques du Campanien.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 203-219, pls. 5-7, text figs. 9-14 (drawings).—Many species illustrated; 19 are discussed, none new.

Foraminifères benthoniques du Bassin Cotier de Tarfaya. 3. Sur le phylum *Robulus incisus* Lys.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 221-225, text figs. 15, 16 (drawings).—*Robulus praeincisus* in the Coniacian and *R. incisus* in the Paleocene or top Maestrichtian.

Foraminifères benthoniques du Bassin Cotier de Tarfaya. 4. Les Nummulites d'un Galet du Moghrebien de la Sebkha el Khemira.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 227-230, text figs. 17, 18 (drawings).

Huang, Tunyow. Some planktonic foraminifers from a bore at Shihshan, near Taitung, Taiwan.—Proc. Geol. Soc. China, No. 12, April 1969, p. 103-118, pls. 1-4, text figs. 1, 2 (electric log, map), tables 1, 2.—Early Pliocene age.

Iturralde-Vinent, Manuel A. Principal characteristics of Cuban Neogene stratigraphy.—Bull. Amer. Assoc. Petr. Geol., v. 53, No. 9, Sept. 1969, p. 1938-1955, text figs. 1-13 (correl. diagram, map, geol. sections, strat. sections, paleogeogr. maps), table 1 (check list).

Jarzeva, M. W., Lotsch, Dieter, and Nemkov, G. I. Zur Nummulitenfauna des mittleren und Höheren Eozäns der Deutschen Demokratischen Republik.—Geologie, Berlin, Jahrg. 17, Heft 4, 1968, p. 418-459, pls. 1-9.—Four species.

Kaesler, Roger L., and Fisher, William L. Population dynamics of *Triticites ventricosus* (Fusulinacea), Hughes Creek Shale, Kansas. —Jour. Pal., v. 43, No. 5, Sept. 1969, p. 1122-1124, text figs. 1, 2 (graphs), table 1.

Kasimova, G. K., and Alieva, D. G. Novye Predstaviteli Miliolid iz Jurskikh Otlozhenij Azerbaidzhana.—Akad. Nauk Azerbaid. SSR, Doklady, Tom 25, No. 5, 1969, p. 39-42, text figs. 1-8.—Three new species of *Spirophthalmidium* from the Jurassic.

Kenawy, Abbas. Die Grossforaminiferen des bayerischen Ultrahelvetikums.—Geol. Bavarica, No. 56, 1966, p. 103-176, pls. 1-19, text figs. 1-8 (maps, diagrams).—Mostly nummulites.

Kennett, James P. Foraminiferal studies of southern ocean deep-sea cores.—Antarctic Jour. of U.S., v. 4, No. 5, Sept.-Oct. 1969, p. 178-179, correl. chart.—Eight intervals of climatic warming during the last 1.2-1.3 million years, and 3 faunal zones: *Globorotalia puncticulata, G. inflata,* and *G. truncatulinoides.*

Koehn-Zaninetti, Louisette, and Brönnimann, Paul. Sur la présence de Foraminifères porcelanés perforés dans le Trias alpin.—Riv. Ital. Paleont. Stratig., v. 74, No. 4, 1968, p. 1057-1062, pl. 67.—Quinqueloculine and biloculine forms of indeterminate genus.

Krasheninnikov, V. A. Geographical and stratigraphical distribution of planktonic foraminifers in Paleogene deposits of tropical and subtropical areas (in Russian).—Acad. Sci. USSR, Geol. Instit., Trans., v. 202, 1969, p. 1-188, tables 1-9.

Le Calvez, Yolande. Les Foraminifères du Paléogène des sondages de Chaignes, Montjavoult, Cires-lès-Mello—Le Tillet et Ludes (Bassin de Paris).—Mém. B. R. G. M., Colloque sur l'Éocène, Paris, May 1968, v. 11, No. 59, 1969, p. 101-106, range chart.—Ranges between Thanetian and Oligocene are shown for about 200 species.

Lehmann, Roger. Les Foraminifères pelagiques du Crétacé du Bassin Cotier de Tarfaya. 1. Planomalinidae et Globotruncanidae du Sondage de Puerto Cansado (Albien Supérieur, Cenomanien Inférieur).—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 153-167, pls. 1, 2, text fig. 1 (drawings).—Eleven species, *Rotalipora klausi* new, from upper Albian.

Les Foraminifères pelagiques du Crétacé du Bassin Cotier de Tarfaya. 2. *Globotruncana concavata* (Brotzen) dans la coupe de la Sebkha Tah.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 169-171, text fig. 2 (drawings).—Variation illustrated by material from Santonian and Coniacian.

Les Foraminifères pelagiques du Crétacé du Bassin Cotier de Tarfaya. 3. Discussion taxonomique et repartition stratigraphique de quelques Foraminifères pelagiques Crétacés du Bassin Cotier de Tarfaya.—Service Géol. Maroc, Notes et Mem., No. 175, Tome II, Paléontologie, 1966, p. 173-175.

Liêm, Nguyen van. Some Triassic Foraminifera from Hoang Mai limestone, Nghe An province, North Vietnam.—Acta Sci. Vietnam., Sec. Sci. Biol. Geogr. Geol., Hanoi, tom I, 1966, p. 37-44, pl. 1.—Eight species (6 new), 1 new subspecies and a forma.

New fusulinids from Quy Dat, Central Vietnam. —Acta Sci. Vietnam., Sec. Sci. Biol. Geogr. Geol., Hanoi, tom I, 1966, p. 45-48, text figs. 1, 2 (photomicrographs, phylogenetic diagram).—*Quydatella* gen. nov. (genotype *Q. staffellaeformis* sp. nov.) and *Palaeostaffella* subgen. nov. of *Pseudoendothyra* (genotype *Staffella moelleri* Ozawa).

Lipps, Jere H. Tertiary plankton from the Clipperton fracture zone, equatorial East Pacific.—Geol. Soc. America Bull., v. 80, No. 9, Sept. 1969, p. 1801-1808, text figs. 1-5 (maps, zone chart), table 1.—Lower Miocene to Holocene in 10 deep-sea cores, correlated with the planktonic zonation and European and Californian stages.

Magné, A., and Espitalié, J. Un nouveau procédé de préparation pour la photographie des microfossiles dégagés.—Revue de Micropaléontologie, v. 12, No. 1, June 1969, p. 63-65, pl. 1.—Using a kind of colorless glaze.

Maisuradze, L. S. Some data on the variability of the Sarmatian Miliolidae and Nonionidae of the West Georgia (English abstract of Russian text).—Akad. Nauk Gruzin. SSR, Instit. Paleobiol., 1968, p. 63-74, pls. 1-3.

Martinez Diaz, Carlos. Estudio Micropaleontologico de Cuatro Cortes del Miocene de Murcia (España).—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 147-180, pls. 1-8, text figs. 1, 2 (map, stratigraphic sections), check list. —Check list of 288 benthonic and 76 planktonic species in the uppermost Miocene ("Elveziano" to Andalusian); many species illustrated.

MARTINEZ P., RUBÉN. Edad y paleoecología del "Piso de Millongue."—El Terciario de Chile, zona central, Soc. Geol. Chile, 1968, p. 125-141, pls. 1, 2, text figs. 2, 3 (map, correl. diagram).—Middle Eocene planktonics illustrated.

Zonación preliminar del Terciario de Chile Central mediante foraminíferos planctónicos y su correlación regional y transcontinental.—El Terciario de Chile, zona central, Soc. Geol. Chile, 1968, p. 191-203, text fig. 1 (range chart and correl. table).—Ranges in Chile between Paleocene and Pleistocene shown for 46 planktonic species.

Foraminíferos y evolución de la línea de costa holocénica en la zona de Concepción.—El Terciario de Chile, zona central, Soc. Geol. Chile, 1968, p. 211-257, pl. 1, text figs. 1-4 (maps, graphs).—Three superposed Foraminifera biofacies, representing ancient coastal zones on a thick coastal plain deposit, interpreted as three stages in the Flandrin transgression between 9,400 and 1,600 years B. P.

MARTINEZ P., RUBÉN, and OSORIO O., ROBERTO. Foraminíferos pliocénicos de Chile Central. II. Edad y paleoecologia de la formacion Tubul.—El Terciario de Chile, zona central, Soc. Geol. Chile, 1968, p. 155-165, text figs. 1, 2 (map, drawings).—Middle Pliocene Foraminifera.

MARTINEZ P., RUBÉN, and PARADA R., CARMEN. Foraminíferos Pliocénicos de Chile Central. III. Foraminíferos Pliocénicos de San Sebastian (Laguna de los Patos), Provincia de Santiago.—El Terciario de Chile, zona central, Soc. Geol. Chile, 1968, p. 167-189, pls. 1, 2, text figs. A, B (map, section).—Middle Pliocene Foraminifera listed and illustrated. The fauna, dominated by *Bolivina argentea,* indicates poor oxygen and low salinity.

MEDIZZA, FABIO. I Generi *Bolivinoides, Aragonia* e *Neoflabellina* (Foraminifera) nelle formazioni Cretaceo-Eoceniche del Veneto.—Mem. Istit. Geol. Min. Univ. Padova, v. 26, 1967-68, 1969, p. 1-44, pls. 1, 2, text figs. 1-6 (map, correl. diagram, range chart, phylogenetic diagram, drawings).—Sixteen species, 1 *Neoflabellina* new.

MELLO, JAMES F. Foraminifera and stratigraphy of the upper part of the Pierre Shale and lower part of the Fox Hills Sandstone (Cretaceous), north-central South Dakota.—U.S. Geol. Survey Prof. Paper 611, Sept. 8, 1969, p. 1-121, pls. 1-12, text figs. 1-14 (maps, range charts, correl. charts, graphs), tables 1, 2.—Includes descriptions and illustrations of 101 species, subspecies, or varieties, 7 new and 12 indeterminate. Three biofacies are recognized. Age is earliest Maestrichtian or latest Campanian. Beds were deposited in waters less than 200 feet deep.

MIKHAILOVA, E. D., and MOROZOVA, V. G. New species of *Cyclammina* and its value for Oligocene zoning stratigraphy (in Russian).—Bull. Moscow Soc. Naturalists, Geol. Ser., v. 44, No. 3, 1969, p. 82-89, pls. 1, 2, 2 text figs. (diagrams).—*Cyclammina kendzhaliensis* sp. nov. and *araldaensis* subsp. nov.

MURRAY, JOHN W. Recent foraminifers from the Atlantic continental shelf of the United States. —Micropaleontology, v. 15, No. 4, Oct. 1969, p. 401-418, pl. 1, text figs. 1-15 (maps, graphs), tables 1-9.—Quantitative record of living and dead populations from Vineyard Sound (a region of fast tidal currents), the shelf off Long Island (a lower energy cold-water environment), and the shelf off Cape Hatteras (site of a large temperature gradient between cooler Virginian coastal water and warmer Carolinian coastal water).

PELHATE-PERON, ANNIK. Micropaleontologie des Calcaires Dinantiens du Bassin de Laval.—Bull. Soc. Geol. Min. Bretagne, n. ser. 1967 (April 1969), p. 27-76, pls. 1-6.—Foraminifera section includes about 45 species and varieties of Dinantian age.

PLOTNIKOVA, L. F. Representative of genus *Hoglundina* in the Upper Cretaceous and Dano-Paleocene deposits of the Konksko-Jalynskoj depression (in Russian with English summary).—Izdat. L'vov. Univ., Paleont. Sbornik, No. 5, vyp. 1, 1968, p. 25-29, 1 pl.—Three species, one new.

POAG, C. WYLIE. Dissolution of molluscan calcite by the attached foraminifer *Vasiglobulina,* new genus (Vasiglobulininae, new subfamily).—Tulane Studies in Geol. and Paleont., v. 7, Nos. 1, 2, July 16, 1969, p. 45-72, pls. 1-10, text figs. 1-4 (photomicrographs, diagrams, stratigraphic table).—A spinose polymorphinid, attached by its spines that produce solution cavities into which the spines are inserted. Type species *Globulina alabamensis* Cushman and McGlamery.

The Pliocene-Pleistocene boundary in the Gulf Coast region.—Tulane Studies in Geol. and Paleont., v. 7, Nos. 1, 2, July 16, 1969, p. 72-74.—Discussion of Foraminifera extinctions.

POPESCU, GH. Some new *Globigerina* (Foraminifera) from the upper Tortonian of the Transylvanian Basin and the Subcarpathians.—Revue Roumaine Géol. Géophys. Géogr., ser.

Géol., tome 13, No. 1, 1969, p. 103-106, pls. 1, 2.—Four species (3 new). *Velapertina* n. gen. (genotype *V. iorgulescui* n. sp.) has bullae covering secondary sutural apertures as well as the umbilical aperture.

PRONINA, T. V. New Silurian and Devonian foraminifers from the Urals (in Russian).—Akad. Nauk SSSR, Paleont. Zhurnal, No. 2, 1969, p. 21-33, pl. 5, text figs. 1, 2 (diagrams).—Ten new species; 2 genera and 1 subgenus are new.

PROSNIAKOVA, L. V. The species of genus *Thalmanninella* Sigal (Foraminifera) from the upper Albian and Cenomanian of the Crimean Plain (in Russian with English summary).—Izdat. L'vov. Univ., Paleont. Sbornik, No. 5, vyp. 1, 1968, p. 18-24, 1 pl.—Four species, none new.

QUILTY, P. G. On two recorded species of Tertiary Foraminifera from Fossil Bluff, Wynyard.—Papers and Proc. Royal Soc. Tasmania, v. 103, 1969, p. 97-98, 1 pl.—One is a broken echinoid spine; the other is given a new name, *Dentalina gadjeni.*

ROBLES-RAMOS, M. L., and FLORES-COVARRUBIAS, C. Catalogo ilustrado de los Foraminiferos planctonicos utilizados en la zonacion de Bolli, 1966.—Instit. Mexicano del Petroleo, Publ. No. 69 AE/047, 1969, p. 37-197, text figs. 1-65, range chart.—Compilation of illustrations and descriptions.

RUGET, CHRISTIANE, and SIGAL, JACQUES. Notas sobre la presencia del genero *Duostomina* (Foraminiferos) en los estratos de edad Triasica de Alhama de Granada, España.—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 237-240, pl. 1.—Free specimens of *Duostomina biconvexa* in Spain.

RUGGIERI, GIULIANO, CATALANO, RAIMONDO, and SPROVIERI, RODOLFO. Considerazioni sulla distribuzione del genere *Globorotalia* nel Pliocene Siciliano.—Boll. Soc. Geol. Ital., v. 87, fasc. 2, 1968, p. 277-284, text fig. 1 (range chart).

SALAJ, JOZEF. *Meandrospiranella* nov. gen., a new mid-Triassic foraminifer from the west Carpathians, Czechoslovakia.—Jour. Pal., v. 43, No. 5, Sept. 1969, p. 1294-1295.—Type species *M. samueli* Salaj, 1967.

SANDO, WILLIAM J., MAMET, BERNARD L., and DUTRO, J. THOMAS, JR. Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the United States.—U. S. Geol. Survey Prof. Paper 613-E, 1969, p. 1-29, pl. 1 (stratigraphic diagram), text figs. 1-7 (map, zonation chart, range charts, correl. chart).—Ranges of Carboniferous Foraminifera in 12 zones.

SCHNITKER, DETMAR. Distribution of Foraminifera on a portion of the continental shelf of the Golfe de Gascogne (Gulf of Biscay).—Bull. Centre Recherches de Pau, v. 3, No. 1, May 31, 1969, p. 33-64, text figs. 1-32 (maps, graphs), tables 1-3.—Study based on 42 samples. A fauna of 77 benthonic and 13 planktonic species is recorded. Percentages of 15 species are plotted on maps.

SCOTT, G. H. Stratigraphy of Hutchinsonian and Awamoan stages (lower Miocene) at Target Gully, Oamaru, New Zealand.—New Zealand Jour. Geol. Geophys., v. 11, No. 5, Dec. 1968, p. 1261-1270, text figs. 1-9 (strat. columns, drawings).—Correlation by planktonics and by trends in lineages.

SEIGLIE, GEORGE A., and BERMUDEZ, PEDRO J. Informe preliminar sobre los Foraminíferos del Terciario del Sur de Puerto Rico.—Carib. Jour. Sci., v. 9, No. 1, 2, March-June 1969, p. 67-80, text figs. 1-3 (map, range chart, correl. chart).—Lists of planktonic and benthonic species from 4 planktonic zones in the Ponce and Juana Diaz Formations.

SHENG, J. C. Permian Fusulinids of Kwangsi, Kueichow and Szechuan (in Chinese and English).—Palaeontologia Sinica, Whole Number 149, New Series B, No. 10, 1963, p. 1-247, pls. 1-36, maps, stratigraphic columns, phylogenetic diagram, tables 1, 2.—Illustrated systematic catalog includes 148 species, 52 species and 5 varieties new. New are the genera *Chenia* and *Neomisellina* and the subgenus *Wutuella* of *Minojapanella.*

SIGAL, JACQUES. Quelques acquisitions récentes concernant la chronostratigraphie des formations sédimentaires de l'équateur.—Rev. Española Micropaleontologia, v. 1, No. 2, 1969, p. 205-236, text figs. 1-3 (correl. chart, maps).—Lists of Foraminifera from Middle Cretaceous to upper Miocene across Ecuador (coastal, andine, and amazonal) and correlation with planktonic zonation.

SLITER, WILLIAM V. Three inner-neritic Recent foraminifers from southern California.—Univ. Kansas Paleont. Contr., Paper 45, Oct. 1, 1969, p. 1-5, pls. 1-6.—Two new species of *Bolivina* and one of *Coryphostoma,* all from Santa Monica Bay, illustrated by stereoscan photos.

TUFESCO, MIRCEA. Sur la présence de *Trichohyalus aguayoi* (Bermudez) dans la Mer Noire.—Revue de Micropaléontologie, v. 12, No. 1, June 1969, p. 46-52, text figs. 1-8 (map, drawings, graphs).—Includes discussion of their origin.

VLERK, I. M. VAN DER, and BANNINK, D. D. Biometrical investigations on *Operculina*.—Proc. Kon. Nederl. Akad. Wetenschappen, ser. B, v. 72, No. 3, 1969, p. 169-174, 1 pl., text figs. 1-3 (diagram, graphs).

VOLOSHINA, A. M. New occurrences of foraminiferal species in Paleogene of the Crimea (in Russian with English summary).—Izdat. L'vov. Univ., Paleont. Sbornik, No. 5, vyp. 1, 1968, p. 30-34, 1 pl.—Four species, none new.

WILLE, URSULA. Die Foraminiferenfauna des Eozäns von Schorn bei Abtenau (Salzburg, Österreich).—Jahrb. Geol. Bundesanstalt, Wien, Band 111, Heft 2, Oct. 1968, p. 213-291, pls. 1-16, text figs. 1-3 (map, zone charts).—A lower Eocene fauna of 69 species, 2 new.

ZAMILATSKAJA, T. K. Lower Permian fine Foraminifera complexes in southeast of Russian platform (in Russian).—Bull. Moscow Soc. Naturalists, Geol. Ser., v. 44, No. 2, 1969, p. 118-130, pls. 1, 2, text figs. 1, 2 (map, columnar section).—Five new species.

DE ZANCHE, VITTORIO. La serie Eocenica e i Nummuliti della Purga di Velo (Lessini Medi-Verona).—Mem. Istit. Geol. Min. Univ. Padova, v. 26, 1967-68, 1969, p. 1-27, pls. 1-3, text figs. 1-9 (maps, columnar section, graphs, drawings).—Nine species, 1 *Nummulites* new.

RUTH TODD
U. S. Geological Survey
Washington, D. C. 20242