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Ecological Analysis of Benthonic Foraminifera in Kagoshima Bay, South Kyūshū, Japan

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Abstract

The assemblages of benthonic foraminifera in Kagoshima Bay, South Kyūshū, Japan were quantitatively analyzed from a paleoecological point of view.

Eighty-six of 146 bottom surface samples collected by gravity corer (PHLEGER's bottom sampler) were used for the ecological analysis of benthonic foraminifera. Living specimens were discriminated by the Rose Bengal staining method. One hundred and thirty-six samples were used for the mechanical analysis (EMERY settling-tube and pipette settling methods). Oceanographic observation on Kagoshima Bay has been carried out in alternate months from 1975 through 1979 by the staff of the Faculty of Fisheries, Kagoshima University. Those data were used for scrutinizing the environmental factors concerning the sea water characteristics in the area.

The intensity and direction of the bottom currents were inferred from the results of mechanical analyses of the bottom sediments and the oceanographic data. For all the species of which living specimens were recognized to occur, the ratio of the number of living specimens to the total (dead and living) number of individuals (L/Tl value) was calculated. Based on the L/Tl value, the relative rate of sedimentation at each sampling station was estimated. It has been pointed out that the L/Tl value well corresponds to the sedimentary environment inferred from the bottom current movement and the distribution of sediments, and it is a good index for sedimentary environment (ŌKI, 1986b, 1988). Taking the L/Tl value into consideration, the distribution patterns of number of individuals of planktonic foraminifera, of radiolaria and of benthonic foraminifera were illustrated (Figs. 19, 20 and 24). Further, the ratio of planktonic foraminifera to the total foraminifera was calculated on each sample and was discussed in relation to water depth.

The total (dead and living) benthonic foraminiferal specimens were divided into six groups through the cluster analysis (DAVIS, 1973) based on the percentage frequency data. The relationship between each clustered group and the environmental condition of its distribution area was discussed.

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Based on the oceanographic data, results of mechanical analyses of bottom sediments and of cluster analysis of benthonic foraminifera, the following five populations of benthonic foraminifera corresponding to the distribution of the water masses were discriminated.

1) Population A: Inhabiting the area under the influence of the open-sea water mass. Predominant species are *Cibicidoides pseudoungerianus, Globocassidulina oriangulata, Paracassidulina quasicarinata, Florilus pauperatus* and *Discorbis mira*.

2) Population B: Inhabiting the area under the influence of the hyposaline water mass. Predominant species are *Cymbaloporetta hemisphaerica, Buliminella elegantissima, Bolivina ordinaria, Protelphidium schmitti* and *Pseudononion japonicum*.

3) Population C: Inhabiting the boundary area between the water masses different in salinity from each other. Predominant species are *Uvigerina vadescens, Bulimina marginata* and *Globocassidulina oriangulata*.

4) Population D: In habiting the basin bottom under the influence of relatively stagnant water mass slightly mixed with the open-sea water. Predominant species is *Bulimina marginata*.

5) Population E: Inhabiting the basin bottom under the influence of the water mass being stagnant through the year and scarcely exchanged with the open-sea water. Predominant species is *Eggerella scabra*.

These populations of benthonic foraminifera in Kagoshima Bay were compared with the similar ones hitherto reported from the seas around Japan.

All the species treated here including twelve new species and two subspecies were described systematically.

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Introduction

The ecological studies on benthonic foraminifera started by PHLEGER and WALTON in the early 1950's have been successfully continued by many authors. Since the discrimination of living specimens by dyeing the protoplasm became possible, even seasonal changes of living population have been studied in detail (LUTZE, 1968; DANIELS, 1970, etc.). The international sysmposium (BENTHONICS '75) held in Halifax, Canada in 1975 has promoted the studies on benthonic foraminifera throughout the world.

In Japan, ecological studies on the Recent foraminifera also started in the early 1950's by ISHIWADA (1950), KUWANO (1953, 1954), NAGAHAMA (1951, 1954) and TAKAYANAGI (1955) and continued by MATSUDA (1957), ISHIWADA (1958, 1964), KUWANO (1962, 1963), UCHIO (1962b), CHIJI and LOPEZ (1968), CHIJI and KONDA (1970), IKEYA (1970, 1971, 1977), MATOBA (1970, 1975, 1976a-c) and MATOBA and NAKAGAWA (1972). Paleoecological studies on the fossil foraminifera in comparison with the Recent foraminifera were carried out by AOSHIMA (1978) and HASEGAWA (1979). During the 55 years from 1925 to 1981, 79 articles dealing with the Recent benthonic foraminifera have been published (NOMURA, 1981-1982). However, only a few papers among them are concerned in the relation between population and environmental condition. Another difficulty is that, as MATOBA (1970) already mentioned, the differences in methods of sampling and of treating samples between the authors have brought about a problem in comparing the populations.

To get fundamental data on the ecology of the benthonic foraminifera of shallow water areas around southern Kyūshū, and at the same time, to determine a method of population analysis, I have continuously studied the Recent foraminiferal specimens preserved in the bottom sediments of Kagoshima Bay in South Kyūshū since 1977. Fortunately, oceanographic data on Kagoshima Bay sufficient for the present study have been accumulated by the staff of the Faculty of Fisheries, of Technology and of Science, Kagoshima University.

In the present article, assemblage of benthonic foraminifera (Tables 11 and 12) is treated from the paleoecological point of view and the systematic description of them is also given. The writer wishes to utilize the results of the present study as the fundamental information for the paleoecological analyses of fossil assemblages of foraminifera in future.

Acknowledgements

I will take this opportunity to express my deep gratitude to Professor Yokichi TAKAYANAGI of the Institute of Geology and Paleontology, Tohoku University, who first introduced me to the study of foraminifera, for his contiguous guidance and supervision during the present study. Deep appreciation is due to Professor Shozo HAYASAKA of the Institute of Earth Sciences, Kagoshima University, who instructed me in his introduction to the actuopaleontological study on benthonic foraminifera and other related problems in the fields and laboratory, for his invaluable guidance and advice throughout the course of this study and reviewing the manuscript. I am also indebted to Professor Yasumochi MATOBA of the Institute of Mining Geology, Akita University, for his valuable suggestions concerning the classification of benthonic foraminifera.

Particular thanks are due to Dr. Kunihiro ISHIZAKI of the Institute of Geology and Paleontology, Tohoku University, for valuable suggestions concerning the statistical analysis of the foraminiferal assemblage; to Dr. Hiroyuki OTSUKA of the Institute of Earth Sciences, Kagoshima University, for his advice and help in field work; to Professor Tomio HENMI, the former captain of R.V. Keiten-maru; and to Associate Professor Seiji HIGASHIKAWA, the captain of R.V. Kagoshima-maru, both of the Faculty of Fisheries, Kagoshima University, for their kind help in field operations and their encouragement.

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Outline of Kagoshima Bay

1. Geography and climate

Kagoshima Bay occupies the central part of Kagoshima Prefecture, which is located in a quadrangle roughly outlined by the lines of 30° 59'N and 32° 11'N Lat. and 130° 06'E to 131° 12'E Long. (Fig. 1) and divided by the existence of the bay into the following three areas; the Hokusatsu area (northern part), the Satsuma Peninsula (southwestern part) and the Ōsumi Peninsula (southeastern part). Kagoshima Bay, lying between the Satsuma and the Ōsumi Peninsulas, is elongate and southward-opening with a length of about 75 km from north to south and a width of about 25 km. The coast-lines of both peninsulas are slightly sinuous and nearly parallel to each other.

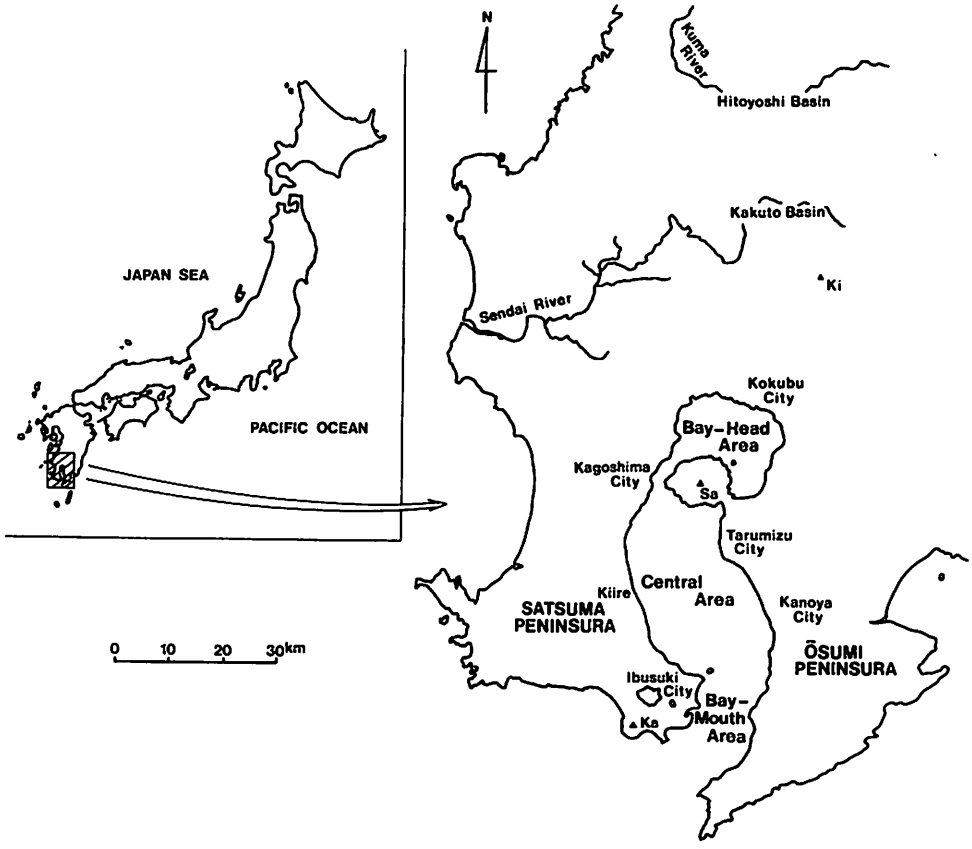

Fig.1. Index map of the studied area (Ki: Mt. Kirishima; Sa: Mt. Sakurajima; Ka: Mt. Kaimon-dake).

Sakurajima, a volcanic island connected to the northern part of the Ōsumi Peninsula to the east, is facing to Kagoshima City (population 500,000) across the West-Sakurajima Passage. Mt. Sakurajima, 1110 m in altitude, has continuously erupted since 1955 attended with heavy ash fall on the lee side neighbouring areas. The Kirishima massif composed of 23 Quaternary volcanic cones is situated to the north of Kagoshima Bay (the Hokusatsu area). Another group of Quaternary volcanoes (the Ibusuki volcanoes) is distributed in the southernmost part of the Satsuma Peninsula.

The climate of Southwest Japan, in which Kagoshima Prefecture is the southern extremity, has been classified as Humid Mesothermal (Subtropical) Climate (Finch and Trewartha, 1949). Temperature data through 30 years (1951-1980) in Kagoshima City indicate that the yearly mean temperature is 17.3 °C, mean temperature in winter is 8.1 °C and that in summer is 26.0 °C. The maximum temperature is in August when the daytime temperature frequently exceeds 30 °C. The highest yearly mean precipitation during the past 30 years (1951-1980) is 2374.6 mm, and the monthly mean precipitation is lowest in December (79.5 mm) and highest in June (474.7 mm), the rainy season in Japan (Kasamura, 1983).

2. Geologic setting

Many stratigraphic units distributed in South Kyūshū can be grouped into five major geological units as follows: 1) The Mesozoic and Palaeogene sedimentary rocks (the Shimanto and the Nichinan Groups) consist mostly of sandstone and shale, which form the basement of the area; 2) granitic rocks intruding into the basement rocks mentioned above (12-16 Ma); 3) The Neogene and Quaternary volcanic rocks and pyroclastic flow deposits; 4) Several late Quaternary pyroclastic flow deposits which resulted from the formation of caldera and the interbedded marine strata; and 5) The volcanic and pyroclastic rocks erupted from the volcanoes (the Kirishima Volcanoes, Sakurajima Volcano and the Ibusuki Volcanoes), of which activity started in the late Pleistocene and continues to the Recent times.

MATUMOTO(1943) proposed the existence of two gigantic calderas within Kagoshima Bay based on detailed studies on the topographic features and the pyroclastic flow deposits around the bay (Fig. 2). One is Aira Caldera at the bay head area and the other is Ata Caldera at the bay mouth area. He also mentioned that the steep slopes on both sides of the bay are fault scarps, so called caldera-walls. Based on his proposal, many geologists assumed that Kagoshima Bay is genetically related to the formation of these calderas. However, it has been recently proposed that Kagoshima Bay is ascribed to the formation of graben, namely "Kagoshima Graben", which is extended northward from the bay mouth area to Hitoyoshi Basin for a distance of about 110 km (OTA *et al.*, 1967; TSUYUKI, 1969; HAYASAKA and ŌKI, 1971; HAYASAKA, 1987). The graben probably formed after the Terukuni Pyroclastic Flow (2.90 ± 0.25 Ma age: SHIBATA *et al.*, 1978) which directly covers the basement rocks (the Shimanto Group). The present

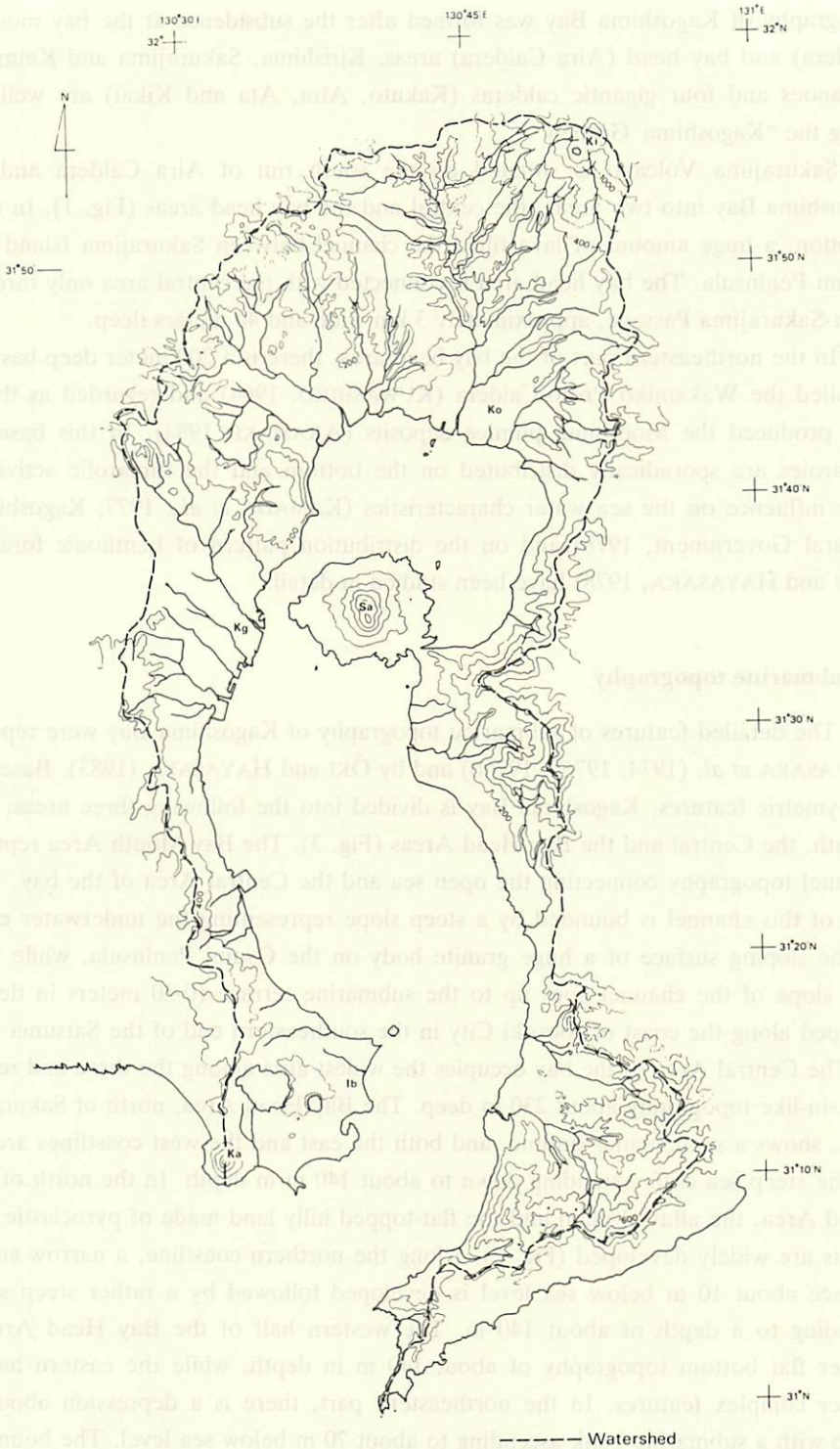

Fig. 2. Map showing the rivers flowing into Kagoshima Bay and their catchment area.

topography of Kagoshima Bay was formed after the subsidence at the bay mouth (Ata Caldera) and bay head (Aira Caldera) areas. Kirishima, Sakurajima and Kaimon-dake volcanoes and four gigantic calderas (Kakuto, Aira, Ata and Kikai) are well aligned along the "Kagoshima Graben".

Sakurajima Volcano is situated on the south rim of Aira Caldera and divides Kagoshima Bay into two areas, the central and the bay head areas (Fig. 1). In the 1914 eruption, a huge amount of lava filled the channel between Sakurajima Island and the Ōsumi Peninsula. The bay head area is connected with the central area only through the West-Sakurajima Passage, approximately 3 km wide and 40 meters deep.

In the northeastern part of the bay head area, there is a 200 meter deep basin which is called the Wakamiko Proto-Caldera (KUWASHIRO, 1964) and regarded as the crater that produced the Moeshima pumice deposits (ARAMAKI, 1984). In this basin, many fumaroles are sporadically distributed on the bottom and the fumarolic activities and their influence on the sea water characteristics (KAMADA *et al.*, 1977; Kagoshima Prefectural Government, 1978) and on the distribution pattern of benthonic foraminifera (ŌKI and HAYASAKA, 1978) have been studied in detail.

3. Submarine topography

The detailed features of submarine topography of Kagoshima Bay were reported by HAYASAKA *et al.* (1974, 1976a, 1976b) and by ŌKI and HAYASAKA (1983). Based on the bathymetric features, Kagoshima Bay is divided into the following three areas; the Bay Mouth, the Central and the Bay Head Areas (Fig. 3). The Bay Mouth Area represents a channel topography connecting the open sea and the Central Area of the bay. The east side of this channel is bounded by a steep slope representing the underwater extension of the sloping surface of a huge granite body on the Ōsumi Peninsula, while the west side slope of the channel goes up to the submarine terrace (0-20 meters in depth) developed along the coast of Ibusuki City in the southeastern end of the Satsuma Peninsula. The Central Area of the bay occupies the widest area among the three and represents a basin-like topography about 230 m deep. The Bay Head Area, north of Sakurajima Island, shows a semicircular outline, and both the east and the west coastlines are formed by the steep sea cliffs extending down to about 140 m in depth. In the north of the Bay Head Area, the alluvial plain and the flat-topped hilly land made of pyroclastic flow deposits are widely developed (Fig. 2). Along the northern coastline, a narrow submarine terrace about 10 m below sea level is developed followed by a rather steep slope descending to a depth of about 140 m. The western half of the Bay Head Area has a rather flat bottom topography of about 140 m in depth, while the eastern half shows rather complex features. In the northeastern part, there is a depression about 200 m deep with a submarine bank ascending to about 70 m below sea level. The boundary between the eastern and western parts of the Bay Head Area is represented by a step-like topography deepening from the west eastwards.

4. Oceanography

Oceanographic observations in Kagoshima Bay have been carried out in alternate months by the Faculty of Fisheries, Kagoshima University. The following is a summary of water temperature, salinity, DO, pH, transparency and the main current based on the unpublished data kindly offered by Prof. Koji NOZAWA of the Faculty of Fisheries, Kagoshima University and the data published by KAMADA *et al.* (1977).

(1) Water temperature

The ranges of temperature (°C) and salinity (‰) at each depth (0, 10, 25, 50, 75, 100, 150 and 200 m) throughout Kagoshima Bay are shown in Figure 4. Figure 4 shows that the water temperature decreases as depth increases and is rather stable throughout the year between 14-18 °C below 150 m. Further, the water temperature at a depth of 100 m is as stable as that at 150 m in depth showing 14-18 °C throughout the year. The water temperature at 100 m in depth in the Central and the Bay Head Areas is around 20°C in summer and autumn and it has a slight difference between winter and summer seasons. On the contrary, the temperature of water shallower than 75 m has rather large seasonal fluctuations; the results of observation carried out from 1975 through 1979 show a wide range from 14.2 to 30.2°C throughout the bay. In the Bay Mouth Area, however, the water temperature does not go below 16°C at the 25 m depth, 15°C at 10 m and 17°C at the sea surface even in winter. In February, the coldest period of the year, the water temperature in the Central and the Bay Head Areas becomes uniform from the surface to the bottom owing to a weak convection in the water mass of these areas (TAKAHASHI, 1981).

(2) Salinity

Although the salinity of water below 50 m tends to decrease from the Bay Mouth to the Bay Head Area, the differences between the three areas of the bay are very slight. Particularly, the salinity of the water below 150 m is very stable at 33.6 to 34.8‰ throughout the year (Fig. 4).

The ranges of the observed values of the salinity at the 50 m depth in each area are as follows:

Area	Salinity range (‰)
Bay Mouth	33.2 - 34.7
Central	33.1 - 34.8
Bay Head	32.9 - 34.3

The salinity of water shallower than 25 m was different from area to area and showed a wide seasonal fluctuation. The ranges of the observed values of salinity in each area in winter and summer are as follows:

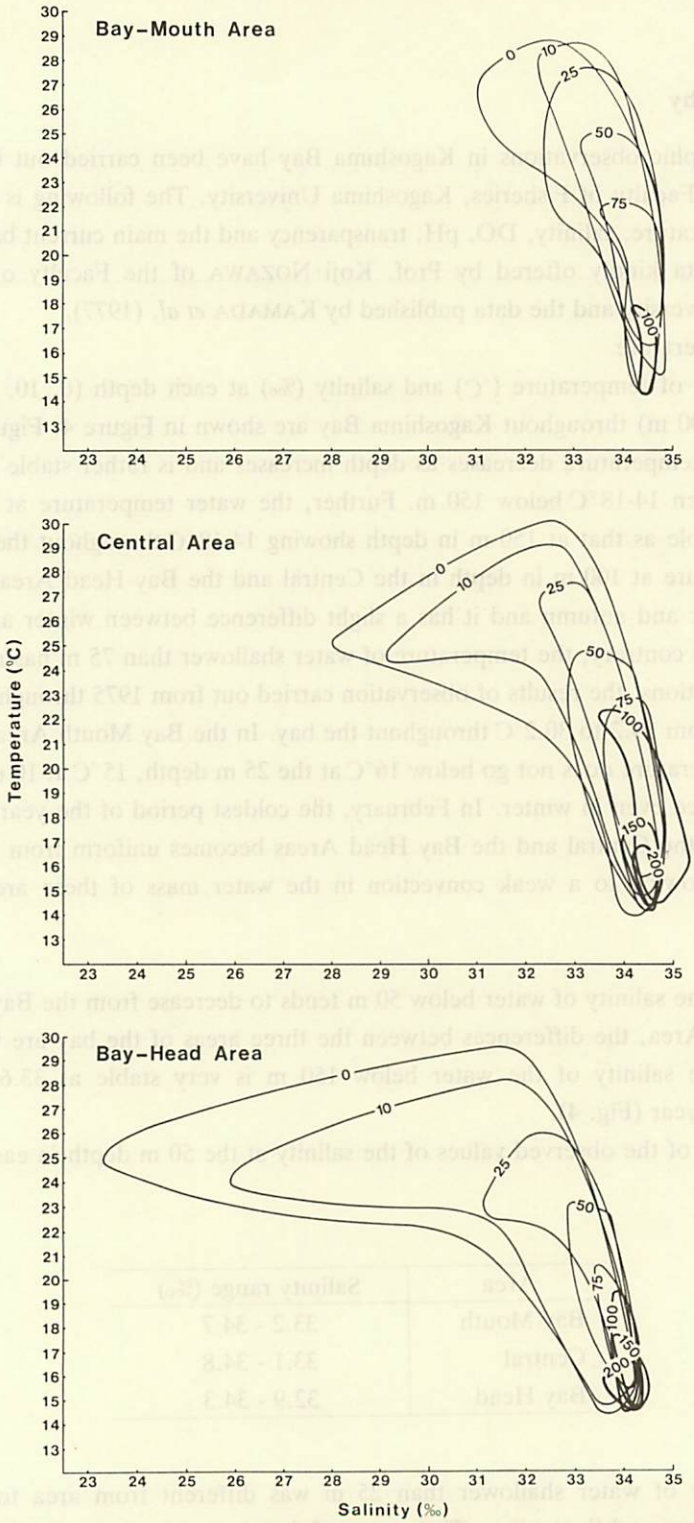

Fig. 4. Ranges of annual variation of water temperature and salinity at various depths (0, 10, 25, 50, 75, 100, 150 and 200 m)(Faculty of Fisheries, Kagoshima University, 1975-1977).

Area	Salinity range (‰)	
	Winter	Summer
Bay Mouth	34.0 - 34.9	31.2 - 34.0
Central	33.9 - 34.8	28.0 - 33.2
Bay Head	33.0 - 34.3	23.3 - 32.7

Although there is a tendency in winter for salinity to decrease toward the Bay Head Area, the values as a whole are not so different from that of open-sea water. In summer, however, the lowering of salinity toward the bay head is striking. Considering that this period of time is the rainy season or the season of heavy rain fall in this area and that the volume of water flowing into the Bay Head Area from the rivers is up to 50% of total volume of water flowing into the bay (Coastal Oceanography Research Committee, the Oceanographical Society of Japan, 1985), the lowering of salinity in the West-Sakurajima Passage and the Bay Head Area is thought to be the results of dilution of surface water by the fresh water supplied as rain and from the rivers flowing into these areas.

SAKURAI and MAEDA (1980) and NOZAWA and SAISHO (1980) studied the horizontal distribution of surface water salinity in the bay based on oceanographic observations made by the Faculty of Fisheries, Kagoshima University. According to them, the salinity of water in this bay is higher on the east side (the Ōsumi Peninsula side) than on the west side (the Satsuma Peninsula side). This tendency is particulaly remarkable in the summer when the water mass in the bay stratifies and the effect of the Kuroshio Current increases. This can be seen in the east- west profile of water salinity shown in Figure 5.

(3) Dissolved oxygen

The DO value is generally high from February through June and low from August through December. In the former period, the DO value ranges from 2.3 to 6.8 ml/l, and in the latter period, it ranges from 0.3 to 5.6 ml/l. The DO value of water shallower than 75 m in the former period, is always above 4.2 ml/l, and in the latter period, it is above 3.0 ml/l.

During the period from August through December, the mean DO values of water at every depth are as shown in Table 1.

As seen in Table 1, the DO values, as a whole, tend to decrease as the water depth increases, though a few partial inversions were observed. The lateral change in DO is not remarkable in the water shallower than 75 m. At more than 100 m however, it is rather distinct; the DO value decreases toward the bay head, and the stations where values of less than 2.5 ml/l were measured are restricted to the Bay Head Area. Especially the deep water in the 200 m deep basin in the Bay Head Area has very low DO values throughout the year except for the coldest season. Concerning this phenomena, KAMADA *et al.* (1977) mentioned that the exceptionally low DO values of water deeper than 100 m in the 200 m deep basin in the Bay Head Area may be caused by the con-

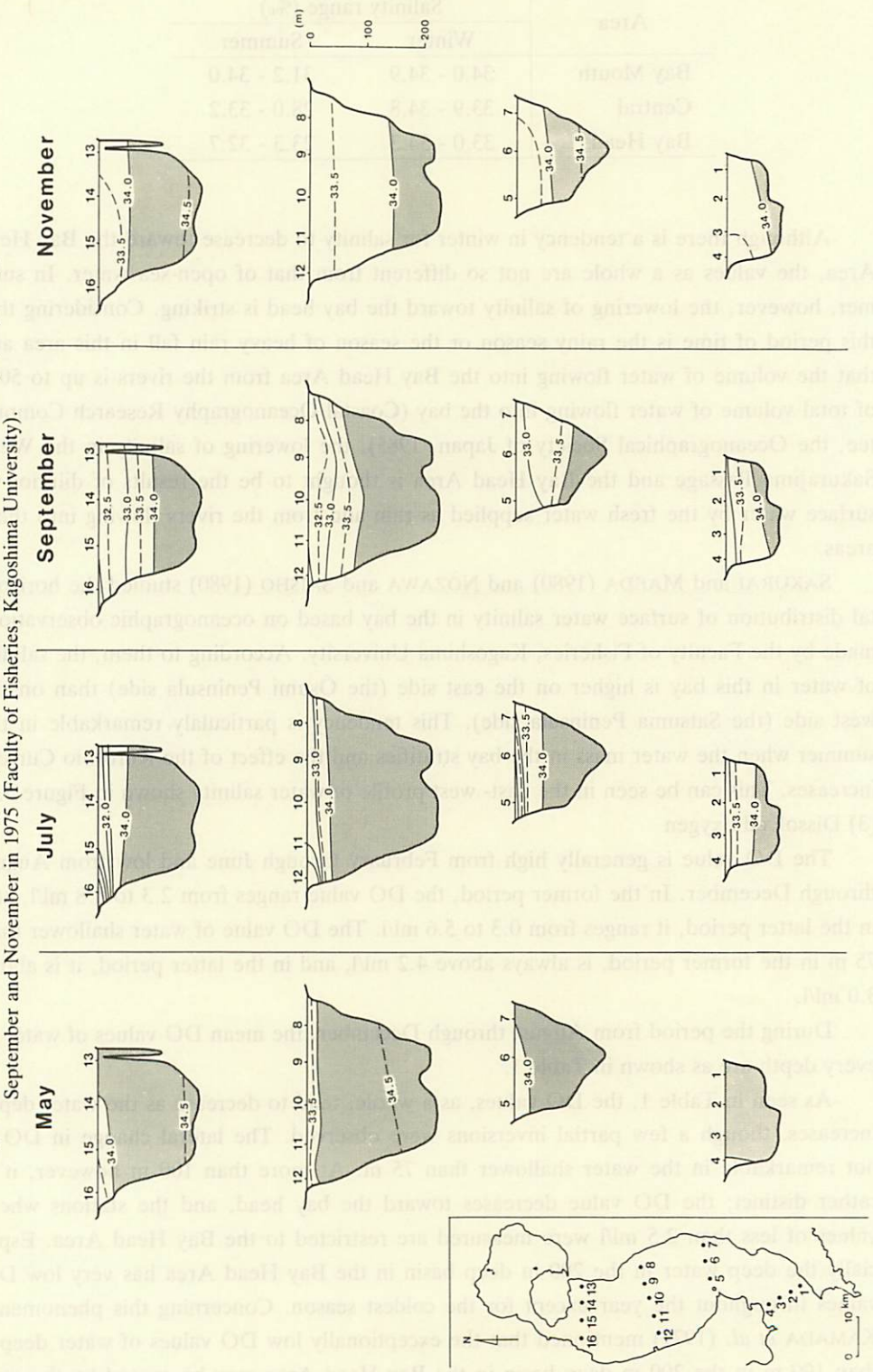

Fig. 5. Distribution of sea water salinity (‰) in the transverse profiles of Kagoshima Bay (May, July, September and November in 1975 (Faculty of Fisheries, Kagoshima University).

Table 1. Mean DO value measured at every depth of water during the period from August through December. The numerals in parenthesis are the mean values excepting the Bay Head Area. The minimum values indicate the strong influence of the extremely low DO value of the deep water in the Bay Head Area.

Depth (m)	DO value (ml/l)	
	Minimum value	Maximum value
0	3.64 (3.64)	5.58 (5.58)
10	3.63 (3.63)	5.48 (5.22)
25	2.81 (3.71)	5.40 (4.99)
50	2.80 (3.14)	5.22 (4.89)
75	1.88 (2.71)	4.34 (4.22)
100	1.96 (2.66)	5.29 (4.06)
150	0.58 (2.68)	5.09 (3.85)
200	0.28 (2.54)	3.70 (3.70)

sumption of oxygen through chemical reactions between sea water and reductive volcanic gases supplied from the fumaroles on the sea bottom of this area.

(4) pH value

The pH values measured through a year at every layer from the surface to the 200 m deep bottom in the Central Area of Kagoshima Bay ranged from 7.9 to 8.3. The pH value of the water in the Bay Head Area rapidly decreases as the depth increases from the 100 m depth layer resulting in an extraordinary low value less than 7.0 near the bottom (Fig. 6)*). This suggests the occurrence of an acidic water mass below 100 m in this area and the genesis of this acidic water mass is explained as follows.

According to the Kagoshima Prefectural Government (1978), the principal component of gases collected directly from fumaroles by submersible is carbon dioxide, which has been measured to be 75-93%. However, carbon dioxide has never been detected from gases collected from bubbles at the sea surface above the fumaroles. This may imply the perfect dissolving of carbon dioxide in the water on the way from the fumaroles at the 200 m deep bottom to the sea surface.

*) The lowest pH value (5.15) was observed near the fumaroles, and mercury, arsenic, montmorillonite, dolomite and stevensite were detected in the bottom sediment near the fumaroles (Kagoshima Prefectural Government, 1978).

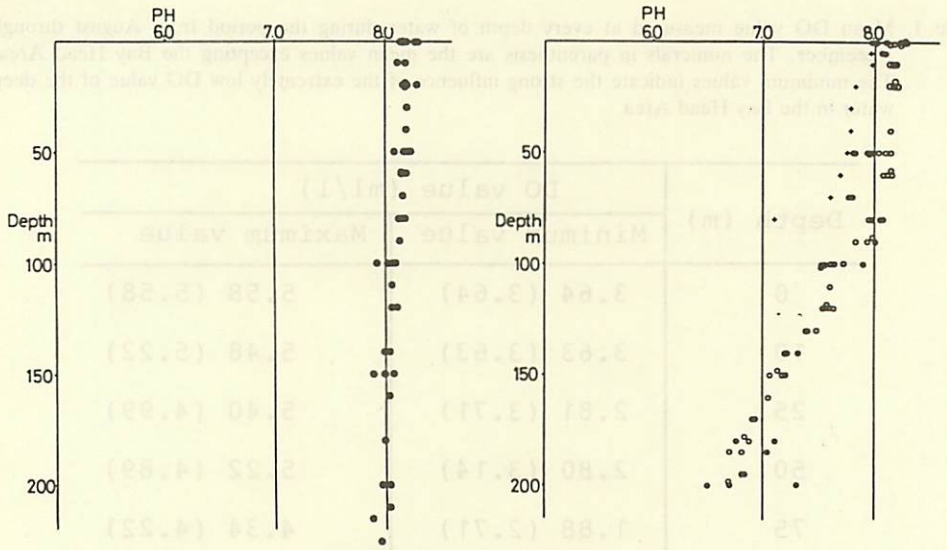

Fig. 6. Graph showing the relation between pH-value and depth of water at the Central (left) and the Bay Head (right) Areas through the period of sea-water layering from spring through autumn (after KAMADA *et al.*, 1977).

(5) Transparency

Generally speaking, the transparency of water in the Bay Head Area is lower than that in the Bay Mouth and the Central Areas. The values of transparency observed in each area is 4.0-22.0 m in the Bay Mouth Area, 2.0-18.1 m in the Central Area and 2.0-19.5 m in the Bay Head Area. In the Bay Mouth Area, transparency is rather stable and 92% of the observed values exceed 10 m. On the other hand, in the Central Area, values higher than 10 m represent only 32.3% of all the observed values. The same figures are strikingly low in the Bay Head Area showing only 12.5%. In winter the value of transparency is rather high ranging from 10.7 to 18.0 m and from spring to autumn it is rather low ranging from 2.0 to 22.0 m.

The available data along the east-west lines are restricted to those obtained in May, July, September and November, 1975, representing a period of low transparency. The mean values of the data obtained through the four times observation at each station provided the equivalent lines shown in Figure 7. In the Bay Mouth Area the values ranged from 13 to 18 m with the higher values in the eastern half (on the Ōsumi Peninsula side) than in the western half (on the Satsuma Peninsula side). In the Central Area, the 10 m equivalent line is drawn in the direction of NNE to SSW, namely, from off Tarumizu City on the Ōsumi Peninsula to off Kiiré-chō on the Satsuma Peninsula. In the vast area east of this line, values of about 12 m are known to occur, but, in the near-shore area along the coast from Kagoshima City to Kiiré-chō, west of the above-mentioned line, transparency rapidly decreases down to less than 6 m off Kagoshima City.

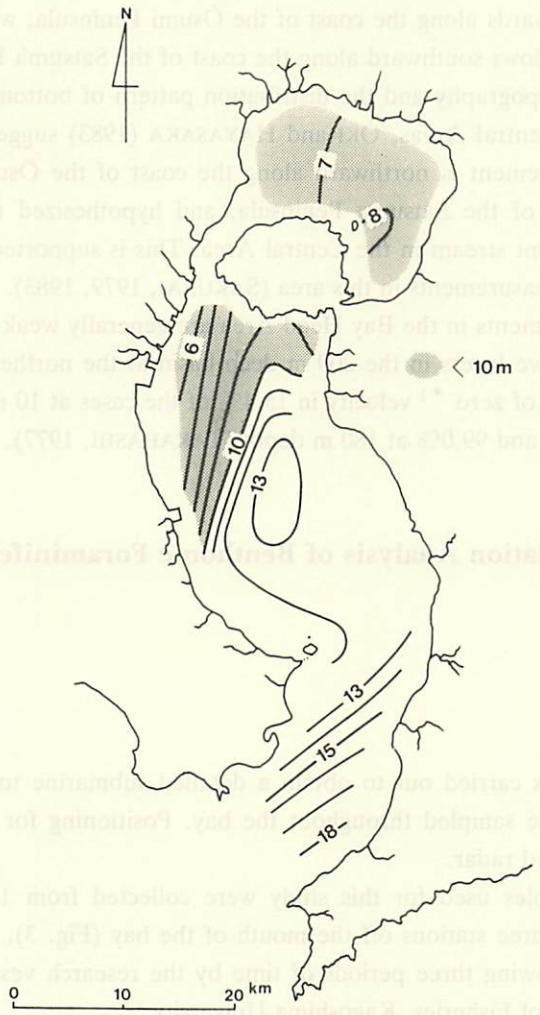

Fig. 7. Distribution of mean values (meter) of the water transparency through the period from May through November, 1975 (Faculty of Fisheries, Kagoshima University, 1975-1977).

(6) Main currents

The surface currents in the Central and the Bay Mouth Areas of Kagoshima bay were estimated based on the distribution pattern of the surface temperature, salinity and transparency obtained through the repeated observations for the past five years by the Faculty of Fisheries, Kagoshima University (SAKURAI and MAEDA, 1980). Based on the fact that the salinity of the water along the Ōsumi Peninsula is higher than that along the

Satsuma Peninsula regardless of season, SAKURAI and MAEDA (1980) concluded that the high salinity open-sea water enters into the bay along the east coast of the Bay Mouth Area and flows northwards along the coast of the Ōsumi Peninsula, while the low salinity embayment water flows southward along the coast of the Satsuma Peninsula. Judging from the submarine topography and the distribution pattern of bottom sediments in the Bay Mouth and the Central Areas, ŌKI and HAYASAKA (1983) suggested that the predominant current movement is northward along the coast of the Ōsumi Peninsula and southward along that of the Satsuma Peninsula, and hypothesized the presence of a counterclockwise current stream in the Central Area. This is supported by the results of the current velocity measurements in this area (SAKURAI, 1979, 1983).

The current movements in the Bay Head Area are generally weak. Current observations at four consecutive layers in the 200 m deep basin at the northeastern part of this area revealed currents of zero *) velocity in 15.4% of the cases at 10 m depth, 57.1% at 40 m, 38.4% at 100 m and 99.0% at 180 m depth (TAKAHASHI, 1977).

Population Analysis of Benthonic Foraminifera

1. Methods

(1) Field work

Echosounding was carried out to obtain a detailed submarine topography and the bottom sediments were sampled throughout the bay. Positioning for the sounding was determined by on-board radar.

The bottom samples used for this study were collected from 143 stations within Kagoshima Bay and three stations off the mouth of the bay (Fig. 3). The sampling was performed in the following three periods of time by the research vessel "Keiten-maru" owned by the Faculty of Fisheries, Kagoshima University.

20th-26th January, 1972	Bay Head Area (Stn. 1-65) and Bay Mouth Area (Stn. 106-142)
20th-22nd February, 1979	Central Area (Stn. 66-105)
4th August, 1978	Outside the bay (Stn. 143-146)

All samples were taken using PHLEGER's gravity corer. The top one centimeter of sediment core, approximately 10 cc of wet sediment, was cut off from each core and preserved in buffered formalin and Rose Bengal, a protein-specific dye for foraminiferal study. The main body of the core sample was wrapped in plastic to keep it from drying.

*) The current meter used here is designed so as to indicate zero value when the velocity is less than 1.2 cm/s.

(2) Laboratory work

A. Bottom sediments

Among 146 samples of bottom sediments collected by the gravity corer from the Kagoshima Bay area, all but ten were sufficient for mechanical analysis. Their upper three centimeters were divided lengthwise and halves were used for mechanical analysis (1 to 4 cm in depth from the surface; a volume of about 15 cc).

Gravels were collected by sieving and weighed in dry condition. The EMERY settling-tube method and pipette technique (KRUMBEIN and PETTIJONE, 1938) were utilized in determining the relative proportions of sand, silt and clay (Table 2); and the textural relations among sediments were plotted on SHEPARD's triangle. Median diameter (Md, Mdϕ), mud content (%), sorting coefficient (So, $\sigma\phi$), and skewness (Sk, $\alpha\phi$) were obtained graphically from the cumulative curve (TRASK, 1932; INMAN, 1952).

Further, based on the grain size composition (ϕ scale), a dendrogram was obtained through cluster analysis after DAVIS (1973), and the samples were grouped according to similarity indicated by the distance coefficient.

B. Foraminifera

The top one centimeter, which was cut off from the top of core sample and preserved in buffered formalin and Rose Bengal, was washed through a 200-mesh (0.074 mm openings) sieve, and ovendried after removal of dye stuff (Rose Bengal). Dry samples were split with a microsplitter to yield an aliquot containing more than 200 specimens. All specimens were then picked from the aliquot. Aliquots containing less than 200 individuals of benthonic foraminifera were supplemented by additional splits. Specimens were spread on a tray, and all specimens of benthonic species were identified and counted. Specimens of planktonic foraminifera and radiolaria within each aliquot were counted without specific identification. SEM micrographs were made of selected benthonic species using a JSM-25S11 (Nihon Denshi Co. Ltd.) at the Institute of Earth Sciences, Faculty of Science, Kagoshima University.

2. Bottom sediments analyses

The results of mechanical analysis of the 136 samples from Kagoshima Bay (Table 2) were already reported by ŌKI and HAYASAKA (1983) and its outline, including additional data, will be presented here along, with the results of a cluster analysis on them.

(1) Results of mechanical analysis

The median diameter (Mdϕ)(Fig. 8), mud content (%)(Fig. 9), sorting coefficient (So)(Fig. 10) and skewness ($\alpha\phi$)(Fig. 11) were determined and used to clarify the following:

a) General features of the bottom sediments in Kagoshima Bay are characterized in the Bay Mouth Area as being predominantly sand and gravel (Mdϕ : -2 ~ 4 ϕ) and in the Bay Head Area occupied by rather stagnant water as sandy or clayey silt. Therefore the bottom sediment character of each area is harmonized quite well with the mean

Table 2. Results of mechanical analysis of the bottom sediments.

Station	Latitude	Longitude	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mdφ	Md	Trask(1932) So	Trask(1932) Sk	Inman(1952) φ	Inman(1952) φ	Bottom Character
1	31°-42'5N	130°-39'2E	102	0.69	35.97	51.22	12.12	5.095	0.029	2.790	1.815	2.180	-0.125	Sandy Silt
2	31°-42'4N	130°-40'4E	135	0.27	47.75	38.51	13.47	4.147	0.056	3.926	0.708	2.761	0.195	Silty Sand
3	31°-42'7N	130°-41'9E	130	0.16	29.98	50.54	19.31	5.268	0.026	3.288	1.040	2.966	0.134	Sandy Silt
4	31°-42'6N	130°-42'9E	116	4.07	43.99	39.91	12.03	4.105	0.058	4.509	1.360	2.953	-0.046	Silty Sand
5	31°-41'6N	130°-37'9E	128	0	20.05	56.51	23.44	5.526	0.022	3.426	0.523	(2.619)	(0.307)	Sand-Silt-Clay
6	31°-41'9N	130°-38'7E	138	1.72	47.21	27.54	23.53	4.079	0.059	6.293	0.284	(3.605)	(0.365)	Sand-Silt-Clay
7	31°-42'0N	130°-40'0E	144	5.05	76.91	11.63	6.42	2.158	0.223	2.040	0.804	1.695	0.267	Sand
8	31°-41'9N	130°-41'3E	146	0.28	18.96	58.75	22.01	6.047	0.015	2.974	1.063	2.684	0.100	Clayey Silt
9	31°-41'9N	130°-42'3E	136	0.05	19.70	54.82	25.43	6.026	0.015	3.448	0.695	(2.708)	(0.110)	Clayey Silt
10	31°-41'7N	130°-43'5E	120	0	25.70	59.17	15.13	4.911	0.033	2.143	0.812	1.711	0.068	Sandy Silt
11	31°-41'6N	130°-44'6E	117	0.36	16.79	75.12	7.74	4.579	0.042	1.414	0.889	0.798	0.221	Silt
12	31°-41'5N	130°-45'7E	122	0.90	25.01	57.93	16.16	4.984	0.032	2.968	0.483	2.442	0.242	Sandy Silt
13	31°-41'5N	130°-46'7E	124	0	28.93	59.81	11.26	4.784	0.037	1.892	0.970	1.263	0.088	Sandy Silt
14	31°-41'2N	130°-38'9E	148	0	29.05	51.68	19.27	5.521	0.022	3.818	1.068	2.890	-0.027	Sandy Silt
15	31°-40'8N	130°-40'1E	152	0.38	26.51	54.14	18.97	5.832	0.017	3.399	1.490	2.703	-0.071	Sandy Silt
16	31°-40'8N	130°-41'1E	150	0.15	17.31	59.06	23.49	6.395	0.012	3.080	1.036	(2.513)	(-0.041)	Clayey Silt
17	31°-40'9N	130°-42'3E	146	0.44	25.28	54.82	19.46	5.753	0.018	3.266	1.134	2.748	-0.044	Sandy Silt
18	31°-41'1N	130°-43'5E	136	0	18.51	65.62	15.88	5.579	0.021	2.321	0.852	2.087	0.142	Sandy Silt
19	31°-41'0N	130°-44'6E	154	0	34.11	56.05	9.85	4.484	0.044	1.852	1.420	1.447	-0.225	Sandy Silt
20	31°-40'9N	130°-45'8E	176	7.78	23.89	56.34	11.99	4.553	0.04	1.902	1.248	1.729	0.035	Sandy Silt
21	31°-40'9N	130°-46'9E	185	0	9.43	79.80	10.77	4.647	0.04	1.178	0.974	0.561	0.427	Silt
22	31°-40'3N	130°-37'3E	144	0	14.97	49.10	35.94	6.658	0.010	(4.0	) (0.367)	(2.566)	(0.077)	Clayey Silt
23	31°-39'9N	130°-37'7E	148	0.36	14.56	63.92	21.17	6.484	0.011	2.561	1.131	2.129	-0.102	Clayey Silt
24	31°-39'8N	130°-39'0E	156	0.26	31.02	44.33	24.39	5.895	0.017	4.880	1.543	(3.15	) (-0.053)	Sand-Silt-Clay
25	31°-39'9N	130°-40'3E	152	0.41	35.18	33.36	31.05	5.947	0.016	(8.660)	(1.035)	(3.611)	(-0.063)	Sand-Silt-Clay
26	31°-39'9N	130°-41'1E	150	0	25.26	44.07	30.69	6.395	0.012	(4.743)	(1.267)	(3.053)	(-0.112)	Sand-Silt-Clay
27	31°-40'0N	130°-43'4E	140	1.02	21.53	42.00	35.45	7.184	0.007	(2.822)	(1.255)	(2.919)	(-0.372)	Sand-Silt-Clay
28	31°-40'1N	130°-44'4E	143	9.03	53.45	31.32	6.20	2.326	0.199	5.809	0.550	3.079	0.113	Silty Sand
29	31°-40'0N	130°-45'6E	230	0	12.18	46.56	41.26	6.579	0.011	(3.525)	(0.337)	(2.500)	(0.162)	Clayey Silt
30	31°-40'1N	130°-47'1E	225	0	5.68	91.26	3.06	5.795	0.018	2.152	0.661	1.442	0.230	Silt
31	31°-38'6N	130°-37'0E	140	0	22.33	32.85	44.81	7.484	0.006	(5.283)	(2.729)	(3.053)	(-0.341)	Sand-Silt-Clay
32	31°-38'9N	130°-37'8E	156											
33	31°-38'9N	130°-39'0E	152	0.18	54.17	26.39	19.34	3.584	0.086	4.697	0.138	3.003	0.599	Silty Sand
34	31°-38'8N	130°-40'1E	149											
35	31°-38'9N	130°-42'4E	140	0.32	19.28	24.78	55.63	8.789	0.002	(5.41	) (8.98	) (3.140)	(-0.691)	Silty Clay
36	31°-38'9N	130°-43'8E	152	15.32	20.78	39.32	24.58	5.5	0.022	7.246	1.736	(4.85	) (-0.295)	Sand-Silt-Clay
37	31°-38'8N	130°-45'1E	124	4.66	37.67	39.00	18.67	4.816	0.034	5.536	1.019	3.334	0.037	Sandy Silt
38	31°-39'2N	130°-45'8E	225	0.02	23.09	66.88	10.02	4.632	0.041	1.428	1.084	0.979	0.043	Sandy Silt
39	31°-39'3N	130°-46'1E	225	0.17	27.04	59.57	13.22	4.474	0.045	1.445	1.192	1.829	0.137	Sandy Silt
40	31°-39'2N	130°-47'0E	228	0.05	18.23	61.37	20.36	4.947	0.032	1.706	0.822	(2.519)	(0.498)	Clayey Silt
41	31°-38'9N	130°-48'0E	182	0	11.13	59.55	29.32	6.684	0.010	3.684	1.131	(2.376)	(0.030)	Clayey Silt
42	31°-39'2N	130°-48'9E	170	0	19.54	61.54	18.92	5.5	0.022	2.455	0.576	(2.677)	(0.036)	Sandy Silt
43	31°-38'1N	130°-36'7E	140	0.30	32.31	37.51	29.88	5.632	0.02	7.86	1.89			Sand-Silt-Clay
44	31°-38'1N	130°-37'5E	144	0.06	36.58	48.78	14.58	5.237	0.027	3.00	1.567	2.432	0.054	Sandy Silt
45	31°-37'9N	130°-38'9E	134	0.42	31.73	45.06	22.78	5.074	0.029	3.271	0.941	3.187	0.196	Sand-Silt-Clay
46	31°-37'9N	130°-40'2E	128	0	34.05	50.21	15.74	5.053	0.03	3.69	1.32			Sandy Silt
47	31°-37'9N	130°-42'4E	108	0.09	28.50	48.42	22.98	5.474	0.02	4.08	0.76			Sand-Silt-Clay
48	31°-37'9N	130°-44'8E	154	1.33	40.09	29.02	29.57	5.358	0.024	(7.268)	(0.633)	(3.582)	(0.090)	Sand-Silt-Clay
49	31°-37'9N	130°-45'8E	112	21.35	50.63	16.32	11.70	1.984	0.52	7.616	0.193	3.974	0.857	Silty Sand
50	31°-38'1N	130°-48'0E	154	0.43	23.78	50.71	25.08	6.263	0.013	3.731	1.286	(3.111)	(-0.030)	Sand-Silt-Clay
51	31°-37'0N	130°-44'8E	134	9.39	48.79	20.30	21.52	3.158	0.113	7.625	0.337	(4.532)	(0.273)	Sand-Silt-Clay
52	31°-37'0N	130°-45'9E	144	0.80	60.18	26.82	12.20	3.179	0.11	4.058	0.393	2.913	0.36	Silty Sand
53	31°-36'9N	130°-47'2E	94	34.05	46.82	5.42	13.71	0.158	0.890	4.551	0.422	3.219	0.436	Clayey Sand
54	31°-36'2N	130°-43'6E	125	2.13	42.47	35.78	19.61	5.105	0.029	5.751	1.662	3.613	-0.024	Sand-Silt-Clay
55	31°-35'8N	130°-44'9E	144	1.60	22.00	56.90	19.50	5.874	0.017	3.470	0.971			Sandy Silt
56	31°-36'4N	130°-46'0E	144	0	17.39	31.31	51.30	8.505	0.003	(3.717	(13.329)	(2.945)	(-0.593)	Silty Clay
57	31°-34'9N	130°-45'0E	144	0	37.8	38.3	23.9	5.621	0.020	5.538	1.469			Sand-Silt-Clay
58	31°-35'1N	130°-46'0E	142	0.14	26.93	58.63	14.30	5.211	0.027	2.058	1.679	2.358	0.045	Sandy Silt
59	31°-35'1N	130°-47'0E	116	1.89	43.53	36.36	18.22	4.658	0.039	5.000	0.852	3.292	0.100	Silty Sand
60	31°-34'4N	130°-43'7E	132	1.71	45.16	35.81	17.32	4.068	0.059	4.134	0.672	2.977	0.211	Silty Sand
61	31°-34'0N	130°-44'4E	138	1.23	36.37	52.76	9.64	5.437	0.023	3.524	2.119	2.329	-0.227	Sandy Silt
62	31°-34'0N	130°-45'7E	138	0.29	63.73	24.06	11.92	3.105	0.116	3.416	0.281	2.903	0.51	Silty Sand
63	31°-36'9N	130°-36'4E	138	6.14	93.04	(0.82)		1.983	0.253	1.685	1.267	1.192	-0.310	Sand
64	31°-36'1N	130°-35'6E	66	26.65	73.36	0	0	-0.121	1.08	1.238	0.889	1.882	0.063	Sand
65	31°-35'1N	130°-34'8E	39	10.22	86.80	2.98	0	1.884	0.266	1.795	1.475	1.474	-0.421	Sand
66	31°-32'0N	130°-35'4E	130	0	32.15	47.09	20.75	5.274	0.026	3.821	0.857	(3.434)	(0.001)	Sand-Silt-Clay
67	31°-31'9N	130°-37'6E	165	0	39.25	46.44	14.31	4.632	0.040	3.561	0.750	2.808	0.084	Sandy Silt
68	31°-32'0N	130°-40'0E	162	0	50.18	43.14	6.67	3.974	0.063	2.693	1.046	2.132	0.124	Silty Sand
69	31°-31'8N	130°-41'0E	150	3.93	70.89	19.52	5.66	2.579	0.169	2.412	0.722	2.132	0.407	Silty Sand
70	31°-30'0N	130°-33'2E	23	20.12	60.78	15.37	3.73	2.105	0.231	2.834	1.260	2.426	-0.148	Sand
71	31°-29'9N	130°-35'4E	88	21.07	47.05	25.17	6.70	2.947	0.130	7.533	0.673	3.211	-0.492	Silty Sand
72	31°-29'8N	130°-37'8E	216	0.32	54.82	26.77	18.09	3.553	0.085	3.606	0.264	(3.095)	(2.211)	Silty Sand
73	31°-30'2N	130°-40'0E	80	6.86	63.05	25.41	4.67	2.895	0.137	2.401	0.656	1.971	0.295	Silty Sand
74	31°-27'9N	130°-32'2E	28	0.60	71.71	22.57	5.11	2.868	0.137	2.047	0.624	1.658	0.413	Silty Sand
75	31°-27'7N	130°-35'4E	93	5.89	49.18	34.98	9.94	3.658	0.079	2.968	0.726	2.374	0.253	Silty Sand
76	31°-27'8N	130°-37'8E	220	0	35.36	41.6	23.04	5.184	0.028	4.366	0.571	(3.021)	(0.272)	Sand-Silt-Clay
77	31°-27'8N	130°-39'9E	196	0	46.61	28.46	24.93	4.716	0.038	6.418	0.410	(3.432)	(0.293)	Sand-Silt-Clay
78	31°-26'1N	130°-33'0E	40	3.19	64.40	22.44	9.97	3.368	0.096	2.113	0.774	2.087	0.412	Silty Sand
79	31°-25'8N	130°-35'4E	100	4.24	54.36	30.86	10.54	3.474	0.09	2.992	0.728	2.408	0.187	Silty Sand
80	31°-25'5N	130°-37'8E	225	1.01	49.87	31.55	17.57	3.947	0.065	4.637	0.326	3.053	0.405	Silty Sand
81	31°-25'9N	130°-39'9E	220	0	44.68	35.8	19.52	4.579	0.042	4.251	0.710	(3.211)	(0.312)	Silty Sand
82	31°-25'8N	130°-42'4E	150	0	38.86	39.45	21.69	4.816	0.035	4.012	0.878	(3.276)	(0.293)	Sand-Silt-Clay
83	31°-24'0N	130°-33'3E	36	0.35	72.46	22.54	4.65	3.526	0.087	1.524	0.962	1.171	0.214	Silty Sand
84	31°-24'1N	130°-35'3E	88	9.66	67.73	17.61	5.00	2.658	0.158	2.115	0.928	1.790	0.147	Silty Sand
85	31°-23'9N	130°-37'6E	220	0.20	41.23	30.86	20.73	4.868	0.035	4.782	0.715	(3.224)	(0.225)	Sand-Silt-Clay
86	31°-24'1N	130°-40'2E	165	5.86	54.60	29.46	10.09	3.358	0.098	2.993	0.542	2.461	0.331	Silty Sand
87	31°-24'1N	130°-42'4E	182	1.32	36.06	37.64	24.98	4.842	0.035	5.401	0.563	(3.395)	(0.264)	Sand-Silt-Clay
88	31°-23'9N	130°-44'4E	78	2.67	76.96	15.46	4.92	2.790	0.143	1.826	0.919	1.487	0.150	Sand
89	31°-22'0N	130°-35'2E	95	0.05	42.47	40.13	17.34	4.526	0.043	4.061	0.838	(3.145)	(0.223)	Silty Sand

90	31°-21'9N	130°-37'8E	215	0.14	45.28	31.65	22.93	4.463	0.045	6.036	0.429	(3.421)(	0.295) Sand-Silt-Clay
91	31°-21'7N	130°-40'0E	207	0.15	43.98	35.90	19.98	4.474	0.045	4.457	0.552	3.179	0.305 Sand-Silt-Clay
92	31°-21'9N	130°-42'6E	185	0	43.93	34.52	21.55	4.505	0.044	5.044	0.437	(3.132)(	0.343) Sand-Silt-Clay
93	31°-21'8N	130°-44'5E	142	0	5.14	63.45	31.42	6.084	0.015	(3.500)	(0.361)	(2.253)(	0.379) Clayey Silt
94	31°-20'0N	130°-35'5E	105	0.10	50.63	33.52	15.74	3.911	0.066	3.660	0.539	2.782	0.338 Silty Sand
95	31°-20'0N	130°-37'6E	170	0.66	40.76	35.93	22.55	4.921	0.033	5.222	1.092	(3.408)(	0.127) Sand-Silt-Clay
96	31°-20'1N	130°-39'7E	188	0.71	36.37	40.37	22.55	5	0.034	5	0.581	(3.237)(	0.195) Sand-Silt-Clay
97	31°-19'9N	130°-42'0E	170	1.34	51.09	31.66	15.92	3.737	0.075	4.532	0.526	3.142	0.355 Silty Sand
98	31°-19'7N	130°-44'3E	145	0.27	50.62	37.42	11.69	3.916	0.066	3.292	1.025	2.595	0.172 Silty Sand
99	31°-19'9N	130°-46'2E	42	2.37	87.76	6.48	3.39	1.511	0.35	1.738	0.933	1.308	0.163 Sand
100	31°-18'1N	130°-37'5E	75	0.08	82.04	13.25	4.64	2.726	0.152	1.905	0.968	1.356	0.037 Sand
101	31°-18'1N	130°-40'0E	119	1.26	56.17	24.38	18.20	3.063	0.12	4.022	0.325	(3.461)(	0.564) Silty Sand
102	31°-18'6N	130°-42'3E	162	0	38.64	43.29	18.07	4.790	0.036	3.881	0.839	(2.921)(	0.234) Sandy Silt
103	31°-17'9N	130°-44'6E	175	0.61	58.29	27.82	13.28	3.395	0.095	3.299	0.449	2.942	0.460 Silty Sand
104	31°-18'0N	130°-46'9E	38	0.39	64.63	28.64	6.35	3.684	0.078	1.531	0.834	0.982	0.303 Silty Sand
105	31°-17'0N	130°-45'7E	97	0.13	39.40	48.06	12.41	4.474	0.045	3.112	1.200	2.5	0.099 Sandy Silt
106	31°-15'8N	130°-41'3E	40										
107	31°-15'9N	130°-42'4E	96										
108	31°-15'9N	130°-43'4E	120	17.00	51.18	9.24	22.58	1.674	0.305	10.868	0.171	(5.037)(	0.457) Clayey Sand
109	31°-16'1N	130°-44'5E	124	9.73	69.21	15.14	5.92	2.211	0.215	2.887	1.462		Sand
110	31°-16'3N	130°-45'4E	110										
111	31°-14'9N	130°-42'4E	90	12.81	68.44	12.50	6.25	1.784	0.290	3.410	0.81		Sand
112	31°-15'1N	130°-43'4E	102	6.55	45.00	3.96	44.49	3.484	0.09	(19.664)	(0.107)	(4.855)(	0.269) Clayey Sand
113	31°-15'0N	130°-44'5E	100										
114	31°-15'3N	130°-46'0E	70	6.80	65.96	19.27	7.98	2.64	0.16	3.368	1.198	2.56	-0.031 Clayey Sand
115	31°-15'2N	130°-46'7E	44	11.11	72.55	11.19	5.15	2.274	0.206	3.162	2.039		Sand
116	31°-14'1N	130°-41'4E	61	14.4	76.9	3.3	5.2	-0.368	1.29	7.497	0.127		Sand
117	31°-14'0N	130°-42'2E	95	11.40	78.80	4.10	5.70	1.6	0.33	2.982	1.119		Sand
118	31°-14'0N	130°-43'4E	101	10.34	59.37	12.68	17.61	1.384	0.38	8.424	0.118	4.447	1.398 Clayey Sand
119	31°-14'0N	130°-44'7E	86	24.21	62.60	9.59	3.60	0.579	0.677	2.454	0.43	2.671	0.123 Sand
120	31°-14'3N	130°-45'7E	60	0	67.17	22.20	10.64	3.305	0.101	2.080	0.470	1.932	0.602 Silty Sand
121	31°-12'9N	130°-42'3E	111	20.76	40.31	9.84	29.08	2.326	0.2	(25.140)	(0.099)	(5.645)(	1.131) Clayey Sand
122	31°-12'9N	130°-43'3E	100	22.7	66.00	6.00	5.30	-0.042	1.03	2.126	0.753		Sand
123	31°-13'2N	130°-44'8E	70	21.86	71.20	5.12	1.82	0.379	0.77	2.51	0.834	2.108	0.517 Sand
124	31°-11'9N	130°-40'3E	20										
125	31°-11'9N	130°-42'6E	140	26.65	27.13	13.51	32.70	1.474	0.36	28.756	0.043	(5.376)(	0.429) Sandy Clay
126	31°-11'9N	130°-43'2E	112	14.32	20.00	63.73	1.95	4.5	0.044	4.294	14.460		Sandy Silt
127	31°-12'0N	130°-44'4E	74	18.21	67.24	8.56	5.99	0.884	0.54	3.541	0.469		Sand
128	31°-11'1N	130°-42'5E	112	21.75	68.51	(9.74)		0.51	0.7	3.29	0.59	2.39	0.24 Sand
129	31°-11'0N	130°-43'3E	102	46.03	40.70	13.09	0.18	-0.516	1.43	9.713	46.13		Sand
130	31°-10'7N	130°-45'1E	52	46.96	29.02	11.62	12.40	-0.78	1.7	8.19	0.11	4.37	0.60 Sand-Silt-Clay
131	31°-09'8N	130°-38'9E	90	24.25	44.56	30.18	1.01	3.053	0.12	6.95	5.36	4.505	0.680 Silty Sand
132	31°-10'0N	130°-40'5E	100	4.09	67.98	18.76	9.18	3.53	0.087	1.612	0.859	1.983	0.228 Silty Sand
133	31°-10'0N	130°-41'3E	108	24.24	61.82	8.68	5.26	0.184	0.89	3.055	0.520	2.637	0.331 Sand
134	31°-10'0N	130°-42'2E	112										
135	31°-10'0N	130°-43'2E	84	52.05	44.32	2.19	1.43	-1.068	2.10	1.925	0.874		Sand
136	31°-10'1N	130°-44'4E	60	27.30	71.82	(0.88)		-0.12	1.08	2.10	0.87	1.625	0.182 Sand
137	31°-08'8N	130°-37'6E	106										
138	31°-09'0N	130°-38'9E	100	16.84	50.99	16.99	15.19	1.395	0.38	5.92	0.39	4.358	0.436 Silty Sand
139	31°-09'0N	130°-40'5E	105										
140	31°-08'9N	130°-42'2E	95	0.06	59.19	27.49	13.26	3.505	0.09	3.742	0.209	2.640	0.564 Silty Sand
141	31°-08'8N	130°-43'4E	60	33.02	66.98	0	0	-0.342	1.25	2.070	0.971	1.506	0.073 Sand
142	31°-09'1N	130°-44'4E	55	10.78	87.67	(1.55)		1.921	0.26	0.830	1.75	1.929	0.377 Sand
143	31°-08'5N	130°-41'0E	96	19.00	68.59	9.39	3.02	0.405	0.760	2.112	1.057	1.919	0.163 Sand
144	31°-05'9N	130°-36'1E	105	15.22	79.29	2.97	2.52	0.353	0.783	1.830	0.914	1.24	-0.041 Sand
145	31°-05'3N	130°-34'2E	155	1.64	86.43	7.81	4.12	2.689	0.155	1.630	1.019	1.084	-0.063 Sand
146	31°-03'8N	130°-32'5E	213	1.64	80.75	11.67	5.94	3.305	0.102	1.437	1.147	0.921	-0.074 Sand

strength of current. The mean value of median diameter (Mdϕ) in each area is as follows; Bay Mouth Area: 0.70 ϕ; Central Area: 3.89 ϕ; Bay Head Area: 5.14 ϕ and West-Sakurajima Passage (Stn. 63 - 65): 1.25 ϕ. At the three open sea stations (Stn. 144 - 146), median diameters change from fine to coarse as the depth decreases (Mdϕ: 3.3 to 0.4 ϕ).

b) Judging from the submarine topography and sediment distribution in the Bay Mouth Area, it is reasonable to say that the predominant surface current flows northward along the Ōsumi Peninsula, while it flows southward along the Satsuma Peninsula.

c) Similar current directions are suggested to occur in the Central Area of the bay and also a counterclockwise current stream is assumed to occur at the northern margin of this area.

d) The longshore current flowing southward along the Satsuma Peninsula is forced to change its direction by the existence of a vast area of reclaimed land off the coast of Kiiré-chō influencing the sediment distribution in that area (Figs. 8, 9 and 13).

e) Correlation between the grain-size composition of sediments and the water depth was scarcely recognized in the Bay Head Area. This suggests that the sediment distribu-

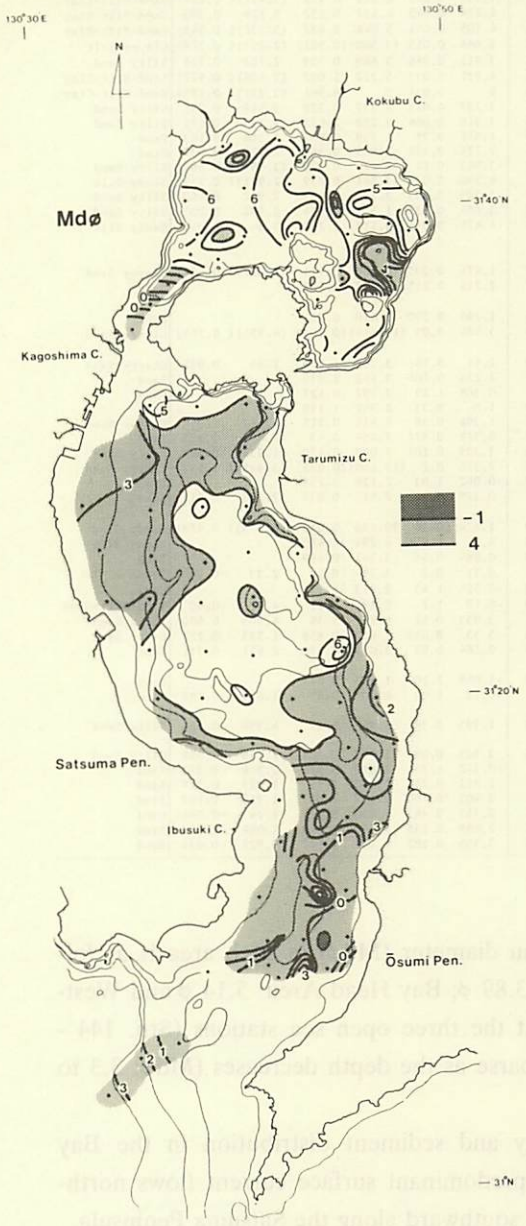

Fig. 8. Distribution of the median diameter (Md ϕ) of bottom surface sediments.

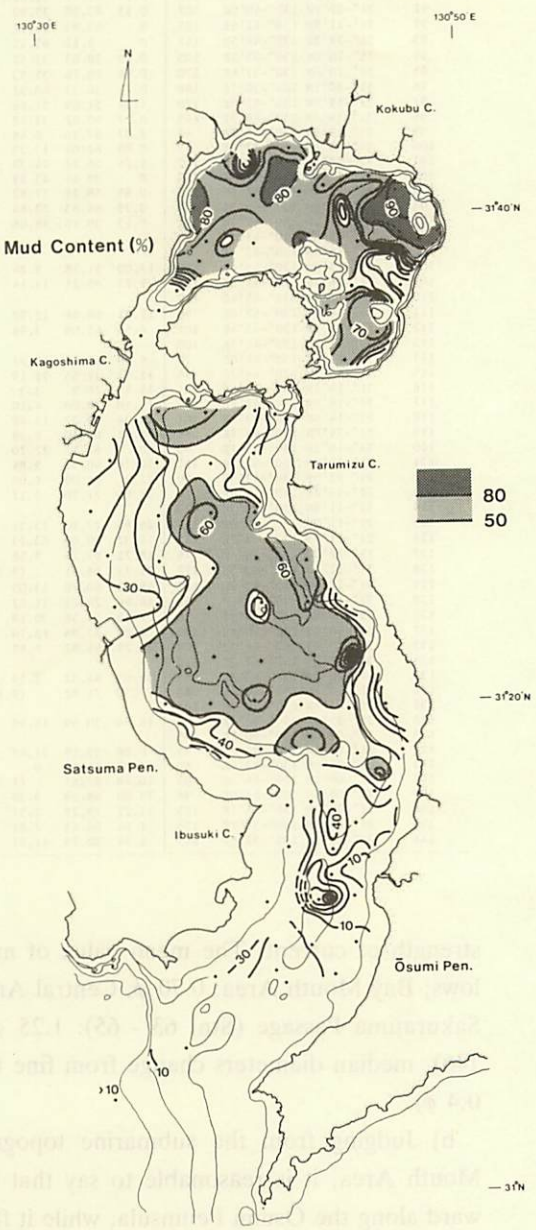

Fig. 9. Distribution of the mud content (%) of bottom surface sediments.

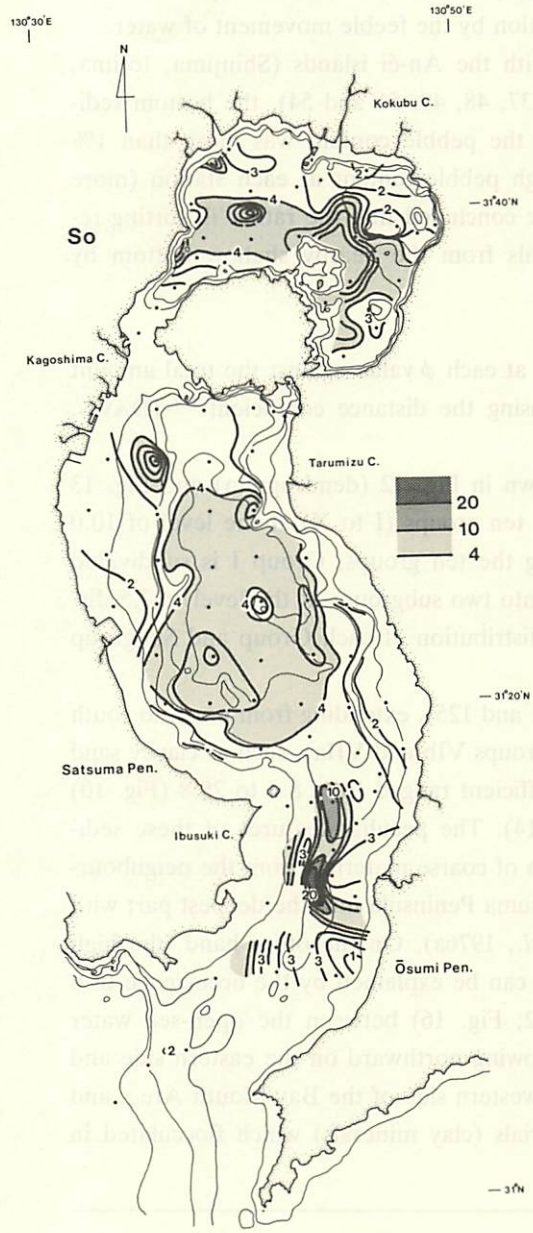

Fig. 10. Distribution of the sorting coefficient (So) of bottom surface sediments.

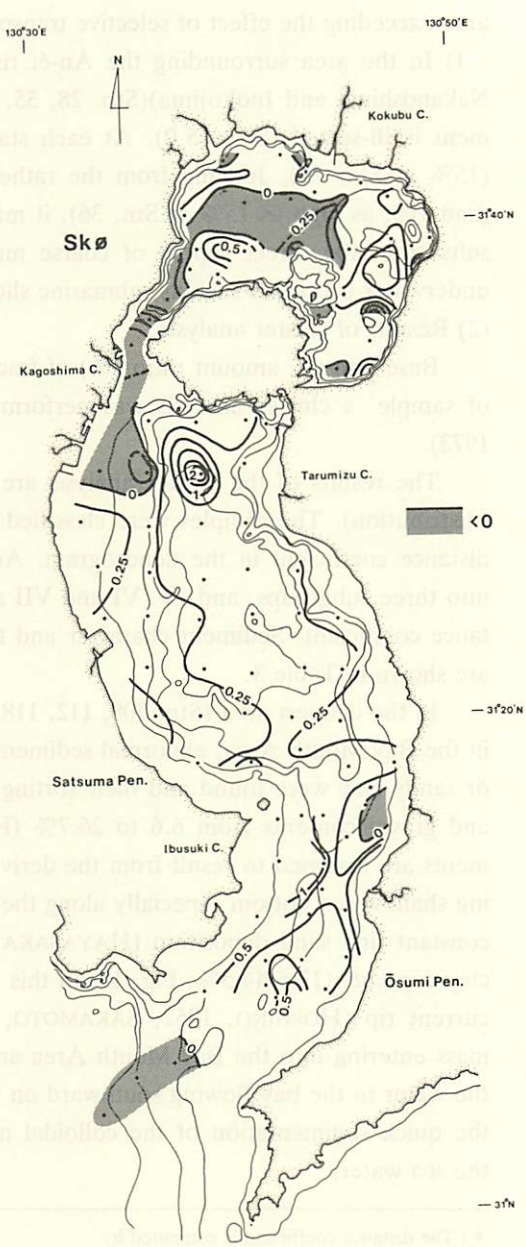

Fig. 11. Distribution of the skewness ($\alpha\phi$) of bottom surface sediments.

tion in this area is strongly influenced by the supply of materials from nearby shallow sea area exceeding the effect of selective transportation by the feeble movement of water.

f) In the area surrounding the An-éi rise with the An-éi islands (Shinjima, Iōjima, Nakanoshima and Inokojima)(Stn. 28, 35, 36, 37, 48, 49, 51 and 54), the bottom sediment is ill-sorted ($So > 5.0$). At each station the pebble content was more than 1% (15% at Stn. 36). Judging from the rather high pebble-content at each station (more than 1%; as high as 15% at Stn. 36), it may be concluded that the rather ill sorting results from the direct supply of coarse materials from the nearby shallow bottom by underwater processes such as submarine sliding.

(2) Results of cluster analysis

Based on the amount ratio (%) of fraction at each ϕ value against the total amount of sample, a cluster analysis was performed using the distance coefficient *) (DAVIS, 1973).

The results of the cluster analysis are shown in Fig. 12 (dendrogram) and Fig. 13 (distribution). The samples were classified into ten groups (I to X) at the level of 10.0 distance coefficient in the dendrogram. Among the ten groups, Group I is subdivided into three subgroups, and IV, VI and VII are into two subgroups at the level of 7.5 distance coefficient. Sediment character and the distribution of each Group and Subgroup are shown in Table 3.

In the deepest area (Stn. 108, 112, 118, 121 and 125), extending from north to south in the Bay Mouth Area, abnormal sediments (groups VIb and VIIa), such as clayey sand or sandy clay were found and their sorting coefficient ranged from 8.4 to 28.8 (Fig. 10) and gravel contents from 6.6 to 26.7% (Fig. 14). The peculiar features of these sediments are assumed to result from the derivation of coarse materials from the neighbouring shallow sea bottom especially along the Satsuma Peninsula into the deepest part with constant fine sand deposition (HAYASAKA *et al.*, 1976a). On the other hand, the high clay contents (17.6-44.5%; Fig. 15) in this area can be explained by the occurrence of a current rip (HOSHINO, 1952; SAKAMOTO, 1982; Fig. 16) between the open-sea water mass entering into the Bay Mouth Area and flowing northward on the eastern side and the water in the bay flowing southward on the western side of the Bay Mouth Area, and the quick sedimentation of the colloidal materials (clay minerals) which flocculated in the sea water.

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*) The distance coefficient is computed by

$$d_{ij} = \sqrt{\frac{\sum_{k=1}^{m}(X_{ik}-X_{jk})^2}{m}}$$

where X_{ik} denotes the kth variable measured on object i and and X_{ik} is the kth variable measured on object j. In all, m variables are measured on each object, and d_{ij} is the distance between object i and object j (DAVIS, 1973).

Table 3. Results of cluster analysis of the grain-size composition of sediment samples.

Group	Characteristics of sediment	Distribution
I	Ill-sorted sediments composed of medium sand to clay.	
	Ia: Having a little higher (10-31%) clay contents without remarkable peak.	Most parts of deep basin bottom in the Bay Head and the Central Areas.
	Ib: Coarse silt, fine and clay fractions show peaks of about 20%.	Basin bottom in the northeastern part of the Bay Head Area (Stn. 12, 41).
	Ic: Very fine sand to medium silt occupy 62-80% of the total weight, and clay contents are 10-15%.	Basin bottom in the northern part of the Bay Head Area (Stn. 10, 13, 19, 20).
II	The sediments with 91% silt contents.	Deep basin bottom in the northeastern part of the Bay Head Area (Stn. 30).
III	The sediments with coarse and medium silt up to 55-77%.	Basin bottom in the northeastern part of the Bay Head Area (Stn. 11, 21, 39).
IV	Sand-dominate sediments.	
	IVa: Sand contents 77-94%, well-sorted.	The area with rather high velocity of longshore current along the Ōsumi Peninsula and West-Sakurajima Passage with rather strong tidal currents. Besides, an exceptional occurrence was found at Station 7 inharmoniously surrounded by the Group Ia sediments*).
	IVb: Medium to very fine sand contents up to 40-80%. Containing small amount of gravel, silt and clay, and rather ill-sorted.	Mainly on the slopes descending to the deepest part in the Central and the Bay Mouth Areas. At the northern part of the Central Area, IVb is distributed from off Kagoshima City to off the coast of Kiiré-chō across the basin bottom covered with fine-grained sediments of the Group I.
V	Very fine sand contents up to 46%, well sorted.	Nearshore areas in the Central and Bay Mouth Areas (Stn. 83, 104, 132) and open sea area (Stn. 146).
VI	Characterized by clay contents of more than 29%.	
	VIa: Mainly composed of silt and clay. Clay contents up to 35-46%.	Basin bottom in the Bay Head Area.
	VIb: Showing bimodal distribution; gravel to coarse sand: 28-48%; clay: 18-44%.	Deepest bottom of channel topography in the Bay Mouth Area.
VII	Sediments characterized by gravels and sands.	
	VIIa: Gravel to coarse sand contents up to 43-79%.	A bank in the Bay Head Area (Stn. 49), shallow bottom in West-Sakurajima Passage (Stn. 64) and the deep bottom of channel topography in the Bay Mouth Area.
	VIIb: Coarse to medium sand contents up to 77% and gravel contents to 15%.	Open sea area (Stn. 144).
VIII	Showing bimodal distribution; gravel and very coarse sand: 59%; clay: 12%.	Shallow bottom in the eastern part of the Bay Mouth Area (Stn. 130).
IX	Showing trimodal distribution; granule and very coarse to coarse sand: 61%; coarse silt: 30%; clay: 14%.	Nearshore area in the eastern part of the Bay Head Area (Stn. 53).
X	Showing trimodal distribution; granule: 21%; very fine sand: 19%; very fine silt: 21%.	Nearshore area in the western part of the Bay Mouth Area (Stn. 131).

*) The sediments at Station 7 consist mostly of pumices and volcanic glasses and comprise far fewer benthonic foraminifera than those at the neighbouring stations and a few shallow water benthonic foraminifera. These features suggest that the sediments at Station 7 were derived directly from shallow water bottoms with rather rapid rate of sedimentation by some underwater processes, such as, submarine sliding.

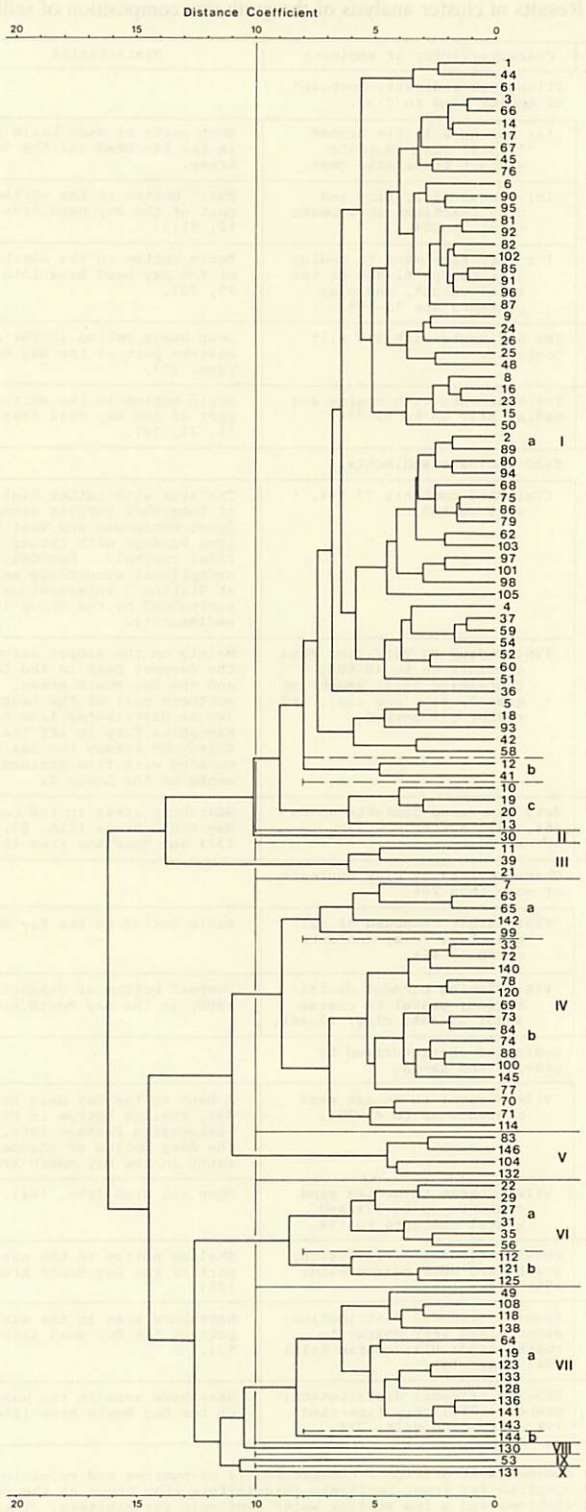

Fig. 12. Dendrogram for the bottom sediments.

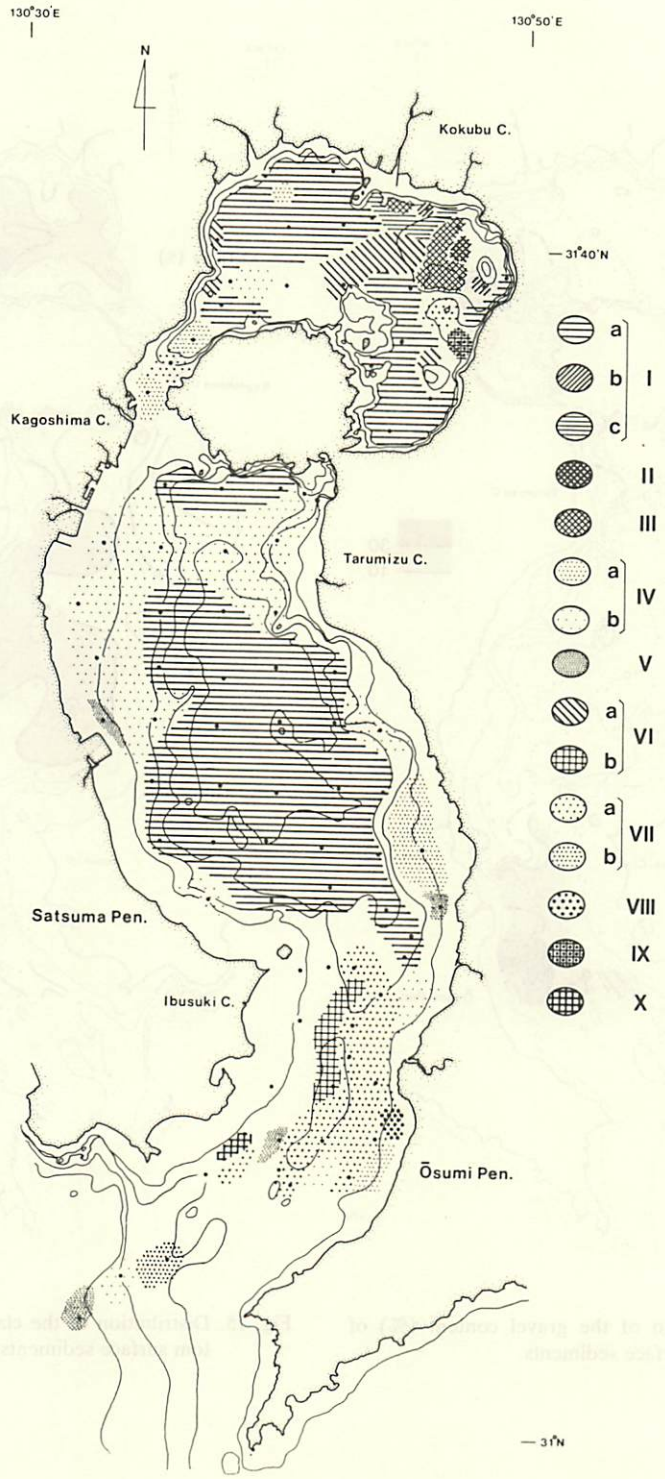

Fig. 13. Distribution of the groups of sediments recognized by cluster analysis.

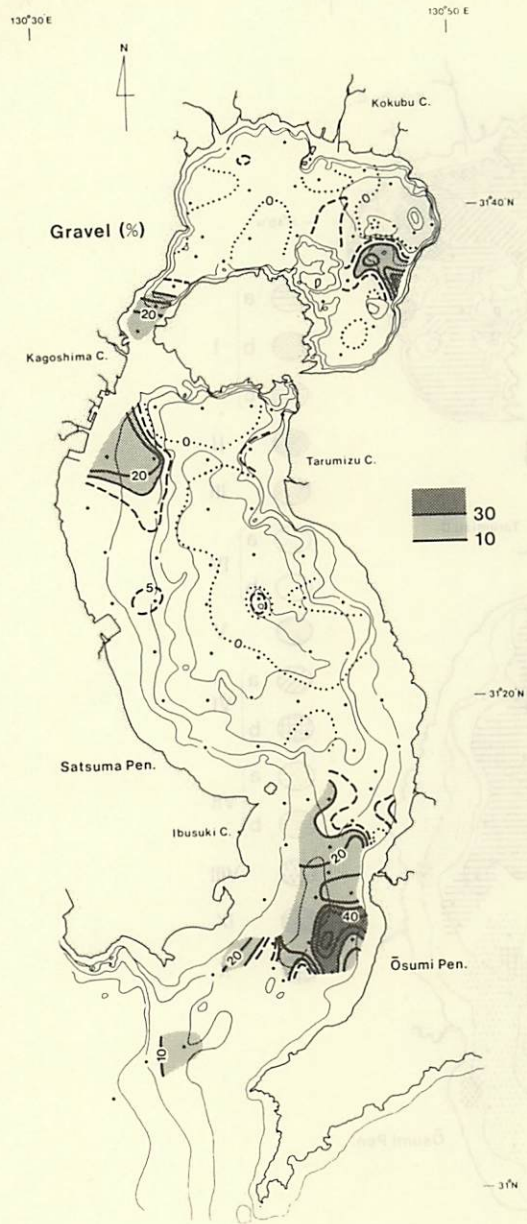

Fig. 14. Distribution of the gravel content (%) of bottom surface sediments.

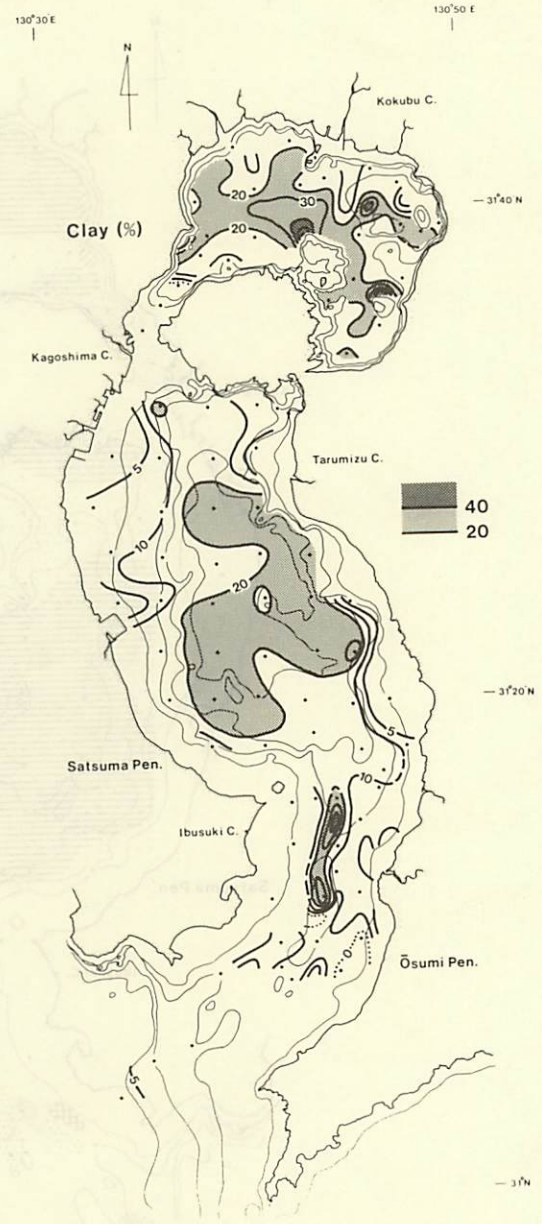

Fig. 15. Distribution of the clay content (%) of bottom surface sediments.

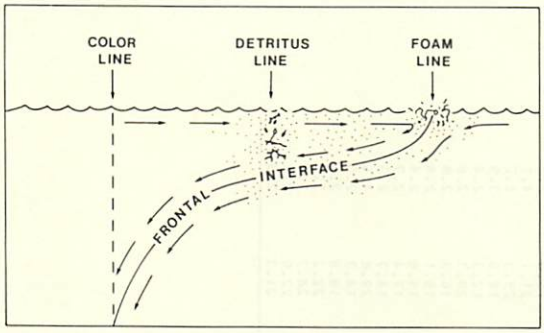

Fig. 16. Schematic distribution of suspended detritus in a current rip area (BOWMAN and IVERSON, 1978 *in* SAKAMOTO, 1982).

3. Rate of sedimentation and relative amount of the derived dead tests

(1) L/Tl value

In 1951, PHLEGER pointed out that the relative rate of sedimentation between sampling stations can be inferred from the ratio of living specimens to the total assemblage of benthonic foraminifera contained in the surface sediments, which has been termed the L/T value by subsequent authors (UCHIO, 1960; MATOBA, 1970). However, the L/T value must be smaller at stations where dead benthonic foraminifera are derived from surrounding areas by bottom currents, and results in under estimation of the sedimentation rate. To correct for this, I proposed to use the number of individuals only of the living species recognized at each station and to designate it Tl instead of T (ŌKI, 1986b, 1988). In addition, the ratio of L/Tl value to the L/T value indicates the relative amount of dead tests derived from outside the sampling station. The L/Tl values of the sediments from Kagoshima Bay are shown in Table 4 and their equivalent lines in Figure 17. The distribution of the ratios of L/Tl to L/T values is shown in Figure 18.

(2) The high L/Tl value areas

On the map showing the equivalent lines of the L/Tl value (Fig. 17), the five areas with a high rate of sedimentation can be seen, namely, 1) outside the bay (Stn. 137, 144, 145 and 146), 2) off Ibusuki City, 3) the boundary area between the Bay Mouth and the Central Areas, 4) near-shore area along the coast between Kagoshima City and Kiiré-chō, and 5) surroundings of the An-éi rise in the Bay Head Area.

a) Outside the bay (open sea) and the boundary area between the Bay Mouth and the Central Areas

The Bay Mouth Area, having a rather narrow channel topography can, at the same time, be regarded as a saddle topography between the deepening both in the north and the south of it. The rather rapid bottom current in the Bay Mouth Area slows down both in the north (Stn. 97, 98, 103 and 108) and the south (Stn. 137, 144, 145 and 146) where the water depth increases resulting in the deposition of fine materials suspendid in

Table 4. Data on the L/T and the L/Tl values and the number of total and living specimens.

Station	Number of Individuals Total*)	Living*)	L/Tl Value	L/Tl Value	L/Tl value / L/T value
1	132	1	0.8	2.0	2.6
3	158	13	8.2	11.4	1.4
12	100	5	5.0	7.6	1.5
15	103	3	2.9	5.9	2.0
17	222	11	5.0	6.2	1.3
18	88	9	10.2	18.2	1.8
21	81	4	4.9	14.8	3.0
22	269	15	5.6	6.9	1.2
32	242	22	9.1	23.7	2.6
34	331	13	3.9	5.2	1.3
35	136	39	28.7	33.3	1.2
37	275	48	17.5	20.4	1.2
40	86	17	19.8	23.0	1.2
41	121	6	5.0	11.9	2.4
42	313	11	3.5	6.4	1.8
44	304	10	3.3	7.6	2.3
45	213	23	10.8	15.7	1.5
51	115	32	27.8	34.1	1.2
53	182	7	3.9	5.8	1.5
54	156	42	26.9	35.0	1.3
58	68	14	20.6	33.3	1.6
61	109	6	5.5	6.7	1.2
63	418	26	6.2	20.8	3.3
64	322	22	6.8	22.7	3.3
65	653	32	4.9	10.5	2.1
66	236	32	13.6	28.4	2.1
67	211	11	5.2	10.0	1.9
68	226	44	19.5	23.2	1.2
69	229	29	12.7	16.6	1.3
70	250	14	5.6	28.2	5.0
71	258	4	1.6	4.4	2.8
72	244	6	2.5	3.9	1.6
73	394	17	4.3	17.2	4.0
74	419	32	7.6	16.7	2.2
75	431	40	9.3	13.7	1.5
76	262	21	8.0	21.8	2.7
77	247	10	4.0	5.9	1.5
78	253	25	9.9	31.2	3.2
79	330	20	6.1	12.1	2.0
80	324	22	9.9	14.9	1.5
81	249	31	12.4	17.9	1.4
82	310	25	8.1	12.4	1.5
83	335	23	6.9	22.3	3.2
84	280	36	12.9	25.4	2.0
85	241	26	10.8	19.5	1.8
86	376	47	12.5	21.7	1.7
87	347	31	8.9	19.2	2.1
88	295	25	8.5	24.3	2.9
89	265	16	6.0	11.8	2.0
90	224	20	8.9	17.5	2.0
91	216	27	12.5	24.3	1.9
92	258	11	4.3	19.6	4.6
93	334	23	6.9	13.6	2.0
94	242	13	5.4	11.3	2.1
95	204	25	12.3	22.0	1.8
96	246	31	12.6	21.4	1.7
97	199	24	12.1	28.9	2.4
98	215	20	9.3	25.3	2.7
99	274	26	9.5	25.3	2.7
100	228	17	7.5	23.9	3.2
101	276	17	6.2	16.2	2.6
102	228	16	7.0	17.8	2.5
103	205	4	2.0	80.0	41.0
104	308	17	5.5	20.5	3.7
105	222	14	6.3	16.3	2.6
106	225	15	6.7	23.9	3.6
107	278	8	2.9	12.3	4.3
108	224	15	6.7	31.1	4.6
110	329	22	6.7	15.0	2.2
113	295	15	5.1	21.1	4.1
116	214	25	11.7	25.3	2.2
118	216	9	4.2	14.5	3.5
122	295	15	5.1	12.3	2.4
124	215	17	7.9	20.7	2.6
125	240	14	5.8	16.3	2.8
127	329	18	5.5	15.1	2.8
132	364	22	6.0	14.8	2.4
134	249	16	6.4	17.4	2.7
136	388	25	6.4	14.7	2.3
137	230	15	6.5	29.8	4.6
139	884	64	7.2	14.2	2.0
141	265	19	7.2	18.8	2.6
143	313	29	9.3	22.2	2.4
144	334	63	19.2	28.7	1.5
145	189	19	10.1	22.0	2.2
146	252	19	7.5	21.3	2.8

*) Numbers are actually counted.

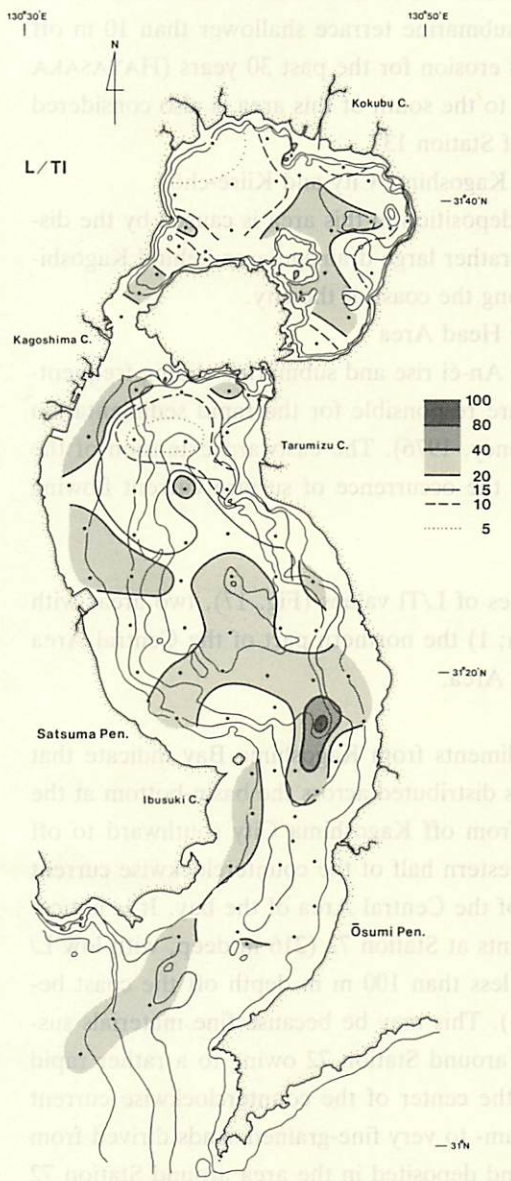

Fig. 17. Distribution of the L/Tl values.

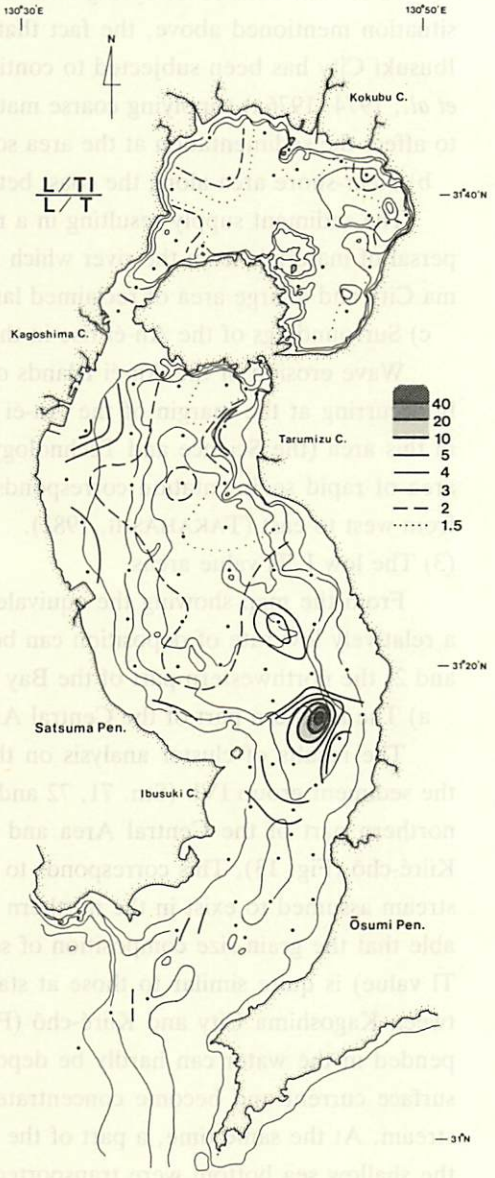

Fig. 18. Distribution of the ratios of L/Tl to L/T values.

the water. An extraordinary high value at Station 103 is noticeable. In addition to the situation mentioned above, the fact that the submarine terrace shallower than 10 m off Ibusuki City has been subjected to continuous erosion for the past 30 years (HAYASAKA *et al.*, 1974, 1976a) supplying coarse materials to the south of this area is also considered to affect the sedimentation at the area south of Station 137.

b) Near-shore area along the coast between Kagoshima City and Kiiré-chō

The sediment supply resulting in a rapid deposition in this area is caused by the dispersal of materials from the river which has a rather large drainage area behind Kagoshima City and a large area of reclaimed land along the coast of the city.

c) Surroundings of the An-éi rise in the Bay Head Area

Wave erosion of the An-éi Islands on the An-éi rise and submarine sliding frequently occurring at the margin of the An-éi rise are responsible for the rapid sedimentation in this area (the Science and Technology Agency, 1976). The eastward extension of the area of rapid sedimentation corresponds with the occurrence of surface current flowing from west to east (TAKAHASHI, 1981).

(3) The low L/Tl value areas

From the map showing the equivalent lines of L/Tl values (Fig. 17), two areas with a relatively low rate of deposition can be seen; 1) the northern part of the Central Area and 2) the northwestern part of the Bay Head Area.

a) The northern part of the Central Area

The results of cluster analysis on the sediments from Kagoshima Bay indicate that the sediment group IVb (Stn. 71, 72 and 77) is distributed across the basin-bottom at the northern part of the Central Area and also from off Kagoshima City southward to off Kiiré-chō (Fig. 13). This corresponds to the western half of the counterclockwise current stream assumed to exist in the northern part of the Central Area of the bay. It is noticeable that the grain-size composition of sediments at Station 72 (216 m deep, with low L/Tl value) is quite similar to those at stations less than 100 m in depth off the coast between Kagoshima City and Kiiré-chō (Fig. 13). This may be because fine materials suspended in the water can hardly be deposited around Station 72 owing to a rather rapid surface current and become concentrated at the center of the counterclockwise current stream. At the same time, a part of the medium- to very fine-grained sands dirived from the shallow sea bottom were transported to and deposited in the area around Station 72 when the surface currents are strong. These explanations are endorsed by the fact that the L/Tl value at Station 76 near the center of the counterclockwise stream is rather high (21.8), the median diameter is 5.2 ϕ and the mud-content up to 64.6%. At Station 71, on the other hand, the rate of sedimentation is rather low compared with the sorrounding areas because of the lack of sediment supply from the east, and the westward-flowing surface current acting as an obstacle to the sediment supply from the shallow sea bottom to the west.

b) The northwestern part of the Bay Head Area

The rather small amount of sedimentary materials supplied to this area may be ex-

plained by the fact that the drainage areas of rivers flowing into this area are rather flat in topography and the slopes of river beds are gentle.

(4) Distribution of the ratio of the L/Tl value to the L/T value

The ratio of the L/Tl value to the L/T value (Fig. 18) can potentially indicate the relative amount of dead tests of benthonic foraminifera derived from outside the stations, namely, the larger the ratio, the more the dead tests transported from the other site.

The areas with rather large ratios are as follows:

1) southwestern part of the Bay Mouth Area (Stn. 137), 2) boundary area between the Bay Mouth and the Central Areas (Stn. 103, 104, 106, 107, 108, 113 and 118), 3) off the reclaimed land in Kiiré-chō (Stn. 83), 4) off Tarumizu City, 5) off Taniyama, Kagoshima City (Stn. 70) and 6) West-Sakurajima Passage. The common feature of these areas is their situation, namely, down stream of rapid surface currents. For example, the foraminiferal dead tests moving northward by the bottom current with clastic materials along the Ōsumi Peninsula must be deposited and concentrated because of a sudden slowing of the current velocity in the boundary area between the Bay Mouth (about 100 m deep) and the Central Areas (about 200 m deep).

4. Planktonic foraminifera

For the planktonic foraminifera, which was not the main subject of this study and therefore treated without specific identification, the number of individuals and their percentages of the total number of individuals of both benthonic and planktonic foraminifera (designated as Pl/Pl + Be value in the following lines), and of planktonic foraminifera plus radiolaria (Pl/Pl + Rads value) was determine.

Considering the L/Tl value of each station, the theoretical number of individuals regarded to have been accumulated during a relative unit of time was estimated based on the actual number of individuals contained in 10cc of surface sediments.

(1) Distribution of planktonic foraminifera throughout the studied area

The number of planktonic foraminifera at each station is shown in Table 5 and the distribution of equivalent lines is in Figure 19.

At the three open sea stations, the individual numbers of planktonic foraminifera seemed to correspond to water depth, namely, the deeper the water, the more abundant the planktonic foraminifera; 654 at Station 144 (105 m), 10,250 at Station 145 (155 m), 20,830 at Station 146 (213 m).

At the Bay Mouth Area, the individual numbers of planktonic foraminifera were rather small (121-1,208) in the channel. This corresponds to the saddle-like topography between the open sea and the Central Area of the bay. This may be caused by rather strong current in the channel. On the other hand, those on the steep slopes north and south of the channel are rather large (1,970-6,744). This is also the case with radiolaria.

At the Central Area of the bay the number of individual planktonic foraminifera tended to decrease in the northeastern part (less than 300) and increase in the western

Table 5. Data on planktonic foraminifera and radiolaria.

Station	Depth (m)	Planktonic Foraminifera Number of Individuals	Pl / Pl + Be	Pl / Pl + Rads	Radiolaria Number of Individuals
1	102	0	- %	- %	+
3	130	0	-	-	10
12	122	+	1.0	1.0	16
15	152	+	1.9	2.5	9
17	146	0	-	-	7
18	136	+	1.1	2.6	13
21	185	0	-	-	14
22	144	2	4.3	17.6	8
32	156	9	2.0	62.5	6
34	149	6	7.8	35.0	11
35	140	0	-	-	18
37	124	0	-	-	18
40	228	0	-	-	5
41	182	0	-	-	5
42	170	+	0.6	4.9	5
44	144	1	0.7	20.0	5
45	134	0	-	-	4
51	134	0	-	-	19
53	94	0	-	-	6
54	125	0	-	-	41
58	142	0	-	-	33
61	138	0	-	-	4
63	138	7	2.1	28.1	19
64	66	25	4.2	100	0
65	39	7	2.5	100	0
66	130	245	10.3	75.0	82
67	165	66	28.2	65.4	35
68	162	1	1.3	12.5	5
69	150	64	9.5	77.4	19
70	23	433	4.6	85.7	72
71	88	335	31.6	88.1	45
72	216	24	24.0	57.5	18
73	80	1233	36.3	89.6	143
74	28	331	6.9	83.8	64
75	93	850	31.0	91.1	83
76	220	453	49.8	74.5	155
77	196	18	23.3	49.7	18
78	40	1078	9.6	87.1	160
79	100	1440	36.0	87.7	201
80	225	233	54.7	71.9	91
81	220	207	53.7	69.6	90
82	150	268	30.3	72.2	103
83	36	571	5.6	90.9	57
84	88	3706	28.9	95.0	195
85	220	345	47.8	72.2	133
86	165	1050	61.7	86.6	163
87	182	450	45.8	72.7	169
88	78	1944	29.8	95.4	93
89	95	680	25.4	82.6	143
90	215	323	50.8	83.1	66
91	207	610	59.2	81.8	136
92	185	731	46.2	79.3	191
93	142	568	43.9	86.4	89
94	105	354	16.8	74.2	123
95	170	252	41.2	79.0	67
96	188	801	48.8	71.6	318
97	170	809	46.8	78.1	227
98	145	2688	43.6	86.0	437
99	42	378	11.3	100	-
100	75	1315	15.9	95.6	61
101	119	472	24.8	84.3	88
102	162	1099	46.0	81.8	245
103	175	800	37.9	89.9	90
104	38	328	7.5	83.3	66
105	97	1074	31.7	78.0	303
106	40	795	5.5	86.7	122
107	96	735	11.2	100	-
108	120	1970	30.7	100	-
110	110	3437	35.2	93.7	230
113	100	270	35.2	97.0	8
116	61	810	10.5	96.2	32
118	101	278	35.7	100	-
122	100	579	33.3	89.1	71
124	20	3	3.2	77.8	1
125	140	121	27.9	93.9	8
127	74	1208	27.5	96.2	48
132	100	6744	32.8	93.7	455
134	112	830	37.4	93.1	61
136	60	616	25.2	99.2	5
137	106	2975	25.3	96.3	114
139	105	2436	37.7	96.9	77
141	60	547	25.6	97.8	12
143	96	4802	35.1	92.3	398
144	105	654	46.0	84.8	117
145	155	10250	49.2	96.3	394
146	213	20830	60.3	98.5	327

Number of Individuals =
(Number of individuals in 10cc) x (L/Tl value) / 100
Pl: Planktonic foraminifera; Be: Benthonic foraminifera;
Rads: Radiolaria.

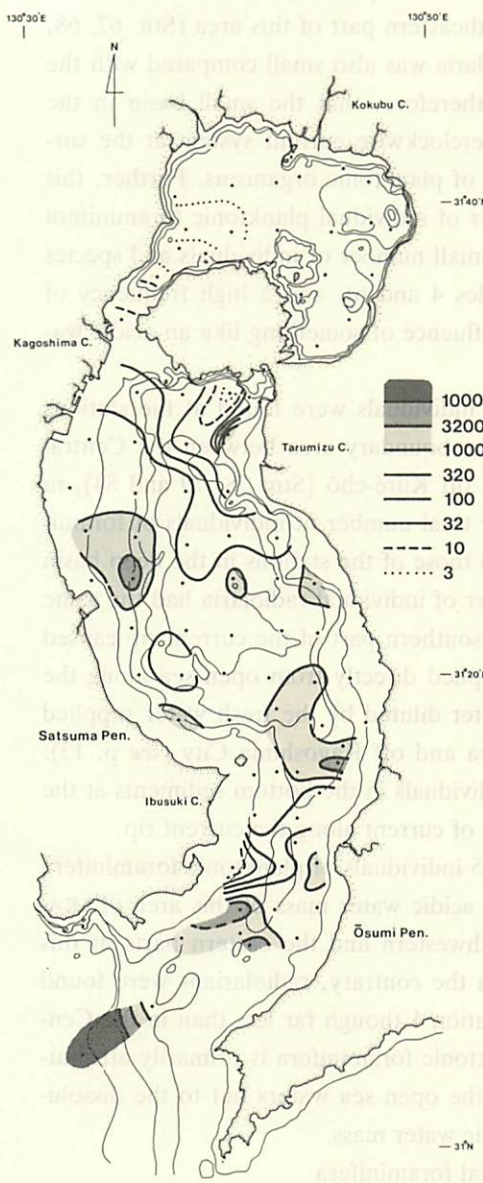

Fig. 19. Distribution of the number of individuals of planktonic foraminifera.

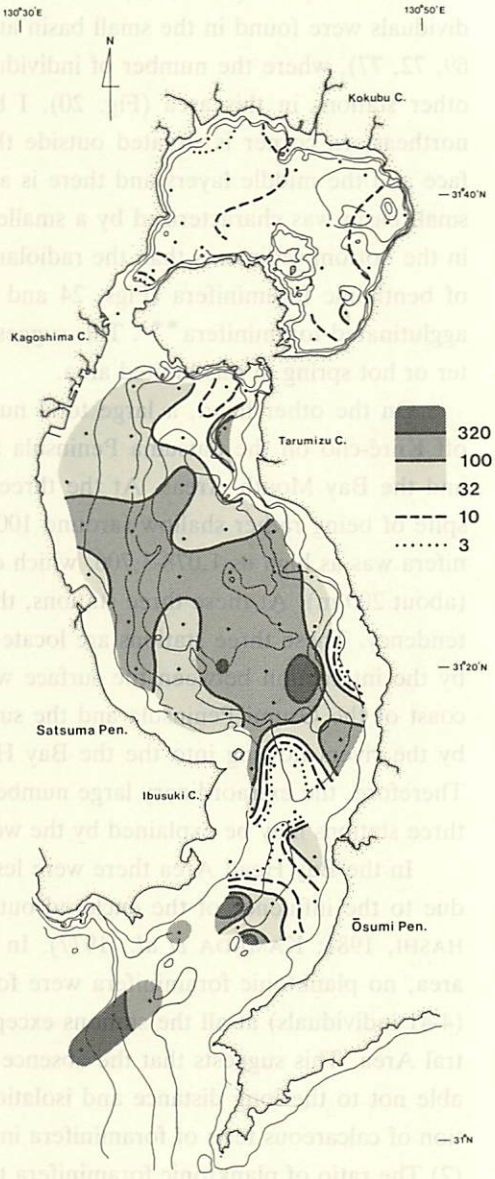

Fig. 20. Distribution of the number of individuals of radiolaria.

and southern parts (300-3,706). Stations which had an exceptionally small number of individuals were found in the small basin at the northeastern part of this area (Stn. 67, 68, 69, 72, 77), where the number of individual radiolaria was also small compared with the other stations in this area (Fig. 20). I believe, therefore, that the small basin in the northeastern corner is situated outside the counterclockwise current system at the surface and the middle layers and there is a scarcity of planktonic organisms. Further, this small basin was characterized by a smaller number of individual planktonic foraminifera in the bottom sediments than the radiolaria*), a small number of individuals and species of benthonic foraminifera (Figs. 24 and 25; Tables 4 and 6), and a high frequency of agglutinated foraminifera**). This suggests the influence of something like an acidic water or hot spring in this limited area.

On the other hand, a large total number of individuals were found at the stations off Kiiré-chō on the Satsuma Peninsula and at the boundary area between the Central and the Bay Mouth Areas. At the three stations off Kiiré-chō (Stn. 78, 79 and 84), in spite of being rather shallow (around 100 m), the total number of individuals of foraminifera was as high as 1,078-3,706, which exceeded those of the stations in the deep basin (about 200 m). At these three stations, the number of individual radiolaria had the same tendency. These three stations are located at the southern part of the current rip caused by the interaction between the surface water supplied directly from open sea along the coast of the Ōsumi Peninsula and the surface water diluted by the fresh water supplied by the rivers flowing into the the Bay Head Area and off Kagoshima City (*see* p. 13). Therefore, the extraordinary large numbers of individuals in the bottom sediments at the three stations may be explained by the weakening of current along the current rip.

In the Bay Head Area there were less than 25 individuals of planktonic foraminifera due to the influence of the enclosed outline and acidic water mass of this area (TAKAHASHI, 1981; KAMADA *et al.*, 1977). In the northwestern and the eastern parts of this area, no planktonic foraminifera were found. On the contrary, radiolarians were found (4-41 individuals) at all the stations except for Station 1 though far less than in the Central Area. This suggests that the absence of planktonic foraminifera is primarily attributable not to the long distance and isolation from the open sea waters but to the dissolution of calcareous tests of foraminifera in the acidic water mass.

(2) The ratio of planktonic foraminifera to the total foraminifera

Planktonic foraminifera contents in the sediments of the Bay Mouth and the Central Areas (Fig. 21) were directly related to water depth. As shown in Figure 22, the data of almost all the stations are plotted on or near the parabolic line drawn in relation to water depth. As seen in Figure 22, the stations where the planktonic foraminifera contents were far less than the values at the corresponding depth on the parabolic line are in the northeastern part of the Central Area and in the area ranging from the southwestern part of the Central Area to the northwestern part of the Bay Mouth Area (Fig. 23).

*) At Stations 68, 72 and 77, the Pl/Pl+Rads values range from 12.5 to 57.5 (Table 5).

**) At Station 68 off the Furusato Spa, the frequency of agglutinated foraminifera attains to 96.9%.

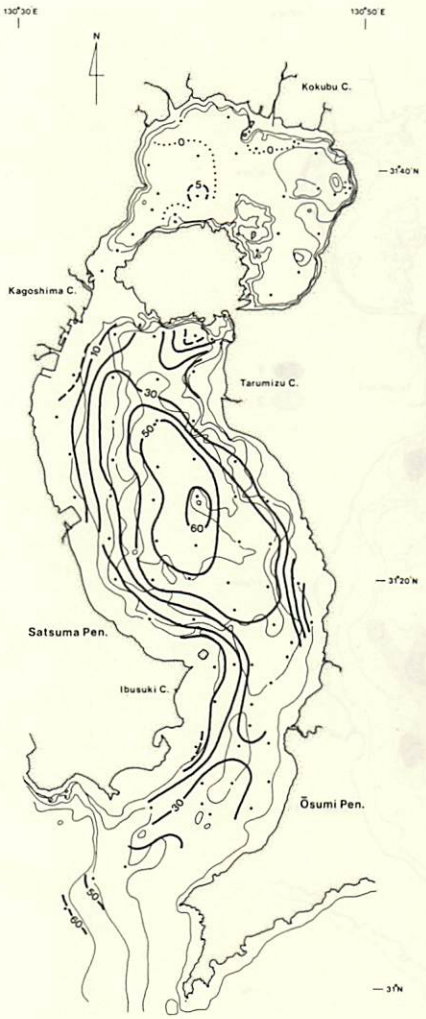

Fig. 21. Distribution of the ratios of planktonic foraminifera to the total foraminifera.

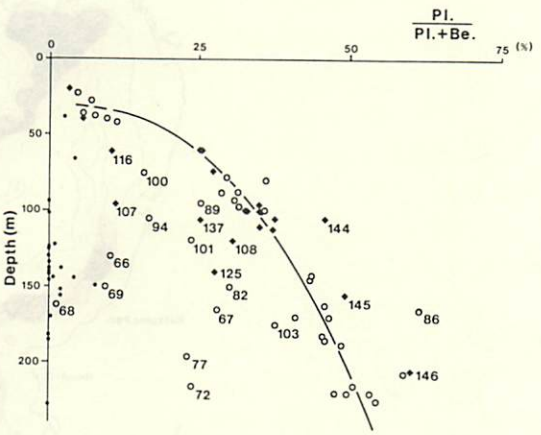

Fig. 22. Correlation between the frequency of planktonic foraminifera in the bottom sediments and the water depth (◆: Bay Mouth Area; ○ : Central (Area; • ; Bay Head Area). Parabolic line was drown omitting the stations of extremely low ratios.

Both areas are situated outside of the counterclockwise current system assumed to exist in the Central Area of the bay.

The planktonic foraminifera contents in the Bay Head Area were quite abnormal reflecting the existence of the acidic water mass. The sediments of almost all the stations in the Bay Head Area did not contain the test of planktonic foraminifera, except for the 11 stations in the West-Sakurajima Passage and the western, northern and northeastern parts of the Bay Head Area, where low values of planktonic foraminifera contents (0.6-7.8%) were obtained.

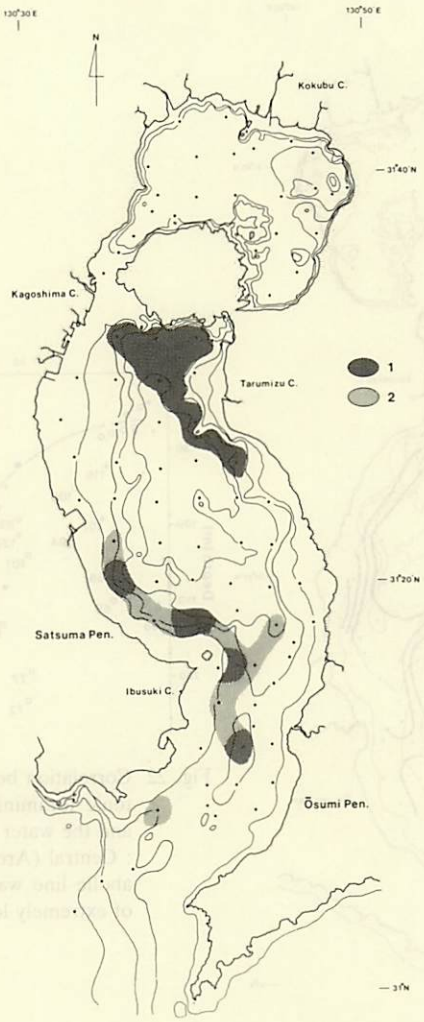

Fig. 23. Areas of the low ratio of planktonic foraminifera to the total foraminifera at the corresponding depth compared with the values on the parabolic line (Fig.22) except for the Bay Head Area (1: extraordinary low ratio; 2: low ratio).

5. Benthonic foraminifera

(1) General features of benthonic foraminifera

a) Number of individuals

The number of individuals at each station was estimated considering the rate of sedimentation (*see* p. 29) and is shown in Table 4 and their corresponding curves are shown in Figure 24.

In the open sea area, the number of individuals was 767 at Station 144 (105 m deep) and more than 10,000 at Stations 145 and 146 (both deeper than 155 m).

In the Bay Mouth Area, the stations which had rather large numbers of individuals (Stn. 106, 107, 116, 132, 137 and 143) were distributed in the northwestern (off Ibusuki City) and the southern part facing the open sea, and those which had rather small numbers (Stn. 113, 118, 124 and 125) were at the deepest part of the channel topography.

The number of individuals in the Central Area corresponded indirectly with the water depth, namely, generally larger in the shallow water part along the coast and smaller at the basin bottom. At the basin bottom, it decreased from south to north, and particularly, at Stations 68, 72 and 77 in the northeastern part supposed to be occupied by a water mass with some peculiar property (*see* p. 36), numbers of individuals were exceptionally small (52-76). On the other hand, the stations showing conspicuously large numbers of individuals were, without exception, in the shallow water along the coastline: from 9,103 to 10,104 at Stations 78, 83 and 84 off Kiiré and 8,873 at Station 99 in the southeastern part of the Central Area. This is interpreted as the influence of nutritious water mass mixed with sewage of human life (NOZAWA and SAISHO, 1980).

In the Bay Head Area, the number of individuals was generally less than 120, except for the six stations in the West-Sakurajima Passage and its environs where it ranged from 130 to 600. The small numbers in this area probably resulted from the existence of an acidic water mass caused by the sea bottom fumaroles of this area.

b) Number of species

Through the present study, 317 species of benthonic foraminifera belonging to 130 genera were collected from the 86 stations within Kagoshima Bay and the three stations outside the bay. For comparison, number of species recognized in 200 individuals picked up at random from each sample is shown in Table 6 and the equivalent curves are in Figure 25.

As seen in Table 6, the numbers of species in the open sea and the Bay Mouth Areas are large (about 60 species) and tend to decrease toward the Bay Head Area.

In the Central Area, most stations had about 50 species, except for the seven stations (Stn. 88, 92, 98, 99, 100, 101 and 102) in the southeastern part which had more than 60 species and the four stations (Stn. 68, 72, 77 and 82) in the northeastern part which had less than 30 species.

In the Bay Head Area, the number of species ranged from 37 to 49 among the four stations (Stn. 44, 63, 64 and 65) in the West-Sakurajima Passage and was less than 30 at

Table 6. Number of species, species diversity and equitability of benthonic foraminifera and the frequency of each type of the test.

Station	Number of Species	Number of Individuals	Diver.	Equi.	Agglu. Tests (%)	Porcel. Tests (%)	Hyaline Tests (%)
1	10	5	1.61	0.50	100	0	0
3	13	36	1.21	0.26	100	0	0
12	14	15	1.82	0.44	98.0	1.0	1.0
15	9	12	1.42	0.46	78.6	0	21.4
17	20	28	1.67	0.26	45.5	0	54.5
18	12	32	1.62	0.42	90.9	0	9.1
21	12	24	1.90	0.56	100	0	0
22	24	37	1.85	0.26	21.6	0	78.4
32	28	459	2.23	0.33	40.5	0	59.5
34	34	69	2.22	0.27	7.6	0.8	91.6
35	13	91	1.41	0.31	100	0	0
37	23	112	1.65	0.23	100	0	0
40	10	40	1.68	0.54	100	0	0
41	18	29	2.33	0.57	95.9	0	4.1
42	30	40	2.74	0.51	97.5	0	2.5
44	46	185	2.79	0.35	36.8	0	63.2
45	30	134	2.24	0.31	48.8	0	51.2
51	14	78	1.54	0.33	100	0	0
53	20	21	1.76	0.29	40.9	0.6	58.5
54	16	109	1.42	0.26	97.4	0	2.6
58	16	45	1.76	0.36	100	0	0
61	12	15	1.43	0.35	100	0	0
63	65	348	3.50	0.51	24.4	0	75.6
64	60	585	3.19	0.14	5.9	14.3	79.8
65	66	274	3.36	0.44	5.8	4.7	89.5
66	57	2145	3.54	0.61	32.2	0.8	67.0
67	52	169	2.92	0.36	24.6	0.5	74.9
68	22	52	1.81	0.28	96.9	0	3.1
69	34	608	2.34	0.31	34.5	0	65.5
70	55	9024	3.55	0.63	8.0	10.8	81.2
71	57	727	3.24	0.45	7.8	0.3	91.9
72	42	76	2.51	0.29	29.5	0.8	69.7
73	79	2169	3.82	0.58	9.6	1.3	89.1
74	65	4478	3.70	0.62	3.8	5.5	90.7
75	60	1890	3.10	0.37	8.4	0.5	91.1
76	53	457	3.16	0.44	17.2	2.7	80.1
77	36	58	2.64	0.39	39.3	0.4	60.3
78	49	10104	3.43	0.63	7.1	7.5	85.4
79	60	2556	3.20	0.41	3.9	1.5	94.6
80	54	193	3.11	0.42	20.7	0.9	78.4
81	54	178	2.94	0.35	27.7	2.0	70.3
82	48	615	2.81	0.35	31.3	0.3	68.4
83	66	9562	3.66	0.59	7.5	4.8	87.7
84	54	9103	3.33	0.52	3.6	0.7	95.7
85	50	376	3.17	0.48	30.7	0.4	68.9
86	75	653	3.67	0.52	18.6	1.3	80.1
87	73	533	3.63	0.52	10.4	1.2	88.4
88	78	4588	3.91	0.64	7.8	1.0	91.2
89	54	2001	3.15	0.43	7.5	0.4	92.1
90	55	314	3.25	0.47	21.0	3.1	75.9
91	60	420	3.41	0.51	18.5	0.9	80.6
92	74	809	3.87	0.65	13.6	0	86.4
93	69	727	3.58	0.52	7.2	2.1	90.7
94	55	1750	3.40	0.54	7.9	0.4	91.7
95	41	359	2.89	0.44	15.7	0	84.3
96	52	842	3.29	0.52	19.1	1.2	79.7
97	54	920	3.44	0.58	18.6	0.5	80.9
98	66	3481	3.69	0.61	7.4	0	92.6
99	70	8873	3.68	0.57	13.9	8.0	78.1
100	63	6975	3.73	0.66	7.5	2.2	90.3
101	74	1431	3.66	0.53	8.0	3.6	88.4
102	63	1299	3.58	0.57	8.3	0	91.7
103	55	1312	3.48	0.59	10.2	0.3	89.5
104	68	4041	3.73	0.61	11.4	5.5	83.1
105	53	2316	3.46	0.60	7.7	1.8	90.5
106	58	13766	3.65	0.66	3.6	13.8	82.6
107	65	5847	3.63	0.58	2.5	5.8	91.7
108	64	4459	3.57	0.55	2.2	7.6	90.2
110	69	6317	3.61	0.53	2.7	2.7	94.6
113	69	498	3.66	0.56	8.1	4.1	87.8
116	61	6930	3.65	0.63	2.3	6.5	91.2
118	64	501	3.72	0.64	6.0	7.4	86.6
122	68	1161	3.69	0.59	4.7	3.7	91.6
124	48	89	3.31	0.57	7.0	20.5	72.5
125	61	313	3.52	0.55	6.7	4.2	89.1
127	65	3179	3.68	0.61	7.6	8.2	84.2
132	76	13791	3.68	0.52	3.6	2.7	93.7
134	65	1386	3.63	0.58	3.6	0.4	96.0
136	78	1825	3.85	0.60	10.8	5.7	83.5
137	77	8773	3.88	0.63	4.8	10.0	85.2
139	103	4017	3.99	0.53	3.5	5.1	91.4
141	65	1594	3.67	0.60	7.2	8.3	84.5
143	81	8894	3.84	0.57	7.0	5.1	87.9
144	78	767	3.93	0.65	14.4	10.8	74.8
145	57	10645	3.56	0.62	9.5	13.8	76.7
146	65	13741	3.67	0.61	8.3	8.7	83.0

Number of Individuals = (Number of individuals in 10cc) x (L/Tl value) / 100
Diver.: Diversity; Equi.: Equitability; Agglu.: Agglutinated; Porcel.: Porcelaneous

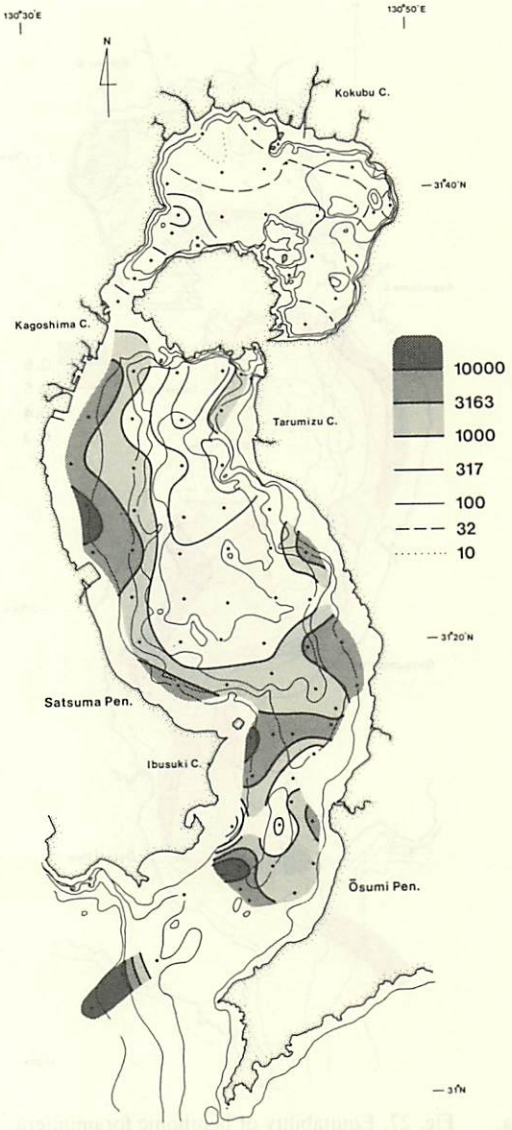

Fig. 24. Distribution of the number of individuals of benthonic foraminifera (N = L/Tl × number of individuals in 10 cc of bottom sediments).

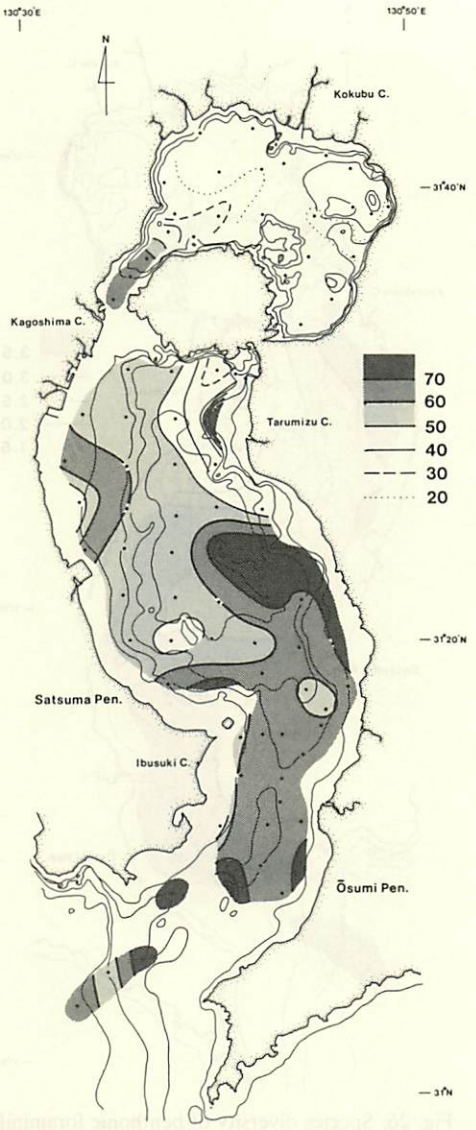

Fig. 25. Number of benthonic foraminiferal species.

the rest of the stations. Particularly, the six stations (Stn. 1, 3, 15, 17, 18 and 35) in the northwestern part, Station 40 at the 200 m deep basin and Station 61 at the innermost part of the Bay Head Area had a remarkably small number of species of less than 10.

c) Species diversity and equitability

Species diversity and equitability*) are shown in Table 6, and the equivalent diversity curves are in Figure 26 and those of equitability are in Figure 27. The relation-

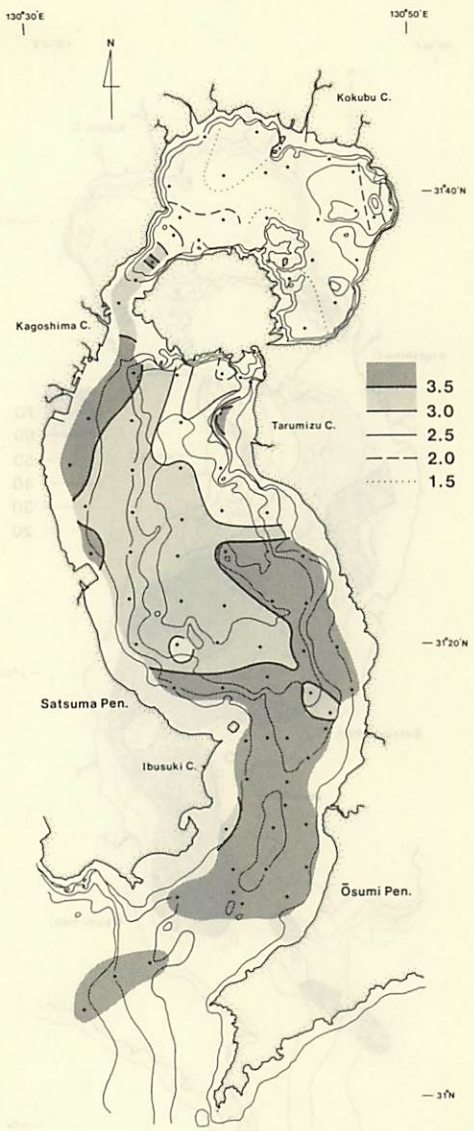

Fig. 26. Species diversity of benthonic foraminifera.

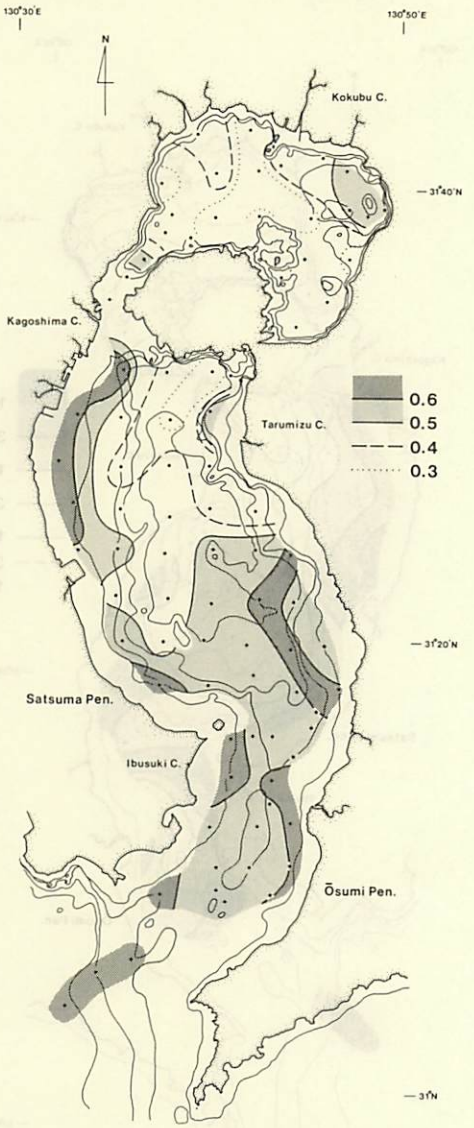

Fig. 27. Equitability of benthonic foraminifera.

ships between water depth and each of the three parameters (species diversity, equitability and number of species) are shown in Figure 28.

As seen in Figure 26, the distribution pattern of the species diversity tends to be much the same as that of the numbers of species (Fig. 25).

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*) SHANNON-WEAVER's function as somewhat revised by BUZAS and GIBSON (1969) is available for calculating of species diversity and equitability (ISHIZAKI and TANIMURA, 1985).
Species diversity and equitability are computed by

$$H = -\sum_{i=1}^{S} p_i \log(p_i), \text{ and } E = \exp(H)/S$$

where p stands for the proportion of the th species in a sample, and S the number of species.

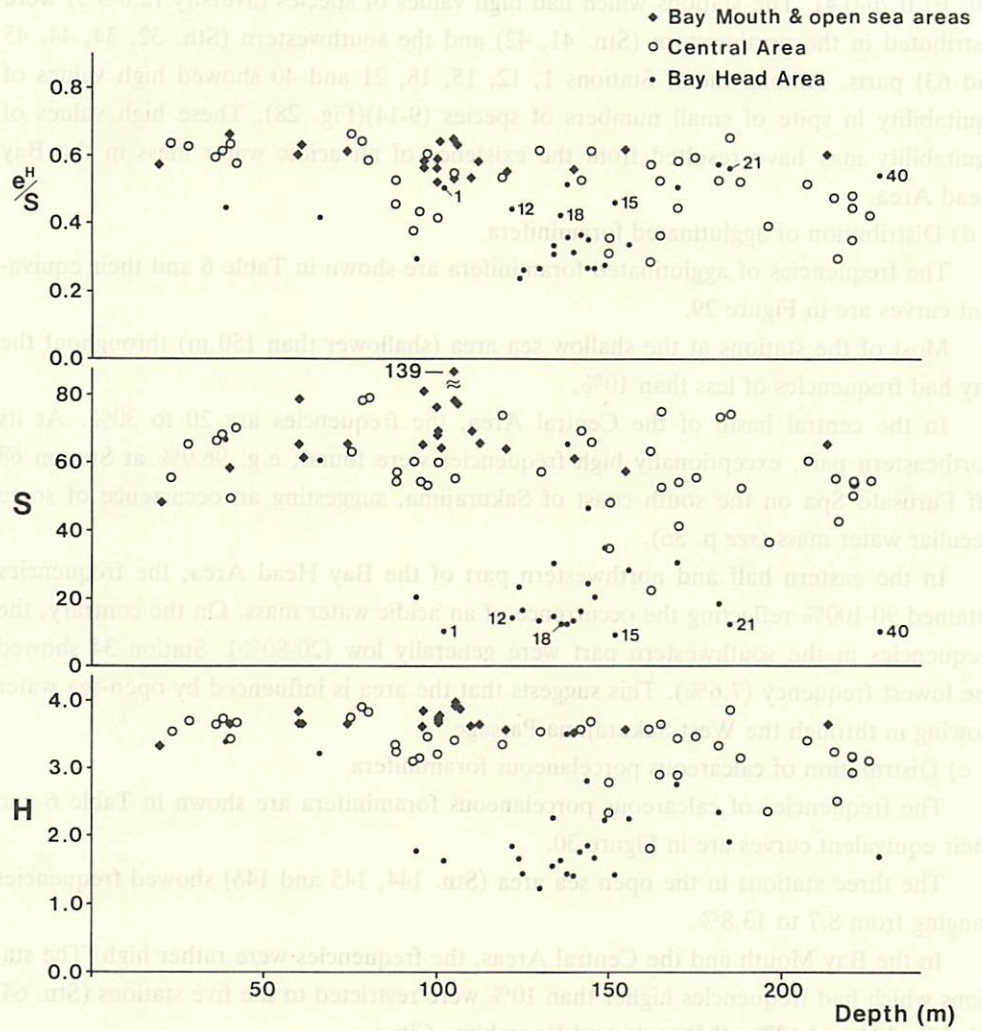

Fig. 28. Diagram showing the relationships between water depth and each of the three parameters; number of species(S), species diversity(H) and equitability.

In the Bay Mouth Area, the values of species diversity were more than 3.5 except for one station (Stn. 124), and the values of equitability were more than 0.5. The five stations (Stn. 136, 137, 139, 143 and 144) which had species diversity values of more than 3.8 were distributed in the boundary between the open sea and Bay Mouth areas.

In the Central Area, the stations showing rather high values of species diversity and equitability (D: 3.5; E: 0.5) were distributed in the southeastern and northwestern parts. The stations (Stn. 67, 68, 69, 72, 77, 81 and 82) which had low values (D: 1.8-3.0; E:< 0.4) were distributed in the northeastern part situated outside of the counterclockwise current system as already mentioned in the preceding chapter (*see* p.18, 37).

In the Bay Head Area, the diversity and equitability values were rather low (D: 1.2-

2.0; E: 0.26-0.4). The stations which had high values of species diversity (2.0-3.5) were distributed in the northeastern (Stn. 41, 42) and the southwestern (Stn. 32, 34, 44, 45 and 63) parts. Among them, Stations 1, 12, 15, 18, 21 and 40 showed high values of equitability in spite of small numbers of species (9-14)(Fig. 28). These high values of equitability may have resulted from the existence of an acidic water mass in the Bay Head Area.

d) Distribution of agglutinated foraminifera

The frequencies of agglutinated foraminifera are shown in Table 6 and their equivalent curves are in Figure 29.

Most of the stations at the shallow sea area (shallower than 150 m) throughout the bay had frequencies of less than 10%.

In the central basin of the Central Area, the frequencies are 20 to 30%. At its northeastern part, exceptionally high frequencies were found, e.g. 96.9% at Station 68 off Furusato Spa on the south coast of Sakurajima, suggesting an occurrence of some peculiar water mass (*see* p. 36).

In the eastern half and northwestern part of the Bay Head Area, the frequencies attained 90-100% reflecting the occurrence of an acidic water mass. On the contrary, the frequencies in the southwestern part were generally low (20-80%). Station 34 showed the lowest frequency (7.6%). This suggests that the area is influenced by open-sea water flowing in through the West-Sakurajima Passage.

e) Distribution of calcareous porcelaneous foraminifera

The frequencies of calcareous porcelaneous foraminifera are shown in Table 6 and their equivalent curves are in Figure 30.

The three stations in the open sea area (Stn. 144, 145 and 146) showed frequencies ranging from 8.7 to 13.8%.

In the Bay Mouth and the Central Areas, the frequencies were rather high. The stations which had frequencies higher than 10% were restricted to the five stations (Stn. 64, 70, 106, 124 and 137) off Ibusuki and Kagoshima Cities.

The frequencies were 0 to 3.6% at the bottom of the Central Area deeper than 100 m and 0 to 1.0% at the basin bottom in the Bay Head Area.

(2) Recognition of the species groups of benthonic foraminifera by cluster analysis and their distribution

Based on the frequencies of the 122 predominant species (Table 7) collected from Kagoshima Bay, a cluster analysis was carried out and a dendrogram (Fig. 31) was obtained based on the frequencies (%) of each species. As a result, the samples collected from the 86 stations were grouped into six groups at the level of 3.0 distance coefficient (Figs. 31 and 32). At the level of 2.0 distance coefficient, Group I was subdivided into three Subgroups (Ia-c), Group II into four Subgroups (IIa-d) and Group V into six Subgroups (Va-f). Further, Subgroup Vd was divided into four minor groups (Vd1-Vd4) at the level of 1.6 distance coefficient and Ve into three minor groups at the level of 1.5 distance coefficient (Ve1-Ve3). The predominant species and the distribution

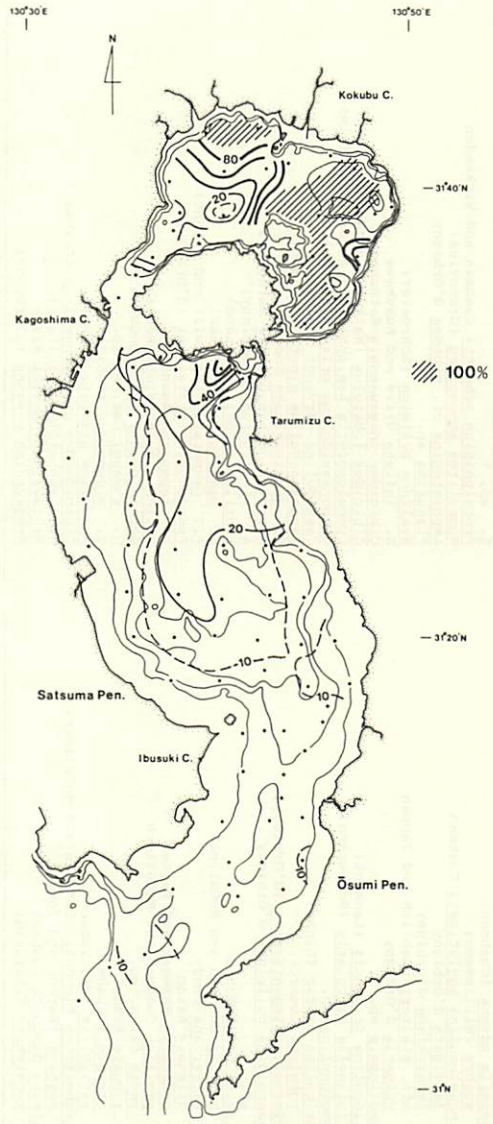

Fig. 29. Distribution of the frequencies (%) of agglutinated foraminifera.

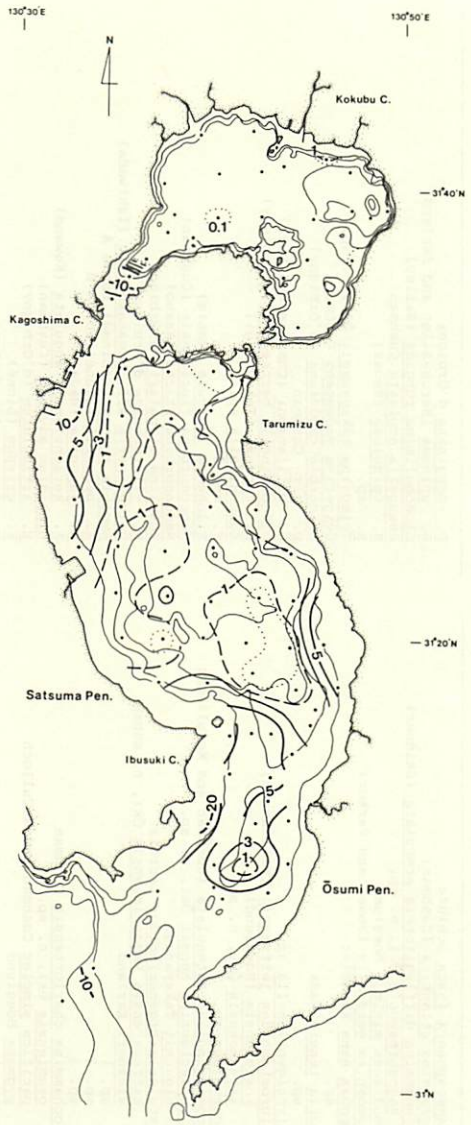

Fig. 30. Distribution of the frequencies of calcareous porcelaneous foraminifera.

Table 7. List of the predominant species used for cluster analysis.

Psammosphaera fusca Schluze
Saccammina atlantica (Cushman)
Lagenammina difflugiformis arenulata (Skinner)
L. kagoshimaensis Ōki, n. sp.
Ammodiscus minimus Hoeglund
Glomospira gordialis (Jones and Parker)
Reophax nana Rhumbler
R. sp.
Nouria tenuis Hada
N. sp.
Spirosigmoilinella sp.
Cribrostomoides jeffreysii (Williamson)
C. kosterensis (Hoeglund)
C. satsumaensis Ōki, n. sp.
Recurvoides sp.
Ammomarginulina catenulata (Cushman and McCulloch)
Spiroplectammina henmii Ōki, n. sp.
S. higuchii Takayanagi
Textularia bigenerinoides Lacroix
T. kattegatensis kagoshimaensis Ōki, n. subsp.
T. wiesneri Earland
T. sp. 1
T. sp. 2
T. sp. 3
Trochammina charlottensis Cushman
T. osumiensis Ōki, n. sp.
T. pacifica simplex Cushman and McCulloch
T. pygmaea Hoeglund
T. sp. 1
Gaudryina nitida Haque
Dorothia sp.
Eggerella advena (Cushman)
E. scabra (Williamson)
Quinqueloculina agglutinata Cushman
Q. laevigata d'Orbigny
Q. lamarckiana d'Orbigny
Q. aff. stalkeri Loeblich and Tappan
Q. vulgaris d'Orbigny
Sigmoilopsis sp.
Triloculina trigonula (Lamarck)
Miliolinella circularis (Bornemann)
Nummoloculina sp.
Lenticulina calcar (Linné)
L. rotulata Lamarck
Buliminella elegantissima (d'Orbigny)
Sphaeroidina bulloides d'Orbigny
S. sp.
Bolivina hadai Uchio
B. humilis Cushman and McCulloch
B. karreriana Brady
B. kiiensis Asano
B. ordinaria Phleger and Parker
B. pacifica Cushman and McCulloch
B. retia Ōki n. sp.
B. robusta Brady
B. striatula Cushman
B. variabilis (Williamson)
Rectobolivina hancocki (Cushman and McCulloch)
R. raphana (Parker and Jones)
Bulimina denudata Cushman
B. kochiensis Takayanagi
B. marginata d'Orbigny
B. spinosa (Heron-Allen and Earland)
Globobulimina turgida (Bailey)
Reussella aculeata Cushman
R. spinulosa (Reuss)
R. sp.
Trimosina takayanagii Ōki, n. sp.
Uvigerina vadescens Cushman
Discorbis candeiana (d'Orbigny)
D. mira Cushman
D. williamsoni (Chapman and Parr)
Discorbinella bertheloti (d'Orbigny)
D. convexa (Takayanagi)
Eoeponidella sp. 1
E. sp. 3
Eilohedra levicula (Resig)
Neoconorbina floridensis (Cushman)
Neoconorbina stachi (Asano)
Rosalina globularis d'Orbigny
R. vilardeboana d'Orbigny
Valvulineria aff. hamanakoensis (Ishiwada)
Ammonia beccarii (Linné) forma A
A. beccarii (Linné) forma B
A. japonica (Hada)
A. ketienziensis angulata (Kuwano)
Elphidium advenum (Cushman)
E. articulatum (d'Orbigny)
E. crispum (Linné)
E. depressulum Cushman
E. jenseni (Cushman)
E. selseyensis (Heron-Allen and Earland)
E. sp. 1
Protelphidium schmitti Cushman and Wickenden
Nummulites ammonoides (Gronovius)
Amphistegina cf. gibbosa d'Orbigny
Planulina sp.
Hyalinea balthica (Schroeter)
H. inflata Ujiié and Kusukawa
Cibicides inagawaensis Matsunaga
Cibicides lobatulus (Walker and Jacob)
Cymbaloporetta hemisphaerica Accordi and Selmi
Globocassidulina oriangulata Belford
Cassidulina nørvangi Thalmann
Paracassidulina minuta (Cushman)
P. quasicarinata Nomura
Astrononion hanyudaense Matsunaga
A. stelligerum (d'Orbigny)
Florilus japonicus (Asano)
F. manpukuziense (Otuka)
F.? pauperatus (Balkwill and Wright)
Pseudononion grateloupi (d'Orbigny)
P. japonicum Asano
Pullenia quinqueloba Reuss
Gyroidinoides acuta Boomgaart
G. kuwanoi Ōki, n. sp.
G. nipponicus (Ishizaki)
Anomalina glabrata Cushman
Cibicidoides pseudoungeriana (Cushman)
C.? subhaidingerii (Parr)
Hanzawaia nipponica Asano
Hoeglundina elegans (d'Orbigny)

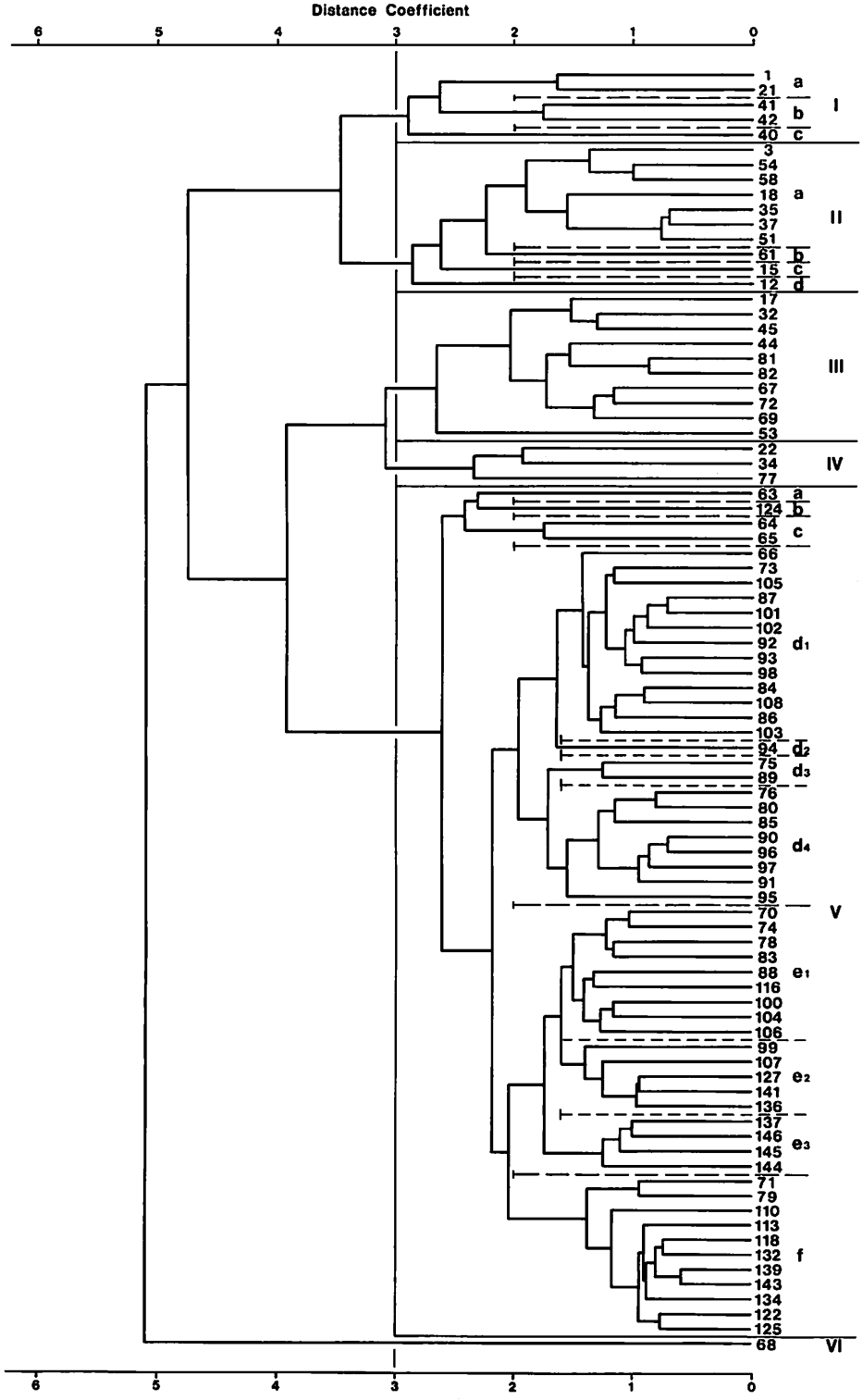

Fig. 31. Dendrogram for benthonic foraminifera.

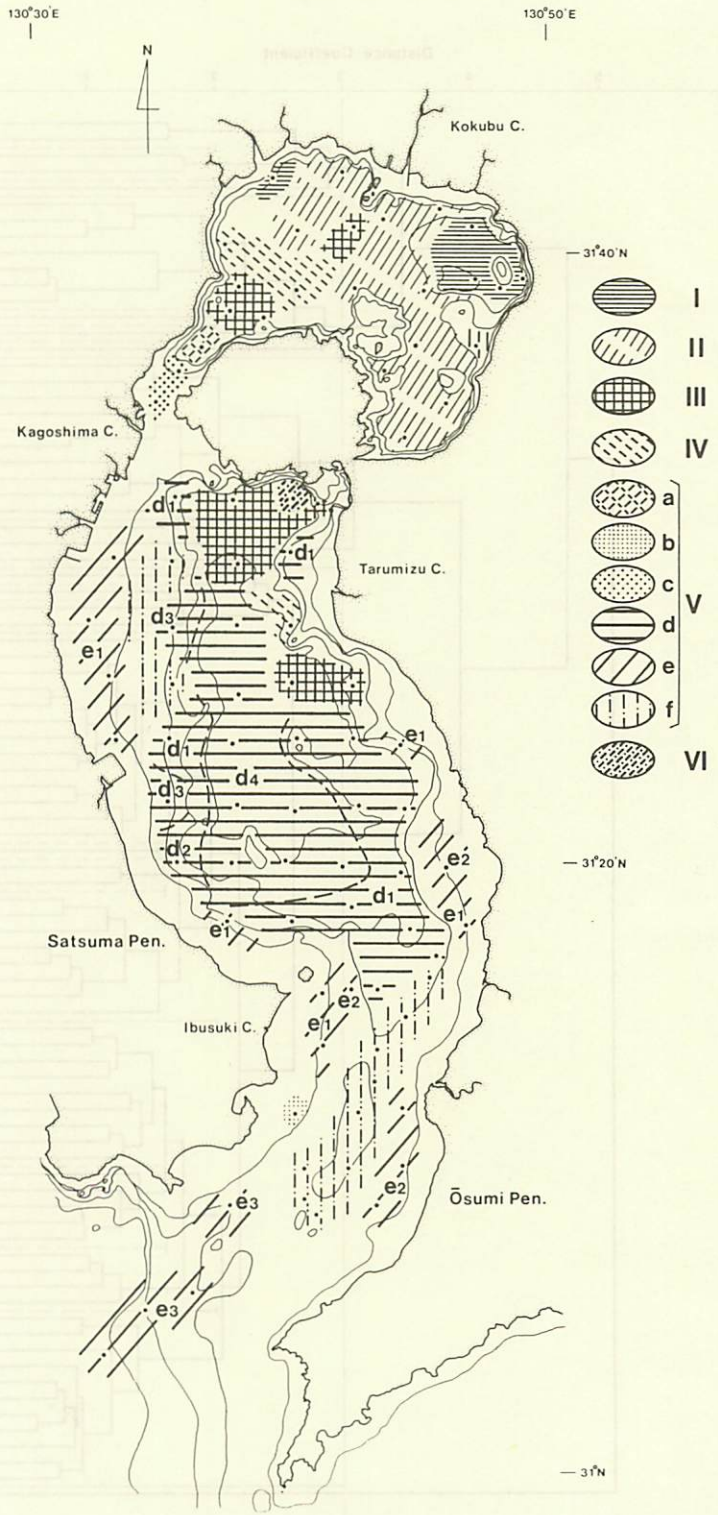

Fig.32. Distribution of the groups of benthonic foraminifera recognized by cluster analysis.

of each Group, Subgroup or minor group are shown in Table 8.

On the 122 species of benthonic foraminifera used for cluster analysis, the frequency of each species in each group is shown in Figure 33.

6. Relation between the number of individuals in each group and the water depth of their habitat

As already mentioned (p.11-13), water temperature and salinity in Kagoshima Bay showed a striking contrast between the water masses above and below a depth of about 100 m. The water mass deeper than 100 m showed rather stable water temperature (14-18°C) and salinity (34.00-34.80‰) throughout the year, while the water shallower than 75 m showed remarkable seasonal changes in water temperature and salinity (Figs. 4 and 5). This may be related to some extent to the existence of the saddle-like topography at the Bay Mouth Area at about 100 m. The open-sea water flowing into the bay through the bay mouth strongly influences the water characters of middle and surface layers, which are shallower than the deepest area at the Bay Mouth (TAKAHASHI, 1981). On the contrary, it does not influence the stagnant water mass having larger specific gravity (Faculty of Fisheries, Kagoshima University, 1975-1977; NOZAWA and SAISHO, 1980; TAKAHASHI, 1981) at the depths greater than 100 m in the Central Area.

On the other hand, the assemblages of benthonic foraminifera in Kagoshima bay indicated a clear difference in species composition between the areas shallower and deeper than 100 m. This seemed to correspond to the differences in water temperature and salinity mentioned above. Therefore, I tried to arrange the groups discriminated by the cluster analysis based on the depth of occurrence. As a result, the groups were grouped into three major groups bounded by and striding over the depth of 100 m. These three major groups are shown in Table 9 with the number of individuals in the unit sample of each group.

As seen in Table 9, the number of individuals in each group of foraminifera tended to be large in the shallow areas and decreased as the water depth increased, except for a few groups which could be explained by the existence of some controlling factors other than the water depth.

(1) The groups which occurred below 100 m in depth

a) The groups which had less than 920 individuals

a-1) The groups which occurred in stagnant water in the deep basin at the Bay Head Area and on the basin bottom at the northeastern part of the Central Area (Groups I, II, IV and VI). The number of individuals ranged from 5 to 112.

a-2) The group distributed on the deepest bottom at the West-Sakurajima Passage (Group Va).

a-3) The group which occupied the basin bottom in the Central Area except for its northeastern part (Group Vd4).

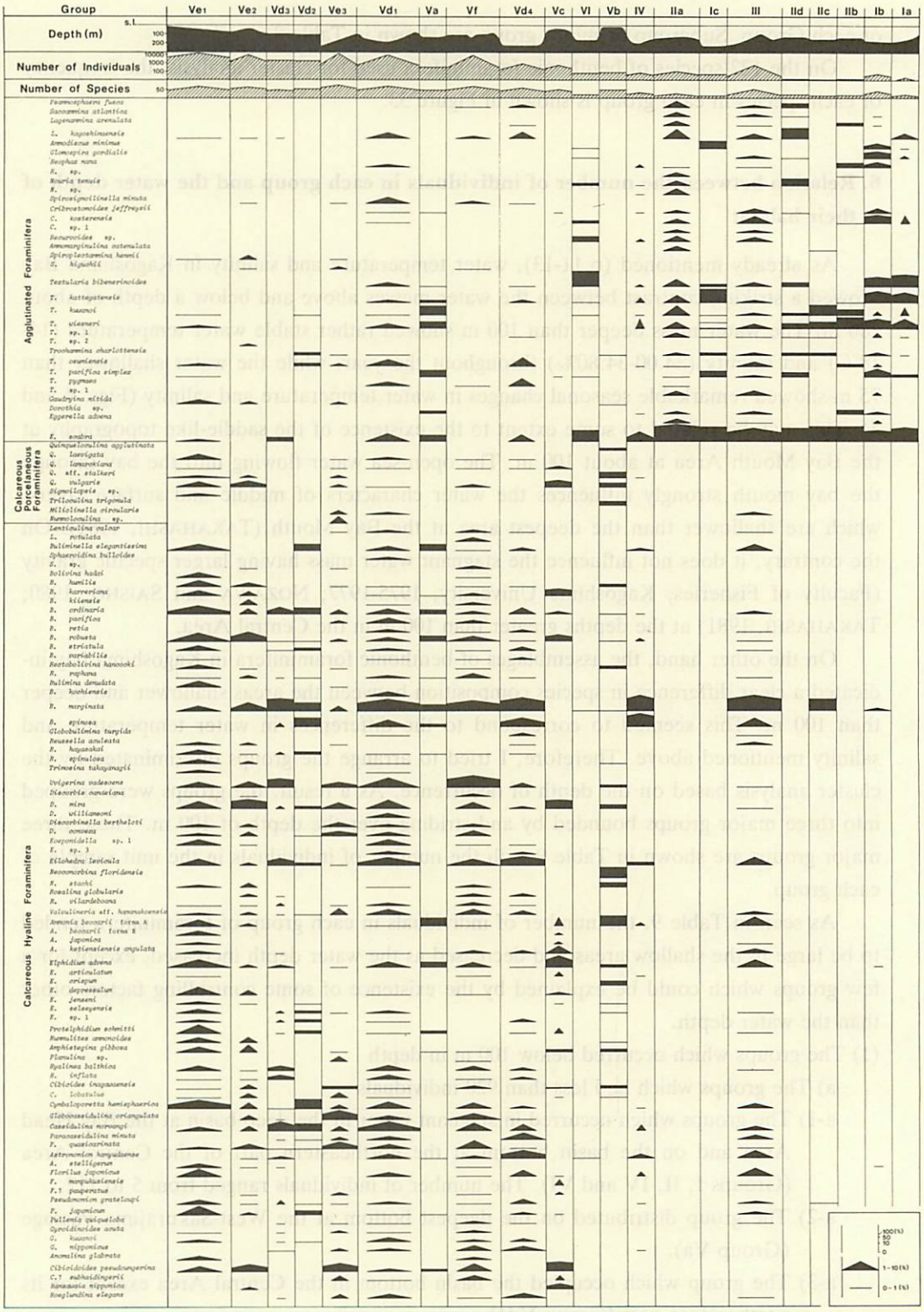

Fig. 33. Frequency of predominant species in each group. The groups are arranged in order of the number of benthonic foraminifera.

b) The groups which had an exceptionally large number of individuals

b-1) The group which occurred on the slope coming down to the basin bottom in the southwestern part of the Central Area, an area influenced by different water masses in each season resulting in a mixture of species of different ecology (Group Vd2).

b-2) The group which inhabited the open-sea bottom and the bottom in the southwestern part of the Bay Mouth under the influence of the Kuroshio Current throughout the year (Group Ve3).

(2) The groups which occurred above 100 m in depth

a) The groups which had more than 1,500 individuals

a-1) The group which occurred at the marginal part of the flat submarine terrace developed along the Satsuma Peninsula, which corresponds to the boundary between the two water masses (Group vd3).

a-2) The groups which inhabited the shallow bottom along the Satsuma Peninsula under the influence of the low salinity and highly nutritious water (NOZAWA and SAISHO, 1980)(Groups Ve1 and Ve2).

b) The groups which had an exceptionally small number of individuals

b-1) The group recognized at Station 124 (24 m in depth) in the shallow area off Yamakawa. The small number of individuals were judged resulted from the destruction of foraminiferal tests by a strong bottom current suggested by the coarse bottom sediments (pebbly sands)(Group Vb).

b-2) The group which occurred on the shallow pebbly sand bottom in the West-Sakurajima Passage, where the strongest tidal current throughout the bay was observed.

(3) The groups distributed across the depth of 100 m

Bulimina marginata having a wide depth range of habitat was recognized as the predominant species in each group. The total numbers of individuals showed a wide range because the distribution covered two different water masses.

a) The group which occupied the basin bottom and the surrounding slopes in the southwestern part of the Bay Head Area and the northeastern part of the Central Area (Group III).

b) The group recognized to occur on the slope (80-185 m in depth) surrounding the basin bottom in the Central Area (Group Vd1).

c) The group which occurred at the margin of the shallow submarine terrace along the Satsuma Peninsula, which corresponds to the boundary between the two water masses different in salinity, and on the deepest bottom of the channel topography in the Bay Mouth Area (Group Vf).

Table 9. Groups of benthonic foraminifera arranged after the water depth of their habitat and the number of individuals in each group.

Depth (m)		Relative abundance of the representative species	Number of Individuals in each Bottom Sample	Environmental Condition and Distribution Area
	102-185	I a: Es(31-39%)-Tb(23-25%)-Tk(7-14%)-Tw(3-12%)	5- 24	a-1) Stagnant water in the deep basin (Bay Head Area; NE part of the Central Area).
	170-182	I b: Es(15-18%)-Tk(10-23%)-Tb(9-11%)-Tw(7-17%)-Ck-Gg	29- 40	
	228	I c: Es(40%)-Tk(29%)-Am-Gg	40	
	124-142	IIa: Es(50-70%)	32- 112	
	138	IIb: Es(56%)-Tw(20%)	15	
100	152	IIc: Es(48%)-Bm(20%)-T1(17%)	12	
	122	IId: Es(38%)-Lk(18%)	15	
	144-196	IV : Bm(24-41%)-Bs(15-30%)-Es(3-16%)	37- 69	
	162	VI : Tb(48%)-Es(20%)-Tw	52	
	138	V a: T1(11%)-Ab	348	a-2) Deepest bottom at the West-Sakurajima Passage.
	170-225	Vd4: Bm(16-27%)-El-Bs	193- 920	a-3) Main part of the basin bottom (Central Area).
	105	Vd2: Ch(11%)-Bs(10%)-Bm-Cn	1750	b-1) Influenced by different water mass in each season. Slope surface (SW part of the Central Area).
	105-213	Ve3: Go(4-11%)-Cp	767-13741	b-2) Influenced by Kuroshio Current throughout the year. (SW part of the Central Area).
	94-220	III : Bm(20-54%)-Es(10-35%)	21- 615	a) Basin bottom and the surrounding slope (SW part of the Bay Head Area; NE part of the Central Area).
Transition	80-185	Vd1: Bm(7-18%)-Cn(2-13%)-El	533- 9103	b) Slope surrounding the main part of basin (Central Area).
	88-140	V f: Uv(8-21%)-Bm(7-16%)	313-13791	c) Boundary between the two water masses at the margin of submarine terrace (west Central Area).
	93- 95	Vd3: Bm(20-27%)-Uv(8-10%)-Cn(5-13%)	1890- 2001	a-1) Boundary between the two water masses at the margin of submarine terrace (west Central Area).
	23- 40	Ve1-1: Ps-Boo-Ea-Ch-Bor-Fj	4478-10104	a-2) Influence by the low salinity and nutritious water. Shallow bottom along the Satsuma Peninsula (west Central Area).
100	61- 78	Ve1-2: Boo(6-10%)-Bm-Ch-Uv	4588-13766	
	38- 75	Ve1-3: Ch(7-10%)-Dm	4041-13766	
	42- 96	Ve2: Dm(6-12%)-Bor(3-11%)-Cp	1594- 8873	
	20	V b: Nf(14%)-Ab(12%)-Qs	89	b-1) Shallow pebbly sand bottom off Yamakawa.
	39- 66	V c: Ea(6-18%)-Cp(9-11%)-Dm	274- 585	b-2) Shallow pebbly sand bottom in the West-Sakurajima Passage.

Es: Eggerella scabra, Tb: Textularia bigenerinoides, Tk: T. kattegatensis,
Tw: T. wiesneri, Ck: Cribrostomoides kosterensis, Gg: Glomospira gordialis,
Am: Ammodiscus minimus, Bm: Bulimina marginata, T1: Textularia sp. 1,
Lk: Lagenammina kagoshimaensis, Bs: Bulimina spinosa, Ab: Ammonia beccarii forma A, El: Eilohedra levicula, Ch: Cymbaloporetta hemisphaerica,
Cn: Cassidulina norvangi, Go: Globocassidulina orianqulata, Cp: Cibicidoides pseudoungerianus, Uv: Uvigerina vadescens, Ps: Protelphidium schmitti,
Boo: Bolivina ordinaria, Ea: Elphidium advena, Bor: Bolivina robusta,
Fj: Florilus japonicus, Dm: Discorbis mira, Nf: Neoconorbina floridensis,
Qs: Quinqueloculina stalkeri.
Ve1-2: Stn. 88 and 116.
Ve1-3: Stn. 100, 104 and 106.
Ve1-1: Stn. 70, 74, 78 and 83.

7. Recognition of the foraminiferal populations*) and their distribution in relation to environmental factors

In Kagoshima Bay, five kinds of water masses are assumed to occur based on the results of oceanographic observation (p. 11-18; Table 10 and Fig. 34).

Judging from the character of each water mass and the distribution patterns of benthonic foraminifera, the Kagoshima Bay area was divided into seven areas of different environment. The characteristics of the bottom sediments is one of the factors controlling the distribution of benthonic foraminifera. In Kagoshima Bay, the correspondence to the bottom character was often observed at the species level. However it was not necessarily ubiquitous; many species were distributed over the different substrata or had biased distributions within an area of the same kind of bottom sediments. For considering the population being a combination of several species, the bottom sediment alone was not regarded to be inadequate as the principal factor controlling the distribution of foraminiferal populations. On the other hand, the water characteristics and the distribution of each water mass were judged to be closely related to the distribution of foraminiferal populations. As shown in Table 10, the five populations of benthonic foraminifera are discriminated in Kagoshima Bay corresponding to the seven divisions of the marine environment.

(1) *Population A*

Predominant species: *Cibicidoides pseudoungerianus, Globocassidulina oriangulata, Paracassidulina quasicarinata, Florilus pauperatus* and *Discorbis mira* (Groups Ve2 and Ve3).

Location: The open sea area (106-213 m in depth) and the coastal water along the Ōsumi Peninsula in the Bay Mouth Area and the southeastern part of the Central Area (43-96 m in depth).

Salinity of water near the bottom where the present population occurred was rather high throughout the year, namely higher than 33.2‰ at 50 m, 33.5‰ at 75 m and 34.2‰ at 100 m (Faculty of Fisheries, Kagoshima University, 1975-1977).

Water temperature at the depth of 50 m changes between 14.2 and 25.0°C through the year, while at the depth of 100 m it shows a very little annual change between 14.4 and 17.7°C.

Bottom sediments of the area were represented by sands (Md ϕ: -0.3 to 3.3) reflecting a rather strong current of the open-sea water flowing into the bay.

(2) *Population B*

Predominant species: *Cymbaloporetta hemisphaerica, Buliminella elegantissima, Bolivina ordinaria, Protelphidium schmitti* and *Pseudononion japonicum* (Groups Vd2 and Ve1).

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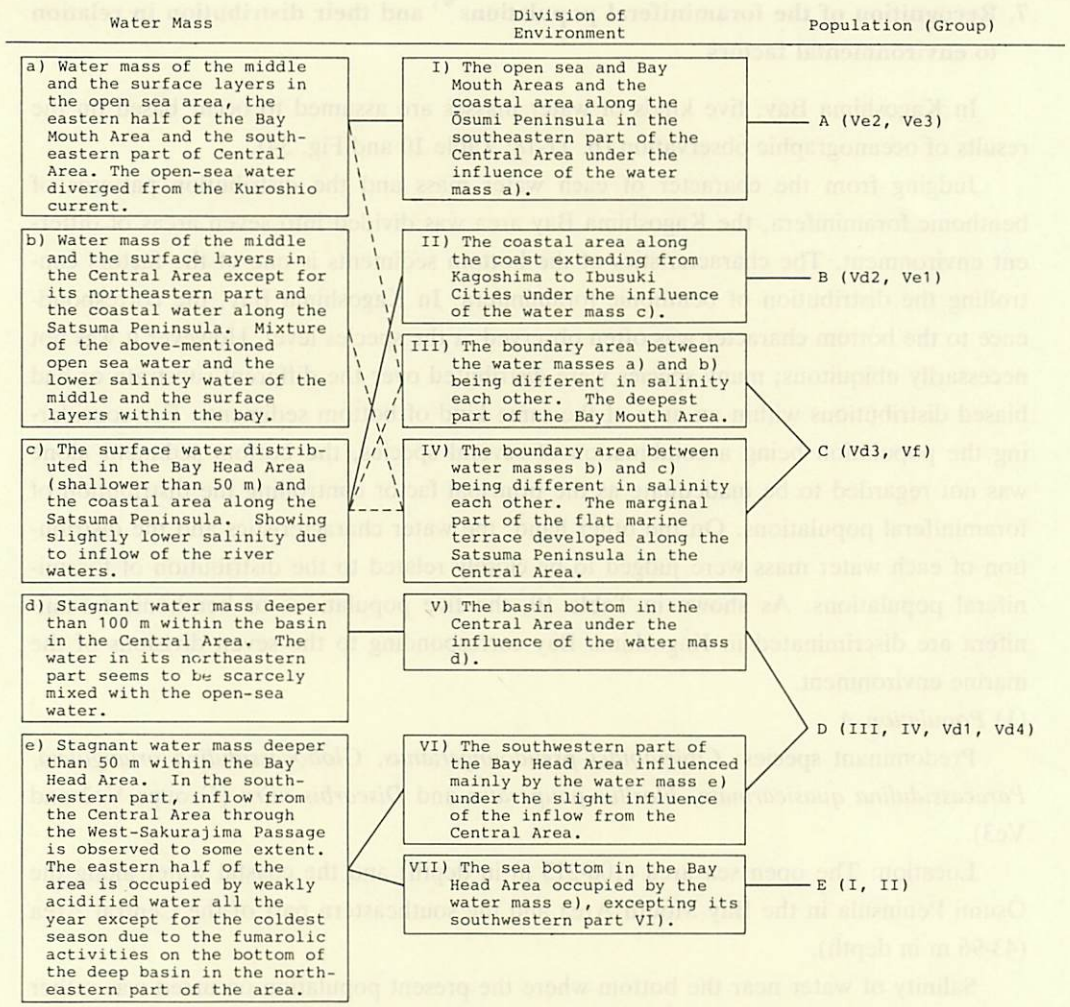
*) Not the "Species Population", but the "Inter-species Population" (ODUM, 1953) mainly based on the number of individuals of several species (MIYADI *et al.*, 1961) of foraminifera.

Table 10. Process for recognizing the foraminiferal populations in Kagoshima Bay.



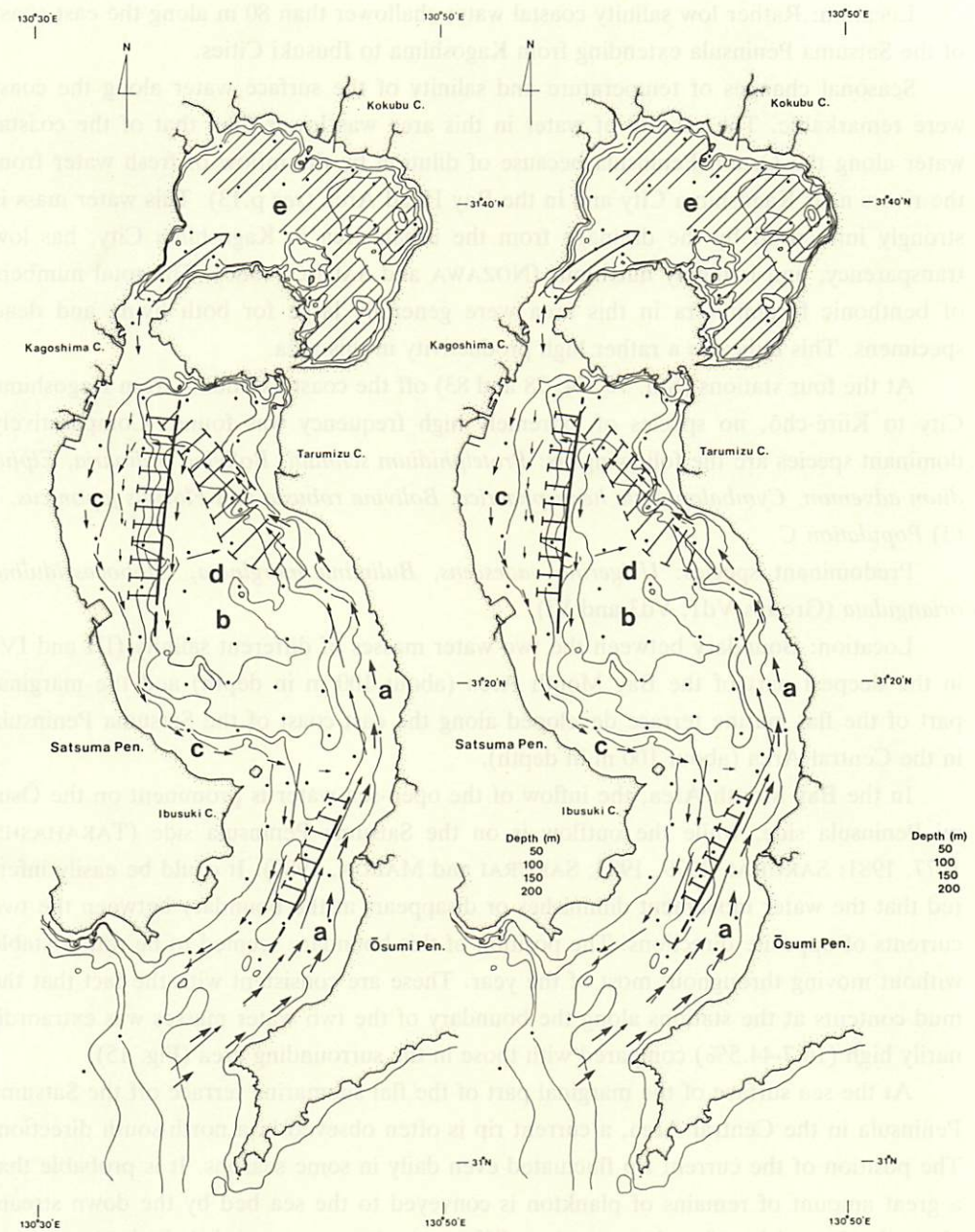


Fig. 34. Distribution of the water masses and the current system in Kagoshima Bay (stereoscopic map).

Location: Rather low salinity coastal water shallower than 80 m along the east coast of the Satsuma Peninsula extending from Kagoshima to Ibusuki Cities.

Seasonal changes of temperature and salinity of the surface water along the coast were remarkable. The salinity of water in this area was lower than that of the coastal water along the Ōsumi Peninsula because of dilution by the inflow of fresh water from the rivers near Kagoshima City and in the Bay Head Area (*see* p.13). This water mass is strongly influenced by the drainage from the urban area in Kagoshima City, has low transparency, and is highly nutritious (NOZAWA and SAISHO, 1980). The total numbers of benthonic foraminifera in this area were generally large for both living and dead specimens. This indicates a rather high productivity in this area.

At the four stations (Stn. 70, 74, 78 and 83) off the coast extending from Kagoshima City to Kiiré-chō, no species of extremely high frequency was found. Comparatively dominant species are the following six: *Protelphidium schmitti, Bolivina ordinaria, Elphidium advenum, Cymbaloporetta hemisphaerica, Bolivina robusta* and *Florilus japonicus.*

(3) *Population C*

Predominant species: *Uvigerina vadescens, Bulimina marginata, Globocassidulina oriangulata* (Groups Vd1, Vd3 and Vf).

Location: Boundary between the two water masses of different salinity (III and IV) in the deepest part of the Bay Mouth Area (about 100 m in depth) and the marginal part of the flat marine terrace developed along the east coast of the Satsuma Peninsula in the Central Area (about 100 m in depth).

In the Bay Mouth Area, the inflow of the open-sea water is prominent on the Ōsumi Peninsula side, while the outflow is on the Satsuma Peninsula side (TAKAHASHI, 1977, 1981; SAKURAI, 1979, 1983; SAKURAI and MAEDA, 1980). It could be easily inferred that the water movement diminishes or disappears at the boundary between the two currents of opposite directions. The position of this boundary seemed to be rather stable without moving throughout most of the year. These are consistent with the fact that the mud contents at the stations along the boundary of the two water masses was extraordinarily high (16.7-44.5%) compared with those in the surrounding area (Fig. 15).

At the sea surface of the marginal part of the flat submarine terrace off the Satsuma Peninsula in the Central Area, a current rip is often obseved in a north-south direction. The position of the current rip fluctuated even daily in some seasons. It is probable that a great amount of remains of plankton is conveyed to the sea bed by the down stream along the frontal interface between two different water masses, and their decomposition consumes oxygen resulting in the low dissolved oxygen near the bottom. It is still in question, however, whether the distribution of *Uvigerina vadescens, Globocassidulina oriangulata* and *Paracassidulina quasicarinata* implys their adaptation to the environment of low dissolved oxygen.

(4) *Population D*

Predominant species: *Bulimina marginata* (Groups III, IV, Vd1 and Vd4).

Location: Deep basin bottom deeper than 100 m in the Central Area filled with

stagnant water (Water mass d), and the sea bottom in the southwestern part of the Bay Head Area (Water mass e).

At the shallowest part of this water mass (about 100 m in depth), water temperature fluctuated between 14.5 and 22.4 °C and salinity between 33.5 and 35.3‰ through the year showing considerable seasonal changes. On the contrary, slight seasonal changes were observed at the depth of 150 m in water temperature (14.4-17.8°C) and salinity (34.0-34.8‰)(Fig. 4).

This population was distributed in the three isolated areas accompanied by a distinctive predominant species coexisting with *Bulimina marginata*. Namely, the population on the slope descending to the basin bottom in the Central Area (80 to 185 m in depth) is characterized by *Cassidulina nørvangi* (Group Vd1); the one on the deep basin bottom of about 200 m in depth in the Central Area except for its northeastern part is characterized by *Eilohedra levicula* and *Astrononion hanyudaense* (Group Vd4); and the other one on the basin bottom in the northeastern part of the Central Area is characterized by *Eggerella scabra* (Group III). The difference in the predominant species associated with *Bulimina marginata* between most of the basin bottom in the Central Area and its northeastern part is attributable to the fact that the latter area is located outside of the counterclockwise current system assumed to occur in the Central Area (*see* p. 18).

(5) *Population E*

Predominant species: *Eggerella scabra* (Groups I, II and III).

Location: Deep basin bottom in the Bay Head Area, occupied by stagnant water (Water mass e).

The temperature and the salinity of the water mass deeper than 50 m are rather stable through the year as follows:

Water Depth	Temperature (°C)	Salinity (‰)
Shallower than 25 m	14.4 - 29.5	23.35 - 34.10
50m	15.5 - 20.4	33.50 - 34.30
Deeper than 150 m	14.5 - 17.6	33.60 - 34.50

Near the basin bottom, the DO of the water changed considerably throughout the year. From summer to winter, the DO decreases from 3.00 to 0.28 (*see* p. 15).

As already mentioned, in the eastern half of the Bay Head Area the water mass is acidified due to the fumarolic activity on the bottom. Among the agglutinated foraminifera predominating in this area, frequencies of *Textularia kattegatensis, Ammodiscus minimus* and *Glomospira gordialis* (Stn. 21, 40, 41 and 42) increased toward the fumaroles (Station 40 being closest).

The bottom sediments near Station 40 contains H_2S (Kagoshima Prefectural Government, 1978). This suggests the presence of a reductive condition near the bottom of this deep basin. It is still unknown, however, whether the above-mentioned three species

are adapted to this peculiar environment or not.

In addition to the foregoing populations, only a single peculiar assemblage of benthonic foraminifera (Group VI) was found at Station 69 off Furusato Spa on the south coast of Sakurajima, the northeastern part of the Central Area. The assemblage (Group VI) is characterized by extraordinary high frequencies of *Textularia bigenerinoides* (48%) and *Eggerella scabra* (20%). This type of species composition was not found at the other stations in Kagoshima Bay. The species composition of this assemblage shows some similarity to that of population E, but differs from the latter because it contained a few species of calcareous hyaline foraminifera. This suggests the influence not of acidic water as seen in the Bay Head Area, but of some peculiar environmental factors, such as hot spring water known to well out at the shallow bottom below low tide line near the Furusato Spa. I regard this unusual assemblage as an exceptional occurrence in Kagoshima Bay.

Discussion

Comparison between the results of population analysis of the benthonic foraminifera in Kagoshima Bay and those in other Japanese waters will be given in the present chapter.

1. Distribution of planktonic foraminifera and radiolaria

Through the estimation using the L/Tl value (*see* p. 29), it was made clear that the numbers of individuals of the planktonic foraminifera and radiolaria preserved in sediments were scarcely related to the water depth (Figs. 19 and 20), but were controlled by the movement and structure of water masses.

It was particularly noticeable that the numbers of individuals of planktonic foraminifera and radiolaria below the current rip in the northeastern part of the Central Area, was two to ten times of those on the basin bottom in the Central Area. PHLEGER (1951) mentioned that mixing of water at the edges of the currents of different productivity may cause deposition of specimens which are killed because of unfavorable ecological conditions. HOSHINO (1952) and SAKAMOTO (1982) also reported on the precipitation and dep osition of suspended matters by the down stream developed at the frontal interface between two water masses.

2. Planktonic ratio

GRIMSDALE and MORKHOVEN (1955) demonstrated the change in the relative proportion of planktonic and benthonic foraminifera with water depth in Recent sediments in the Gulf of Mexico. ŌKI (1983, 1985) reported that the planktonic foraminifera con-

tents (Planktonic ratio) in the bottom sediments in the Tañon Strait, the Philippines and off the southeast coast of Viti Levu Island, Fiji are plotted around a parabolic line on the graph of abundance against water depth.

In the Bay Mouth and the Central Areas of Kagoshima Bay, the planktonic ratios were generally related to water depth but there was no relationship between the number of individuals of the planktonic foraminifera in sediments and water depth (Figs. 21 and 22). A rather good interrelation between the planktonic ratio and water depth exists in deep embayments or open sea stable environments (KUWANO, 1953; MATOBA, 1976a).

3. Peculiar occurrence of benthonic foraminifera

In his pioneer work on the Recent foraminifera in Kagoshima Bay, KUWANO (1962-63) mentioned that the numbers of individuals both of living and total populations in Kagoshima Bay are larger than those in the bay mouth area of Tokyo Bay and off the Bōsō Peninsula. On the other hand, I recognized generally smaller sizes of the foraminifera specimens from Kagoshima Bay, and presume that they have alternation of generation at the earlier growth stages. The foregoing features of the benthonic foraminifera strongly suggests that Kagoshima Bay furnishes an environment suited to the survival of the benthonic foraminifera.

Only a few authors discussed the relation between the numbers of living individuals and of the total (living and dead) individuals. MATOBA (1970) reported that in Matsushima Bay these two values do not have a positive correlation with each other. This must be due to the very shallow depths (less than 12.5 m) of Matsushima Bay, which results in extreme seasonal changes in sea condition and in number of living individuals.

In embayments or the open sea deeper than 50 m having rather stable water masses, the distribution pattern of benthonic foraminifera does not seem to change seasonally. Generally speaking, unless the post-mortem movement is taken into consideration, the numbers of living and dead individuals of the benthonic foraminifera must be directly related.

The high frequencies of the agglutinated foraminifera among the total benthonic foraminifera usually occur in the open sea area ranging from the continental shelf to the ocean floor (BOLTOVSKOY and WRIGHT, 1970). It is also known, however, that rather high frequencies of the agglutinated foraminifera occur in the inner bay and the brackish-water lakes characterized by a rather scanty occurrence of calcareous foraminifera. Many believe that assemblages dominated by agglutinated forms or a poor population of calcareous benthonic foraminifera may be caused by the oligo-oxygen status (ISHIWADA, 1964). MATOBA (1970) also mentioned that the assemblages showing high frequencies of agglutinated foraminifera are influenced by river waters, either directly or indirectly, namely, under the influence of lower chlorinity and/or deep penetration of embayments into the land.

As already mentioned, in the Bay Head Area of Kagoshima Bay, especially in its

eastern half, the agglutinated foraminifera make up the greatest part of the population under the influence of acidic water mass caused by submarine fumarolic activities (*see* p. 15). In their study on the foraminiferal decimation and repopulation in an active volcanic caldera on Deception Island, Antactica, FINGER and LIPPS (1981) reported that foraminifera were rare and almost exclusively arenaceous in shallow water samples obtained near fumaroles. KITAZATO (1979) applied the information on the unusual occurrence of benthonic foraminifera in the Bay Head Area of Kagoshima Bay to the explanation of sedimentary environment of the "Kuroko-deposits" in relation to the fossils of benthonic foraminifera.

4. Distribution of foraminiferal populations and the environmental factors

In this section, each of the five populations of foraminifera found in Kagoshima Bay will be compared with those mainly from the Japanese waters in relation to the environmental factors.

(1) Population A (predominant species: *Cibicidoides pseudoungerianus, Globocassidulina oriangulata, Paracassidulina quasicarinata, Florilus pauperatus, Discorbis mira*)

Cibicidoides pseudoungerianus occurs in many places on the continental shelf and slope around the Japanese Islands. *Globocassidulina oriangulata, Paracassidulina quasicarinata*, and *Florilus pauperatus* are regarded to be the species characteristic of the Kuroshio area, but hitherto unknown from north of Kyūshū. *Discorbis mira* distributed in the low saline coastal water along the Satsuma Peninsula is also a common inhabitant in the coastal water under the influence of the Kuroshio Current.

(2) Population B (predominant species: *Cymbaloporetta hemisphaerica, Buliminella elegantissima, Bolivina ordinaria, Protelphidium schmitti, Pseudononion japonicum*)

Buliminella elegantissima seems to be abundant in the nearshore and bay areas, and its high frequencies are known in areas near the outfall of sewage. The geographic distribution of this species may be divided into two areas: one is around northeast Japan (37° to 45°N) and the other is around southwestern Japan (31° to 35°N). This biogeographic information leads to the following two different hypotheses: 1) this form is originally a cold water species, and its southwestern counterpart became isolated in the postglacial age; 2) this form is a cosmopolitan species and has a sporadic distribution off Japan (ŌKI, 1989).

Pseudononion japonicum has been known to occur in the shallow water to the continental shelf around Japan. *Cymbaloporetta hemisphaerica, Bolivina ordinaria, Protelphidium schmitti* have been unknown around Japan, were found from Kagoshima Bay for the first time.

(3) Population C (predominant species: *Uvigerina vadescens, Bulimina marginata, Globocassidulina oriangulata*)

ISHIWADA (1964) recorded the occurrence of assemblage composed of *Bulimina marginata* and *Uvigerina vadescens* at the edge of the continental shelf (120-280 m in