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Faunal Analysis and Oceanic Environment of the Recent Benthonic Foraminifera from the West and South Sea of Korea

HAE-KYUNG CHEONG[1], KWANG-HO PAIK[2] AND BYONG-KWON PARK[3]
[1]*School of Liberal Arts, Kyungsan University, Kyungsan 712-240, Korea*
[2]*Department of Geology, Korea University, Seoul 136-701, Korea*
[3]*Korea Ocean Research and Development Institute, Ansan 425-600, Korea*

한국 서남해에서 산출된 현생저서 유공충의 동물군 분석 및 해양환경 연구

정혜경[1] · 백광호[2] · 박병권[3]
[1]경산대학교 교양학부
[2]고려대학교 지질학과
[3]한국 해양 연구소

As a result of faunal analysis on 50 bottom samples bearing a total of 183 species of the Recent benthonic foraminifers from the West and South Sea of Korea, five bioassociations (groups of species) and five biotopes (groups of samples) were discriminated. From the areal distribution of biotopes in combination with bioassociations and the available ecological data of foraminiferal species, five biofacies are recognized: (1) Southern Inner Shelf Biofacies; (2) Southern Coast Biofacies; (3) Northern Middle Shelf Biofacies; (4) Central Middle Shelf Biofacies; and (5) Southern Outer Shelf and Upper Slope Biofacies. The biofacies are defined by a group of sampling stations containing a diagnostic species association and can be related to the major current patrerns and water masses in the West and South Sea of Korea: Southern Inner Shelf Biofacies is related to the Coastal Waters and drainage from China; Southern Coast Biofacies is related to the Coastal Waters and drainage from Korea; Northern Middle Shelf Biofacies is related to the Coastal Waters and Yellow Sea Cold Water; Central Middle Shelf Biofacies is related to the Yellow Sea Warm Current; and Southern Outer Shelf and Upper Slope Biofacies is related to the Tsushima Warm Current.

한국의 서해와 남해에서 채집된 50개의 시료에서 채출된 183종의 저서 유공충의 분포자료를 동물군 분석한 결과, 5개의 생물군집(bioassociation)과 5개의 생물장(biotope)이 구분되었다. 생물군집, 생물장의 지리적 분포 및 유공충 종의 이용가능한 생태학적 자료로부터 5개의 생물상(biofacies)이 인지되었다: (1) 남부 내대륙붕 생물상; (2) 남부 해안 생물상; (3) 북부 중대륙대 생물상; (4) 중앙 중대륙대 생물상; (5) 남부 외대륙붕 및 상대륙사면 생물상.

특징적인 종 군집을 포함하는 시료들의 집단으로 정의되는 생물상은 연구해역에서 주요 해류 분포양상과 밀접한 관계가 있다. 남부 내대륙붕 생물상은 연안류와 중국으로부터 유입되는 하천수의 영향을, 남부 해안 생물상은 연안류와 한반도로부터 유입되는 하천수의 영향을 크게 받고 있는 것으로 보인다. 또한 북부 중대륙붕 생물상은 연안류와 황해 냉수층, 중앙 중대륙붕 생물상은 황해 난류, 그리고 남부 외대륙붕 및 상대륙사면 생물상은 쓰시마 난류와 밀접한 관계가 있는 것으로 보인다.

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INTRODUCTION

Due to their biologic and geologic importance, the distribution of Recent foraminifera from the Yellow Sea and the East China Sea has been studied intensively; for the past 30 years since the early work of Polski (1959) who studied the Recent foraminiferal biofacies off the north Asiatic coast. Kim et al. (1970) analyzed 12 dredged and 9 cored samples taken from off the southwestern coast of Korea and identified 14 species belonging to 6 genera of planktonic foraminifera and 124 species belonging to 57 genera of benthonic foraminifera. Chang and Lee (1983, 1984) studied the Recent benthic foraminifera from the intertidal flats on the western coast of Korea with particular attention to faunal assemblage and related micropaleontological characteristics such as faunal composition, dominance, diversity, and equitability of the live and total populations. Chang (1984) published the Recent benthic foraminifera as a sedimentary tool and presented micropaleontological relationship with the sedimentation of the western coast of Korea.

Although foraminifera in the bottom sediments from the seas neighboring China have been investigated by the Chinese scientists over the last 30 years, it was only a few years ago when the publication of a volume of the investigation results become available (Wang et al., 1985). The present paper delineates the distribution patterns of the Recent benthonic foraminifera from the West and South Sea of Korea and analyses these data quantitatively to obtain the relationship between the benthonic foraminiferal biofacies and the environmental parameters.

METHODS

50 surface samples from the West and South Sea of Korea, bounded by latitudes 32°00′ N and 36°10′ N and longitudes 122 30' E and 128° 30′ E, were selected for the present study (Fig. 1 and Table 1). The surface sediments used in the study were taken by the Korea Ocean Research and Development Institute (KORDI). Twenty-two samples

Table 1. Locations and water depths of the study samples.

Station No.	longitude	latitude	Water depth(m)
Y-1	126°00′	36°10′	35
YS-2	125°30′	〃	63
YS-3	126°00′	35°40′	42
YS-4	125°30′	〃	73
YS-5	124°30′	〃	86
YS-6	123°30′	〃	72
YS-7	122°45′	〃	66
YS-8	125°45′	35°10′	25
YS-9	124°45′	〃	90
YS-10	123°45′	〃	77
YS-11	123°00′	〃	69
YS-12	122°45′	〃	69
YS-13	125°45′	34°40′	37
YS-14	124°45′	〃	92
YS-15	123°00′	〃	72
YS-16	123°45′	〃	77
YS-17	122°45′	〃	68
YS-18	128°30′	34°30′	66
YS-19	128°00′	〃	34
YS-20	126°00′	34°10′	46
YS-21	125°30′	〃	80
YS-22	124°30′	〃	90
YS-23	123°30′	〃	71
YS-24	122°45′	〃	60
YS-25	128°30′	34°00′	100
YS-26	127°30′	〃	75
YS-27	126°30′	34°00′	43
YS-28	125°30′	〃	77
YS-29	124°30′	〃	80
YS-30	123°30′	〃	68
YS-31	128°30′	33°30′	120
YS-32	127°30′	〃	101
YS-33	125°30′	〃	93
YS-34	124°30′	〃	72
YS-35	123°30′	〃	62
YS-36	128°15′	33°00′	183
YS-37	127°30′	〃	145
YS-38	126°30′	〃	103
YS-39	125°30′	〃	96
YS-40	124°30′	〃	64
YS-41	123°30′	〃	36
YS-42	127°30′	32°30′	131
YS-43	126°30′R	〃	105
YS-44	125°30′	〃	72
YS-45	124°30′	〃	48
YS-46	123°30′	〃	40
YS-47	126°00′	32°00′	60
YS-48	125°30′	〃	63
YS-49	124°30′	〃	42
YS-50	123°30′	〃	38

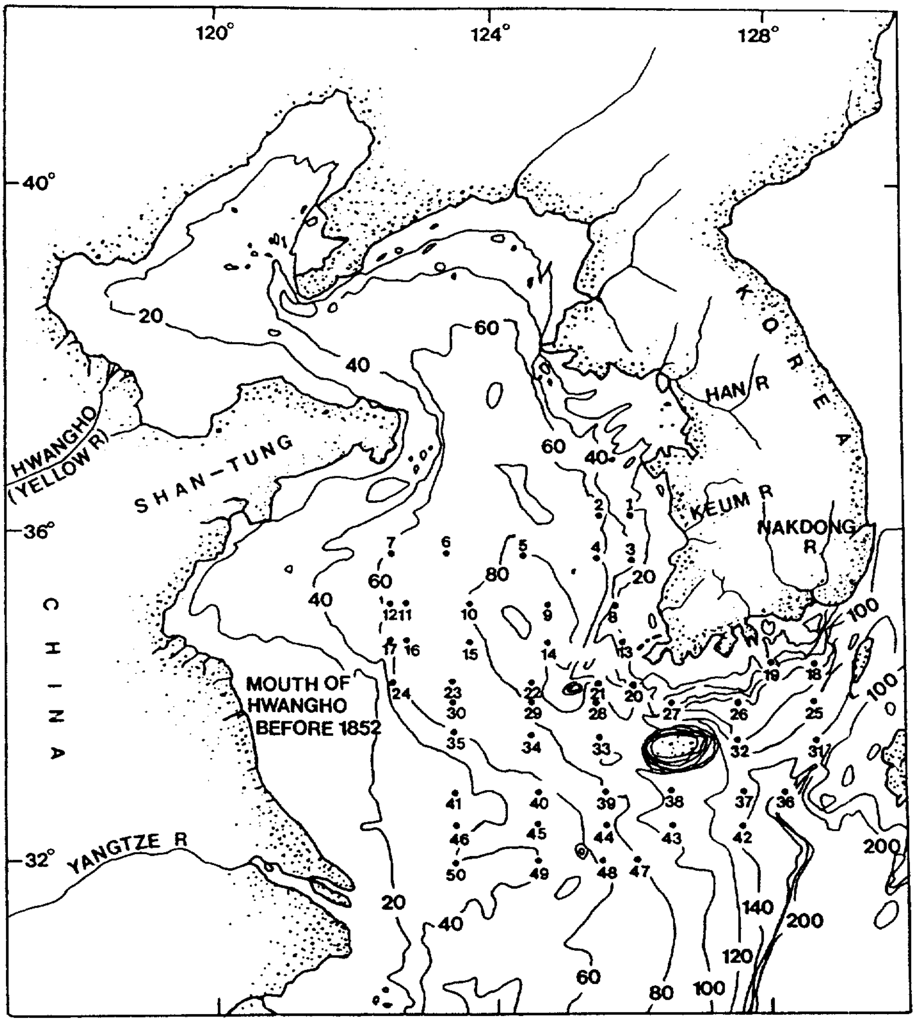

Fig. 1. Locations of sampling stations and bathymmetry of the study area.

(YS-1 to YS-24 except for YS-18 and 19) were collected during Aug. 25 to Sep. 10, 1983 using Shipek and McIntyre grab sampler and Twenty-eight samples (YS-18 and 19, YS-25 to YS-50) were obtained during Apr. 20, 1985 using Shipek and Van Veen grab sampler.

All the samples were washed over a screen with average openings of 0.063 mm (250 mesh) and from the dried residues, approximately three hundred benthonic foraminifera and accompanying planktonic foraminifera were counted.

Data on the distribution and relative abundance of foraminifera in the 50 samples were analyzed through both Q- and R-mode of Principle Component Analysis (PCA) using correlation coefficient. For the present quantitative study, the number of variables used in Q- and R-mode of PCA was limited to only the 80 most frequently recorded species. The total process of analysis used in this paper can be found in Cheong (1991). More detailed discussions of the theory and mathematics of principal component analysis can be found in Davis (1973, 1986), J eskog et al. (1976), Hazel (1977), Loudon (1979), and Koh (1988).

RESULTS

FORAMINIFERAL BIOASSOCIATIONS

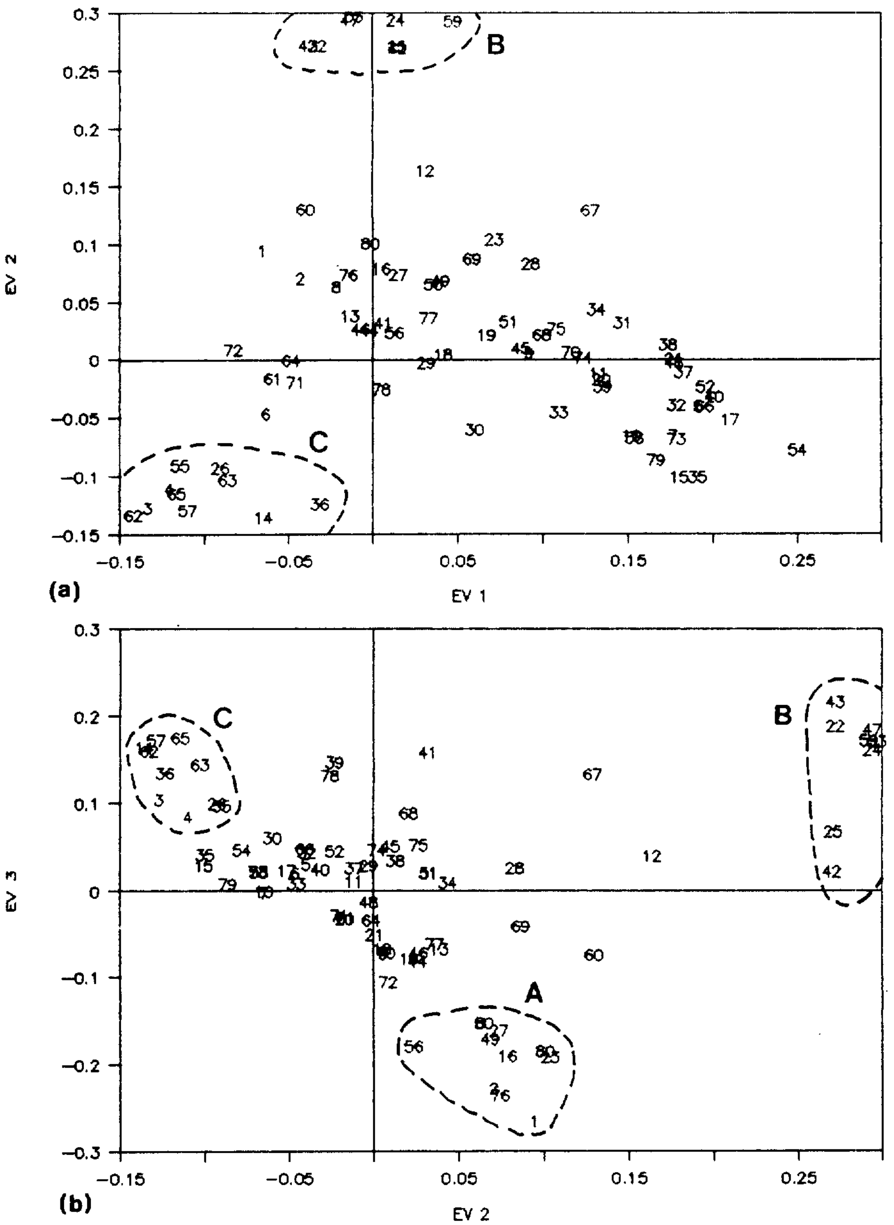

Fig. 2. Result of R-mode Principal Components Analysis of 80 commonly occurred foraminiferal species from the sourthern Yellow Sea: (a) plotted on axes 1 and 2; (b) plotted on axes 2 and 3; (c) plotted on axes 3 and 4; (d) plotted on axes 2 and 4.

The seven principal components were extracted from the PCA and the first five components account for approximately 42.78 percent of the variation. In Figs. 2a-d, the 80 foraminiferal species were plotted on the 1, 2, 3, and 4 axes (eigenvectors) obtained by PCA analysis. Five clusters could be discriminated from these figures. Baded on the assumption that each cluster may contain a group of species having similar environmental requirements or tolerance, the clusters were designated as bioassociations, marked by capital letters from A to E.

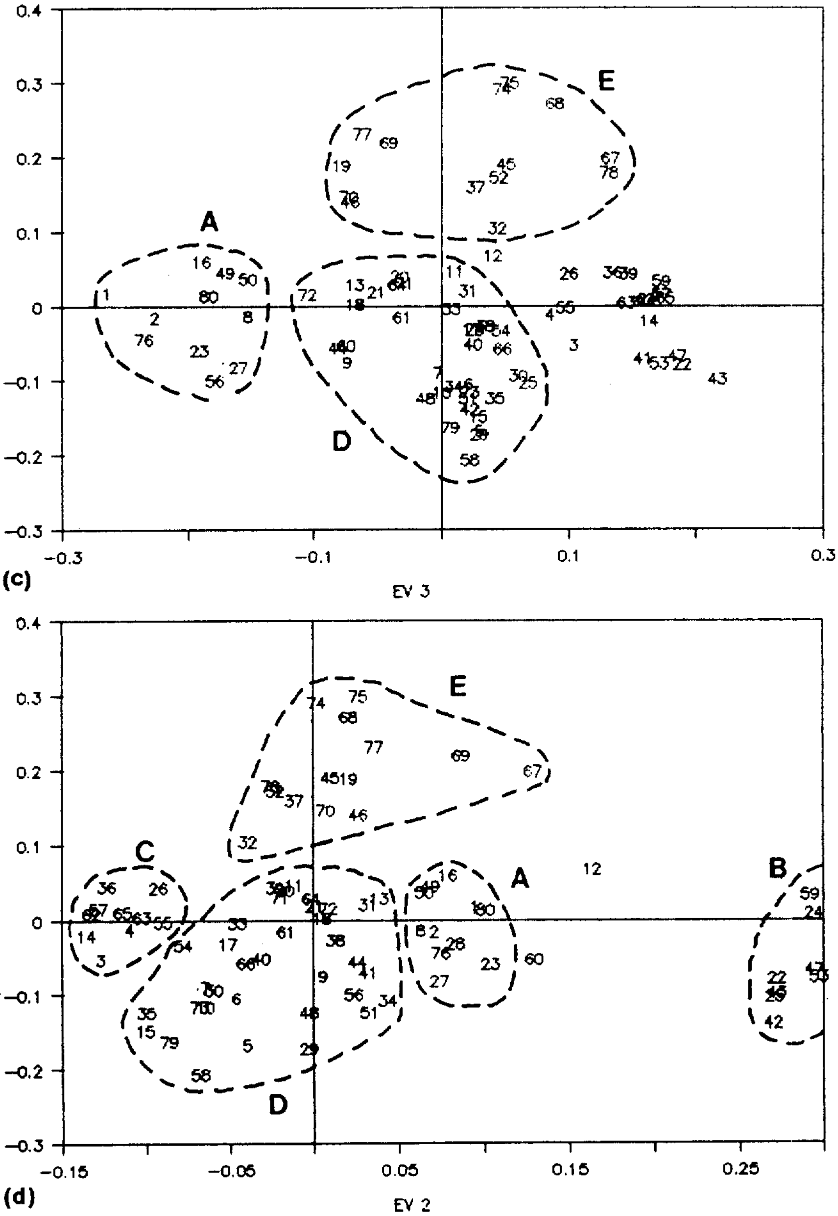

Fig. 2. continued.

Bioassociation A

This bioassociation includes 11 species that are abundant in five samples (YS-41, 45, 46, 49 and 50) from the southwestern part of the study area: *Ammonia* var. *compressiuscula* (Brady), *Quinqueloculina lamarckiana* d'Orbigny, *Ammonia beccarii* tepida (Cushman), *Epistominella naraensis* (Kuwano), *Elphidium advenum* (Cushman), *Rosalina globularis* d'Orbigny, *Bolivina pusilla* Schwager, *Cyclammina* sp. A, *Spiroloculina rugosa* Cushman and Todd, *Rosalina bradyi* (Cushman), and *Cancris auriculus* (Fichtel and Moll). In samples YS-41, 45, 46, and 49, *Ammonia* var. *compressiuscula* (Brady) is a characteristic dominant species which occupies high percentages (62% to 39%) in relative abundance, but is absent or rare in most of other samples.

Quinqueloculina lamarckiana (d'Orbigny), *Ammonia beccarii* tepida (Cushman), and *Epistominella naraensis* (Kuwano) are dominant species.

Bioassociation B

This bioassociation includes 8 species that are abundant in only one sample (YS-19) from the southern coast of the Korean peninsula: Nonionella stella Cushman and Moyer, *Rotalinoides annectens* (Parker and Jones), *Elphidium etigoense* Husezima and Maruhasi, *Elphidium var. advenum* (Cushman), *Pseudoeponides japonicus* Uchio, *Cribrononion subincertum* (Asano), *Gaudryina robusta* Cushman, and *Nonionella japonicum* Asano. In sample YS-19, *Nonionella stella* Cushman and Moyer is a characteristic dominant species having 24% in relative abundance and the next is *Rotalinoides annectens* (Parker and Jones) showing the relative abundance of 16%. However their proportion remarkably decrease in other samples of the study area. Especially, *Rotalinoides annectens* (Parker and Jones) occurs in six samples (YS-19, 26, 30, 33, 46, and 49) from the study area and it is very rare in all but YS-19 samples.

Bioassociation C

This bioassociation contains 10 species that are very abundant in eighteen samples (YS-1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 14, 15, 16, 17, 22, 23, and 24) from the northwestern part of the study area: *Reophax bulbosa* Champman and Parr, *Ammonia ketienziensis* (Ishizaki), *Eggerella advena* (Cushman), *Hanzawaia nipponica Asano, Reophax excentricus Cushman, Ammobaculites cubensis* Cushman and Bermudez, *Reophax curtus Cushman, Ammonia nakamurai* (Ishizaki), *Elphidium tsudai* Chiji and Nakaseko, and *Bulimina exilis tenuata* (Cushman). *Reophax bulbosa* Champman and Parr and *Ammonia ketienziensis* (Ishizaki) are characteristic dominant species and *Eggerella advena* (Cushman), *Hanzawaia nipponica* Asano and *Reophax excentricus* Cushman are dominant species. The arenaceous population in this bioassociation is most dominant than those of other bioassociations from the study area. None of the porcelaneous forms are included in this bioassociation.

Bioassociation D

Thlis bioassociation comprises 32 species that are most abundant eighteen samples (YS- 8, 13, 18, 20, 21, 26, 27, 28, 29, 30, 33, 34, 35, 39, 40, 44, 47, and 48) from central part of the study area: *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Earland, *Cassidulina refulgens* Montfort, Bulimina marginata d'Orbigny, *Nonionella turgida* (Williamson), *Cassidulina carinata* Silvestri, *Haplophragmoides columbiense evolutum* Cushman and McCulloch, *Gyroidinoides nipponica* Ishizaki, *Cibicides margaritiferus* (Brady), *Buccella* sp. A, *Fissurina laevigata* Reuss, *Trochammina rotaliformis* J. Wright, *Cibicides deprimus* Phleger and Parker, *Fissurina* var *marginata* (Montagu), *Rosalina* cf. *isabelleana* d'Orbigny, *Haplophragmoides columbiense* Cushman, *Fissurina* sp. B, *Bolivina subspinescens* Cushman, *Bolivina floridana* Cushman, *Hyalinea balthica* (Gmelin), *Textularia foliacea* Heron-Allen and Earland, *Uvigerina proboscidea* Schwager, *Spirolocammina tenuis* Earland, *Lenticulina calcar* (Linné), *Angulogerina semitrigona* (Galloway and Wissler), *Gaudryina arenaria* Galloway and Wissler, *Globocassidulina parva* (Asano and Nakamura), *Hanzawaia hamadaensis* Asano, *Bolivina spissa* Cushman, *Spiroloculina communis* Cushman and Todd, *Miliolinella circularis* (Bronemann), and *Reophax difflugiformis arenulata* Skinner. This bioassociation forms the largest species group among five bioassociations from the present study. The characteristic dominant species of this bioassociation are *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Earland, and the dominant species are *Cibicides refulgens* Montfort, *Bulimina marginata* d'Orbigny, *Cassidulina carinata* Silvestri, *Haplophragmoides columbiense evolutum* Cushman and McCulloch, and *Cibicides margaritiferus* (Brady).

Bioassociation E

The bioassociation E comprises 13 species that are abundant in eight samples (YS-25, 31, 32, 36, 37, 38, 42, and 43) from the southeastern part of the study area: *Globocassidulina oriangulata* Belford, *Cibicides lobatulus* (Walker and Jacob), *Spiroplectammina* sp. A, *Rosalina viladeboana* d'Orbigny, *Hoeglundina elegans* (d'Orbigny), *Quinqueloculina akne-*

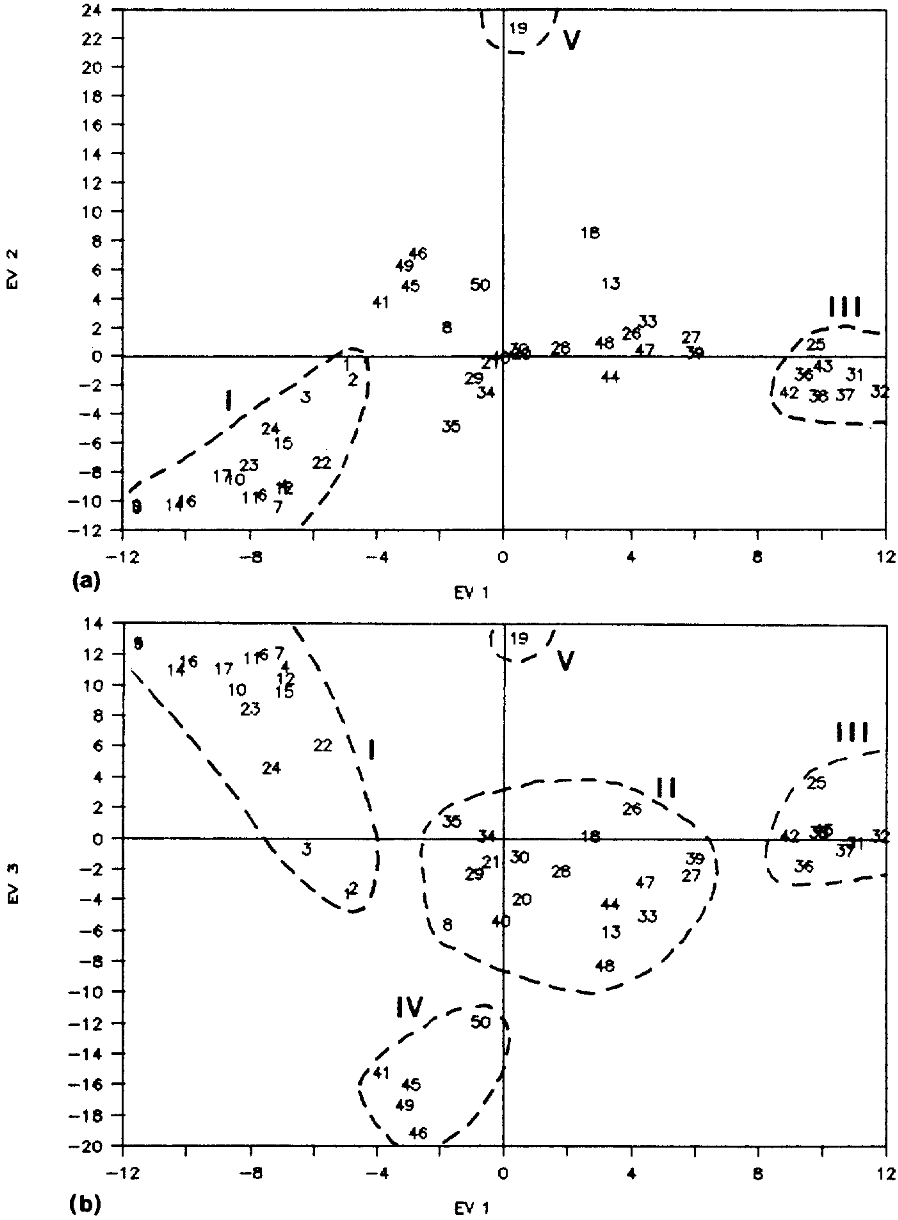

Fig. 3. Results of Q-mode Principal Components Analysis of 50 samples from the southern Yellow Sea: (a) plotted on axes 1 and 2; (b) plotted on axes 1 and 3; (c) plotted on axes 2 and 3.

riana d'Orbigny, *Q. anguina wiesneri* Parr, *Textularia conica* d'Orbigny, *Textularia articulata* d'Orbigny, *Q. vulgaris* d'Orbigny, *Sigmoilopsis moyi* Atkinson, emend. Haynes, *Paracassidulina sagamiensis* (Asano and Nakamura), and *Textularia agglutinans fistula* Cushman. The species of this bioassociation are rare or absent in other samples. Among them, two dominant species, *Globocassidulina oriangulata* Belford and *Spiroplectammina* sp. A, are largely restricted to this area in their distribution and abundance. In this bioassociation, the arenaceous and porcelaneous population occupy nearly 50% in relative abundance.

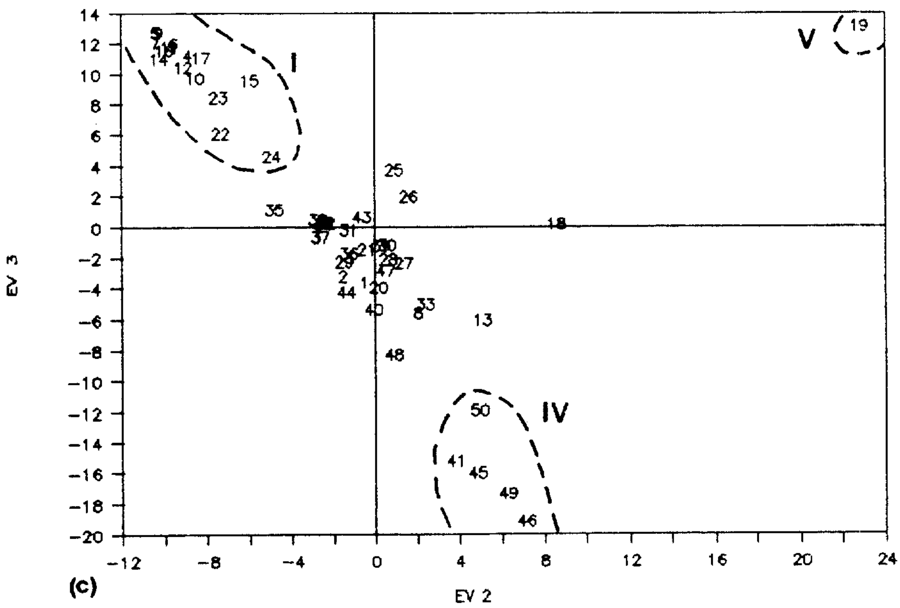

Fig. 3. continued.

FORAMINIFERAL BIOTOPES

Samples are plotted on the various combinations of the first three axes which account for a total of 31.37% of the variance. Figs. 3a-c show plots of samples for axes 1 and 2, axes 1 and 3, and axes 2 and 3, respectively. As a result, five groups of samples labelled I-V were delineated. Samples of each group contain similar foraminifera fauna which are restricted to a specific ecological unit. Therefore, each sample group could be designated as biotope.

Biotope I

This biotope contains eighteen samples (YS-1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 14, 15, 16, 17, 22, 23, and 24), from sand and muddy sand substrate occupying the northwestern part of the study area. The water depths of these samples are from 60 m to 92 m except for YS-1 and 3 having less than 50 m. Samples of this biotope are dominated by members of the bioassociation C. The foraminifera fauna of this biotope is characterized by *Reophax bulbosa* Champman and Parr, *Ammonia Ketienziensis* (Ishizaki) and *Eggerella advena* (Cushman). Other common foraminifera species include *Hanzawaia nipponica* Asano, *Ammobaculites cubensis* Cushman and Bermudez, and *Reophax excentricus* Cushman.

Biotope II

This biotope comprises eighteen samples (YS-8, 13, 18, 20, 21, 26, 27, 28, 29, 30, 33, 34, 35, 39, 40, 44, 47, and 48) taken from the central part of the study area, of which bottom is dominantly composed of sandy mud and muddy sand sediments. The water depths of these samples are from 60 m to 96 m except for samples YS-8, 13, 20, and 27 showing less than 50 m deep. Biotope II is dominated by the members of the bioassociation D. Its dominant species are *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Earland, *Cibicides refulgens* Montfort, *Bulimina marginata* d' Orbigny, *Cassidulina carinata* Silvestri, and *Cibicides margaritiferus* (Brady). Particularly in samples YS-47 and 48, *Bolivina robusta* Brady and *Astrononion italicum* Cushman and Earland comprise more than 40% in relative abundance. Several dominant species of biotope I, such as *Reophax bulbosa* Champman and Parr, *Ammonia ketienziensis* (Ishizaki), *Eggerella advena* (Cushman), and *Hanzawaia nipponica* Asano, show a decreasing trend in abundance, whereas *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Edwards, and *Cibicides refulgens* Montfort show a increasing trend in number.

Biotope III

This biotope includes eight samples (YS-25, 31, 32, 36, 37, 38, 42, and 43) from the southeastern part of the study area on the sandy and muddy sand sediments. Biotope III is highly dominated by the species of the bioassociation E. This biotope is characterized by the relatively high proportion of the arenaceous and porcelaneous populations. Dominant species are *Globocassidulina oriangulata* Belford, *Cibicides lobatulus* (Walker and Jacob), and *Spiroplectammina* sp. A. Most species from biotope III are nearly restricted to this biotope in distribution and the samples of this biotope lies in the depth of greater than 100 m.

Biotope IV

This biotope contains five samples (YS-41, 45, 46, 49, and 50) from the southwestern part of the study area, which were taken from the muddy sand bottom. The water depths of the samples included in this biotope are less than 50 m. Biotope IV is highly dominated by the members of the bioassociation A. It is noteworthy that an exceptionally high occurrence of *Ammonia* var. *compressiuscula* (Brady) having a maximum value of 62 % in relative abundance in sample YS-45. Other dominant species are *Quinqueloculina lamarckiana* d'Orbigny, *Ammonia beccarii tepida* (Cushman), *Epistominella naraensis* (Kuwano), *Elphidium advenum* (Cushman), and *Rosalina globularis* d'Orbigny.

Biotope V

This biotope contains only one sample (YS-19) taken from the 34 m deep muddy bottom in the southern coast of the Korean peninsula. This biotope is characterized by its unique faunal composition. It is dominated by the species of the bioassociation B. Abundant species are *Nonionella stella* Cushman and Moyer and *Rotalinoides annectens* (Parker and Jones). Other common species are *Elphidium etigoense* Husezima and Maruhasi, *E.* var.

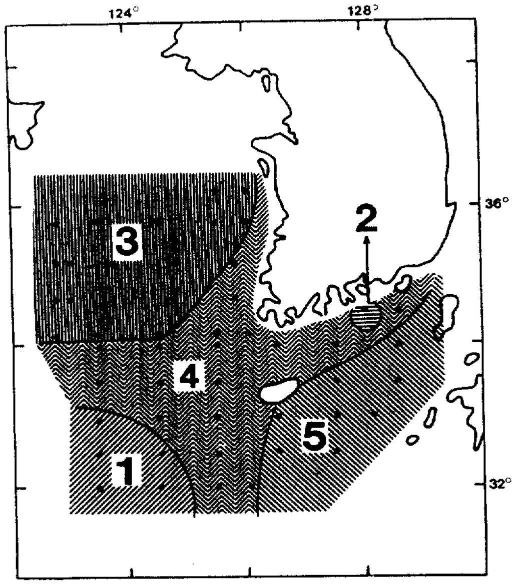

Fig. 4. Benthonic foraminiferal biofacies in the West and South Sea of Korea: (1) Southern Inner Shelf Biofacies; (2) Southern Coast Biofacies; (3) Northern Middle Shelf Biofacies; (4) Central Middle Shelf Biofacies; (5) Southern Outer Shelf and Upper Slope Biofacies.

advenum (Cushman), *Pseudoeponides japonicus* Uchio, *Cribrononion japonicum* (Asano), *Gaudryina robusta* Cushman, and *Nonion japonicum* Asano.

FORAMINIFERAL BIOFACIES

From the areal distributions of biotopes in combination with bioassociations and the available ecological data of foraminiferal species, five main groups of samples or biofacies are discriminated as follows (Fig. 4): (1) Southern Inner Shelf Biofacies (*Ammonia* var. *compressiuscula* (Brady) and *Quinqueloculina lamarckiana* (d'Orbigny)); (2) Southern Coast Biofacies (*Nonionella stella* Cushman and Moyer and *Rotalinoides annectens* (Parker and Jones)); (3) Northern Middle Shelf Biofacies (*Reophax bulbosa* Champman and Parr and *Ammonia ketienziensis* (Ishizaki)); (4) Central Middle Shelf Biofacies (*Bolivina robusta* Brady and *Astrononion italicum* Cushman and Edwards) and (5) Southern Outer Shelf and Upper Slope Biofacies (*Globocassidulina oriangulata* Belford and *Cibicides lobatulus* (Walker and Jacob)).

Southern Inner Shelf Biofacies

This biofacies corresponds to the southwestern part of the study area. The constituents of bioassociation A, which are the dominant species of biotope IV, are generally confined to this biofacies in their distribution and abundance. Five dominant species of this biofacies which occupy more than 80% of total population, are all inner shelf species: *Ammonia* var. *compressiuscula* (Brady), *Quinqueloculina ,lamarckiana* d'Orbigny, *Ammonia beccarii* tepida (Cushman), *Epistominella naraensis* (Kuwano), and *Elphidium advenum* (Cushman). *Ammonia beccarii tepida* (Cushman) is nearshore and littoral species and inhabits in various shallow water environments along the entire China coast including estuary, littoral zone, and inner shelf (Wang et al., 1985). *Epistominella naraensis* (Kuwano) and *Elphidium advenum* (Cushman) are common species occurring in the Changjiang estuary and Hangzhou Bay at a water depth less than 20 m. And *Quinqueloculina lamarckiana* d'Orbigny is also relatively restricted to nearshore area, but more abundant in the inner shelf north of the Changjiang River mouth which is controlled by the Coastal Waters and drainage from China (Wang et al., 1985). In fact this biofacies located to the inner shelf north of the Changjiang River mouth at the water depths ranging from 32 m-48 m, and the faunal composition agrees well with that from the inner shelf of the northern part of the East China Sea. The planktonic foraminifera accounts for less than 15% of the total population. Judging from above facts, it is inferred that the oceanic environments of this biofacies must be subjected to complicated oceanographic conditions such as Coastal Waters, drainage from land areas, and greater seasonal variations of temperature and salinity.

Southern Coast Biofacies

This biofacies occupying the south coast of the Korean Peninsula is dominated by the species of the bioassociation B which are dominant species of biotope V. The dominant species are *Nonionella stella* Cushman and Moyer, *Rotalinoides annectens* (Parker and Jones), *Elphidium etigoense* Husezima and Maruhasi, and *Elphidium* var. *advenum* (Cushman). The species of genus *Elphidium* commonly occur in the inner shelf area and *Nonionella stella* and *Rotalinoides annectens* (Parker and Jones) have been reported to prefer the fine-grained sediments in the inner shelf. In the central shelf area of Japan, *Nonionella stella* Cushman and Moyer is dominant in the living foraminiferal population and becomes more abundant in the near-shore area on the fine-grained bottom (Matoba, 1976). The abundant occurrence of the species of genus *Elphidium* suggests that the strong influence of the river flows from the neighboring land area but the other dominant species, *Nonionella stella* Cushman and Moyer and *Rotalinoides annectens* (Parker and Jones) are normal marine species. Uchio (1962 a, 1962b) in his study of foraminiferal thanatocoenosis found abundant specimens of *Trochammina hadai* Uchio, a characteristic species in Japanese brackish waters (Matoba, 1970) in the open sea bottom of the Japan Sea off the Shinano River. The salinity, however, of the bottom water in the area is as high as that of normal sea water, because the river water does not reach the sea bottom. From this fact, Uchio concluded that the detrital materials and organic fragments carried by the river and deposited on the sea floor may influence the distribution of such foraminifera, rather than the fresh water (temperature, salinity). The condition described by Uchio is also observed in this biofacies, although the fauna is marine and not brackish. Accordingly, the character of the water and the fine-grained sediments is inferred to cause the faunal variation in this biofacies.

Northern Middle Shelf Biofacies

This biofacies occupying northwestern part of the study area is characterized by the high abundance of *Reophax bulbosa* Champman and Parr and *Ammonia ketienziensis* (Ishizaki), and *Eggerella advena* (Cushman). These species are the dominant elements of the the bioassociation C and dominant species of biotope I. These three species are widely distributed over a large area of the middle shelf, water depths 60 m-92 m. Among them, *A. ketienziensis* (Ishizaki) and *Eggerella advena* (Cushman) are inferred to be a cool-water type by the occurrence of main benthonic foraminiferal species in the East China Sea and seas off East Asia (Saidova, 1961; Fursenko et al., 1979; Zheng, 1979; Wang et al., 1980; Tu, 1983;). This biofacies is located in the north of 34° 0N and contains less than 10% of planktonic foraminifera in the relative abundance. Thus it is considered that the environment of this biofacies is strongly affected by the Coastal Waters and the Yellow Sea Cold Water having generally a relatively low temperature and a low salinity.

Central Middle Shelf Biofacies

This biofacies corresponds to the central part of the study area, and is predominantly occupied by the species of the bioassociation D which are dominant species of biotope II. In this biofacies, the abrupt decrease in abundance of cool-water species, *Ammonia ketienziensis* (Ishizaki) and *Eggerella advena* (Cushman), which are the dominant elements of the Northern Middle Shelf Biofacies is noteworthy. It suggests that the influence of the Coastal Waters becomes considerably weak. This inference is supported by the occurrence of characteristic warm-water species, *Cibicides margaritiferus* (Brady), *Hyalinea balthica* (Gmelin) and *Spiroloculina communis* Cushman and Todd, which are common elements of the middle shelf fauna. Other dominant species in this biofacies are *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Edwards, and *Cibicides refulgens* Montfort. *Bolivina robusta* Brady is characteristic species under the Middle Water of the Tsushima Current at water depths ranging from 50 m-150 m from Toyama Bay to off Sakata along the central and northeastern coast of Japan (Matoba, 1976). Similarly the present biofacies is located in the middle shelf at water depths ranging from 43 m-93 m except for two samples where the Yellow Sea Warm Current flows. Besides, the oceanic environment of this biofacies is strongly influenced by the Yellow Sea Warm Current having high temperature and high salinity.

Southern Outer Shelf and Upper Slope Biofacies

This biofacies corresponding to the southeastern part of the study area is dominated by the members of bioassociation E which are dominant elements of biotope III. This biofacies is clearly distinguished from other biofacies by its high proportion of deep water species and planktonic foraminifera. Characteristic deep water species occurring at the outer edge of the shelf and the top of the slope, water depths ranging from 100 m-200 m, include *Globocassidulina oriangulata* Belford, *Spiroplectammina* sp. *A*, *Hoeglundina elegans* (d'Orbigny), *Cibicides lobatulus* (Walker and Jacob), and *Paracassidulina sagamiensis* (Asano and Nakamura). These species are restricted to the outer shelf area of South China Sea, East China Sea, southern part of Yellow Sea and/or Korean South Sea, strongly affected by Warm Kuroshio Current and its branches (Zheng, 1979; Wang et al., 1985). Other rare but characteristic warm-water species, *Cibicides margaritiferus* (Brady), *Hyalinea balthica* (Gmelin), and *Spiroloculina communis* Cushman and Todd, are also found in this biotope. The relative abundance of the planktonic foraminifera is more than 70%. Faunal composition of this biofacies is quite similar to that of the outer shelf and the top of the slope of the East China Sea which is strongly affected by Kuroshio and Taiwan Warm currents. Hence, it is considered that the oceanic environment of this biofacies at water depths ranging from 100 m- 183 m is strongly affected by the warm water mass, the Tsushima Warm Current.

DISCUSSION

With regard to the pattern of bathymetric zonations of benthic foraminifera, the general faunal trend is in close agreement with those of the other seas. For example, in the near shore areas it is characterized by the predominance of trochospiral and planispiral forms; in the offshore areas, by the predominance of serial forms. However, water depths of the assemblage lines and the appearance of assemblage are different from area to area. For instant, the boundaries of assemblages are 50 m, 100 m and 200 m isobaths in the Wset and South SEa of Korea; 20 m, 50 m, 100 m, 150 m and

700 m in the East China Sea (Wang et al., 1985); 18 m, 55 m, 183 m and 549 m in the Gulf of Mexico; 25 m, 80 m, 180 m and 350 m in the Gulf of California (Murray, 1973).

As known, the water depth is not an independent factor to control the organism distribution but a synthetic factor of hydrostatic pressure, density, temperature, salinity, oxygen, etc. In the different regions, the relationship between the above various environmental factors and water depth is not exactly the same, therefore the bathymetric range of foraminifera in the different seas of the world should not be equal to each other.

There is a distinct correlation between surface temperature and foraminiferal distribution in the West and South Sea of Korea. For instance, there are two distinct benthonic foraminiferal biofacies in the middle shelf: Northern Middle Shelf Biofacies and Central Middle Shelf Biofacies. The characteristic species of the former affected by the Coastal Waters is *Ammonia ketienziensis* (Ishizaki) and *Eggerella advena* (Cushman), while the latter affected by the Tsushima Warm Current is *Bolivina robusta* Brady, *Astrononion italicum* Cushman and Edwards and *Cibicides margaritiferus* (Brady). In the West and South Sea of Korea, three temperature-related faunas may be distinguished based on their latitudinal occurrence and water mass: the cool water type (*Eggerella advena* (Cushman) and *Ammonia ketienziensis* (Ishizaki)), the eurytherm and/or temperate water type (*Ammonia beccarii tepida* (Cushman) and *A.* var. *compressiuscula* (Brady)), and the warm water type *Bolivina robusta* Brady, *Cibicides margaritiferus* (Brady), and *Astrononion italicum* Cushman). These temperature related fauna agree well with those from the East China Sea (Wang et al., 1985).

Phleger (1964) stated that there is little or no specific information on the interactions between the patterns of benthonic foraminiferal faunas and the natural environments that control these patterns. He introduced two general concepts of marine environment useful for interpreting the faunal distribution: the concept of variability within an environment, and the concept of an ecologic water mass which has a uniform ecologic effect in that it supports a distinctive population. The character of the bottom sediments also seems to have relation to the faunal distribution, but the kind and distribution of the sediment are due directly to the oceanographic condition.

Certain assemblages of benthic foraminifera can be related to particular sediment types. Murray (1973), for example, summarized the benthic species occurring in various shelf environments: assemblages found in clastic environments differ from those found in carbonate environments. This distinction, however is evident mainly at the biofacies level. On a larger scale, foraminiferal biofacies appear to be more realistically related to water masses. For example, on the Atlantic margin of North America, sediment substrate type is probably important in distinguishing only one biofacies (the Bahama) from the other six which can be related to particular water mass distributions (Culver and Buzas, 1981).

In the West and South Sea of Krea, the salinity to the foraminiferal distribution is a major factor in the nearshore areas or estuaries where salinity displays a great variation. In the areas of normal salinity, temperature plays an important role in the foraminiferal distribution. And the sediment type affects the foraminiferal distribution to a certain extent. Arenaceous tests were found more abundantly in sandy sediments, and some species prefer fine-grained muddy sediments in the study area.

CONCLUSION

1. As the result of faunal analysis, employed by the Principal Component Analysis, 5 bioassociations (groups of species) and 5 biotopes (groups of samples) were discriminated from the study area. In general, samples of each biotope correspond very well to a specific oceanographical condition, and are dominated by elements of specific foraminiferal bioassociation.

2. From the areal distribution of the biotopes in combination with bioassociations and the available ecologic data of foraminiferal species, five biofacies are discriminated. The geographic distri-

bution of the major biofacies is depth-related (inner shelf, middle shelf, and outer shelf to upper slope) and latitudinally restricted.

3. The main environmental factors which may affect the foraminiferal distribution are the water depth and water temperature in the study area. The salinity and sediments type are minor factors. However, all of these factors are closely related to water masses. Consequently, the distributional pattern of foraminiferal biofacies can be best explained by reference to the major current patterns and water masses in the study area.

(1) Southern Inner Shelf Biofacies is related to the Coastal Waters and drainage from China; (2) Southern Coast Biofacies to the Coastal Waters and drainage from Korea; (3) Northern Middle Shelf Biofacies to the Coastal Waters and the Yellow Sea Cold Water; (4) Central Middle Shelf Biofacies to the Yellow Sea Warm Current; and (5) Southern Outer Shelf and Upper Slope Biofacies to the Tsushima Warm Current.

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