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MICROBIOGENIC SEDIMENTS IN THE NAGDONG ESTUARY, KOREA

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ABSTRACT

The ostracode and foraminifera microbiogenic sediments of the Nagdong Estuary, which is a deltaic estuary, have been analysed. Twenty four species representing seventeen genera of ostracodes and some species representing twenty three genera of foraminifera are identified and counted. From these data their geographical distribution patterns are obtained and biotopes are determined in relation to the sediment distribution and hydrological parameters.

There are several tendencies in the distribution of ostracodes and foraminifera. Both ostracode and foraminiferal population increased seaward. The ratio of foraminiferal population to the sum of the ostrcode and the foraminiferal population, as well as the ratio of calcareous foraminifera to the sum of calcareous and agglutinated foraminiferal population, also increased seaward. The biotopes can be divided into two. Biotope I is the innershore environment and Biotope II offshore environment.

INTRODUCTION

The Nagdong deltaic estuary and its adjacent shallow sea in the southeast end of the Korean Peninsula (Fig. 1) have been of prime interest from the various view points of marine science, in particular, in view of physical oceanography, sedimentation, and pollution (Won, 1964; Choi *et al.*, 1971; Kim *et al.*, 1975; Won and Yang, 1978a, 1978b; Song *et al.*, 1978; Lee *et al.*, 1978; Lee *et al.*, 1979). However, there has not been any study on the faunas of recent ostracodes and foraminifera in the deltaic estuary in Korea, even though there are increasing interests in microorganisms and microfossils in the Holocene deltaic estuaries.

The writers attempted to study the distribution tendencies of ostracodes, foraminifera, and to relate them to the sedimentary conditions. In fact, the present study is to delineate the distribution patterns of ostracodes and foraminifera in the estuarine sedimentary environment. To date, such study in the deltaic estuarine environment is the first attempt in Korea.

GENERAL FEATURES OF THE STUDY AREA

The study area is situated in the southeast end of the Korean Peninsula, as shown in Figure 1. The estuary is sheltered by the Gadeog Island and several barrier islands such as Jinwoodo, Nambindeung, and Namusumdeung (Fig. 2).

Through this estuary, the Nagdong River discharges about 63 billion tons of fresh water per year and 71.4% of discharging water (45 billion tons) is emptied during flood times from June to September (Choi *et al.*, 1971). Out of the river mouth, main fresh water mass flows parallel to the Seodo Island through the upper 0～3m water layer, and is mixed with salt water from the lower water mass near the area of Mogdo Island, and then, flows into Japan Sea during ebb tide. But during flood tide, fresh water discharge pattern is complicate because of the

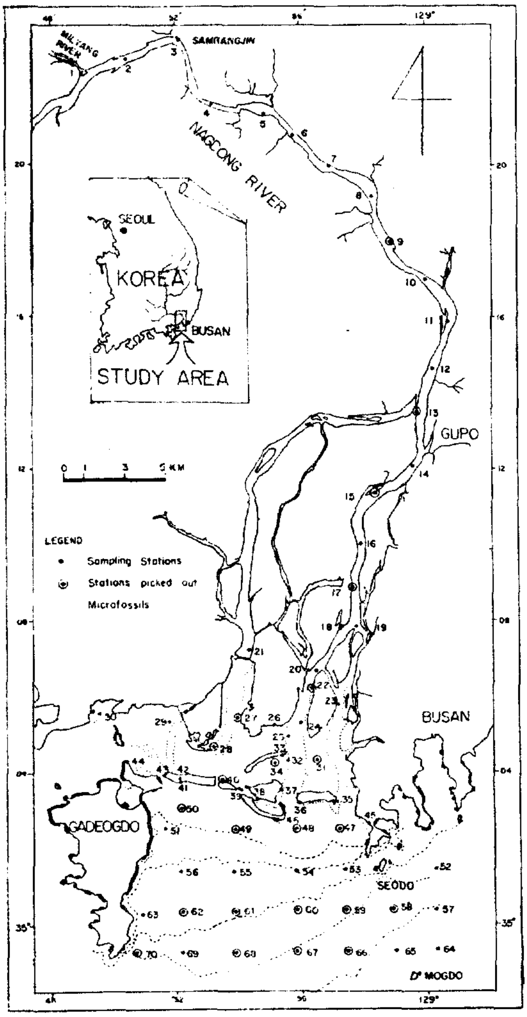

Fig. 1. The Nagdong Estuary and the sampling stations.

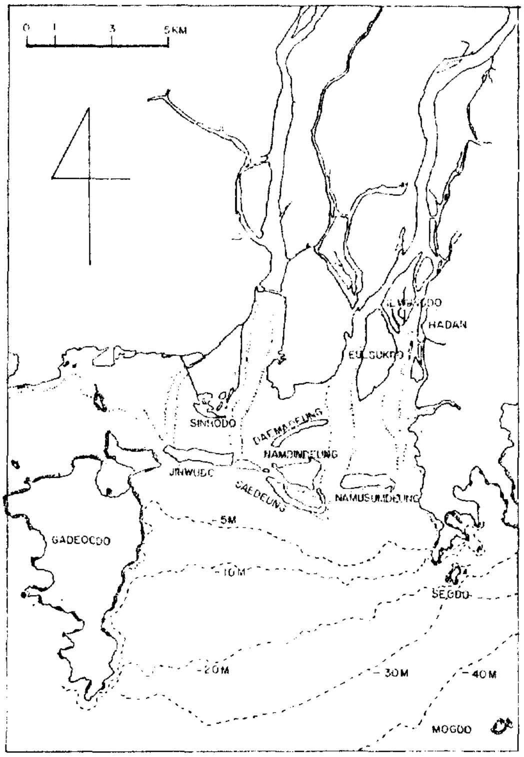

Fig. 2. The barrier islands and the bathymetry in the Nagdong Estuary area.

different conditions of spring tide and neap tide. Accordingly, the salinity of the upper layer is variable and the one of the bottom layer deeper than 20m is scarcely affected by the fresh water and it always shows about 34 per milli (Chu, 1978; Lee *et al.*, 1979).

The tidal range at the river mouth is 1.7m during spring tide and 0.4m during neap tide. The tidal effects extend up to to the distance of 58km upstream from the river mouth (Fig. 1; Won and Yang, 1978b).

The Nagdong River is 527km long and the drainage basin of the river comprises an area of 23,656km^2, which is mainly covered with Mesozoic sedimentary rocks, igneous rocks, and Quaternary deposits. The mean annual precipitation in the drainge area is about 1,160mm and the two-thirds of the precipitation concentrates from July to September (Chu, 1978). The total amount of sediment discharge by the Nagdong River is as much as 10 million tons per year (Ministry of Construction, 1974).

In the estuary area, there are three main distributaries. Among them the left distributary was damed in 1934 and most of the river water is discharged through the other two distributaries. The central distributary discharges more river water, and has faster current than the right distributary (Lee *et al.*, 1979).

MATERIALS AND METHODS

Many samples (Station 18~70) for the present study were obtained from Korea Ocean Research and Development Institute. Some additional samples (Station 1~17) were taken by the writers during April, 1979. The total 70 stations on which superficial sediments were taken are shown in Figure 1.

For the study of sediment texture distribution, the grain-size analyses were carried out with sieve and pippette methods. For the mathematical treatment of the grain-size data, the method of the Moment Statistics (McBride, 1970) was used. For the nomenclature of the sand-silt-clay mixtures, Folk's Triangular Diagram was used (Fig. 3).

For the study of ostracodes and foraminifera, 30g of dry sediments from each of 24 stations (Fig. 1) was treated and a 200 mesh (0.062mm) sieve was used. On identification of ostracodes and foraminifera, the writers followed the classification of Moor (1961, 1964) in genus and that of many East Asia authors in species (Kim, 1965; Kim *et al.*, 1970; Kim and Han, 1971; Kim and Chang, 1974; Kim and Choi, 1975; Takayanagi, 1955; Ishizaki, 1966, 1968, 1969, 1971; Matoba, 1970; Huang, 1974, 1975).

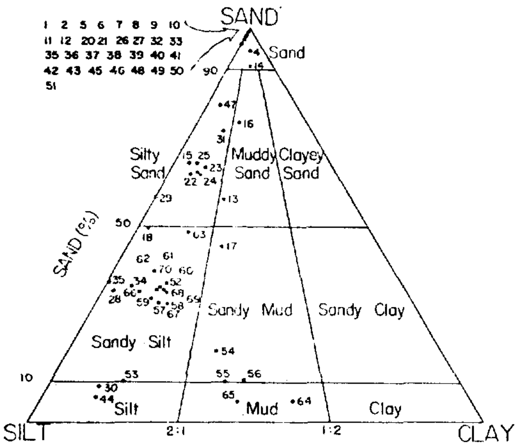

Fig. 3. The grain-size distribution (after Folk's triangular diagram).

For biotope analysis, cluster analysis based on ostracode population was adapted and compared with the various data such as, distribution of salinity, water depth, sediments, and foraminifera. From the computer program of cluster analysis suggested by Davis (1973) in FORTRAN-IV, Subroutine DENDRO was eliminated and Subroutines for the coefficients of Sorenson and COS θ were added (Kim, 1980; Cheetham and Hazel, 1969; Sneath and Sokal, 1973). A dendrogram wasdrawn in weighted pair-group method with simple arithmetic average (Mello and Buzas, 1968).

For calculating these programs and taking the photographs of ostracodes and foraminifera, the writers used the I.B.M.-370 computer series and the JSM-35 scanning electron microscope in the Seoul National University.

RESULTS AND DISCUSSION

(1) Distribution of Sediments

As the distribution pattern of superficial sediments is represented in Figure 4, the upstream area, the barrier islands, and their surroundings are covered with sands, while the area of nearly 20~40m in water depth is covered with sandy silt and the offshore area deeper than 40m with mud.

The coarsest grains of the sediments in the study area are 2mm~1mm and these are restricted to the river beds or the barrier islands. In the offshore area deeper than 10m in water depth, the grain-size of the sediments decreases seaward from coarse to fine sand. The mean grain-size values range from 1.32 to 1.95 in the upstream area and the values generally decrease seaward.

The sediment sorting values are locally complicate. However, the values of 0.39~0.50 (well

Table 1. List of ostracodes

Station / Sediment / Ostracode species	17	22	27	28	31	34	40	47	48	49	50	58	59	60	61	62	66	67	68	70	TOTAL
Sediment	Sandy mud	Silty sand	Sand	Silty sand	Silty sand	Sandy silt	Sand	Silty sand	Sand	Sand	Sand	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	
Aurila sp. A																				5	5
Basslerites sp. A																	1	6	1		8
Cushmanidea miurensis						2	2			3	4				1					3	15
C. japonica							1	1		6	3										11
C. subjaponica							1			1	4										6
Cytherois sp. A													2								2
Cytheromorpha sp. A																				1	1
Cytheropteron sp. A																				5	5
Cytherura sp. A															1			1		1	3
C. sp. B												2									2
Echinocythereis bradyformis														1			1	4	2		8
Hemicytherura sp. A																	1				1
H. sp. B												1	1								2
Kobayashiina sp. A												1						2	2		5
Krithe sp. A													1					2			3
Leguminocythereis hodgii												8	6	4	4		11	5	4	12	54
L. sp. A											2										2
Loxoconcha sp. A																				1	1
Munseyella japonica														1	6	8	3	3		7	28
Nipponocythere sp. A	2											2		5			5	5	6	7	32
Ruggieria sp. A														5	3				4	6	18
R. sp. B																				1	1
R. sp. C																	1		2		3
Semicytherura sp. A													1	1							2
Instars		4		2						5		4	1	17	25	37	28	28	27	55	
TOTAL(30g)	2	4	0	2	0	2	4	1	0	15	13	18	12	34	40	45	51	56	48	104	

sorted) in the barrier islands, 0.44~0.92 (moderately sorted) in the surroundings of barrier islands, and 0.41~1.32 (poorly sorted) in the upstream area are characteristic.

(2) **Distribution of Ostracodes**

Total twenty four species representing seventeen genera of ostracdes were identified(Table 1). The number of the ostracode in Table 1 refers to the valve number in 30g of dry sediments. No specimen was found from the sandy sediments of the upstream river beds (Station 1, 9, 13, 15), the river mouth channel (Station 27, 48), and tidal flat (Station 31). In general, the sandy sediments contain much less ostracode specimens than the muddy or the silty sediments

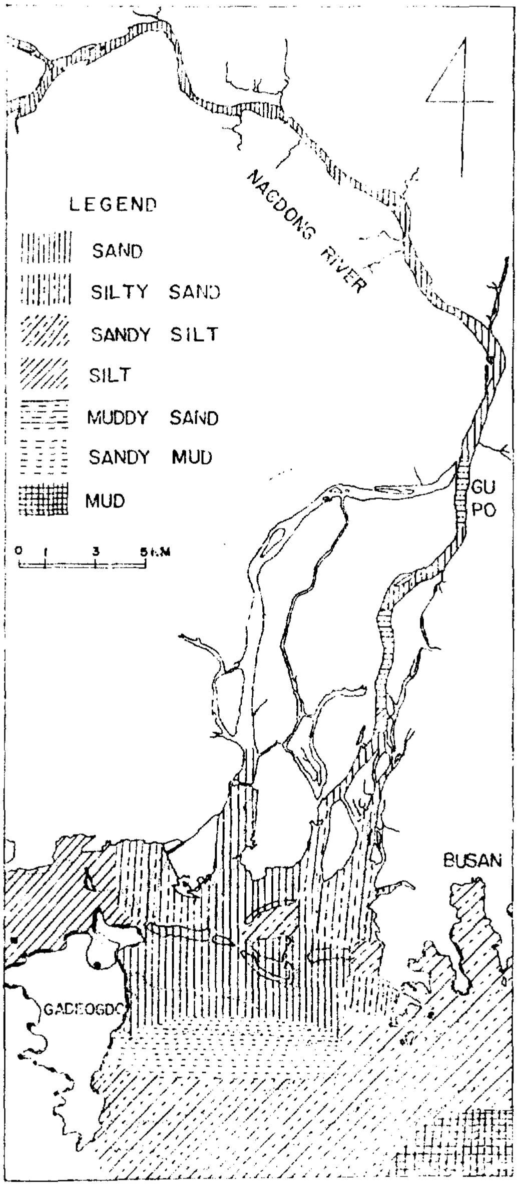

Fig. 4. The grain-size distribution of the superficial sediments in the Nagdong Estuary area.

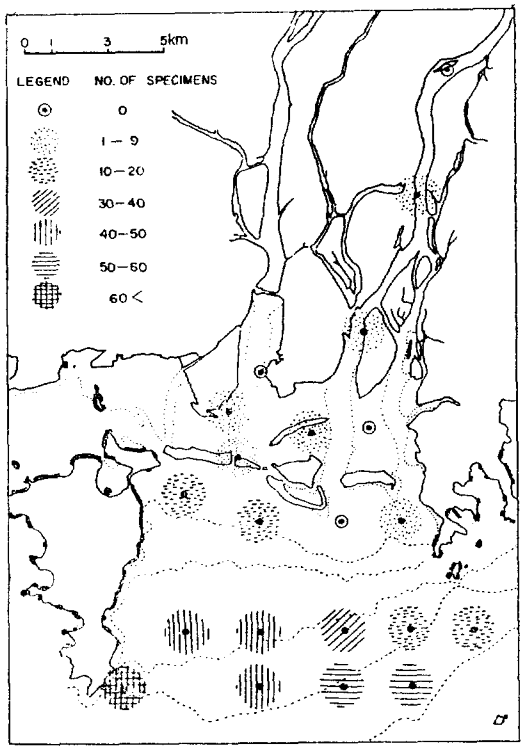

Fig. 5. Distribution of the total ostracode population per 30g of dry sediments.

in this study area (Fig., 5). Concerning about the relationship of the density of ostracodes to the substrate variance, Mckenzie (1964) stated that it would be certainly of local importance but it might be difficult to assess into its regional significance. However, many authors stated that ostracode specimens were scarcely found in the sandy sediments (Kilenyi, 1969; Ishizaki, 1968, 1971; Hazel, 1975). Moreover, Benson (1961) stated that fossil ostracodes were seldom found in river sand deposits because of the poor opportunity for preservation and the instability of sediments. Therefore, the rareness of ostracodes in the sandy sediments in this study area is similar to other results. However, the scarcity of ostracodes in the finer sediments from the river mouth stations seems to be due to the prohibiting factors such as pollution, turbidity, rapid deposition of finer sediments (Postma, 1967; Kilenyi, 1969; Lee *et al.*, 1979).

The quantitative distributions of ostracodes are controlled by water depth, penetration of light, total dissolved solids, carbonate contents (Bhatia and Singh, 1971), food (Swain and Gilby, 1974), salinity (Kontrovitz and Bitter, 1976), post-mortem displacement(Kilenyi, 1969; Kontrovitz, 1975). Therefore, the recent distri-

Table 2. List of foraminifera

Station / Sediment / Foraminifera genera	17	22	27	28	31	34	40	47	48	49	50	58	59	60	61	62	66	67	68	70	TOTAL
	Sandy mud	Silty sand	Sand	Silty sand	Silty sand	Sandy silt	Sand	Silty sand	Sand	Sand	Sand	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	Sandy silt	
Ammobaculites				1						1	1										3
Ammonia			1	33	2			1		1	3	4	1	3	3	3	2	11	9	5	82
Asterorotalia								6		1		90	29	36	13	9	64	19	17	12	297
Brizalina									1						4	1	2			3	11
Bulimina												2			3	2		1		1	9
Eggerella												1	1		1					4	7
Elphidium	1							9	1	4		17	22	22	20	30	16	19	40	20	227
Eponides								1		1		10	8	12	20	39	4	21	34	15	176
Epistominella		2						1		3		5	4	1	21	19	5	3	19	15	103
Fissurina												2	4	2	9		1	8	5	7	39
Florilus						1						5	3	3	1	4	3	6	6	7	40
Globigerina												12	2		1			2		1	19
Globigerinoides															1		1	2		1	5
Haplophragmoides	2		3	15		3	1				1	11	2	1					1	5	45
Lagena													1			2		1		3	7
Lenticulina								1				3	1			1	1				7
Nonionella	1							2		2		4	8	10	17	15	4	5	8	25	101
Quinqueloculina	1							5		1	1	2	20	14	4	2				15	65
Pararotalia						1						1									2
Rectobolivina												1					1				2
Textularia																	4				4
Triculina												3	5	1	2	2	2			1	16
Trochammia				2												1			1		4
Instars	4	15	5	13	2	7	4	5	15	4	8	359	357	400	491	592	874	756	1415	968	
TOTAL(30g)	9	17	9	64	4	12	5	31	17	18	14	532	468	505	611	722	984	854	1555	1108	

bution patterns of ostracodes in sediments are valid for interpretation of similar thanatocoenosis in ancient sediments, because what is being interpreted is the depositional environment of the sediments rather than the life-environment of ostracodes.

As it is shown in Figure 5, the offshore stations show much denser population than the innershore ones. Jinhae Bay situated adjacent to this estuary has shown less distinct seaward increase of population than this area. However, Jinhae Bay has shown much higher diversities in species and populations (Kim and Choi, 1975). Curtis (1960) compared east Mississippi Delta area to San Antonio Bay, and stated that the delta area had less ostracodes because of unstable hydrolic energy and rapid sedimentation. These differences between estuary and bay environments can be considered in interpreting details of paleo-environments.

It is interesting that *Ruggieria* sp. A, *Ruggieria* sp. B, and *Ruggieria* sp. C are found for the first time from Korean waters in the present study.

(3) Distribution of Foraminifera

As shown in Table 2, twenty three genera and some species of foraminifera (Plate II)

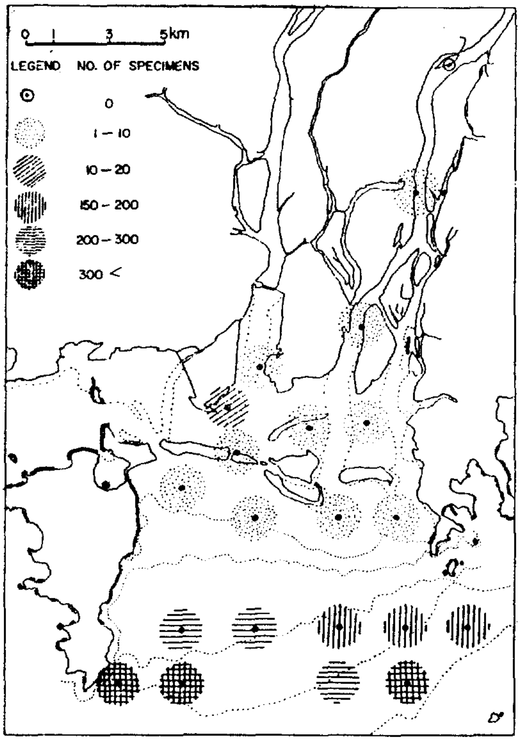

Fig. 6. Distribution of the total foraminiferal population per 10g of dry sediments.

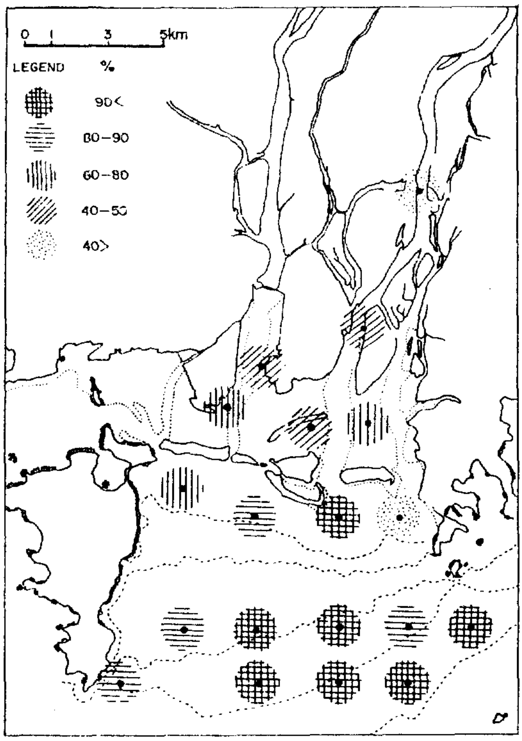

Fig. 7. Distribution of the ratio (%) of calcareous foraminiferal population to the calcareous and the agglutinated formainiferal population.

have been identified in the present study. Among them, planktonic species are *Globigerina apertura*, *G. triloculinoides*, and *Globigerinoides ruber. ruber* which are the typical open ocean indicaters (Phleger, 1960; Kim and Han, 1971; Albani, 1978). The others are benthonic foraminifera which are commonly distributed in the shallow sea around Korea and Japan (Kim *et al*., 1970; Kim and Han, 1971; Kim and Chang, 1974; Kim, 1974; Takayanagi, 1955; Matoba, 1970). Among the benthonic foraminifera, the typical brackish water species are *Haplophragmoides carnariensis* and *Trochammina globigeriniformis* (Takayanagi, 1955; Phleger, 1960; Matoba, 1970).

The density of the total population abruptly increases seaward and the upstream limit of occurrence is Station 17 which is located 8km upstream from the river mouth (Fig. 6). Generally, higher diversity is correlated with more fertile food, greater depth, finer sediment, and higher salinity. Most of them are the characteristics of the offshore marginal marine environment where foraminifera assemblages are more diverse.

In this study area, the ratio of calcareous foraminifera to the sum of calcareous and agglutinated foraminifera ranges from less than 40% to more than 90%. And the ratio generally increases seaward except some stations (Fig. 7). Even though it can be said that calcareous foraminifera prefer sandy bottom and agglutinated foraminifera prefer muddy bottom, the ratio of calcareous foraminifera has generally increased seaward in many nearshore areas.

The ratio of foraminifera to the total population of foraminifera and ostracodes ranges from 80% to nealy 100% in this study area (Fig. 8).

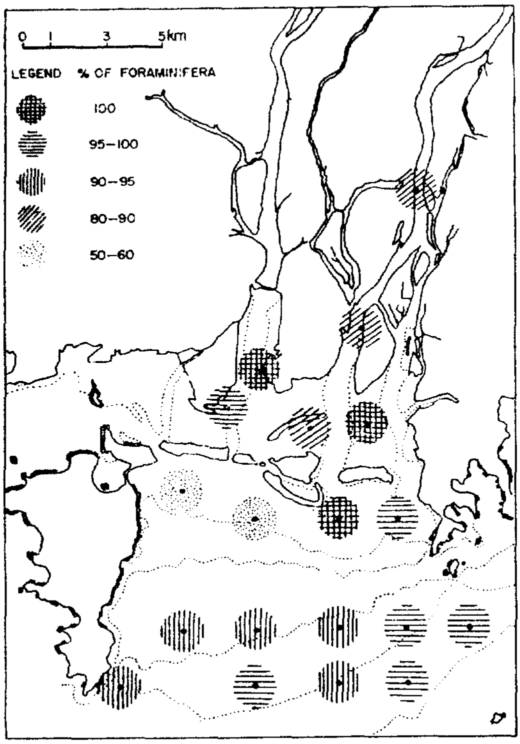

Fig. 8. Distribution of the ratio (%) of the foraminiferal population to the total population of foraminifera and ostracodes.

Also, the ratio values are irregular in the surroundings of the barrier islands. These irregularity seems to be the result of the destruction and burial of the skeletons of foraminifera and ostracodes by high physical energy and rapid sedimentation.

Few workers have attempted to compare variations in modern populations of both foraminifera and ostracodes (Krutak, 1975; Bandy, 1964). Bandy (1964) studied the ratio of foraminifera to ostracodes in the Gulf of Batabano, Cuba, and concluded that the foraminifera were generally more than 10-50 times as abundant as the ostracodes and the ratio values were much higher in deeper areas.

(4) Biotope Analysis

In order to define the areas of similar environmental conditions, based on the ostracode

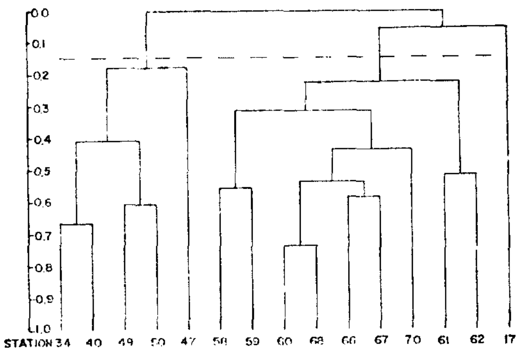

Fig. 9. Dendrogram for Q-mode cluster analysis of the total ostracode population.

population, Q-mode (station to station) cluster analysis has been applied to the ostracode species as the initial data (Table 1). From the results of the Q-mode cluster analysis with Sorenson's Coefficient (Kim,1980), a dendrogram is drawn (Fig. 9). There are two major clusters at the level of 0.15 similarity coefficients except Station 17 where the sample was taken only in different season. At Station 17, the microfauna is composed of one species of ostracode, *Nipponocythere* sp. A, and four species of foraminifera, *Elphidium advenum*, *Haplophragmoides carnariensis*, *Nonionella miocenica stella*, *Quinqueloculina lamarckiana*. They are composed of brackish water species and open shallow-water types. It seems that Station 17 is a brackish water environment which is strongly affected by coastal water.

The two major clusters may be taken as biotopes and they seem to be mappable (Fig. 10). In Biotope I, three species of ostracodes are dominant. They are *Cushmanidea miurensis*, *C. japonica*, *C. subjaponica*. *Cushmanidea japonica* and *C. subjaponica* have been found exclusively in this biotope (Table 1). They seem to be euryhaline species because they were found in any type of sediments affected by inflow current of open sea water (Ishizaki, 1968, 1969, 1971). In foraminifera, 13 genera have been found in this biotope. Among them, typical brackish water

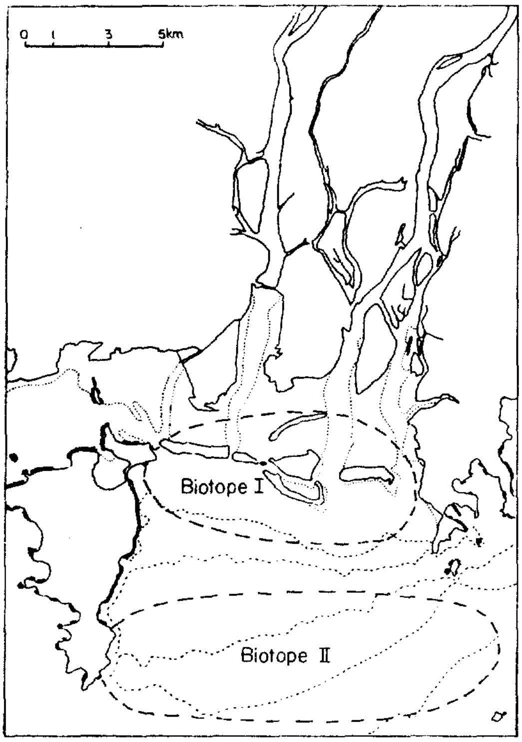

Fig. 10. Geographical distribution of the biotopes.

types are *Haplophragmoides carnariensis, Trochammina globigeriniformis,* and most of the rest are open shallow-water types (Table 2).

Biotope I is shallower than 5m in water depth, and has high physical energy such as tide, wave, and current. The substrate of the biotope ranges from sand to silty sand (Fig. 4), and the bottom salinity ranges from 9.42 per milli to 33.86 per milli (Lee *et al.*, 1979). The good sorting values of sediments indicate that considerable destruction and "sorting out" of shell material undoubtedly take place in this environment. Therefore, several factors previously mentioned synchronously contribute to the low diversities in species and population in this environment.

Biotope II is deeper than 20m in water depth and covered with sandy silts (Fig. 2; Fig. 4). The bottom salinity is generally more than 34 per milli, and scarcely affected by freshwater (Chu, 1978). This biotope has higher diversity in species and population than Biotope I (Table 1; Table 2). Almost every ostracode species and foraminifera genus has been found in Biotope II. The occurrence of planktonic foraminifera indicates that Biotope II is affected by oceanic water mass.

The ratio of the planktonic foraminifera to the total population of the planktonic and benthonic foraminifera is less than 1%. It seems that the sediment of Biotope II is getting affected by oceanic water mass.

The occurrence of the brackish foraminifera species shows that Biotope II is also affected by brackish water sediments. In fact, there is no direct effect of freshwater. However, Biotope II seems to be a sedimentary environment which is affected both by river-born sediments and oceanic sediments. Biotope I seems to be dominantly affected by river-born sediments and scarcely affectly by oceanic sediments.

CONCLUSIONS

1. There are several tendencies in the distribution of ostracodes and foraminifera. Both ostracode and foraminiferal population increase seaward. The ratio of foraminiferal population to the sum of ostracode and foraminiferal population, as well as the ratio of calcareous foraminifera to the sum of calcareous and agglutinated foraminiferal population, has also increased seaward.

2. Twenty four species representng seventeen genera of ostracodes and some species representing twenty three genera of foraminifera are identified in the present study. Among them, *Ruggieria* sp. A, *Ruggieria* sp. B, and *Ruggieria* sp. C are found for the first time from Korean waters. The occurrence limit of planktonic foraminifera seems to be the area deeper than 20m in water depth, which is a peculiar fact in the deltaic estuary.

3. Q-mode cluster analysis based on ostracode population divides the study area into two biotopes. Each Biotope has distinctly different depth, salinity, texture of sediments, and diversities of foraminifera. The two biotopes seem to be different sedimentary environments. Biotope I is dominantly influenced by river-born sediments and Biotope II by river-born and oceanic sediments.

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Plate I. Ostracodes in the Negdong Estuary Area

Fig. 1. *Aurila* sp. A: Lateral view of left valve, ×83.
Fig. 2. *Basslerites* sp. A: Lateral view of left valve, ×48.
Fig. 3. *Cushmanidea miurensis* Hanai: Lateral view of right valve, ×48.
Fig. 4. *C. japonica* Hanai: Laterl view of right valve, ×48.
Fig. 5. *C. subjaponica* Hanai: Lateral view of left valve, ×48.
Fig. 6. *Cytherois* sp. A: Lateral view of left valve, ×48.
Fig. 7. *Cytheromorpha* sp. A: Lateral view of left valve, ×90.
Fig. 8. *Cytheropteron* sp. A: Lateral view of right valve, ×48.
Figs. 9, 10. *Cytherura* sp. A: 9-lateral view of left valve, ×86. 10-lateral view of right valve, ×86.
Fig. 11. *Echinocythereis bradyformis* Ishizaki: Lateral view of right valve, ×48.
Fig. 12. *Hemicytherura* sp. A: Lateral view of left valve, ×92.
Fig. 13. *H.* sp. B: Lateral view of rightvalve, ×92.
Fig. 14. *Kobayashiina* sp. A: Lateral view of left valve, ×92.
Fig. 15. *Krithe* sp. A: Lateral view of left valve, ×86.
Figs. 16, 17. *Leguminocythereis hodgii* (Brady): 16-lateral view of left valve, ×48.
17-lateral view right valve, ×58.
Fig. 18. *L.* sp. A: Lateral view of right valve, ×48.
Fig. 19. *Loxoconcha* sp. A: Lateral view of right valve, ×86.
Figs. 20, 21. *Munseyella japonica* (Hanai): 20-lateral view of left valve, ×48.
21-lateral view of right valve, ×106.
Figs. 22, 23, 24, 25. *Nipponcythere* sp. A: 22-lateral view of right valve (female), ×106.
23- lateral view of left valve (female), ×48.
24-lateral view of right valve (male), ×106.
25-lateral view of left valve (male), ×48.
Figs. 26, 27. *Ruggieria* sp. A: 26-lateral view of right valve, ×53.
27-lateral view of left valve, ×53.
Fig. 28. *R.* sp. B: Lateral view of left valve, ×100.
Figs. 29, 30. *R.* sp. C: 29-lateral view of left valve, ×48.
30-lateral view of right valve, ×48.
Fig. 31. *Semicytherura* sp. A: Lateral view of left valve, ×100.

Plate II. Foraminifera in the Nagdong Estuary Area

Fig. 1. *Ammobaculites formosensis* Nakamura: ×130.
Figs. 2, 3. *Ammonia* sp. A: ×48.
Figs. 4, 5. *Asterorotalia inflate* (Millet): ×48.
Fig. 6. *Brizalina* sp. A: ×48.
Fig. 7. *Bulimina* sp. A: ×48.
Fig. 8. *Elphidium advenum* (Cushman): ×48.
Fig. 9. *Haplophragmoides carnariensis* (d'Orbigny): ×48.
Fig. 10. *Nonionella miocenica stella* Cushman and Meyer: ×48.
Fig. 11. *Quinqueloculina lamarckina* d'Orbigny: ×43.
Figs. 12, 13. *Trochammia globigerinigormis* (Parker and Jones): ×48.
Fig. 14. *T.* sp. A: ×68.
Fig. 15. *Ammobaculites* sp. A: ×48.
Fig. 16. *Trochamminita* sp. A: ×48.
Fig. 17. *Globigerina apertura* Cushman: ×120.
Figs. 18, 19. *G. triloculinoides* Plumer: ×120.
Figs. 20, 21. *Globigerinoides ruber ruber* (d'Orbigny): ×48

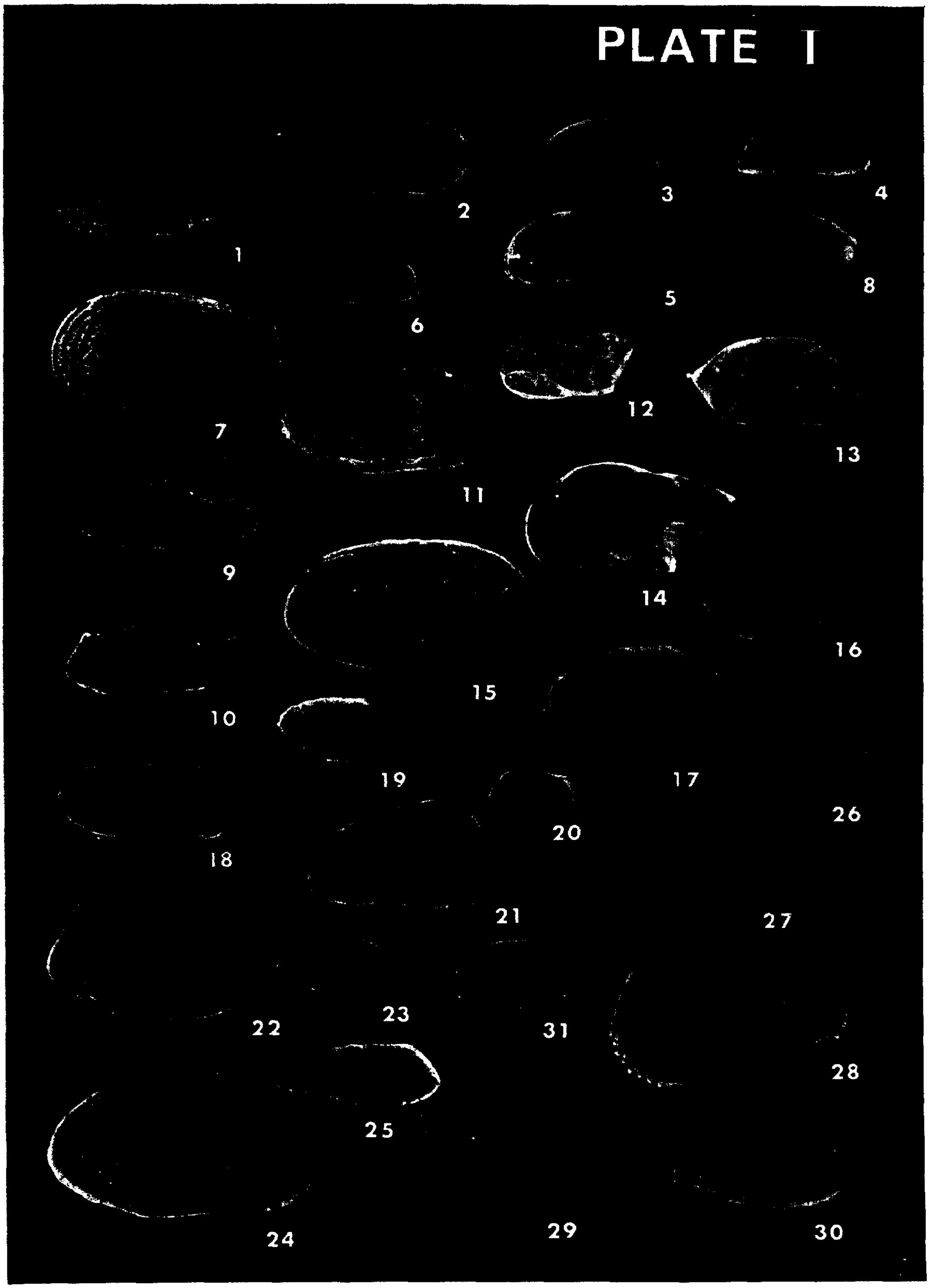
PLATE I
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PLATE II