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Distribution of Recent benthic foraminiferal assemblages in the surface sediments of the Hyuganada area, off Kyushu and Shikoku, Japan

Kazumi Akimoto* and Masayuki Torii**

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Abstract : The distribution of Recent benthic foraminiferal faunas is discussed with reference to different oceanographic conditions. Recent benthic foraminiferal assemblages from 33 sediment samples were obtained during the GH83-2 Cruise (Hyuganada area).

Based on the Q-mode factor analysis of the distribution of benthic foraminifera from including 33 sediment samples, eight assemblages were recognized, (1) *Cibicidoides mediocris-Hanzawaia nipponica* Assemblage representing the sublittoral zone (100-200 m), (2) *Cibicides refulgens-Elphidium crispum* Assemblage is distributed within the coarse grained sediments below the surface water, (3) *Uvigerina hispidocostata-Sphaeroidina compacta* Assemblage is characterized in the upper part of the salinity minimum zone (water depth interval between ca. 700m and 1000 m) near off Ashizurimisaki, (4) *Bolivina robusta-Bulimina marginata* Assemblage is characterized in coastal waters (70-200m) off Nichinan City, (5) *Bulimina marginata-Discorbinella convexa* Assemblage is distributed in the surface waters of the Kuroshio Current, (6) *Hoeglundina elegans-Evolvocassidulina brevis* Assemblage is characteristic of the outer sublittoral and upper bathyal zone, (7) *Gyroidinoides nipponicus* Assemblage represents the salinity minimum zone (water depth interval between ca. 400m and 700m) off Toimisaki, and (8) *Sphaeroidina compacta-Uvigerina hispida* Assemblage is indicative of the oxygen minimum zone below a water depth of 900m.

Introduction

In 1983, sediment samples were collected from the Hyuganada area during the GH83-2 Cruise by the Geological Survey of Japan for sedimentological mapping. We had the opportunity to examine the benthic foraminifers in these samples.

Systematic research in the Hyuganada area had been hitherto made by two workers. Aoshima (1978) revealed the distribution of Recent benthic foraminiferal species in five traverses off southwest Japan, and recognized

* Nagoya Jiyu Gakuin Junior College
** Department of Geology, Natural Science, Kumamoto University

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four assemblages on the basis of their depth range. Inoue (1989) reported 6 benthic foraminiferal assemblages at depths from 40m to 5000m around the Japanese Arc. These previous studies recognized that the content of the benthic foraminiferal assemblages were varied in each of the traverses off southwest Japan. This study intends to establish the faunal assemblages relating their distribution with the various environments.

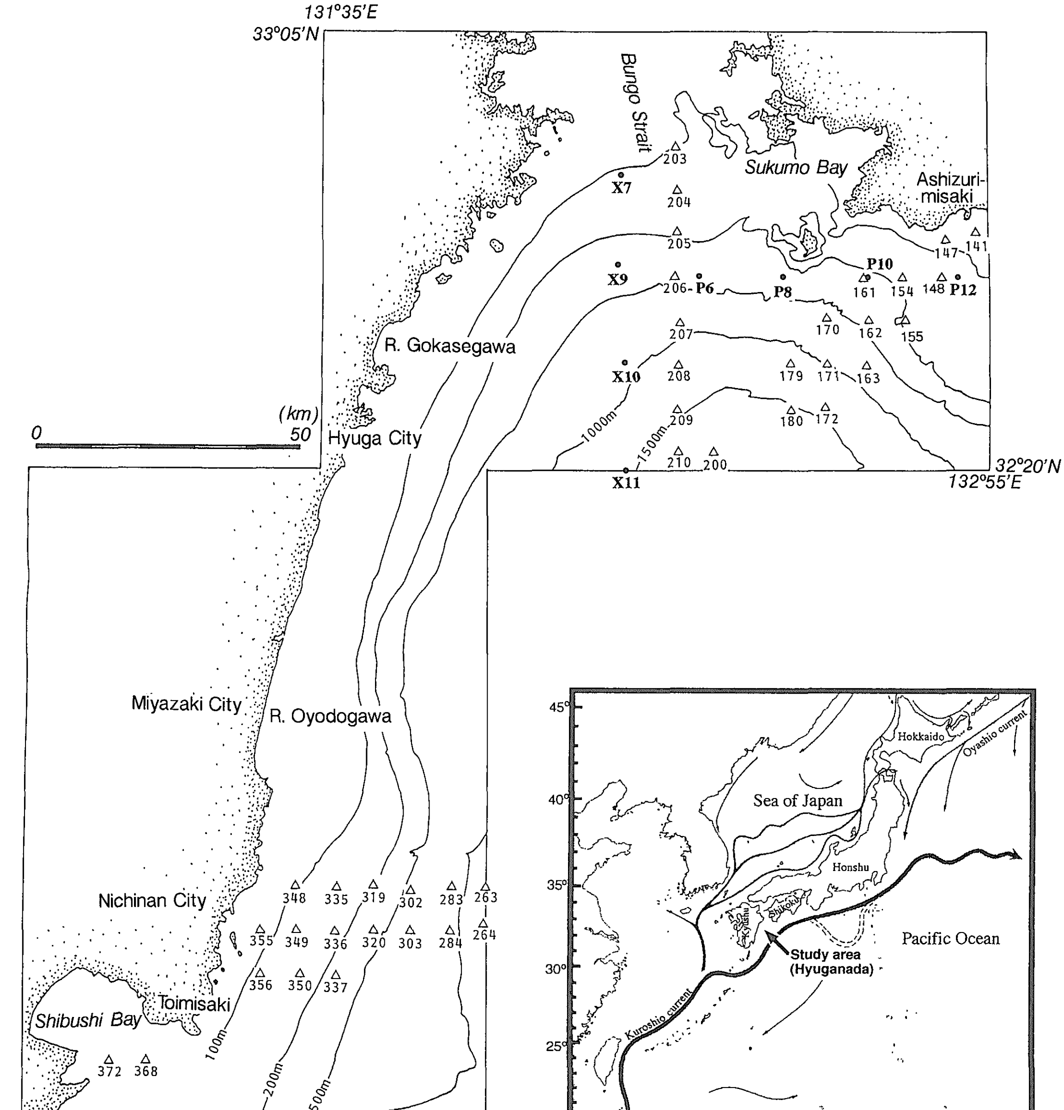

Fig. 1. Bathymetry of the Hyuganada area with the locations of the sampling stations used in this study. Open triangle ; sampling station, solid circle ; oceanographic measurement station.

Oceanographic conditions

1. Bathymetry

Figure 1 shows the submarine topography in the study area. The Bungo Strait is situated between Shikoku and Kyushu, and has a maximum depth of about 100m. The Bungo Strait is less than 20km wide, and the water depth of the shelf edge is approximately 140m. The continental slope develops off the eastern coast of Kyushu and the southern coast of Shikoku, and extends into the Nankai Trough located to the east. Several terraces have developed on the slope at depths of 800-1000m and 1600-1800m.

2. Water mass

The coastal waters of the Hyuganada area are influenced by the warm Kuroshio Current (Fig. 1). Temperature, salinity and dissolved oxygen within, and off the Bungo strait are illustrated in Figures 2 and 3. Figure 4 shows the average temperature, salinity and dissolved oxygen of the off—shore water in the Hyuganada area, and Figure 5 illustrates the same parameters for offshore Toimisaki. Figures 2-4, and 5 are compiled from basic oceanographic data published by the Kobe Marine Observatory and the Japan Meteorological Agency, respectively.

Coastal water is distinguished from the offshore water by its low salinity (Figs. 2 and 3). The coastal water is widely distributed along the coast line, and at the surface this water flows from the Bungo Strait to off Nichinan City (Chaen, 1992). The depth to the bottom of the coastal water is approximately 100m, and the width is more than 30km. The salinity of the coastal water is about 34.6‰ during the winter and less than 34.0‰ in the summer, as shown in Figs. 2 and 3. The temperature at the surface of the coastal water ranges from about 19°C in the winter reaching apporoximately 30°C during the summer.

Figure 4 shows that the temperature is constantly 19°C at the boundary between the surface waters and the thermocline, whereas the surface water (seasonal layer) temperature ranges from 20°C in winter to 29°C during the summer. Water temperature rapidly decreases below the thermocline, reaching about 3°C at a water depth of 1000m. The boundary between the thermocline and the underlying deep waters coincides with this depth. The temperature of the deep water is 2°C, and is invariable throughout the water column.

The salinity of surface water ranges from 34.2‰ in summer to 34.8‰ during in winter. Salinity increases slightly downwards towards depths of 150m. There is a regular decrease in salinity within the thermocline down to a little less than 34.3‰ at a depth of 600m, however slight increases in salinity occur below 800m. The salinity minimum zone exists in a depth interval between 500 and 800m. The thermocline has minimum salinity values of less than 34.3‰ at depths of approximately 400m near to Toimisaki, as shown in Figure 5. The depths of the upper and lower boundaries of the salinity minimum zone become shallower near to Toimisaki in comparison to Figs. 4 and 5.

Surface waters have an average dissolved oxygen content of about 4.3ml/l in summer. This value decreases regularly with depth, where it reaches about 1.5ml/l at water depths of 1000m with slight increase below 1200 m. Thus, the upper and lower boundaries of the oxygen minimum zone in the Hyuganada area are at water depths of approximately 800m and 1200m, respectively.

3. Sediments

The distribution of surface sediments in the Hyuganada area was revealed by Ikehara (1985). He showed that coarse and medium grained sands are widely distributed around the Bungo Strait and on the continental shelf and slope near Ashizurimisaki. The boundary between the areas of silt and fine grained sand corresponds to the 600m water depth contour.

The mud content shows a rough zonal distribution in the area off Ashizurimisaki and the Bungo Strait. The values are more than 50% at most points below water depths of 600 m. A point with less than 10% mud content was recognized as an area under the influence of coastal waters (Figs. 6 and 7).

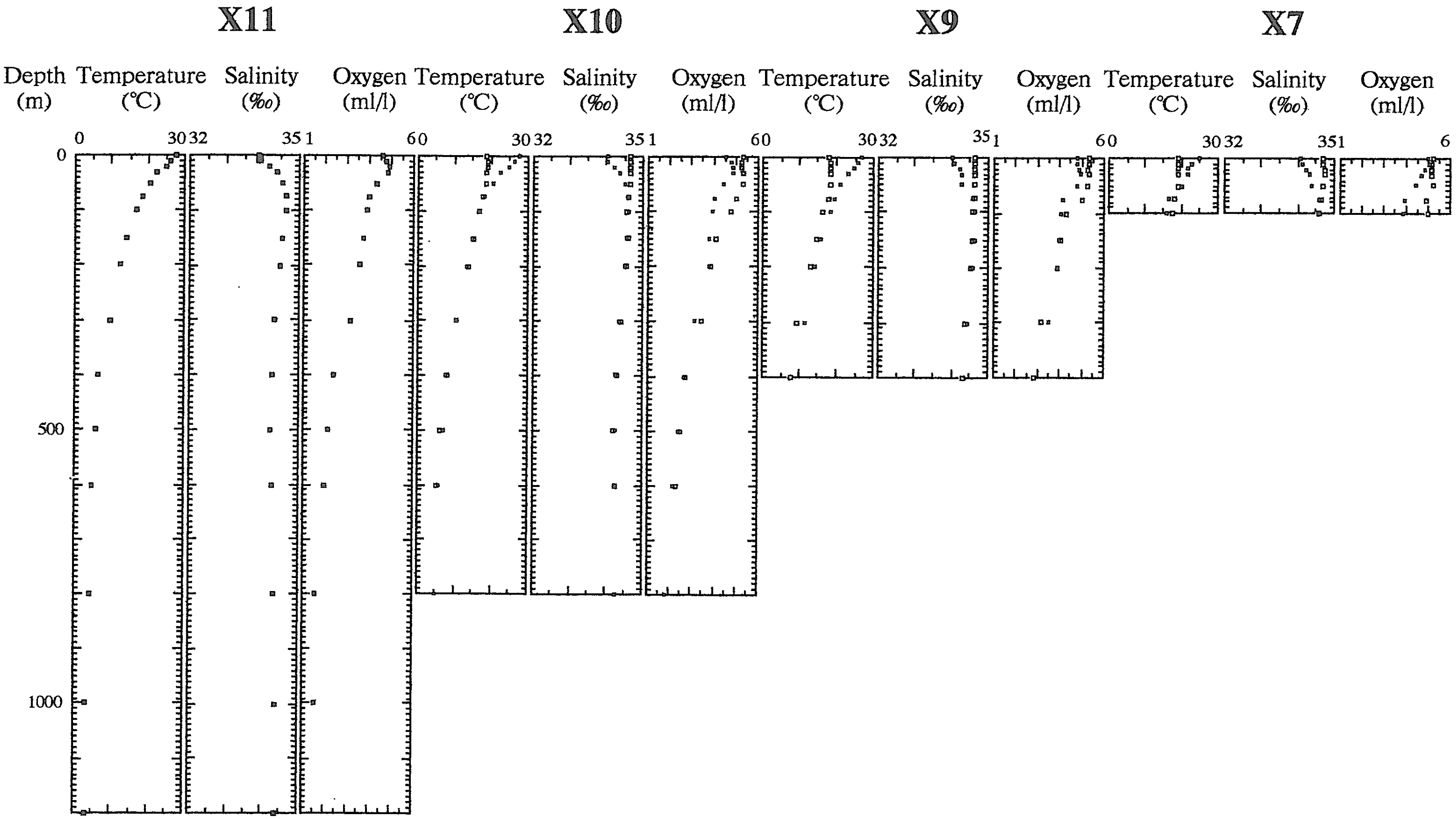

Fig. 2. Vertical profiles of temperature, salinity and dissolved oxygen in the east-west traverse off the Bungo Strait. Open square ; winter, solid square ; summer (Data obtained from the Kobe Marine Observatory, 1971-73).

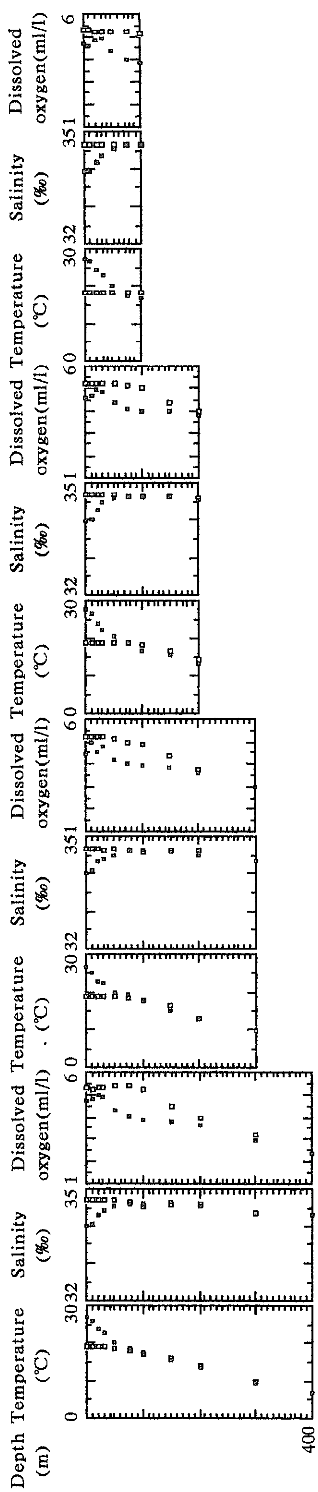

Fig. 3. Vertical profiles of temperature, salinity and dissolved oxygen in the north – south traverse off the Bungo Strait. Open square ; winter, solid square ; summer (Data obtained from the Kobe Marine Observatory, 1971-73).

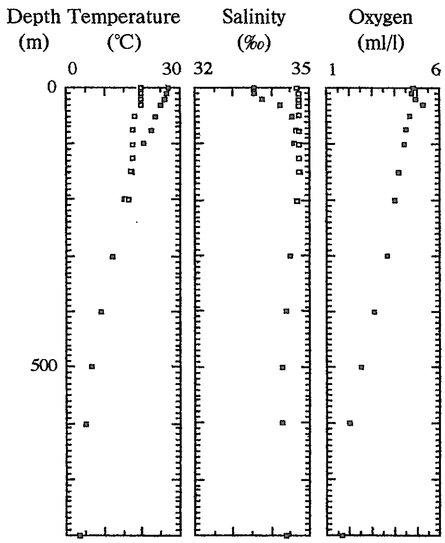

Fig. 4. Vertical profiles of temperature, salinity and dissolved oxygen in the north-south traverse off Toimisaki. Open square ; winter, solid square ; summer (Data obtained from the Kobe Marine Observatory, 1969).

Conversely, silty sediments are widely distributed on the continental shelf and slope off Nichinan City and Toimisaki (Ikehara, 1985). Sediment samples on the continental slope and shelf have rather high frequencies of mud content (more than 50%), except for sample 319 (Fig.8). Thus, the continental shelf and slope off Nichinan City and Toimisaki are characterized by a higher mud content than those offshore of Ashizurimisaki and in the Bungo Strait.

Distribution of benthic foraminifera

1. Materials and method

Thirty-three sediment samples were collected by using a Smith-McIntyre sampler. The samples examined represent the uppermost 2 cm of the sediment columns collected.

All of the samples were washed on a 0.063mm (250-mesh) sieve screen and dried. Each of the samples analyzed were divided by a sample splitter into aliquot parts. In most cases, approximately 200 specimens of benthic foraminifers larger than 0.125mm were picked

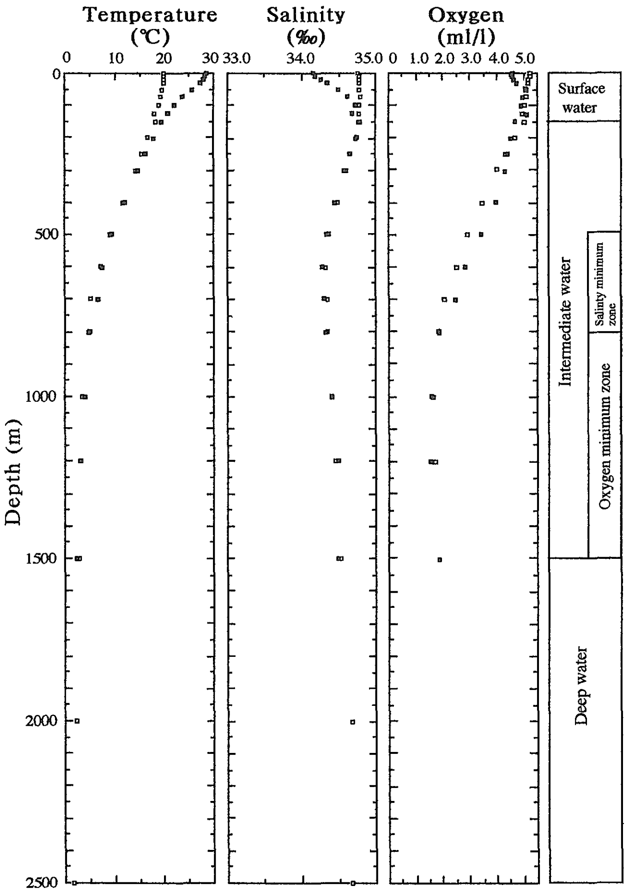

Fig. 5. Vertical profiles of temperature, salinity and dissolved oxygen in the Hyuganada area. Open square ; winter, solid square ; summer (Data obtained from the Marine Meteorological and Oceanographical Observations, 1906-1981).

from an aliquot under a binocular microscope. The specimens of planktonic foraminifers were picked from this split-part and counted.

2. General microfaunal trend

The distribution of foraminifers in the modern ocean is fundamentally in harmony with the distribution of water masses and the patterns of surface water currents (Akimoto, 1990). This study intends to delineate the faunal statistics to interpret the relationship between the distribution of the foraminiferal assemblages and the environments within the water masses. Figures 6-8 show the faunal statistics in the Hyuganada area. Planktonic foraminiferal numbers and benthic foraminiferal numbers are the number of individuals of planktonic and benthic foraminifera contained in 1g of dry sediments, respectively. P/T and A/T ratios show the ratio of planktonic foraminifera to total foraminifera, and the ratio of agglutinated foraminifera to total benthic foraminifera, respectively.

a. Planktonic foraminiferal numbers

The numbers regularly increase with water depth down to approximately 600m, then rapidly decrease between 600m and 700m, to become roughly constant below this depth off

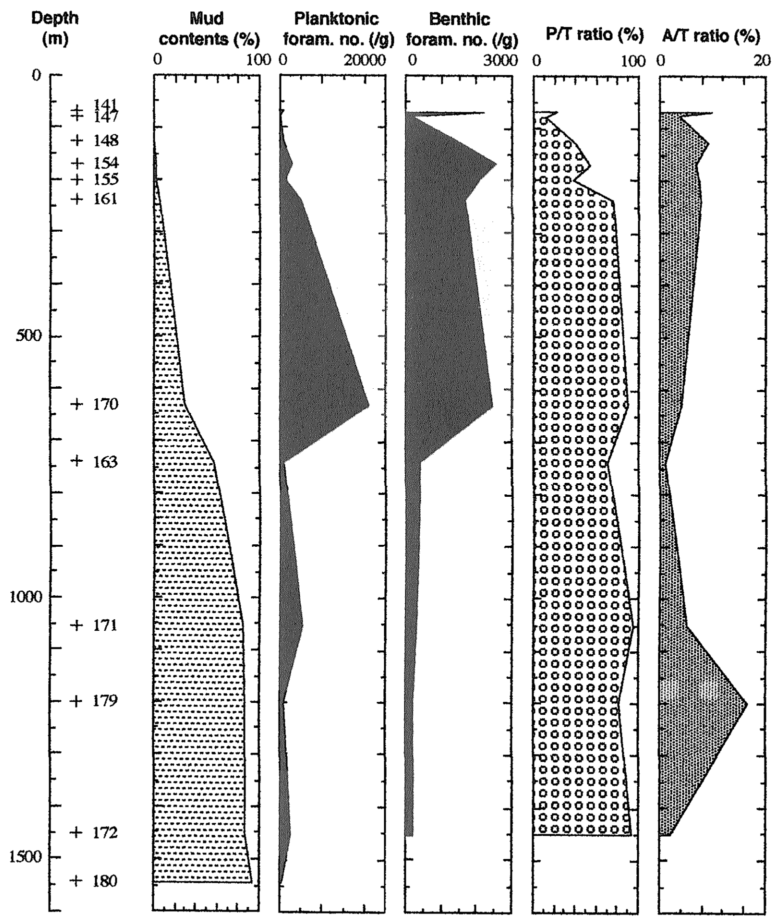

Fig. 6. Distribution of mud content (%), planktonic foraminiferal and benthic foraminiferal numbers, planktonic foraminifera/total foraminifera ratio (%) and agglutinated foraminifera/total benthic foraminifera ratio (%) vs. water depth off Ashizurimisaki. Cross ; sampling point with sample number.

Ashizurimisaki and the Bungo Strait (Figs. 6 and 7). According to Figure 8, the number of planktonic foraminifera basically increases with depth down to about 300m, (except for sample 350 which has maximum values of about 3000), with a slight decrease downward below 350m in the traverse off Toimisaki.

b. Benthic foraminiferal numbers

Large numbers of benthic foraminifera (more than 2000) are generally confined to a depth range of 70m to 630m off Ashizurimisaki (Fig. 6). The numbers essentially increase with depth down to 430m, but decrease below this depth in the traverse off the Bungo Strait (Fig. 7). In the traverse off Toimisaki, the number of benthic foraminifera is less than 200 in the surface water, and is more than 400 in the depth interval between 200 and 270m, but this number rapidly decreases downward below this depth (Fig. 8).

c. P/T ratio

The P/T ratio rapidly increases with water depth down to about 200m, and is then constant down to depths of 1500m in the traverses off Ashizurimisaki and the Bungo Strait (Figs. 6 and 7). In the traverse off Toimisaki, the P/T ratio is rather high (more than 60%) at most points, and generally increases with

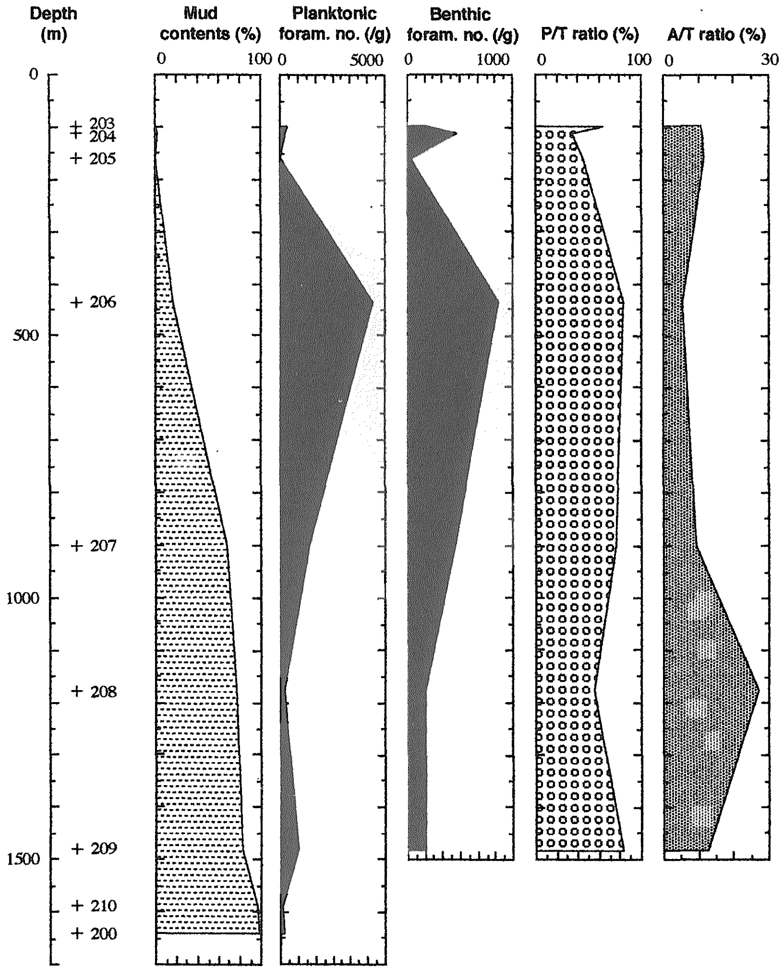

Fig. 7. Distribution of mud content (%), planktonic foraminiferal and benthic foraminiferal numbers, planktonic foraminifera/total foraminifera ratio (%) and agglutinated foraminifera/total benthic foraminifera ratio (%) vs. water depth off the Bungo Strait. Cross ; sampling point with sample number.

depth, as shown in Fig. 8.

d. A/T ratio

The A/T ratio is rather small (less than 10%) at most points, except for samples 179 and 208. These sample points, which are located at water depths of 1200m off the Bungo Strait, have values of over 20%.

3. Factor analysis

Factor analysis (Q-mode) was used to classify the data into statistically meaningful groups. Factors are patterns reflecting the distribution of the variables. A variable, in this case, a foraminifera, can have a similarity to a factor (factor loading) ranging from +1.0 to −1.0. In this analysis, any variable with a factor loading greater than | 0.5 | can be said to be related to a factor. Samples can be related to a factor by factor score. A sample strongly related to a factor occurs when its score exceeds 1.0. A varimax rotation of the factors produces a less abstract result, since each varimax factor is constrained to have a faunal composition very similar to that actually obser-

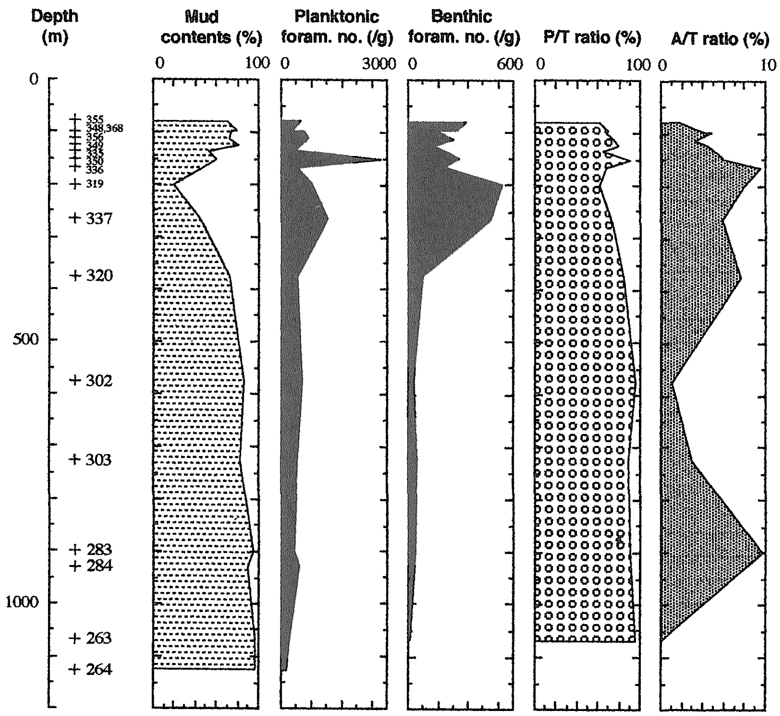

Fig. 8. Distribution of mud content (%), planktonic foraminiferal and benthic foraminiferal numbers, planktonic foraminifera/total foraminifera ratio (%) and agglutinated foraminifera/total benthic foraminifera ratio (%) vs. water depth off Toimisaki. Cross ; sampling point with sample number.

ved in at least one sample (Davis, 1973). Factor analysis with a varimax rotation was performed to detect the major environmental factors that are likely to have controlled the distribution of the benthic foraminifera in the sediments of the study area.

In this study, benthic foraminifera from 33 sediment samples were identified, as listed in Table 1. The data matrix for the Factor analysis is composed of 33 samples and includes 89 species, which are represented by three or more individuals in each of the samples listed in Table 1. Statistical analysis was performed using an US SPSS Inc. program on a Macintosh personal computer.

Factor analysis identified 8 factors which account for 63.6 % of the variability of the data obtained from the 33 samples (Table 2). Tables 3 and 4 list the factor loadings of the 33 samples, and the varimax factor scores for each species within each factor, respectively. Figures 9-11 illustrate the depth distribution of the factor loadings.

Factor 1 accounts for 19.4% of the variance, with a high positive value of factor 1 loading being restricted to the samples in the depth interval between 70m and 250m off Ashizurimisaki. The distribution of this value is associated with the presence of coastal waters, which are characterized by low salinity and the seasonal fluctuation of the oxygen content, in comparison with Figs 2, 3 and 9. Thus, Factor 1 is considered to represent the coastal water mass off Ashizurimisaki. The assemblage represented by Factor 1 is dominated by *Cibicidoides mediocris* and *Hanzawaia nipponica*. These are the species that are positively related to Factor 1 which characterizes the coastal water mass off Ashizurimisaki.

Factor 2 accounts for 18.1% of the variance, and is marked by the presence of *Bulimina marginata* and *Bolivina robusta*. The high positive value of Factor 2 loading is distributed in the depth interval between 70m and 200m off Nichinan City (Fig. 11). The samples which have a high positive loading of the second factor are located in the southern margin of the coastal water mass. Aoshima (1978) and Inoue (1989) reported the distribution of *B. marginata* and *B. robusta* in the Hyuganada area. According to their reports, the two species are dominant in the samples from off Miyazaki City and the Bungo Strait, which are located under the influence of low salinity costal water, but that they are rare off Toimisaki in the offshore waters. Thus, the distribution of *B. marginata* and *B. robusta* are restricted to the costal waters from the Bungo Strait to offshore of Nichinan City.

Salinity of the coastal water in the depth interval from 70m to 200m off Hyuga City is approximately 34.5‰ (Fig. 2), and one sample of the offshore water in same depth interval located near Toimisaki is 34.8‰ (Fig. 4). Factor 2 is related to the low salinity costal waters off Nichinan City.

Factor 3 accounting for 10.6% of the variance in the species distribution, is characterized by the occurrences of *Sphaeroidina compacta*, *Uvigerina hispida* and *Bulimina aculeata*. The samples having a positive high value of the Factor 3 loading are distributed below water depths of 900m (Figs 9-11). This depth coincides with the upper limit of the oxygen minimum zone (Fig. 5). Thus, Factor 3 apparently reflects the influence of the oxygen minimum zone.

Factor 4 accounts for 4.1% of the variance. The samples representing high positive value of Factor 4 loading have a restricted distribution in the depth interval between 70m and 120m off Toimisaki (Fig. 11). This depth interval in the water column occurs at the surface of the offshore waters (Fig. 5). Planktonic foraminifers/total foraminifers (P/T) ratios range from 60 to 80% in these samples (Fig. 8), but is less than 60% from the samples in the same depth interval off Ashizurimisaki and the Bungo Strait (Figs. 6 and 7). This value reflects the influence of offshore waters. Thus, Factor 4 indicates that the offshore water flows in the depth interval between 70m and 120m off Toimisaki from the southeast. The assemblage which is recognized by Factor 4 is characterized by the occurrence of *Bulimina marginata* and *Discorbinella convexa*.

Factor 5 accounts for 3.8% of the variance, and exists in samples 163, 171 and 207. These samples are located in the silt to very fine sandy bottom sediments, including rich organic material on the continental slope off Ashizurimisaki (Fig. 6 and 7), and in the interval at a depth between 730m and 1050m under the intermediate water (Fig. 5). The assemblage is characterized by the occurrence of *Bulimina marginata*, *Cibicides wuellerstorfi*, *Sphaeroidina compacta*, *Tosaia hanzawai* and *Uvigerina hispidocostata*.

Factor 6 accounts for 3.2% of the variance, and is recognized in samples such as 302, 303 and 320 from the continental slope under the salinity minimum zone off Toimisaki (Fig. 5). This factor loading of more than 0.5 does not exist in the samples under the same water mass off Ashizurimisaki and the Bungo Strait. This is due to a difference in the grain size of the sediments between offshore Toimisaki and Ashizurimisaki. The former area has silty bottom sediments (Fig. 8), but the sediments are sandier in the latter (Figs. 6 and 7). Thus, Factor 6 is thought to express the influence of fine grained sediments under the salinity minimum zone. The assemblage represented by Factor 6 is marked by the presence of *Gyroidinoides nipponicus*.

Factor 7 accounts for 2.2% of the variance, and is distributed in samples 336 (170 m water depth) and 350 (150m). These samples are located on the edge of the continental shelf and at the boundary between the surface and intermediate waters off Toimisaki. On the edge of the continental shelf off Ashizurimisaki and the Bungo Strait, the high positive value of Factor 7 loading is not recognized in the samples collected at the same depth under the influence of coastal waters. Thus, Factor 7 indicates the boundary between the surface and intermediate waters without the influence of coastal waters. The assemblage is represented by the occurrence of *Evolvocassidulina brevis*

Table 1. Occurrence of Recent benthic foraminifera from the Hyuganada area.

Table 2. Summary of the factor analysis in the Hyuganada area.

Factor	Eigenvalue	Percent of variable	Cumulative percent
1	6.4	19.4	19.4
2	6.0	18.1	37.5
3	3.5	10.6	48.1
4	1.4	4.1	52.2
5	1.3	3.8	56.0
6	1.1	3.2	59.3
7	0.7	2.2	61.5
8	0.7	2.1	63.6

and *Hoeglundina elegans*.

Factor 8 accounting for 2.1% of the variance, is only recognized in sample 141. This sample is located in the sandy bottom sediments on the continental shelf off Ashizurimisaki (Fig. 6), at a water depth of 67m below the coastal waters (Fig. 3). The seasonal change of salinity in the water layer above this depth is larger when compared to the water mass below this water depth. Thus, Factor 8 is considered to be indicative of surface waters with seasonal changes in salinity. The assemblage represented by Factor 8 is marked by *Cibicides refulgens*, *Elphidium crispum* and *Globocassidulina bisecta*.

Table 3. Factor loadings for the Hyuganada area.

Sample no.	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
141	0.75368	-0.02302	-0.05024	-0.04228	-0.00440	-0.01596	-0.09235	0.61055
147	0.59453	-0.01796	-0.00328	-0.03927	-0.06856	0.00317	0.18032	0.21788
148	0.80197	-0.07796	-0.06381	-0.03923	-0.00109	0.00470	0.04310	0.24992
154	0.79912	0.18973	-0.03111	-0.10481	-0.03685	-0.02070	-0.03714	-0.18694
155	0.86858	0.08374	0.05037	-0.03519	-0.07007	-0.04312	0.09058	0.13804
161	0.81945	0.13663	0.02119	0.11715	0.04250	-0.01944	0.19633	-0.09756
163	-0.02651	0.18333	0.09284	0.33407	0.80616	0.28590	0.04266	-0.01547
170	-0.04476	0.52338	0.07867	0.38952	0.45116	0.32068	0.05678	0.01497
171	-0.05907	0.06805	0.50551	0.09050	0.72042	0.06711	0.02324	-0.00967
172	-0.08169	-0.01001	0.67983	0.04654	0.52417	0.18277	0.00695	0.02191
179	0.11736	-0.00507	0.57167	-0.07485	0.07522	-0.02042	-0.00595	-0.00127
203	0.48061	-0.05162	-0.07027	-0.00632	0.02490	-0.04061	-0.13422	-0.34664
204	0.91827	0.09323	0.09014	-0.01971	-0.05115	-0.04459	0.05733	-0.20577
205	0.71102	-0.01163	0.03776	-0.03560	-0.08215	0.03134	0.35665	-0.03986
206	0.38339	0.44013	-0.02968	0.02792	0.03048	0.07896	-0.02187	-0.11993
207	-0.06646	0.06595	0.43017	0.15397	0.51355	0.04332	-0.00665	-0.00594
208	-0.11058	-0.11870	0.44201	-0.15220	0.35218	0.00569	-0.05724	-0.01905
209	0.13319	-0.01038	0.84818	-0.07612	0.14175	-0.00777	0.00904	0.01029
263	-0.07873	-0.11297	0.59951	-0.00994	-0.03922	0.19066	0.02567	-0.00085
283	-0.08183	-0.01099	0.41922	0.23156	0.08673	0.34932	-0.03863	0.00531
302	-0.01738	-0.13363	0.11042	0.03781	0.11497	0.55311	0.12910	0.01397
303	-0.05045	0.25347	0.24869	0.14737	0.32281	0.62022	-0.01368	0.01223
319	0.26503	0.74401	-0.02150	0.09695	-0.01201	0.32874	0.10209	-0.04149
320	-0.04912	0.30709	-0.00965	0.47686	-0.07542	0.59832	-0.07858	-0.04255
335	0.18460	0.50784	-0.05390	0.16652	0.08086	-0.02337	0.10083	-0.03600
336	0.16955	-0.06481	-0.09106	-0.08270	-0.07083	0.03034	0.77660	0.01942
337	0.21892	0.45714	0.12096	0.33015	0.25022	0.43354	0.43849	0.02048
348	-0.11647	0.62401	-0.07206	0.29211	0.08946	-0.15588	-0.00913	0.07043
349	-0.04270	0.08669	-0.05368	0.74470	0.04213	0.26896	-0.02772	-0.01436
350	0.30345	0.32984	0.09394	0.13462	0.16561	0.09708	0.63080	0.00555
355	-0.10049	0.74095	-0.06503	0.05093	-0.01196	-0.01711	-0.03962	0.04854
356	-0.02458	0.22122	-0.04788	0.84758	0.15152	0.20927	0.00162	-0.03343
368	-0.04450	0.33465	-0.03430	0.76884	0.26345	-0.16952	0.07344	0.04400

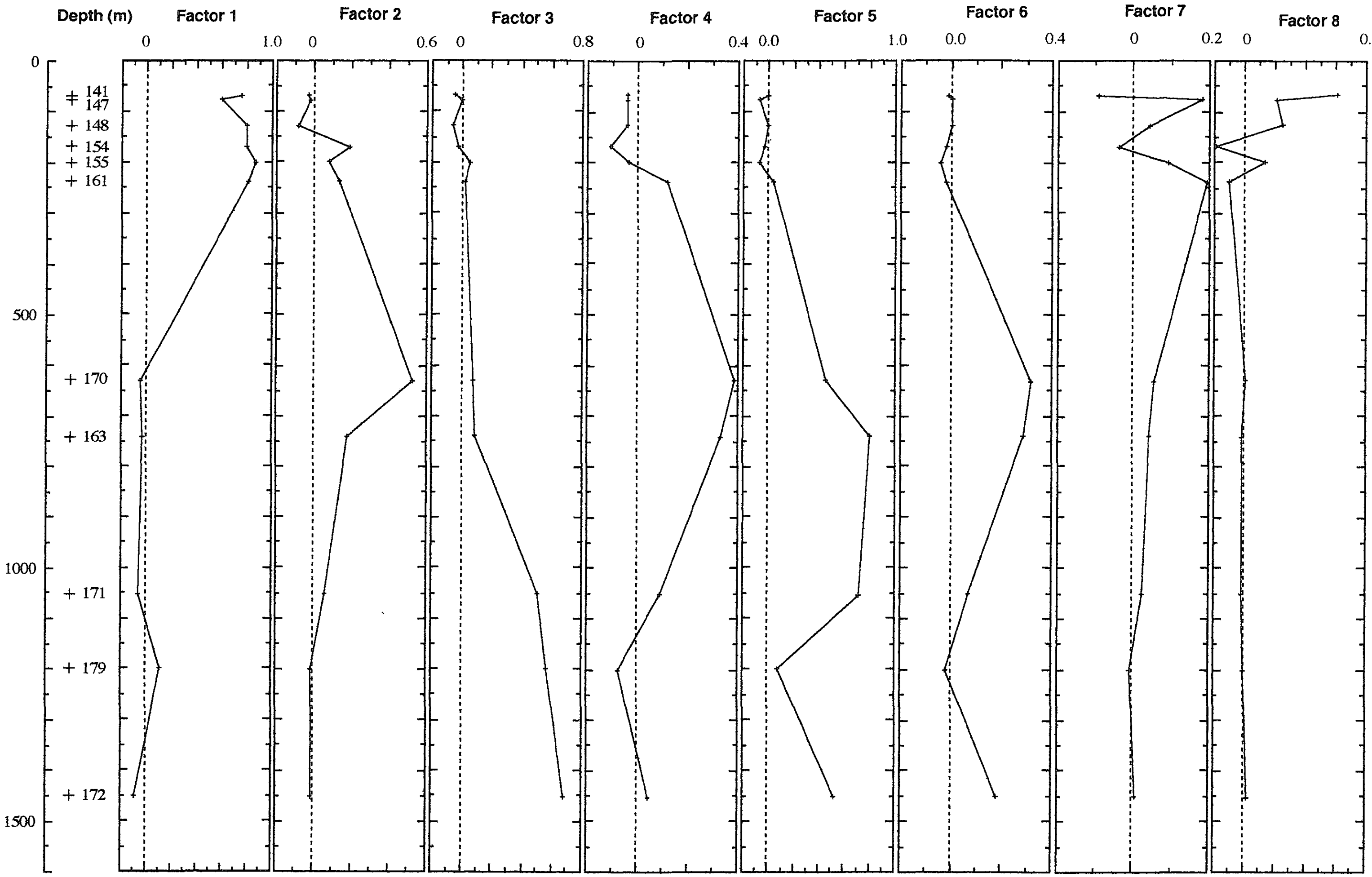

Fig. 9. Distribution of the varimax loadings for each of the first eight factors off Ashizurimisaki.
Cross ; sampling point with sample number.

Table 4. Factor scores for the Hyuganada area.

Species	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Karreriella apicularis (Cushman)	-0.27232	-0.27103	-0.25376	-0.21533	-0.07349	-0.20855	-0.11419	-0.23015
Martinottiella communis (d'Orbigny)	-0.25937	-0.16764	-0.15822	-0.15102	-0.34157	-0.26358	-0.08821	-0.22993
Saccorhiza ramosa Brady	-0.28277	-0.27407	-0.24770	-0.22218	-0.06509	-0.22245	-0.11303	-0.20853
Spiroplectammina henmii Oki	-0.26274	-0.32645	-0.36797	-0.19486	-0.11809	-0.20093	0.54560	-0.15162
S. higuchii Takayanagi	0.45810	-0.09856	-0.53691	-0.22997	0.12161	-0.30670	-0.43813	-1.12950
Textularia conica d'Orbigny	0.15262	-0.26655	-0.49015	-0.20068	0.04414	-0.09331	-0.66909	2.38603
Trochammina globigeriniformis (Parker and Jones)	-0.29323	-0.27711	-0.24163	-0.22902	-0.05668	-0.23636	-0.11188	-0.18691
Ammonia ketienziensis (Ishizaki)	0.20197	0.04000	-0.50700	-0.28064	-0.00852	-0.43768	0.45395	-0.74100
A. ketienziensis angulata (Kuwano)	-0.07606	-0.11248	-0.44495	-0.27817	-0.00468	-0.11075	-0.37079	-0.33387
Amphistegina radiata (Fichtel and Moll)	-0.19038	-0.33040	-0.33070	-0.16228	-0.14502	-0.11353	0.04250	0.03432
Anomalinoides glabrata (Cushman)	-0.15197	-0.41244	-0.14883	0.92149	-0.54241	-0.30025	-0.24057	-0.54135
A. globulosa (Chapman and Parr)	-0.19888	-0.29613	-0.17293	-0.26196	-0.04870	0.42734	-0.33487	-0.42433
Astrononion stellatum Cushman and Edwards	-0.24532	0.38313	-0.30032	-0.24613	-0.15344	-0.37197	-0.25530	-0.27242
Bolivina robusta Brady	-0.52904	6.30381	-0.20354	-1.94237	-0.93931	1.47076	-0.28663	0.41020
Brizalina karreriana (Brady)	-0.20110	-0.24674	-0.10799	-0.02151	-0.55211	0.77745	-0.36487	-0.39186
Bulimina aculeata d'Orbigny	-0.33211	-0.33441	2.70326	-0.25221	-0.00045	-0.50922	-0.21353	0.01417
B. kochiensis Takayanagi	-0.31575	0.11590	-0.27177	-0.29612	-0.14000	-0.23481	-0.17017	-0.12405
B. marginata d'Orbigny	0.03694	3.50158	-0.17838	5.88865	3.75890	0.40427	1.23548	0.07512
B. rostrata Brady	-0.22156	-0.11188	2.31554	-0.28325	0.67003	-0.91255	-0.36211	-0.17131
B. striata d'Orbigny	-0.29539	-0.39989	0.52996	-0.22399	0.53162	0.08679	-0.30328	-0.08674
Cassidulina carinata Silvestri	-0.16749	-0.86506	0.33256	-0.26364	-0.00964	1.20900	-0.03494	-0.00147
C. norvangi Thalmann	-0.33392	-0.58572	-0.25331	0.31756	-0.46475	0.02755	-0.13580	0.02775
Chilostomella ovoidea Reuss	-0.28259	-0.51355	0.62367	0.50464	-1.73149	1.91132	-0.58443	0.04369
Cibicides aknerianus (d'Orbigny)	-0.15102	-0.08584	-1.16533	-0.38883	1.29884	0.49301	-0.39127	-0.11366
C. praecinctus (Karrer)	1.72710	-0.98530	-0.47859	-0.04874	0.09921	-0.10210	0.55577	-0.23631
C. refulgens Montfort	1.80934	-0.86042	-0.76239	-0.00047	0.33735	0.04574	-0.98572	4.40189
C. robertsonianus (Karrer)	-0.20730	-0.27155	-0.40380	-0.22340	-0.04850	-0.08004	-0.23941	-0.13897
C. wuellerstorfi (Schwager)	-0.04608	-0.37680	-1.23566	-0.56777	2.66415	-0.11461	-0.43647	-0.43238
Cibicidoides mediocris (Finlay)	8.01269	1.41713	1.27251	-0.13666	-0.67760	-0.33190	0.97059	-0.59477
Discorbinella convexa (Takayanagi)	-0.12268	-1.14212	0.10083	4.21692	-1.39770	0.02118	-0.65523	-0.18281
Elphidium advena (Cushman)	-0.12316	-0.00005	-0.14015	0.43707	-0.24980	-0.82890	0.01688	0.28718
E. crispum (Linne)	0.93576	-0.39199	-0.52467	-0.25641	0.02727	0.14939	-0.75666	4.22082
Evolvocassidulina brevis (Aoki)	-0.54221	-0.33301	-0.51639	-0.35110	-0.14170	0.03325	4.54770	0.45268
Gavelinopsis lobatulus (Parr)	-0.19400	-0.24171	0.04381	0.10578	-0.90893	1.52961	-0.56798	-0.41852
G. praegeri (Heron-Allen and Earland)	-0.31296	0.04950	-0.33464	0.12205	-0.28469	-0.09755	-0.28258	0.00476
Globocassidulina bisecta Nomura	0.33374	-0.27344	-0.59014	-0.21389	0.12817	-0.07739	-0.94307	3.75898
G. cressa (d'Orbigny)	-0.26881	-0.54471	-0.32019	0.14789	-0.23876	0.11497	-0.14500	-0.11734
G. oriangulata (Belford)	-0.03489	0.02443	-0.20075	-0.32852	-0.25105	-0.17670	-0.11139	0.02742
G. subglobosa (Brady)	0.23788	-0.28450	-0.17727	-0.01595	-0.13482	-0.23430	0.04774	-1.32370
G. subparva Nomura	-0.22171	0.37069	-0.21341	-0.26829	-0.03866	-0.18711	-0.32460	-0.28318
Gyroidina cushmani Boomgaart	-0.03128	-0.40359	-0.36921	0.98063	-0.28927	-0.28701	-0.49943	-0.54537
Gyroidinoides nipponicus (Ishizaki)	-0.06274	0.10973	-0.37378	1.97485	-0.76716	5.94415	-0.59829	-0.13562
Hanzawaia nipponica Asano	2.38939	-0.66804	-0.69345	-0.13121	0.43948	-0.17005	-1.26547	-3.44497
H. sp. A	-0.31208	0.65999	-0.29672	-0.53500	-0.26871	0.02516	0.83808	-0.38903
Heterolepa haidingerii (d'Orbigny)	-0.19544	-0.30997	-0.32003	-0.16543	-0.13947	-0.11658	-0.00056	-0.06941
H. subpraecinctus (Asano)	-0.00929	-0.04234	-0.52234	-0.33012	0.05494	-0.10355	-0.49561	-0.32087
Hoeglundina elegans (d'Orbigny)	0.52436	-0.94775	-0.23436	-0.13294	-0.55339	1.01735	4.84663	0.48596
Lagena sulcata spicata Cushman and McCulloch	-0.25443	-0.14030	-0.23329	0.65163	-0.13139	-1.08385	-0.03323	-0.09942
Lernella ogasawarai Nomura	-0.34076	0.00615	-0.32943	-0.28148	-0.17377	-0.32568	-0.00432	-0.08575
Miliolinella circularis (Bornemann)	0.29456	-0.32937	-0.12595	-0.03557	-0.15808	-0.28917	-0.27152	-1.35144
Nonion japonica Asano	-0.24409	-0.16626	-0.24641	0.46104	-0.12967	-0.86261	-0.05351	-0.15952
Nonionella basiloba Cushman and McCollch	-0.33344	0.17734	-0.26871	-0.31643	-0.14268	-0.25309	-0.17834	-0.08475
Nonionellina labradorica (Dawson)	-0.59638	1.50295	-0.12618	1.37548	-0.20821	-2.84024	-0.16685	0.87888
Nuttallides umboniferus (Cushman)	-0.16477	-0.08946	-0.40408	-0.21281	0.09425	-0.41248	-0.26871	-0.40896
Oridorsalis tener (Brady)	-0.23442	-0.15998	0.48613	-0.06312	-0.35862	-0.29833	-0.16825	-0.18376
O. umbonatus (Reuss)	-0.23796	-0.14672	0.59703	-0.04724	-0.39215	-0.32308	-0.17498	-0.15860
Paracassidulina neocarinata (Thalmann)	-0.14629	0.97669	-0.15155	-0.46289	-0.84472	1.01958	-0.71514	-0.66265
P. sulcata (Belford)	-0.38425	-0.35025	0.54208	-0.20219	-0.38169	-0.16676	-0.12365	0.15428

Pararotalia nipponica (Asano)	-0.19038	-0.33040	-0.33070	-0.16228	-0.14502	-0.11353	0.04250	0.03432
Parrelloides bradyi (Trauth)	-0.33202	-0.17409	0.65162	-0.10884	-0.31651	-0.44819	-0.16456	0.03599
Planulina ariminensis d'Orbigny	0.38227	-0.07009	-0.42357	-0.19159	0.04540	-0.19907	-0.34785	-1.16422
Pseudononion decora (Heron-Allen and Earland)	-0.34684	1.28776	-0.38202	-0.75692	-0.39129	0.10249	-0.18647	-0.15826
P. japonicum Asano	-0.31575	0.11590	-0.27177	-0.29612	-0.14000	-0.23481	-0.17017	-0.12405
Pseudoparrella exigua (Brady)	-0.33218	-0.29943	2.15058	0.18805	-0.29057	-0.07843	-0.34530	0.14050
Pseudorotalia gaimardii (d'Orbigny)	-0.40036	-0.03242	-0.40144	-0.31022	-0.17365	-0.41205	0.59075	0.12389
Pullenia bulloides (d'Orbigny)	-0.28889	-0.54586	2.38584	0.01607	-0.40075	0.55734	-0.24576	-0.03408
P. quinqueloba (Reuss)	-0.24129	-0.20587	0.57982	-0.28810	0.04220	-0.71296	-0.07960	-0.39787
Quinqueloculina akneriana d'Orbigny	1.22233	-0.42594	-0.85845	-0.33357	0.36301	0.11643	-1.08743	1.80308
Q. seminula (Linne)	-0.25127	0.48912	-0.30201	-0.25811	-0.15836	-0.41310	-0.27766	-0.25785
Rectobolivina bifrons (Brady)	-0.23829	-0.01889	-0.23324	-0.25389	-0.19084	0.77213	1.07561	-0.35314
R. raphana (Parker and Jones)	-0.29856	1.01620	-0.21786	-0.45412	-0.25070	-0.47492	-0.29571	0.27984
Reussella aculeata Cushman	-0.31453	-0.04563	-0.32158	-0.26004	-0.16380	-0.28557	-0.02768	-0.14057
Robulus calcar (Linne)	-0.41718	-0.29242	-0.35048	-0.25752	-0.11059	-0.41200	2.40491	-0.07216
R. orbicularis d'Orbigny	-0.15128	-0.37427	-0.29905	-0.21804	-0.15428	0.05560	0.19985	0.53107
R. pseudorotulatus Asano	-0.14067	-0.39635	-0.30067	-0.22600	-0.15980	0.08846	0.25821	0.69306
R. sagamiensis Asano	-0.25937	-0.16764	-0.15822	-0.15102	-0.34157	-0.26358	-0.08821	-0.22993
R. surugaensis Asano	-0.25610	-0.31724	-0.35824	-0.19229	-0.11882	-0.19146	0.46226	-0.17765
Rosalina vilardeboana d'Orbigny	-0.37212	1.26796	-0.23990	0.54734	-0.46156	-0.88360	-0.45375	-0.04081
Rutherfordoides mexicanus (Phleger and Parker)	-0.13381	-0.50617	0.54962	-0.11009	-0.25078	0.41073	-0.21885	-0.34312
Sigmoilopsis schlumbergeri (Silvestri)	-0.27232	-0.27103	-0.25376	-0.21533	-0.07349	-0.20855	-0.11419	-0.23015
Sphaeroidina compacta Cushman and Todd	-0.31614	-0.10454	4.65284	-0.90713	3.76841	1.81316	0.56395	0.41896
Tosaia hanzawai Takayanagi	-0.20945	-0.35518	0.25939	-0.80876	2.75344	0.82065	-0.64127	-0.13476
Uvigerina hispida Schwager	-0.34349	0.10543	3.93709	-0.04049	-0.92203	-1.09774	-0.13229	0.14390
U. hispidocostata Cushman and Todd	-0.07606	-0.85005	-0.56425	-0.92378	4.11095	0.29287	-0.31731	-0.31158
U. proboscidea Schwager	-0.25923	-0.21261	-0.22879	2.12858	-0.35246	-1.12061	-0.35119	0.04838
U. proboscidea vadescens Cushman	-0.27835	0.78883	-0.31544	-0.57436	-0.29485	0.11921	0.38999	-0.39441
U. proboscidea vadescens Cushman forma A	-0.34587	0.61188	-0.44930	-0.58733	-0.30075	0.53373	1.81673	0.03060
Valvulineria hamanakoensis (Ishiwada)	-0.38651	0.36168	-0.25952	-0.37735	-0.15073	-0.30792	-0.20286	0.03316
V. rugosa minuta (Schubert)	-0.26628	-0.25209	-0.21898	-0.05062	-0.33350	-0.24687	-0.10852	-0.24943

Discussion

The authors examined 33 samples from the Hyuganada area, and recognized eight benthic foraminiferal assemblages by Q-mode Factor analysis. They are named the *Cibicidoides mediocris-Hanzawaia nipponica*, *Bolivina robusta-Bulimina marginata*, *Sphaeroidina compacta-Uvigerina hispida*, *Bulimina marginata-Discorbinella convexa*, *Uvigerina hispidocostata-Sphaeroidina compacta*, *Gyroidinoides nipponicus*, *Hoeglundina elegans-Evolvocassidulina brevis*, and *Cibicides refulgens-Elphidium crispum* Assemblages based on the dominant and subordinate species present. The relationship of the assemblages with their areal distribution and water depth are shown in Fig. 12.

Aoshima (1978) and Inoue (1989) investigated the Recent benthic foraminiferal faunas in the Hyuganada area, and mentioned the relationship between the faunas and oceanographic conditions. The benthic foraminiferal assemblages distinguished by these workers are also shown in Fig. 12.

Inoue (1989) described 6 assemblages based on the dominant species in the Northwest Pacific off Kyushu, Shikoku and the central part of Honshu Islands. According to Inoue (1989), four assemblages were recognized in this area, and named the *Bolivina robusta*, *Cassidulina carinata*, *Bulimina aculeata*, and *Bulimina aculeata-Melonis parkerae* Assemblages.

The *Bolivina robusta* Assemblage identified by Inoue (1989) was distributed between water depths of 70-100m and 300-400m under the Kuroshio Surface Water, and includes *B. robusta*, *Bulimina. marginata*,

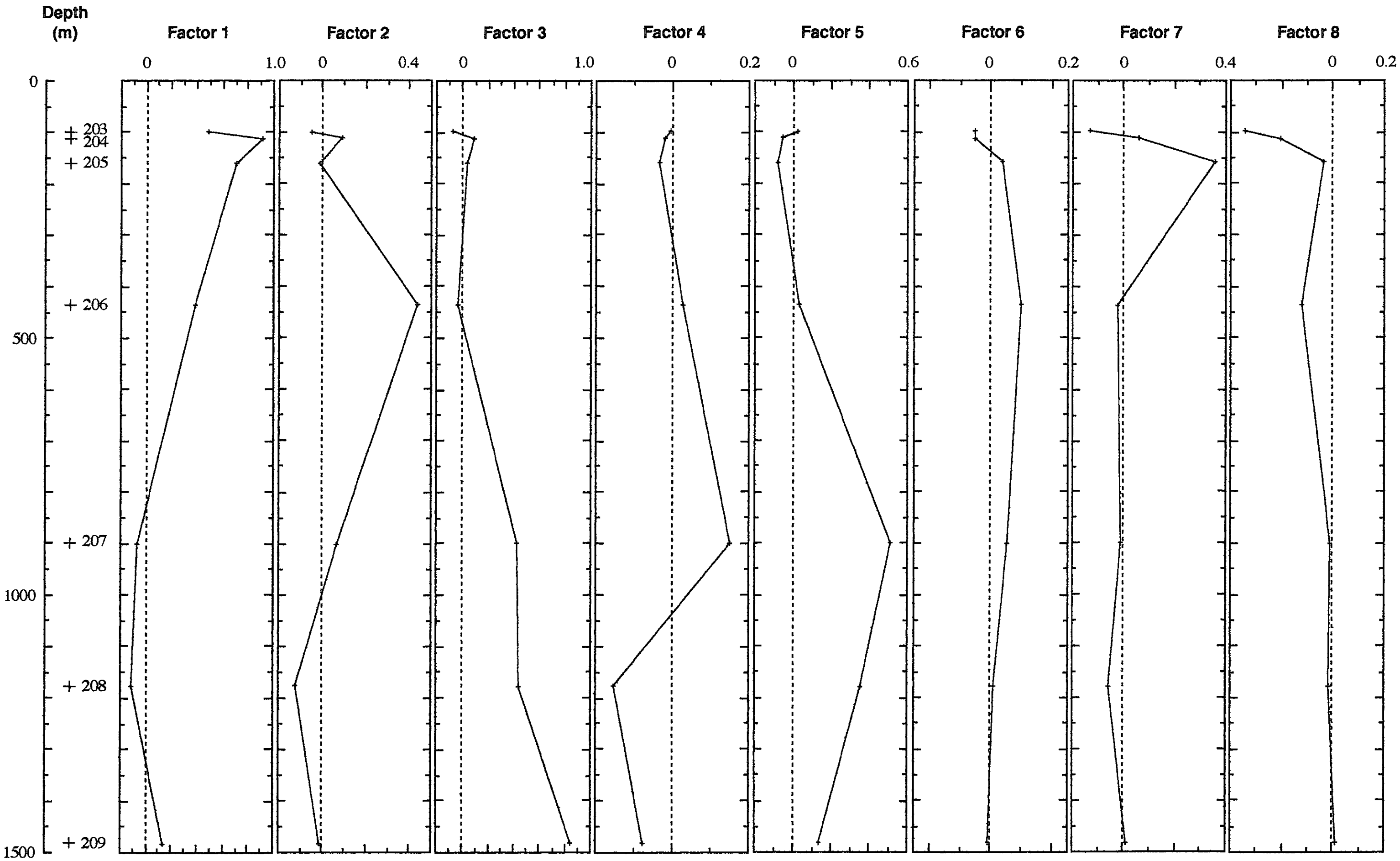

Fig. 10. Distribution of the varimax loadings for each of the first eight factors off the Bungo Strait.
Cross ; sampling point with sample number.

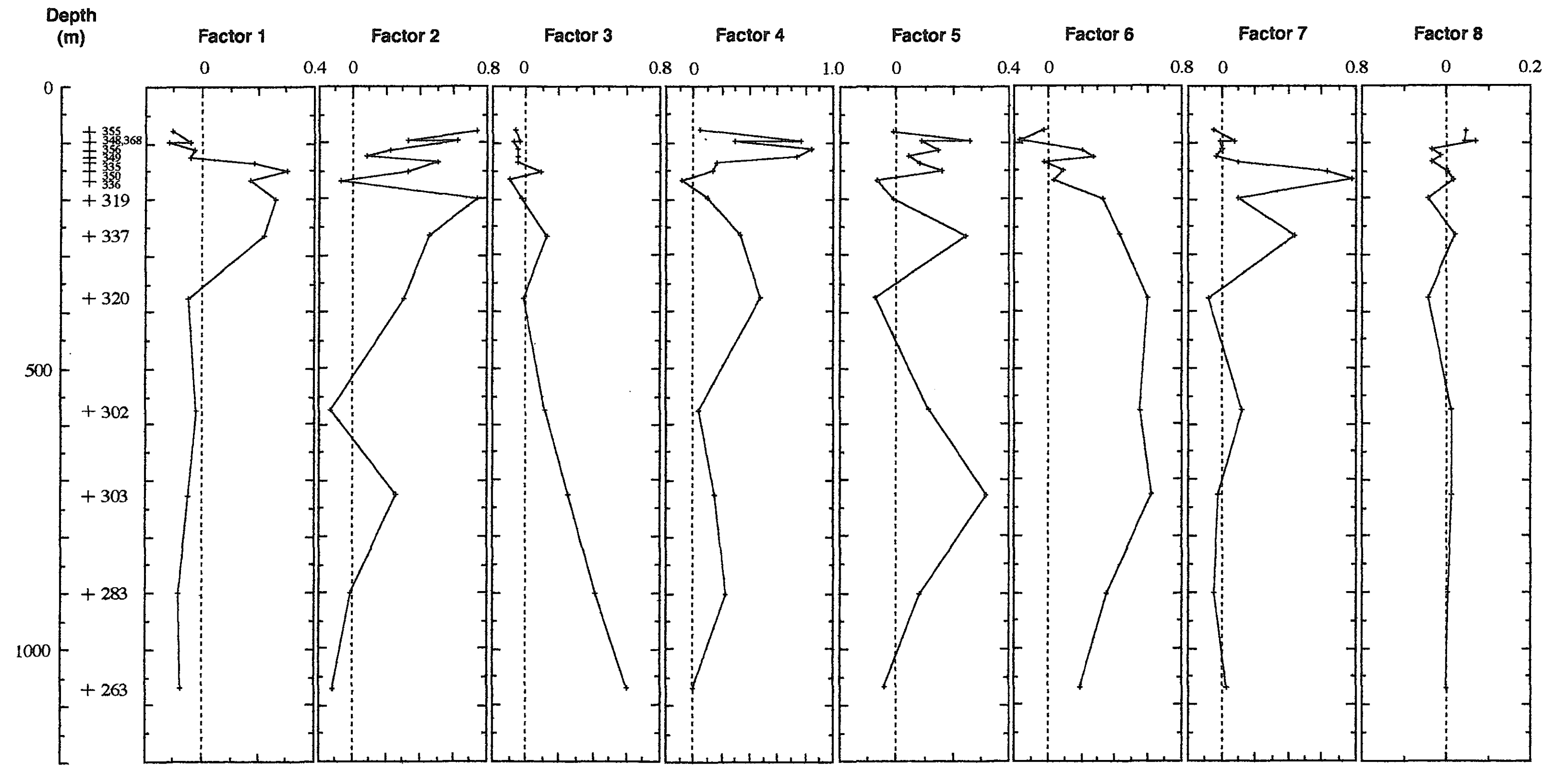

Fig. 11. Distribution of the varimax loadings for each of the first eight factors off Toimisaki. Cross ; sampling point with sample number.

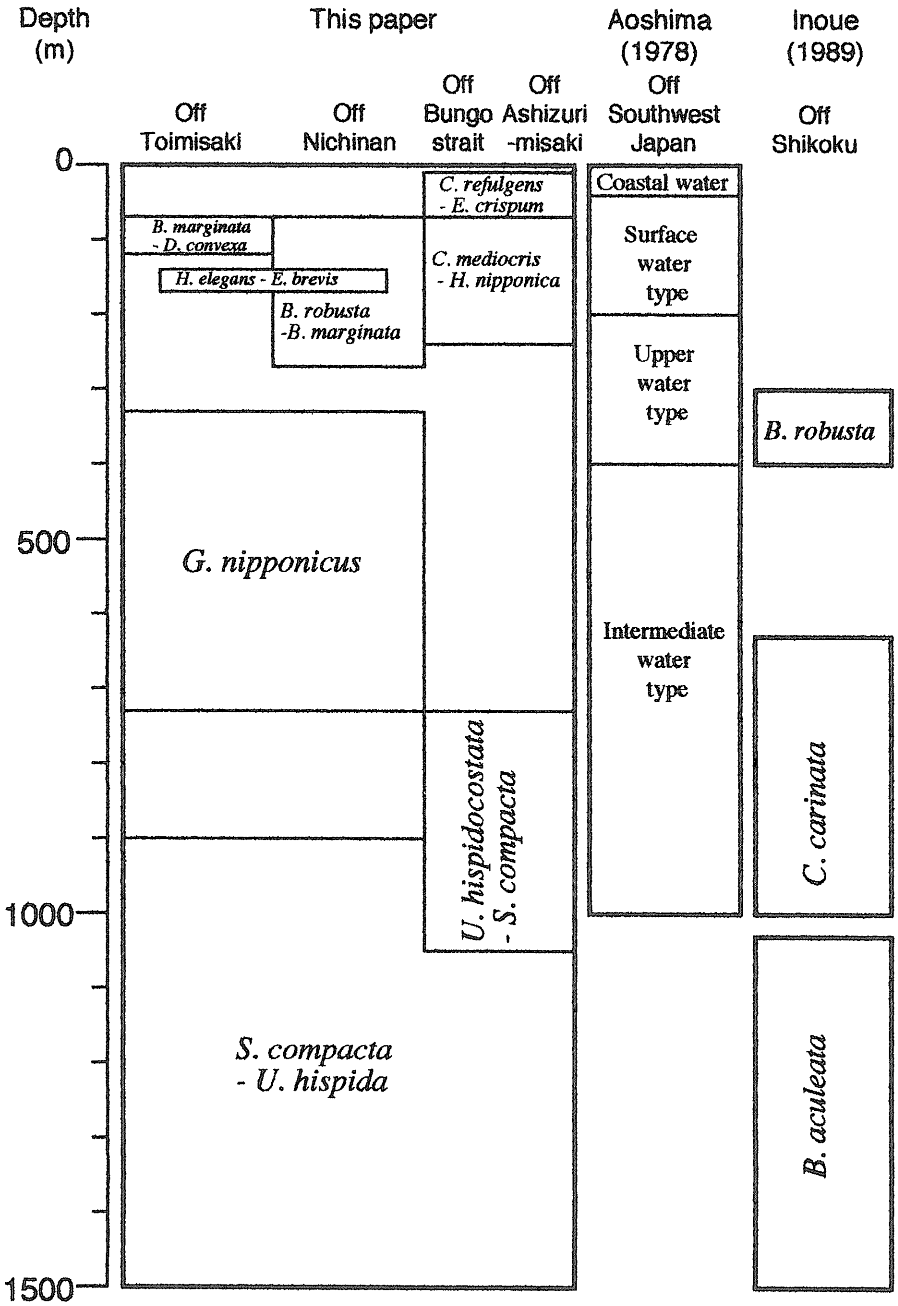

Fig. 12. Distribution of benthic foraminiferal assemblages as distinguished by a Q-mode Factor analysis. Assemblages by Aoshima (1978) and Inoue (1989) are also shown.

Cassidulina carinata, *Rectobolivina raphana* and *Uvigerina proboscidea vadescens*. This assemblage is similar to *Bolivina robusta-Bulimina marginata* Assemblage described in this study, however, its distribution differs from the results of Inoue (1989). It is clear that this assemblage has a restricted distribution in the coastal water off Nichinan City from the results of the Q-mode Factor Analysis.

The *Cassidulina carinata* Assemblage was characterized by abundant occurrences of *Cassidulina carinata*, and was confined to 630m to 1002m water depths on the upper to middle parts of the continental slope off Shikoku Island (Inoue, 1989). However, this study has recognized the presence of the *Uvigerina hispidula-Sphaeroidina compacta* Assemblages in the same depth interval.

The *Bulimina aculeata* Assemblage occurs at depths from 1067 to 1774m (Inoue, 1989). In this study, the *Sphaeroidina compacta -Uvigerina hispida* Assemblage occupies the oxygen minimum zone below water depths of 900m instead of the *B. aculeata* Assemblage identified by Inoue (1989). However, *Bolivinita quadrilatera*, *Bulimina striata*, *Cibicides wuellerstorfi*, *Martinottiella communis*, and several species of the genus *Uvigerina*, which accompany the species of the *B. aculeata* Assemblage of Inoue (1989), are also found in *Sphaeroidina compacta-Uvigerina hispida* Assemblage as subordinate species in this study. Thus, the boundary of the benthic foraminiferal assemblage exists at this water depth in the Hyuganada area.

Aoshima (1978) reported four assemblages related to water masses off southwest Japan. The species association of those four assemblages was not described in his paper, however, among the species, six types of distribution were recognized relative to the water masses. According to his distribution chart, *Bolivina robusta*, *Hanzawaia nipponica*, *Rosalina vilardeboana*, *Quinqueloculina* cf. *polygona* and *Quinqueloculina. seminula* are numerous in the coastal waters, *B. robusta*, *Chilostomella ovoidea* and *Pseudorotalia gaimardii* are dominant in the surface water, and *Bulimina. aculeata* and *Bulimina marginata* occur in the intermediate water off Miyazaki City. The species having a high frequency except for *B. robusta* and *H. nipponica* in the coastal and surface waters differ from the results of this study.

The assemblages identified in this study in the Hyuganada area off Ashizurimisaki coincide with the results of Inoue (1989), but differ from those described by Aoshima (1978) for off Miyazaki City. Thus, it is considered that the difference in the species and frequency of the benthic foraminiferal assemblages between Ashizurimisaki and Miyazaki City reflects the variable character of the water masses and sediments. This survey of benthic foraminifera in the traverse from Ashizurimisaki to Miyazaki will serve to elucidate this problem.

This study establishes faunal assemblages related to their distribution within various environments in order to obtain the basic data required for zonation and paleoenvironmental analysis by means of fossil benthic foraminifera. The Neogene Miyazaki Group is situated around Miyazaki City. Suzuki (1987) reconstructed the paleoenvironments of the Miyazaki Group based upon the benthic foraminiferal fossil content. The foraminiferal species present in the Miyazaki Group resemble those Recent species found in the Hyuganada area. Therefore, the results of the relationship between the distribution of Recent benthic foraminiferal assemblages and the environmental factors in the Hyuganada area can be applied to a paleoenvironmental study in the Miyazaki region.

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日向灘海域における現世底生有孔虫群集の分布

秋元和實・鳥井真之

要　旨

新第三系宮崎層群の古環境解析の基準を構築するために，四国ならびに九州沖の日向灘海域において現世底生有孔虫群集の分布を調査した．小論では，現世底生有孔虫群集の分布と環境因子との関係を議論した．第 GH83-2航海によって得られた33底質試料に産した現世底生有孔虫群集をＱモード因子分析によって検討した結果，水深に対応した以下の群集を認めた．１）*Cibicidoides mediocris-Hanzawaia nipponica* 群集は浅海帯に，２）*Cibicides refulgens-Elphidium crispum* 群集は表層水下の砂底に，３）*Uvigerina hispidocostata-Sphaeroidina compacta* 群集は足摺岬沖の塩分濃度極小帯の上部に，４）*Bolivina robusta-Bulimina marginata* 群集は日南市沖の沿岸水に，５）*Bulimina marginata-Discorbinella convexa* 群集は黒潮の表層水に，６）*Hoeglundina elegans-Evolvocassidulina brevis* 群集は外部浅海帯および上部漸深海帯に，７）*Gyroidinoides nipponicus* 群集は都井岬沖の塩分濃度極小帯に，８）*Sphaeroidina compacta-Uvigerina hispida* 群集は溶存酸素極小帯に分布する．