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Biostratigraphy and Isotopic Paleotemperature of some Deep-Sea Cores from the Indian Ocean

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ABSTRACT

Of the six deep-sea cores obtained from the central equatorial Indian Ocean along Long. 78°E. from Lat. 6°N. to Lat. 2°S., the northern three cores are composed of *Globigerina* ooze and calcareous clay and the other cores from 4,700–4,800 m in depth are of brown clay with some layers of secondary deposited sediments.

Paleotemperature curves of the northern three cores based on the oxygen isotopic method showed two temperature oscillations with an amplitude of about 6°C. and resemble closely those of the many deep-sea cores from the Atlantic, Pacific and Caribbean Sea measured by Emiliani (1955, –1967) and Rosholt *et al.* (1961, 1962). The late Pleistocene chronology since the Mindel-Riss interglacial was considered on the basis of the paleotemperature curves, radiocarbon dates, and rate of sedimentation measured by the Io/Th method.

Planktonic foraminiferal number in the sediments decreases generally with increasing depth. The coarser fractions larger than 74 μ and calcium carbonate percentage in the sediment are proportional to the planktonic foraminiferal number, and are larger during the glacial stage than during the interglacial stage.

Analysis of the planktonic Foraminifera of the cores showed that the fluctuation curves of the warm water fauna coincides roughly with the paleotemperature curves gained by the oxygen isotopic method. The planktonic Foraminifera in the cores obtained from relatively deep water are almost broken and the few perfect specimens are those of the species with thick shelled test.

The rate of dissolution of the test was estimated from the damaged test of *Globorotalia menardii,* and the results were in good agreement with the percentage of the benthonic Foraminifera. The agreement is not due to the increase of benthonic Foraminifera but to the decreased number of specimens of the planktonic ones. The dissolution effect of the test was also found in the cores obtained from relatively shallow water.

Factor analysis of the planktonic foraminiferal assemblages in the cores revealed the mutual relationships of each species and of each sample (horizon of the core) mathematically most concisely. R-technique factor analysis revealed that the species in the cores was controlled by the factors in the order of decreasing statistical significance of I: province, II: water temperature, and III: dissolution of the test. Likewise, it was inferred by the Q-technique factor analysis that the dissolution effect of the test in the cores obtained from deep water had affected the assemblage more strongly than the water temperature.

The existence of the undamaged tests in the deep-sea floor of more than 4,700 m in depth is due to the protection of the tests from the dissolution of calcium carbonate by masking of the rapidly deposited sediments carried by turbidity currents.

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INTRODUCTION AND PREVIOUS WORKS

A modern approach to the study of the Pleistocene epoch in the deep-sea core was initiated in 1935 by Schott, who found well-defined changes in the abundancy of some planktonic foraminiferal species in the sequence of the bottom sediments. He examined the distributions of the species in the bottom surface sediment samples from the equatorial Atlantic, and recognized higher latitude faunas below the surface sediments in numerous short cores. Especially, the fauna in the lower part of the cores was differentiated from the modern fauna in the relative rarity of *Globorotalia menardii*. Later, in early 1950, the study of the planktonic Foraminifera from the deep-sea core had been made by mainly Cushman or Phleger etc. (Cushman *et al.*, 1937; Stubbings, 1937; Phleger, 1939; Cushman and Henbest, 1940; Cushman, 1941; Phleger, 1942; Phleger and Hamilton, 1946; Phleger, 1947, 1948, 1951; Schott, 1952; Phleger *et al.*, 1953). These authors considered on the paleoclimatic change based on a comparison of the planktonic foraminiferal fauna of the bottom surface sediment with that in the cores, based on the ratio between two species which are representatives of the warm and cold water faunas respectively. They observed the existences of a colder water fauna in the cores than in the bottom surface sediments and correlated them with the glacial stages or substages of the Pleistocene. Phleger (1948) and Phleger *et al.* (1953) reported numerous samples containing abundant broken tests of planktonic Foraminifera in the cores especially from the depths greater than 5,000 m, and stated that the breakage was fundamentally due to dissolution of calcium carbonate. Phleger (1939, 1951), Cushman *et al.* (1941), and Schott (1952) found that a large planktonic foraminiferal number was encountered in the warm stage defined by the increase of a warm water fauna in the assemblage.

Since early 1950, many geochemical methods have been applied to the study of the deep-sea cores besides the lithological and micropaleontological studies, and various arguments have been developed by many workers.

Arrhenius (1952) carried out chemical, micropaleontological, and lithological studies on a number of the cores from the eastern equatorial Pacific, and found marked changes in the concentration of the calcium carbonate in the sediments of the cores. He explained this as being due to the high rate of production of planktonic Foraminifera at the surface of the ocean during the ice ages. That is, during the ice ages, the rate of circulation of the deep water is likely to have increased and an extensive supply of nutrients to the euphotic layer made possible by the upwelling in the divergence. Consequently, the rate of production of the phytoplankton is prompted, and this results from the increased production of zooplankton (Foraminifera, and Radiolaria etc.). Ultimately, he suggested that the period representing the high concentration of the calcium carbonate in the sediment of the core corresponds to the cold stage.

With regard to the suggestion, Emiliani (1955) determined the paleotemperatures of the superficial water in the equatorial Atlantic, Caribbean, and Pacific Ocean by the oxygen isotopic method of some planktonic foraminiferal tests in the deep-sea cores, and found several temperature oscillations during the Pleistocene with an amplitude of about 6°C. He also determined the late Pleistocene chronology adding the absolute ages based on radiocarbon data. Of the numerous deep-sea cores which he used, three cores from the Pacific Ocean were previously examined by Arrhenius (1952). He calculated the correlation coefficients between the paleotemperatures and the calcium carbonate percentages of the three cores with the results of 0.07, –0.11, and –0.70. Consequently, two of them have no correlation between the paleotemperature and the calcium carbonate contents, whereas the remaining one tends to support Arrhenius's opinion. While, with respect to the cores from the Atlantic and Caribbean, he showed very close agreements between the paleotemperature curves and the curves of the coaser fractions larger than 62 or 74 μ. Hence, he stated that the high concentrations of calcium carbonate in the sediments of the cores correspond to the warm stage. Thereafter, there have been published many discussions on the relationship between the paleoclimate and the calcium carbonate contents in the sediment of the deep-sea core (Hough, 1953; Wiseman, 1954, 1959a, 1959b, Hamilton, 1957; Yalkosky, 1957; Wangersky, 1958, 1967; Emiliani and Mayeda, 1961; Rosholt *et al.*, 1961; Emiliani and Flint, 1963; Nayudu, 1964). Among these studies, Hamilton (1957) and Nayudu (1964) reported results that support Arrhenius's opinion. On the contrary, Wiseman (1954, 1959b), Emiliani and Mayeda (1961) observed the direct relationship between the total carbonate percentages and paleotemperatures. Other authors demonstrated that there was no relationship between them.

Meanwhile, Ericson *et al.* (1956a, 1956b, 1961) studied in detail the lithology and micropaleontology of the numerous Atlantic and Caribbean deep-sea cores. They correlated the cores with each other by means of many criteria, and established six faunal zones in the sequence of the late Pleistocene on the basis of the relative abundance of the *Globorotalia menardii* group. And they determined the late Pleistocene chronology based on the relative frequency curves of the warm- and cold-water planktonic Foraminifera, the ratios of the number of *Globorotalia menardii* to the weight of the material coarser than 74 μ, and radiocarbon data. Moreover, he found definite occurrences of *Globorotalia menardii flexuosa* in the sequence of the cores. Of the cores which Ericson *et al.* used, three were previously examined by Emiliani (1955). They compared the climatic curves derived from the micropaleontological method with isotopic paleotemperature curves. As a result, there was close correlation in the upper part of the sections, but lower in the sections there was a marked divergence. Their opinions are entirely divided with respect to the subdivision of the late Pleistocene (Ericson *et al.*, 1956b, 1961, 1964; Emiliani, 1957, 1958, 1964). There are some other micropaleontological studies of the deep-sea cores (Kane, 1956; Todd, 1958; Parker, 1958; Olausson, 1960, 1961).

To infer the accurate paleoclimatic change from the analysis of the foraminiferal assemblage in the deep-sea core, it is essential to know the details on the distribution and ecology of the living planktonic Foraminifera. The regional and areal distribution of the planktonic foraminiferal species were studied by Bradshaw (1959) in the north and equatorial Pacific, Bè (1969, 1960) in the western north Atlantic, Parker (1960) in the equatorial and southeast Pacific, Belyaeva (1964) in the Indian Ocean, Bè and Hamilton (1967) in the north Atlantic, and Jones (1967) in the eqatorial Atlantic. Thereafter, there are many studies on the deep-sea cores based on these ecological informations of the planktonic Foraminifera (Ericson *et al.*, 1961, 1964; Todd, 1964; Lidz, 1966; Blackman and Somayajulu, 1966; Oba, 1967, Frerichs, 1968).

However, another important problem has arisen for the analysis of the planktonic foraminiferal assemblage in the deep-sea core, although the problem had been already recognized by a few workers (Phleger, 1948; Arrhenius, 1952; Phleger *et al.*, 1953; Hamilton, 1957). This problem is the dissolution of the test by the cold bottom water. Berger (1967), in his field experiment of the dissolution effect of the foraminiferal test exposed to ocean water for four months in the central Pacific, observed that the dissolution of the test took place everywhere below the surface waters and acted selectively on the test of different species. The dissolution of the test, therefore, tends to reduce the diversity of an assemblange (Berger, 1967, 1968; Pytkowicz and Fowler, 1967; Ruddiman and Heezen, 1967). For such reason, one must always consider the dissolution effect of the test, if the core was obtained from water depths especially deeper than 4,500 m or so in low latitudes.

Recently, Blackman and Somayajulu (1966) applied the vector analysis to the study of the planktonic foraminiferal assemblanges in two cores from the southeast Pacific. They examined the faunal assemblages in the top samples of 56 gravity cores from Lat. 1°N. to 42.8°S., and recognized four faunal groups in a concise statistical way. They delineated a fluctuation curve by determining the proportion of the four groups in a core sample and considered the paleoclimatic change. Such a statistical technique is an important method for judging the data objectively.

In the present study, the writer attempted by some methods to solve the paleoclimatic change and some other problems; the relationship between the paleotemperature and the calcium carbonate content in the sediment of the cores, the late Pleistocene chronology, and dissolution effect of the test, etc.

The purpose of the present study is 1) to determine the paleoclimatic change during the late Pleistocene in the six deep-sea cores from the Indian Ocean using three different methods; oxygen isotopic, micropalleontological, and statistical methods. And, 2) to discuss the relationship between the paleoclimate and the mechanism of deep-sea sedimentation.

This paper consists of three main contents, that is, isotopic paleotemperature that includes its principle, technical problems, and the results applied to the cores; planktonic foraminiferal biostratigraphy, this includes several micropaleontological methods for the interpretation of paleoclimate, the problems as to the dissolution of planktonic foraminiferal test, and correlation of the cores; and, the factor analysis of the planktonic foraminiferal assemblages provides the most objective method for the determination of the factors which had controlled the foraminiferal assemblages in the cores.

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MATERIALS

Original Data

The six deep-sea cores used for the present study are from the central equatorial Indian Ocean, along approximately Long. 78°E. from Lat. 6°N. to Lat. 2°S. Four of them (core nos. IC-6, IC-5, IC-4 and IC-3) were collected in December 1962 by the S.S. Umitaka-maru of the Tokyo University of Fisheries, and the other two (core nos. Ka-18 and Ka-15) in December 1963 by the S.S. Kagoshima-maru of the Kagoshima University, in the International Indian Ocean Expedition Years. The stations of the cores are plotted

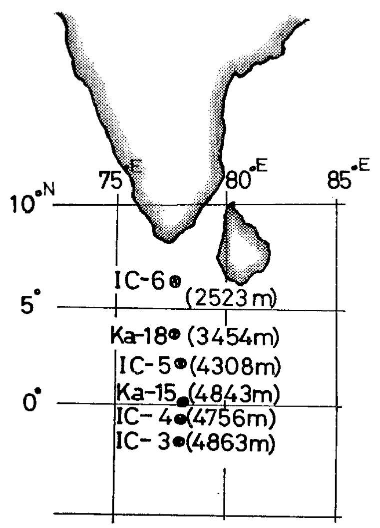


Fig. 1. Location of the cores.

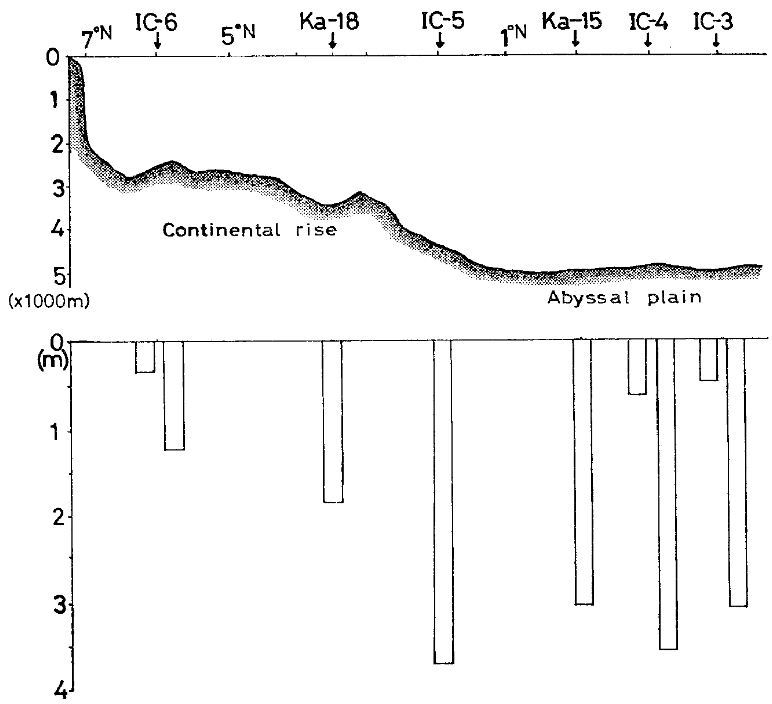


Fig. 2. Profile along Long. 78°E. and the core lengths.

Table 1. Data of sampling station

Station no.	Latitude	Longitude	Depth (m)	Core length (cm)	Sediments
IC-6	5°56.2′N.	77°50.7′E.	2523	123 (33)	*Globigerina* ooze
Ka-18	3°29.7′N.	77°49.6′E.	3435	185	*Globigerina* ooze
IC-5	1°58.2′N.	78°55.8′E.	4308	384	calcareous clay
Ka-15	0°00.5′N.	78°08.8′E.	4843	305	alternation of calcareous clay and brown clay
IC-4	0°58.1′S.	78°01.5′E.	4756	352 (67)	brown clay
IC-3	1°56.0′S.	78°01.6′E.	4863	325.5(51)	brown clay

in Fig. 1, and the data in Table 1. The depths of the cores increase gradually from north to south, and the shallowest is 2523 m (core IC-6), whereas the deepest is 4863 m (core IC-3). The core lengths measure from 123 cm (shortest, core IC-6) to 384 cm (longest, core IC-5). The cores were collected by the piston corer modified from the original Kullenberg corer. The submarine surface sediments were obtained by the gravity corer used as the trigger weight on the piston corer, and the three pilot cores are of several ten centimeters in length.

The profile along Long. 78°E. and the submarine topography (Heezen and Tharp, 1964) of the north-east Indian Ocean are shown in Figs. 2 and 3. Cores IC-6 and Ka-18 were taken from the continental rise which extends in south-southeast direction from off Cap Comorin of the Indian Peninsula and core IC-5 from near the southern skirts of the continental rise. The three other cores are from the Ceylon abyssal plain. The submarine topography shows that the Ganges cone is developed from near the mouth of the Ganges River from where it extends to the deep-sea floor for about 3,000 km. Numerous deep-sea channels incise the Ganges cone.

Deep-sea channels were also reported by Dietz (1954) from the deep-sea floor at about several hundred kilometers south-east of Ceylon.

The longitudinal halves of the cores Ka-18 and Ka-15 previously studied by Oba (1967) are stored in the Institute of Geology and Paleontology, Tohoku University, whereas halves of the cores IC-6, IC-5, IC-4 and IC-3 are preserved in the collection of the Tokyo University of Fisheries.

Treatment of the Cores

The cores were cut lengthwise into two equal halves with a rotational saw. One of the halves was photographed and the sediments described. The other half was cut again lengthwise for lithological and micropaleontological investigations. From the fourth section of the whole core, the samples were taken from 1.0 cm thick horizontal slices cut at the intervals of 5 cm and 10 cm. Concerning the interval of sampling in a single core, Arrhenius (1952) stated "It is meaningless to define the sample level closer than 10 cm thick and the sample thickness less than 2–3 cm because of reworking of the sediments by mud eating bottom animals". Usually, it is adequate to take the 1.0 cm thick slices at 5 cm interval for study of the lithology, micropaleontology and paleoclimatology. The samples were trimmed of their outer several millimeters to avoid contamination of the sediments by the drag caused by the friction with the tube. Each sample was measured to one gram dry weight and then carefully washed through a 200-mesh sieve. The fraction remaining on the sieve was weighed and recorded as percentage of the coarse fraction. A quantitative analysis of the calcium carbonate was made to measure the volume of generated gas with the reaction of one gram of dried sediment and 2 cc. of 2 N. hydrochloric acid, using the apparatus described by Hülsemann (1966). In the case of *Globigerina* ooze from the

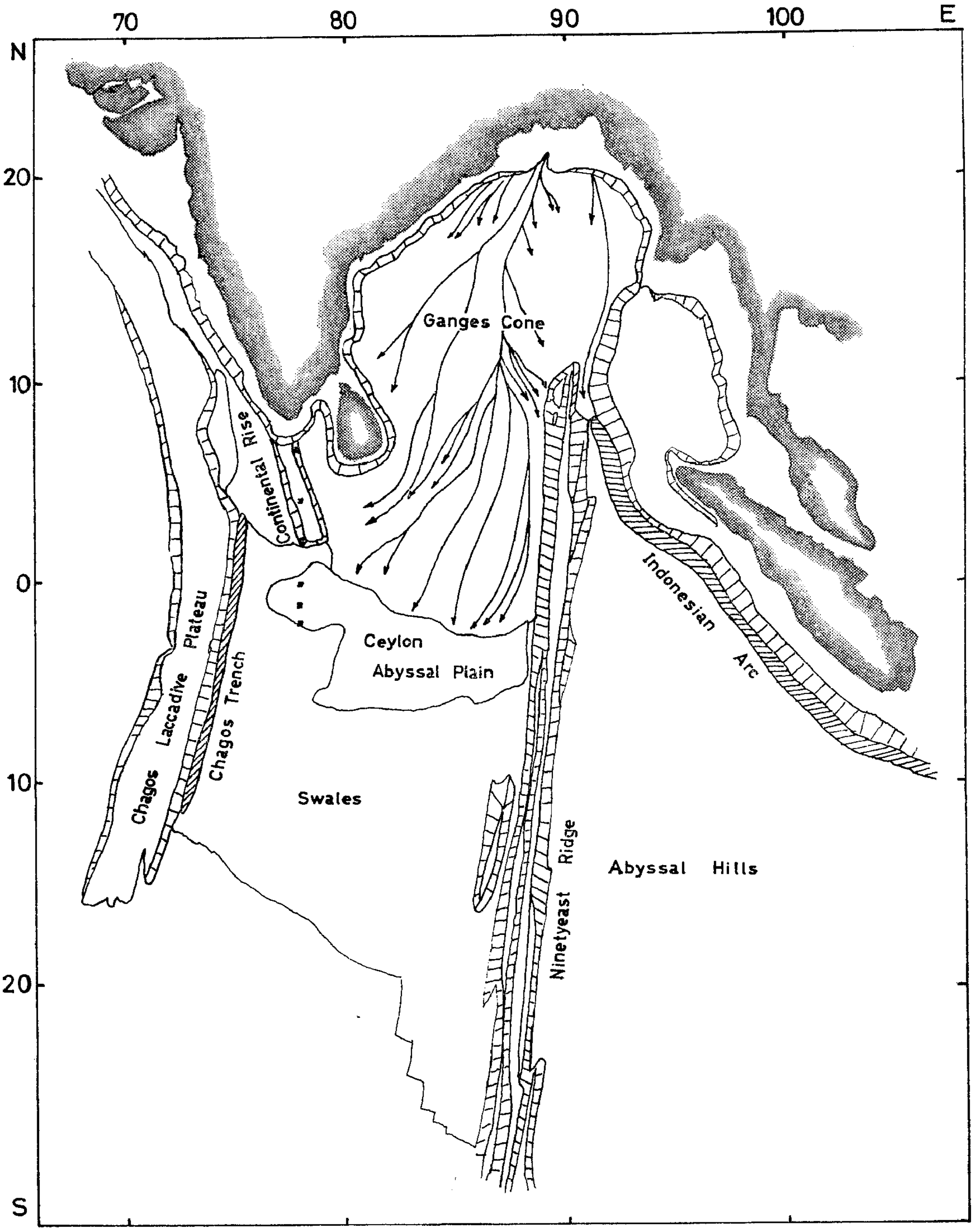


Fig. 3. Physiographic provinces of the north-east Indian Ocean. (compiled from Heezen and Tharp, 1964).

deep-sea floor, the volume of the generated gas is considered as representative of the calcium carbonate in the sediment, because the tests of planktonic Foraminifera are composed of pure calcium carbonate. X-ray investigation on the sediments of all the cores showed the presence of calcite, quartz, feldspar and clay minerals. The clay mineral could not be classified notwithstanding the exception of calcium carbonate in the sediments by acid decomposition.

Description of the Cores

The sediments of the cores before drying were described as to color, pattern, composition and grain size. The color description is based upon the Rock-color chart distributed by the Geological Society of America, New York, N. Y., reprinted in 1963. The general lithological descriptions of the cores were principally based on the microscopic examinations of the constituents larger than 74 μ and on the thin sections of the sediments. Coarse fractions and the content of calcium carbonate were measured on the slices taken at 10 cm interval of all the cores.

Core IC-6

Location: Lat. 5°56.2′N., Long. 77°50.7′E.
Depth: 2523 m
Core length: 123 cm (piston core), 33 cm (pilot core)
Date of collection: December 18, 1962
Photograph: Plate 20

Color and pattern: The sediments of both the pilot and piston cores are of uniform grayish olive color except for the upper several centimeters thick part of the pilot core which is dusky brownish yellow in color, probably due to the oxidized state. Although there is no remarkable color change and pattern in the sediments of the piston core, very slight color changes from light grayish olive to dark grayish olive are seen at about 65 and 80 cm from the top. The precise color boundaries, however, are hardly distinguishable.

Composition: The sediments of both the pilot and piston cores contain thoughout abundant planktonic foraminiferal tests, with the average foraminiferal number of about 5,100; the benthonic one is 470. Other organisms, Radiolaria, diatoms and coccolithophorids also occur thoughout the core and a considerable concentration of Radiolaria is found in the pilot core, though the quantity is not comparable with that of the planktonic Foraminifera. A muddy layer with large amounts of broken tests of planktonic Foraminifera and Radiolaria is found near the bottom (110 cm) of the piston core. Other layers containing rather abundant broken tests of planktonic Foraminifera are found from the top down to 15 cm of the pilot core, from the top down to 5 cm and at 100–120 cm from the top of the piston core. The planktonic foraminiferal assemblage of the core is characterized by abundant specimens of *Globigerina bulloides* and *Globigerinita glutinata* which occupy 50 percent of the fauna on average. The core yielded very small amounts of plant-fiber, sponge-spicules, quartz, mica and other organic or inorganic materials.

Coarse fraction: Coarse fractions of the core amount to about 20 percent on average (Fig. 4) and consists of almost planktonic foraminiferal tests. Other materials remaining on a 200-mesh sieve, such as Radiolaria, sponge-spicules, plant-fiber, mica, and quartz, are of low quantity. There are somewhat low percentage layers of the coarse fraction at the top and 100–120 cm from the top of the piston core and in the entire pilot core, where the layers roughly correspond to the horizons with abundant Radiolaria and large amounts of broken tests of planktonic Foraminifera.

Calcium carbonate: The calcium carbonate content of the core changes from 31 percent to 54 percent at the maximum, being 43 percent on average (Fig. 4). The layers at the minimum which represent the relative low percentage of calcium carbonate correspond to the low percent layers of the coarse fractions.

Core IC-5

Location: Lat. 1°58.2′N., Long. 77°55.8′E.
Depth: 4308 m
Core length: 384 cm
Date of collection: December 15, 1962
Photograph: Plate 21

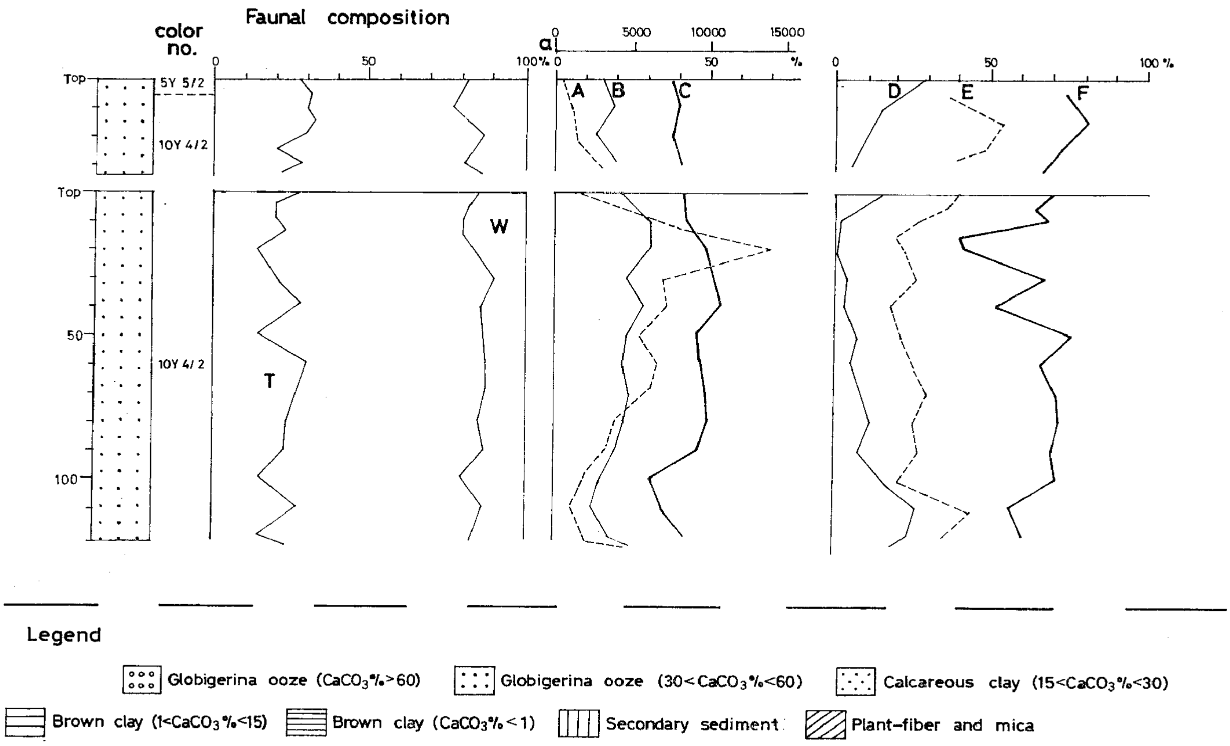


Fig. 4. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core IC–6.
T: Temperate water fauna, W: Warm water fauna
A: Planktonic foraminiferal number (scale ....a).
B: Coarse fraction.
C: Calcium carbonate content.
D: Percent of benthonic Foraminifera.
E: Percent of damaged tests of *Globorotalia menardii*.
F: Percent of fragments of *G. menardii*.

Color and pattern: The hue of the core IC-5 resembles that of the core Ka-18, and is as a whole yellowish gray to light olive gray in color. There is no remarkable color change and pattern except for a clear brown band of 1 cm which occurred at 13 cm from the top of the core. Faintly distinguishable color boundaries changing from yellowish gray to light olive gray are found at 228 cm and the reverse color change at 367 cm from the top; these may correspond to the horizons at 107 cm and 178 cm from the top of the core Ka-18, respectively.

Composition: The core contains abundant tests of planktonic Foraminifera and Radiolaria, the average planktonic foraminiferal number is 980 and the benthonic one is 85. However, the larger part of the planktonic foraminiferal tests are broken, and the layers that contain the abundant broken tests are separated from one another by the layers with relatively abundant undamaged tests of planktonic Foraminifera. In the extreme case, the layer is composed entirely of the fragments, especially keel fragments of *Globorotalia menardii* and *G. tumida*. Thus this core is characterized by including abundant Radiolaria and large amounts of broken tests of planktonic Foraminifera in comparison to the cores IC-6 and Ka-18, and the average foraminiferal number is far less than that of the cores IC-6 and Ka-18. The core contains throughout or sporadically small amounts of other organic and inorganic matters such as diatoms, coccolithophorids, sponge-spicules, quartz, and mica, although their quantity is out of question.

Coarse fraction: The coarse fraction of the core is composed entirely of the tests or fragments of Foraminifera and Radiolaria, and amounts to 18 percent on average, changing from 10 to 25 percent (Fig. 5). Although Radiolaria is abundant in the core, it is quantitatively not comparable with that of the planktonic Foraminifera.

Calcium carbonate: The content of calcium carbonate of the core changes from 12 to 48 percent, being 38 percent on average (Fig. 5). There are some layers with a low content of calcium carbonate, and they correspond to the low percentages of the coarse fractions. Especially the layer with a conspicuous low content of calcium carbonate at 100–110 cm from the top of the core may be correlated to the layers at 100–110 cm from the top of the core IC-6 and at 5–15 cm from the top of the core Ka-18, respectively.

Core IC-4

Location: 0°58.1′S., 78°01.5′E.
Depth: 4756 m
Core length: 352 cm (piston core), 67 cm (pilot core)
Date of collection: December 12, 1962
Photograph: Plate 22

Color and pattern: The color of this core, as a whole, changes from yellowish moderate brown to grayish olive, and the color boundaries are very clear (see color number in Fig. 6). Usually, the color boundaries represent an upward convex surface due to the drag caused by the friction against the inner wall of the tube. But the boundary at 67 cm from the top of the core represents a rather upward concave surface and the sediment between 59 cm and 67 cm from the top consists of pale green colored silt. The same kind of silt layer of 1 cm thick is found at 290 cm from the top, although both its upper and lower boundaries have upward convex surface. There are asymmetrial boundaries between 235 cm and 245 cm from the top caused by a strong drag on one side of the tube, and some mottles are found at 136–143 cm and 250–260 cm from the top of the core.

Composition: This core is entirely composed of clay size particles except for the two silt layers at 59–67 cm and 290–291 cm from the top of the core. The contents of the organic remains are very few, in comparison to the cores IC-6, Ka-18 and IC-5. Especially the amount of Foraminifera is extremely low and its average planktonic foraminiferal number is 13 and the benthonic one is 16. Most of the planktonic foraminiferal tests are broken, and concentrated in the yellowish gray layers. On the other hand, many undamaged tests of planktonic Foraminifera are found in the grayish olive colored layers at 170–180, 270, 310, and 340–350 cm respectively from the top. Except for the Foraminifera, the core contains thoughout or sporadically many kinds of organic and inorganic matters such as Radiolaria, diatoms, plant-fiber, sponge-spicules, mica, scoria, and quartz, although their quantity is very small. Especially in the pale green silt layer at 59–67 cm from the top of the core, high concentrations of Foraminifera, Radiolaria, sponge-spicules, Mollusca, plant-fiber, and mica are found, and almost all of the planktonic and benthonic foraminiferal tests are thin shelled immature forms. Abundant tests and fragments of Pelecypoda, Gastropoda, Pteropoda and Ostracoda are also found in this part of the core, especially of their larval stages. The layer is correlated to the horizon at 139–149 cm from the top of the core Ka-15, which was described (Oba, 1967) as a secondary sediment transported and deposited by turbidity current. The layer (1 cm thick) which is composed of constituents the same as the part of the cores mentioned above is found at 290 cm from the top of the core. In these silt layers, the benthonic foramini-

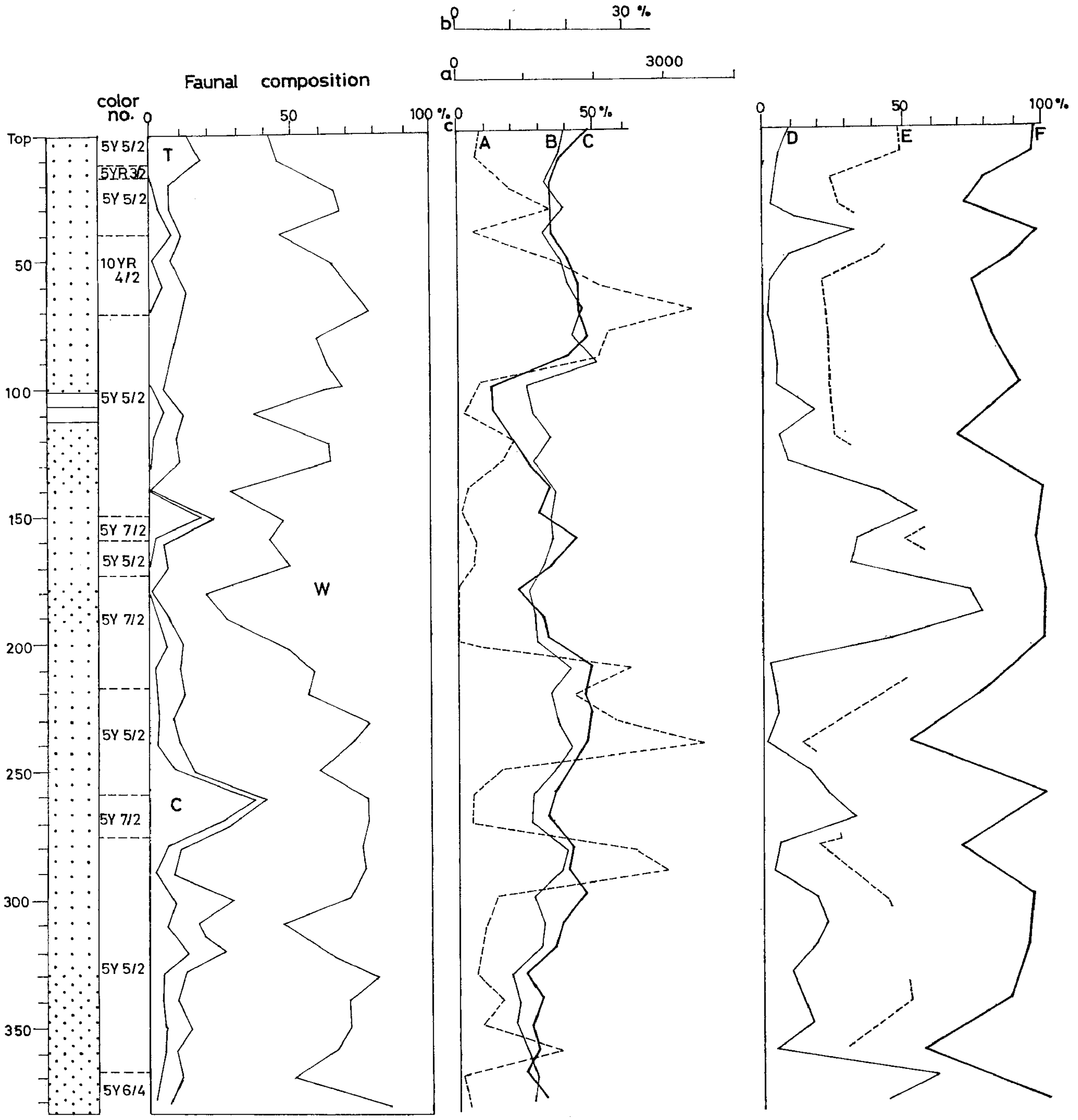


Fig. 5. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core IC-5.

C: Cold water fauna, T: Temperate water fauna, W: Warm water fauna.
A: Planktonic foraminiferal number (scale....a).
B: Coarse fraction (scale....b).
C: Calcium carbonate content (scale....c)
D: Percent of benthonic Foraminifera.
E: Percent of damaged tests of *Globorotalia menardii*.
F: Percent of fragments of *G. menardii*.

feral assemblage including *Ammonia beccarii* and some miliolids and abundant Ostracoda of shallow (50 m or so) sea water habitats indicate that the sediments were evidently derived from a shallow-water region by turbidity currents. Considering the submarine topography, the sediments were probably transported from a shallow-water region of the

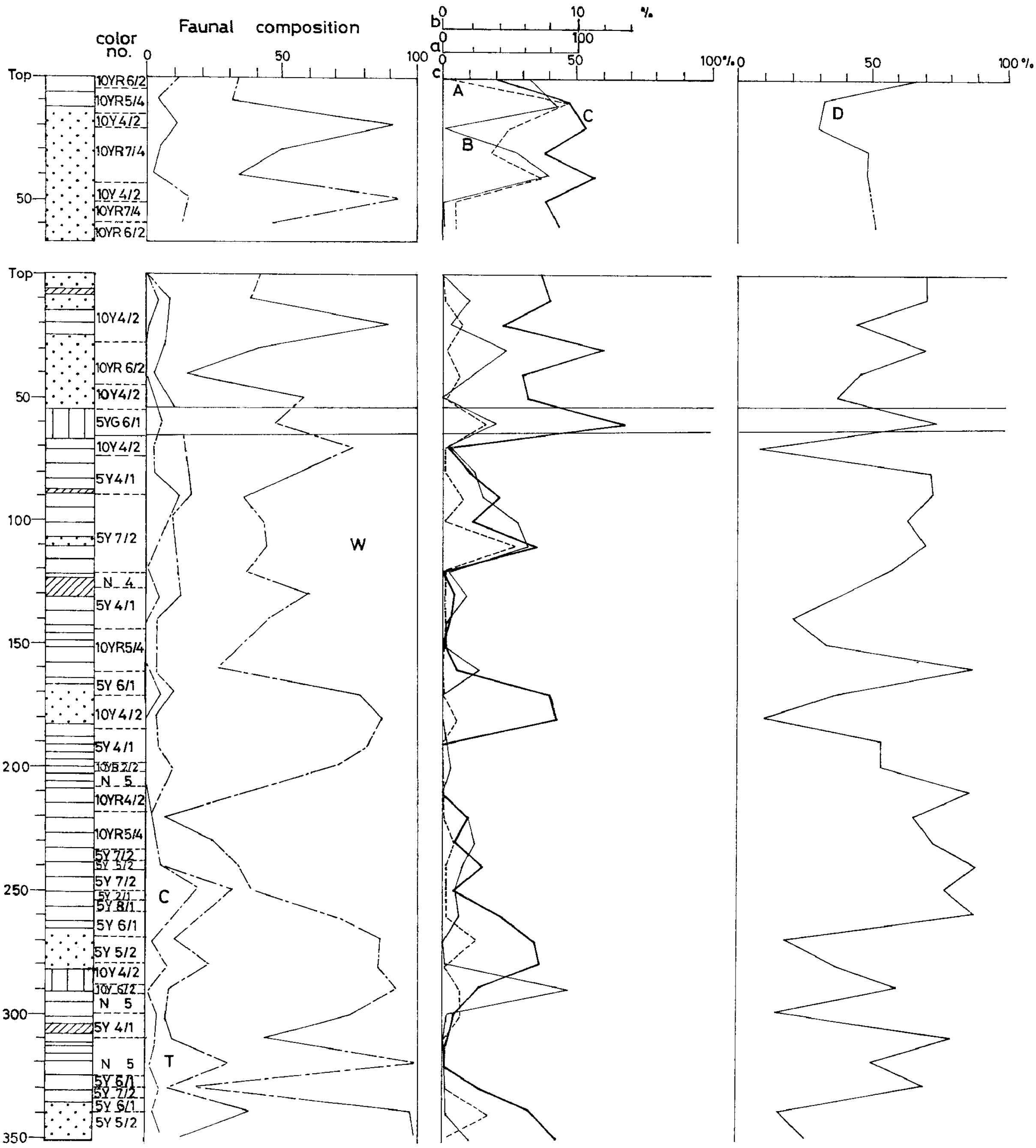


Fig. 6. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core IC-4.
C: Cold water fauna, T: Temperate water fauna, W: Warm water fauna.
A: Planktonic foraminiferal number (scale....a).
B: Coarse fraction (scale....b).
C: Calcium carbonate content (scale....c).
D: Percent of benthonic Foraminifera.

Bay of Bengal. Possibly some of the previously deposited sediments were lost through this action at least in case of deposition of the layer between 59 cm and 67 cm from the top of the core, because the layer has irregular boundary at the base. Small amounts of fine scoria are sporadically found in the core, and its relatively high concentrations at 25-40 cm and 160 cm from the top. Considerable concentrations of plant-fiber and mica are found at 125–130 cm and 305 cm from the top of the core.

Coarse fraction: The coarse fraction of the core is only about 2 percent on average (Fig. 6), and composed of Foraminifera, Radiolaria, plant-fiber, sponge-spicules, Mollusca, Ostracoda, mica, scoria, and quartz, but the larger part consists of planktonic Foraminifera. That is, the layers where the coarse fraction are almost composed of planktonic Foraminifera are at 10–20 cm and 40–50 cm from the top of the pilot core and at 30–40, 80–110, 220–260, and 350 cm respectively from the top of the piston core, where the layers correspond to the yellow colored layers. The planktonic foraminiferal number in the layers do not always exceed those of the olive colored layers, because of the almost broken tests in the yellow colored layers. Other layers representing relative high percentages of coarse fractions correspond to the layers including the secondary sediments at 60 cm and 290 cm, large amounts of scoria at 10, 30–40, 100, and 160 cm, and plant-fiber and mica at 110 cm respectively from the top of the core.

Calcium carbonate: The content of calcium carbonate of the core is less than 30 percent and its average is about 9 percent (Fig. 6). Relatively high contents of the calcium carbonate correspond to the high values of the coarse fraction and the layers containing abundant undamaged tests of planktonic Foraminifera at 110, 170–180, 270–280, and 340–350 cm respectively from the top of the core.

Core IC–3
Location: 1°56.0′S., 78°01.6′E.
Depth: 4863 m
Core length: 325.5 cm (piston core), 51 cm (pilot core)
Date of collection: December 11, 1962
Photograph: Plate 23

Color and pattern: The color of the core IC–3 is brownish gray or brownish black. The upper and lower parts of the pilot core have slightly olive gray layers. The part above 185 cm from the top of the piston core is brownish black and interbedded with brownish gray layers of several cm to 10 cm thick. Four and two interbedded layers exist between the top and 50 cm from the top and between 120 cm and 150 cm from the top of the core, respectively. The part below 185 cm from the top of the core shows a brownish gray color. All of the color boundaries are distinguishable and bent slightly upward.

Composition: The core is composed of clay size particles, except for the clayey silt layer between 64 cm and 86 cm from the top of the core, and contains throughout or sporadically organic and inorganic matters such as Foraminifera, Radiolaria, plant-fiber, sponge-spicules, mica, scoria, and quartz, although their quantity is very small. The planktonic foraminiferal tests are almost all broken, and some layers are entirely composed of keel-fragments of *Globorotalia menardii* and *G. tumida* and fragments of thick shelled species as *Sphaeroidinella dehiscens* and *Globoquadrina dutertrei*. The layers with abundant fragments of planktonic Foraminifera correspond to the brownish gray layers. On the other hand, the brownish black layers contain many undamged tests of planktonic Foraminifera at 35–50, 87–164 and 215 cm respectively from the top of the core. The layer between 64 cm to 86 cm from the top, although without distinguishable color change, contains abundant tests of Foraminifera, Radiolaria, Pelecypoda, Gastropoda, Ostracoda, plant-fiber, and mica. The planktonic and benthonic Foraminifera in the layer are chracterized by their thin shelled immature forms. On the basis of the constitutents and characters, the layer is correlated to the layers at 139–149 cm from the top of the core

Ka-15 and at 59–67 cm from the top of the core IC–4, respectively. A small amount of Radiolaria is found throughout the core and are concentrated especially at 20 cm and 50 cm from the top of the pilot core and at 15 cm and 55 cm from the top of the piston core. Scoria is concentrated at the upper part of the core, especially at 10 cm and 55 cm from the top of the piston core. Plant-fiber and mica are rather abundant at 105 cm and 145 cm from the top of the piston core. These materials are also used for correlation among the cores Ka–15, IC–4, and IC–3.

Coarse fraction: The coarse fraction of the core is almost several percent or less,

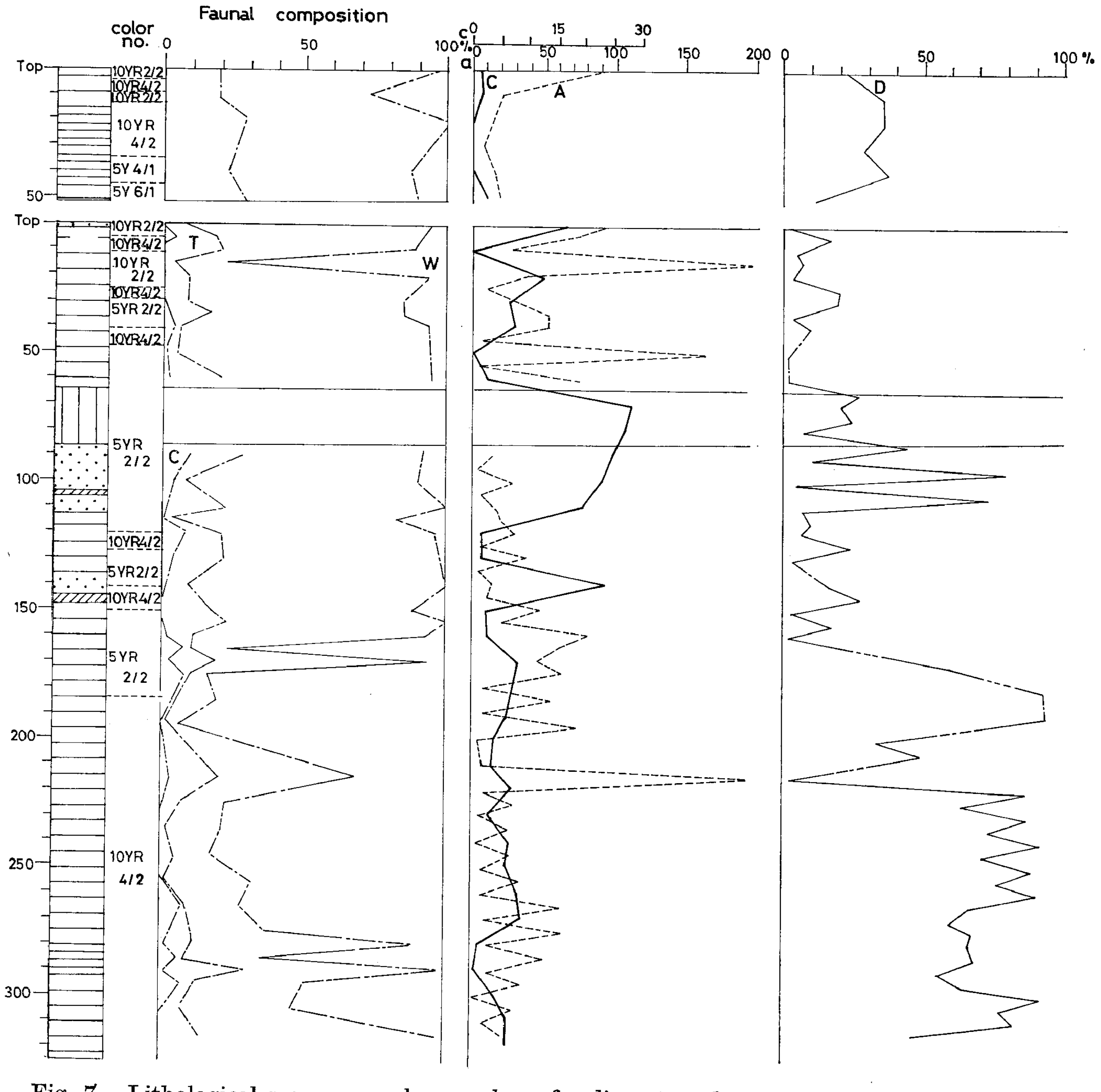


Fig. 7. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core IC–3.

C: Cold water fauna, T: Temperate water fauna, W: Warm water fauna.
A: Planktonic foraminiferal number (scale. . . . a).
C: Calcium carbonate content (scale. . . . c).
D: Percent of benthonic Foraminifera.

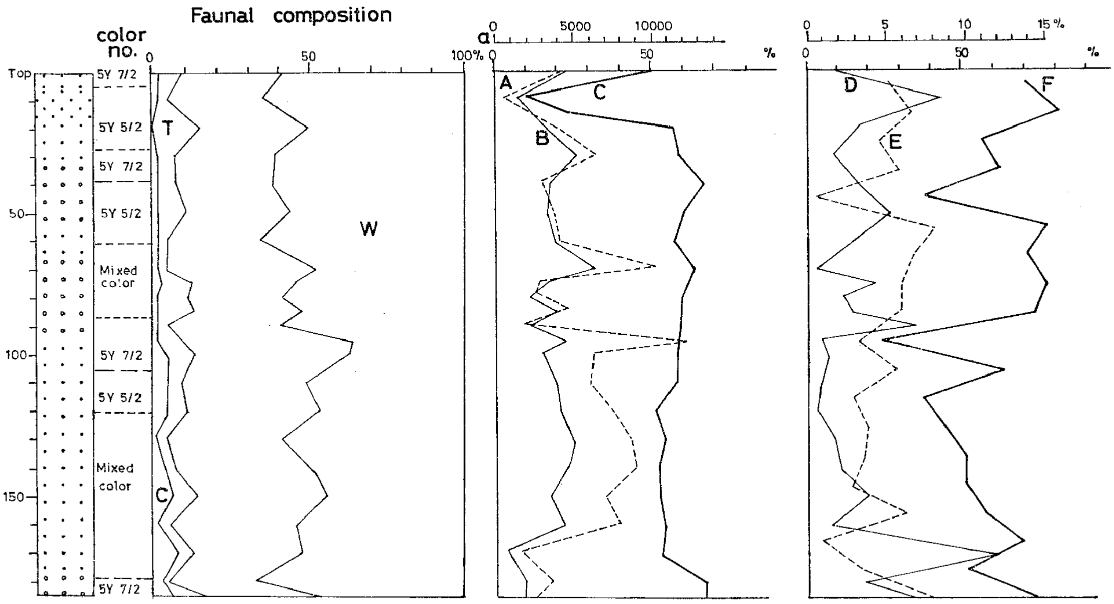


Fig. 8. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core Ka–18.
C: Cold water fauna, T: Temperate water fauna, W: Warm water fauna.
A: Planktonic foraminiferal number (scale....a).
B: Coarse fraction.
C: Calcium carbonate content.
D: Percent of benthonic Foraminifera (scale....d).
E: Percent of damaged tests of *Globorotalia menardii*.
F: Percent of fragments of *G. menardii*.

and slight high values of it are found in the brownish gray layers rather than in the brownish black layers.

Calcium carbonate: The content of calcium carbonate of the core is less than 30 percent and 6 percent on average (Fig. 7). The relative high values of the calcium carbonate contents are found at 170–110 cm and 140 cm, where the layers contain secondary sediments or plant fiber and mica. This may be due to that the carbonate matters are protected from the dissolution of calcium carbonate by the masking of the relatively rapidly deposited sediments.

Calcium carbonate content of the cores Ka–18 and Ka–15: The content of the calcium carbonate of the core Ka–18 is between 52 and 69 percent, except for the low content (10–13 percent) layer at 5–15 cm from the top. The average of the calcium carbonate content is 53 percent (Fig. 8). In the core Ka–15, the calcium carbonate content is less than 30 percent, except for the secondary sediment layer between 67 cm and 149 cm from the top of the core. (Fig. 9). The core generally shows relatively high calcium carbonate content in the light olive gray layers containing abundant tests of planktonic Foraminifera, in contrast to the low content in the brown clay layers. The content of calcium carbonate in the secondary sediment layer shows a gradual decrease in percentage from 149 cm to 67 cm from the top of the core.

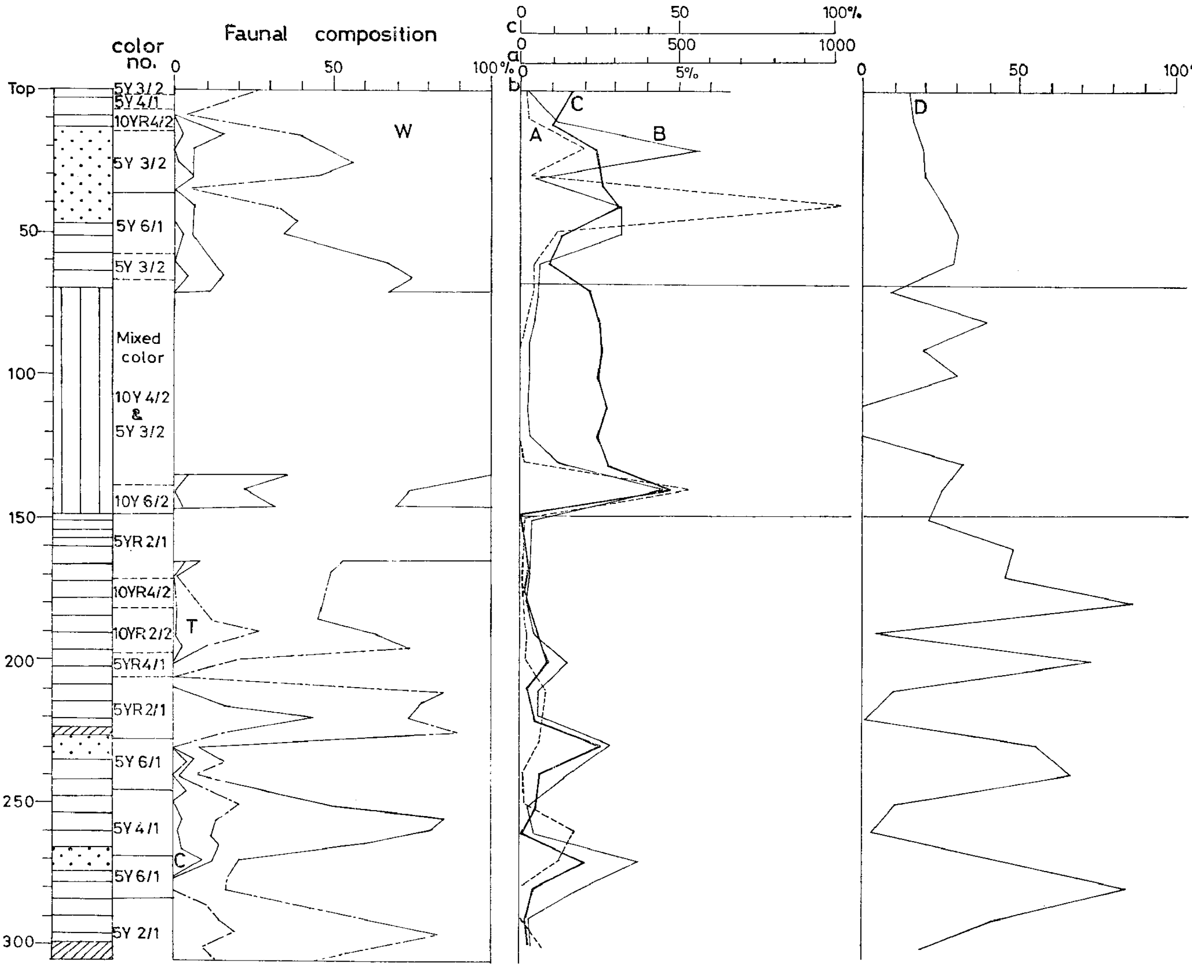


Fig. 9. Lithological sequence, color number of sediment and statistics of foraminiferal assemblages in core Ka–15.
C: Cold water fauna, T: Temperate water fauna, W: Warm water fauna.
A: Planktonic foraminiferal number (scale. . . . a).
B: Coarse fraction (scale. . . . b).
C: Calcium carbonate content (scale. . . . c).
D: Percent of benthonic Foraminifera.

METHOD OF STUDY

Using the planktonic Foraminifera in the cores, the following three approaches were adopted to study the precise paleotemperature and the mechanism of deep-sea sedimentation.

1. Isotope paleotemperature
2. Planktonic foraminiferal biostratigraphy
3. Factor analysis of planktonic foraminiferal assemblages

Each method was carried out as follows: (The details are given in each chapter.)

1. Isotope paleotemperature

The cores used for the isotope paleotemperatures are IC–6, Ka–18, and IC–5. Several hundred specimens of *Globorotalia menardii* were picked up from the 1.0 cm thick slices at 10 cm intervals of the cores IC–6 and Ka–18, and at 20 cm intervals of the core IC–5. The other three cores did not contain a sufficient number of specimens of *G. menardii* for the measurements by the oxygen isotope method. The measurements were also practiced on the 19 species which were picked up at 123–125 cm from the top of the core Ka–18.

2. Planktonic foraminiferal biostratigraphy

The following investigations based on the planktonic foraminiferal analysis of the cores were performed to infer the paleoclimate, content of Foraminifera, dissolution of foraminiferal tests, and correlation of the cores.

a) Faunal change of the cores
b) Planktonic foraminiferal number
c) Percent of benthonic Foraminifera
d) Dissolution of the test of *Globorotalia menardii*
e) Amounts of fragments of *Globorotalia menardii*
f) Coiling direction of *Globorotalia crassaformis*

The samples were taken from one gram of sediment at 5 cm or 10 cm intervals of all cores and several grams of sediment at 10 cm or 20 cm intervals of the three cores IC–6, Ka–18, and IC–5 for the investigations connected with *G. menardii*.

3. Factor analysis of planktonic foraminiferal assemblages

To reveal the mutual relationships of each species and of each horizon of the sampled sediments of the cores and to know the causal elements which formed the planktonic foraminiferal assemblage of a horizon of the cores, the factor analysis was applied to the cores IC–6, Ka–18, IC–5 and Ka–15. Both Q-technique and R-technique factor analysis were performed by using 43 horizons of the cores IC–6 and Ka–18 and 93 horizons of the four cores mentioned above, respectively.

ISOTOPIC PALEOTEMPERATURE

Principle

Urey (1947) found that the ratio of stable oxygen isotopes, oxygen–18 and oxygen–16, changed slightly with temperature in the same compound and suggested that the ratio in the same compound had a possibility to become a geological thermometer. That is, in the following isotope exchange reaction between water and carbonate ion:

$$H_2O + \frac{1}{3} CO_3^{16=} \rightleftarrows H_2O^{16} + \frac{1}{3} CO_3^{18=}$$

the heavier isotope (O^{18}) usually concentrates in $(CO_3^{18})^=$ ion. This is because the vibrational energy of each molecule controls the fractionation of the isotope, as the total energy of the system becomes to a minimum. The fractionation factor, K, expressed in the following manner:

$$K = \frac{[(CO_3^{18=})/(CO_3^{16=})]^{1/3}}{(H_2O^{18})/(H_2O^{16})}$$

is different with temperature and approaches unity with increasing temperature. Several theoretical values for K in the CO_3–H_2O equilibrium system were reported by some workers as:

	K at 0°C	K at 25°C	K/T
Epstein (1951)	1.025	1.021	0.000196/°C
Urey *et al.* (1951)	1.022	1.018	0.000176/°C
Thorley (1961)	1.018	1.014	0.000152/°C

Hence, Using the fossils whose calcareous shells were deposited in isotopic equilibrium with the surrounding water, it should be possible to measure the temperature of the water where they lived within an accuracy of 0.5°C by determining the O^{18}/O^{16} ratios of the CO_2 extracted from the $CaCO_3$ in their shells to an accuracy of 0.1 permille. However, absolutely correct figures for the theoretical values have not been obtained because of the indistinctness of the precise vibrational energy of the molecules which include oxygen isotopes. Therefore, to determine the water temperature in the past by the oxygen isotope method, one must obtain experimentally a relation between temperature and O^{18} concentration in the carbonate, and presume the paleotemperature based upon it. Such relationships were experimentally examined inorganically by McCrea (1950) and organically by Epstein *et al.* (1953), respectively. But there are some problems on their accuracies. At present, there are some problems on the oxygen isotope method besides the determination of a more accurate paleotemperature scale, namely the problems on the aptitude of the organisms used as the sample, the technique of the sample preparation, and paleo-oceanic isotopic composition. The former two problems have been considerably solved by many workers (Urey *et al.*, 1951; Epstein *et al.*, 1953; Epstein and Lowenstam, 1953; and Emiliani 1954). But one must check whether the organisms are suitable for the sample of oxygen isotope method and perform prudently the sample preparation. The last one requires another paleotemperature estimation method to determine the O^{18} concentration in the ancient sea water, using some compound such as phosphate and silicate. Now we must assume that the isotopic composition of the paleo-ocean remained the same as the isotopic composition in the present ocean.

Sample

The carbonate organisms to be subjected to the oxygen isotope analysis must fullfill several requirements, of which the planktonic Foraminifera are most suitable for the following reasons:

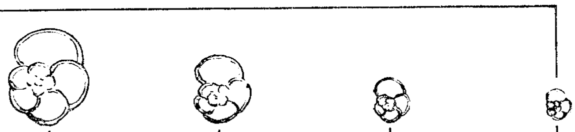
1. The habitat of the planktonic Foraminifera is in the open sea where the sea water has a constant 0^{18} concentration.
2. As the planktonic Foraminifera has a shallow water depth habitat, the O^{18} concentration of the test is inferred to express clearly the paleoclimatic change.
3. It has been empirically recognized that the planktonic Foraminifera has a very small *vital effect* (Urey *et al.*, 1951), so that the calcium carbonate of the planktonic foraminiferal test is in equilibrium with the surrounding water within the accuracy of experimental error.
4. The shell materials of the planktonic Foraminifera are composed of nearly pure calcite, and the contents of magnesium and strontium in the test are slight (Emiliani, 1955b)
5. On the basis of microstructural study of the test, the post-depositional recrystallization of the calcite is easily recognized.
6. The ecologic behavior of the planktonic Foraminifera is well known.

There are many ecological studies of the living planktonic Foraminifera, especially on the vertical distribution (Phleger 1945, 1951, Bradshaw 1959, Bè 1960, Parker 1960, and Belyaeva 1964). These studies are in agreement that the greatest concentration of the planktonic Foraminifera is in the upper 200 m depth of water. On the other hand, Emiliani (1954) analysed the O^{18} concentration of the tests of several species and suggested that different species occupy different depth habitats, for example *Globorotalia menardii* has a habitat down to about 200 m depth for the average population, whereas *Globigerinoides ruber* and *G. sacculifer* live close to the ocean surface. Bè (1960) observed that significant seasonal variations in the relative and absolute abundance of living planktonic species are found in the oceanic water around Bermuda and the large thick shelled specimens of *Globorotalia menardii, G. truncatulinoides, G. tumida* and *Sphaeroidinella dehiscens* were generally more abundant in the water below 150 m depth (Bè 1965, 1966).

Recently, more accurate knowledges on the depth habitat of planktonic Foraminifera have been obtained from the studies of the distribution of some species on the continental shelf by Orr (1967), of some living species caught by the plankton net by Jones (1967) and the analytical study of the O^{18} concentration in the tests of some species by Lidz *et al.* (1968). Jones observed (*op. cit.*) on the species stratification with depth, and found that *G. menardii* showed a relative high percentage relatively to the total foraminiferal population below the undercurrent water, in contrast to the relatively high values of *Globigerinoides trilobus* and *G. ruber* above the undercurrent water. In the studies of the deep-sea cores, Emiliani (1954) and Lidz *et al.* (1968) demonstrated that the different species display similar paleotemperature curves, although their absolute temperatures are different from each other. Thus, the different species of the planktonic Foraminifera appear to deposit their calcium carbonate at different depths. Accordingly, the oxygen isotopic analysis of the deep-sea cores must be performed on monospecific samples. The planktonic foraminiferal test is very small, measuring from several to several hundred microns in size. In the present study, *G. menardii* was adopted for the sample of oxygen isotope method, for the reason that the species has the largest test in the fauna and is individually most abundant in the cores.

Bè (1960, 1966) suggested that *G. menardii* showed selective thickening of calcite on the earlier chamber of the last whorl of the specimens caught in deep water tows (300 m or deeper). If *G. menardii* sinks in deeper water as it grows into the adult stage, the 0^{18} concentration of the test should change with size of the test. The analytical result of *G. menardii* with different size of the test is shown in Table 2. The larger test of the species have slightly higher values of 0^{18} concentration, but the difference is within about 0.5°C with respect to the tests larger than 177 μ.

Table 2. Relationship between 0^{18}(‰) content in the test and size of *Globorotalia menardii*

Globorotalia menardii (d'Orbigny)				
size (μ)	> 500	350	250	177
pure sample	+0.044	+0.036 +0.065	-0.046 -0.067	
dirty sample	+0.101	+0.111	+0.015	+0.005

Sample preparation

About 300 to 500 tests of *G. menardii* larger than 250 μ were picked up from a 1.0 cm thick slice at 5 cm or 10 cm intervals of the cores IC–6 and Ka–18 and at 10 cm or 20 cm intervals of the core IC–5. They were crushed into fragments by the ultrasonic generator for one or two minutes. The fragments were ground in an agate motar (it is not necessary to grind into fine powder). Subsequently, the powdered sample of about 10 mg was subjected to the purification process for destruction of the organically precipitated materials in the test. This was achieved using the same apparatus as described by Epstein *et al.* (1953), by roasting the sample in Pt-boats at 470°C, in a stream of helium flowing at about 0.4 cc/sec. (Fig. 10). The result of the experiments carried out to determine the length of time necessary for heating the powder is shown in Table 3. With this heat treatment, the

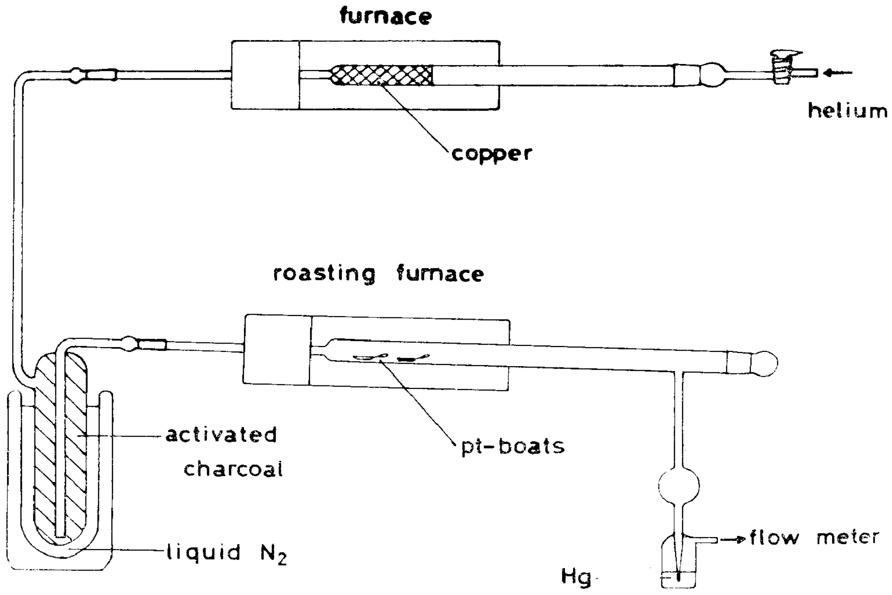


Fig. 10. Carbonate roasting system.

Table 3. Relationship between 0(‰) content in the test and heating time

Heating time in Helium (hour)	0	0.5	1	1.5	2	3
Globorotalia menardiii	−0.86 −0.87	−1.01	−1.08	−1.02	−1.26	−1.12

calcium carbonate changed to a gray color, and the relative O^{18} concentration of the sample was decreased in most cases. This indicates the presence of variable amounts of organic impurity in the tests. It was sufficient to roast the sample in a furnace at least for 30 minutes after the temperature of the furnace reaches 470°C. Sometimes, it was necessary to flow hydrogen gas for the reduction of CuO while increasing the temperature of the furnace and to heat the trap filled with activated charcoal for elimination of vapor. The purified sample was placed in a reaction vessel, and about 5 cc of pure H_3PO_4 acid was poured into the side arm. After evacuation of the vessel, the vessel was tilted to pour the acid on the sample in a precise thermostat at 25.3±0.01°C. The generated CO_2, after allowing the vessel to remain overnight in the thermostat, was subjected to the CO_2-extraction system (Fig. 11), and condensed into a U-tube trap by means of liquid nitrogen cooling. The system was pumped to remove any residue of non-condensible gas. Then the U-tube trap was cooled with dry ice slush (mixture of CH_4, $CHCl_3$, and dry ice), at the same time another U-tube trap was cooled with liquid nitrogen. In this manner, only CO_2 was transferred to the trap cooled with the liquid nitrogen, and the vapor remaind in another trap, the gas was purified by repeating the process two or three times. In the meantime the amount of CO_2 was measured manometrically, and transferred to a sample tube for introduction into the inlet system of the mass spectrometer. The mass spectrometer "PANDORA" for the measurement of oxygen isotopic ratio which is now being used at the Ocean Research Institute, University of Tokyo, measures the 0^{18} concentration in the carbonate to an accuracy of 0.02 permille. That is, such an accuracy would correspond to the temperature of about 0.1°C. The measurement was made by determining the difference in the $0^{18}/0^{16}$ ratio between the sample and standard working gas, i.e.;

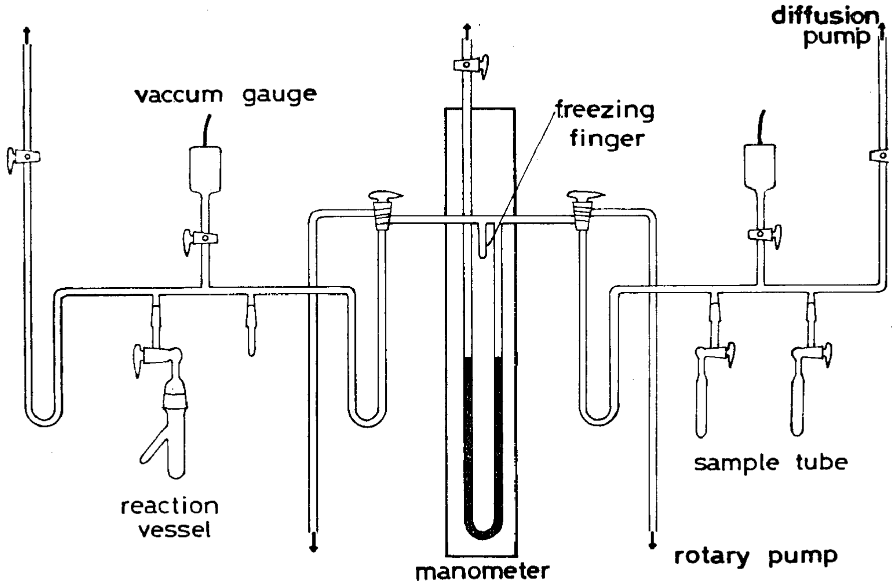


Fig. 11. CO_2-extraction system.

$$\delta O^{18}‰ = \frac{O^{18}/O^{16} \text{ sample}}{O^{18}/O^{16} \text{ standard}} - 1 \times 10000$$

As the relationship of the standard working gas to NBS–1 gas is known (Horibe 1966), the results are expressed in the parts permille relative to SMOW, after applying corrections characteristic to the mass spectrometer, and corrections in order to convert the carbon oxide mass ratio difference into the oxygen isotope ratio differences and convert the measured 0^{18} concentration of the sample into the 0^{18} concentration in SMOW scale (Craig, 1957, Horibe, 1966). Then the paleotemperature estimation was practiced to apply the results to the new paleotemperature scale which we established.

Paleotemperature Scale

At present, the paleotemperature scale established by Epstein *et al.* (1953) has been widely used. McCrea's (1950) paleotemperature scale which used inorganically precipitated calcium carbonate is similar to that of Epstein *et al.* These paleotemperature scales, however, include some problems on their accuracies. That is, Epstein *et al.* used in part the marine animals with calcareous shells taken from localities where the annual variations of temperature are about 5°C. And, most of their crystal forms are of aragonite, which is thermodynamically an unstable crystal form and usually breaks down to a stable calcite form rather quickly. Consequently it is customary to avoid using fossils of which hard parts are aragonite as sample for subjection to the oxygen isotope method. Moreover, it may well be doubted whether the different form, aragonite and calcite, will give the same curve of the paleotemperature scale. On the other hand, McCrea (1950) did not report on the 0^{18} concentration of the sea water which he used, and there are considerable variations of the 0^{18} concentration in the calcium carbonate synthesized under constant temperature. In addition, the accuracy of the mass spectrometer at present is more improved and far better than at that time. For this reason, Horibe, Oba, and Niitsuma (1969) worked out a new paleotemperature scale (Fig. 12). The experiment was carried out inorganically in the same method as McCrea (1950). The paleotemperature is, for convenience, presumed on the basis of this newly proposed paleotemperature scale.

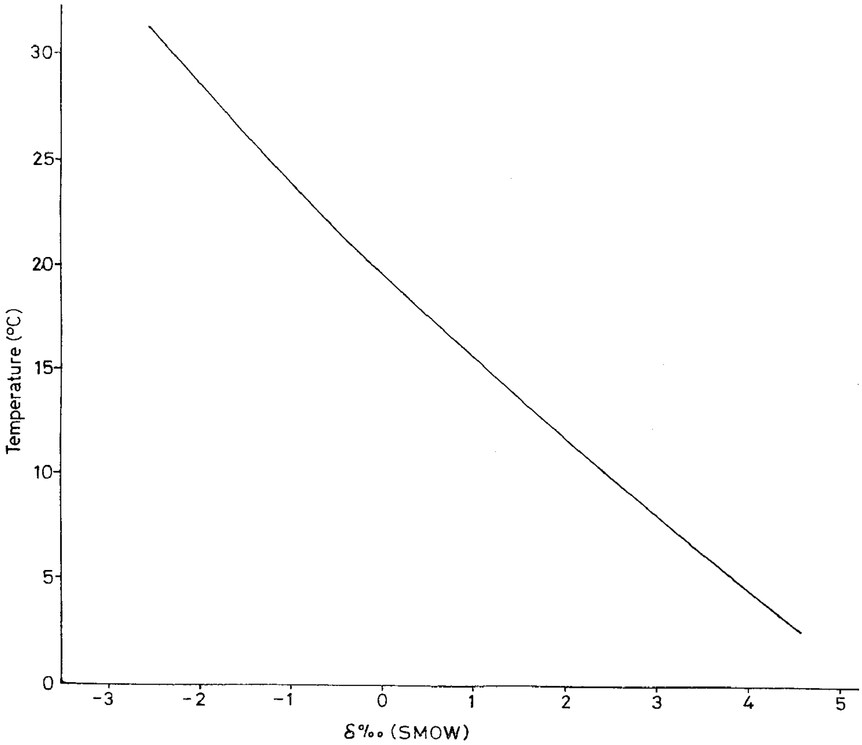


Fig. 12. Paleotemperature scale (after Horibe, Oba, and Niitsuma, 1969).

Result

1. Paleotemperature of the cores

Almost all of the horizons of the cores IC–6 and Ka–18 yielded abundant specimens of *G. menardii* as much as two measurements could be made, whereas the core IC–5 did not yield so many specimens. The sampled levels of the former two cores are of nearer intervals than that of the core IC–5. Therefore, the paleotemperature curves of the cores IC–6 and Ka–18 are more accurate than that of core IC–5. From the result of the two measurements performed on the samples from 22 horizons, the error associated with the preparation of a sample, extraction of the gas and mass spectrometric measurement was shown to be 0.007 parts permille, corresponding to a precision better than 0.4°C with 95 percent confidence. The isotopic data are reported in Table 4 and illustrated in Fig. 13.

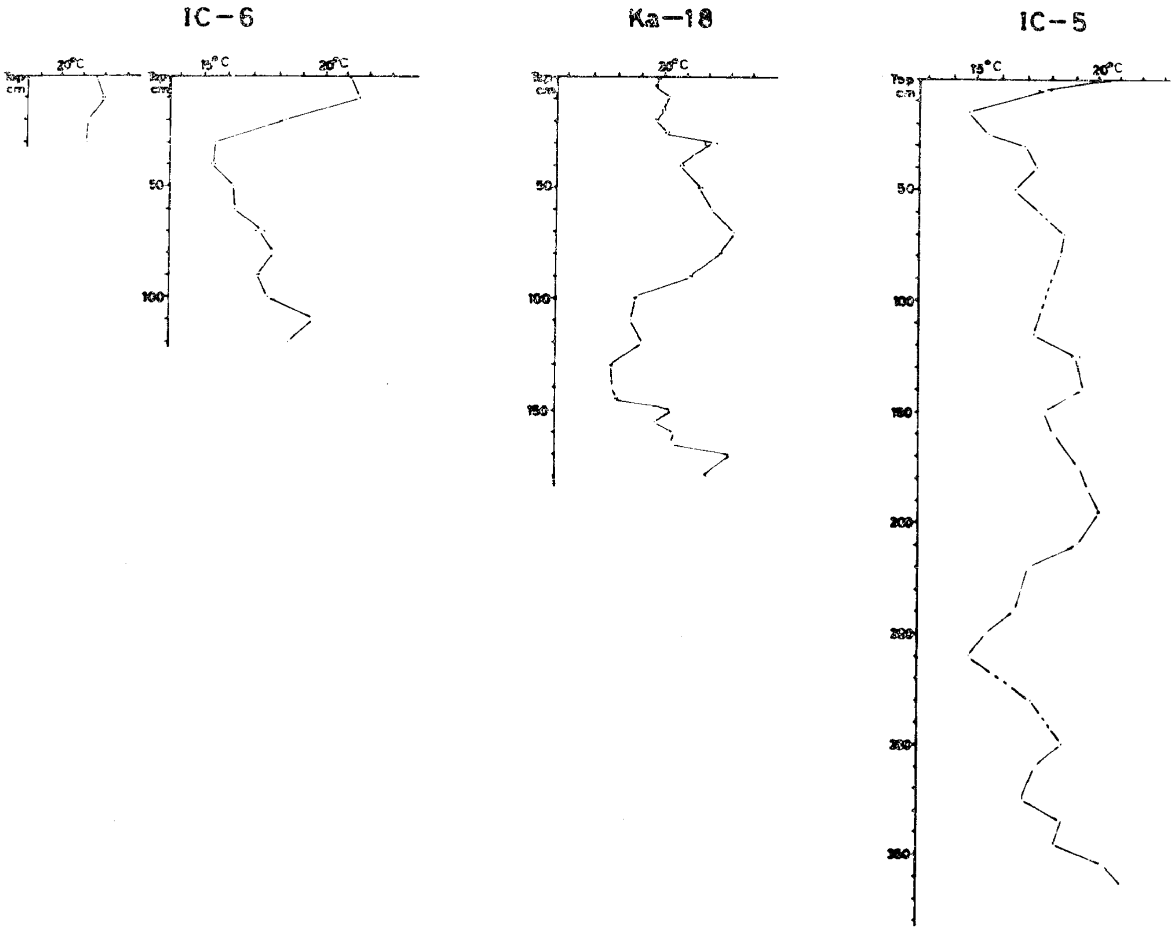
Core IC–6

A sample of *G. menardii* taken from the top of the pilot core, representing essentially modern sediment, gives a temperature of 21.5°C. The temperature of the surface water at the location of the core IC–6 at the present time is almost 27°C–29°C. The seasonal variation of the temperature is negligible around the equatorial regions of 10°N.–10°S. The value of 21.5°C given by *G. menardii* would clearly indicate an average depth habitat where the species lived from birth to death. According to the oceanographical reports (Chief editor, Hidaka, 1966) of the participation of Japan in the International Indian Ocean Expedition in 1962–1964, a remarkable upwelling exists along the coastal region just above the station of the core IC–6, and the depth corresponding to the water temperature of 21.5°C is at about 150 m from the sea surface. In the paleotemperature curve of the pilot core, a slightly high temperature of 21.9°C is seen at 10 cm from the top. The paleotemperature at 30 cm from the top represents 21.1°C value somewhat lower than that of the top sample. The paleotemperature at the top of the piston core is 21.0°C, and the

Table 4. Results of oxgen isotopic analysis of the cores IC-6, Ka-18, and IC-5

Core IC-6		Core Ka-18		Core IC-5	
Depth below top (cm)	(‰)	Depth below top (cm)	(‰)	Depth below top (cm)	(‰)
pilot		top	−0.047	top	−0.214
top	−0.473		−0.050	5	+0.397
10	−0.537	4	−0.022		+0.514
	−0.564		−0.046	15	+1.232
20	−0.398	9	−0.162	25	+1.030
30	−0.388	15	−0.078	30	+0.649
piston			−0.123	40	+0.526
top	−0.365	19	−0.011	50	+0.754
10	−0.462		−0.046	70	+0.238
20	−0.303	20	−0.089	80	+0.289
30	+1.025	25	−0.127	115	+0.552
40	+1.022		−0.158	125	+0.076
	+1.069	30	−0.522		+0.168
50	+0.836		−0.655	140	+0.044
60	+0.826	40	−0.260	150	+0.436
70	+0.511		−0.312	160	+0.344
	+0.600	50	−0.473	175	+0.080
80	+0.408		−0.503	185	−0.026
	+0.583	60	−0.602	190	−0.134
90	+0.559	70	−0.848		−0.139
	+0.572	80	−0.683	210	+0.084
100	+0.489		−0.706	220	+0.599
110	−0.000	90	−0.381	240	+0.732
120	+0.263		−0.405	250	+1.037
		100	+0.172	260	+1.215
			+0.186	280	+0.562
		110	+0.245	300	+0.233
		120	+0.100	310	+0.511
		130	+0.415	325	+0.639
			+0.438	335	+0.229
		140	+0.415	345	+0.306
		145	+0.356	355	−0.210
			+0.377	365	−0.412
		150	−0.203		
		155	−0.027		
		160	−0.247		
		165	−0.200		
		170	−0.818		
		180	−0.483		
			−0.506		

curve between the top and at 15 cm from the top resembles the pattern of the pilot core. Namely the paleotemperature at 10 cm of the piston core is slightly higher (21.5°C) than that of the top sample. Hence, the top sample of the piston core seems to indicate the sediment at the present or of the very near past time. From 15 cm to 25 cm from the top of the piston core, the paleotemperature decreases rapidly and gives a minimum temperature of 15.5°C at 30–40 cm from the top of the core. The difference between 10 cm and 30 cm from the top is about 6.0°C. The paleotemperature improved gradually from 40 cm to 100 cm with a minor fluctuation representing slightly increased temperature at 70–80 cm from the top. The sample at 110 cm from the top gives a paleotemperature of 19.5°C, which may be an indication of increasing temperature.



Eig. 13. Paleotemperature curves of the cores IC-6, Ka-18, and IC-5.

Core Ka–18

This core is not accompanied with a pilot core. The paleotemperature given by the top sample of the core is 19.7°C and this value is considerably lower than that of the top sample of the core IC–6. On the whole, the paleotemperature curve represents a relative low value at the top– 20 cm and at 95–165 cm and high value at 30–90 cm and at 170 to the bottom, respectively from the top of the core. Minor fluctuations of the curve represent the decreasing temperature at 40 cm and the increasing one at 120 cm and 160 cm from the top of the core. The maximum value is 23.6°C at 70 cm and the minimum is 17.7°C at 130 cm respectively from the top of the core.

Core IC–5

The top sample of the core gives a paleotemperature of 20.4°C, and the value decreases rapidly to 14.6°C at 15 cm from the top. There are relative low temperatures at 10–120 cm and 220–340 cm with minor fluctuations representing slightly increased temperatures at 30–40, 70–80, 240 and 280–310 cm, and high temperatures at top–5, 130–210 and 350–365 cm with minor flucutuation at 150 cm respectively from the top of the core. The maximum paleotemperature is 21.1°C at 365 cm and the minimum is 14.6°C at 15 cm from the top of the core.

The cores should be correlated with one another by means of the paleotemperature curve, if the sediments were deposited continuously and preserved as it was deposited. The core IC–6 can not be correlated to the core Ka–18, although the curve between 90 cm and

Table 5. Benthonic species subjected to the oxygen isotopic analysis

Species	Core Ka-18	
	81-83 cm	123-125 cm
Cassidulina norcrossi Cushman		1
C. subglobosa Brady	36	
Chilostomella oolina Schwager	11	2
Cibicides cicatricosus (Schwager)	39	6
C. mundulus (Brady, Parker and Jones)	2	
C. wuellerstorfi (Schwager)	28	41
Cibicidina bradyi (Trauth)	33	28
Dentalina filifornis (d'Orbigny)	3	
Eggerella bradyi (Cushman)	36	9
Eponides bradyi Earland	6	1
Fissurina annectens (Burrows and Holland)	9	13
F. orbignyana Seguenza	7	2
F. cucullata Silvestri	1	
F. cf. *exsculpta* (Brady)	1	
F. seminiformis (Schwager)	1	
F. submarginata (Boomgart)	3	4
Gyroidinoides neosoldanii Brotzen	9	4
Karreriella bradyi (Cushman)	5	
Lagena cf. *gracillima* (Schwager)	3	1
Laticarinina halophora (Stache)	8	
Marginulina sp.	1	
Melonis barleeanum (Williamson)	15	8
M. pompilioides (Fichtel and Moll)	7	7
Oolina apiculata Reuss	2	
O. globasa setosa (Earland)	1	
O. seminuda (Brady)	4	
Oridorsalis tenera (Brady)	43	42
Parafissurina sp.	1	
Pullenia bulloides (d'Orbigny)	17	1
P. subcarinata (d'Orbigny)	7	4
Pyrgo murrhyna (Schwager)	23	31
Quinqueloculina sp.	2	
Sphaeroidina bulloides d'Orbigny	21	11
Sigmoilinopsis schlumbergeri (Silvestri)	3	
Textularia cf. *porrecta* Brady	3	6
Uvigerina peregrina Cushman	8	30
Virgulina bradyi Cushman		2

120 cm from the top of the core IC–6 is quite similar to that between the top and 40 cm of the core Ka–18. The correlation of the core IC–6 to the core IC–5 is possible between 20–120 cm of the core IC–6 and top–150 cm of the core IC–5. This means that the upper several ten centimeters of the core IC–5 is missing. The whole curve of the core Ka–18 is probably correlated with that between 100 cm and 365 cm from the top of the core IC–5. Consequently, from the top to 40 of the core Ka–18 can be correlated to the lower part between 90 cm and 120 cm of the core IC–6. The core Ka–18 evidently lacks its upper several tens centimeters.

2. Benthonic Foraminifera

Two samples of benthonic Foraminifera have been analyzed isotopically. The samples containing the many calcareous benthonic species (Table 5) were selected from the sediments at 81–83 cm and 123–125 cm from the top of the core Ka–18, where the levels roughly represent the maximum and minimum paleotemperatures. The analytical results are shown in Table 6. These temperatures have not been corrected for isotopic composition of the deep water.

Table 6. O^{18}(‰) contents and temperatures of the benthonic Foraminifera and *Globorotalia menardii* from core Ka-18

Core Ka-18 Depth below top	Benthonic Foraminifera		*Globorotalia menardii*	
	(‰)	T. (°C)	(‰)	T. (°C)
81-83 cm	+3.51	6.0	−0.70	22.6
123-125 cm	+4.47	2.6	+0.25	18.4

The results, although only of two samples, indicate that the bottom temperature showed the same tendency as the variation of the surface water temperature.

3. Depth habitats of some planktonic Foraminifera

As the different species of planktonic Foraminifera seem to occupy different depth habitats (Emiliani 1954, Bè and Hamilton, 1967), the 0^{18} concentration of the tests may establish the mean temperature of the depth at which the species lived, strictly speaking, at which the shell deposition took place cumulatively. The analytical results of 19 species from the sample at 123–125 cm from the top of the core Ka–18 are shown in Table 7 in order of increasing the 0^{18} concentration in the tests. This sequence is in good agreement with informations from the oxygen isotope analysis by Emiliani (1954), Lidz *et al.* (1968) and with the recent two data by Chen (1966) and Jones (1967). This means that the planktonic Foraminifera have different depth habitats range with different species.

Table 7. Results of oxygen isotopic analysis of 19 planktonic foraminiferal species

species	δ(‰)	T(°C)
Globigerina bulloides	−1. 65	27. 1
Globigerinita glutinata	−1. 62	26. 9
Globigerinoides ruber	−0. 96, −0. 83	23. 4
G. sacculifer	−0. 85, −0. 76	23. 0
G. conglobatus	−0. 51, −0. 40	21. 5
Orbulina universa	−0. 63, −0. 27	21. 4
Globoquadrina dutertrei	−0. 44, −0. 36	21. 2
Pulleniatina obliquiloculata	−0. 31, −0. 25	20. 7
Sphaeroidinella dehiscens	−0. 26, −0. 07	20. 1
Globorotalia crassaformis R.	−0. 19, −0. 14	20. 1
Globigerinella siphonifera	−0. 13, +0. 05	19. 8
Globoquadrina conglomerata	+0. 01, +0. 08	19. 3
Globorotalia menardii	+0. 19, +0. 22, +0. 26	18. 6
G. crassaformis L.	+0. 40, +0. 45	17. 8
Globigerina calida	+0. 83	16. 2
Globorotalia tumida	+0. 87, +0. 87	16. 0
G. hirsuta	+0. 71	12. 7
G. truncatulinoides	+1. 93, +1. 95	11. 8
Globoquadrina hexagona	+2. 12	11. 2
Globorotalia scitula	+3. 08	7. 6

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

Faunal Change of the Cores

Planktonic Foraminifera have been regarded as valuable for studying problems related with paleoclimatology. Because many planktonic Foraminifera are distributed in the upper layer of water, the species are more or less influenced by the water temperature, and they are drifted about by ocean currents, their distributions are ocean wide. Therefore, the variations in surface water temperature of the past should be recorded in the sequence of the bottom sediments.

To understand the paleoecology of planktonic Foraminifera depends obviously on the study of their living distribution and ecologic conditions in the ocean, and of a comparison of their horizontal distribution in the ocean with that of their empty tests distributed on the ocean floor. Such studies on the regional and areal distribution of the living planktonic Foraminifera have been made by Bradshaw (1959) in the north and equatorial Pacific, Bè (1959, 1960) in the western north Atlantic, Parker (1960) in the eastern equatorial and southerst Pacific, Boltovskoy (1962) in the south Atlantic, Belyaeva (1964) in the Indian Ocean, Bè and Hamilton (1967) in the north Atlantic, and Jones (1967) in the equatorial Atlantic. These studies show that the greatest concentration of the planktonic Foraminifera is in the upper 200 m water layer depth and that their distribution depends upon the surface water masses characterized by the temperature and salinity. Most investigators are in the opinion that temperature is more critical than salinity in controlling the distribution of the fauna, and that their distribution roughly corresponds with latitude. However, the patch distribution of species within a water mass is probably due to many oceanographical conditions such as temperature, salinity, oxygen content, nutrient salts, transparency and composition of planktonic organisms, etc.

The Indian Ocean is oceanographically divisible into three major climatic zones which are closely related with oceanic convergence, that is, antarctic zone, temperate zone, and tropical zone. The antarctic zone and tropical zone are divided into two water masses by the divergence. Each zone reflects the water mass characterized by physico-chemical elements such as temperature, salinity, transparency, oxygen and salts content etc., and also the distribution of the phytoplankton and zooplankton. In consequence, planktonic organisms such as Foraminifera, Radiolaria, coccolithophorids, and diatoms differ with the water mass and they are utilized as a good indicators of each water mass.

Belyaeva (1964) studied the distribution of the planktonic Foraminifera in the surface water and on the ocean floor of the Indian Ocean, and proposed three major faunas in accordance with the distribution of the surface water mass, that is, cold water fauna, temperate fauna, and tropical fauna, and two transitional faunas in the zones where two distinct faunas are mixed (Fig. 14). Moreover, she found considerable coincidence between the distribution of the living planktonic Foraminifera and that of the empty tests on the ocean floor (Fig. 14). The three faunas in the thanatocoenose were defined by Belyaeva as follows.

Cold water fauna:
Globigerina pachyderma (Ehrenberg)

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

Warm water fauna:
Globigerinella siphonifera (d'Orbigny)
Globigerinoides conglobatus (Brady)
G. sacculifer (Brady)
Pulleniatina obliquiloculata (Parker and Jones)
Sphaeroidinella dehiscens (Parker and Jones)
Globorotalia menardii (d'Orbigny)
G. tumida (Brady)

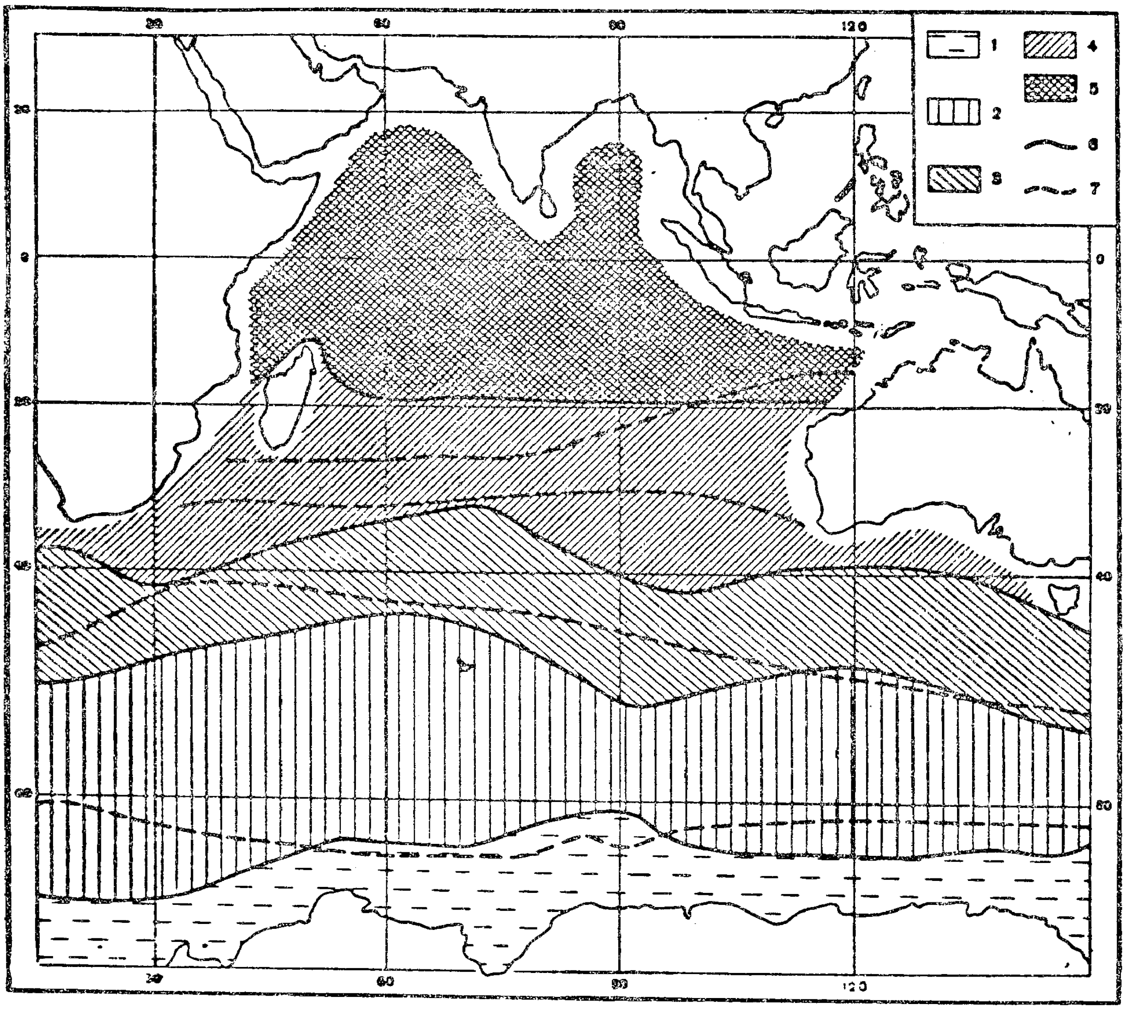


Fig. 14. Distribution of planktonic Foraminifera in the Indian Ocean.
1. Cold-water fauna 2. Transitional fauna 3. Temperate fauna 4. Transitional fauna
5. Tropical fauna 6. Biocoenoses 7. Thanatocoenoses (after Belyaeva, 1964)

Globoquadrina conglomerata (Schwager)
Candeina nitida d'Orbigny

Cosmopolitan fauna:

Globigerinoides ruber (d'Orbigny)
Orbulina universa d'Orbigny
Globoquadrina dutertrei (d'Orbigny)
Globigerinita glutinata (Egger)

There are two major problems on the paleoclimate inferred from an analysis of the planktonic foraminiferal fauna in the cores. One problem is the position where the core was obtained. If the core was obtained from the ocean floor near the boundary of two distinct water masses, the core should represent a conspicuous alternation of different fauna, which corresponds to climatic changes. If the core was obtained from the ocean floor at the central part or the vicinity of a water mass, remarkable faunal changes in the sedimentary sequence of the core would not be expected. However, as it is recognized that the temperature is more critical than salinity in controlling the distribution of species, the relative frequencies of the species in the core should change in accordance with temperature change of the surface water even within the same water mass. Another problem is concerned with the depth where the core was obtained. The planktonic foraminiferal test is more or less subjected to dissolution depending upon the water depth, and the more fragile tests of some species may thus be nearly or entirely destroyed, with the result that the assemblage may appear to be dominated by thick shelled forms which were originally of minor importance. The degree of dissolving by dissolution of the test on the ocean floor may reflect some causal events such as change of the bottom water temperature and hydrostatic pressure etc. which are related to climatic change. Unfortunately, the cores used for the present study were obtained from the rather deep ocean floor near the center of the tropical faunal region far from the transitional faunal region situated south of the tropical faunal region.

The samples used for the discrimination of the Foraminifera were selected from 1.0 cm thick horizontal slices at the intervals of 10 cm and 5 cm, and one gram of dried sediment taken therefrom was washed through a 200-mesh sieve. Subsequently, 200 specimens of planktonic Foraminfiera retained on a 115-mesh sieve were picked up from each sample. The classification of the planktonic Foraminifera in the present study is according to the method of Parker (1962) who studied the sediments from the Pacific Ocean. The writer identified in total 10 genera, 32 species, and one subspecies from the sediments of the cores. There remain some doubt as to the identity of the specimen which was assigned to *Globigerina pachyderma*. It has 4 or 4 1/2 chambers in the last whorl and some of the specimens may be immature forms of *Globoquadrina dutertrei*.

Faunal analysis in the vertical sequence of the core is based entirely upon the faunal grouping of Belyaeva (1964) mentioned earlier, 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 core, cosmopolitan species as *Globoquadrina dutertrei*, *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. In the previous study on the deep-sea core obtained from near the present area, Oba (1967) suggested that the relative frequency curve of the warm water fauna, especially of the *Globorotalia menardii* complex seems to represent the climatic changes of the past.

The fluctuation curve of the planktonic Foraminifera in the core IC–6 is characterized by the small amount (about 10–20 percent) of the warm water fauna and a relatively large percentage (about 15–30 percent) of the temperate water fauna which is almost explained by the frequency of *Globigerina bulloides* (Table 16). The fluctuation curve from the top down to 20 cm of the piston core resembles that of the pilot core, especially with respect to the warm water fauna (Fig. 4). Consequently, the top sample of the piston core probably represents the modern sediment. From the top to 20 cm and 110–123 cm of the piston core, the warm water fauna shows a relatively higher percentage than that between 30 to 100 cm from the top of the core, although the percentage difference is slight. The fluctuation curve of the warm water fauna coincides well with the paleotemperature curve gained by the oxygen isotope method. This is interpreted to indicate the warmer water condition at the upper and lower parts of the core than between 30 to 100 cm from the top of the core. The assemblage of the core IC–6 is extremely different from the tropical fauna reported by Belyaeva, that is to say, *Globigerina bulloides* and *Globigerinita glutinata* are predominant in the core and sometimes occupy 50 percent of the total population. Such an assemblage rather corresponds to the tropical-temperate transitional fauna of Belyaeva (1964). From the distribution patterns of each species (Belyaeva, 1964, Fig. 4–10). The high concentration of *G. bulloides* is found in the area of divergence, equator, and coastal region where the deep-water with high nutrient content upwells. The subsurface water above the core IC–6 which is from near the coastal region gives a somewhat lower temperature than that of the same depth of the surrounding water. The faunal assemblage of the core may be one of the

the patches which had existed for a long time in the tropical faunal region.

Most of the samples used for the faunal analysis of the core LC–5 yielded more than 200 specimens, but the planktonic foraminiferal number is not so large as that of cores IC–6 and Ka–18 (Table 17). The fluctuation curve of the warm water fauna, as a whole, represents a relatively high percentage near the top (top–10 cm) and middle part (140–200 cm) of the core and low values between 20 cm and 130 cm and the lower part (210–385 cm) of the core, although the fluctuation curve shows an abrupt change (Fig. 5). The fluctuation curve of the warm water fauna generally tends to coincide with the paleotemperature curve gained by the oxygen isotope method. Some layers (110, 140, 180, and 190 cm) with high contents of the warm water fauna consists almost of thick shelled specimens as *Globorotalia menardii*, *G. tumida*, *Sphaeroidinella dehiscens*, and *Globigerina digitata*. On the other hand, other layers (260, 270 cm) with low contents of the warm water fauna consist also of almost thick shelled specimens as of *Globigerina pachyderma* and *Globorotalia crassaformis*. The faunal assemblage in these layers were evidently influenced by the dissolving of the test, because only the thick shelled species remain in the assemblage. If the dissolution of the test had taken place during a warm water condition, the thick shelled species of the warm water fauna should remain in the assemblage. If the dissolution of the test had taken place during a cold water condition, the thick shelled species of the cold and temperate fauna should chiefly remain in the assemblage. Therefore, the layers with a large warm water fauna in the core are interpreted to represent a warm water condition and a small warm water fauna a cold water condition. This interpretation is also supported by the paleotemperature curve gained by the oxygen isotope method.

Most of the samples of the core IC–4 yielded very small amounts of planktonic foraminiferal tests of less than 200 specimens in several grams of sediments (Table 18). It is impossible, therefore, to know the accurate paleoclimatic changes from the faunal analysis of the core. The fluctuation curve from the top down to 50 cm of the piston core resembles that from the top down to 50 cm of the pilot core (Fig. 6). Consequently the top sample of the piston core appears to be the modern sediment. As a whole, the fluctuation curve of the warm water fauna varies from 5 to 95 percent of the total population. The layers representing a high percentage of the warm water fauna are nearly composed of specimens and their fragments of the thick shelled species as *Globorotalia tumida*, *G. menardii*, *Sphaeroidinella dehiscens*, and *Globigerina digitata*. On the other hand, the layers representing a low percentage of the warm water fauna are mainly composed of perfect specimens of the species with thin shelled or hispid test as *Globigerinoides ruber*, *Globigerinita glutinata*, *Globigerina bulloides*, and *G. rubescens*.

The samples of the core IC–3 also contains very small amounts of planktonic Foraminifera of less than 200 specimens in several grams of sediments (Table 19). It is difficult to infer the paleoclimate from a faunal analysis of the core. The fluctuation curve of the warm water fauna varies from 5 to 95 percent of the total population (Fig. 7). The part of the core above 160 cm represents a low percentage of the warm water fauna and contains perfect specimens with thin shelled and hispid test of such species as *Globigerinoides ruber*, *Globigerinita glutinata*, *Globigerina bulloides*, and *G. rubescens*. The part of the core blow 160 yielded many tests and their fragments of thick shelled species as *Globorotalia tumida*, *G. menardii*, *Sphaeroidinella dehiscens*, *Globoquadrina dutertrei*, and *Pulleniatina obliquiloculata*.

As the core was described in chaper 3, this core and core IC–4 include secondary deposited sediments transported by turbidity current and other coarse materials as mica, scoria, and plant-fiber. Consequently, it may be considered that the thin shelled species were protected from the dissolution of the test by the masking of the rapidly deposited sediments or by the stagnation of the bottom water saturated with respect to calcium carbonate.

Content of Foraminifera

In a quantitative study of planktonic Foraminifera, the writer adopted the "Foraminiferal number" as indicating the number of specimens larger than 125 μ in size per gram (dry weight) of sediment. The core IC–6 contains throughout abundant tests of planktonic Foraminifera. The foraminiferal number in the core is 5,100 in average, and varies from 1,200 at the minimum to 14,500 at the maximum (Fig. 4). The lower values of the foraminiferal number are found from the top down to 20 cm of the pilot core and at the top and between 100 cm and 120 cm of the piston core. The high value is found at 20 cm from the top of the piston core. The frequency curve of the foraminiferal number coincides with the curves of the coarse fraction and calcium carbonate content and represents the reverse relationship to the paleotemperature curve gained by the oxygen isotope method and the frequency curve of the warm water fauna (Fig. 4).

Benthonic foraminiferal number in the core IC–6 varies from 95 to 1,025 and amounts to 470 in average. The benthonic foraminiferal percentage in the core is shown in Fig. 4.

The planktonic foraminiferal number in the core IC–5 is far less than in the core IC–6 and the average value is 980 (Fig. 5). Relatively high values of the foraminiferal number are found from 60 cm to 90 cm, 210–240 cm and 280–290 cm from the top of the core where the frequency curve of the warm water fauna shows relatively low percentage, and the paleotemperature curve changes from a cold to a warm condition or from a warm to a cold water condition. The frequency curve of the planktonic foraminiferal number coincides with the curves of the coarse fraction and calcium carbonate content.

The benthonic foraminiferal number in the core IC–5 varies from 18 at the minimum to 124 at the maximum and the average value is 84. The percentage of the benthonic Foraminifera is shown in Fig. 5. Relatively high percentages of the benthonic Foraminifera are found at 40, 140–200, 250–270, and 370–380 cm from the top of the core, where the thick shelled specimens are found abundantly.

The planktonic foraminiferal number of the cores IC–4 and IC–3 are very small and the average values are 12 and 25, respectively (Fig. 6 and 7). The average percentage of the benthonic Foraminifera to the total population is 50 percent in the core IC–4 and 44.5 percent in the core IC–3, respectively.

In general, the cores obtained from shallow depths yielded abundant planktonic and benthonic Foraminifera and represent a small percentage of the benthonic Foraminifera. Whereas the cores obtained from deep water did not contain abundant foraminiferal tests, especially planktonic Foraminifera were very few. The main cause controlling the content of planktonic Foraminifera in the cores appear to be the dissolution of the calcareous matters with increasing depth.

Dissolution of the Test

Murray and Renard (1891) found that the calcareous content of the sediments in the Pacific varies with depth but disappears abruptly within a narrow depth range of between 4,000 m and 5,000 m. This depth range, so-called the calcium carbonate compensation depth, lies at about 4,500–4,700 m depth in the low latitudes of the Indian Ocean (Belyaeva, 1963). From many studies as to the dissolution of calcium carbonate in sea water based on laboratory and field experiments (Pytkowicz, 1964; Kennett, 1966; Peterson, 1966; Berger, 1967; Pytkowicz and Fowler 1967; Pytkowicz *et al.*, 1967), it was verified that the ocean is undersaturated with respect to calcium carbonate at all depths but the upper several hundred meters, and the rapid dissolution of the calcium carbonate occurs near the compensation depth. Moreover, the dissolution acts selectively on the tests of different species of planktonic Foraminifera (Ruddiman and Heezen 1967; Berger, 1967, 1968). On the other hand, Belyaeva (1964) estimated that the rate of deposition of the empty tests of planktonic Foraminifera is relatively fast for the reason that no dissolution effects were recognized of the tests obtained from the deep-sea tows, though many tests of planktonic Foraminifera on the deep-sea floor were dissolved by the cold bottom water from the Antarctic Sea. Consequently, the dissolution of the planktonic foraminiferal tests on the deep-sea floor tends to reduce the diversity of an assemblage in compliance with the amount of selective destruction which it experienced.

Four of the six cores for the present study were obtained from the deep-sea floor between 4,300 m and 4,900 m depth, their depths are just above and below the calcium carbonate compensation depth around this area of the Indian Ocean. These cores (core no. IC–5, Ka–15, IC–4 and IC–3) show large variations in the faunal compositions. Some layers of the cores have assemblages with 80–90 percent of the warm water fauna, especially of the thick shelled species. Such assemblages are never seen in the living population of the tropical fauna. The most conspicuous phenomenon representing the dissolution of the test is the almost absence of *Hastigerina pelagica*, a species having thin shell and very fragile test, on and in the deep-sea sediments, whereas the species is distributed abundantly in the surface water. It is therefore considered that the faunal assemblages in the cores were affected by the selective dissolution of the planktonic foraminiferal test. The rate of dissolution differs with depth and the bottom condition such as water temperature, static pressure, salinity, pratical pressure of the carbon dioxide generated by the respiration of the benthonic organisms.

The writer attempted to estimate the rate of dissolution from the damaged tests of *Globorotalia menardii*. *G. menardii* has a thick keel around the chambers and a thin shell at the central part of each chamber. The cores from depths exceeding 4,000 m have many fragments and damaged tests of *G. menardii*, their damaged tests have holes on the thin shelled chamber and around the holes the shell is thinner (Fig. 15). Such damaged tests are considered to be caused not by mechanical destruction, but by chemical dissolution of the calcareous matters on the deep-sea floor. The writer counted the specimens of both perfect and damaged tests having a hole on the chamber and also the fragments (having early stage on the dorsal view), from the cores IC–6, Ka–18 and IC–5.

The ratio of the damaged tests to the perfect specimens of the core IC–6 is given

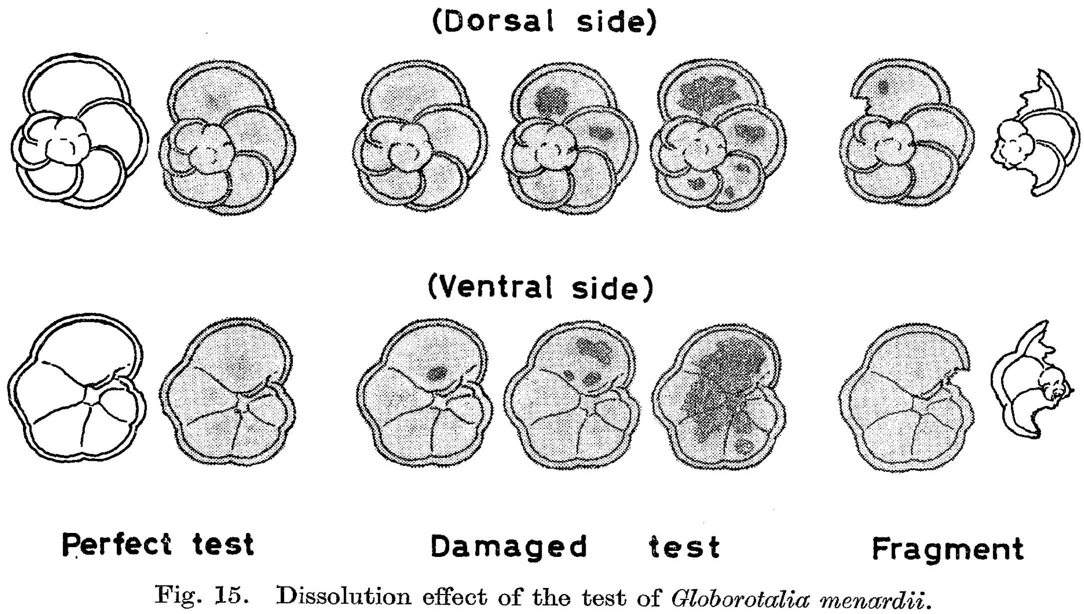


Fig. 15. Dissolution effect of the test of *Globorotalia menardii*.

in Fig. 4. The values of the ratio are relatively small, 25 percent on average, and the fluctuation curve roughly agrees with that of the benthonic foraminiferal percentage. The high values of the ratio at the upper and lower parts of the piston core means that the planktonic foraminiferal tests were dissolved by the cold bottom water, and as the result of the decrease of the planktonic foraminifer specimens, the percentage of the benthonic Foraminifera increased. The ratio of the fragments to the total specimens of the core IC-6 is shown in Fig. 4. There is no clear relationship between the ratios of the fragments and the damaged tests. However, the minimum value (40 percent) at 15–20 cm from the top of the core corresponds to the maximum planktonic foraminiferal number. This means that the layer was not strongly affected by chemical dissolution of the tests.

The ratios of the damaged test to the perfect specimens and the fragments to the total specimens of the core Ka-18 are shown in Fig. 8. Their fluctuation curves agree with each other except at 165 cm from the top of the core. As the fragments are expected to dissolve more quickly than the perfect and damaged tests, the fragmentations may be mainly due to the strong dissolution of the test. But their curves are different from that of the benthonic foraminiferal percentage, because their measured layers are different.

The core IC-5 does not contain so many planktonic foraminiferal tests. Some layers (40, 130–150, 170–200, 250–270 and 370–380 cm) are entirely composed of the fragments and few perfect specimens of the species with thick shelled tests such as, *Globorotalia tumida*, *Sphaeroidinella dehiscens*, *Globoquadrina dutertrei*, *Globorotalia crassaformis*, *Globigerina pachyderma*, *G. digitata* and *Pulleniatina obliquiloculata*. It is inferred that the assemblages in the layers were evidently affected by strong dissolution of the test. The ratios of the damaged tests to the perfect specimens and the fragment to the total specimens of the core IC-5 are shown in Fig. 5. The fluctuation curve of the damaged test tends to agree with that of the fragments. Moreover the fluctuation curve of the fragments to the total specimens is precisely in agreement with that of the percentage of the benthonic Foraminifera. The ratios of the fragments to the total specimens and the benthonic foraminiferal percentage of the core IC-5 are much higher than those of the cores IC-6 and Ka-18. This evidently indicates that the dissolution of the planktonic foraminiferal tests in this core took place more vigorously than in the cores IC-6 and Ka-18. Consequently very large amounts of planktonic foraminiferal tests would be dissolved by the cold bottom water, especially at the layers with high concentrations of the fragments.

Correlation of the Cores

The six cores used in the present study are correlated with one another based upon the following criteria:

a) Faunal change
b) Coiling direction of *Globorotalia crassaformis*
c) Occurrence of *Globorotalia menardii flexuosa*
d) Abundant concentration of *Globorotalia truncatulinoides*

The correlations of the pilot to the piston cores are based upon the faunal change of the cores. The frequency curve of the warm water fauna from the top down to 20 cm of the pilot core IC-6 is correlated to the piston core from the top down to 20 cm. Likewise, the curve from the top down to 50 cm of the pilot core IC-4 is correlated to that from the top down to 50 cm of the piston core. But the pilot core IC-3 cannot be correlated with the piston core, because of its very small contents of Foraminifera. The correlation of the six piston cores with one another based upon the faunal change is difficult because of the different assemblages and degrees of dissolution of the tests in the cores. The coiling change of *Globorotalia crassaformis* is useful in making correlation between the six cores (Fig. 16).

In the Indian Ocean, the geographical distributions of right and left coiling forms of *Globorotalia crassaformis* are entirely unknown. But the results of the measurement on

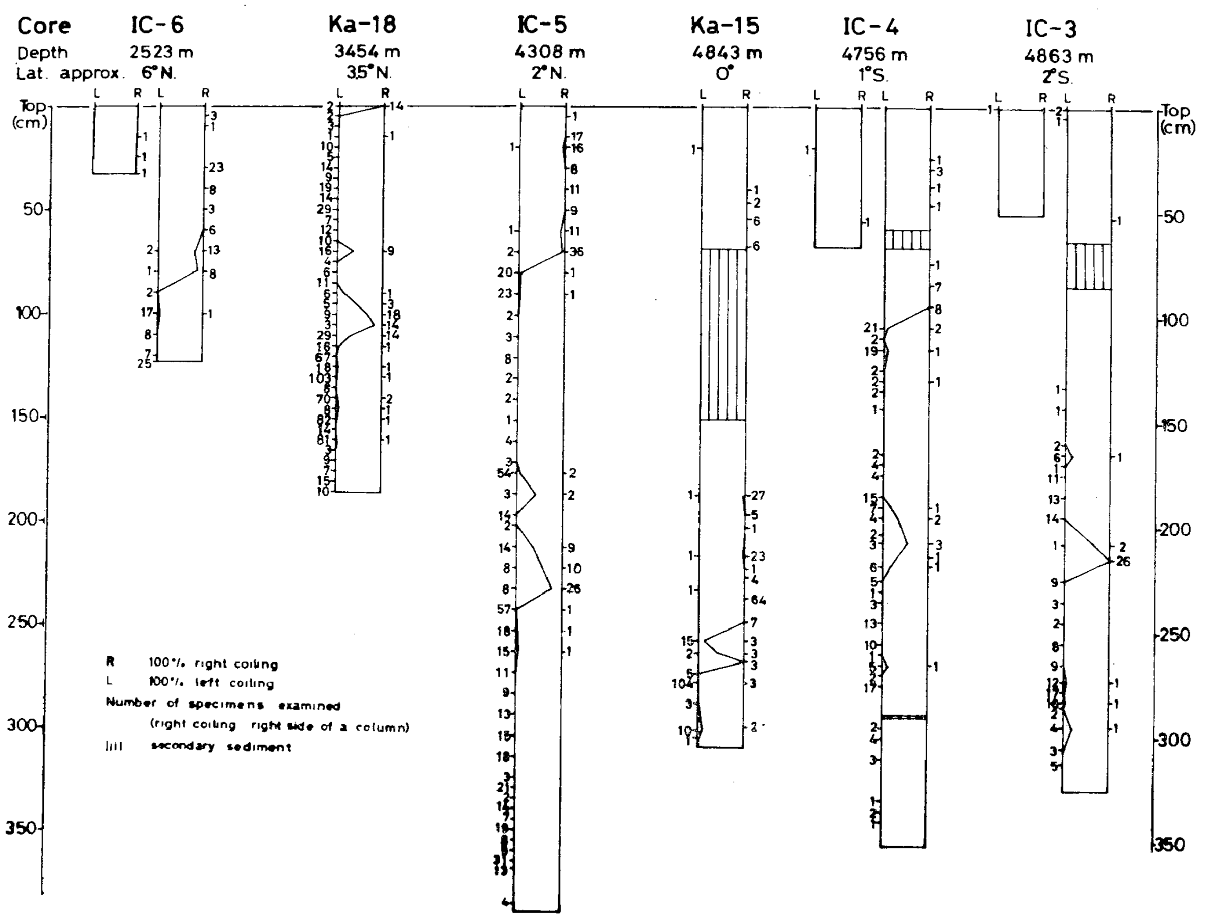


Fig. 16. Coiling change of *Globorotalia crassaformis* in the cores.

the right and left coiling forms of the species by the oxygen isotope method gave a lower water temperature for the left coiling form than for the right one. Blackman and Somayajulu (1966) reported in their study on the distribution of the planktonic Foraminifera in the bottom sediments of the south Pacific, that the left coiling of *Globorotalia crassaformis* was abundant in the sediments in the area south of their study. Consequently, the coiling change of the species appear to be caused by a change related to the ecological condition, although there is no relationship between the coiling direction and the paleotemperature curve in the core. To get the accurate coiling change of the species, several grams of the sediments were taken from all cores at 5 cm or 10 cm intervals. The coiling directions of the species and other *Globorotalia* were examined. The right coiling forms of the species are found at the following layers in the six cores; from the top down to 80 cm in the core IC–6, top of the core Ka–18, from the top down to 70 cm in the core IC–5, from 30 cm to 265 cm in the core Ka–15, from 20 cm down to 95 cm in the core IC–4, and at the level of 55 cm of the core IC–3, and their layers are correlated with one another, although there are some left coiling forms at the upper parts of the cores Ka–15, IC–4, and IC–3. Some peaks of the right coiling form of the species are found at the levels of 105 cm in the core Ka–18, at 230 cm in the core IC–5, at 215 cm in the core IC–4, and at 215 cm in the core IC–3, and their layers are correlated with one another. Minor peaks of the right coiling form are found at the level of 70 cm in the core Ka–18 and at 185 cm in the core IC–5, and their layers are correlated with each other. The occurrences of *Gr. menardii flexuosa* are found at the levels of 155–165 cm in the core Ka–18, at 325–355 cm in the core IC–5, and at 283 cm in the core IC–3, and their layers are correlated with each other. At the same time, considerable concentrations of *Gr. truncatulinoides* are found at the levels of 155–160 cm in the core Ka–18, at 325 cm in the core IC–5, and at 275 cm in the core IC–4, and their layers are also correlated with one another. The occurrence of the species is usually very small (one or two specimens) in a sample. The numbers of *Globorotalia menardii flexuosa* and *G. truncatulinoides* are shown in Table 8.

Table 8. Number of specimens of *Globorotalia menardii flexuosa* and *G. truncatulinoides* in the cores

Core no.	Depth below top (cm)	*Globorotalia menardii flexuosa*	*Globorotalia truncatulinoides*
Ka-18	155	15	13
	160	30	34
	165	10	0
IC-5	325	3	18
	335	0	0
	345	3	4
	355	1	0
IC-4	275	0	15
IC-3	283	1	0

FACTOR ANALYSIS OF PLANKTONIC FORAMINIFERAL ASSEMBLAGE

Procedure

A multivariate statistical technique known as factor analysis can be used to advantage in analyzing the relative large matrix of which the underlying cause is obscure, for example, the ecological relationships between each planktonic foraminiferal species or their relative frequencies in some core samples. This method gives equal weight to all variables and reveals the mutual relationships among them. It is an important aid in revealing the simple patterns in a complex information by determining the minimum number of independent dimensions needed to account for most of the variables and in considering objectively the causal factor without prior knowledge.

Observations on the planktonic foraminiferal assemblages in the cores of the Indian Ocean (Tables 16, 17, 20, and 21), show that there are some species with frequency curves very similar to other species, and, species showing arbitrary changes in frequency without relation with other species. The method for revealing the mutual relationships between species is the R-technique factor analysis, and the species are compared with each other by analyzing the 31 X 31 (in the present case) matrix of the relationships between all pairs of species on the basis of all samples. The planktonic foraminiferal assemblage, likewise, in a sample of the core is very similar to the assemblages in some samples, whereas other samples have quite different assemblages. Q-technique factor analysis is a method to know the relationships between the samples in the core on the basis of all species and to determine the minimum number of the casual influences which had dominated the assemblage in the sample. Both R-technique and Q-technique factor analysis are used for the principal factor solution in the present paper. The programming of the principal factor solution for an HITAC 5020 computer was made available through the Computer

Center of the University of Tokyo, and the work were done by N. Niitsuma and T. Sakai of the Institute of Geology and Paleontology, Tohoku University.

Since the detailed explanations of the factor analysis have been described by (Harman 1960, Imbrie and Purdy 1963, Imbrie and van Andel 1964, Hattori 1967), only a brief outline of the objectives and procedures will be described below. The data matrixes in some tables are constructed from 31 species in the rows and 43 or 93 samples in the columns. In the Q-technique, a sample can be defined as a vector in 31-dimensional spaces, and the position is uniquely determined by the proportion of each species in the assemblage. Having determined the unique position of each sample vector, the angles between each vector and every other vector can be calculated. The cosines of these angles then represent the degree of proportional similarity between the samples. If two sample vectors are colinear, then the cosine will be 1, indicating perfect similarity. If the vectors are 90° apart, the cosine will be 0, indicating complete dissimilarity. The cos-θ matrix contains all the information of the relationships between the sample vectors and shows the degree of similarity between all the sample vectors, but does not show these relationships in an easily interpreted form. For analyzing a table of the cos-θ matrix, the suitable procedure is the factor analysis which offers the advantage to determine the minimum number of independent dimensions necessary to account for the information in the cos-θ matrix. This is done by erecting mutual orthogonal axes (factor axes) in multidimensional space so that the first axis accounts for most of the information in the cos-θ matrix, the second for most of the remaining information, and so on. The positions of the sample vectors as related to the factor axes are determined by projection (factor loadings) onto the axes, and the sizes of the factor loadings indicate the extent to which each factor axis controls the position of each vector. The matrix of factor loadings shows the relationships between the sample vectors in the way that is mathematically most concise. As the factor axes usually do not locate in the most meaningful positions with respect to the locations of the sample vectors, they are sometimes rotated to positions which make interpretation easier. The sum of the squared loadings for a specific sample vector is referred to as its communality, and reflects the degree to which that sample vector has been explained by the set of factor axes. A communality of 1 indicates a perfect explanation. If the communality is smaller than 1, the sample vector includes its own speciality (uniqueness) not depending upon the factor axes.

R-technique Factor Analysis

R-technique factor analysis was applied to the data matrix constructed with 31 species and 43 samples of the cores IC–6 and Ka–18 (one sample from the top of the core Ka-15). Table 9 shows the eigen-values and their percentages for first ten factors. The first three factors account for 49 percent of the information and ten factors are necessary for the explanation of at least more than 90 percent of all informations. Hence, it is understood that the distribution of the planktonic Foraminifera is controlled by many ecological factors. Table 10 gives the matrix of the factor loadings for the 31 species on the first six axes. As all the species have a very high communality, their detail descriptions, especially with respect to the ecological conditions, are made by interpreting their factors. As it is, however, difficult to express and consider the factors in the multidimensional space, only the first three factors are considered in the present study. To reveal the meanings of these factors, one must revert to the field data and compare the factors with them. All factor loadings of the factor I represent the positive side and their sizes of the numbers correspond to the frequencies of each species in the cores IC-6 and Ka-18, that is, the predominant species such as *Globoquadrina dutertrei*, *Globigerinita glutinata*, *Globigerinoides ruber*, and *Globorotalia menardii* in both cores give the large numbers of the factor loadings. On the contrary, the rare species usch as *Globorotalia inflata*, *G. pumilio*,

Table 9. First ten eigen-values and their percentages of R-technique factor analysis

Factor	Eigen-value	Percentage
1	8. 4736	28. 24
2	3. 8983	12. 99
3	2. 3356	7. 79
4	2. 0466	6. 82
5	1. 9161	6. 38
6	1. 6473	5. 49
7	1. 3683	4. 56
8	1. 1583	3. 52
9	1. 0511	3. 50
10	0. 9702	3. 23
.	.	.
.	.	.
Sum 31	30. 4169	100. 00

Table 10. Communalities and first six factor loadings for 31 species

Species		Commun-ality	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
Globigerina	*bulloides*	0. 9973	0. 32494	−0. 58821	0. 11093	−0. 20663	0. 32776	0. 18806
	calida	0. 9943	0. 50765	−0. 36729	−0. 36220	−0. 20651	0. 23189	−0. 17373
	digitata	0. 9928	0. 43567	0. 45591	0. 11842	0. 29598	0. 36971	0. 13933
	falconensis	0. 9968	0. 47891	0. 05615	0. 29304	0. 38058	0. 11073	−0. 15653
	pachyderma	0. 9939	0. 45813	0. 13679	0. 47424	0. 04822	−0. 37541	−0. 49233
	quinqueloba	0. 9801	0. 28381	−0. 43070	0. 23499	−0. 11505	0. 20528	−0. 14172
	rubescens	0. 9642	0. 64770	−0. 47859	0. 07318	0. 19124	0. 24272	0. 00034
Globigerinella	*siphonifera*	0. 9993	0. 70564	0. 47683	−0. 36476	0. 06877	0. 04374	−0. 04131
Globigerinoides	*conglobatus*	0. 9373	0. 42365	0. 43990	0. 02607	−0. 34020	−0. 05262	−0. 05081
	sacculifer	0. 9900	0. 73023	0. 06923	−0. 37835	−0. 06660	−0. 17584	−0. 24406
	ruber	0. 9973	0. 77316	−0. 30155	−0. 36812	0. 00160	−0. 10289	−0. 16683
	tenellus	0. 9957	0. 47832	−0. 65424	−0. 09486	−0. 12718	−0. 07536	0. 03176
Globorotalia	*crassaformis*	0. 9946	0. 60678	0. 20844	0. 47862	0. 08783	−0. 31879	−0. 03134
	menardii	0. 9980	0. 71718	0. 49768	0. 24372	−0. 06852	0. 19184	−0. 03708
	inflata	0. 9981	0. 21117	0. 17251	−0. 19441	0. 66506	0. 04987	0. 21187
	hirsuta	0. 8951	0. 44766	−0. 12158	0. 19721	−0. 18411	0. 31069	0. 06808
	pumilio	0. 9907	0. 09017	−0. 25778	−0. 12943	0. 26422	0. 05338	−0. 46298
	scitula	0. 9962	0. 48443	−0. 13380	−0. 15399	0. 69055	−0. 08472	−0. 10372
	truncatulinoides	0. 9309	0. 24149	0. 09445	−0. 47760	0. 19186	−0. 15442	0. 00725
	tumida	0. 9072	0. 42173	0. 35490	0. 29345	−0. 09166	0. 00368	0. 42119
Globoquadrina	*conglomerata*	0. 9717	0. 58783	0. 48154	−0. 31197	−0. 12345	0. 06717	0. 15780
	dutertrei	0. 9967	0. 82449	0011278	0. 21090	−0. 17074	0. 15572	−0. 11754
	hexagona	0. 9791	0. 66224	−0. 51957	−0. 13451	−0. 17189	0. 03418	−0. 08403
Globigerinita	*glutinata*	0. 9910	0. 74691	−0. 36084	0. 08128	0. 10348	0. 24042	0. 24698
	humilis	0. 9975	0. 35705	−0. 21540	0. 36502	0. 02599	−0. 51085	−0. 08088
	iota	0. 9962	0. 46449	−0. 23492	0. 27174	0. 01702	−0. 53928	0. 12234
	uvula	0. 9904	0. 26299	−0. 40037	0. 25900	0. 11788	−0. 06802	0. 60180
Orbulina	*universa*	0. 9645	0. 53051	0. 13258	−0. 22945	0. 12951	−0. 25613	0. 34058
Pulleniatina	*obliquiloculata*	0. 9997	0. 72939	0. 48988	−0. 13288	−0. 26990	−0. 06921	0. 07691
Sphaeroidinella	*dehiscens*	0. 9961	0. 27435	0. 02029	−0. 23340	−0. 51322	−0. 26249	0. 09050
Candeina	*nitida*	0. 9839	0. 12154	0. 33022	0. 31632	−0. 05144	0. 48642	−0. 32824

G. truncatulinoides, *Sphaeroidinella dehiscens*, and *Candeina nitida* give the small numbers. The species as *Globigerina bulloides* which is not included so much in the core Ka-18 but abundantly in core IC-6 does not give the large number. On the other hand, the species included nearly equally in both cores for example, *Globigerinella siphonifera*, *Globigerinoides sacculifer*, and *Pulleniatina obliquiloculata* give the relative large numbers of the factor loadings. Thus the factor I is the so-called general factor representing the similarity of the frequencies of each species in all samples of both cores and it may reflect the province. Figure 17 shows the results of plotting the factor ladings of the factors II and III. The plots indicate the mathematically the most coincise relationship between all the species with respect to the factors II and III. Seeing the arrangement of the species in factor II, the species representing the relatively large positive values of the factor loadings are *Globorotalia menardii*, *Pulleniatina obliquiloculata*, *Globoquadrina conglomerata*, *Globigerinella siphonifera*, *Globigerina digitata*, *Globigerinoides conglobatus*, and *Globorotalia tumida*, which entirely belong to the warm water fauna defined by Belyaeva (1964) in the Indian Ocean expect one species, *Globigerina digitata*, whose distribution in the ocean water has not been clarified. On the other hand the species having the relatively large negative values of the factor loadings are *Globigerinoides tenellus*, *Globigerina bulloides*, *Globoquadrina hexagona*, *Globigerina rubescens*, *G. quinqueloba*, *G. calida*, *Globigerinita uvula*, and *G. glutinata*. Among these species, the following ones are found abundantly in the cold water regions; *Globigerina bulloides*, *G. quinqueloba*, *Globigerinita uvula*, *G. glutinata* (Bradshaw 1959, Smith 1963, 1964, Chen 1966, and Lipps and Warme 1966). The remaining ones are not well known as to their distributions in the ocean water. Thus the factor II is a bipolar factor and seems to represent the water temperature of the sea, and the positive side indicates a water condition warmer than the negative side. The specimens here assigned to "*Globigerina pachyderma*" may include some immature forms of *Globoquadrina dutertrei*. Factor III also has bipolar factor loadings. The relatively large positive values are represented, except for the rare species, by the positions of such species as "*Globigerina pachyderma*", *Globorotalia crassaformis*, *G. tumida*, *Globigerinita humilis*, *G. iota*, *G. uvula*, *Globigerina falconensis*, *Globorotalia menardii*, *Globigerina quinqueloba*, and *Globoquadrina dutertrei*. Among these species, the following ones have relatively thick shells; "*Globigerina pachyderma*", *Globorotalia crassaformis*, *G. tumida*, *G. menardii*, and *Globoquadrina dutertrei* and smooth surfaced walls; *Globigerinita humilis*, *G. iota*, and *G. uvula*. On the contrary, the species representing the relatively large negative values of the factor loadings, except rare species, are *Globigerinoides sacculifer*, *G. ruber*, *Globigerinella siphonifera*, *Globigerina calida*, *Globoquadrina conglomerata*, and *Orbulina universa*, which are the species with the most fragile tests. According to Berger (1967) who observed the dissolution effect of planktonic foraminiferal tests through the field experiment in the central Pacific Ocean, the spinose genera *Globigerina*, *Globigerinoides*, and *Globigerinella* are less resistant to solution than the smooth surfaced genera *Globorotalia*, *Globigerinita*, and *Candeina*. Thus the factor III seems to indicate the degree of fragmentation of the foraminiferal test, caused by mechanical or chemical destruction of the test on the deep-sea floor.

Q-technique Factor Analysis

One of the data matrix for the Q-technique factor analysis is the same as the matrix used for the R-technique factor analysis, namely, it is constructed with 31 species and 43 samples of the cores IC-6 and Ka-18 obtained from relatively shallow water depths. Another matrix is constructed with 31 species in the rows and 93 samples in th columns from the horizons that yielded more than 200 specimens among the cores IC-6, Ka-18, Ka-15, and IC-5 utilized for the paleontological investigation. The reason for carrying out twice the Q-technique factor analysis using 43 and 93 samples respectively is that the dissolution effect of the foraminiferal test in the deeper cores becomes a factor affecting the

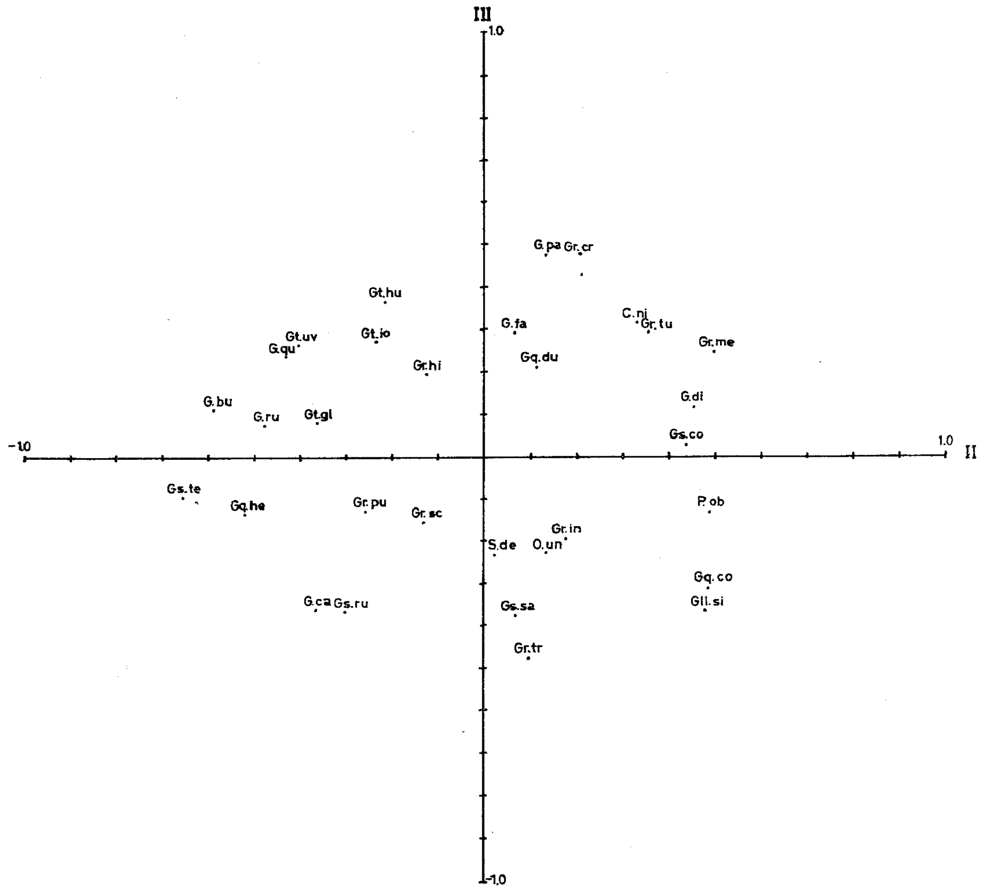


Fig. 17. Plots of 31 species on the plane of factor axes II and III.

Specles	Abbreviations	Species	Abbreviations
Globigerina bulloides	G. bu	*G. pumilio*	Gr. pu
G. calida	G. ca	*G. scitula*	Gr. sc
G. digitata	G. di	*G. truncatulinoides*	Gr. tr
G. falconensis	G. fa	*G. tumida*	Gr. tu
G. pachyderma	G. pa	*Globoquadrina conglomerata*	Gq. co
G. quinqueloba	G. qu	*G. dutertrei*	Gq. du
G. rubescens	G. ru	*G. hexagona*	Gq. he
Globigerinella siphonifera	Gll. si	*Globigerinita glutinata*	Gt. gl
Globigerinoides conglobatus	Gs. co	*G. humilis*	Gt. hu
G. sacculifer	Gs. sa	*G. iota*	Gt. oi
G. ruber	Gs. ru	*G. uvula*	Gt. uv
G. tenellus	Gs. te	*Orbulina universa*	O. un
Globorotalia crassaformis	Gr. cr	*Pulleniatina obliquiloculata*	P. ob
G. hirsuta	Gr. hi	*Sphaeroidinella dehiscens*	S. de
G. inflata	Gr. in	*Candeina nitida*	C. ni
G. menardii	Gr. me		

assemblage of planktonic Foraminifera in the core. First, the relationships between the 43 sample vectors were evaluated based on 31 components. As the correlation matrix represents consipicuous high positive correlations of each sample, the communality of each sample was taken as 1. From the result of the analysis, only six eigen-values and their percentages are expressed in Table 11. The first three factors account for 92.7 percent of all the informations. The matrix of the factor loadings on the first six factor axes is

Table 11. First six eigen-values and their percentages of Q-technique factor analysis based upon 43 samples

Factor	Eigen-value	Percentage
1	31. 8499	74. 07
2	6. 0157	14. 00
3	2. 0104	4. 68
4	1. 3366	3. 11
5	0. 5522	1. 30
6	0. 3129	0. 73
.	.	.
.	.	.
Sum 43	43. 000	100. 00

shown in Table 12. All factor loadings of the factor I have considerably high positive values. Comparing the factor loadings with the assemblage of the planktonic Foraminifera in the sample high values of the factor loadings are found in the sample having an average assemblage in all the samples. On the other hand, relatively low values are found in the samples consisted of an extreme assemblage, for example as in the following sample; bottom sample, 20, 90, 95, 130, and 180 cm from the top of the core Ka-18, bottom sample of the core Ka-15, top and 60 cm from the top of the core IC-6. Thus the factor I is a general factor representing the similarity of the assemblages of the planktonic Foraminifera in all the samples. The factor loadings of the factor II and III are plotted at a time in Fig. 18. All the samples of the core IC-6 are plotted on the positive side of the factor II. On the contrary, the samples of the core Ka-18 are plotted on the negative side of the factor II except for one sample at 95 cm from the top. As stated in the previous chapter, the assemblage of the planktonic Foraminifera in the core IC-6 is quite different from that of core Ka-18 and characterized by the two dominant species *Globigerina bulloides* and *Globigerinita glutinata*. To consider the meanings of these factors, the writer calculated the total specimens of the species representing the negative factor loadings of the factor II and III obtained by the R-technique factor analysis respectively for each sample and plotted them at a time in Fig. 19. The axes obtained by the R-technique factor analysis are expressed in the present paper as factor I_R, II_R and III_R. The total number of specimens of the species with the negative values of the factor II_R represents a degree of the water temperature, and the large value indicates a cold water temperature. Consequently, the relatively large values on the positive side of the factor II in Fig. 19, strictly speaking at the direction of the axis rotated anticlockwise about 20°, indicate a condition of cold water temperature. Thus the factor II seems to be a factor reflecting the water temperature of the ocean, and the large negative value indicate a condition of the warm water temperature. Likewise, the total specimens of the species with the large negative values of the factor III_R for each sample were plotted on the two-dimensional plane in Fig. 19. Consequently, they are distributed near the relatively large positive side of the factor III, strictly at the direction of the axis rotated anticlockwise about 20°. Practically, the samples with relatively large value of the factor III, for example, 95, 130, 160 and 70 cm from the top of the core Ka-18 and 20 cm from the top of the core IC-6 include abundant specimens of *Globigerinoides ruber* and *G. sacculifer* which are representative species with the most fragile tests (Berger, 1968). Thus the factor III may reflect a degree of the fragmentation of the planktonic foraminiferal test, caused by mechanical destruction or chemical dissolution of the test. The factor loadings of the factors II and III in relation to the rotated factor axes are determined by projecting the vectors onto the axes, and plotted in

Table 12. First six factor loadings for 43 samples

Sample (from top) (cm)	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
Ka-18 B.S.	0. 80326	−0. 42929	−0. 30270	−0. 17209	0. 07406	−0. 17534
top	0. 92635	−0. 28446	−0. 04983	0. 00073	−0. 12295	−0. 01027
10	0. 89334	−0. 26384	−0. 08189	0. 30321	−0. 08431	0. 04370
20	0. 89140	−0. . 3153	−0. 07440	0. 41010	−0. 10618	−0. 06072
30	0. 88305	−0. 34214	0. 12263	−0. 02771	−0. 23821	0. 15381
40	0. 88346	−0. 42057	−0. 05345	0. 09570	−0. 10785	−0. 02540
50	0. 93328	−0. 23508	−0. 18866	0. 04045	−0. 00634	0. 17305
60	0. 82618	−0. 44981	−0. 04700	−0. 06523	−0. 06687	0. 23832
70	0. 87728	−0. 23165	0. 35408	0. 13209	0. 06736	−0. 03628
75	0. 93741	−0. 12490	−0. 15109	0. 16827	−0. 04317	0. 00622
80	0. 92216	−0. 26965	−0. 16705	0. 03100	0. 05310	−0. 08069
85	0. 96054	−0. 14514	−0. 09554	0. 00907	−0. 08054	−0. 12461
90	0. 82613	−0. 41502	−0. 33924	0. 09328	0. 11566	0. 00055
95	0. 75083	0. 02090	0. 62775	0. 07151	0. 02110	−0. 14702
100	0. 93021	−0. 04266	0. 21911	0. 21207	0. 15941	−0. 07979
110	0. 90393	−0. 19428	0. 74150	0. 27250	0. 10659	0. 15576
120	0. 83512	−0. 29133	0. 28708	−0. 25955	0. 13044	0. 14427
130	0. 74631	−0. 39802	0. 43583	−0. 18168	−0. 16928	0. 07945
140	0. 89654	−0. 35276	0. 14898	−0. 01646	0. 16488	−0. 00470
150	0. 87735	−0. 30639	0. 12146	−0. 15047	0. 22063	−0. 07935
160	0. 76281	−0. 46043	0. 35500	−0. 22200	−0. 08405	−0. 05640
170	0. 83808	−0. 41658	−0. 25909	0. 09246	0. 14223	−0. 02478
180	0. 73596	−0. 61222	−0. 14553	−0. 17243	−0. 13993	−0. 05417
185	0. 91783	−0. 23358	−0. 22443	−0. 08844	0. 04145	−0. 10641
Ka-15 B.S.	0. 75615	−0. 52979	−0. 22247	−0. 28153	−0. 00944	−0. 05001
IC-6 20	0. 78526	0. 31967	0. 49916	0. 03025	−0. 04314	−0. 05990
10	0. 91284	0. 34385	0. 13681	−0. 08556	0. 05288	0. 01470
top	0. 82231	0. 50836	−0. 17639	0. 06338	−0. 09923	−0. 05920
30	0. 90106	0. 38754	0. 05819	0. 01388	0. 14432	0. 00077
40	0. 85326	0. 46893	−0. 19363	−0. 06671	0. 04367	−0. 01207
50	0. 92534	0. 23044	0. 03675	0. 10904	0. 23130	0. 06153
60	0. 75432	0. 50633	−0. 22462	−0. 32164	0. 07077	0. 04831
70	0. 80905	0. 48405	−0. 14954	−0. 21845	0. 08498	0. 10379
80	0. 90147	0. 34752	−0. 10820	−0. 15613	0. 13427	0. 03487
90	0. 86006	0. 47404	0. 07693	−0. 09138	−0. 02024	0. 05218
100	0. 91779	0. 29205	−0. 04925	0. 06340	0. 00284	0. 00138
110	0. 80221	0. 56514	−0. 03069	0. 11150	−0. 12935	0. 01298
120	0. 88403	0. 28083	0. 04282	0. 35138	0. 03750	0. 02904
123	0. 91421	0. 37992	−0. 04323	0. 07889	−0. 02737	0. 00910
pilot top	0. 84741	0. 42189	−0. 16997	0. 20858	−0. 14548	−0. 01379
10	0. 85448	0. 42084	−0. 05336	−0. 22054	−0. 16101	−0. 05475
20	0. 82123	0. 52082	0. 10548	−0. 12853	−0. 09460	−0. 05431
30	0. 83594	0. 45122	0. 01202	−0. 29290	−0. 08668	−0. 01681

the columns of each core (Figs. 20 and 21). Almost all factor loadings of the factor I with respect to the cores IC-6 and Ka-18 are between 0.75 and 0.95, and the assemblages in these cores have not so large variations. The factor loadings of the factor II in the core IC-6 also does not represent large variation. The core Ka-18, however, represent the conspicuous variation with respect to te factr loadings of the factor II, namely the maximum value (0.24) at 95 cm from the top and the minimum value (–0.26) at 180 cm from the top, respectively. The positive value indicates a condition of cold water temperature, and the fluctuation curve agrees excessively with the fluctuation curve of the warm water fauna. Likewise, the fluctuation curves of the factor III resembles those of the planktonic foraminiferal number in both cores, especially in the core Ka-18. Namely, the

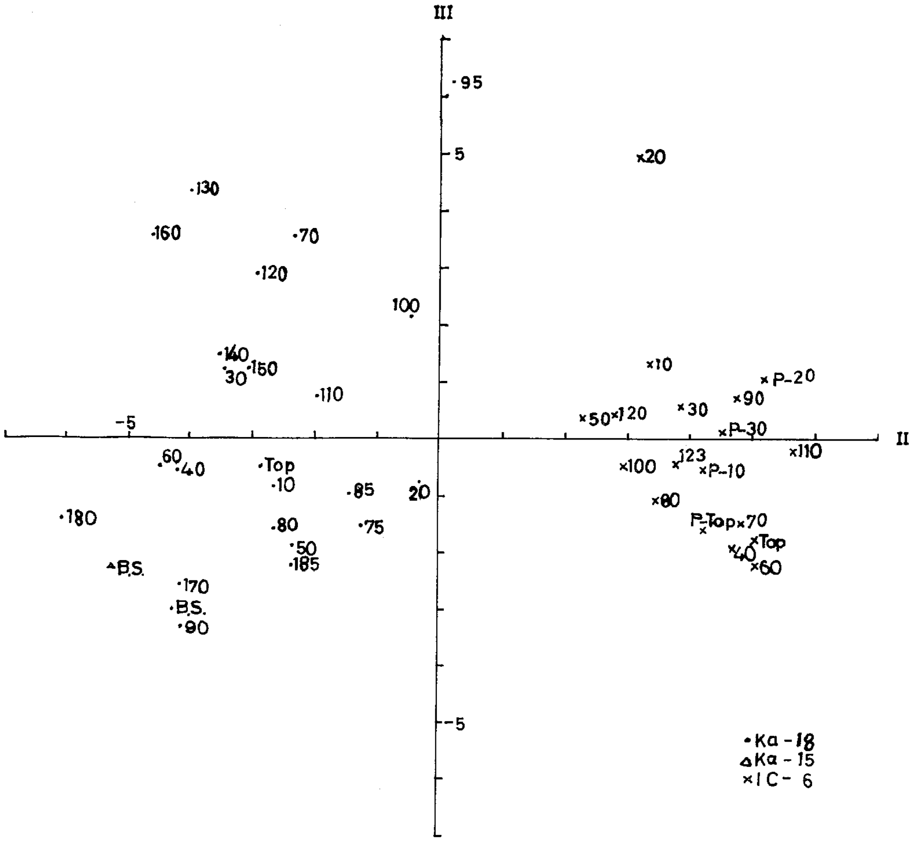


Fig. 18. Plots of 43 samples on the plane of factor axes II and III.

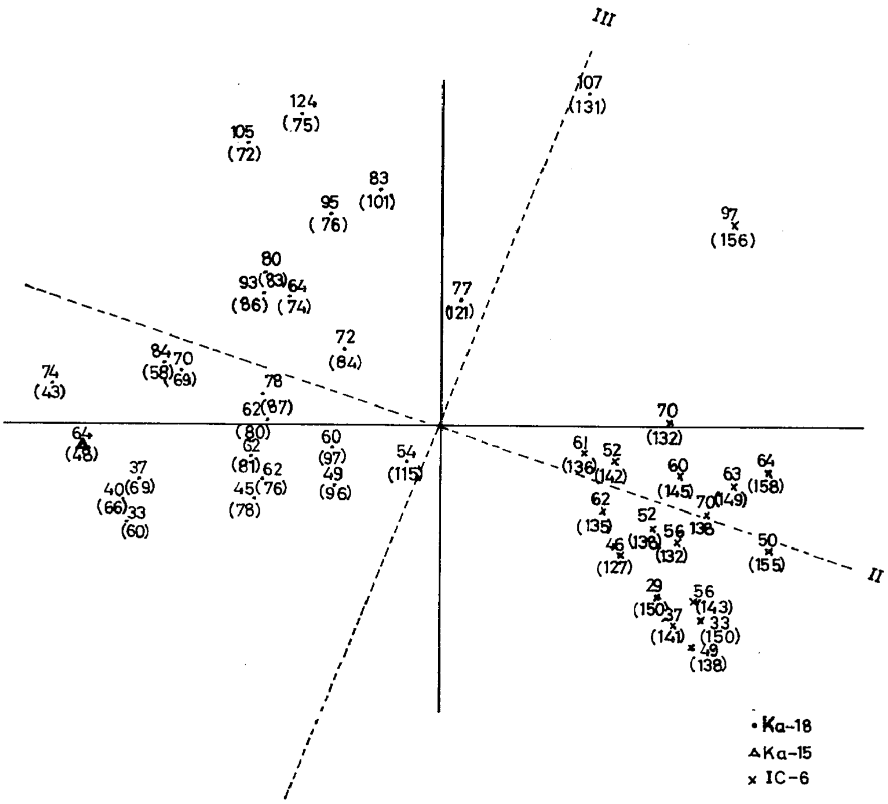


Fig. 19. Plots of total specimens related to factor II_R and III_R in Fig. 18. (The factor axes were rotated anticlockwise about 10°) The number in parenthesis is the sum of factor II_R.

Table 13. First six eigen-values and their percentages of Q-technique factor analysis based upon 93 samples

Factor	Eigen-value	Percentage
1	62. 7598	67. 48
2	10. 0711	10. 83
3	4. 9521	5. 32
4	4. 5177	4. 86
5	2. 7931	3. 00
6	2. 3331	2. 51
.	.	.
.	.	.
Sum 93	93. 0000	100. 00

large positive values are found in the following samples; at 20 cm from the top of the core IC-6 and at 70, 95, 130, and 160 cm from the top of the core Ka-18, in which the planktonic foraminiferal number are very high, *Globigerinoides ruber* and *G. sacculifer* being the representatives of the species with the most fragile test are abundantly included. This is presumably due to that these samples did not accept the strong dissolution of the planktonic foraminiferal test.

Q-technique factor analysis based on 93 samples of the cores IC-6, Ka-18, Ka-15, and IC-5 was practised in the same way as the analysis based on 43 samples. Table 13 shows the eigen-values and their percentages for first six factors. The first three factors account for 83.6 percent of all the information. Table 14 shows the matrix of the factor loadings on the first six factors. All factor loadings of the first three factors were plotted in the columns of each core (Fig. 20, 21, 22, and 23). In this case, it was unnecessary to rotate the factor axes. In the cores IC-6 and Ka-18, the fluctuation curves of the factor loadings of the factor I represent the same patterns as the case of analysis based on 43 samples. While the fluctuation curves of the factor I in the cores Ka-15 and IC-5, give very large variations, especially as shown in ghe following samples; at 235 cm and 275 cm from the top of the core Ka 15 and 200–270 cm and 300–320 cm from the top of the core IC-5. These samples have extreme assemblages of planktonic Foraminifera. Namely the samples at 235 cm and 275 cm of the core Ka-15 include abundant *Globorotalia tumida,* which occupies 67 and 52 percent of the total population. And the samples at 260 cm and 270 cm of the core IC-5 include abundant "*Globigerina pachyderma*", which occupies 39 and 26 percent of the total population. On the other hand, the samples giving the relatively large values of the factor loadings consist of the average assemblages of the planktonic Foraminifera in all the samples. Thus the factor I seems to be a general factor representing the similarity between all the samples, in common with the results of the R-technique and Q-technique factor analyses based on 43 samples. To consider the meanings of the fractors II and III, the factor loadings of them are plotted in Fig. 24. And the total specimens of the species with the negative factor loadings of the factor II_R and III_R are also plotted in the Fig. 25, for each sample respectively. As the result, the values of the factor II_R increase toward the negative side of the factor II along the axis. Hence, it is understood that the factor II is a factor reflecting the water temperature of the ocean and the negative side of the factor II indicates a condition of the water temperature warmer than the positive side. While the values of the factor III_R also increase toward the positive side of the factor II along the axis. This means the factor II represents a degree of the fragmentation of the foraminiferal test. The negative side of the factor II indicates a condition affected with fragmentation of the test stronger than the positive side. Thus the factor II,

Table 14. First six factor loadings for 93 samples.

Sample (from top) (cm)	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
Ka-18 B.S.	0. 77708	−0. 41901	0. 02902	0. 27583	−0. 32222	0. 01903
top	0. 91985	−0. 16338	0. 14330	0. 11167	−0. 14600	−0. 14694
10	0. 90176	−0. 08206	0. 32120	0. 23494	0. 06486	−0. 03729
20	0. 87400	0. 21785	0. 28986	0. 27500	−0. 06313	−0. 01685
30	0. 90149	−0. 21392	0. 18231	−0. 06956	−0. 04534	−0. 24832
40	0. 88514	−0. 24095	0. 285. 3	0. 12582	−0. 14136	−0. 09759
50	0. 93452	−0. 19463	0. 06757	0. 23635	−0. 04514	−0. 04124
60	0. 84801	−0. 38876	0. 13588	0. 03962	−0. 09626	−0. 12628
70	0. 90501	0. 02805	0. 27546	−0. 23086	−0. 13264	−0. 00578
75	0. 93411	−0. 04422	0. 13641	0. 26408	0. 07753	−0. 00882
80	0. 90181	−0. 18013	0. 09743	0. 23681	−0. 20283	−0. 09801
85	0. 94140	−0. 06916	0. 04717	0. 17787	−0. 12783	−0. 11524
90	0. 82461	−0. 34519	0. 18258	0. 35493	−0. 13535	0. 09157
95	0. 77760	0. 27291	0. 18008	−0. 46043	−0. 04069	−0. 08077
100	0. 93846	0. 17921	0. 18368	−0. 06745	−0. 11299	0. 11529
110	0. 93056	−0. 01784	0. 24106	0. 04756	0. 01899	0. 10964
120	0. 87583	−0. 28023	−0. 04207	−0. 32404	−0. 08137	−0. 02042
130	0. 78241	−0. 23895	0. 17754	−0. 40716	−0. 12794	−0. 28432
140	0. 91782	−0. 19362	0. 17738	0. 10909	−0. 19608	0. 05755
150	0. 90095	−0. 24930	0. 02517	−0. 15986	−0. 17403	0. 14232
160	0. 79998	−0. 31822	0. 17990	−0. 36684	−0. 15451	−0. 18027
170	0. 84858	−0. 33962	0. 19202	0. 25056	−0. 09847	0. 17973
180	0. 74293	−0. 55381	0. 17902	0. 07866	−0. 20208	−0. 14314
185	0. 90376	−0. 23176	−0. 02273	0. 20110	−0. 16337	0. 05122
Ka-15 B.S.	0. 75568	−0. 56108	0. 02478	0. 14273	−0. 22533	−0. 12310
20	0. 89600	0. 17606	0. 27317	−0. 19014	−0. 06272	−0. 11548
25	0. 77761	0. 41403	0. 27794	−0. 28758	0. 06563	−0. 05361
40	0. 65939	−0. 64356	−0. 03755	0. 15378	−0. 07977	−0. 24923
45	0. 60355	−0. 73059	−0. 08543	0. 14851	−0. 19172	−0. 06817
65	0. 79419	0. 31186	0. 21833	−0. 35558	0. 02830	−0. 01371
135	0. 72311	0. 19431	−0. 24100	0. 27193	−0. 09328	0. 38469
140	0. 69075	0. 40058	0. 27992	0. 37383	−0. 04893	0. 21357
145	0. 77048	−0. 05978	0. 06308	0. 43985	−0. 26106	0. 19576
185	0. 96017	−0. 03830	0. 11126	−0. 07636	−0. 03483	−0. 09782
195	0. 82715	0. 31317	0. 30106	−0. 27166	0. 07129	0. 04603
215	0. 88742	0. 35592	0. 16993	−0. 14257	0. 04540	0. 07368
235	0. 04029	−0. 31815	0. 08097	0. 17390	0. 78657	0. 09252
245	0. 71712	−0. 31265	0. 26448	0. 25262	0. 45761	−0. 02157
255	0. 86629	0. 31520	0. 15061	−0. 24751	0. 06682	0. 07221
260	0. 91557	0. 11577	0. 08724	−0. 21192	−0. 05202	0. 07234
265	0. 87982	0. 29642	0. 09384	−0. 27044	0. 03814	−0. 12292
275	0. 27181	−0. 61559	0. 15043	0. 29673	0. 54084	−0. 02332
295	0. 79698	0. 47851	0. 10490	−0. 26754	0. 12891	0. 00565
IC-6 20	0. 79317	0. 45085	−0. 04765	−0. 33340	0. 06286	−0. 10730
10	0. 89569	0. 30211	−0. 29366	−0. 04784	−0. 01691	−0. 03671
top	0. 76394	0. 43476	−0. 32443	0. 30619	0. 01324	−0. 07347
30	0. 87797	0. 37480	−0. 24743	0. 05622	−0. 01290	0. 06856
40	0. 78220	0. 24081	−0. 36169	0. 23326	−0. 16411	0. 25274
50	0. 91889	0. 27587	−0. 10758	0. 08605	−0. 02520	0. 14118
60	0. 70355	0. 23475	−0. 61850	0. 21488	−0. 02297	−0. 03836
60	0. 77116	0. 27143	−0. 52347	0. 17468	0. 02330	−0. 00689
80	0. 87355	0. 20608	−0. 39911	0. 14603	−0. 03004	0. 04567
90	0. 83290	0. 39107	−0. 35252	0. 00472	0. 07881	−0. 05385
100	0. 88840	0. 31289	−0. 14766	0. 18609	−0. 00762	−0. 04410
110	0. 73790	0. 48365	−0. 14277	0. 07683	0. 21816	−0. 28377
120	0. 87008	0. 43208	0. 05378	0. 15987	0. 03684	0. 07894
123	0. 88509	0. 36559	−0. 21818	0. 15765	0. 03473	−0. 00001

Table 14. Continued

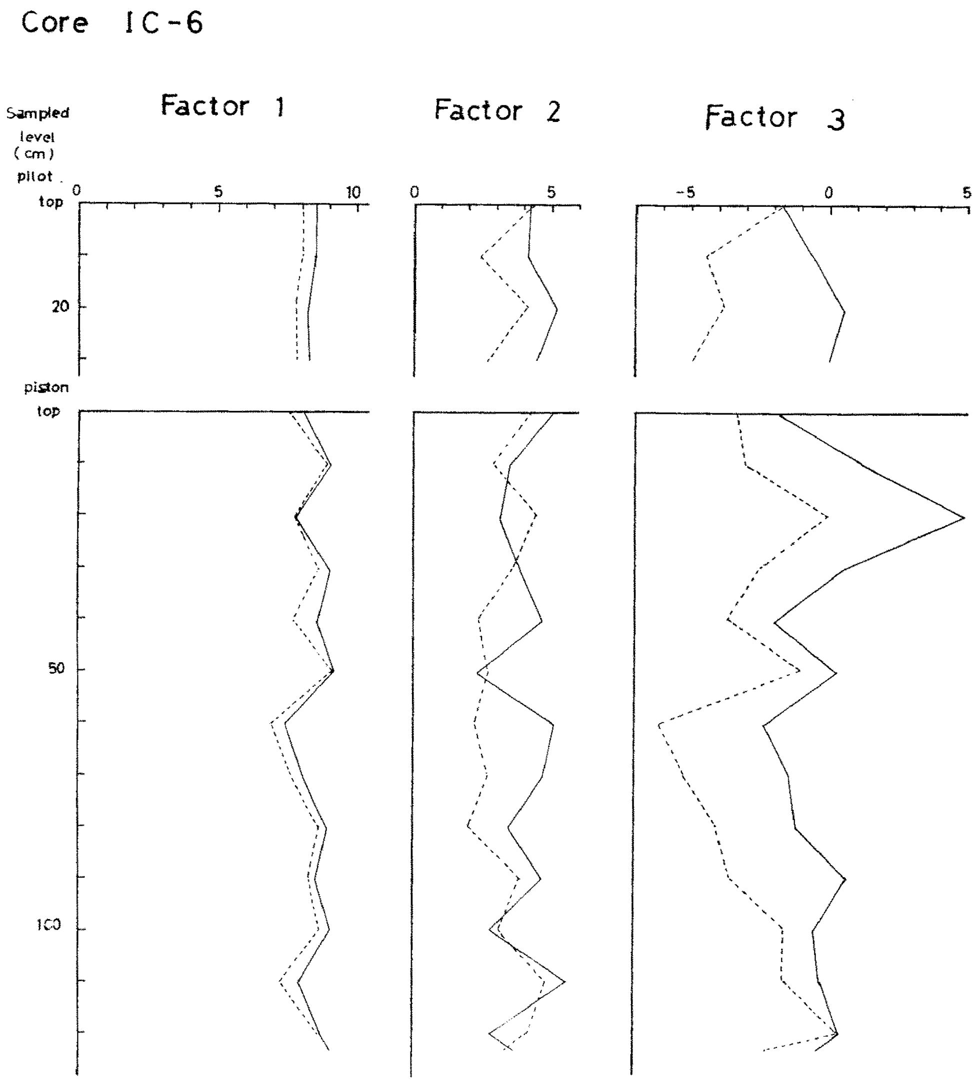
Sample (from top) (cm)	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
pilot top	0.80061	0.42517	−0.16870	0.33104	0.05444	−0.06468
10	0.81227	0.25447	−0.44153	0.09522	0.02887	−0.17746
20	0.78899	0.41860	−0.38252	−0.01887	0.09125	−0.10407
30	0.79761	0.27269	−0.49562	0.01512	0.01492	−0.15226
IC-5 top	0.63560	−0.58352	−0.39620	0.02253	−0.00033	−0.22730
10	0.56957	−0.31922	−0.52540	−0.21338	−0.16065	−0.36812
20	0.94259	−0.05338	0.04625	−0.20392	0.15638	−0.05743
30	0.95517	−0.17613	0.09996	−0.01494	−0.06563	0.10026
40	0.59977	−0.66431	−0.00001	0.14757	0.38520	0.10300
50	0.94708	0.18396	0.14097	0.02618	0.06143	−0.04359
60	0.94347	0.18842	0.12074	0.01494	0.17224	0.09528
70	0.87788	0.39856	0.05643	−0.10064	0.06454	−0.07859
80	0.83554	−0.14526	−0.05811	0.08112	0.20914	−0.14418
90	0.87944	0.17563	0.16033	0.22311	0.16453	−0.09274
100	0.91491	0.22717	0.25378	−0.14392	0.06173	−0.01123
120	0.95942	−0.04891	0.01271	0.13132	0.12628	−0.03676
130	0.95703	0.07625	−0.02554	−0.05005	0.14986	−0.16728
160	0.55880	−0.46159	−0.07760	−0.25208	0.45852	−0.17012
170	0.83166	−0.05462	0.16765	0.18577	0.42401	−0.06114
210	0.67527	−0.29797	−0.26442	−0.50470	−0.11525	−0.08013
220	0.67630	−0.41619	−0.31913	−0.36822	−0.02149	0.02436
230	0.83055	−0.13569	−0.07996	−0.16436	−0.02702	0.31080
240	0.97635	0.04577	0.00850	−0.11660	0.06336	−0.00847
250	0.59460	−0.60223	−0.27600	−0.13573	0.11601	0.16016
260	0.21533	−0.25541	−0.09826	−0.41786	0.10160	0.53053
270	0.44590	−0.39221	−0.14623	−0.43540	0.09532	0.55586
280	0.91633	−0.06706	0.11369	0.08706	−0.13372	0.29262
290	0.93795	0.00017	0.04826	−0.02894	−0.04954	0.20936
300	0.69778	−0.32298	−0.45145	−0.33080	0.13022	0.15821
310	0.59854	−0.65457	−0.27345	0.01899	0.13709	−0.04004
320	0.64702	−0.45691	−0.49154	−0.16648	−0.02535	0.17803
330	0.93205	0.21878	0.03565	0.00242	−0.03956	0.20818
340	0.95354	0.09866	0.16533	−0.05312	0.08414	0.04619
350	0.97851	0.02418	0.05032	0.00814	−0.03662	0.08526
360	0.94317	−0.00954	0.15846	−0.05431	−0.05910	0.00034
380	0.88722	−0.28276	−0.10016	0.00700	0.12299	0.17481

on the basis of Q-technique factor analysis on 93 samples, is interpreted to indicate a factor reflecting not only the water temperature of the ocean but also the degree of the fragmentation of the planktonic foraminiferal test. The writer attempts to consider on this subject later. With respect to the factor III, the relatively large positive values of the factor loadings correspond to the assemblage with dominant species as *Globorotalia menardii* and *Globigerinita glutinata*. The relatively large negative values of the factor loadings correspond to the assemblage with abundant *Globigerina bulloides* and *Globoquadrina dutertrei*. As there is no detail information about the distribution of the assemblages of the planktonic Foraminifera, the factor III could not be interpreted in the present study.

CORRELATION AND AGE OF THE CORES, AND RATE OF SEDIMENTATION

Correlation of the Cores

In many cases, correlation of the cores can be made by lithological, micropaleontological, and some other methods, if the cores are from stations not so distant from one another.

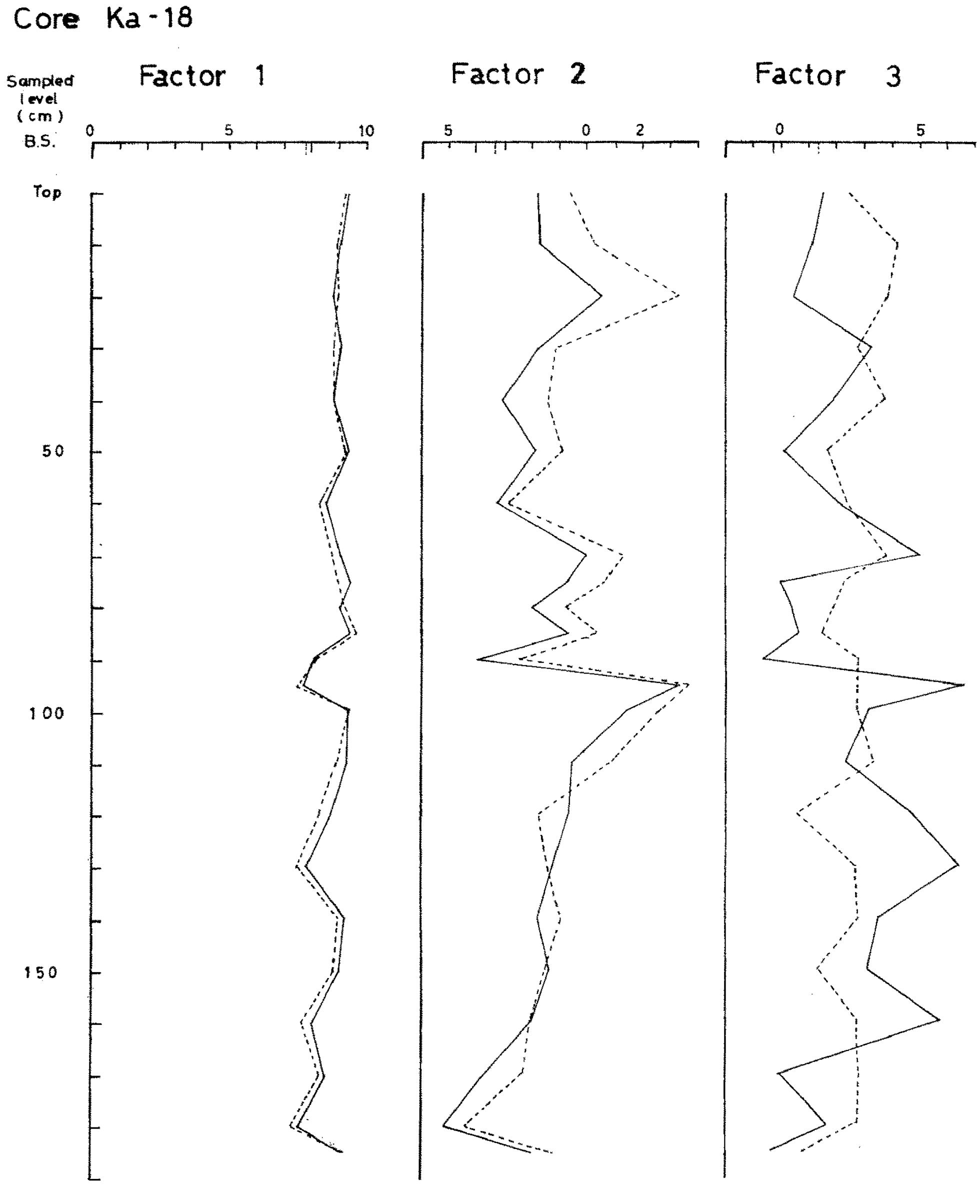


—— based on 43 samples ----- based on 93 samples

Fig. 20. Fluctuation curves of three factor loadings in core IC–6.

In the present study, the six deep-sea cores were obtained from approximately Lat. 6°N. to Lat. 2°S. of the Indian Ocean and thus can be correlated with one another by lithological, micropaleontological and the oxygen isotopic method. The following eleven criteria were used for the correlation of the cores.

1. Color boundary
2. Secondary deposited sediment
3. High concentration of plant-fiber and mica
4. High concentration of scoria
5. Faunal change of planktonic Foraminifera
6. Coiling change of *Globorotalia crassaformis*
7. Occurrence of *Globorotalia menardii flexuosa*
8. Abundant occurrence of *Globorotalia truncatulinoides*
9. High concentration of Radiolaria
10. Paleotemperature curve
11. Radiocarbon data



—— based on 43 samples ----- based on 93 samples

Fig. 21. Fluctuation curves of three factor loadings in core Ka-18.

These criteria do not have equal value for the correlation of the cores. In general, the qualitative change of the composition is more valid for the correlation of the cores than the quantitative change. Namely, the existence of the secondary deposited sediment and the occurrence of *Globorotalia menardii flexuosa* are more valid than the high concentration of plant-fiber and mica, scoria, Radiolaria, and *Globorotalia truncatulinoides*. Likewise, the abrupt change in the coiling direction of *Globorotalia crassaformis* is more valid than the continuous change of the composition such as the faunal change of planktonic Foraminifera and paleotemperature curve. Consequently the correlation of the cores was first performed by the secondary deposited sediment, occurrence of *Globorotalia menardii flexuosa*, and coiling change of *Globorotalia crassaformis*. Other criteria were used as supplementary methods. Hence, the six cores are satisfactorily correlated with one another, especially the correspondance between the northern three cores is excellent (Fig. 26).

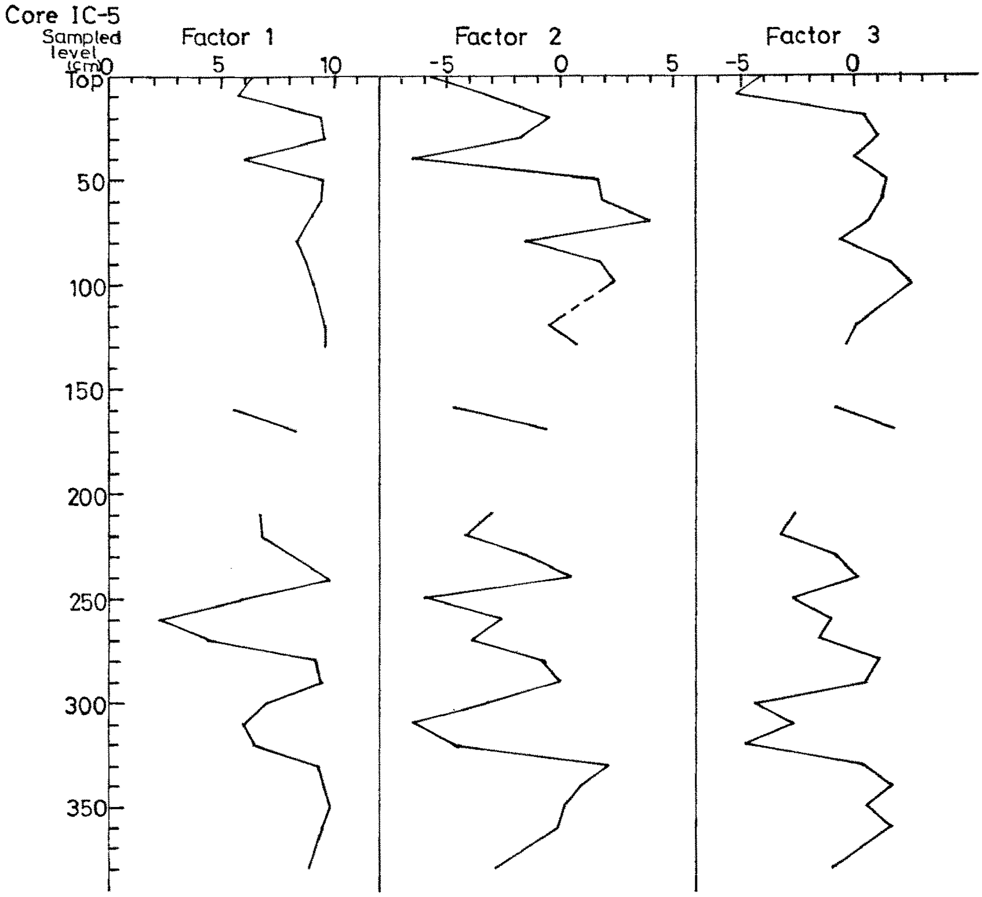


Fig. 22. Fluctuation curves of three factor loadings in core IC–5.

Age of the Cores

From the experimental results of the oxygen isotopic method, it was found that the method gave very high confidence of the measurements. The oxygen isotopic method, therefore, is the most effective for inferring the relative change of the sea-water temperature in the past than any other method such as lithological or micropaleontological investigations. It can not, however, determine the absolute temperature of the ancient sea-water, since we can not estimate the 0^{18} concentration in the ancient sea-water.

The paleotemperature curves based on the oxygen isotopic method was determined for the northern three cores IC–6, Ka–18, and IC–5 (Fig. 27). The absolute date based on the radiocarbon method was determined by Dr. K. Kigoshi of the Department of Chemistry, Faculty of Science, Gakushuin University, for the cores IC–6 and Ka–15 as follows:

core no.	from the top	Age years B.P.	measurement no.
IC-6	25-30 cm	14,200±400	GaK-1740
	51-55.5 cm	$27{,}200^{+3{,}200}_{-2{,}300}$	GaK-1741
Ka-15	41-45 cm	13,270±370	GaK-1742

The rate of sedimentation of the core IC–6 was determined by Dr. Y. Sugimura of the Meteorological Research Institute, Tokyo, using the Io/Th ratio method. The result gives 15.9 mm per 1,000 years as a average rate of sedimentation of the core IC–6.

The late Pleistocene chronology will be considered on the basis of the data mentioned above.

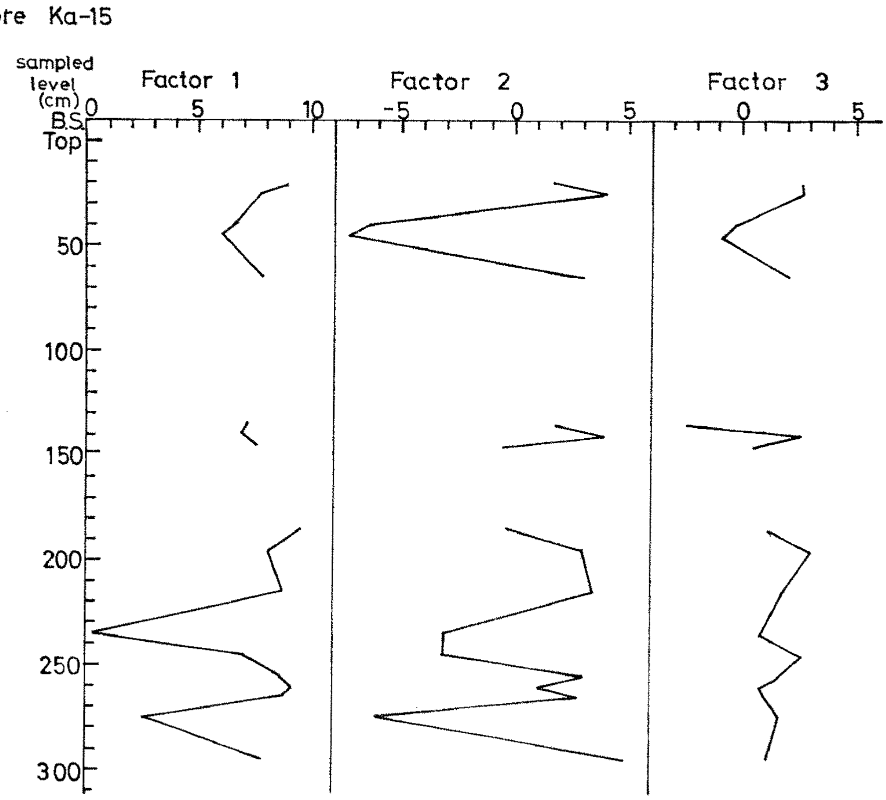


Fig. 23. Fluctuation curves of three factor loadings in core Ka–15.

As the paleotemperature curve between the top down to 15 cm of the piston core IC–6 resembles the pattern of the pilot core, the top of the piston core seems to indicate the modern sediment. The absolute age at 25–30 cm from the top of the piston core is 14,200± 400 years B.P. Accordingly, the age at 15 cm from the top of the core where the paleotemperature gives a slightly higher value than at present indicates about 5,000 years B.P., and probably corresponds to the "Climatic Optimum" of the postglacial. The paleotemperature curve at about 20 cm from the top represents an abrupt decrease of 6°C from 21.9°C at 10 cm to 15.5°C at 30 cm, and the age at 20 cm is about 10,000 years B.P., this age corresponds to the transitional period from the Würm glacial to the postglacial. The paleotemperature at 30–40 cm from the top gives a minimum value of 15.5°C, the corresponding age is about 15,000 and 20,000 years B.P. Consequentary, the age seems to be the maximum period of the Würm glacial. As a whole, the paleotemperature gives relatively low values between 30 cm and 105 cm from the top of the core, and the age at at 51–55.5 cm and the constant rate of sedimentation (15.9 mm/1,000 years) is about 60,000 years B.P. Therefore, the period representing a relatively low paleotemperature between 30 cm and 105 cm from the top of the core corresponds to the Würm glacial stage. There is a minor improvement of the paleotemperature at 70–80 cm from the top of the core, and the period corresponds to the interstitial substage in the Würm glacial. Consequently, the 105 cm from the top estimated on the basis of the absolute age 27,200 $^{+3,200}_{-2,300}$ years B.P. main Würm substage probably corresponds to between 25 cm and 60 cm and the early Würm substage to between 90 cm and 100 cm, respectively. As the horizon at 110 cm from the top of the core IC–6 is correlated with the horizon at 40 cm from the top of the core Ka–18, the age from the top down to 25 cm of the core Ka–18 is the early Würm substage. The paleotemperature curve between 40 cm and 90 cm from the top of the core

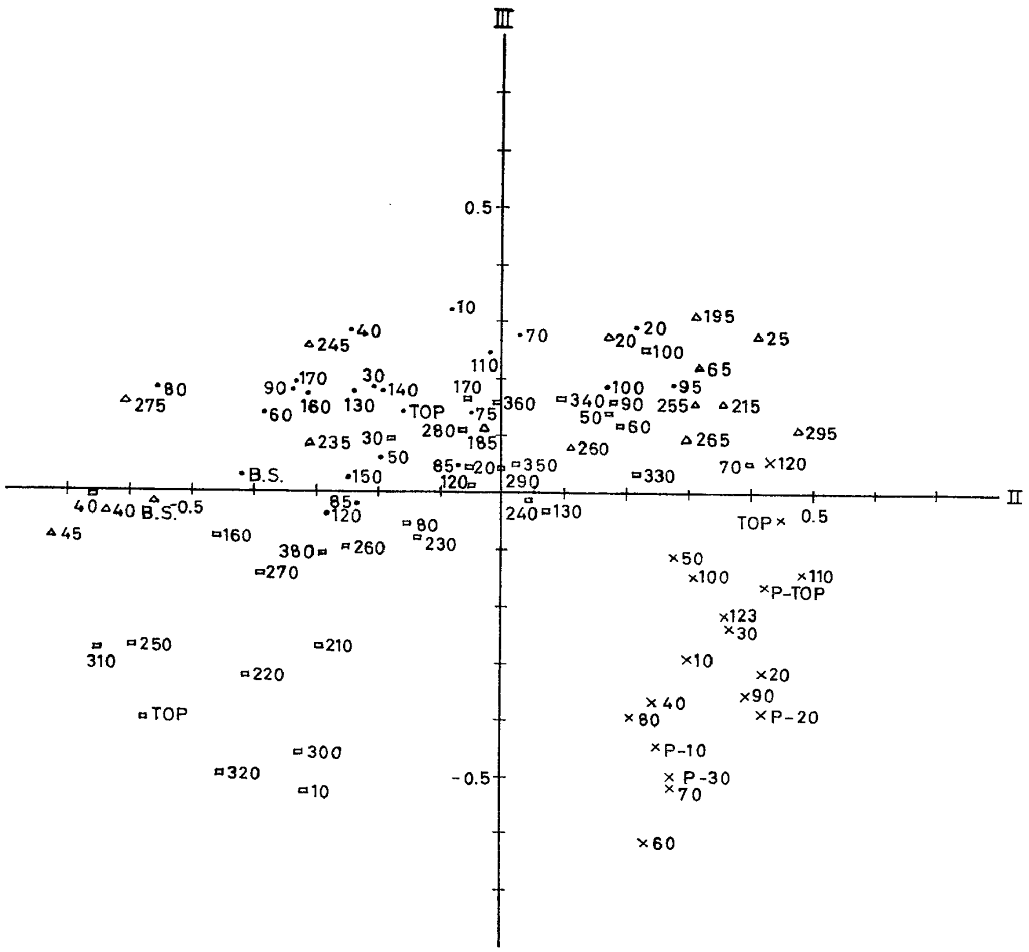


Fig. 24. Plots of 93 samples on the plane of factor axes II and III.
Legend • Ka–18, △ Ka–15, × IC–6, □ IC–5.

Ka–18 represents a relatively high temperature, therefore the periods just mentioned above and between 110 cm and the bottom of the core IC–6 probably correspond to the Riss-Würm interglacial stage, because the horizon at 130 cm from the top of the core Ka–18 is correlated with the horizon at 260 cm from the top of the core IC–5 where the paleotemperature gives a low temperature (14.7°C) as cold as the maximum period in the Würm glacial at 30–40 cm from the top of the core IC–6 or at 15–25 cm from the top of the core IC–5, and the period between 95 cm and 165 cm from the top of the core Ka–18 is considered to indicate the Riss glacial stage. The paleotemperature at 170–180 cm from the top of the core Ka–18 gives considerably high values (23.1°C and 21.8°C) as compared with the maximum of the Riss-Würm interglacial stage, and the period probably corresponds to the late Mindel-Riss interglacial stage. With respect to the core IC–5, the subdivision of the late Pleistocene chronology is made by comparision the core IC–5 with the cores IC–5 and Ka–18 and considered as follows:

(from the top of core IC–5)	stage and substage
near the top	postglacial
5 cm–115 cm	Würm glacial
15 cm–50 cm	main Würm
70 cm–80 cm	warm interstitial

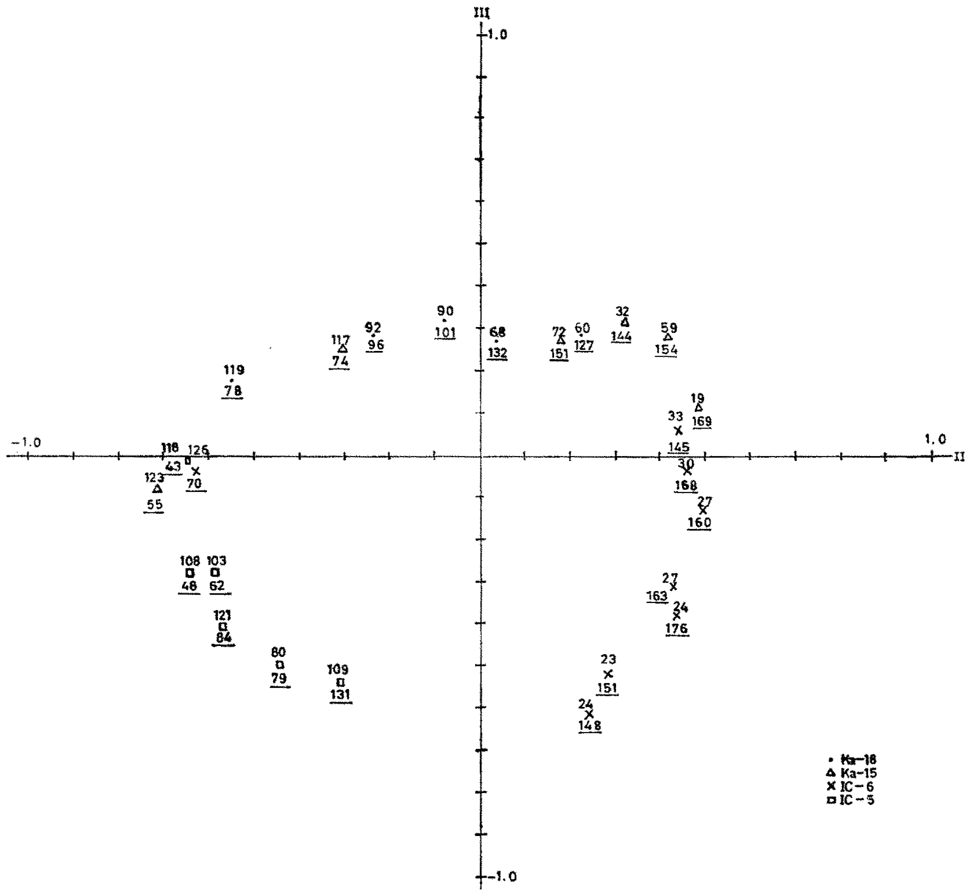


Fig. 25. Plots of total specimens related to factor II_R and III_R in Fig. 24. The number with underline is the sum of factor III_R.

90 (?)–115 cm	early Würm
125 cm–210 cm	Riss-Würm interglacial
220 cm–345 cm	Riss glacial
350 cm–the bottom	Mindel-Riss interglacial

The subdivisions of the late Pleistocene chronology with respect to the other three cores are made based on the correlation of the cores (Fig. 27).

These paleotemperature curves resemble closely those of the many deep-sea cores from the Atlantic, Pacific, and Caribbean Sea measured by Emiliani and Rosholt *et al.*, using the oxygen isotopic method (Emiliani, 1955, 1958, 1964, 1966; Rosholt *et al.*, 1961, 1962). Rosholt *et al.* (1961, 1962) measured the ages of various levels in the deep-sea cores from the Atlantic by means of the Th^{230}/Th^{232} method, and gave the following ages for the Pleistocene stages or substages: postglacial, 0–10,000 years; main Würm, 10,000–30,000 years; main Würm-early Würm interval, 30,000–50,000 years; early Würm, 50,000–65,000 years; Riss-Würm interglacial, 65,000–Z00,000 years; Riss glacial, 100,000–130,000 years; and Mindel-Riss interglacial, 130,000–175,000 years. The writer's data and his opinion for the subdivision of the late Pleistocene chronology agrees essentially with the ages suggested by them.

Biostratigraphically, *Globorotalia menardii flexuosa* is the most important time indicator species in the late Pleistocene age. This subspecies has not been reported from Recent material. Ericson *et al.* (1956, 1961, 1964) found that the subspecies was restricted

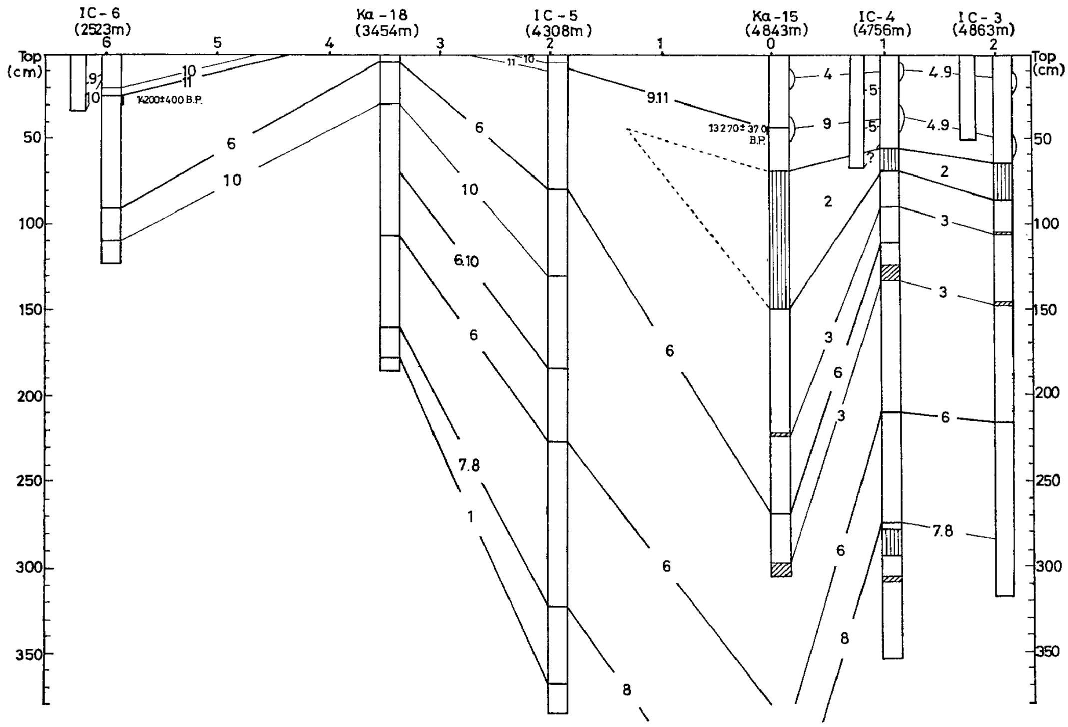


Fig. 26. Correlation of the cores.
1. color boundary. 2. secondary deposited sediment. 3. high concentration of plant-fiber. and mica. 4. high concentration of scoria. 5. faunal change of planktonic Foraminifera. 6. coiling change of *Globorotalia crassaformis*. 7. occurrence of *Globorotalia menardii flexuosa*. 8. abundant occurrence of *Globorotalia truncatulinoides*. 9. high concentration of Radiolaria. 10. paleotemperature curve. 11. radiocarbon data.

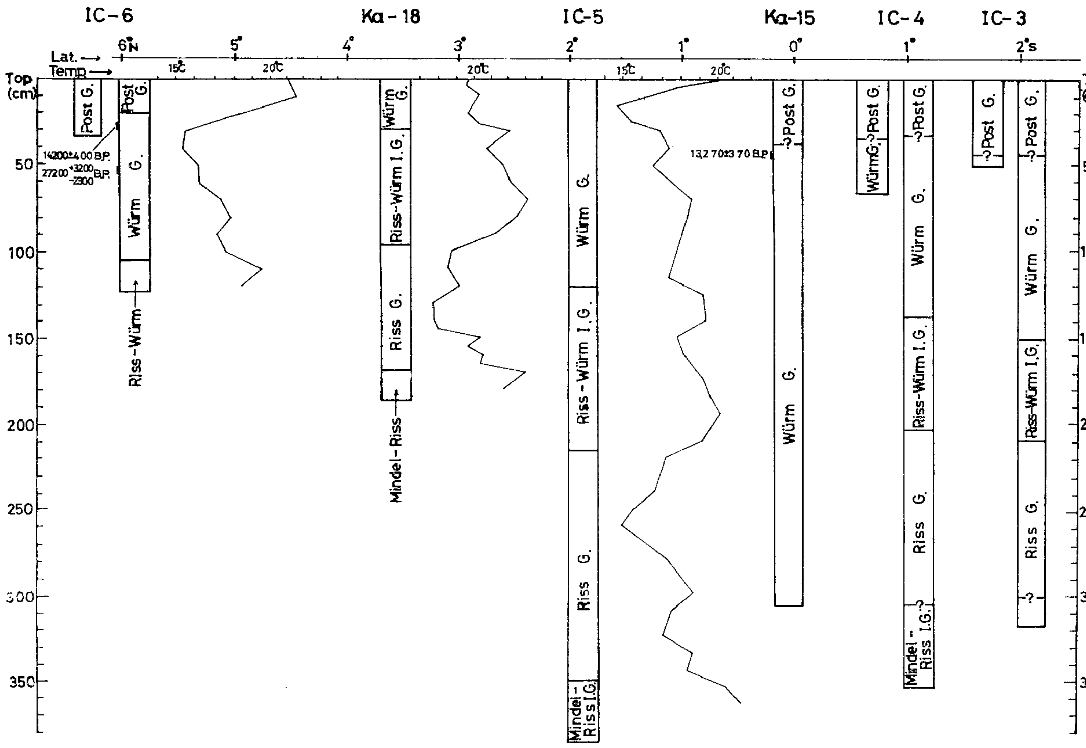


Fig. 27. Age of the cores. G: glacial stage I.G.: interglacial stage

to the warm interstitial substage of the last glacial and the last interglacial stage. 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. But their opinions in relation to the subdivision of the Pleistocene are different from Emiliani's, and those substage and stage roughly correspond to the Riss-Würm interglacial and Mindel-Riss interglacial of Emiliani's subdivision, respectively. The writer had formerly suggested that the occurrence of *Globorotalia menardii flexuosa* at 160 cm from the top of the core Ka–18 might be correlated to the supper part of the Riss-Würm interglacial (Oba, 1967). After detail investigation, it was found that the occurrences of the subspecies at 155–165 cm of the core Ka–18, at 325, 345, and 355 cm of the core IC–5 and at 283 cm of the core IC–3 correspond to near the boundary between the Riss glacial and Mindel-Riss interglacial.

Rate of Sedimentation

The rate of sedimentation in the core IC–6 was measured by the Io/Th method at 5 cm (above 50 cm from the top) and 10 cm (below 50 cm from the top) intervals, and an average of 15.9 mm/1,000 years was obtained. The value calculated based on the radiocarbon dates between 25–30 cm and 51–55.5 cm from the top of the core gave about 19.8 mm/1,000 years. The rate of sedimentation of the other cores can be roughly estimated on the basis of the correlation of the cores. The rate in the core IC–5 seems to be approximately equal at least at the upper part from the top down to 80 cm to the rate in the core IC–6 except from 80 cm to 150 cm of the core, where the rate might be somewhat larger. The core Ka–18 represents the rate of about two-thirds or half (below 150 cm from the top) of the core IC–5. The rate of sedimentation in the core Ka–15 except for the secondary deposited layer is about twice as large as in the cores IC–5 and IC–6. The rates in the cores IC–4 and IC–3 except the secondary deposited layer are roughly equal to the rate in the core Ka–18. Ultimately, the rate of sedimentation of these cores are roughly 1–3 cm/1,000 years. Such relative large values in the cores Ka–15, IC–4, and IC–3, notwithstanding very small amounts of the coarse fragments, are evidently due to the supply of clay or silt size particles by the turbidity currents. As the results the perfect specimens with thin shelled and hispid tests of the species are protected from the dissolution of calcium carbonate by masking of the relatively rapidly deposited sediments.

DISCUSSION

Arrhenius (1952) suggested that the high concentrations of calcium carbonates in the sediments of the deep-sea cores from the equatorial east Pacific corresponded to the glacial stage. On the contrary, Emiliani (1955), in numerous deep-sea cores from the equatorial Atlantic and Caribbean, found good agreement between the coarser fractions larger than 62 or 74 μ and the paleotemperature derived by the oxygen isotopic method and demonstrated that the high percentage of the coarse fractions in the core indicated the interglacial stage. Of the six deep-sea cores investigated in the present study, the three cores obtained from relatively shallow water were examined for their paleotemperature curves by the oxygen isotopic method. The mutual relationships between the paleotemperature curves and the curves of the calcium carbonate content and coarse fractions are as follow. The calcium carbonate content of the core IC–6 shows good agreement with the coarse fractions, and their high concentrations found in the glacial stages, when the paleotemperature by the oxygen isotopic method indicated low temperatures. Namely, the results of this core support Arrhenius's opinion. The core Ka–18, however, shows no relationship between the calcium carbonate content and the coarse fractions, and they have no correlation to the paleotemperature. The calcium carbonate content of the core IC–5 shows the proportional relation to the coarse fractions, but they have no correlation to the paleotemperature. The calcium carbonate contents and coarse fractions of these cores, except for the calcium carbonate of the core Ka–18, are proportional to the planktonic foraminiferal numbers of each core, respectively. This means that the larger parts of the calcium carbonate and coarse fractions are of the planktonic foraminiferal tests and their fragments. They, the calcium carbonate content, coarse fractions, and planktonic foraminiferal numbers, represent a reverse relation to the benthonic foraminiferal percentages, and then the benthonic foraminiferal percentages show proportional relation to the dissolution effect of the planktonic foraminiferal test which was illustrated by using the test of *Globorotalia menardii*. (But the benthonic foraminiferal percentage of the core Ka–18 fails to compare with the dissolution effect, because their measured layers are different). That is, the layers representing the large dissolution effect of the test contain small amounts of planktonic Foraminifera, which reflects the small concentrations of the calcium carbonate and coarse fractions, and the large percentage of the benthonic Foraminifera. The tendancy is clearer in the cores obtained from relatively deep water. That is, the planktonic foraminiferal numbers of the cores Ka–15, IC–4, and IC–3 are extremely small, and the contents of the calcium carbonate and coarse fractions also are very small. Almost all of the planktonic foraminiferal tests are broken, and only thick shelled species have perfect tests in these cores. The layers including large amounts of fragments of the planktonic Foraminifera represent a high percentage of the benthonic Foraminifera. This is not due to the increased specimens of benthonic Foraminifera but to the abrupt decrease of the planktonic ones. In the shallow water region, the planktonic foraminiferal percentage aids as an indicator of the distance from the land (Smith, 1955), but the ratio in the deep-sea floor may become a good indicator for the inferrence of the dissolution effect of the test.

The contents of the planktonic Foraminifera are different layer by layer in the core. (For example, 1,700 at 90 cm from the top of the core Ka–18 and 13,400 at 95 cm). This may be due to the different condition on the deep-sea floor, with respect to the water saturated or undersaturated with calcium carbonate, bottom water temperature, salinity amounts and kinds of benthonic organisms, supply of planktonic Foraminifera and other planktons, and the rate of sedimentation of the inorganic matters etc. However, the contents of the planktonic Foraminifera, coarse fractions and calcium carbonate are generally different between the glacial and interglacial stages (Table, 15). The temperature of the bottom water during the glacial stage was lower than during the interglacial stage (Emiliani, 1954; Smith and Emiliani, 1968; in the present paper), and the solubility of the calcium carbonate is prompted by cold water temperature. In spite of the decreased temperature of the bottom water during the glacial stage, their contents are larger than during the interglacial stage, except for the calcium carbonate content of the core Ka–18. This means that the rate of production of planktonic Foraminifera at the surface water during the glacial stage was more vigorous than during the interglacial stage. The interpretation is satisfactorily admitted in the case of the core IC–6, because the rate of sedimentation of the core IC–6 is constant throughout.

The relationship between the planktonic foraminiferal number and paleoclimate of the core Ka–18 was probably obscured by the arbitrary dissolution of the test. The content of the calcium carbonate is almost constant throughout the core except for between 5 cm and 15 cm from the top of the core. The glacial stages, however, yield about twice the number of planktonic foraminiferal tests as the interglacial stages. This may be interpreted as; since the planktonic foraminiferal number is the number of specimens larger than 125 μ for one gram of dried sediment, the large amounts of fine calcareous matters smaller than 125 as coccolithophorids and small tests or fragments of Foraminifera were probably dissolved during the glacial stage, while the fine calcareous matters

Table 15. Contents between the glacial and interglacial stages of calcium carbonate, coarser factions, planktonic and benthonic foraminiferal number in the cores

Core no. (Depth)	$CaCO_3$ (%)		Coarser fraction >74μ (%)		Planktonic foraminiferal no.		Benthonic foraminiferal no.	
IC-6 (1523m)	43.3	I. 39.8 G. 46.8	17.6	I. 16.3 G. 20.4	5,100	I. 3,700 G. 6,500	470	I. 525 G. 415
Ka-18 (3454m)	53.1	I. 61.8 G. 44.5	17.4	I. 15.3 G. 19.9	5,400	I. 4,100 G. 7,100	130	I. 138 G. 125
IC-5 (4308m)	35.1	I. 33.0 G. 36.0	18.1	I. 17.1 G. 18.7	980	I. 310 G. 1,315	84	I. 82 G. 85
Ka-15 (4834m)	10.1		1.2		91		36	
IC-4 (4753m)	9.1		2.1		12		12	
IC-3 (4863m)	6.3		—		25		20	

were almost preserved during the interglacial stage.

In the cores Ka–15, IC–4, and IC–3 obtained from relatively deep water, the faunal composition changes remarkably. Especially the warm water fauna varies from 5 to 95 percent of the total population. The layers with high percentage are almost of the tests or fragments of the thick shelled species. This means that the assemblages had been influenced by the selective dissolution of the tests. On the other hand, in the cores obtained from relatively shallow water, Belyaeva (1964) recognized that there is no remarkable faunal changes by the selective dissolution of the test. According to Belyaeva, there is very good agreement between the faunal composition on the deep-sea floor shallower than 4,500–4,700 m in depth and the living faunal composition in the surface water, and the distribution of the thanatocoenose also agree well with that of the biocoenose. However, the dissolution effect of the planktonic foraminiferal test was observed even in relatively shallow water (in the present paper, Berger 1967). Consequently, it is an important problem in the deep-sea stratigraphy whether the faunal changes in the core are due to the changes of paleoecological condition or to the dissolution effect of the test, or which of them had more strongly affected the assemblage. The fluctuation curves of the warm water fauna in the cores IC–6 and IC–5 as a whole agree with the paleotemperature curves, respectively. But the relationship between them in the core Ka–18 does not always shows good correlation. To find the cause which had determined the faunal assemblage in the core, the factor analysis was practiced. As a result, three main factors were determined. The result of Q-technique factor analysis using 43 samples (IC–6 and Ka–18) indicated that the factor I was a general factor representing the similarity of the assemblages in the samples, the factor II was the water temperature in the past, and the factor III was the dissolution effect of the test. The principle factor solution method determines each factor so that the first axis accounts for most of the information in the correlation matrix, the second for most of the remaining information and so on. Consequently, it was understood in the cores IC–6 and Ka–18 that the water temperature acted more strongly to change the assemblage than the dissolution effect of the test. On the contrary, the result of Q-technique factor analysis based on 93 smaples including the cores IC–5 and Ka–15 indicated that the factor II represented the faunal arrangments along the factor axis so as to be interpreted by both the water temperature and the dissolution effect of the test. As to the selective dissolution of the planktonic foraminiferal tests in the tropical region, Berger (1968) proposed their average susceptibility to dissolution in order as follow:

1. *Globigerinoides ruber*
2. *Orbulina universa*
3. *Globigerinella aequilateralis*
4. *Globigerinoides sacculifer*
5. *G. conglobatus*
6. *"Globigerina bulloides"*
7. *Globorotalia hirsuta*
8. *G. truncatulinoides*
9. *Globorotalia inflata*
10. *G. menardii*
11. *Globoquadrina eggeri*
12. *Pulleniatina obliquiloculata*
13. *Globorotalia crassaformis*
14. *Sphaeroidinella dehiscens*
15. *Globorotalia tumida*

Namely, the assemblage affected by the dissolution effect changes the assemblage that consisted of only abundant specimens of the more resistant species, which almost belong to the warm water fauna of Belyaeva's faunal grouping. Consequently, the factor II in the cores IC–5 and Ka–15 is interpreted to include both the water temperature and dissolution effect of the test. As the flucutation curve of the warm water fauna agree with the paleotemperature curve in the core IC–5, the water temperature seems to have controlled the assemblage more strongly than the dissolution effect of the test. On the contrary, the dissolution effect of the test in the core Ka–15 seems to have affected the assemblage more strongly than the water temperature, because the age at 41–45 cm from the top of the core indicates 13,270+370 years B.P. in the main Würm glacial, although there the warm water fauna was dominant. Likewise, the faunal assemblages in the cores IC–4 and IC–3 were strongly affected by the dissolution of the test, because these cores have some layers nearly composed of specimens and their fragments of the thick shelled species as *Globorotalia tumida*, *G. menardii*, *G. crassaformis*, *Sphaeroidinella dehiscens*, *Globoquadrina dutertrei*, and *Pulleniatina obliquiloculata*. Such assemblages are never seen in the living population and they can not be used for inferrence of the paleoclimatic change, but may provide valid information for the study of the dissolution of the test.

SUMMARY

(1) The six deep-sea cores were obtained from the central equatorial Indian Ocean, along approximately Long. 78°E. from Lat. 6°N. to 2°S. The northern three cores (IC–6, Ka–18, and IC–5) from relative shallow water are composed of *Globigerina* ooze and calcareous clay, The other cores (Ka–15, IC–4, and IC–3) from about 4,700–4,800 m in depth are of brown clay. The former yielded abundant planktonic foraminiferal tests and small amounts of benthonic Foraminifera, Radiolaria, diatoms, and coccolithophorids. The latter cores are almost composed of clay size particles and very small amounts of Foraminifera, Radiolaria, diatoms, coccolithophorids, sponge-spicules, plant-fiber, mica scoria, and quartz, and accompanied with some secondary deposited silt layers. The secondary deposits include many benthonic Foraminifera, Ostracoda, and Mollusca which were evidently derived from a shallow water region by turbidity currents.

(2) The planktonic foraminiferal number in the sediment generally decreases with increasing depth, that is, the average of 5,000 tests in the *Globigerina* ooze, 1,000 in the calcareous clay, and less than 100 in the brown clay. The planktonic Foraminifera in the cores obtained from relatively deep water are almost broken and the few perfect specimens are those of the species with thick shelled tests. The coarser fractions larger than 74μ

and calcium carbonate percentage in the sediment are proportional to the planktonic foraminiferal number, respectively except for the calcium carbonate content in the core Ka–18. Consequently, the larger parts of the coarse fractions and calcium carbonate content consist of the planktonic foraminiferal test and their fragments. However, there are some layers consisting entirely of the fragments and layers representing relatively high concentration of the calcium carbonate, notwithstanding very small amounts of the planktonic Foraminifera and coarse fractions, as in the secondary deposited sediments in the cores Ka–15, IC–4, and IC–3.

(3) The result of the review of the problems on the samples, technique, and paleotemperature scale of the oxygen isotopic method indicated that this method could determine the relative change of the paleotemperature with an accuracy of 0.4°C. The paleotemperature curves of the cores IC–6, Ka–18, and IC–5 showed periodic oscillations with an amplitude of about 6°C. and resemble closely those of the many deep-sea cores from the Atlantic, Pacific, and Caribbean Sea measured by Emiliani (1955–,1967) and Rosholt *et al.* (1961, 1962). From the results of measurements on 19 species of planktonic Foraminifera, it is inferred that the different species occupy their own depth habitat ranges.

(4) Faunal analysis of the cores based upon the faunal grouping proposed by Belyaeva (1964) showed agreement between the fluctuation curves of the warm water fauna and the paleotemperature curves at least of the core IC–6 and IC–5. The warm water faunas in the cores obtained from relatively deep water varied from 5 to 95 percent of the total population, such assemblages are never seen in the living population. The layers representing the high percentage are almost composed of specimens and their fragments of the thick shelled species as *Globorotalia tumida, C. menardii, Sphaeroidinella dehiscens, Globoquadrina dutertrei, Pulleniatina obliquiloculata*, and *Globigerina digitata*, while the low percentage layers contain many undamaged specimens with thin shelled and hispid tests of such species as *Globigerinoides ruber, Globigerinita glutinata, Globigerina bulloides*, and *G. rubescens*.

(5) The estimation of the rate of dissolution from the damaged tests of *Globorotalia menardii* showed that the vigorous dissolution corresponded to the layers with abundant fragments and tests of the thick shelled species. The dissolution effect was found to be arbitrary in all the cores, although the rate is more or less different with each core, and it reduces the planktonic foraminiferal number in the sediment. Consequently, the coarse fractions and calcium carbonate content in the sediment of the core are also influenced. The planktonic foraminiferal number or benthonic foraminiferal percentage seems to be a good indicator to represent the rate of dissolution of the test in the deep-sea floor.

(6) To infer the cause which determined the faunal assemblage in the core, the factor analysis was applied. The mutual relationship between all the species, including the species of which ecology had not been known, was revealed by the R-technique factor analysis. The first three factors are interpreted to indicate the province, water temperature, and rate of dissolution of the test. Likewise, the Q-technique factor analysis gave the concise mutual relationship between all the samples. It was considered from the interpretation of the factors that the water temperature had affected the assemblage more strongly than the dissolution effect of the test in the cores obtained from relatively shallow water, whereas the reverse relation was found in the cores from deep water.

(7) The correlation of the cores with one another was made by lithological, micropaleontological, and paleotemperature curves, especially the following criteria were found to be valid for the correlation of the cores; secondary deposited sediments, occurrence of *Globorotalia menardii flexuosa*, and coiling change of *Globorotalia crassaformis*. The absence of some sediments in the cores were found by means of cross-correlation of the cores.

(8) The late Pleistocene chronology was considered on the basis of the paleotemperature curves, radiocarbon dates, and rate of sedimentation using the Io/Th method. Consequently, the subdivision of the late Pleistocene is of the same pattern as proposed by Emiliani (1955). During the glacial periods, however, planktonic foraminiferal number, coarse fractions, and calcium carbonate content in the cores were larger than during the interglacial periods, and this is recognized satisfactorily in the core IC–6.

(9) The rate of sedimentation of the cores are roughly 1–3 cm/1,000 years. Such relative large values in the cores Ka–15, IC–4, and IC–3, notwithstanding the very small contents of coarse fragments, are evidently due to the supply of clay or silt size particles by the turbidity currents. As a result, the perfect specimens with thin shell and hispid test of the species were protected from the dissolution of calcium carbonate by masking of the relatively rapidly deposited sediments.

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Table 16. Distribution of planktonic Foraminifera in core IC-6

		Pilot core				Piston core													
Species	Sample (cm)	Top	10	20	30	Top	10	20	30	40	50	60	70	80	90	100	110	120	1225
Globigerina	bulloides	55	58	58	57	62	41	26	39	55	27	59	55	45	47	31	53	25	40
G.	calida				3	4	4	6	1		5	2	4	1	2	1	1	1	4
G.	digitata	1	1							1				1	2	1	2	1	1
G.	falconensis		1						1	2		2		3		1	1	1	
G.	pachyderma									2				1			1	4	4
G.	quinqueloba							4		1	2	1	2	4	1	4		4	2
G.	rubescens	2	4	3	3	5	6	10	7	7	4	11	2	6	10	15	9	7	7
Globigerinella	siphonifera		1	2	4		3	3	2	1	1			1	2	2	3		1
Globigerinoides	conglobatus			2	1		1				1				1		2	1	
G.	sacculifer	2	9	5	8	7	15	13	4	5	2	2	2	5	2	4	3	4	4
G.	ruber	11	25	36	28	10	29	45	26	11	24	11	15	19	30	17	19	19	20
G.	tenellus	2	3	5	3	2	5	13	11	4	10	5	1	2	1	9	4	5	2
Globorotalia	crassaformis								3		1			1		4		2	1
G.	menardii	19	19	8	14	15	9	4	9	14	12	12	9	14	7	18	5	11	14
G.	inflata																		
G.	hirsuta		1					2		1	2	3	1	1			2		1
G.	pumilio																		
G.	scitula							1			1		1	2	1	1	2		
G.	truncatulinoides				1				1			1							
G.	tumida	1	1	2		1				1	1		1	1		1	1	1	1
Globoquadrina	conglomerata	2	2		2	2	4	2	2	1	1	3	1	1	2	2	1	2	4
G.	dutertrei	15	19	17	22	17	29	11	30	28	36	30	32	36	22	19	11	20	21
G.	hexagona	2	2	7	11	6	4	10	11	11	11	16	20	7	11	15	6	10	6
Globigerinita	glutinata	77	38	45	33	63	44	40	47	48	50	28	37	39	43	42	59	68	51
G.	humilis		1			2			1			2	2	1	1	1			1
G.	iota			1		1		1	2	1		1			1	1		2	4
G.	uvula	1	1	1		1		1		2	1	2	3	1	1		1	1	
Orbulina	universa		2	1	1					1		2	2	1	1		1		3
Pulleniatina	obliquiloculata	9	11	6	9	2	6	8	2	3	5	7	10	7	11	10	9	8	8
Sphaeroidinella	dehiscens	1	1	1							1					1	1		
Candeina	nitida																		
Miscellaneous									1		1						3		
Total		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Benthonic Foraminifera		56	30	26	12	35	4	1	9	9	15	12	18	23	16	32	54	47	37
Percent of benthonic Foram.		28	15	13	6	17.5	2.1	0.7	4.7	4.5	7.8	6.1	9	11.4	8.2	16.3	26.9	23.7	18.4
Foraminiferal No.	Benthonic	248	224	245	208	312	128	96	352	352	480	448	640	560	336	440	512	656	1024
	Planktonic	640	1250	1570	3200	1470	7490	1440	7150	7550	5660	6940	6500	4320	3800	2260	1390	2110	4560

Table 17. Distribution of planktonic Foraminifera in core IC-5

Species	Sample (cm)	Top	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380
Globigerina	bulloides	26	38	12	8	7	14	16	21	16	15	8	10	18	23	1	2	8	13			3	18	17	9	17	12	6	6	7	10	23	18	28	16	10	18	10	3	8
G.	calida	2	5		2		4	1	3	2	3	1		4	3			2				2	2	4	3	2	5	5	3			2	1	2	1	1		1		
G.	digitata	7	2		1	4	2				1			1	2	4	3	6	3	1	1	1	3	3			17	11	4			6	3	5	2	1			1	2
G.	falconensis			1	1	2	2	2	4	3	2				2	1					1				3	2				1	1							2		
G.	pachyderma			1	5	14	1	11	1	1		1	5	2			23	2	1		1	4	2	5	5	4	18	78	52	10	3	18	12	28	8	7	9	8	1	3
G.	quinqueloba																									1	1	1			2						1			
G.	rubescens	1		3	6		4	6	12	15	8	4		3	9										11	3	3			11	10	2	1		6	6	1		1	5
Globigerinella	siphonifera	7	7	5	1		3	1	5	2	2	4	2	1	2	6		2	1			2	2	8	5	1		5	1	2	1	1	3	3	1	1		1		
Globigerinoides	conglobatus	2	7	1	2	1		1	1	4	7	2			1	2		1	1				6	4	2		2			1	3		2	5	2		3			
G.	sacculifer	22	36	9	8	2	11	3	5	2	2	13	5	5	13	4		6	12	1	1	1	32	22	6	10	10	10	2	7	9	15	4	12	10	11	6	20	1	2
G.	ruber	10	18	32	24	9	23	27	33	15	14	36	4	18	29	9	4	29	17	1	1	7	37	28	28	29	12	29	36	18	25	23	11	16	23	26	29	24	4	12
G.	tenellus			1	2	1	3	4	5	6	6	2		3												6	1			6	6	4	2		12	5	3	5		2
Globorotalia	crassaformis			6	2	7	1	1		1	1	2	1	2		2		3	1			1	2		1	6	8	6	8	1		5	1	1	1	3	2	8		3
G.	menardii	30	20	20	28	31	17	18	12	19	20	16	20	24	21	32	13	14	22	7	7	5	13	11	10	19	19	12	16	26	17	8	33	21	13	18	29	26	2	13
G.	inflata										1										1															1				
G.	hirsuta			1					2									1							2					3	3	2				1				
G.	pumilio																										1													
G.	scitula	1			1					2													1			1											1			
G.	truncatulinoides				1					1														1	1				1				3							
G.	tumida	12		6	2	30	4	9		8	7	7	9	8	10	10	28	22	34	9	8	21	3	8	7	4	7	4	8	2	3	6	10		1	4	3	1	12	8
Globoquadrina	conglomerata	11	18	2	2	10	11	5	1	10	5	8	12	6	3	15		7	5				11	17	10	2	7	2	3	3	1	3	3	6	1	2	5			
G.	dutertrei	35	28	29	36	31	23	20	12	23	16	20	19	29	19	20	19	28	20	1	2	5	39	47	53	26	34	16	39	43	43	37	41	39	32	24	29	24	4	20
G.	hexagona	1		9	4	1	4	7	13	7	6	12	1	4	4				5	1		1	2	4	6	7		1		7	3		1	3	8	5	6	8		3
Globigerinita	glutinata	1		32	35	9	50	48	45	26	52	50	1	42	37	1	2	7	43			3	5	4	27	36	5	2	1	43	41	8	1	4	49	46	41	40	5	11
G.	humilis	1	2	1	2		1		2	1				2		1		1					3				1				1	5	1		2	1	2			
G.	iota				4			3	7	3	1	1		2	1											2				3	1	1			3	3				1
G.	uvula								1				1												1						2	1					1	1		
Orbulina	universa	1		5	4		1				3	2	2		2	1									3	1	4	1			1	3			1	2		1		
Pulleniatina	obliquiloculata	22	18	23	18	24	18	15	14	33	26	9	25	26	19	29	10	51	18		1	4	11	16	7	19	27	7	8	5	11	23	45	23	6	21	9	17	2	6
Sphaeroidinella	dehiscens	8	1			1	1	1			1	1	1			5	1	9	3	1	1	1	2				6	3	5		1		4	4						1
Candeina	nitida			1							1								1																					
Miscellaneous					1	3	2	1				1						1	1			3	6	1		2		1	7	1	2	4			2	1	2	3		
Total		200	200	200	200	187	200	200	200	200	200	200	118	200	200	143	105	200	200	22	25	64	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	36	100
Percent of benthonic Foram.		9.5	5.8	4.5	2.9	36.1	8.7	3	2.1	4.9	5.7	6.3	20.3	6.7	10.7	40	55.2	33.4	31.9	73.4	78.3	45.5	1.8	4.1	5	2	16.7	23.6	32.9	5.5	4.5	19	22.7	18.2	9.8	13.5	17.6	3.8	63.2	43.7
Benthonic foraminiferal Number		40	18	32	44	91	128	64	96	112	128	22	31	64	76	100	137	94	120	61	101	51	48	72	124	96	120	74	112	136	144	128	120	84	36	100	76	64	67	80
Planktonic foraminiferal Number		380	293	692	1500	190	1340	2050	3470	2170	2100	310	122	900	630	150	111	290	260	22	25	64	2560	1680	2340	3680	600	240	230	2350	3070	540	410	376	330	650	356	1600	39	103

Table 18. Distribution of planktonic Foraminifera in core IC-4

Species	Sample (cm)	Pilot core							Piston core																																				
		Top	10	20	30	40	50	60	Top	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
Globigerina	bulloides	3	6	6	3	2	2	3		1	3	10	1	2	4	3	7			4	3	6	1		1	3	2	1	2	1				4	2	10	2	2	4	12	3	1	44	4
G.	calida		6	2	5	5		1												1																5								1
G.	digitata	1	7		9	8	1					5	2					1		2		1				1					3	5	2		1				1					
G.	falconensis			1						1	1			1	1		1							1	1	1		1					1							2	2			1
G.	pachyderma									3	1			1	4	1	2	6	3	3		4		1		3					2	1	2	6	2	2	1		3	5		1	2	2
G.	quinqueloba			10							3						1		1		1			1					1															3
G.	rubescens				1			1	1		3			2	3		1		1	2		1	1		1	4	3		1						1	7	2	1	8		1		5	1
Globigerinella	siphonifera		3		1				1	2		10		3							1										1					3		5	1					1
Globigerinoides	conglobatus		3		1							4											1																			1		
G.	sacculifer		4								1	7		1		2	1				3	1	3		1	6	1					1				13			8	1		2	2	1
G.	ruber		5	3	2		5	1	1		2	5		3		2	3		1	7	1	13	2			8	22	4	1			1	4	1	3	31	1	2	22	23			6	4
G.	tenellus			1	1						1					1				1		1	2		1	2	1	1					1		1	11			2	1			5	3
Globorotalia	crassaformis			1								3								2		3				4		1			1	1			1	2			4	3		1	1	
G.	menardii		65	4	8	41	1	6	2	28	3.	69	20	11	3	2	5	3	8	3	6	15	5	1	1	4	6		2		29	3	1	1		6	2	2	14	36		3	2	
G.	inflata																																											
G.	hirsuta			1						1		1				1	1			1		1														1		1	1		1			
G.	pumilio																																											
G.	scitula																										1						1			1							1	
G.	truncatulinoides																	2													1					1								
G.	tumida	4	25		17	17		8		5	1	18	24	1	27	1	18	28	12	37	7	19	2		21			4	5		145	32	25	17	7				1	13		20		
Globoquadrina	conglomerata		1					1				2					2			2		2	1			1													2	10				
G.	dutertrei	1	28		10	17	1	4	2	4		34		3	1		4	1	2	3		10	2			3	4						1			15			7	25		1	10	
G.	hexagona		1	16	1	1			3	7	16	5		3	4	3	6	3		1	1	6	1			2	1	1	3			3			2	10	1		6	2			13	3
Globigerinita	glutinata	1	1	15	2	1	4		3	5	16	5	2	6	9	10	11	4	6	8	1	10	3	2	4	5	12	5	7	1	2			2	2	25	4	1	23	15	4	2	31	15
G.	humilis										1	1														2	1									3		5	1					1
G.	iota			3	2				2	2	1				2		1					3						4				2						6	8		3		1	7
G.	uvula			1																	1																							
Orbulina	universa																									1														2				
Pulleniatina	obliquiloculata		27	2	9	11		1	4	2		17	4	1	1	2	1			1		2	3			2						1		1		·2			4	46				
Sphaeroidinella	dehiscens	2	11		3	3				1			4			2	1			2		1				1					13	5		1								2	1	
Candeina	nitida																																											
Miscellaneous			7					1		1	6	4	3	2	2	8			1		2	1				11	1	1			3	1				8	1	5	4	1				
Total		12	200	66	77	106	14	27	29	65	61	200	60	40	65	38	68	48	35	80	27	100	27	6	31	64	55	23	22	2	200	56	38	33	21	152	14	25	122	200	14	34	124	46
Percent of benthonic Foram.		67	32	30	49	49	0	52	71	71	44	71	46	37	75	7	73	74	65	72	60	38	21	33	89	39	10	54	55	88	67	74	91	78	91	18	36	61	15	82	50	71	16	25
Benthonic foraminiferal Number		26	44	21	35	71	0	12	3	4	12	11	11	2	96	0.2	8	47	4	83	5	2	1	0.3	12	1.4	1.2	1	1	1	·1	27	41	13	36	5	1	20	2	11	1.6	4	6	0.6
Planktonic foraminiferal Number		6	95	50	36	72	10	11	1	2	15	4	13	3	33	3	3	16	2	53	3	3	3	1	1	2	11	1	05	0.2	06	9	4	4	3	26	2	13	14	2	2	1.5	31	2

Table 19. Distribution of planktonic Foraminifera in core IC–3

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
Foraminifera No. 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

Table 20. Distribution of planktonic Foraminifera in core Ka-18

Species \ Sample (cm)	Pilot core Top	10	20	30	40	50	Piston core Top	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
Globigerina bulloides	14	2	2	1	1	4	4	8	4	6	2		2	7	1		6	1	9			
G. calida	3						2				1			1			4		2			
G digitata								1		3												
G falconensis	1	1					5	1	3	1	1		1		3		10		4			
G pachyderma								3		1				1	2				1			
G quinqueloba																	1					
G rubescens	13	1				1	6	6			7		1	3	5		12		5			
Globigerinella siphonifera							1	1		6			1	2								
Globigerinoides conglobatus				1			1			3					1	1	3					
G. sacculifer	2	3		1		1				1	1		1	2			1					
G. ruber	28	5	3		5	4	38	22	6	4	9	1	5	9	18	1	48	1	15			
G. tenellus	8	1	3	1		2	5	6	2		2		1		4	1	22		4			
Globorotalia crassaformis	1						2	1					2				1		4			
G menardii	1	1			1	1		4	1	95	1	1		1			5		3			
G. inflata	2	1	1		1		2	1	1								1		2			
G. hirsuta											1						1		2			
G pumilio																						
G. scitula																						
G truncatulinoides	1		1		1		1	1														
G tumida										27			2		1							
Globoquadrina conglomerata										3				1								
G. dutertrei	4		1		1	1		2		18				1	1		2		1			
G. hexagona	3											1					4		2			
Globigerinita glutinata	5	1		1	1	2	14	10	5		9	1	4	13	9		18		11			
G. humilis							2	3						2	2		8		3			
G. iota	1								1				2				1		2			
G. uvula	1																					
Orbulina universa																						
Pulleniatina obliquiloculata		1			1		1	1	1	20				2	1		1		1			
Sphaeroidinella dehiscens									1	7												
Candeina nitida																						
Miscellaneous	7				2		9			5	1		2	5	1		15		2			
Total	95	17	11	5	14	16	95	71	25	200	35	4	25	50	49	3	164	2	73			
Percent of benthonic Foram	22	35	35	28	37	11	1	16,5	37	<65	<28	20	19	2	9		18		<13	<28	20	<24
Benthonic foraminiferal Number	4,8	3	1,5	0,7	23	0,7	1	14		14		1	6	1	5		3			76	22	62
Planktonic foraminiferal Number	16	57	28	17	47	53	95	71	25	>200	35	4	25	50	50	3	164	2	73	>200	90	>200

Species \ Sample (cm)	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195
Globigerina bulloides			1				2		3		3		1		5	4	2	1	5	1				
G. calida					1				1		1		1	2										
G digitata																						1		
G falconensis					1		2		1		2		1	1			3		2					
G pachyderma			1		1				2		1			1			1	5	1	5		2		
G quinqueloba															1									
G rubescens			1		1		1	1	1				2		3	1	5		2					
Globigerinella siphonifera									1										1					1
Globigerinoides conglobatus					1												1			1				
G. sacculifer				1	1	1		3							1		3				1	1		1
G. ruber			5		10	1	3	8	5	2	13	[illegible]	4	3	18	1	16	2	9		1	1		1
G. tenellus					1		2	1	2		1				3		10	1	4					
Globorotalia crassaformis					1	1											2		1	1		1		
G menardii					1	1									3		2	5	2	4		1		2
G. inflata			1		1	1	1				2						3							
G. hirsuta															3		1		2					
G pumilio																								
G. scitula																	1							
G truncatulinoides											1						1							
G tumida			1												1		1	43		42	1	41	2	59
Globoquadrina conglomerata											1				1							1		
G. dutertrei					2		1				1				1		1	3	1			2		2
G. hexagona					1						1					8			2					
Globigerinita glutinata			1		4		2	3	7		4	1	3	1	5	4	18	1	8	2	2	2	2	1
G. humilis					1				1		2						6		2					
G. iota															1				1				1	
G. uvula																								
Orbulina universa															1									
Pulleniatina obliquiloculata										1										4		2		5
Sphaeroidinella dehiscens																				1				1
Candeina nitida																								
Miscellaneous								1	2		3						6		1					
Total			11	1	28	5	14	17	26	3	36	2	12	8	47	18	83	61	44	61	5	55	5	73
Percent of benthonic Foram	6	44	83	80	<35	75	<6,6	10,5	7	25	<3		17	27	<2	18	<12		60		94		95	
Benthonic foraminiferal Number	2	17	1	4		12		2	2	1			2	3		4		>74	64	>123	77	>119	90	>181
Planktonic foraminiferal Number	31	72	11	1	28	5	14	17	26	3	36	2	12	8	47	18	83	61	44	63	5	61	5	74

Species \ Sample (cm)	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	310	315
Globigerina bulloides			1	29	1	2				1			1	1	1	4			2	2		1	1	1
G. calida				8								1				1				1				
G digitata				1										1										
G falconensis				1		1										1	1							1
G pachyderma				5	1									4		2		2		2				
G quinqueloba									1															
G rubescens				3	1						2			1		2	2	1		2		1		3
Globigerinella siphonifera				5									1	2										
Globigerinoides conglobatus				3						1													1	
G. sacculifer				12						1				2	1	2		3					1	1
G. ruber	1	1	3	29	3		2	1		1	2	1	1	4	2	4	2	4	3	1		3	2	8
G. tenellus			1	1	1			1		1	1						1	1	2	1		1		4
Globorotalia crassaformis				3								2					1	1		1				
G menardii				22		1		1		1		1	1	4		8	1	2		1		2	2	
G. inflata											1						1				1	1		1
G. hirsuta															1									
G pumilio																								
G. scitula				1														2						
G truncatulinoides				2															1					
G tumida		1		1		21		18		16		23		36		29		25		16		13		
Globoquadrina conglomerata				12														1						
G. dutertrei				15		3		3		1		4	1	4		5		4		3		2		
G. hexagona				8										1		1				1		1		
Globigerinita glutinata		1		17		1	2		1			2		1	1	3	1	1	1	2			1	
G. humilis	1			1																				
G. iota				3															1					
G. uvula															1									
Orbulina universa				4														1		3		3		
Pulleniatina obliquiloculata				11						3				1		5		3		1		1		
Sphaeroidinella dehiscens				1		3								2		1								
Candeina nitida																								
Miscellaneous			1	1																		1		1
Total	2	3	6	200	7	32	4	24	2	26	6	34	5	64	7	68	10	51	10	37	1	30	8	20
Percent of benthonic Foram	33	50		<24	87	64	90	74	94	72	90	77	93	67	59	69	68	69	57	65	94	79	84	47
Benthonic foraminiferal Number	1	3		5	46	57	35	74	30	67	64	112	77	131	10	154	21	111	13	65	16	115	42	19
Planktonic foraminiferal Number	2	3	6	>200	7	32	4	25	2	26	7	34	5	64	7	66	10	51	10	37	1	30	8	20

Table 20. Distribution of plan

Species	Sample (cm)	Pilot core																													
		Top	10	20	30	40	50	Top	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
Globigerina	bulloides	14	2	2	1	1	4	4	8	4	6	2		2	7	1		6	1	9						1				2	
G.	calida	3						2				1			1			4		2								1			
G.	digitata								1		3																				
G.	falconensis	1	1					5	1	3	1	1		1		3		10		4								1		2	
G.	pachyderma								3		1				1	2				1						1		1			
G.	quinqueloba																	1													
G.	rubescens	13	1				1	6	6			7		1	3	5		12		5						1		1		1	1
Globigerinella	siphonifera							1	1		6			1	2																
Globigerinoides	conglobatus				1			1			3					1	1	3										1			
G.	sacculifer	2	3		1		1				1	1		1	2			1									1	1	1		3
G.	ruber	28	5	3		5	4	38	22	6	4	9	1	5	9	18	1	48	1	15						5		10	1	3	8
G.	tenellus	8	1	3	1		2	5	6	2		2		1		4	1	22		4								1		2	1
Globorotalia	crassaformis	1						2	1					2				1		4								1	1		
G.	menardii	1	1			1	1		4	1	95	1	1		1			5		3								1	1		
G.	inflata	2	1	1		1		2	1	1								1		2						1		1	1	1	
G.	hirsuta											1						1		2											
G.	pumilio																														
G.	scitula																														
G.	truncatulinoides	1		1		1		1	1																						
G.	tumida										27			2		1										1					
Globoquadrina	conglomerata										3				1																
G.	dutertrei	4		1		1	1		2		18				1	1		2		1								2		1	
G.	hexagona	3											1					4		2								1			
Globigerinita	glutinata	5	1		1	1	2	14	10	5		9	1	4	13	9		18		11						1		4		2	3
G.	humilis							2	3						2	2		8		3								1			
G.	iota	1								1				2				1		2											
G.	uvula	1																													
Orbulina	universa																														
Pulleniatina	obliquiloculata		1			1		1	1	1	20				2	1		1		1											
Sphaeroidinella	dehiscens									1	7																				
Candeina	nitida																														
Miscellaneous		7				2		9			5	1		2	5	1		15		2											1
Total		95	17	11	5	14	16	95	71	25	200	35	4	25	50	49	3	164	2	73						11	1	28	5	14	17
Percent of benthonic Foram		22	35	35	28	37	11	1	16.5	37	<65	<28	20	19	2	9		18		<13	<28	20	<24	6	44	83	80	<35	75	<6.6	105
Benthonic foraminiferal Number		4.8	3	1.5	0.7	23	0.7	1	14		14		1	6	1	5		3			76	22	62	2	17	1	4		12		2
Planktonic foraminiferal Number		16	57	28	17	47	53	95	71	25	>200	35	4	25	50	50	3	164	2	73	>200	90	>200	31	72	11	1	28	5	14	17

ktonic Foraminifera in core Ka-18

Piston core

120	125	130	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	310	315
3		3		1		5	4	2	1	5	1							1	29	1	2				1			1	1	1	4			2	2		1	1	1
1		1		1	2														8								1				1				1				
													1						1										1										
1		2		1	1			3		2									1		1										1	1							1
2		1			1			1	5	1	5		2						5	1									4		2		2		2				
						1																		1															
1				2		3	1	5		2									3	1						2			1		2	2	1		2		1		3
1										1					1				5									1	2										
								1			1								3						1													1	
						1		3				1	1		1				12						1				2	1	2		3					1	1
5	2	13	'	4	3	18	1	16	2	9		1	1		1	1	1	3	29	3		2	1		1	2	1	1	4	2	4	2	4	3	1		3	2	8
2		1				3		10	1	4								1	1	1			1		1	1						1	1	2	1		1		4
								2		1	1		1						3								2					1	1		1				
						3		2	5	2	4		1		2				22		1		1		1		1	1	4		8	1	2		1		2	2	
		2						3																		1						1				1	1		1
						3		1		2																				1									
								1											1														2						
		1						1											2															1					
						1		1	43		42	1	41	2	59		1		1		21		18		16		23		36		29		25		16		13		
		1				1							1						12														1						
		1				1		1	3	1			2		2				15		3		3		1		4	1	4		5		4		3		2		
		1					8			2									8										1		1				1		1		
7		4	1	3	1	5	4	18	1	8	2	2	2	2	1		1		17		1	2		1			2		1	1	3	1	1	1	2			1	
1		2						6		2						1			1																				
						1				1				1					3															1					
																														1									
						1													4														1		3		3		
	1										4		2		5				11						3				1		5		3		1		1		
											1				1				1		3								2		1								
2		3						6		1								1	1																		1		1
26	3	36	2	12	8	47	18	83	61	44	61	5	55	5	73	2	3	6	200	7	32	4	24	2	26	6	34	5	64	7	60	10	51	10	37	1	30	8	20
7	25	<3		17	27	<2	18	<12		60		94		95		33	50		<24	87	64	90	74	94	72	90	77	93	67	59	69	68	69	57	65	94	79	84	47
2	1			2	3		4		>74	64	>123	77	>119	90	>181	1	3		5	46	57	35	74	30	67	64	112	77	131	10	154	21	111	13	65	16	115	42	19
26	3	36	2	12	8	47	18	83	61	44	63	5	61	5	74	2	3	6	>200	7	32	4	25	2	26	7	34	5	64	7	66	10	51	10	37	1	30	8	20

Table 21. Distribution of planktonic Foraminifera in core Ka-15

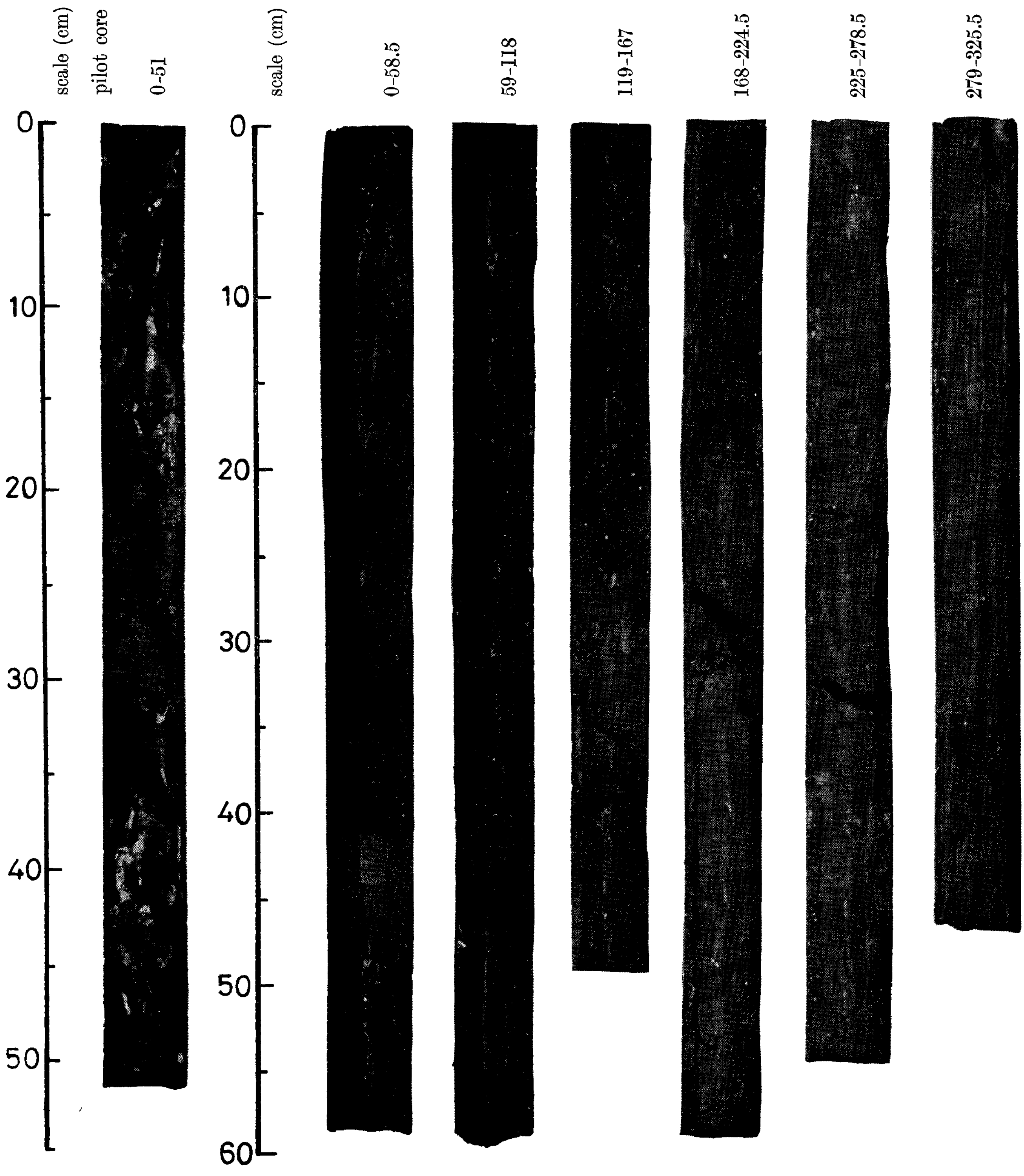
Species \ Sample(cm)	B.S.	Top	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Globigerina bulloides	11 5				5 2	6 2	6 4			13 4	10 2	3 1		3 2	10 3	3 3				2		1 1
G. calida	2 1					1 1	3 2	1		2 1					2							1
G. digitata					2 2		4 4	1		2 1	3 3	1										
G. falconensis											1										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	
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		
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
Benthonic Foraminifera	35	3	0	6	12	4	3	8	0	24	1000	50	0	19	13	5	0	16	0	2	6	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
Foraminifera No. Benthonic	10	3		6		4		8		384		50		19		5		16		2		1
Foraminifera No. Planktonic	10	16		30		200		31		1032		109		44		49		22		8		2

Species \ Sample(cm)	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205
Globigerina bulloides							24 8	5 3	12 3				1 1				13 5	3 1	4 1		
G. calida								1	3 1								8 4		7 5		
G. digitata									1												
G. falconensis							6 3	1	8 3								1	1 1	4 4		
G. pachyderma							4 2		1 1				1				2 2		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		
Globigerinella siphonifera													2				2	3	1		
Globigerinoides conglobatus													1				2 1				
G. sacculifera													1 1				17 7		1	2 1	1 1
G. ruber							2 1		2 1				8 2	1			26 11	4 1	54 29	1	
G. tenellus													2				1	2	3		
Globorotalia crassaformis																	2 2		1 1	1 1	
G. menardii							2	13 1	30 1				3	3			25		14	1	
G. inflata																					
G. hirsuta							1	3 1	4 1										3 2		
G. pumilio								4 1										1			
G. scitula							5 4	4 4	15 14								1 1		1 1		
G. truncatulinoides																					
G. tumida																	5		1	10	12
Globoquadrina conglomerata																	11 7	1 1	4 3		
G. dutertrei							49 47	23 20	32 31				3 3	2 2			24 24		16 16	2 2	
G. hexagona						1	9 5	5 3	5 2					1 1			1 1		7 5		
Globigerinita glutinata				1 1		1 1	43 13	79 39	34 17	3 1			6 2			1	36 20	5 4	55 29	1	
G. humilis													7 6								
G. iota							9 4		3 3				1 1				1		1 1		
G. uvula							7 1	3 2	6 3												
Orbulina universa																					
Pulleniatina obliquiloculata								1					1 1	1			13 13		10 10	1 1	1 1
Sphaeroidinella dehiscens																					
Candeina nitida																					
Miscellaneous							23	20	13	3			3						3		
Total	0	0	0	1	0	2	195	200	177	7	0	0	54	8	0	1	200	21	200	19	14
Benthonic Foraminifera	0	0	0	0	0	1	63	53	37	2	0	0	5	7	0	9	20	1	5	58	50
Percent of benthonic Foram.						33.3		26.7		22.2		50		46.5		90		4.5		75.4	
Foraminifera No. Benthonic		0		0		1		204		2		1		7		9		1		58	
Foraminifera No. Planktonic		0		1		2		572		7		1		8		1		21		19	

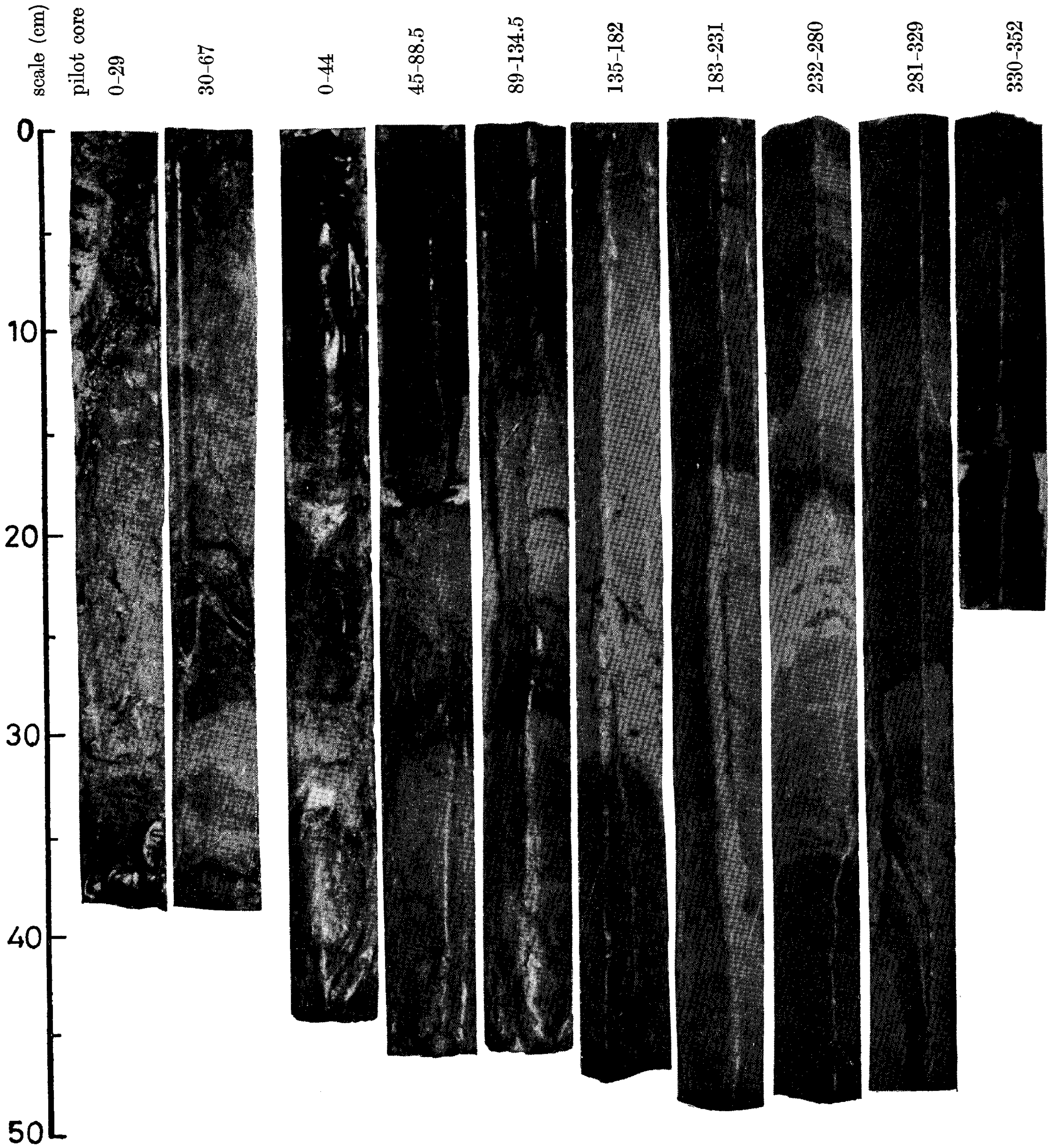
Species \ Sample(cm)	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305
Globigerina bulloides		14 6	11 5	1		1 1		5 3	3 3	12 2	12 2	17 7	2 1			1		18 7	2 2	
G. calida		7 4	1 1							6 2		6 4		1				1 1		
G. digitata						1 1		1 1						6 4						1 1
G. falconensis			1 1		9 9						2 2	1 1								
G. pachyderma						8 8		10 10		3 3	2 2	2 2	13 13	2 1			1 1		1 1	2 2
G. quinqueloba																				
G. rubescens		11 6	1	3 1		1				17 9	1	6 4		1 1				9 5	11 7	
Globigerinella siphonifera		2				3		4		1		8		6				3	1	1
Globigerinoides conglobatus	1										1 1	1 1		6 2					1 1	
G. sacculifera		4 1	1		1 1	1		7 5		2 1	9 2	12 4	2 1					2 2	2 1	
G. ruber	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	4	1	4	2						8	3	1						3		
Globorotalia crassaformis		2 2	1 1		1	2 2		1 1		1 1	5 3	1 1	5	10 1		1		2 2	1	
G. menardii	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		2 1	1 1								2 2							1		
G. pumilio																				
G. scitula				1 1						1 1		1 1								
G. truncatulinoides																				
G. tumida		1			38	90	12	39		1	3	1	77	73	4	3	1	2	1	5
Globoquadrina conglomerata		2 2	2 1			3 1		8 5	3	3 2	5 4	14 7		4 3				1 1		
G. dutertrei	7 7	24 24	3 3	1 1	3 3	10 10	1 1	16 16	4 4	21 21	20 20	14 14	5 5	25 25	1 1	2 2		11 11	1 1	2 2
G. hexagona		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	25 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		1	4 2							2		1						4	2 1	
G. iota		1								1		3 2				1		1	1	
G. uvula												1								
Orbulina universa		3						1												
Pulleniatina obliquiloculata		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	14		3		1		1		2	2	2	1	5			1		4	5	
Total	80	200	75	32	67	134	15	200	16	200	186	200	134	200	6	14	8	178	69	23
Benthonic Foraminifera	9	3	1	1	87	36	31	46	2	12	5	6	112	52	37	10	6	20	16	14
Percent of benthonic Foram.	10		1.3		56.5		67.3		11.1		2.6		45.5		86		42.8		18.8	
Foraminifera No. Benthonic	9		1		87		31		2		5		112		37		6		16	
Foraminifera No. Planktonic	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.

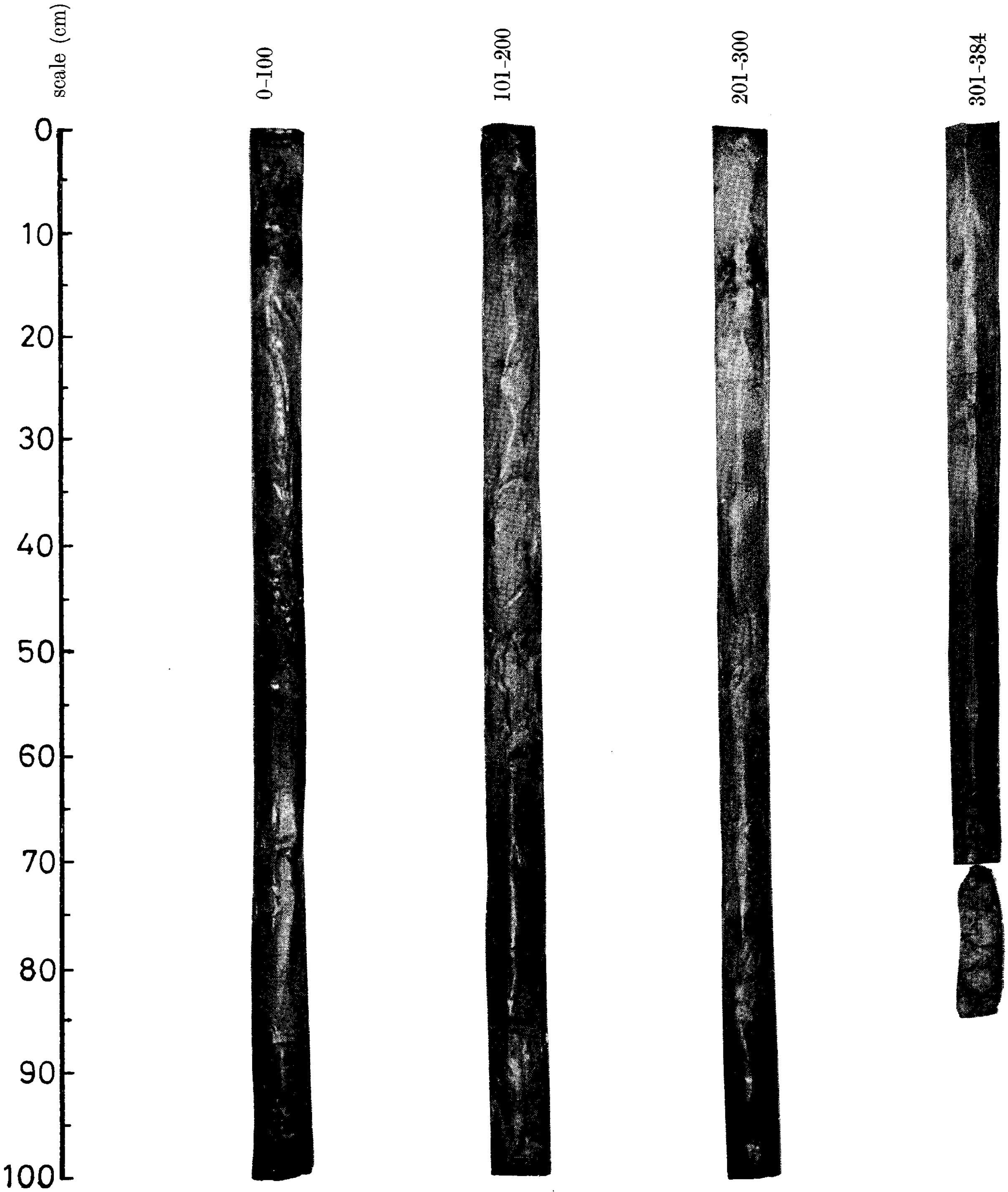
Longitudinal sections of the Core IC-3



Longitudinal sections of the Core IC-4



Longitudinal sections of the Core IC-5



Longitudinal sections of the Core IC-6