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Planktonic Foraminifera from the Deep-Sea Cores of the Indian Ocean

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ABSTRACT

Of the eight piston cores from the deep-sea floor of the Indian Ocean, two contained abundant planktonic Foraminifera. One core is composed of uniform *Globigerina* ooze, and other of an alternation of brown clay and *Globigerina* ooze interbedded with a layer of secondary deposit.

The vertical changes of the species in the foraminiferal assemblage in the *Globigerina* ooze are inferred to reflect the paleoclimate at least since the last interglacial age. Analysis of the planktonic Foraminifera show that the alternation of brown clay and *Globigerina* ooze were deposited during cold and warm periods, respectively. This is interpreted also by that the bathymetric change of compensation depth of calcium carbonate occurred between glacial and interglacial ages.

The secondary deposits were carried by turbidity current from a shallow water region to the deep-sea floor.

CONTENTS

INTRODUCTION

During November of 1963 and February of 1964, the S.S. Kagoshima-Maru of the Kagoshima University participated in the International Indian Ocean Expedition.

Dr. Shozo Hayasaka* formerly of the Institute of Geology and Paleontology, Tohoku University, and then a member of the research party, boarded the Kagoshima-Maru, and was successful in collecting seven piston cores from along two traverses, viz. from off the southernmost part of the Indian Peninsula to Lat. 21°30.9′S. along Long. approx. 78°E. and from Lat. 2°02.5′N. to Lat. 5°14.3′S. along approx. 86°E. The majority of the cores were obtained from depths exceeding 4,000 m and their average length is approximately 304 cm. They are composed of *Globigerina* ooze, alternation of *Globigerina* ooze and brown clay with secondary sediments, Radiolaria ooze, red clay and gray colored clay. However only the first two cores were used for the micropaleontological study.

In general, the marine record which has the advantage of being slow and of continuous deposition is convenient for the study of the Pleistocene history. Especially the distribution of the planktonic Foraminifera which are closely related to the surface

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water temperature are valuable criteria for understanding problems of paleoclimatology. The two cores which yielded abundant tests of planktonic Foraminifera provide an ideal record of the marine sedimentary realm for the inference of the paleoclimate and include many problems.

Since Stubbings (1939) reported on the Foraminifera of six cores from the Arabian Sea, no micropaleontological study of the cores has been published from the equatorial Indian Ocean. In the meantime, micropaleontological investigations of the cores from the Atlantic and Pacific regions have progressed remarkably. At present, there is an interesting problem, mutual to both the Atlantic and Pacific regions. That is, Schott (1935), for the first time, found that the sediments deposited during the glacial age in the equatorial Atlantic region was poor in calcium carbonate, while Arrhenius (1952) in his study of the equatorial Pacific region, found the sediments of the glacial age to be rich in calcium carbonate. It is an interesting problem whether the content of calcium carbonate in the equatorial Indian Ocean during the glacial age corresponds to that of the Atlantic Ocean or to that of the Pacific Ocean.

The purpose of present paper is: 1) to describe the vertical distributions of the planktonic foraminiferal fauna washed out of two cores and based on them to infer the paleoclimate during the late Pleistocene from the ecological point of view of the Recent planktonic Foraminifera, 2) to interpret the geologic age of the different fauna or species in the cores, and 3) to attempt to discuss the relationship between the mechanism of the deep-sea sedimentation and paleoclimate.

To interpret the foraminiferal fauna washed out of the two cores, the report by Belyaeva (1964) on the ecologic distribution of living planktonic Foraminifera in the equatorial Indian Ocean is of importance. In the present paper the writer has made an attempt to review the works on the paleoclimate of cores, and to consider the two cores from the Indian Ocean from the view of paleontology, oceanography and sedimentology.

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MATERIALS

The cores studied were obtained from the middle part (along Long. approx. 78°E. from Lat. 3°29.7′N. to Lat. 21°30.9′S. and along Long. approx. 86°E. from Lat. 2°02.5′N. to Lat. 5°14.3′S.) of the Indian Ocean, during November and December, 1963 and January, 1964, by the research vessel S.S. Kagoshima-Maru of the Kagoshima University. One core (core no. Um–18) was collected in January, 1963 by the S.S. Umitaka-Maru of the Tokyo University of Fisheries. The stations of the 12 cores are plotted in Fig. 1, and listed in Table 1.

The stations of core operation and the submarine topography are shown in Fig. 2; the profiles are cut along the dashed lines. The shallowest depth where the cores were taken is 3,367 m, whereas the deepest is 5,442 m. In general, the majority of the cores were obtained from depths exceeding 4,000 m and those from eight of the 12 stations measure 215.5 cm to 349.0 cm in length and the average is approximately 304

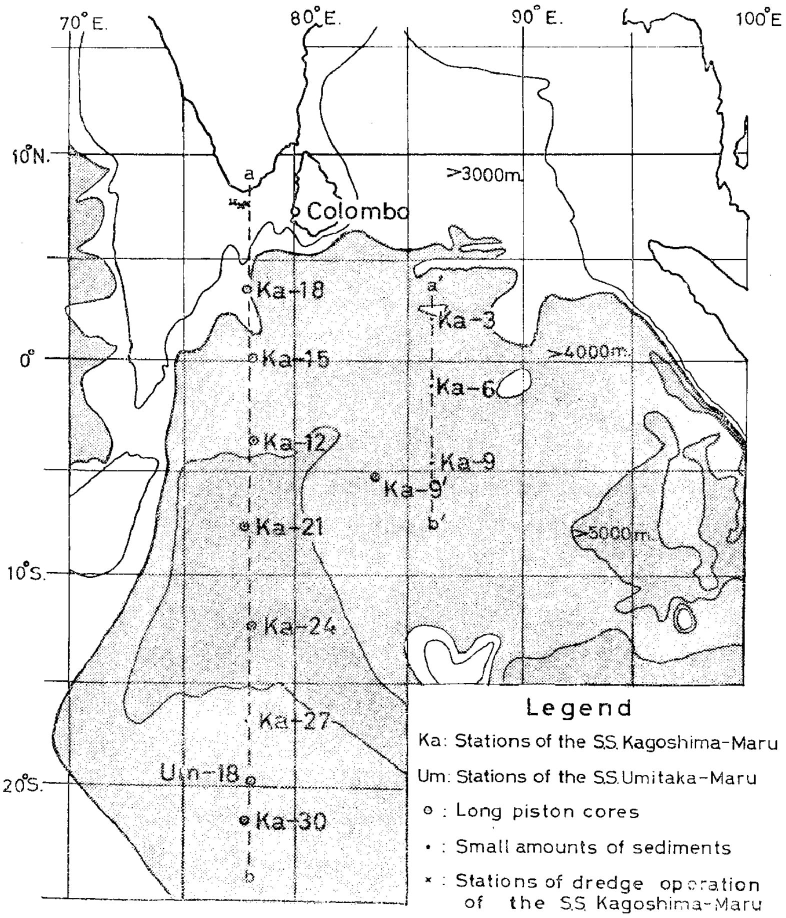

Fig. 1. Location of the cores and bathymetric chart of the Indian Ocean.

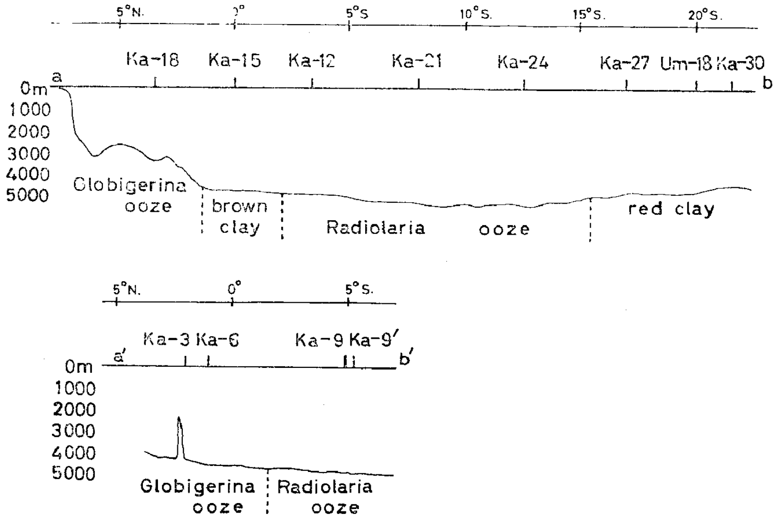

Fig. 2. Profiles along the lines a-b and a′-b′ shown in Fig. 1.

cm. The cores were collected by a piston corer. The sediments of the top layer of the corer are in a fluid condition, and often considerably disturbed, because the long coring tube is usually handled in a horizontal position on board the ship. The bottom surface sediment samples of the oceanic basin were collected with a simple gravity corer used as the trigger weight on the piston corer. By this instrument a relatively undisturbed bottom

Table 1. Data of sampling stations.

Station number	Latitude	Longitude	Depth (in meters)	Core length (in centimeters)	Bottom surface sediments	
Ka-3	2°02.4′N.	86°02.4′E.	4347	15	grayish orange	*Globigerina* ooze
Ka-6	1°06.9′S.	86°02.5′E.	4643	10	moderate yellowish gray	
Ka-18	3°29.7′N.	77°49.6′E.	3454	205.5	yellowish gray	
Ka-15	0°00.5′N.	78°08.8′E.	4843	319	grayish olive green	clay
Ka-9′	5°27.9′S.	83°37.7′E.	4938	260.5	olive gray	
Ka-9	4°56.1′S.	85°55.3′E.	4882	—	dark yellow brown	Radiolaria ooze
Ka-12	3°19.6′S.	78°06.5′E.	4890	349, 12	moderate brown	
Ka-21	7°58.2′S.	77°46.8′E.	5389	336.5	moderate brown	
Ka-24	12°31.9′S.	77°55.3′E.	5433	341	moderate brown	
Ka-27	16°52.0′S.	77°50.4′E.	4771	—	vandyke brown	Red clay
Ka-30	21°30.9′S.	77°55.0′E.	4587	303	vandyke brown	
Um-18	19°52.9′S.	77°56.′0′E.	4374	308, 30	vandyke brown	

Ka-: Kagoshima-Maru Um-: Umitaka-Maru

surface sample ould be obtained.

DESCRIPTION OF THE CORES

The cores obtained by the piston corer were cut into sections 90 cm long, and both ends were closed with celluloid caps. In this way they were stored for about 10 months. On unpacking, the plastic inner tubes were cut through lengthwise into two equal halves with a rotational saw. One of the two halves was photographed, and the sediments were described as to color,* composition, grain size, structure and other characters. The other half of the core was sealed with a vinyl sheet and stored in the Institute of Geology and Paleontology, Tohoku University. The general lithological descriptions of the cores are based principally upon the microscopic examinations of the constituents larger than 74μ in size.

Core Ka–18

Location: Lat. 3°29.7′N., Long. 77°49.6′E.
Depth: 3454 m
Core length: 185 cm
Date[1]: December 15, 1963

The core is composed of a remarkably uniform light yellowish gray *Globigerina* ooze, containing throughout abundant and large tests of Foraminifera. The three muddy layers, one near the top (10 cm), at the middle (90 cm), and near the bottom (170 cm) mark the only departures from the apparent homogeneity of the sediments of the core. Although there are some slight changes in the color from yellowish gray to light olive gray, these colors

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* Rock-color chart distributed by the Geological Society of America, New York, N.Y., reprinted in 1963.

[1] Date of collection.

are mixed in part and relatively clear color boundaries are seen at 107 and 178 cm from the top. The mixed colors of the sediments may be due to reworking by mud eating bottom animals. Arrhenius (1952) stated that it is common that the normal deep sea sediments are disturbed by mud eating animals. The core yielded an overwhelming number of planktonic Foraminifera, that is to say, 5,400 specimens on average per gram of sediment, and a few percent (average 3.5%) of benthonic Foraminifera. Considerable amounts of broken foraminiferal tests are found in several parts of the core, at 10–20, 80–100, and 170–180 cm from the top, respectively. The yield of Radiolaria is low in percentage, but a few concentrations were found at about 60 cm from the top of the core. Abundant coccolithophorids were found throughout the core. At 10–20 and 180 cm from the top, the core yielded some fragments of fine quartz, mica, plant-fiber, and organic materials. Two blank parts, not filled with sediment, occurred at 41 cm and between 170 cm and 180 cm from the top.

Coarse fraction ($>74\,\mu$) in the core Ka–18: For the study of Foraminifera, 1 ± 0.0001 gram of sediment was washed on a 200 mesh sieve. The coarse fraction remaining on the sieve was weighed and recorded as percentage of coarse fraction. It provides not only an approximate estimation of the quantity of the calcium carbonate content, but also evidence for abnormal sedimentation when the calcium carbonate is not present. Practically the coarse fraction caught on the sieve consists almost entirely of the tests of planktonic Foraminifera. In the core Ka–18, the average of the coarse fraction is 20 percent (Fig. 4).

Core Ka–15
Location: Lat. 0°00.5′N., Long. 78°08.8′E.
Depth: 4843 m
Core length: 304.0 cm
Date: December 12, 1963

This core is essentially composed of an alternation of *Globigerina* ooze and brown clay with an interbedded layer of secondary deposited sediments. As a whole, it is poor in organic material except for some layers which are characterized by light olive gray color and high concentration of foraminiferal tests and their fragments. The brownish gray layers are mainly composed of clay size particles including very fine quartz, mica, etc., which are probably terrigineous in origin. A relatively coarse sediment layer is found at the lower part of the pale yellow greenish gray clay. There were a few to one thousand specimens of planktonic Foraminifera per gram of sediment. Abundant foraminiferal tests were found in the layers at 20, 40 and 140 cm from the top of the core and their fragments at 230–240, and 270–280 cm. Concentrations of Radiolaria were found at about 60 cm and 130–140 cm. Siliceous organic materials (Radiolaria, diatom) are included as much as in the core Ka–18. The fragments of mica, quartz, plant-fiber, sponge spicules, Mollusca, and Ostracoda are more abundant in the greenish gray colored clay than in any other part of the core. Small fragments of coccolithophorids, though less than in the core Ka–18, are found from the top to the bottom of the core.

Top–67 cm: Alternation of dark brown and light olive gray colored sediments.

The color of the top part of the core coincides with the color of the bottom surface sediment sample obtained by the gravity corer. The upper part is light brownish gray but changes gradually to dark brownish gray towards and in the middle part. At 20–25 cm from the top there is a relatively high concentration of planktonic Foraminifera. A sharp color boundary, changing from dark brown to light olive gray, occurs at 37 cm, where the layer is bent upward by the friction against the inner wall of the tube. A conspicuous maximum in the concentration of Foraminifera occurs at 40–45 cm from the top of the core. Below 58 cm the color again becomes darker brown but both its upper and lower boundaries show a gradual change upwards and downwards.

67–139 cm: Olive gray colored sediments.

A homogeneous olive gray clay occurs from 67 cm to 139 cm from the top of the core. The materials such as mica, plant-fiber, and sponge spicules are concentrated in that part of the core, and the concentration of organic material is abnormally low. Especially the few foraminiferal tests are mostly thin shelled immature forms of ill preservation. The sediment is probably the result of rapid deposition.

139–149 cm: Pale olive colored sediment.

In the part of the core mentioned above, there is a structural feature (Pl. 17), consisting of slightly coarse sediment (silt grain size), mostly of quartz and mica, which shows distinct grading and lamination parallel to the irregular shape of the lower boundary; the upper boundary is faint. Compared with the superjacent section (67–139 cm), a larger number of foraminiferal tests were found, but with no marked change in the faunal character. Abundant tests and fragments of Ostracoda, Mollusca (Pelecypoda and Gastropoda) were found in this part of the core, especially of their larval stage are predominant. The sediment from 67 cm to 149 cm from the top seems to have been derived from elsewhere by turbidity current, and possibly some of the previously deposited sediment was lost through this action. Dietz (1954) suggested possible deep-sea turbidity current channels in the eastern Indian Ocean about 400 nautical miles northeast of the locality of core Ka–15. He explained that the deep-sea channels were formed by turbidity currents flowing out from the Bay of Bengal.

149–304 cm: Alternation of dark brownish gray and light olive gray colored sediments.

In the part of the core, there are five dark brownish gray layers and four light olive gray layers, their boundaries are sharply defined by the change in color of the sediments. The light olive gray layers do not represent relatively high value of foraminiferal number as expected, but a considerable concentration of fragments of planktonic foraminiferal tests. The lowermost part (304 cm) of the core contains abundant fragments of relatively large mica, quartz, and plant-fiber.

Coarse fraction ($>74\ \mu$) in the core Ka–15: In normal abyssal brown clay, such as in core Ka–15, the coarse fraction is less than 1 percent of the total as a rule. The light olive gray sections contain a few percent of carbonaceous matter (Fig. 5). When the rate of coarse fraction represents a high percent, in spite of the absence of carbonates, the coarse fraction is frequently useful for distinguishing between sediments of slow continuous accumulation and interbedded layers of abnormal deposition by turbidity currents and slumping etc. Turbidity current deposition may be suspected wherever the percentage of the coarse fraction changes abruptly at the base and decreases gradually from the bottom to the top of the layer. The gradual decrease in percentage of coarse fraction in the lower part of the greenish gray colored clay of the core Ka–15 represents a layer inferred to have been deposited by turbidity currents.

Core Ka–9′

Location: Lat. 5°27.9′S., Long. 83°37.7′E.
Depth: 4938 m
Core length: 260.5 cm
Date: December 5, 1963

The core is composed of homogeneous gray clay characterized with abundant fine fragments of mica (mostly sericite). The top of the core, down to 50 cm, is composed of relatively coarse clay including many fragments of quartz, large mica, and manganese particles. The concentration of Radiolaria is found in the layers from the top of the core down to 50 cm. The content of Foraminifera is extremely low and sporadic, whereas coccolithophorids occur throughout the core.

Core Ka–12

Location: Lat. 3°19.6′S., Long. 78°06.5′E.
Depth: 4890 m
Core length: 349.0 cm
Date: December 9, 1963

The core is composed of yellowish brown Radiolaria ooze with abundant diatoms. The Foraminifera and coccolithophorids are completely dissolved. Small amounts of fine quartz, mica, and sponge spicules were observed throughout the core. Some other organic materials were found at the top and at 20 cm from the top. Between 230 and 250 cm from the top of the core many black spots inferred to be manganese micronodules were found.

Core Ka–21

Location: Lat. 7°58.2′S., Long. 77°46.8′E.
Depth: 5389 m
Core length: 336.5 cm
Date: December 28, 1963

The core is composed of moderate yellow brown Radiolaria ooze with abundant diatoms. Structures of thin layers and irregular shapes with boundaries sharply defined by color changes are found throughout the core. No tests of Foraminifera or coccolithophorids were found. Sponge spicules occur throughout the core.

Core Ka–24

Location: Lat. 12°31.9′S., Long. 77°55.3′E.
Depth: 5433 m
Core length: 341.0 cm
Date: December 31, 1963

The sediment of the core bears close resemblance to core Ka–21 with regard to the composition and structure. It is composed of moderate yellow brown Radiolaria ooze with abundant diatoms. The concentrations of organic material such as Radiolaria, diatom, and sponge spicules in both cores (Ka–21 and Ka–24) are almost equal in quantity and amount to about five percent per gram of sediment. No tests of Foraminifera or coccolithophorids were found.

Core Ka–30

Location: Lat. 21°30.9′S., Long 77°55.0′E.
Depth: 4587 m
Core length: 139.5 cm
Date: January 7, 1964

The core is composed of homogenous reddish brown clay, so-called "red-clay" which is characterized by the presence of large amounts of halmeic minerals such as phillipsite, a kind of zeolite mineral, manganese micronodules and small amounts of fine quartz. According to Arrhenius' classification of pelagic sediments (1952) the term "red-clay" (*s. s.*) corresponds to "ferrugeneous pelagic clay", which may be the type having wide areal distribution in the Indian Ocean. The core contains sporadically some tests or fragments of Radiolaria, Foraminifera, fish bones and Pteropoda.

Core Um–18

Location: Lat. 19°52.9′S., Long. 77°56.0′E.
Depth: 4374 m
Core length: 308.0 cm
Date: January 5, 1963

The information of this core was received from K. Oshite (1965, personal communication).

The core is composed of homogeneous red to deep chocolate colored clay, so-called "red-clay". There is considerable difference in composition of the sediments between the upper and the lower parts of the core. The former contains many kinds of organic materials such as Foraminifera (e.g. *Rotalia*), diatom (e.g. *Coscinodiscus*), Radiolaria, and Copepoda fragments, whereas the latter is characterized by microparticles of manganese nodules and microcrystals, presumably in situ phosphorite. Besides round quartz grains and relatively large fragments of quartz, which are probably of volcanic origin, a large amount of cosmic dust was discovered by H. Niino. Rather large manganese nodules with an approximate diameter of 4 cm, were found in the upper part of the core and these nodules show radioactivity twice as much as made on the normal ocean floor.

The following small amounts of sediments were collected by the piston corer or gravity corer.

Core Ka–3: grayish yellow brown colored *Globigerina* ooze, with Radiolaria, mica (biotite), and quartz.

Core Ka–6: (by gravity corer), dark yellow brown colored clay with abundant fragments of foraminiferal tests, and with Radiolaria, mica, plant-fiber, and quartz.

Core Ka–6: (by piston corer), dark olive colored clay, with abundant angular and large quartz and mica (biotite and muscovite).

The loss of the top layer of the piston core is conceivable.

Core Ka–9: moderate yellow brown colored Radiolaria ooze, with manganese particles, mica, and diatom.

Core Ka–27: vandyke brown colored clay, so-called "red-clay", with Radiolaria, manganese particles, quartz, and phillipsite.

All of the cores are shown on Pls. 18–20. Their surface sediments, remaining on a 200-mesh sieve, are illustrated on Pl. 24.

METHOD OF STUDY

In several of the cores, there were some parts not filled with sediments, but the writer believes that the tube was filled with sediments and they were originally continuous. The samples used for the discrimination of Foraminifera were selected from a fourth longitudinal section of the whole core. The fourth section of the core was cut transversally into 1.0 cm thick horizontal slices at the intervals of 10 cm or 5 cm. Concerning the interval of sampling in a single core, Arrhenius (1952) stated "Reworking of the sediment by mud eating bottom animals was found to be a characteristic feature in all normal pelagic deposits which made it meaningless to define the sample levels closer than 10 cm thick. For the same reason decrease of the sample distances to less than 2–3 cm does not involve an increase of the stratigraphical accuracy in bathyal pelagic deposits brecciated by scavengers." Approximately 4 mm width of the outer portion of each of the samples were trimmed to avoid faunal contamination by drag caused by the friction with the tube. Each sample was measured to 1 ± 0.0001 gram dry weight and then carefully washed through a 200-mesh sieve, which retains all the adult and juvenile Foraminifera. After drying again only the fraction retained on a 115-mesh sieve was used for the present study. Almost all the adult Foraminifera were retained on this sieve. The residual material retained on a 115-mesh sieve commonly contains several thousand specimens of planktonic Foraminifera. For this reason the splitting process was repeated till obtaining a sample of convenient quantity. All the specimens in this divided sample were counted separately as to planktonic and benthonic Foraminifera, and the total number of specimens per gram of sediment was estimated; this is the "Foraminiferal number" proposed by

Schott (1935) in his extensive study of the deep-sea cores collected from the equatorial Atlantic. A sample is spread as evenly as possible on a picking tray having a grid system. All specimens in some squares which are selected at random are counted, the squares are straggered on some regular system so that the squares selected represent the entire surface. In this manner, 200 specimens of planktonic Foraminifera were picked up from each sample, at the same time some benthonic Foraminifera were also counted. This method is adequate and assures that no concentrations of specimens or species, though some rare species are overlooked in such a procedure. The faunal data thus obtained are divided into planktonic and benthonic Foraminifera as percentages of total populations (Table 2 and 3). The ratio of benthonic Foraminifera to total populations in each sample was determined, the analysis of benthonic Foraminifera, however, is employed only as additional data.

PREVIOUS WORKS

So far, only a few cores from the Indian Ocean have been analyzed micropaleontologically.

Philippi (1912), in the description and interpretation of the cores taken by the "Gauss" in the South Atlantic and southern Indian Ocean, pointed out that the lower boundary of the zone of tropical Foraminifera coincided with the top of red clay deposits. He interpreted both the absence of tropical Foraminifera and the presence of red clay below a blanket of *Globigerina* ooze as indicating generally colder water throughout the ocean at the last glacial stage and the greater extent of areas in which red clay was deposited in the past was due to the solvent and oxidizing effect of the greater quantities of carbon dioxide and oxygen that the cold water of that epoch could hold. Schott (1935) found in the cores of the equatorial Atlantic region that the upper boundary of the cool water zone was indicated by a cold-water foraminiferal fauna coincided approximately with the top of a zone of red clay.

Stubbings (1939), in his study of the Foraminifera of six relatively short submarine cores from the Arabian Sea, recognized an inverse population ratio between *Globigerina bulloides* and *Globorotalia menardii*. According to Stubbings (op. cit., p. 186), "In comparing the cores it is sufficient to use only a few of the species as indicators of condition. *Globigerina bulloides* and *Globorotalia menardii*, as the two commonest, at once suggest themselves. The former species is mainly an inhabitant of cold water, whereas the latter is restricted to tropical and subtropical waters. Moreover, from the counts made there seems to be an inverse relationship between these two species." Using the ratio *Globigerina bulloides*/*Globorotalia menardii*, he interpreted that four high values can be recognized in the longest core (no. 128), from the South Somali Basin, at a depth of 4,060 m; the core length was 132.0 cm. These four values represent a colder water condition, probably glacial, than now existing in that region.

Ericson *et al.* (1963) defined the "Pliocene-Pleistocene" boundary by following the paleontological criteria in seven deep-sea cores from the Atlantic Ocean and one in the Indian Ocean. Their criteria were:

1) Extinction of all discoasters.
2) Change in the coiling direction of members of the *Globorotalia menardii* complex from 95 percent dextral coiling below the boundary to 95 percent sinistral coiling above it and at all higher levels in the Pleistocene.
3) Appearance of *Globorotalia truncatulinoides* in abundance above the boundary.
4) Extinction of *Globigerinoides sacculifera fistulosa*.
5) Reduction of the *Globorotalia menardii* complex to a single fairly uniform race

above the boundary.

6) Increase in the average diameter of the tests of *Globorotalia menardii* and reduction in their number with respect to the assemblage of Foraminifera above the boundary.

They placed the "Pliocene-Pleistocene" boundary in the Indian Ocean core V16–66, Lat. 42°39′S. Long. 45°40′E. depth 2,995 m core length 1108 cm, at about 235 cm from the top based on the appearance of *Globorotalia truncatulinoides* and the disappearance of the discoasters. Bandy (1963), however, criticized these criteria and stated that the boundary was actually the "Miocene-Pleistocene" boundary.

Fortunately, Belyaeva (1964) found, in her detail study with regard to the distribution of living planktonic Foraminifera in the Indian Ocean, that the foraminiferal fauna is closely related to the water mass (Fig. 3). The equatorial and temperate regions contain larger number of specimens of planktonic Foraminifera than elsewhere. But the central-water region generally supports small concentrations and is characterized by the range in temperature from 10 to 23 degrees, in salinity from 34.7 to 35.7‰, and low productivity of organisms. The fewest number of species (1 or 2 species) and least individuals are found in the Antarctic region (10–20 specimens per 1000 m^3 water filltered). On and in the bottom sediments, abundant tests of planktonic Foraminifera are widely distributed northwards of the Antarctic convergence above 4,500–4,700 m in depth, particualry on the Middle Indian Ridge and continental shelf. Below the depth of 4,500–4,700 m from the sea-level, *Globigerina* ooze gradually changes into red clay or brown clay with some foraminiferal tests showing the effect of fusion as in the case of the present cores Ka–15, Ka–27, Ka–30, and Um–18. At depths greater than 5,000 m, Radiolaria ooze is widely distributed in the oceanic sediments, such as seen in the present cores Ka–9, Ka–12, Ka–21, and Ka–24. Far north of the Middle Indian Ridge, the largest concentrations of Foraminifera were found in the sediments between 2,234–4,400 m in depth, while south of Lat. 40°S. between 1,500–2,257 m in depth. This is evidently due to the dissolving of the tests of the planktonic Foraminifera below these depths by the cold bottom water from the Antarctic Sea. According to Belyaeva (1964), the distribution of planktonic Foraminifera in the surface water of the Indian Ocean could be divided into cold-water fauna, temperate (=temperate water) fauna, and tropical (=warm water) fauna. There are two transitional fauna recognized in the zones where two distinct faunas are mixed.

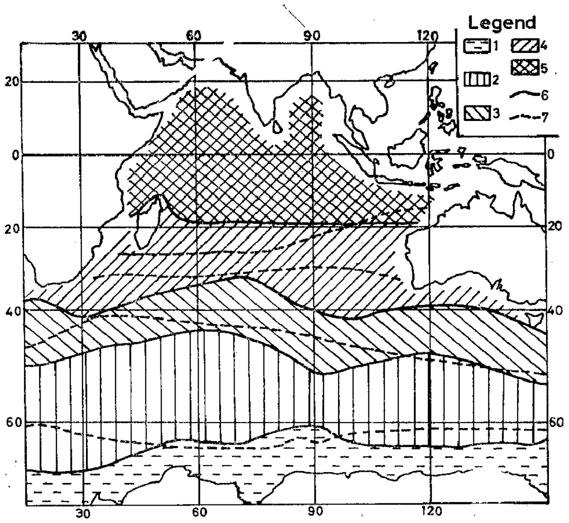


Fig. 3. Distribution of planktonic Foraminifera in the Indian Ocean.
1. Cold-water fauna 2. Transitional fauna 3. Temperate fauna
4. Transitional fauna 5. Tropical fauna 6. Biocoenoses
7. Thanatocoenoses (after N.V. Belyaeva 1964)

In general, these grouping of the foraminiferal assemblages are based upon the distribution of the living species according to the distribution of the surface water masses. There is stated to be considerable coincidence between the distribution of biocoenose and thanatocoenose and were defined by Belyaeva as follows.

Cold-water fauna:

This fauna is characterized by species restricted to the Antarctic region, and also includes a few of the temperate fauna. The most common species, *Globigerina pachyderma,* occupies the highest frequency of 94 to 100 percent of the total population. *Globigerina bulloides* is second in importance in this region though it has never high frequency in occurrence. The following species rarely occur in this region; *Globorotalia truncatulinoides, G. inflata, G. scitula, Globoquadrina dutertrei, Globigerinoides ruber,* and *Pulleniatina obliquiloculata.*

Temperate fauna:

This fauna is composed of species abundant in the temperate region and of cosmopolitan distribution, the abundant species are: *Globigerina bulloides, Globorotalia truncatulinoides, G. hirsuta, G. scitula* and *Orbulina universa. Globigerina pachyderma* appears to diminish at the north of this region. Typical in the tropical region and occur for the first time in this temperate fauna are: *Globorotalia menardii, G. tumida, Globoquadrina conglomerata, Sphaeroidinella dehiscens, Globigerinoides conglobatus, Globigerinella siphonifera.*

Tropical fauna:

This fauna consists of species limited to the tropical region and cosmopolitan forms. The species almost restricted to this area or are more common in the tropical region are: *Globorotalia menardii, G. tumida, Globoquadrina conglomerata, Pulleniatina obliquiloculata, Globigerinoides conglobatus, G. sacculifer, Sphaeroidinella dehiscens, Globigerinella siphonifera,* and *Candeina nitida.* Species more abundant in the temperate region although common in the tropical fauna are: *Globigerina bulloides, Globigerinoides ruber, Globoquadrina dutertrei,* and *Orbulina universa.*

The species which are treated as representative of each fauna in this paper are:

Cold water fauna:
- *Globigerina pachyderma* (Ehrenberg)

Temperate water fauna:
- *Globigerina bulloides* d'Orbigny
- *Globorotalia truncatulinoides* (d' Orbigny)
- *G. inflata* (d'Orbigny)
- *G. hirsuta* (d'Orbigny)
- *G. scitula* (Brady)

Warm water fauna:
- *Globorotalia menardii* (d'Orbigny)
- *G. tumida* (Brady)
- *Globoquadrina conglomerata* (Schwager)
- *Pulleniatina obliquiloculata* (Parker and Jones)
- *Sphaeroidinella dehiscens* (Parker and Jones)
- *Candeina nitida* d'Orbigny
- *Globigerinoides conglobatus* (Brady)
- *G. sacculifer* (Brady)
- *Globigerinella siphonifera* (d'Orbigny)

Cosmopolitan fauna:
- *Globigerinoides ruber* (d'Orbigny)
- *Globoquadrina dutertrei* (d'Orbigny)
- *G. hexagona* (Natland)
- *Orbulina universa* d'Orbigny

FORAMINIFERAL FAUNA OF THE CORES

Foraminiferal tests are found in the cores Ka–18 and Ka–15. The former yielded abundant tests of planktonic Foraminifera, the latter is composed essentially of an alternation of brown clay and *Globigerina* ooze. Although the definition of *Globigerina* ooze in the core Ka–15 is not in strict sense. The classification of planktonic Foraminifera in the present paper is after Parker (1962) who studied the sediments from the Pacific Ocean. The writer identified 10 genera, 32 species, and one subspecies as shown in Table 2 and 3. from the sediments of the cores. There remains some doubt as to the identity of *Globigerina pachyderma* and *G. bulloides.* The specimens here assigned to *G. pachyderma* are rather small and some may be immature forms of *Globoquadrina dutertrei.* The specimens assigned to *G. bulloides* have a large umbilical aperture. Among them the predominant ones in both cores are: *Globorotalia menardii, Globoquadrina dutertrei, Globigerinita glutinata, Globigerinoides ruber, G. sacculifer, Pulleniatina obliquiloculata.* The following species are next in abundance: *Globigerina bulloides, Globigerinella siphonifera, Globoquadrina conglomerata, G. hexagona, and Globorotalia tumida.* These species mostly belong to the tropical fauna and some are cosmopolitan in distribution. The top of the piston cores seem to be present-day deposits because of their coincidence with the sediment sample taken by the gravity corer, being similar to each other in color, foraminiferal number, benthonic foraminiferal percentage, and foraminiferal assemblage. In a quantiative study of the planktonic Foraminifera, the writer adopted the "Foraminiferal number" as indicating the number of specimens per gram (dry weight) of sediment. The core Ka-18 contains throughout abundant tests of planktonic Foraminifera. The foraminiferal number in the core Ka-18 is 5,400 specimens per gram of sediment in average, and varies from 700 at the minimum to 13,400 at the maximum (Fig. 4). The lower values of the foraminiferal number are found at 10, 90 and 170 cm respectively, from the top. On the contrary, its high values abruptly occur at 70 and 95 cm from the top. The frequency curve of the foraminiferal number precisely coincides with the curve of coarse fraction. According to Arrhenius (1952, p. 52), the concentration of calcium carbonate is in proportion to the foraminiferal number, shown as a function of the foraminiferal fragments. The foraminiferal number in the core Ka–15 is far less than in the core Ka-18 and the average value is 90 specimens per gram sediment. The maximum content of planktonic Foraminifera is 1,032 specimens per gram of sediment at 40 cm from the top, and several layers contain a few or no tests of Foraminifera (Fig. 5). In the core Ka–15, the relationship between the frequency curve of foraminiferal number and one of the coarse fraction does not coincide so closely as in the case of the core Ka–18. Several layers contain abundant foraminiferal tests at 20, 40, and 140 cm, respectively from the top, and fragments at 200, 230–240, and 270–280 cm. Generally the percentage of coarse fraction in the light olive gray clay is higher than in the one of brown clay, and not much can be expected of the foraminiferal number at 200, 230–240, and 270–280 cm from the top of the core. This suggests that the abundancy of *Globorotalia tumida* and benthonic Foraminifera at these layers are caused by an abnormally far-reaching dissolution or fragmentation, contrary to the low content of coarse fraction in the brown clay. Especially the foraminiferal numbers are relatively large at 210–220, 260, and 300 cm levels at which the percentage of coarse fraction is low. The planktonic Foraminifera in these layers consists of almost unbroken tests, which suggests that they were protected from the solution effect of bottom water by the concentration of calcium carbonate which is higher when the percentage of coarse fraction is high.

The average percentage of benthonic Foraminifera to the total population is 3.4 percent in the core Ka-18 and 33.4 percent in the core Ka-15, respectively (Figs. 4, 5). Some layers which are relatively high in value of benthonic foraminiferal percentage may be

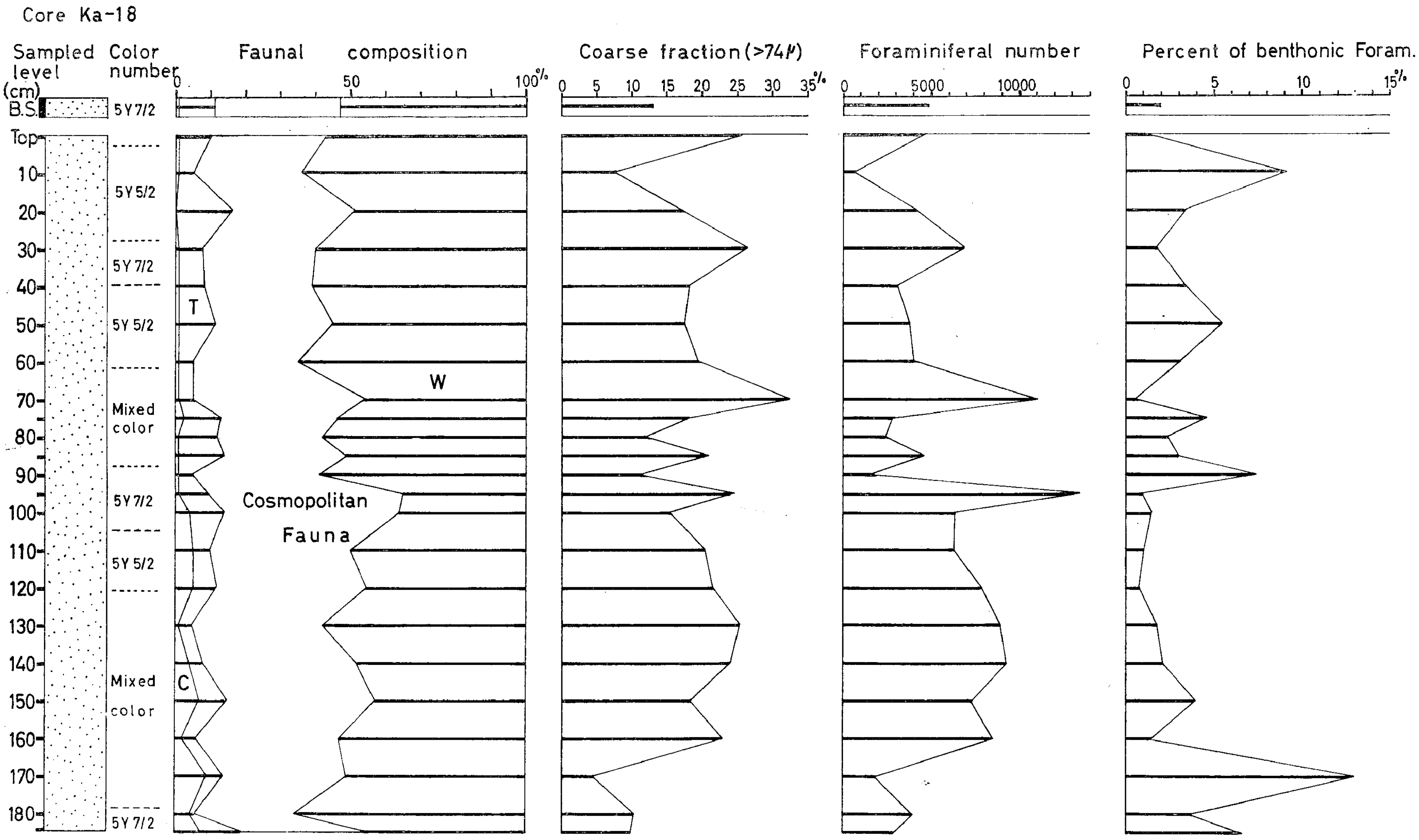
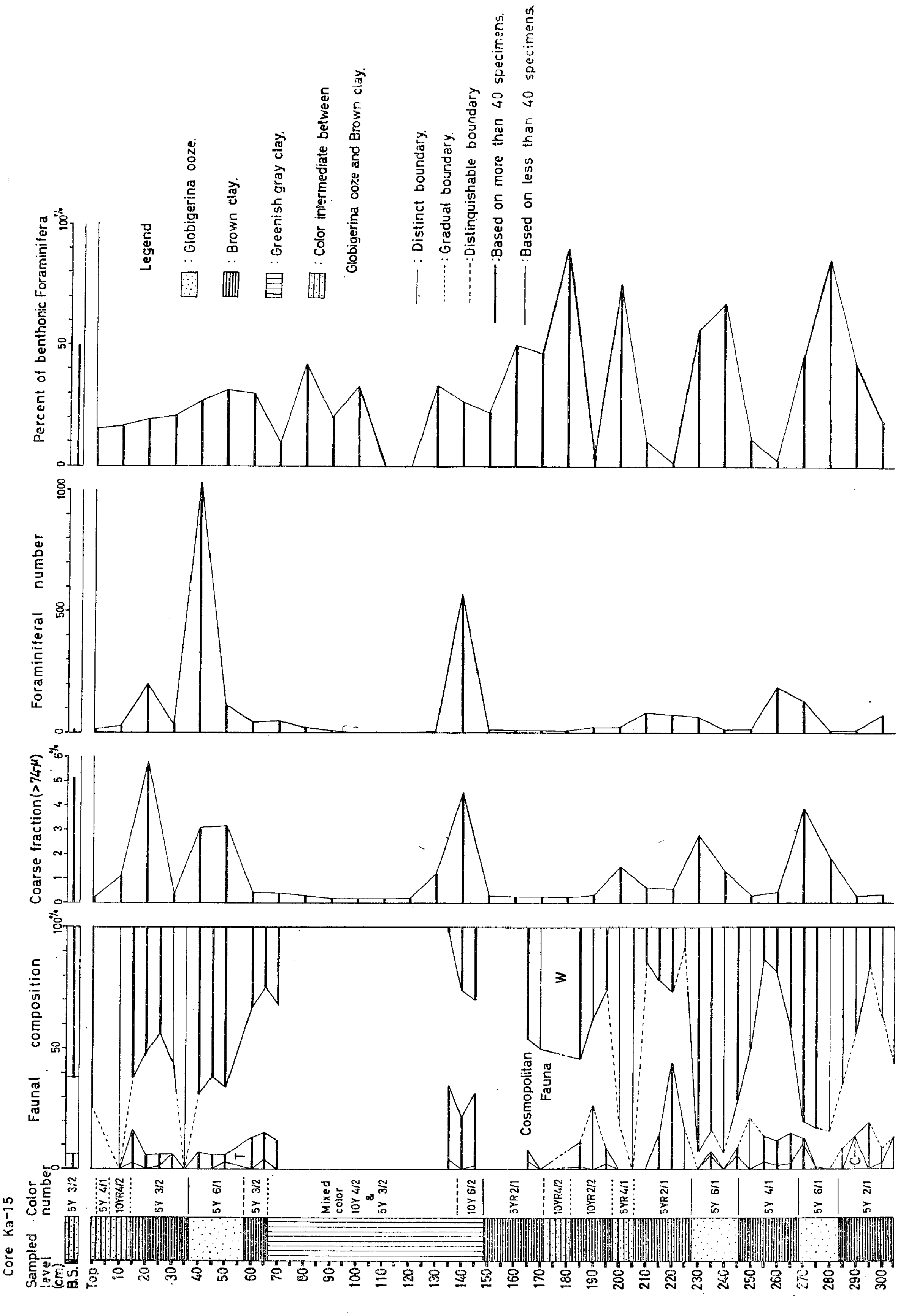


Fig. 4. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core Ka-18. B.S.: Bottom sample obtained by gravity corer. W: Warm water fauna, T: Temperate water fauna, C: Cold water fauna

Legend. ▨: Globigerina ooze. -----: Distinguishable boundary. -------: Gradual boundary.



B.S. : Bottom Sample obtained by gravity corer W : Warm water fauna, T : Temperate water fauna, C : Cold water fauna,

Fig. 5. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core Ka-15.

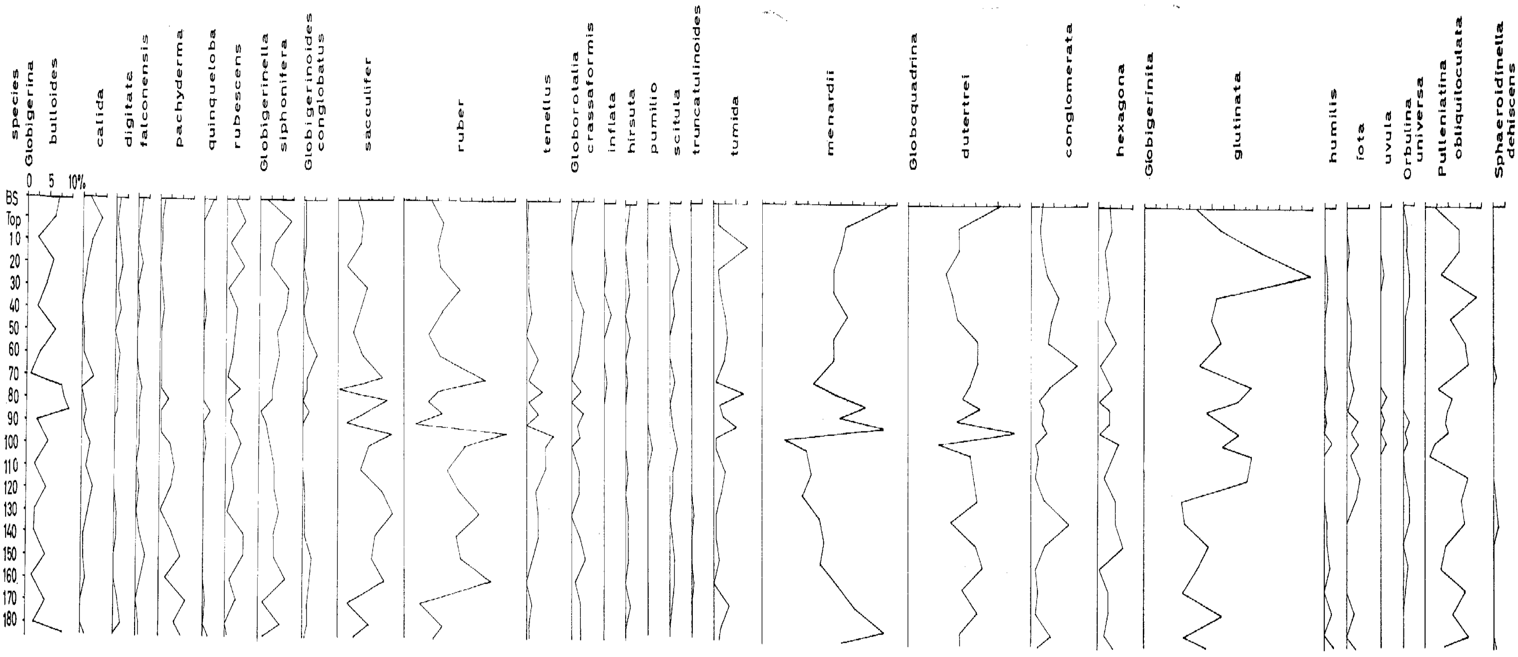


Fig. 6. Frequency Curve of the species from core Ka-18

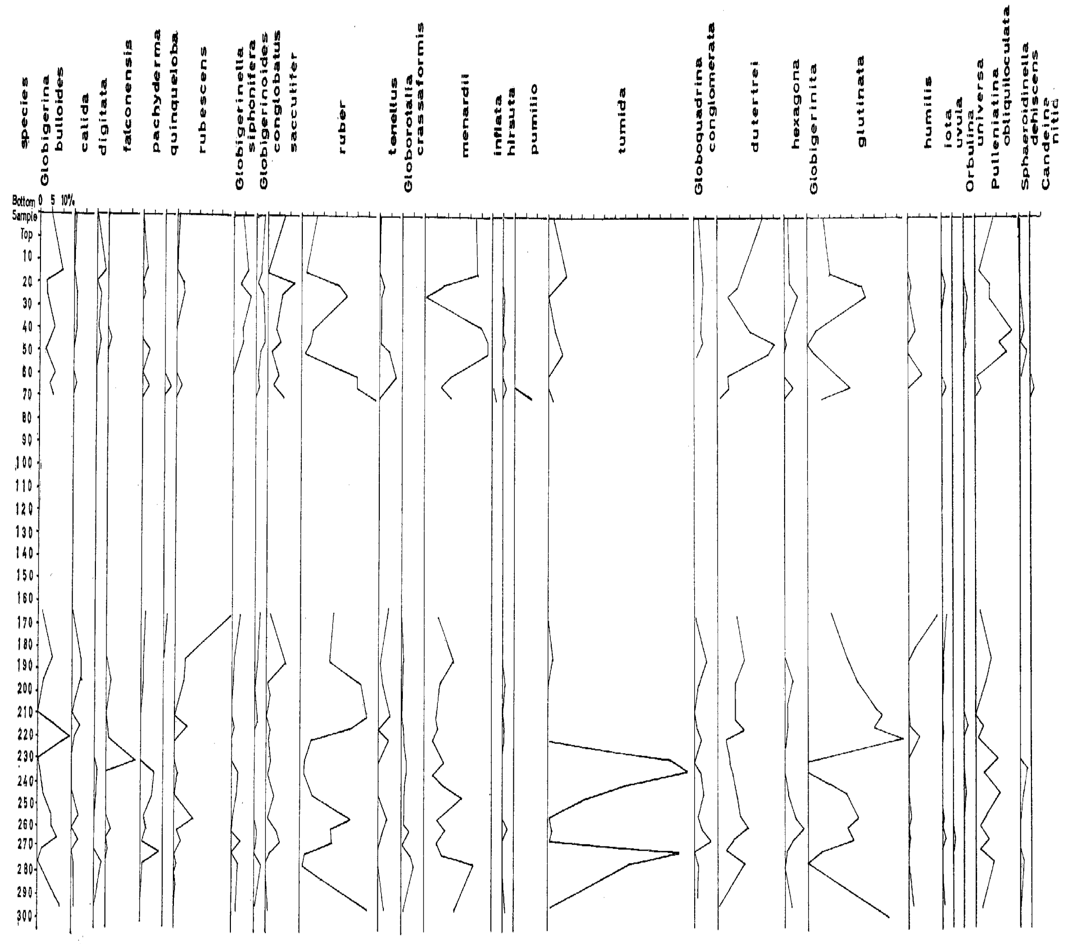


Fig. 7. Frequency Curve of the species from core Ka-15

probably due to the fragmentation of the planktonic Foraminifera or to the slow rate of sedimentation. In the core Ka–15, the percentage of benthonic Foraminifera is higher in the light olive gray clay than in the brown clay.

Analysis of the vertical sequence of the faunas in the two cores is summarized in Figs. 4 and 5. The faunal changes shown by the modern type assemblages of Foraminifera are based entirely upon the distribution of the modern planktonic species. The criteria used in interpreting the vertical sequences are based upon the faunal grouping of Belyaeva (1964) described in the previous section, although there are some differences between the present core assemblage and Belyaeva's assemblage in the tropical fauna with regard to the frequency of each species. In general, in the assemblage of the present cores, cosmopolitan species as *Globoquadrina dutertrei, G. hexagona, Globigerinoides ruber*, and *Globigerinita glutinata* are more abundant than in Belyaeva's assemblage and tropical species such as *Globigerinoides conglobatus, G. sacculifer*, and *Globoquadrina conglomerata* are fewer. The differences mentioned above may be due to the latitudinal situations.

As discussed already, the fauna present in the sediments at the top of the piston core is considered to consist of the population that accumulated during the very near past and presumably still in the process of deposition. Comparison was made between the faunal assemblage at the top of the piston core or gravity core and the one of the vertical section. From the fauna taken from the different levels of the vertical section, it is possible to ascertain the changes in the percentage of the foraminiferal assemblage and their evolution in terms of climatic change and faunal assemblages. In the two cores there is a continuous fluctuation in the percentage composition of the faunal assemblage, and this enables determination of the thermal fluctuations of the younger Cenozoic.

The fluctuation curve of the Foraminifera in the core Ka-18 indicates a comparatively colder water condition in the sequence compared with the top sample at the depths of 20, 70–75, 100–120, 140–150, 170 and 185 cm from the sea bottom. The faunas of the layers indicating a cold water condition are separated from each other by layers with Foraminifera showing a warm water condition. The faunal assemblage of the top sample coincides with that of the bottom suface sample obtained by a gravity corer. The faunas at 20 cm and 70 cm from the top appear to represent somewhat colder water than that of the top sample. This is shown by the sharp increase in frequency of *Globigerinita glutinata* and low percentages of the typical warm water forms as *Globorotalia tumida, Pulleniatina obliquiloculata, Globigerinoides sacculifer*, and *Globigerinella siphonifera*. Between 30 cm and 60 cm the faunas have a relatively high percentage of *Globorotalia menardii, Globoquadrina conglomerata*, and *Pulleniatina obliquiloculata*, and a low frequency of *Globigerinita glutinata*, and *Globigerinoides ruber*. This is interpreted to represent a more temperate condition compared with the above. Between 80 cm and 90 cm, *Globorotalia menardii* increases abundantly and *Globigerinoides ruber* decreases and the assemblage is interpreted to represent a warm water condition. The cold water condition at 100–120 cm is more remarkable than the other cold water condition, as shown by the low frequency of *Globorotalia menardii, Globoquadrina conglomerata* and *Globigerinoides conglobatus*, and the increase of *Globigerina pachyderma, Globigerinoides tenellus*, and *Globigerinita glutinata*. There is a gradual shift to a warm water condition at 130 cm and again to become cold at 140–150 cm as shown by a reduction in the frequency of the warm water species such as *Globoquadrina conglomerata* and *Pulleniatina obliquiloculata* and an increase of *Globigerina pachyderma* and *Globigerinita glutinata*. At 170 cm from the core top the fauna is interpreted as a cold water one, but this layer may be questionable because of considerable fragmentation of the tests. According to the observations, the zone indicating the warm water condition of the sequence seems to be at a depth of 180 cm from the bottom surface as indicated by the abundancy of *Globorotalia* *menardii*. At 160 cm *Globorotalia menardii flexuosa* occurs in abundance (accurate foraminiferal number is 30) in response to a decrease of *Globorotalia tumida*. This subspecies was first described by Koch (1923) as *Pulvinulina tumida var. flexuosa* from the late Tertiary of Java. It has not been reported from Recent material. In the deep sea cores from the North Atlantic Ocean, this subspecies was first recognized in the lower parts of the cores by Phleger and others (1953, p. 20), they lumped it together as the *Globorotalia menardii-tumida* group. Ericson and others (1961, 1964) also observed this same phenomenon in their study of North Atlantic cores, and they found that this subspecies was restricted to the last interglacial and the warm interstitial of the last glacial.

As a whole, the core Ka-18 is composed of a relative uniform assemblage and there are no remarkable changes of the fluctuation curve. The most remarkable cold water condition is found at about 100 cm and a relatively cold one at 140–150 cm. Fig. 6 shows the actual percentage frequency of each species in the core Ka-18. *Globigerina bulloides* which is a member of the temperate fauna is not a valuable indicator in the core Ka-18. The percentage frequency curves of *Globigerinoides ruber* and *G. sacculifer* coincide with the warm fauna between the depths of 100 cm and 185 cm from the top of the core. The species whose frequency curves coincide with that of the cold and temperate fauna, are as follows; *Globigerina calida, G. falconensis, G. rubescens, G. quinqueloba, Globigerinoides tenellus, Globigerinita glutinata*. The species which accompany the warm water fauna are *Globoquadrina hexagona*, and *Globigerina digitata*.

The fluctuation curve of the Foraminifera in the core Ka-15 represents changes of the faunal assemblage more remarkablely than in the core Ka-18, although the foraminiferal content is pauce. In general, the difference in the faunal assemblage corresponds to the lithological difference. That is to say, the light olive gray colored clay of the core yielding abundant fragments of foraminiferal tests is composed mainly of the warm water fauna, while the dark brown colored clay with few foraminiferal tests is characterized by the increase of members of the cold and temperate water fauna. The tests of planktonic Foraminifera in both parts of the clay represent the solution effect. There are at least seven dark brown layers, in which warm water species are relatively rare, at the depths of 15–30, 60–70, 165, 185–195, 210–225, 250–265, and 290–305 cm, respectively from the top of the core. The layers with cold water Foraminifera are separated from each other by layers with warm water Foraminifera, although those indicating warm water at the depths of 170 cm and 200–205 cm below the top are not clear either lithologically or paleontologically. Some boundaries between the light olive gray colored clay and dark brown clay are remarkably sharp, although the faunal assemblages show only gradual change. The sequence between 69 cm and 149 cm is composed of secondarily deposited sediments. The faunal assemblage of the top sample coincides well with that of the bottom surface sample obtained by a gravity corer and they comprise mainly warm water Foraminifera very similar to the modern assemblage. The fauna between 15 cm and 30 cm from the core top appears to represent a condition somewhat colder than the top sample. There is at that place a sharp increase in frequency of *Globigerinita glutinata* and *Globigerinoides ruber* and a low percentage of *Globorotalia menardii, G. tumida, Pulleniatina obliquiloculata*, and *Globoquadrina dutertrei*. Between 60 cm and 70 cm the foraminiferal fauna indicates a definitely cold water condition shown by the addition to the above assemblage of *Globigerina pachyderma, G. quinqueloba* and *Globigerinoides tenellus*. At about 160 cm the frequency curve is not clear, but represents probably a cold water condition. At layers between 185 cm and 195 cm the fauna gradually transforms to indicate a cold water condition. Between 210 cm and 225 cm, there is low frequency of *Globorotalia menardii, G. tumida, Pulleniatina obliquiloculata*, and *Globoquadrina conglomerata* and high frequency of *Globigerina bulloides, Globigerinoides tenellus, G. ruber*, and *Globigerinita glutinata*. This is interpreted as representing a water condition colder than between 185 cm and 195 cm. Also between 250 cm and 265 cm the fauna represents a cold water condition similar to the above assemblage. From 290 cm to the bottom of the core, the frequency of the warm water Foraminifera typified by *Globorotalia tumida, G. menardii,* and *Pulleniatina obliquiloculata* is reduced, and on the contrary, that of *Globigerina bulloides, Globigerinita glutinata,* and *Globigerinoides ruber* are increased. This is interpreted to indicate a cold water condition. There are some such layers with remarkably high frequency of *Globorotalia tumida* at the depths of 200–205, 230–235, and 265–270 cm below the top of the core. The percentage frequency of each species in the core Ka-15 is shown in Fig. 7. *Globigerina pachyderma* and *Globigerinoides sacculifer* are not so valuable indicators in the core Ka–15. The percentage frequency curves of *Globigerinita glutinata, Globigerina rubescens,* and *Globigerinoides ruber* coincide with the cold and temperate water fauna. The frequency curve of *Globoquadrina dutertrei* corresponds with the cold and temperate water fauna occurring between the top of the core and 65 cm depth. The frequency curve of *Globigerina digitata* agrees with that of the warm water species as *Globorotalia tumida, G. menardii,* and *Pulleniatina obliquiloculata.*

The most significant stratigraphical change in faunal composition which was found by Schott (1935) in the sediments from the equatorial Atlantic Ocean, was the alternating dominance of the *Globorotalia menardii* complex (including *G. menardii* and *G. tumida*). That is, the cold periods are based upon the relative rarity of the *Globorotalia menardii* complex, while the warm periods upon the relative abundancy of the *Globorotalia menardii* complex. The present results as to the frequency of the *Globorotalia menardii* complex are shown in Figs. 8 and 9. The frequency curve of the *Globorotalia menardii* complex in the core Ka-15 is precisely in agreement with the fluctuation curve of the faunal composition. Especially the layers of warm water fauna are characterized by the abundancy of *Globorotalia tumida.* In the core Ka-18, the cold peaks indicated by the frequency curve of the *Globorotalia menardii* complex coincide with the fluctuation curve of the faunal composition. There is a remarkable abundance of the *Globorotalia menardii* complex at 10 cm, from 75 cm to 90 cm, and from 170 cm to 180 cm from the top of the core. From 95 cm to 160 cm a gradual increase of the *Globorotalia menardii* complex is found. According to the opinion of Schott, the low values of the *Globorotalia menardii* complex between 20 cm and 70 cm and between 95 cm and 150 cm indicate glacial periods or substages of the last glacial. There are some layers with abundant *Globorotalia tumida* at 10, 75, 90, and 170 cm depth below the top.

In the present work the writer used the "frequency-to-weight-ratio" method of Ericson and his collaborators (1956). This involves the counting of the ratio of the number of tests to the weight of the coarse fraction ($>74\,\mu$). Ericson *et al.* considered that the high ratio of the number of the *Globorotalia menardii* complex to weight of the material coarser than $74\,\mu$ indicates a period of warm surface water. The present results are shown in Figs. 8 and 9.

The relationships between the concentration of planktonic Foraminifera and faunal percentage of the *Globorotalia menardii* complex in the two cores are shown in Fig. 10. There is a significant relationship between the two properties, although the dispersion is great in the core Ka-15. Low percentages of the *Globorotalia menardii* complex are believed to indicate a cold water condition and this is obviously connected with the high concentration of planktonic Foraminifera. Therefore the layers with such of Foraminifera are inferred to have been deposited during periods of cold temperature of the ocean surface. The main factor of the dispersion in figure is believed to be the fragmentation and dissolution of the tests. The results of the present work rather agree with Arrhenius' data (1952). However, the reverse relationship, namely the low concentration of planktonic Foraminifera, does not always indicate a warmer water condition because of the

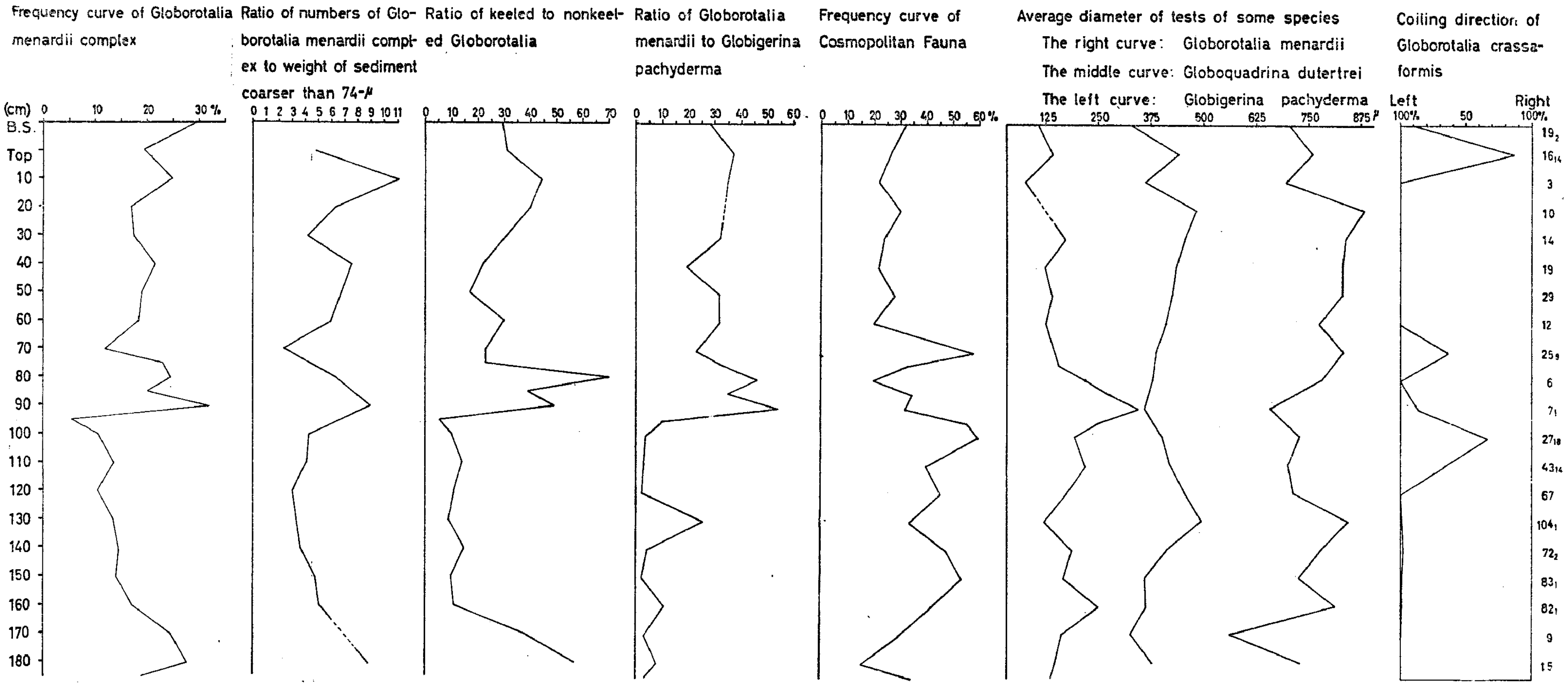


Fig. 8. Analysis of change in foraminiferal sequence in core Ka-18

B.S. Bottom Sample obtained by gravity corer

Number of specimens examined (right coiling small numbers)

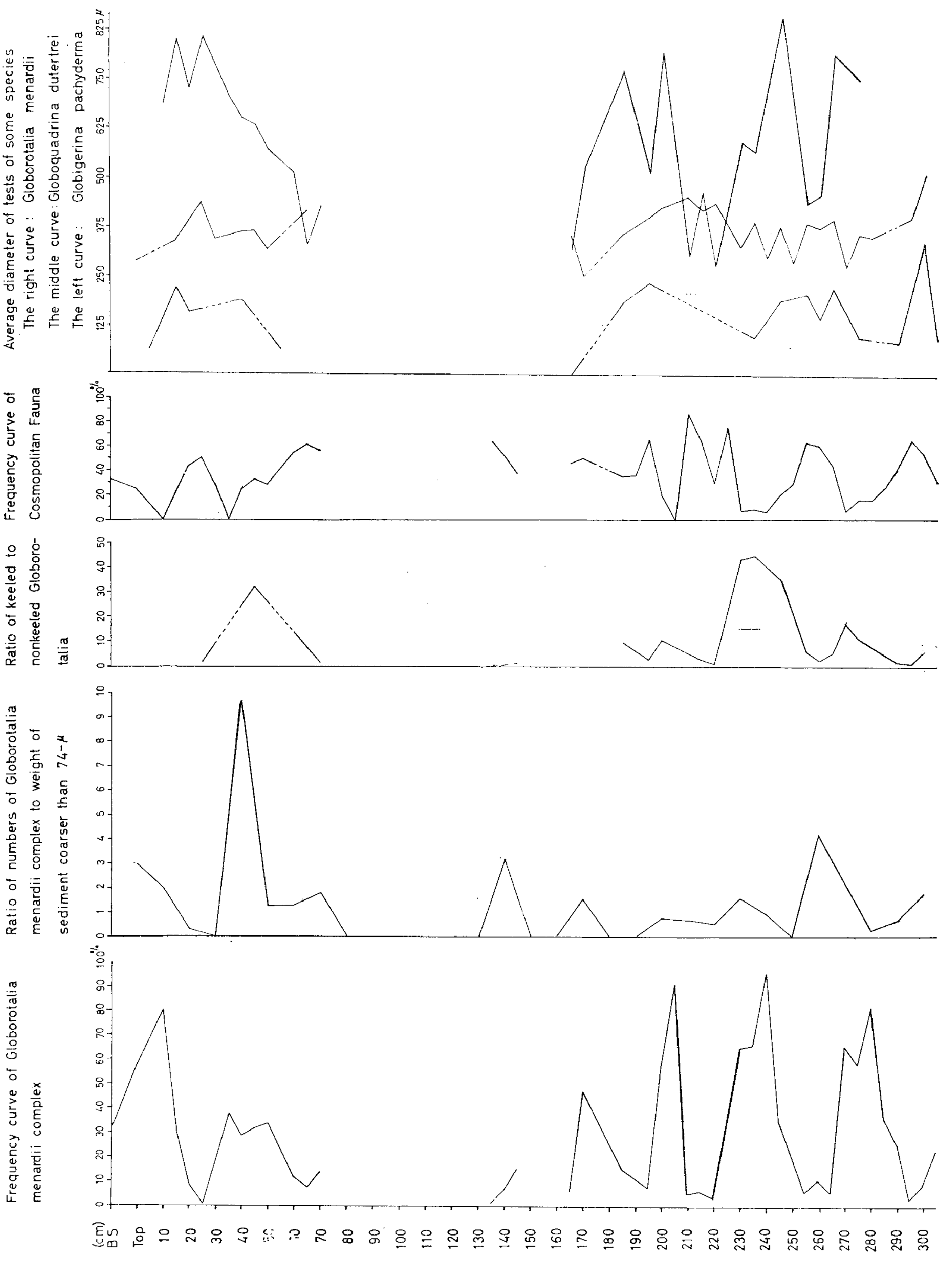


Fig. 9. Analysis of change in foraminiferal sequence in core Ka-15.

BS.: Bottom Sample obtained by gravity corer.

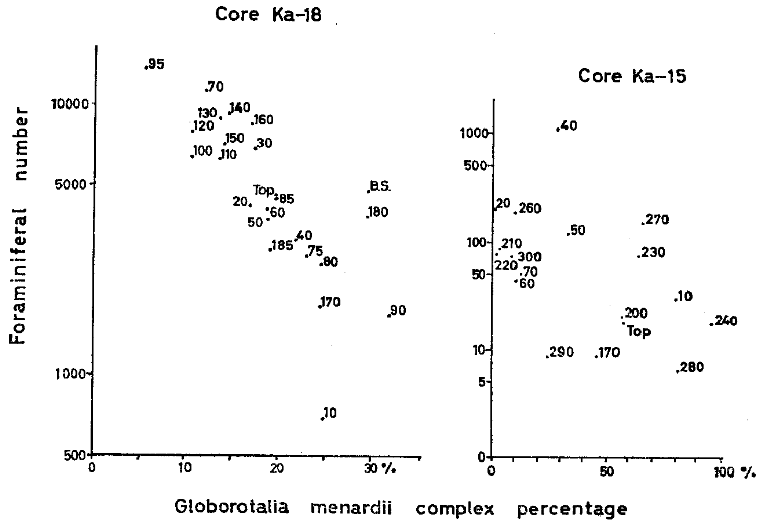


Fig. 10. Relation between percentage of the *Globorotalia menardii* complex and foraminiferal number

dissolution or fragmentation of the tests and rapid sedimentation of the inorganic materials.

An examination of the surface temperature ranges of the various planktonic foraminiferal groups provides interesting and useful information on the environment. Keeled *Globorotalia* are restricted to a temperature warmer than about 17°C. and the nonkeeled *Globorotalia* to water warmer than about 9°C. The ratios of the keeled to nonkeeled *Globorotalia* are shown in Figs. 8 and 9. *Globorotalia crassaformis, G. hirsuta, G. inflata, G. pumilio,* and *G. scitula* which belong to the nonkeeled *Globorotalia,* are counted as to the number of specimens per gram sediment. The results show that the ratios of the keeled to nonkeeled *Globorotalia* increase between 80 cm and 90 cm, and between 170 cm and 180 cm from the top. Particularly between 30 cm and 60 cm, 100 cm and 160 cm from the top, the nonkeeled *Globorotalia* are abundant and interpreted as indicating a cold water condition. In the core Ka-15, the relation is not so clear as the core Ka-18 because of the few specimens. The high frequency of nonkeeled *Globorotalia* corresponds to the cold periods.

Stubbings (1939) used "the ratio of *Globigerina bulloides* to *Globorotalia menardii*" to examine the faunal changes in the six cores from the Arabian Sea and found that the ratio in the cores shows well marked fluctuations, corresponding to changes in the climatic condition. High values for the ratio indicate relatively large numbers of *Globigerina bulloides* and consequently a cold water condition. The method was employed using *Globigerina pachyderma* and *Globorotalia menardii* as shown in Figs. 8 and 9. These species indicate cold water and warm water condition, respectively, although *Globigerina pachyderma* is not the most common species. The graph showing the ratio of *Globigerina pachyderma* to *Globorotalia menardii* in the core Ka-18 indicates high values in the lower part of the core, due to the increased number of *Globigerina pachyderma.* Consequently the ratio is inferred to indicate a relatively cold water condition in the lower part of that core.

Phleger (1951) in his study of many cores from the Gulf of Mexico, found that the fauna in the lower part of the core differs from the upper warm water fauna by the greater abundance of species having an apparent wide range of temperature toleration. The frequency of cosmopolitan species in the two cores were examined as shown in Figs. 8 and 9. According to Belyaeva, *Globigerinoides ruber, Globoquadrina dutertrei, G. hexagona,* and *Orbulina universa* are cosmopolitan in distribution. The present results show that the high

Table 2. Distribution of Foraminifera in core Ka-18.

Species Sample(cm)	B.S.	Top	10	20	30	40	50	60	70	75	80	85	90	95	100	110	120	130	140	150	160	170	180	185
Globigerina bulloides	14 6	13 8	5 2	12 8	9 3	5	13 1	6 2	2 1	16 6	17 4	19 3	5 3	9 2	10 2	4 1	9 3	4 2	4 2	9 2	3 2	4 2	4 1	17 5
G. calida	3 1	8 4	3 2	2 2	1		1 1	1	5 3		1 1	2 1	1	2	4	2	5	3 1	1	1	2 1			2
G. digitata	2 2	1 1	2 2	3 1	1	2 2		2 1	1 1		1 1	1						1 1	1			2	3 2	
G. falconensis	2 2	1 1		2 2		1 1			1	2 1	1	1 1	1 1		1		1 1		1 1	4 2	2		1 1	1
G. pachyderma	2 2	1 1	1		1 1	2 2	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	5 5	7 6	8 7	1 1	6 6	10 10	3 3	12 12	7 7	10 10
G. quinqueloba	2 1					1						3 3			1							1 1		2 2
G. rubescens	4 1	8 6	2 1	8 4	1	5 1	4 1	3 2	1 1	6 5	1	3 1	2	5 2	7 3	3 1	4 1	1	8 2	8 6	2 1	5 3		1 1
Globigerinella siphonifera	3	14	7	5	13	12	8	9	7	6	6	1	3	4	5	7	7	9	7	7	12	2	10	2
Globigerinoides conglobatus	1	1 1	1		2 2		2 1	6 2	2 1	2		3					1	1 1	1 1	4	3 2	2 1	2	1
G. sacculifer	9 4	11 6	10 2	4	13 3	10 6	7 4	11 4	20 6	1	22 8	13 6	4 4	24 7	14 8	10 3	20 8	25 12	17 8	15 7	21 9	4 1	14 6	7 3
G. ruber	12 6	18 10	15 8	16 11	25 7	17 5	11 6	16 9	37 17	17 7	11 6	17 12	5 2	46 22	29 12	19 13	24 15	34 15	23 10	25 10	40 22	9 5	17 4	13 5
G. tenellus	1		1 1	1 1	1 1	2 1		5 3	1	7 4	1 1	5 2		12 4	8 4	8 1	4 2	5 4	5 2	2		2 1	1	1 1
Globorotalia crassaformis	3 1	1 1			2	5	4	3		4 4		5	3	4 1		3	3		4	6	2	4	4 3	4
G. menardii	57	37 1	35	32 2	32 1	38 1	32 2	32 2	23	33	46	35	54 2	10	20	22	18	26	28	26 1	34	42	55 2	36
G. inflata				1 1		3 3			1 1															
G. hirsuta	2 1	1		1 1	2		2		1	2 1						1		1	1	1		2 1		
G. pumilio															2 2									
G. scitula			1 1	4 1	1 1	2 1			2 2				1 1	2 2	3 3	1 1	1 1		1	2 1	2 1	1 1		
G. truncatulinoides																		1			1 1			
G. tumida	2	2	15 1	2	3	5	6	5	1	13	3	4	10	1	1	5	3	1	1	2		7	3	2
Globoquadrina conglomerata	5 1	4 2	5 3	7 3	12 4	9 3	8 3	21 10	8 5	4 3	6 1	5 2	7 6	2	3 2	2	6	17 8	6 2	2 1	3 3	2 1	9 6	3 1
G. dutertrei	41 39	23 23	23 21	17 17	20 20	22 22	31 31	31 31	28 28	25 25	32 32	22 21	47 47	14 12	28 28	29 29	28 28	19 19	30 30	33 31	24 23	35 35	27 27	27 27
G. hexagona	3 2	6 4	3 3	4 3	5 1	3 2	8 5	1	6 3	1 1	5 1	5 4	1 1	9 3	7 4	3 2	8 5	8 5	11 9	1 1	5 2	5 2	3 1	7 5
Globigerinita glutinata	23 10	33 20	49 27	64 33	30 13	32 15	35 18	25 11	42 28	42 19	44 16	35 14	42 24	35 17	48 14	46 27	17 10	19 9	29 16	23 18	18 10	34 18	18 9	28 17
G. humilis				1	1 1				1			1 1		3 2				1	1 1	2 2		3 3		4 3
G. iota			1			2 2	2	1 1	3 1	2	1 1	5 2	2 1	5 3	2 2	6 3	4 3					3 2		4 2
G. uvula				2						3 3		2 1		3 1										
Orbulina universa		2	2	3	2	1	1	1				3	1	2		1	3	3		2	1			
Pulleniatina obliquiloculata	4 4	15 14	15 15	7 7	23 23	11 11	18 18	19 19	6 6	12 12	10 10	9 9	10 10	4 4	2 2	19 19	16 15	17 17	9 9	7 7	18 17	12 12	19 19	9 9
Sphaeroidinella dehiscens										1							1	2						1
Candeina nitida	1																						1	
Miscellaneous	4	4	4	2		10	6	1			1			3		2	9	1	1	8	4	7	2	18
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Benthonic Foraminifera	3	4	6	5	4	5	9	5	2	8	7	6	8	2	3	2	2	5	6	9	4	14	4	12
Percent of benthonic Foram.	2.0	1.3	9.1	3.4	1.8	3.4	5.5	3.1	0.6	4.6	2.4	3.0	7.4	1.0	1.5	1.0	0.8	1.8	2.1	4.0	1.5	13.0	3.6	6.6
Foraminifera No. Benthonic	100	60	60	140	130	110	210	130	60	130	60	140	130	130	100	60	60	160	190	290	130	230	140	190
Planktonic	4900	4700	700	4200	7000	3200	3800	4100	11200	2800	2600	4600	1700	13400	6400	6400	8000	9000	9300	7200	8600	1800	3900	2900

Small numerals in lower part of each row indicate right coiling form.
B.S.: Bottom sample obtained by gravity corer.

peaks of the frequency of the cosmopolitan fauna found at 70 cm, 100 cm, and 150 cm in the core Ka-18, can be interpreted as indicating cold water conditions. In the core Ka-15, the frequency curve of the cosmopolitan forms coincides well with that of the faunal composition.

Phleger and Hamilton (1946) measured the average diameter of certain species and found that *Globorotalia menardii* increases in size as the water temperature becomes warmer. Measurements were made of the average diameter of *Globigerina pachyderma*, *Globoquadrina dutertrei*, and *Globorotalia menardii* as shown in Figs. 8 and 9. The results show that

Globorotalia menardii changes the average diameter of test as same as the faunal frequency curve. Generally, the warm water species appear to change in their average diameter of tests in correspondance with the change of *Globorotalia menardii*, whereas the cold and temperate water species seem to represent the inverse change to those of the warm water fauna.

The coiling direction of all the species were examined as shown in Tables 2 and 3. *Globorotalia crassaformis* shows abrupt changes in coiling at some layers of the core Ka-18 (Fig. 8), while in the core Ka-15 such change is not clear due to the few specimens. The following species are entirely left coiling; *Globorotalia menardii*, *G. tumida*, and *G. hirsuta*, and entirely right coiling species are *Globigerina pachyderma*, *Globoquadrina dutertrei*, and *Pulleniatina obliquiloculata*. Other species have irregular changes in coiling direction. *Globorotalia truncatulinoides* is almost right coiling, although its frequency is very low. A few left coiling tests were found at 40 cm and 130 cm in the core Ka-18 and they occupied 60 and 50 percent in these sections, respectively. Ericson *et al.* (1954, 1961) suggested that the coiling change of *Globorotalia truncatulinoides* was useful in making correlation between sediment cores during the late Pleistocene.

DISCUSSION

In general, the normal rate of sedimentation is extremely slow on the deep-sea floor being of the order of less than 1 cm per 1000 years, as pointed out by Kuenen (1937). Arrhenius (1952) estimated the rate to be about 1 cm or more per 1000 years in the calcareous facies of the equatorial Pacific region. The process of sedimentation in the two cores was probably normal except for the greenish gray sediments between 69 cm and 149 cm from the top of the core Ka-15. The bottom parts of the cores may extend back to a few hundred thousand years. Accordingly, the alternation of cold and warm periods, as shown by the fluctuation curve of the faunal assemblage, probably corresponds to the climatic change during the glacial and interglacial or substages of the last glacial. Ericson *et al.* (1956, 1961, 1964) found that *Globorotalia menardii flexuosa* occurred in great abundance in the warm interstitial of the last glacial and lower parts of the Sangamon interglacial. The former age was determined as 65,000 to 70,000 years B.P. by the extrapolation of radiocarbon dates and one direct dating by the ionium method. Using the same cores, Emiliani (1955, 1958), Emiliani and Flint (1963) made paleotemperature curves by means of oxygen-isotopic analysis. And they suggested that the last occurrence of *Globorotalia menardii flexuosa* was in the upper part of the last interglacial. The occurrence of *Globorotalia menardii flexuosa* at 160 cm of the core Ka-18 may thus be correlated to the upper part of the last interglacial. It has been recognized by many previous authors that the species of most significance as indicators of the climate in equatorial waters are *Globorotalia menardii* and its allied forms. Schott (1935) and Ericson *et al.* (1956b, 1961) have demonstrated that *Globorotalia menardii* is an excellent indicator of the sections in the north and equatorial Atlantic cores deposited in relatively warm intervals and hence that the presence or absence of this species shows the sequence of warm and cold time intervals reflected on the core sediments. Consequently, it is inferred that the cold stage between 95 cm and 150 cm represents the early Würm. Above the early Würm, there is a distinct warm interstitial period of the last glacial between 75 cm and 90 cm. In this case, the late Würm may be considered to be represented by the low concentration of the *Globorotalia menardii* complex and high concentration of nonkeeled *Globorotalia* and *Orbulina universa* between 20 cm and 70 cm. It contains two definite cold periods at 20 cm and 70 cm. In the section, however, there is considerable difference between the faunal composition and the frequency of the *Globorotalia menardii* complex. This may be due to

Table 3. Distribution of Foraminifera in core Ka-15.

Species / Sample(cm)	B.S.	Top	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
Globigerina bulloides	11 5				5 2	6 2	6 4			13 4	10 2	3 1		3 2	10 3	3 3				2		1 1						
G. calida	2 1					1 1	3 2	1		2 1					2							1						
G. digitata					2 2		4 4	1		2 1	3 3	1																
G. falconensis											1										1							
G. pachyderma					1		1 1	1 1				3 3			4 4													
G. quinqueloba															3 3					4	1 1							
G. rubescens	2 2					5 2	6 1	1 1						1 1	12 6						3 2							
Globigerinella siphonifera	8				3	7	15			8	9	3																
Globigerinoides conglobatus	7 4				1	2 2	6 3			7 2	7 1	2 1			2 2													
G. sacculifera	15 7					24 7	13 4	3 1	2 1	8 5	11 5	2 1		2 1	5 1	4 1												
G. ruber	14 7	3 1			1 1	33 18	40 17		1	11 4	8 6	2 1		11 5	50 19	17 9												
G. tenellus	1					4	2			1		4		3	7													
Globorotalia crassaformis																												
G. menardii	55	8		18	12	18	2		3	52	56	37		5	15 1	6					1							
G. inflata																1 1												
G. hirsuta							1 1				2 1				2													
G. pumilio								1								4 2												
G. scitula																												
G. truncatulinoides																												
G. tumida	5	1		6	4					6	8	7				1												
Globoquadrina conglomerata	4 3				2 1	7 2	6 4	1 1		6 3	7 5	1		1 1	2													
G. dutertrei	40 40	1 1			6 6	18 18	11 11	8 7		31 30	52 52	26 26		2 2	9 9	1 1		1										
G. hexagona	3 1				1 1	6 4	11 4				1				7 7						2 2							1
Globigerinita glutinata	15 4			1 1	5 4	48 19	52 24	5 2		8 5		3 2		6 5	38 23	3		5 4		1						1 1		1 1
G. humilis						3 3	1 1	3 2	1 1	6 5				3 1				10 6										
G. iota						3 2	1								3 2						1							
G. uvula																		3 1										
Orbulina universa						1	3				2							3		1								
Pulleniatina obliquiloculata	16 16			4 4	1 1	13 10	12 11	6 5	1 1	33 32	21 21	17 17			4 4													
Sphaeroidinella dehiscens	1	3					1			3	1	3																
Candeina nitida															1 1													
Miscellaneous	1			1	7	1	3	3		3	1	1		7	8	9					2							
Total	200	16	0	30	51	200	200	31	8	200	200	115	0	44	184	49	0	22	0	8	11	2	0	0	0	1	0	2
Benthonic Foraminifera	35	3	0	6	12	4	3	8	0	24	1000	50	0	19	13	5	0	16	0	2	6	1	0	0	0	0	0	1
Percent of benthonic Foram.	50	15.6		16.7		19.6		20.5		27.1		31.4		30.2		9.3		42.1		20		33.3						33.3
Foraminifera No. Benthonic	10	3		6		4		8		384		50		19		5		16		2		1		0		0		1
Planktonic	10	16		30		200		31		1032		109		44		49		22		8		2		0		1		2

Species / Sample(cm)	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305
Globigerina bulloides	24 8	5 3	12 3				1 1				13 5	3 1	4 1				14 6	11 5	1		1 1		5 3	3 3	12 2	12 2	17 7	2 1			1		18 7	2 2	
G. calida		1	3 1								8 4		7 5				7 4	1 1							6 2		6 4		1				1 1		
G. digitata			1																		1 1		1 1						6 4						1 1
G. falconensis	6 3	1	8 3								1	1 1	4 4					1 1		9 9						2 2	1 1								
G. pachyderma	4 2		1 1				1				2 2		2 2								8 8		10 10		3 3	2 2	2 2	13 13	2 1			1 1		1 1	2 2
G. quinqueloba	9 1	15 5	5 1	1			1					1 1																							
G. rubescens	2	23 8	3 1				13 7				9 4		8 3				11 6	1	3 1		1				17 9	1	6 4		1 1				9 5	11 7	
Globigerinella siphonifera							2				2	3	1				2				3		4		1		8		6				3	1	1
Globigerinoides conglobatus							1				2 1					1										1 1	1 1		6 2					1 1	
G. sacculifera							1 1				17 7		1	2 1	1 1		4 1	1		1 1	1		7 5		2 1	9 2	12 4	2 1					2 2	2 1	
G. ruber	2 1		2 1				8 2	1			26 11	4 1	54 29	1		24 10	44 20	4 4	5 4	1	2 1		11 5		44 20	38 18	39 22	2 2	3 2			3 2	51 26	17 7	1
G. tenellus							2				1	2	3			4	1	4	2						8	3	1						3		
Globorotalia crassaformis											2 2		1 1	1 1			2 2	1 1		1	2 2		1 1		1 1	5 3	1 1	5	10 1		1		2 2	1	
G. menardii	2	13 1	30 1				3	3			25		14	1		4	11 1	3		6	5		33 1		11	18	11	11 1	44 1	1 1	2	1	3	6	
G. inflata																																1			
G. hirsuta	1	3 1	4 1										3 2				2 1	1 1								2 2							1		
G. pumilio		4 1										1																							
G. scitula	5 4	4 4	15 14								1 1		1 1						1 1						1 1		1 1								
G. truncatulinoides																																			
G. tumida											5		1	10	12		1			38	90	12	39		1	3	1	77	73	4	3	1	2	1	5
Globoquadrina conglomerata											11 7	1 1	4 3				2 2	2 1			3 1		8 5	3	3 2	5 4	14 7		4 3				1 1		
G. dutertrei	49 47	23 20	32 31				3 3	2 2			24 24		16 16	2 2		7 7	24 24	3 3	1 1	3 3	10 10	1 1	18 18	4 4	21 21	28 28	14 14	5 5	25 25	1 1	2 2		11 11	1 1	2 2
G. hexagona	9 5	5 3	5 2					1 1			1 1		7 5				3 2	1 1	3 2				3 1		9 8	16 14	7 4	1			1 1		5 5	1 1	2 1
Globigerinita glutinata	43 13	79 39	34 17	3 1			6 2			1	36 20	5 4	55 29	1		26 15	60 39	33 19	15 7				35 22		45 20	36 24	41 21	8 2	1				52 29	14 6	6 4
G. humilis							7 6										1	4 2							2		1						4	2 1	
G. iota	9 4		3 3				1 1				1		1 1				1								1		3 2				1		1	1	
G. uvula	7 1	3 2	6 3																								1								
Orbulina universa																	3						1												
Pulleniatina obliquiloculata		1					1 1	1			13 13		10 10	1 1	1 1		7 7	1 1	1 1	7 7	4 4	1 1	22 22	4 4	10 10	3 3	11 11	3 3	16 16		1 1	1 1	5 5	2 2	3 3
Sphaeroidinella dehiscens																					3		2						2		1				
Candeina nitida																																			
Miscellaneous	23	20	13	3			3						3			14		3		1		1		2	2	2	1	5			1		4	5	
Total	195	200	177	7	0	0	54	8	0	1	200	21	200	19	14	80	200	75	32	67	134	15	200	16	200	186	200	134	200	6	14	8	178	69	23
Benthonic Foraminifera	63	53	37	2	0	0	5	7	0	9	20	1	5	58	50	9	3	1	1	87	36	31	46	2	12	5	6	112	52	37	10	6	20	16	14
Percent of benthonic Foram.		26.7		22.2		50		46.5		90		4.5		75.4		10		1.3		56.5		67.3		11.1		2.6		45.5		86		42.8		18.8	
Foraminifera No. Benthonic		204		2		1		7		9		1		58		9		1		87		31		2		5		112		37		6		16	
Planktonic		572		7		1		8		1		21		19		80		75		67		15		16		186		134		6		8		69	

Small numerals in lower part of each row indicates right coiling form. B.S.: Bottom sample obtained by gravity corer.

inclusion of the relatively wide temperature tolerant species as *Globigerinella siphonifera*, *Globigerinoides sacculifer*, and *G. conglobatus* into the warm water fauna. Post-glacial time would be represented only by the sample at the top down to 10 cm of the core. The correlation between the core Ka-18 and the core Ka-15 can be made only above 70 cm of the core Ka-15, because of the possibility that the previously deposited sediment was mixed with later ones by churning. As comparison with the frequency curve patterns of the most common species in both cores (Figs. 6, 7), core Ka-15 can be correlated with core Ka-18 also by the similar rate of sedimentation between the top down to 70 cm. Arrhenius (1952) suggested that the vertical circulation of the ocean became vigorous during the glacial age and consequently the productivity of planktonic organisms in the surface water increased in the regions of the Equatorial Divergence of the Pacific Ocean. In the Indian Ocean Belyaeva (1964) found that the number of foraminiferal tests decreased abruptly below a depth of 4,500–4,700 m. The core Ka-18 is shallower than the compensation depth* of calcium carbonate and does not show a trace of solution effect on the foraminiferal tests. It is generally accepted that the rate of inorganic sedimentation was vigorous during the glacial age. Analysis of the core Ka-18 shows that the cold periods yield about twice the number of foraminiferal tests as the warm periods. This is good evidence indicating that the productivity of planktonic Foraminifera was large during glacial ages. The core Ka-15 is geographically situated near the boundary of the brown clay and *Globigerina* ooze, and is deeper than the compensation depth of calcium carbonate. Kuenen (1950, p. 359) stated that over vast areas of the deep-sea floor calcareous matter forming foraminiferal tests and coccolithophorids frustules is attacked by solution. And there remains only a fine lutite of reddish brown to chocolate color, called red clay. The small amount of foraminiferal tests in the core Ka-15 is thus inferred to be due to the dissolution of the tests by the cold bottom water from the Antarctic Sea. The concentration of siliceous organisms (Radiolaria and diatom) in the core Ka-15 represents as much as the core Ka-18. In spite of representing high productivity of planktonic Foraminifera in the equatorial Indian Ocean during the glacial ages, as proved by the core Ka-18, red clay was deposited during the cold periods represented by the layers in the core Ka-15. This is due to that the rate of dissolution of calcium carbonate on the deep-sea floor had exceeded the rate of production of planktonic Foraminifera in the surface water. The dissolution of calcium carbonate is prompted by low temperature, low salinity, high hydrostatic pressure and high partial pressure of CO_2, generated by oxidation of organic matter at the sediment surface. Among these factors, low temperature seems to be most important for the dissolution of calcium carbonate. It shoud also be stated that the alternation of brown clay and *Globigerina* ooze in the core Ka-15 corresponds without exception to the cold and warm periods indicated by the fluctuation of the faunal composition. Similar results in the alternation of red clay and *Globigerina* ooze were reported by Phillipi (1912), Schott (1935) and Hough (1953). Emiliani (1955a, 1958) suggested that there was 4°C. difference in bottom temperature between the sediments deposited during the glacial and interglacial ages at the depth of 3,600 m in the equatorial Atlantic Ocean, and that the difference of bottom temperature in the Pacific Ocean was smaller. In consequence, it seems evident that the brown clay extended to a shallower region toward the north during the glacial ages, and retreated to a deeper region toward the south during the interglacial ages. Namely, the bathymetric changes of the compensation depth of calcium carbonate occurred during the glacial and interglacial ages. Phleger *et al.* (1953) and Hamilton (1957) suggested that the selective dissolution of planktonic foraminiferal tests was found in the core they

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* The depth, where the dissolution of calcium carbonate balances the rate of production of calcium carbonate and the rate of accumulation of calcium carbonate becomes zero.

studied. But the concentration of *Globorotalia tumida* in the two cores studied by the writer is found in the sections of remarkable fragmentation.

REWORKED FAUNA

The green colored sediments in the core Ka-15 may have been derived from some other region as already mentioned in the chapter of "Description of the Cores". This inference is also proved paleontologically in this section.

The olive gray sediment between 69 cm and 139 cm from the top of the core contains almost no Foraminifera, whereas the pale olive deposit between 140 cm and 149 cm yields relatively abundant tests of Foraminifera. These Foraminifera are composed mostly of Recent species with marked characters, namely they are thin shelled immature forms and their tests are in ill preserved condition. The fauna consists mainly of the genera *Globigerina, Globigerinita, Globoquadrina,* and *Globorotalia,* whereas *Globigerinoides, Globigerinella, Pulleniatina, Sphaeroidinella, Orbulina,* and *Candeina* are almost absent. The common species in the sediments of the lower part of the core mentioned above are *Globigerinita glutinata, Globoquadrina dutertrei, Globigerina bulloides, G. quinqueloba, G. rubescens, Globorotalia menardii, G. scitula,* and *Globoquadrina hexagona.* This assemblage indicates that the surface temperature of the ocean was conspicuously low during the deposition of those sediments. Such species as *Globorotalia pseudoscitula,* and *G. elongata* which are restricted to the Paleogene age were found in the lower part between 135 cm and 149 cm from the top of the core. There are some other species, which have relatively long range from Miocene to Recent but more or less different morphologically from the Recent species. These fossil Foraminifera were derived from some other region, where the older sediments outcropped on the sea-bottom. These Foraminifera indicate that the region of deposition was originally of shallow-water condition, as shown by an investigation of the benthonic Foraminifera. That is, the benthonic assemblage includes *Ammonia beccarii* and Miliolids, in addition to the normal deep-sea assemblage as shown below.

Genera	Depth from top of the core		
	135 cm	140 cm	145 cm
Ammonia		1	1
Bolivina	7	8	6
Bulimina	4	2	2
Cassidulina	9	10	15
Cibicides	2	2	5
Ehrenbergina		1	
Epistominella		1	3
Fissurina	3		2
Gyroidina		3	
Hyalinea		1	
Lagena	8		
Nonion	4	1	1
Nonionella		2	
Pyrgo	1		
Quinqueloculina		1	
Rosalina	2	1	
Spirosigmoilinella		2	1
Textularia		2	
Triloculina		1	
Uvigerina	3	3	
Valvulineria	3	2	
Virgulina	16	9	
Total	62	52	36

The following list of Ostracoda are those found in the lower part of the sediments; immature forms are especially abundant. For the identification and interpretation of these Ostracoda, the writer is indebted to Dr. K. Ishizaki of the Institute of Geology and Paleontology, Tohoku University.

Species	Habitat
Aurila sp.	epineritic
Bradleya dictyon (Brady)	marine
Bradleya polytrema (Brady)	marine
Cytherura cf. *cuneata* Norman	mesohaline to littoral
Cytherura cf. *nigrescens* (Baird)	mesohaline to littoral
Cytherura cf. *skippa* Hanai	mesohaline to littoral
Cytheropteron sp.	all depths; deeper forms?
Loxoconcha elliptica Brady	mesohaline to littoral
Loxoconcha cf. *hastata* (Reuss)	mesohaline to littoral
Loxoconcha sp.	mesohaline to littoral
Monoceratina cf. *bifurcata* Puri	marine
Xestoleberis nana Brady	littoral to epineritic

(littoral to epineritic=shallower than 50 m or so)

The abundant occurrence of Ostracoda and their known habitat indicate that the sediments bearing them were evidently derived from a shallow-water region. The abundancy of immature forms of Ostracoda, Foraminifera, and Mollusca are probably due to transportation from elsewhere where the depth of their habitat was favorable. This phenomenon probably occurred in a shallow-water region during the glacial age. Accordingly, such a phenomenon may be related to the subsidence of sea-level.

CONCLUSIONS

The climatic changes in the two cores were interpreted by the vertical changes of the planktonic foraminiferal assemblage. The low frequency of warm water fauna, especially the *Globorotalia menardii* complex, is interpreted to point to a glacial period or substages of the last glacial, when the sea water surface temperature was lower than the present in the equatorial Indian Ocean.

The high concentration of calcium carbonate in the equatorial Indian Ocean was during the glacial ages, when the productivity of planktonic Foraminifera was vigorous in the surface water.

The bathymetric change of the compensation depth of calcium carbonate was found between the glacial and interglacial ages. In consequence, the brown clay developed toward the north during the glacial ages and *Globigerina* ooze extended towards the south during the interglacial ages.

The evidence of turbidity current is shown by the sediment which was reworked from a shallow-water region to the ocean basin. Some fossil Foraminifera in the secondary sediments of the core Ka-15 indicate the Paleogene age. The phenomenon was probably due to the lowering of the sea-level during the glacial period.

REFERENCES

Arrhenius, G., 1952, Sediment Cores from the East Pacific. *Rep. Swedish Deep-Sea Exped.*, **1947–1948**, *Göteborg*, v. 5, p. 1–227, 200 text-figs., 12 tab.

Bandy, O.L., 1956, Ecology of Foraminifera in northeastern Gulf of Mexico. *U.S. Geol. Surv. Prof. Paper*, 274-G, p. 178–204, text-figs. 25–28, 4 tab., 7 charts, pls. 29–31.

————, 1963, Miocene-Pliocene boundary in the Philippines as related to Late Tertiary stratigraphy of deep-sea sediments. *Sci.*, v. 142, no. 3597, p. 1290–1292, 1 text-fig.

Bé, A.W.H., 1959, Ecology of Recent planktonic Foraminifera. Part 1-Areal distribution in the western North Atlantic. *Micropal.*, v. 5, no. 1, p. 77–100, 52 text-figs., 2 tab., 2 pls.

————, 1960a, On Arctic planktonic Foraminifera. *Cushman Found. Foram. Res., Contr.*, v. 11, pt. 2, p. 64–68, 1 text-fig., 1 tab.

————, 1960b, Ecology of Recent planktonic Foraminifera. Part 2-Bathymetric and seasonal distributions in the Sargasso sea off Bermuda. *Micropal.*, v. 6, no. 4, p. 373–392, 19 text-figs., 6 tab.

Belyaeva, N.V., 1963 Distribution of planktonic Foraminifera on the floor in Indian Ocean. *Voprosy Mikropal.*, no. 7, 9 text-figs. (in Russian).

————, 1964, Distribution of planktonic Foraminifera in the water and on the floor in Indian Ocean. *Trudy Okeanol. Acad. Sci. S.S.S.R.*, v. 68, 27 text-figs., 22 tab., 3 pls. (in Russian).

Bradshaw, G.S., 1959, Ecology of living planktonic Foraminifera in the North and Equatorial Pacific Ocean. *Cushman Found. Foram. Res., Contr.*, v. 10, pt. 2, p. 25–64, 43 text-figs., 1 tab., pls. 6–8.

Bramlette, M.N., and Bradley, W.H., 1940, Geology and biology of North Atlantic deep-sea cores between Newfoundland and Ireland. Part 1-Lithology and geologic interpretations. *U.S. Geol. Surv. Prof. Paper*, 196–A, p. XV+1–34, 10 text-figs., 7 tab., 7 pls.

Cushman, J.A., 1941, A study of the Foraminifera contained in cores from the Bartlett deep. *Amer. Jour. Sci.*, v. 239, p. 128–147, 10 text-figs., 6 pls.

————, and Henbest, L.G., 1940, Geology and biology of North Atlantic deep-sea cores between Newfoundland and Ireland. Part 2-Foraminifera. *U.S. Geol. Surv. Prof. Paper*, 196–A, p. 35–50, 11–21, text-figs. pls. 8–10.

Dietz, R., 1954, Possible deep-sea turbidity current channels in the Indian Ocean. *Geol. Soc. Amer. Bull.*, v. 64, p. 375–378, 1 text-figs., 1 pl.

Emiliani, C., 1954, Depth habitats of some species of pelagic Foraminifera as indicated by oxygen isotope ratios. *Amer. Jour. Sci.*, v. 252, p. 149–158, 4 text-figs., 6 tab.

————, 1955, Pleistocene temperature. *Jour. Geol.*, v. 63, no. 6, p. 538–578, 15 text-figs., 30 tab.

————, 1957, Temperature and age analysis of deep-sea cores. *Sci.*, v. 125, no. 3244, p. 383–387, 2 text-figs., 3 tab.

————, 1958, Paleotemperature analysis of core 280 and Pleistocene correlations. *Jour. Geol.*, v. 66, no. 3, p. 264–275, 5 text-figs., 3 tab.

————, and Flint, R.F., 1963, The Pleistocene record. *in* The Sea, Hill, M.N., ed., p. 888–927. Intrescience Publ., New York.

Ericson, D.B., Wollin, G., and Wollin, J., 1954, Coiling direction of *Globorotalia truncatulinoides* in deep-sea cores. *Deep-Sea Res.*, v. 2, no. 2, p. 152–158 text-figs. 2–4, 1 pl.

————, and Wollin, G., 1956, Micropaleontological and isotopic determinations of Pleistocene climates. *Micropal.*, v. 2, no. 3, p. 257–270, 7 text-figs., 5 tab.

————, Ewing, M., Wollin, G., and Heezen, B.C., 1961, Atlantic deep-sea sediment cores. *Geol. Soc. Amer. Bull.*, v. 72, p. 193–286.

————, Ewing, M., and Wollin, G., 1963, Pliocene-Pleistocene boundary in deep-sea sediments. *Sci.*, v. 139, no. 3556, p 727–737, 14 text-figs., 1 tab.

————, Ewing, M., and Wollin, G., 1964, The Pleistocene Epoch in deep-sea sediments. *Sci.*, v. 146, no. 3645, p. 723–732, 5 text-figs.

Flint, F.R., and Brandtner, F., 1961, Climatic changes since the last Interglacial. *Amer. Jour. Sci.*, v. 259, p. 321–328, 1 text-fig.

Hamilton, E.L., 1957, Planktonic Foraminifera from an Equatorial Pacific core. *Micropal.*, v. 3, no. 1, p. 69–73.

Hough, J.K., 1953, Pleistocene climatic record in a Pacific Ocean core sample. *Jour. Geol.*, v. 61, no. 3, p. 252–262, 3 text-figs., 1 tab.

Jenkins, D.G., 1964, Location of the Pliocene-Pleistocene boundary. *Cushman Found. Foram. Res., Contr.*, v. 15, pt. 1, p. 25–27, 1 text-fig.

Kuenen, P.H., 1950, Marine Geology. John Wiley and Sons, New York., 568 p.

————, 1956, The difference between sliding and turbidity flow. *Deep-Sea Res.*, v. 3, no. 2, p. 134–139, 1 text-fig.

Nayudu, Y.R., 1964, Carbonate deposits and paleoclimatic implications in the Northeast Pacific Ocean. *Sci.*, v. 146, no. 3643, p. 515–517, 4 text-figs.

Parker, F.L., 1958, Eastern Mediterranean Foraminifera. *Rep. Swedish Deep-Sea Exped.*, v. 8, no. 4, p. 217–283, 6 text-figs., 22 tab., 6 pls.

———, 1960, Living planktonic Foraminifera from the Equatorial and Southeast Pacific. *Tohoku Univ., Sci. Rep., 2nd ser. (Geol.), Spec. Vol.* no. 4, p. 71–82, 20 text-figs., 1 tab.

———, 1962, Planktonic foraminiferal species in Pacific sediments. *Micropal.*, v. 8, no. 2, p. 219–254, 4 tab., 10 pls.

Philippi, E., 1912, Die Grundproben der deutschen Südpolar Expedition. *in* Drygalski, E., Deutsche Südpolar Exped. 1901–1903., Band 2, Heft 6, p. 431–434.

Phleger, F.B., 1939, Foraminifera of submarine cores from the continental slope. *Geol. Soc. Amer. Bull.*, v. 50, p. 1395–1422, 4 text-figs., 3 tab., 3 pls.

———, 1942, Foraminifera of submarine cores from the continental slope. Part 2., *Geol. Soc. Amer. Bull.*, v. 53, p. 1073–1098, 6 text-figs., 1 tab., 3 pls.

———, 1945, Vertical distribution of pelagic Foraminifera. *Amer. Jour. Sci.*, v. 243, p. 377–383, 2 text-figs.

———, 1948, Foraminifera of a submarine core from the Caribbean Sea. *Göteborgs, Kungl. Vetensk. och Vitterhets Samhälles Hand., Sjätte Följden, Ser. B*, no. 14, p. 1–9, 2 tab., 1 pl.

———, 1951, Ecology of Foraminifera, northwest Gulf of Mexico. Part 1-Foraminifera distribution. *Geol. Soc. Amer. Mem.*, v. 46, p. 1–88, 33 text-figs., 37 tab., 20 pls.

———, 1955, Foraminiferal faunas in cores offshore from the Mississippi Delta, Papers in Marine Biology and Oceanography. *Deep-Sea Res.*, v. 3 (Supp.), p. 45–57, 3 text-figs., 4 tab.

———, and Hamilton, W.A., 1946 Foraminifera of two submarine cores from the North Atlantic basin. *Geol. Soc. Amer. Bull.*, v. 57, p. 951–966, 3 text-figs., 3 tab., 1 pl.

———, Parker, F.L. and Peirson, J.F., 1953, North Atlantic core Foraminifera. *Rep. Swedish Deep-Sea Exped.*, v. 7, no. 1, p. 1–122, 26 text-figs., 38 tab., 12 pls.

Riedel, W.R., Bramlette, M.N., and Parker, F.L., 1963, Pliocene-Pleistocene boundary in deep-sea sediments. *Sci.*, v. 140, no. 3572, p. 1238–1240, 1 text-fig.

———, and Funnell, B.M., 1964, Tertiary sediment cores and microfossils from the Pacific Ocean floor. *Geol. Soc. London, Quart. Jour.*, v. 120, p. 305–368, 5 text-figs., pls. 14–32.

Said, R., 1950, The distribution of Foraminifera in the Northern Red Sea. *Cushman Found. Foram. Res., Contr.*, v. 1, pt. 1, p. 9–29, 4 text-figs., 1 tab.

Schott, W., 1935, Die Foraminiferen in dem äquatrialen Teil des Atlantischen Ozeans. *Wiss. Ergeb. Deutschen Atlantischen Exped. Meteor*, 1925–1927., Band 3, Teil 3, Lief 1, p. 42–134, text-figs. 18–57, 3 pls.

———, 1952, On the sequence of deposits in the Equatorial Atlantic Ocean. *Göteborgs Kungl. Vetensk. och Vitterhets Samhälles Handl., Sjätte Följden Ser. B.*, v. 6, no. 2, p. 1–15, 3 text-figs.

Stubbings, H.G., 1937, Stratification of biological remains in marine deposits. *John Murray Exped., Sci. Rep.*, v. 3, no. 3, p. 154–192, 4 text-figs., 8 tab.

Sverdrup, H.U., Johnson, M.W., and Fleming, R.H., 1942, The Oceans, their physics, chemistry and general biology. Prentice-Hall, New York. 1087 p.

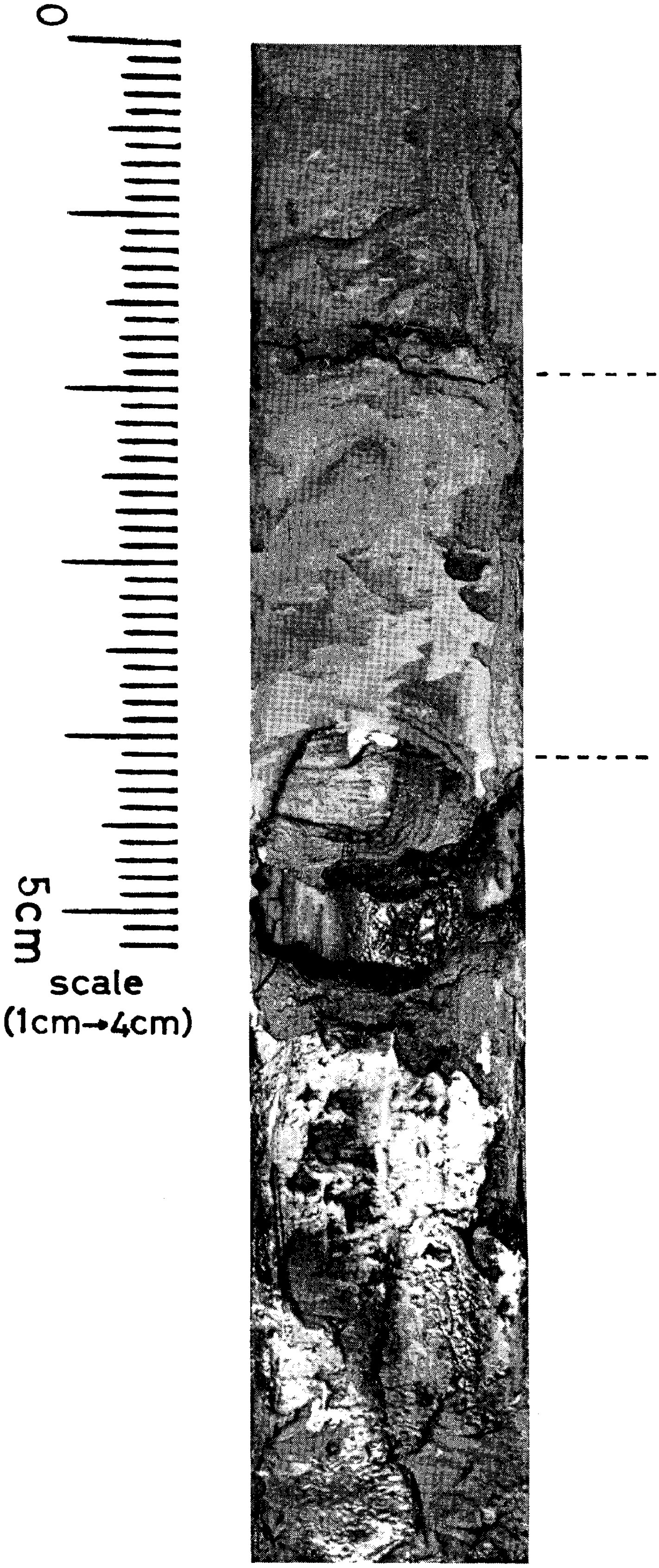
Todd, R., 1958, Foraminifera from western Mediterranean deep-sea cores. *Rep. Swedish Deep-Sea Exped.*, v. 8, fasc. 2, p. 167–216, 5 text-figs., 20 tab., 3 pls.

———, 1964, Planktonic Foraminifera from deep-sea cores off Eniwetok Atoll. *U.S. Geol. Surv. Prof. Paper*, 260–CC, p. 1067–1100, text-figs. 319–320, 3 tab., pls. 289–295.

Plate 17

Plate 17. Core Ka–15 showing the reworked sediment between 132 and 166 cm from the top.

Core Ka-15 (132 cm-166 cm)



olive gray clayey-silt
sand$_{5}$ silt$_{54}$ clay$_{41}$
Mz: 6.40, Mdø: 6.720

pale olive corse-silt
sand$_{11}$ silt$_{85}$ clay$_{4}$
Mz: 4.70, Mdø: 4.943

dark brown clay
sand$_{0.25}$ silt$_{14}$ clay$_{85.75}$
Mz: 10.41, Mdø: 10.133

abbreviation
Mz: Mean diameter
Mdø: Median diameter in phi scale

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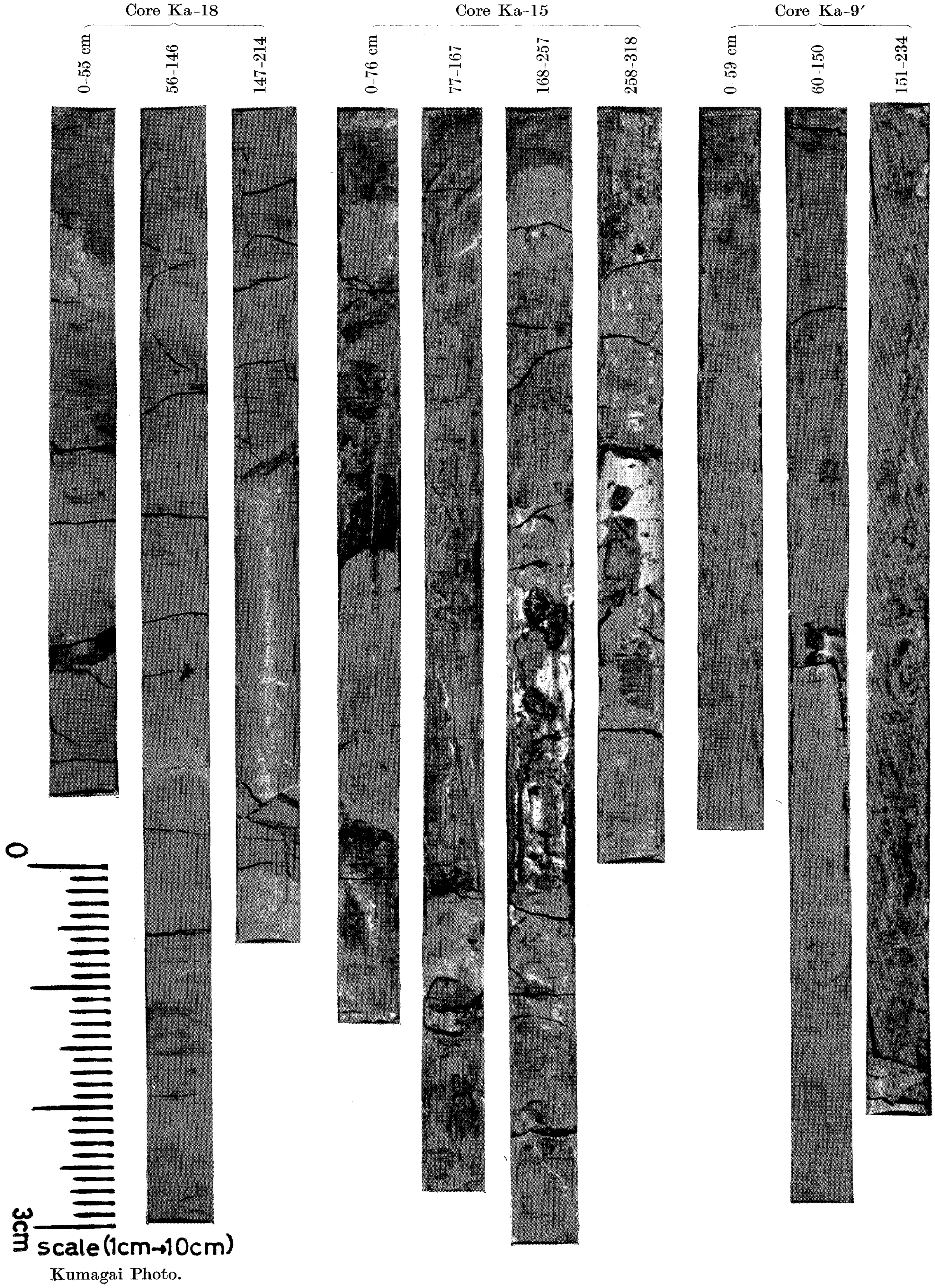

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Plate 18

Plate 18. Longitudinal sections of the cores Ka–18, Ka–15, and Ka–9′.

Showing some blank parts, not filled with sediment, are found at the depth as follows.

41–43 cm, 173–200 cm from the top of the core Ka–18. 151–153 cm, 290–299 cm from the top of the core Ka–15. 60–62 cm, 101–104 cm, 151–152 cm from the top of the core Ka–9′.

Plate 19

Plate 19. Longitudinal sections of the cores Ka–12, and Ka–21, showing banding, layers, and mottling.

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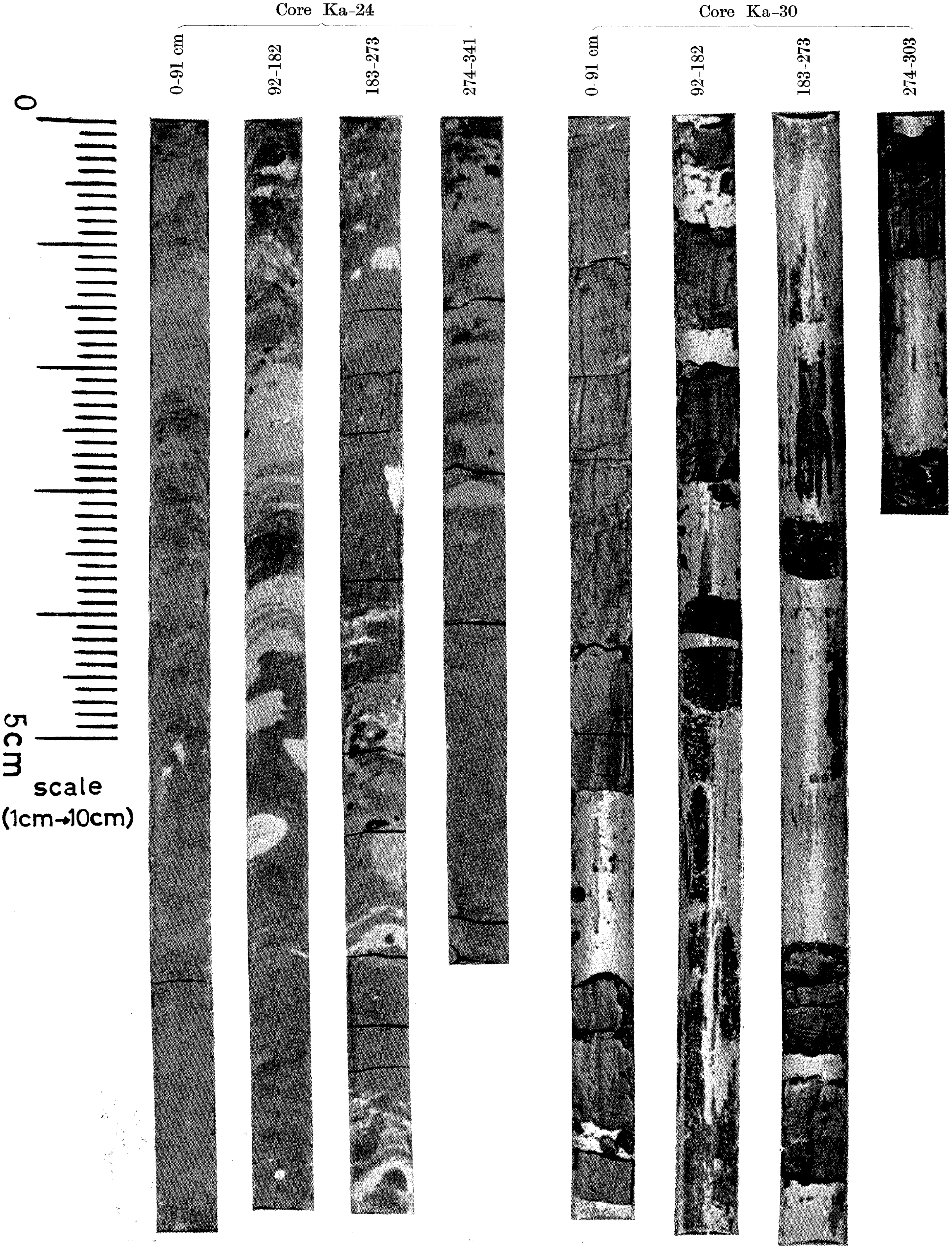

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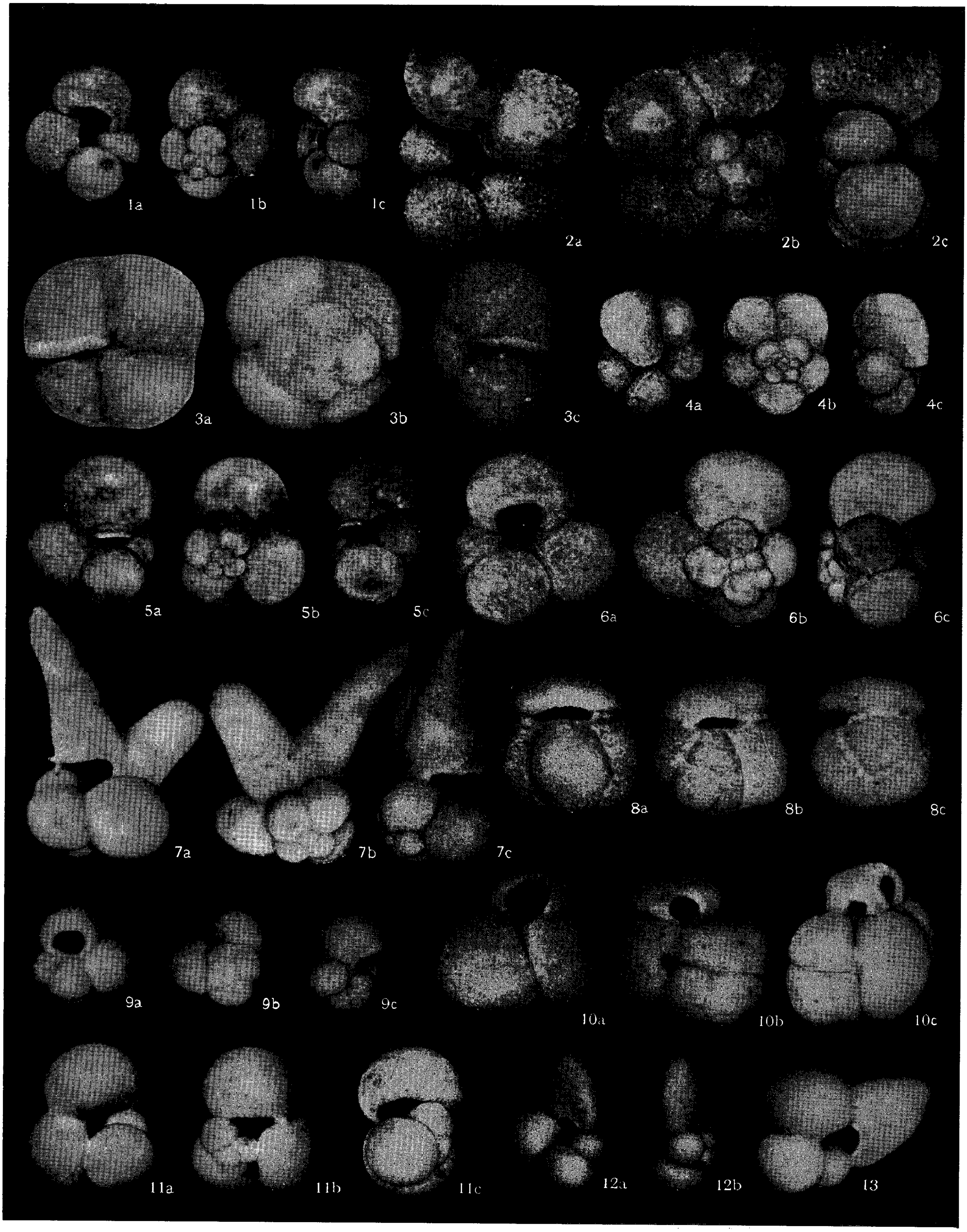
Plate 20

Plate 20. Longitudinal sections of the cores Ka–24, and Ka–30. Showing the many blank parts (light colored), not filled with sediment, in the core Ka–30. Mottling is well shown in the core Ka–24.

Plate 21

Figs. 1a–c. *Globigerina bulloides* d'Orbigny
From core Ka–15 (135 cm) ×68.
Figs. 2a–c. *Globigerina calida* Parker
From core Ka–15 (195 cm) ×70.
Figs. 3a–c. *Globigerina pachyderma* (Ehrenberg)
From core Ka–15 (270 cm) ×122.
Figs. 4a–c. *Globigerina quinqueloba* Natland
From core Ka–18 (bottom sample) ×111.
Figs. 5a–c. *Globigerina falconensis* Blow
From core Ka–15 (145 cm) ×125.
Figs. 6a–c. *Globigerina rubescens* Hofker
From core Ka–18 (170 cm) ×122.
Figs. 7a–c. *Globigerina digitata* Brady
From core Ka–15 (275 cm) ×67.
Figs. 8a–c. *Globigerinoides conglobatus* (Brady)
From core Ka–18 (bottom sample) ×34.
Figs. 9a–c. *Globigerinoides tenellus* Parker
From core Ka–18 (130 cm) ×69.
Figs. 10a–c. *Globigerinoides ruber* (d'Orbigny)
From core Ka–18 (100 cm) ×67.
Figs. 11a–c. *Globigerinoides sacculifer* (Brady)
From core Ka–18 (170 cm) ×35.
Figs. 12a–b. *Globigerinoides sacculifer* (Brady)
From core Ka–18 (170 cm) ×34.
Fig. 13. *Globigerinoides sacculifer* (Brady)
From core Ka–18 (130 cm) ×40.



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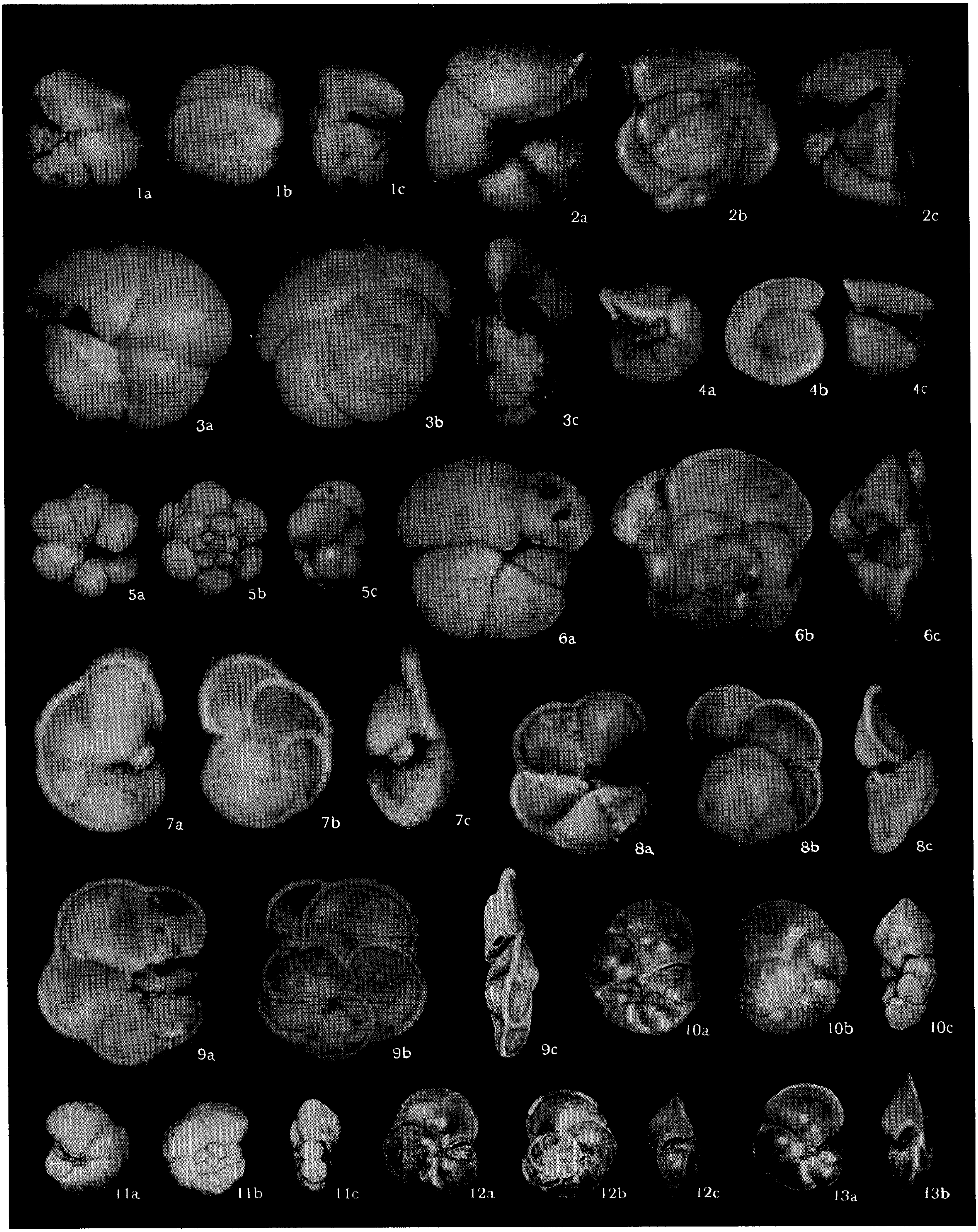

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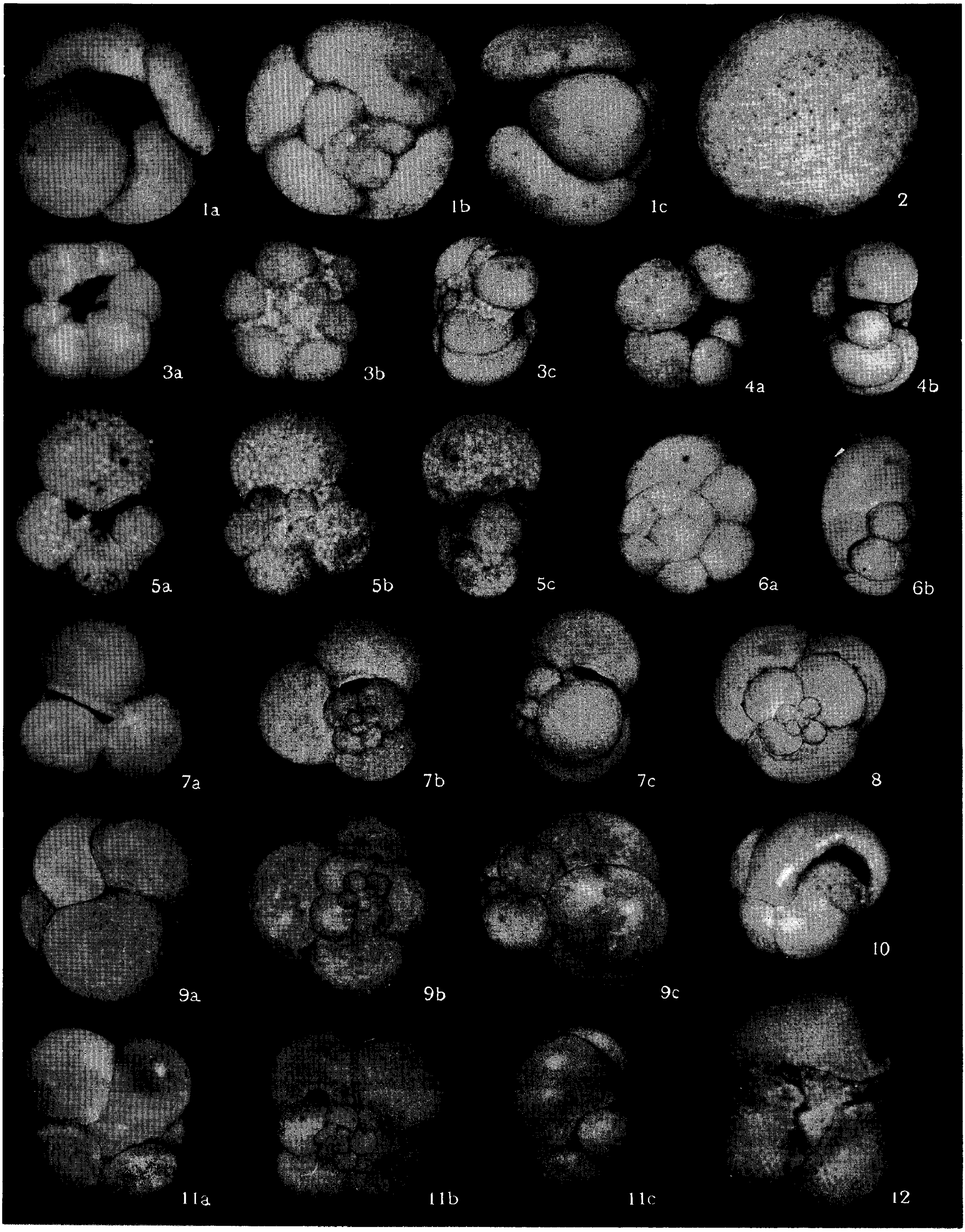
Plate 22

Figs. 1a–c. *Globorotalia inflata* (d'Orbigny)
From core Ka–15 (70 cm) ×67.
Figs. 2a–c. *Globorotalia crassaformis* (Galloway and Wissler)
From core Ka–18 (60 cm) ×68.
Figs. 3a–c. *Globorotalia scitula* (Brady)
From core Ka–18 (30 cm) ×69.
Figs. 4a–c. *Globorotalia truncatulinoides* (d'Orbigny)
From core Ka–18 (160 cm) ×35.
Figs. 5a–c. *Globorotalia pumilio* Parker
From core Ka–18 (70 cm) ×86.
Figs. 6a–c. *Globorotalia hirsuta* (d'Orbigny)
From core Ka–18 (130 cm) ×67.
Figs. 7a–c. *Globorotalia tumida* (Brady)
From core Ka–15 (230 cm) ×39.
Figs. 8a–c. *Globorotalia menardii flexuosa* (Koch)
From core Ka–18 (160 cm) ×25.
Figs. 9a–c. *Globorotalia menardii* (d'Orbigny)
From core Ka–18 (100 cm) ×23.
Figs. 10a–c. *Globorotalia elongata* Glaessner
From core Ka–15 (135 cm) ×82.
Figs. 11a–c. *Globorotalia elongata* Glaessner
From core Ka–15 (145 cm) ×86.
Figs. 12a–c. *Globorotalia pseudoscitula* Glaessner
From core Ka–15 (140 cm) ×82.
Figs. 13a–b. *Globorotalia pseudoscitula* Glaessner
From core Ka–15 (135 cm) ×63.

Plate 23

Figs. 1a–c. *Globoquadrina conglomerata* (Schwager)
From core Ka–15 (40 cm) ×40.
Fig. 2. *Orbulina universa* d'Orbigny
From core Ka–18 (140 cm) ×40.
Figs. 3a–c. *Globoquadrina dutertrei* (d'Orbigny)
From core Ka–18 (140 cm) ×41.
Figs. 4a–b. *Globigerinella siphonifera* (d'Orbigny)
From core Ka–18 (110 cm) ×37.
Figs. 5a–c. *Globoquadrina hexagana* (Natland)
From core Ka–15 (140 cm) ×81.
Figs. 6a–b. *Globigerinita humilis* (Brady)
From core Ka–15 (295 cm) ×140.
Figs. 7a–c. *Globigerinita glutinata* (Egger)
From core Ka–18 (90 cm) ×80.
Fig. 8. *Candeina nitida* d'Orbigny
From core Ka–18 (bottom sample) ×112.
Figs. 9a–c. *Globigerinita uvula* (Ehrenberg)
From core Ka–15 (135 cm) ×142.
Fig. 10. *Pulleniatina obliquiloculata* (Parker and Jones)
From core Ka–15 (20 cm) ×40.
Figs. 11a-c. *Globigerinita iota* Parker
From core Ka–18 (95 cm) ×140.
Fig. 12. *Sphaeroidinella dehiscens* (Parker and Jones)
From core Ka–18 (120 cm) ×42.



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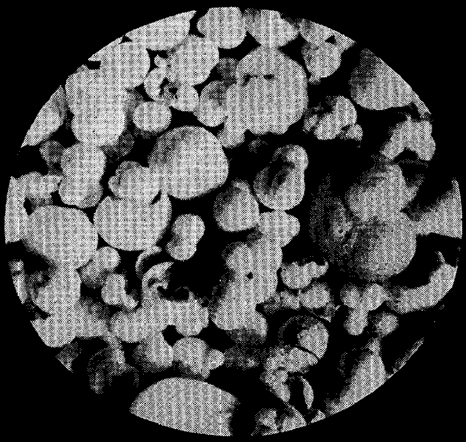

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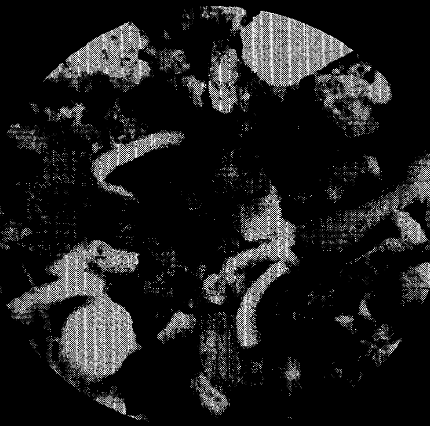

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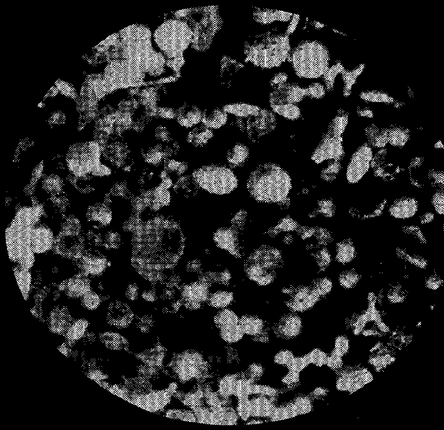

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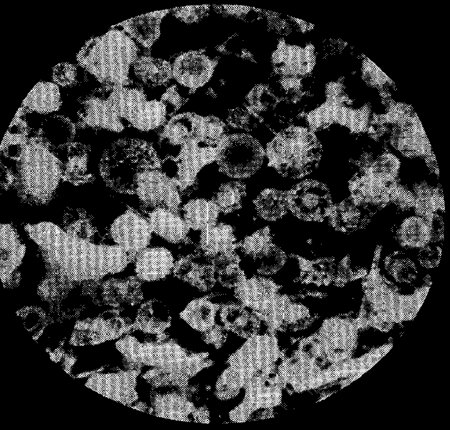

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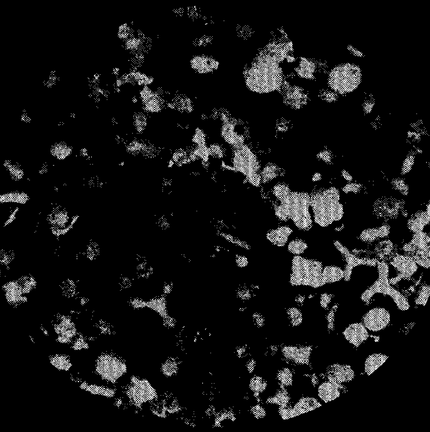

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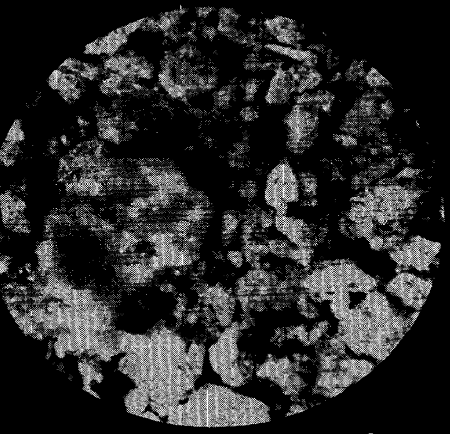

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Plate 24

Fig. 1. *Globigerina* ooze remaining on 200 mesh sieve.
From core Ka–18 (bottom sample) ×9.
Fig. 2. Materials remaining on 200 mesh sieve.
From core Ka–15 (bottom sample) ×19.
Fig. 3. Materials remaining on 200 mesh sieve.
From core Ka–9' (bottom sample) ×24.
Fig. 4. Radiolaria ooze remaining on 200 mesh sieve.
From core Ka–12 (bottom sample) ×23.
Fig. 5. Radiolaria ooze remaining on 200 mesh sieve.
From core Ka–21 (bottom sample) ×31.
Fig. 6. Radiolaria ooze remaining on 200 mesh sieve.
From core Ka–24 (bottom sample) ×20.
Fig. 7. Red clay remaining on 200 mesh sieve.
From core Ka–30 (bottom sample) ×22.
Fig. 8. Red clay remaining on 200 mesh sieve.
From core Um–18 (top sample) ×24.