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https://doi.org/10.5109/1544092

出版情報：九州大學理學部紀要 : Series D, Geology. 21 (2), pp.177-205, 1972-12-25. Faculty of Science, Kyushu University

Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol., Vol. XXI, No. 2,
pp. 177-205, tables 1-8, text-figs. 1-9, pls. 25-32, December 25, 1972.

An Application of Quantitative Method for the Analysis of Fossil Benthonic Foraminiferal Assemblage

By

Tokuhiko KAMEYAMA

Abstract

31 samples were collected along three columns of one locality at Tonda, Koyu-Gun, Miyazaki Prefecture. The each column was settled in an area of about 3 m high and 5 m wide on an almost vertical cutting. Grain size, calcium carbonate content and organic carbon content were examined and the benthonic foraminiferal assemblages were analyzed. The benthonic foraminiferal assemblages were divided into four assemblages named as *Cassidulina carinata* assemblage, *Rectobolivina raphana* assemblage, *Gyroidina orbicularis–Nonion japonicum assemblage* and *Pseudononion japonicum* assemblage.

To represent the complexity of benthonic foraminiferal assemblages, the MOTOMURA's formula was applied. Principal factor analysis was applied to infer the cause which determined the faunal assemblage in the sample. In the present study, first four factors can be expressed within both of Q- and R-technique factor analyses. The first four factors of Q-technique factor analysis are interpreted to indicate the province, the mechanism of sedimentation, the bottom sediment in which the benthonic foraminifers lived and the temperature and/or depth of water respectively. Likewise the first four factors of R-technique factor analysis are the depositional mechanism, the threshold velocity of bottom current, the bottom sediments in which the benthonic foraminifers lived and the temperature and/or depth of water respectively.

Using the preceding results, the environments during deposition of sediments of this sampling locality can be reappeared.

The results are promising enough for the author with a perspective for extracting autochthonous assemblages from several thanatocoenoses to make a firm basis for further ecological consideration.

Introduction

Hitherto benthonic foraminifers have been treated mainly as parameters for the correlation of the strata within local areas and of environments during the deposition. In recent years, many studies have been done on the recent benthonic foraminifers and accumulation of knowledge has given the basis for paleobiological treatment of that taxonomic group. Most of analyses of the benthonic foraminiferal assemblages are done from a biostratigraphical view-point still now, while a few studies stand on a biological and paleoenvironmental view-point. Furthermore assemblages of benthonic foraminifers are usually treated not as communities but as mere aggregation of species. Therefore the faunal assemblages are recognized on the basis of frequency distribution of species, in other

Manuscript received July 19, 1972.

words, the boundary of the faunal assemblages is determined by changing points of frequency curves drawn from frequency of each species. It is, however, evident that this method includes inevitable faults as follows; (1) subjectivity is prepossessed in the selection of the representative species, (2) widely and densely distributed species are despised or, in the extreme case, disregarded, (3) while the species occurring in a few limited samples and/or in the specialized environments is highly evaluated, even if the numbers of individuals are small.

In recent years, quantitative methods have been introduced for recognition of the biofacies of recent foraminiferal fauna (BUZAS, 1968a, b; KAESLER, 1966; MADDOCKS, 1966; and so on). While, concerning fossil assemblages, the quantitative analysis and its application to geology seem to have just started.

The quantitative analysis of benthonic foraminiferal assemblages is based on several indices, which include coefficient of JACCARD, simple matching coefficient, SIMPSON's index 2, MORISITA's index and correlation coefficient. Among these indices, coefficient of JACCARD, simple matching coefficient and SIMPSON's index 2 are based simply on presence or absence of species. That is, the number of individuals of each species is left out of the consideration. Numerical values calculated by these methods change irregularly according to change of the size of "quadrata" or samples and consequently according to the total number of species. This fault may lead to an erroneous result of the further analytical work of fossil foraminiferal assemblages. MORISITA's index (MORISITA, 1959a, b) is a valuable method for the analysis of assemblage, when the number of individual is larger than certain level, but the values of this index may be contradictional when the number of individual is extremely small. A revised formula of this index was proposed to eliminate the weakness just mentioned. If the correlation coefficient is adopted, species with dense population are excessively evaluated and species with low frequency are dispised (KAESLER, 1966). This is apparently a defect for the biological analysis of assemblages, while it is rather advantageous to get an outline of the environmental features. MOTOMURA's formula was proposed by MOTOMURA (1932) as expression of the structure of population. It is now recognized as a partial law, but it is still valuable to discriminate complexity of a population.

In the case of paleoenvironmental and, in the further study, paleoecological studies, it is very important to resolve the real meaning of each paleoecological factor and to reappear the each factor's weight in all the informations. In this study, the present author applied the factor analysis for the determination of the factors which had controlled the structure of benthonic foraminiferal assemblages in the samples. The purpose of the present study is the quantitative evaluation of paleoenvironmental factors during deposition using the quantitative method to discriminate autochthonous elements from allochthonous ones within a single sample and also to recognize autochthonous assemblages for the basis of the further ecological study.

The factor analysis is a method mathematically developed from the analysis with its basis on the correlation coefficient (HARMAN, 1960; LAWLEY and MAXWELL, 1963; SHIMIZU and SAITO, 1960). This method is founded on an idea that the frequencies of each constituent of each assemblage can be described by linear model. Every factor is a normalized orthogonal vector. This method was applied in paleontological and sedimentological studies by some authors (IMBRIE and PURDY, 1962; BLACKMAN and SOMAYAJULU, 1966; OBA, 1969; NIITSUMA, 1971).

The sampling locality was selected under the conditions as follows for making easier to analyze the concealed factors; (1) it was possible to get some impressions of environments during deposition from the features of outcrop, (2) the geological research work had been well done, (3) there were both assemblages of autochthonous fossil and allochthonous fossil, (4) in a single outcrop, there were sandy and muddy sediment, and (5) the fossil shells were not dissolved.

Acknowledgements

The author wishes to express his cordinal thanks to Professor Ryuzo TORIYAMA of Kyushu University for his appropriate guidance and criticism and reading the manuscript. The author is deeply indepted to Associate Professor Tsugio SHUTO of Kyushu University for his kind advice, valuable criticism and appropriate suggestions through which the study has been carried out and reading the manuscript. Dr. Itaru HAYAMI gave him valuable suggestions and advice concerning statistical methods. Associate Professor Kametoshi KAMMERA and Mr. Masafumi ARITA of Kyushu University gave him valuable suggestions concerning the sedimentological evidence. Dr. Nobuaki NIITSUMA and Mr. Toyosaburo SAKAI of Tohoku University offered the program of the principal factor analysis for NEAC 2200 Model 500 in the Computer Center of Tohoku University. Dr. Suzuomi TOMITA of Kyushu University helped him in the course of analysis of organic carbon content. Drs. Juichi YANAGIDA and Takeshi ISHIBASHI kindly helped and encouraged in the course of the study.

The author wishes to express here his hearty thanks to these persons without whose supports the study could not have been executed.

Geological setting and sampling locality

The Miyazaki Group is distributed from Tsuno in the north to Aburatsu in the south in the Miyazaki district, southeast Kyushu, Japan occupying 1300 square kilometers. The stratigraphical sequence of the Miyazaki Group in the northern part north of the River Oyodo is as shown in Text Fig. 1 (after SHUTO, 1961). The strata of this part are outlined as a comparatively simple clastic facies consisting of very thick strata of mudstone, siltstone, sandstone, alternation of sandstone and siltstone and conglomerate. They exhibit rather simple structure with gentle seaward dip, ranging between 6 to 12 degrees. This part of the Miyazaki Group was divided into two megafacies, the Tsuma facies and the Miyazaki facies by SHUTO. The strata of the Tsuma facies were called the Koyu Formation and were characterized by very thick and monotonous siltstone, and those of the Miyazaki facies were divided into three formations, the Higashimorogata Formation at the west, the Honjogawa Formation at the east and the Kiyotake Formation at the south. The Kiyotake Formation is excluded from the Text Fig. 1, for that formation being distributed on the south of the River

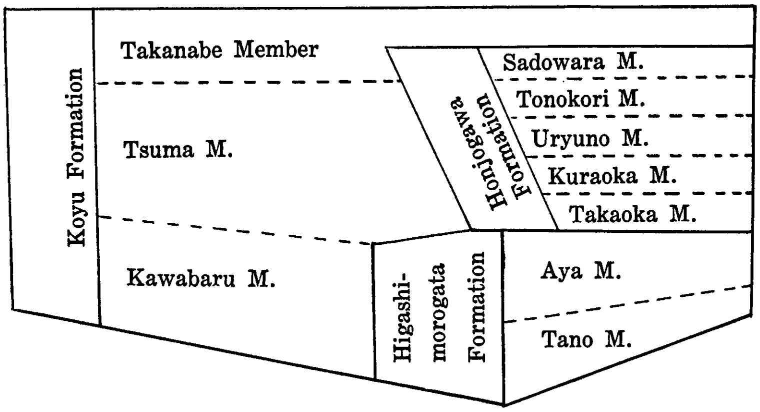

Fig. 1. Stratigraphical sequence of the Miyazaki Group (after SHUTO).

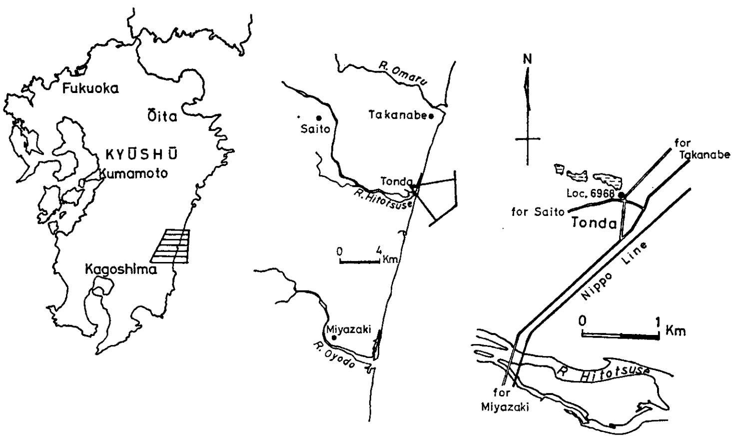

Fig. 2. Index map.

Oyodo. The Miyazaki facies is characterized by the large-scale alternation of relatively thick mudstone and thick sandstone.

In 1928, YOKOYAMA divided the group of the northern area into four zones (A to D) in his stratigraphic study on mollusca, which respectively represent, according him, Lower Musashino or Upper Pliocene, upper Lower Pliocene, and Lower Pliocene. OTSUKA (1930) offered a refined result of the stratigraphic investigation of the Miyazaki Group of the area surrounding Takanabe and Saito (Tsuma) City. He stated that the strata were divided into two parts with a major unconformity, and named the Tsuma Group to the lower part and the Takanabe Group to the upper. He correlated these groups to Upper Miocene and Plaisancian, respectively. UCHIO (1947) scrutinized OTSUKA's frame work of the local stratigraphy in the area surrounding Miyazaki City, and also recognized the unconformity between the lower and upper parts, that is to say,

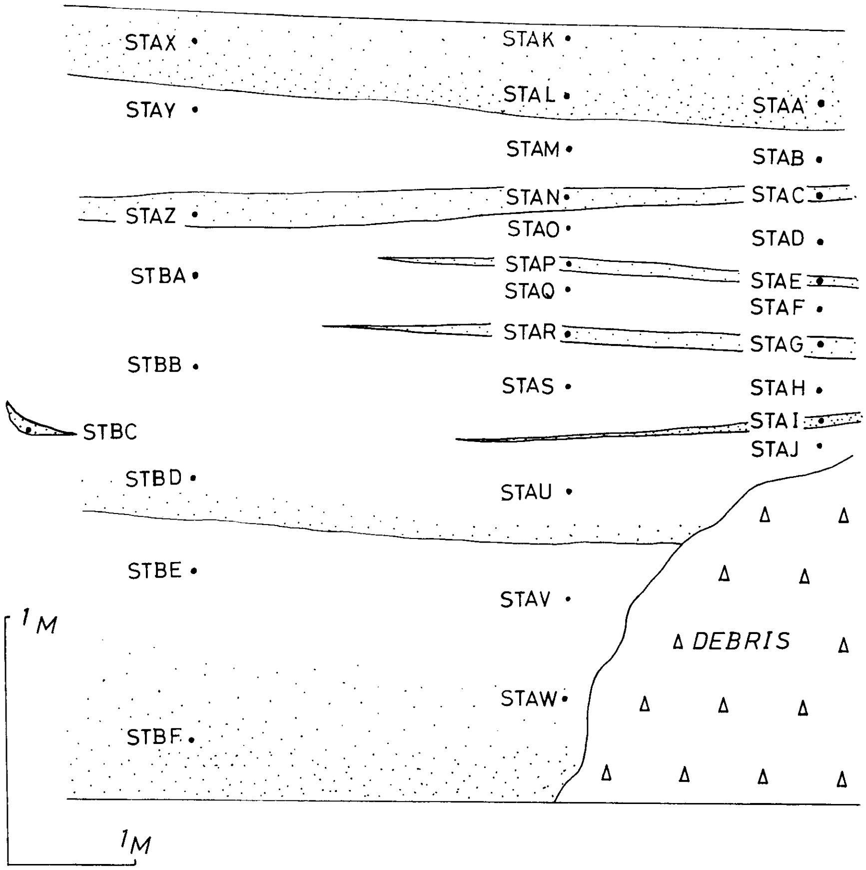

Fig. 3. Features of locality 6968 and points of 31 stations.

between his "Miyazaki Group" and the "Uryuno Formation", which he correlated to the Tsuma and the Takanabe Group, respectively. SHUTO (1961) united these units under a single group name "Miyazaki Group", on the basis of the conformable field relation. He correlated the Miyazaki Group to Upper Helvetian to Middle Plaisancian on the basis of the molluscan fossils, index larger foraminifers and planktonic foraminifers. Concerning the stratigraphical relation of the units and their geological ages, the author's conclusions (1969, M. S.) agree with SHUTO's.

The sampling locality, locality number 6968, was selected in the road side cutting of the National Road No. 10, in Tonda, Koyu-Gun, Miyazaki Prefecture, and is involved in the Takanabe member of the Tsuma facies. 31 stations were settled on the almost vertical cutting at this locality as shown in Text Fig. 3, and named as STAA, STAB,...., and STBF, respectively.

Character of sediments

The general feature of the sampling locality is shown in Text Fig. 4a, b. Abundant fossil molluscs were yielded in the beds anywhere, especially in the

a

b

Fig. 4. a: General feature of the sampling locality.
b: Occurrence of molluscan specimens in sandy bed.

sandy beds. Some of those fossils are sporadically distributed, but many are densely aggregated near the basal plane of some beds. There are few perfectly preserved specimens of bivalves. The grading is not recognized in the sandy strata expect in two beds in which the stations STAU, STBD, STAW and STBF were settled. Except one station, STAX, granules and larger grains are not contained throughout the locality. The sample of each station was cut off at about 1.5 cm thick in parallel to a bedding plane. The analyses of grain-size, content of $CaCO_3$ and content of organic carbon were carried out using part of these 31 samples.

The procedure of the grain analysis is as follows. The dried samples were weighed at 30 grams exactly, and then those samples were disintegrated and washed on the sieve of 250 mesh (62 μ opening). The residue on the sieve was dried, weighed and calculated in term of percentage. The percentage is expressed as sand content (Table 1). The residue was used for the grain analysis by mean of Emery tube. And then, mean size (M_Z), standard deviation (σ_I), skewness (S_{KI}), and kurtosis (K_G) were calculated after FOLK and WARD (1957). The results of calculations are also shown in Table 1.

The results of the grain analysis, though they refer only to the sand size,

Table 1. The results of grain analysis

Station name	M_Z	σ_I	S_{KI}	K_G	Sand Content (Wt. %)
STAA	3.35	0.40	0.07	0.85	49.30
STAB	3.58	0.33	−0.36	0.86	11.78
STAC	3.33	0.49	−0.25	1.12	38.87
STAD	3.43	0.39	−0.40	0.75	25.09
STAE	3.45	0.39	−0.56	0.82	36.99
STAF	3.58	0.29	−0.33	0.92	12.08
STAG	3.37	0.51	−0.38	1.23	49.66
STAH	3.50	0.42	−0.48	0.99	15.59
STAI	3.23	0.46	−0.03	0.91	62.02
STAJ	3.60	0.34	−0.49	0.87	8.39
STAK	3.56	0.34	−0.66	1.25	11.07
STAL	3.31	0.39	−0.22	0.82	38.18
STAM	3.58	0.30	−0.61	0.92	14.14
STAN	3.34	0.42	−0.27	0.91	35.47
STAO	3.51	0.36	−0.40	0.82	15.10
STAP	3.42	0.39	−0.23	0.85	39.24
STAQ	3.61	0.27	−0.61	0.97	12.75
STAR	3.43	0.44	−0.36	1.02	18.79
STAS	3.61	0.27	−0.54	1.11	10.07
STAU	3.56	0.27	−0.47	0.72	6.02
STAV	3.41	0.37	−0.03	0.69	9.06
STAW	3.37	0.38	−0.20	0.89	31.87
STAX	3.43	0.48	−0.43	0.91	15.38
STAY	3.37	0.44	−0.20	0.88	17.17
STAZ	3.30	0.41	−0.03	0.81	26.96
STBA	3.53	0.33	−0.46	0.85	8.05
STBB	3.66	0.27	−0.40	0.85	7.72
STBC	3.30	0.40	−0.08	0.86	32.73
STBD	3.54	0.29	−0.49	0.92	8.39
STBE	3.51	0.33	−0.49	0.75	10.07
STBF	3.48	0.36	−0.17	0.74	73.13

show that the sorting is "well sorted" and "very well sorted" in all the samples, skewness is "negative" to "very negative skewed" in most of the samples and kurtosis is "platy-kurtic" in 18 samples and "mesokurtic" in 10 samples and "lept-kurtic" in 3 samples. The cause of negative to very negative skewed values in most of the samples are explained by the high content of silt- and clay-size materials as shown in the column of sand content. According to FOLK and WARD (1957), the value under 0.9 of kurtosis (platy-kurtic to very platy-kurtic) is often represented in the channel deposits.

The examination of the occurrence of allochthonous molluscs indicates that shells of molluscs and other organisms of similar volume take a similar movement to pebbles in the transportational and depositional process. The weight content of $CaCO_3$ is largely represented by the weight content of shells of molluscs and other organisms, because shell volume of macro organisms like molluscs is definitely larger than the other meio organisms such as foraminifers. On the contrary, plant drifts, the major component of the organic carbon in the samples, seem to take similar depositional behavior to very fine materials. In

Table 2. Contents of $CaCO_3$ and Organic Carbon (Wt. %)

Station name	$CaCO_3$ Content	Organic Carbon
STAA	10.26	3.50
STAB	7.89	5.60
STAC	13.39	3.52
STAD	10.98	4.40
STAE	6.90	3.61
STAF	5.26	5.25
STAG	3.94	4.46
STAH	9.80	5.34
STAI	20.79	2.68
STAJ	7.41	5.73
STAK	39.21	4.82
STAL	3.41	4.64
STAM	6.67	5.39
STAN	3.67	3.40
STAO	4.26	5.39
STAP	9.60	3.97
STAQ	5.00	5.22
STAR	3.45	6.98
STAS	6.25	5.16
STAU	5.26	5.60
STAV	6.90	5.71
STAW	37.98	5.19
STAX	24.14	6.11
STAY	5.56	4.89
STAZ	8.14	5.09
STBA	7.69	6.00
STBB	8.00	6.26
STBC	21.74	2.42
STBD	7.41	6.06
STBE	6.25	5.52
STBF	2.71	2.49

other words, weight contents of $CaCO_3$ and organic carbon were taken as parameters of depositional mechanism. This is the reason why analyses of content of those things were carried out.

The analytical methods of $CaCO_3$ and organic carbon contents are as follows. For $CaCO_3$ content, dried block samples were crushed and washed through 250 mesh sieve, and then the residue on the sieve were dried and weighed. Then the residue was treated by 12.5 percent HCl sufficiently and left for about two hours. After that, the residue was washed, dried and weighed. To obtain the organic carbon content, the analysis of Ash Contents follows the definite procedure of the Proximate Analysis of Coal (JIS—M 8812).

The results, shown in Table 2, show that the two kinds of contents appear to reflect the activity of the medium of transportation as far as the present samples are concerned and support the assumption mentioned above.

Preparation and counting of the individuals of benthonic foraminifers

The procedure of the preparation of the rock samples for the foraminiferal analysis is briefly described below. Dried rock samples were weighed at 20 grams and crushed. Then the sodium sulfate method described by SAITO (1960) was applied to all samples except for the loose sand sediments. After washing with a 200 mesh sieve, each sample was divided into smaller fractions through the two-fold division. The counting and identification of the benthonic foraminifers were practised using these small fractions until the number of individuals became over 200. If a single small fraction did not provide 200 individuals, additional fractions were used in turn. After that the whole number of foraminifers in each sample was calculated. Complete list of the benthonic foraminifers is showed in Table 3. The planktonic foraminifers were not identified specifically but counted as a group.

Benthonic foraminiferal assemblage

87 species were found from the stations of locality 6968. These species do not indicate a definite geological age, and most of them are distributed in the lower-sublittoral to the upper-bathyal zone of the present seas.

The benthonic foraminiferal assemblages of each sample of these stations are similar in general aspect to each other except for a few stations, for example station STAI. The benthonic foraminiferal assemblages can be divided into 4 groups by a close comparison, and they are named as *Cassidulina carinata* assemblage, *Rectobolivina raphana* assemblage, *Gyroidina orbicularis–Nonion japonicum* assemblage and *Pseudononion japonicum* assemblage, respectively. These assemblages, except for *Cassidulina carinata* assemblage, are not apparently dominated by one or two species, but leaded by several, equally ranked species.

Cassidulina carinata assemblage

Occurrence; all the stations except for stations STAG, STAI, STAJ, STAS, STAX and STBF.

This assemblage is characterized by abundant occurrence of *Cassidulina carinata, Hyalina balthica* and *Trifarina kokozuraensis. Bolivinita quadrilatera, Bolivina robusta, Cassidulina yabei* and *Globocassidulina subglobosa* are secondly abundant in this assemblage. The benthonic foraminiferal fauna occurred at locality 6968 is outlined by this assemblage.

The fauna of this assemblage is inferred to have flourished in the lower-sublittoral to the upper-bathyal zone under a temperate condition.

Rectobolivina raphana assemblage

Occurrence; STAG, STAX

This assemblage is characterized by predominance of *Rectobolivina raphana* with association of *Elphidium advenum* and *Hanzawaia nipponica.* In this assemblage, *Cassidulina carinata, Pseudononion japonicum* and *Bolivina robusta* also show some dominancy. The assemblage consists of the species both of the shallow water and relatively deep one.

Gyroidina orbicularis–Nonion japonicum assemblage

Occurrence; STAI

This assemblage is characterized by abundant occurrence of *Gyroidina orbicularis* and *Nonion japonicum.* Other representative species are *Bolivina* cf. *semicostata, Ammonia ketienziensis, Rectobolivina raphana* and *Hanzawaia nipponica.* The assemblage is featured by these species with relatively large shell, and there are few species characterized by small volume like *Cassidulina* spp.

Pseudononion japonicum assemblage

Occurrence; STBF

Abundant occurrence of *Pseudononion japonicum* characterizes this assemblage. Associated leading species are *Planulina wuellerstorfi, Elphidium advenum, Bolivina robusta* and *Cassidulina carinata.* The species of shallow and deep water are mixed in this assemblage too.

Mathematical analysis of the benthonic foraminiferal assemblage

Motomura's formula

MOTOMURA's formula was proposed by MOTOMURA (1932) based on the fact that the frequencies of constituents of the population in a marsh satisfied the relation of a geometric progression. That relation was described by the following equality;

$$\log y+ax=b$$

where, x is the rank of frequency of a constituent in a population, y is the frequency of the constituent, a and b are constants which characterize the population, for example, value of a indicates complexity of the population. If the population is composed of the "simple assemblage" of species, in other words, one species in the population have a high dominancy, the value of a is big.

Although validity of this equation was verified by MOTOMURA (1947), KATO (1935) and UCHIDA (1943), it is now recognized as a partial law applicable only to the group of dominant species. It is, however, still valuable to discriminate complexity of the population. In 1968, NIITSUMA discussed about this equation, whence he modified it as follows;

$$\log y+a(x-1)=\log B$$

$$\sum_{x=1}^{\infty} y=\frac{B}{1-(1/10^{a})}$$

and

$$B=100\left(1-\frac{1}{1-(1/10^{a})}\right)$$

The detailed explanations about MOTOMURA's formula was described by NIITSUMA (1968) and NIITSUMA et al (1971).

Table 3. Complete list of benthonic foraminifers

Species name	STAA	STAB	STAC	STAD	STAE	STAF	STAG	STAH	STAI	STAJ	STAK	STAL	STAM	STAN	STAO	STAP	STAQ	STAR	STAS	STAU	STAV	STAW	STAX	STAY	STAZ	STBA	STBB	STBC	STBD	STBE	STBF
Textularia articulata ASANO		6		2				4			2	4						2			8					2	4	4	4	4	
Siphotextularia sp.		4	1				4									4											4				
Gaudryina arenaria GALLOWAY & WISSLER	12		1	10	46		8	4	88	2	8	4	6	8	4	8	12	4	16	8	20	6	8	16	8	2			4	8	20
Martinottiella communis D'ORBIGNY	2								16																12	2				4	
Quinqueloculina akneriana D'ORBIGNY							6																								
Q. sawanensis ASANO					6		6		40			8																			
Q. seminulum (LINNÉ)	2					4	6	4	16		2	4											4			2				4	16
Sigmoilopsis schlumbergeri (SILVESTRI)		6		4	10			2							4	12		2	8		4		4		8	4					
Amphicolina scalaris (BATCH)	2		1	4	2	4		2		2			2				4	2		8			4			2					8
Dentalina setanaensis ASANO										2												6									
D. emaciata REUSS					4							8																			
Frondicularia advena CUSHMAN		2													4		8	2			8					2			4		
Lagena laevis (MONTAGU)															4				4									4			16
L. striata (D'ORBIGNY)			1	2		10	4	2			6		4		4			2						8		8	12	16	4	8	16
L. gracillis WILLIAMSON						8									4																
Lenticulina abensis ASANO					10			2	24							4							4								
L. calcar (LINNÉ)		2	2	2	2		4	4	40	4		8			4			6	4	4	8		4	16	16	6	16		16	12	
L. nikoberensis (SCHWAGER)										4				4																4	
L. surugaensis (ASANO)					6			2	32							4															
Saracenaria angularis NATLAND										2																4					
Plectofrondicularia totomiensis MAKIYAMA			2	4	2	4				4				4		4	4	4	12			2				4		4	8	12	
Guttulina sadoensis (CUSHMAN & OZAWA)				2	4				8		2				4						4			8	4						
Oolina melo D'ORBIGNY														4				4													
Fissulina cucurbitasema LOEBLICH & TAPPAN																											12				16
F. marginata (MONTAGU)		4	1				2	6		2	2	4	2		4	4	4	2	4	4	4		4				8	4		4	
Bolivinita quadrilatera (SCHWAGER)	8	20	2	12	10	14	14	12		16	34	8	32	8	24	4	48	4	40	48	36	6	8		16	22	52	36	16	28	16
Bolivina nitida BRADY			3									4		8																	
B. robusta BRADY	54	34	9	28	24	42	30	18	16	38	18	48	66	40	100	44	112	12	52	36	68	20	28	168	24	22	56	40	56	72	88
B. spissa CUSHMAN						2							4		4				4					8	4					4	8
B. spinescens CUSHMAN			1												4	8				8	4			8		2				8	
B. cf. *semicostata* CUSHMAN			1	2	6		8	2	96			4				8	4	6		4	4	2		8	8						
B. cf. *tokiokai* UCHIO						2	6	8	8		10		8	8	4	4	20				4	6	8			6	12		12		
Rectobolivina raphana (PARKER & JONES)	40	6	5	20	16	6	64	10	120	2	16	80	4	36	12	32	24	8	8	12	32	10	20	24	36	4	32	28		12	64
Islandiella sp.						2																							8		
Cassidulinoides bradyi (NORMAN)	6	10	3	4	4	2	2		8	8		4					4			16	4		4		8	4		8			
C. parkerianus (BRADY)										6										4											
Siphonodosaria oinomikadoi (ISHIZAKI)	8	8			4	14		2		6	14	4	8	12	8	4	12	4	4	12	12	2		8	8	14	8	8	20	20	16
S. japonica (ISHIZAKI)				2									2				4		4			2			12						
Stilostimella lepidula (SCHWAGER)		2			4	8				8			2		4		4		8	12							4	4	8	8	8
Bulimina aculeata D'ORBIGNY		6	2		4	14	4		8	8	26		6		4	4	12	2	12	40	8		4		8	4	12	28	24	16	40
B. marginata D'ORBIGNY	4	4				4	8	4	8	4	10				4	4		2	12	20	12	4	8	16	4	10	8	20	8	12	24
B. striata D'ORBIGNY	10	6	3	20	14	14	22	8	32	8	26	8	4	20	28	4	8	6	20	28	8	6		16	12	6	24	12	16	24	32
B. tenuata (CUSHMAN)		2			4			6		4	12		6		12	4	12	4	4	4	8	4	8	8		14	12	16		12	
Reussella pacifica CUSHMAN & McCULLOCH			1									4									4		4	8		2	4				40
Uvigerina nitidula SCHWAGER	22	10	8	6	8	4	16	4		14	8	56	10	20		8	8		4	8	20	8	8	56	16	4	4		12	20	24
U. proboscidea SCHWAGER				2		8	8	2	8		4		6	4			12	16	16		4	4		16	8		8	4	8	12	56
Siphouvigerina asperula (CZJZK)		2		4	2	2	2			2	8	4	2		4		8		8	4		2				8	16	4			
Trifarina kokozuraensis (ASANO)	8	44	5	10	8	74	8	22		52	64	12	66	4	32	28	148	36	152	76	56	12	40	64	64	82	192	60	76	60	24
Uvigerinella glabra (MILLETT)													2						4				4				4		4	12	
Discorbinella nitida (WILLIAMSON)	4				2		4							8					4			2	4					4	4	4	24
Epistominella pulchella HUSEZIMA & MARUHASHI				2		6	2				2		2				4			12											8
E. nipponica KUWANO		6		2	6	6				4	2	4	12		4	4	24	8	24	32		2	8	8		2	28	28	12	20	16
Baggina philippinensis (CUSHMAN)			2	2		2	4			2	2		4		8			4			12	2			4	4			4		8
Valvulineria nipponica ISHIZAKI																					4						8				
Patellina corrugata WILLIAMSON												4									4			8					8	4	
Ammonia beccarii (LINNÉ)	12	2	4	4	8		8		32			20	12	4		12	12	4	4	4	8			16	4	2	12	12	4	8	56
A. ketienziensis (KUWANO)	12	6	8	16	42	18	2	6	96	8	4	28	10	8	12	12	8	2	12	8	88	4		24	28	18		4	4	12	
A. takanabensis (ISHIZAKI)	6			12	24		16		16		6	16	4	12	4	4		2		8				16	8	4					
Pseudorotalia gaimardii (D'ORBIGNY)					4		2		16									6				2									
Elphidium advenum (CUSHMAN)	18	10	7	18	14	4	34	4	72	4	4	8	6	28	8	12	8	10	4	12	36	6	8	32	20	4	8	8	28	8	88
E. crispun (LINNÉ)			1						24															8							
E. subarcticum CUSHMAN							2	2				4	4				12	2				2	8			4		4			16
Eponides umbonatus (REUSS)	10	12	6	20	8	8		10	16	12	2	16	18	8	16	20	20	8	12	12	8	4	4		8	6	20		12	28	16
Planulina wuellerstorfi (SCHWAGER)			1				12			6			2				4	4			8							4			96
Hyalina balthica (SCHRÖTER)	16	46	22	70	52	48	18	64	8	42	90	56	66	56	84	68	88	38	72	92	64	28	68	96	36	36	84	44	68	100	48
Cibicides aknerianus (D'ORBIGNY)	2	18	3	22	14	4	6	2	48	4	8	12	4	16	28	20	12	10	28		8	8			32	12					
C. haidingerii (D'ORBIGNY)	6			4	18	6	12		96			20	2			4		2					12		16					4	8
C. lobatulus (WALKER & JACOB)					2			4					10			4	8	8	4					40			4		16	24	
C. reflugens MONTFORT	8	4						6										6		4						4	4	16		12	16
"Virgulina" rotundata PARR							4				4		2				4						4					4			
Loxostomum karrerianum (BRADY)	12	2	3	6	6	10	8		8	18	34	24	8	28	32	12	40	2	28	12	16	4	20	48	24	8	36	28		24	40
Cassidulina carinata SILVESTRI	92	90	20	96	84	110	58	64	24	44	116	176	198	76	164	140	204	50	140	128	64	44	96	216	40	72	180	168	156	120	128
C. yabei ASANO	20	12	5	34	12	14	16	16		16	28	72	44	12	20	32	52	18	64	40	20	14	96	104	8	14	52	60	12	32	64
C. depressa ASANO	2	2	2			4	2	2			6		4				4	2	4	4		4	4	8		6	12	8	8		
Glabocassidulina subglobosa (BRADY)	24	32	9	32	16	56	22	34	32	32	22	24	30	24	36	16	68	14	108	72	44	8	40	104	36	24	60	44	60	68	128
Nonion grateloupi (D'ORBIGNY)			1							2				4				2	8	12		2									
N. japonicum ASANO	10	8	4	6	24	2	12	18	160			16	6	12	12	16	12	2	4	4	4	2		24	24	12	8			24	16
N. scaphum (FITCHEL & MOLL)		2														4											8		8		8
Pseudononion japonicum ASANO	22	14	2	16	2	8	54		16	12	18	16	12	12	20	32	20	2	28	20	16	16	84	40	12	12	20	28	20	32	264
Gyroidina nipponica ISHIZAKI	6	4		2	2	8	6	10		8	4		8	4		8	12	8	24	24	8	18	16	32	8	24	16	8	20	12	48
G. orbicularis D'ORBIGNY	4	4	2	6	24		2		184	2		8	2					6		24	12	2			4	2		4	4		
G. sp. A	1	10	2	6	8	44	10	30		12	6	12	28	4	48	4	24	24	76	72	32	8		8	4	6	60	12	80	80	32
Anomalina glabrata CUSHMAN			1																					24							
Hanazawaia nipponica ASANO	10		4	20	12		26	2	104			40		36		8		8		12		4	16	24	12						
Melonis nikoberensis (CUSHMAN)	8		5	10	2	4	14	4		6	6	8	14	12	4			4	8	8	12	4	32	16		8	16	12	8	32	32
M. pompilioides (FICHTEL & MOLL)					2				16	4	2																				
Hoeglundina elegane (D'ORBIGNY)		6	5	8			4			6	2		2	4	8			4		8	8	2	12	8	4			4	12	16	16
Total of benthonic foraminifers	482	468	171	554	588	604	592	408	1536	442	640	864	760	548	788	628	1112	390	1056	980	916	294	708	1376	618	526	1140	804	856	1154	1708
Percentage of plunctonic foraminifers	47.8	50.8	48.9	39.0	46.4	49.1	44.5	42.1	37.5	43.9	46.3	37.8	45.7	48.5	46.9	49.5	43.5	37.8	44.8	48.9	51.6	50.0	44.4	46.8	42.7	53.1	49.5	49.0	47.6	45.5	39.4

Table 4. The values of MOTOMURA's Index

Station name	MOTOMURA's "a"	MOTOMURA's "B-percent"
STAA	0.1285	15.8063
STAB	0.1100	16.0140
STAC	0.0969	11.7184
STAD	0.1263	15.1737
STAE	0.1076	13.0066
STAF	0.0810	15.4617
STAG	0.0862	11.5885
STAH	0.1200	16.8188
STAI	0.0612	11.3443
STAJ	0.0789	12.7551
STAK	0.1323	17.6603
STAL	0.0970	14.8574
STAM	0.1044	16.8918
STAN	0.0797	12.2780
STAO	0.1464	19.2850
STAP	0.1236	15.8700
STAQ	0.1167	17.7601
STAR	0.1035	12.9885
STAS	0.0828	14.7087
STAU	0.0706	11.9311
STAV	0.0502	10.2499
STAW	0.0932	12.5163
STAX	0.0895	15.6565
STAY	0.0963	14.6502
STAZ	0.0469	8.5204
STBA	0.1276	14.7780
STBB	0.1215	16.1476
STBC	0.1044	13.6222
STBD	0.0757	13.9948
STBE	0.0587	10.8729
STBF	0.0857	11.6480

The results of calculation for 31 stations are shown in Table 4 and plotted on the "MOTOMURA's Plane" (NIITSUMA, 1968).

Factor analysis

The factor analysis is a part of the multivariate analysis and is a technique to treat the structure of correlation matrix or covariance matrix. A principal object of the factor analysis is to explain the relatively large correlation matrix or covariance matrix by the minimum or, at least, minor hypothetical variates of factors. This is to say, it can be used to analyze the underlying behaviors of the data represented as the correlation matrix or covariance matrix, for example, the ecological relationships between each benthonic foraminiferal species or their relative frequencies in some samples.

The basic factor equation is represented as follow;

$$x_i=\sum_{r=1}^{k} l_{ir}f_r+e_i \quad (i=1, 2, \cdots, p)$$

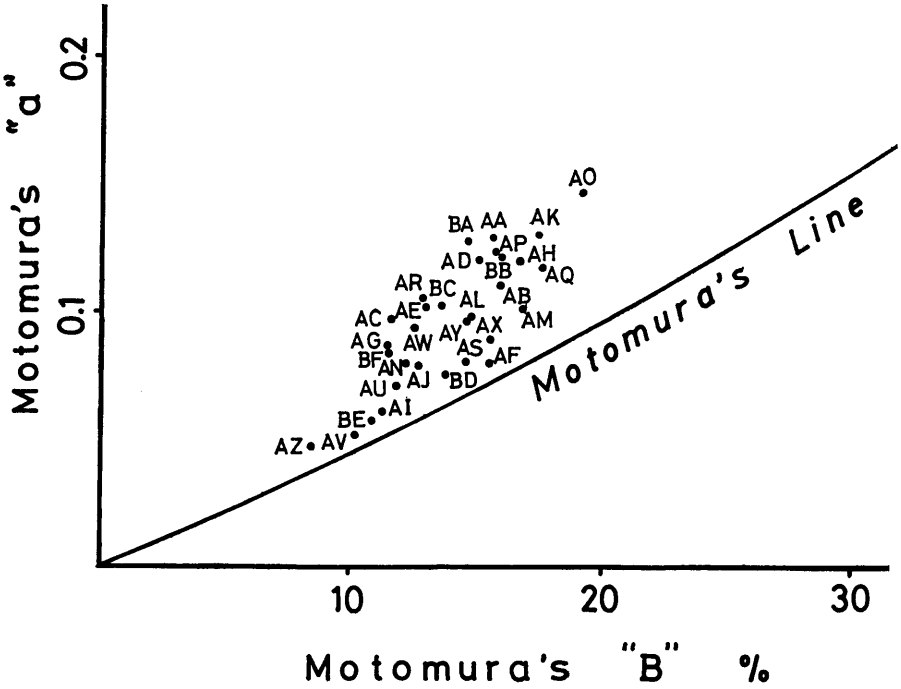

Fig. 5. Points of 31 samples on the MOTOMURA's Plain.

where, f_r is the r-th common factor, k is the stated constant and e_i is the residual that expresses the cause of characteristic fluctuation of variate x_i. And it is supposed that the p random variates e_i are independent with one another and with k variates f_r. Usually l_{ir} is named as "loading" of r-th factor of i-th variate.

The detailed explanations about factor analysis have been described by HARMAN (1960), LAWLY and MAXWELL (1963), SHIMIZU and SAITO (1960) and so on.

The principal factor analysis is used for both Q- and R-technique in this paper. The program of the principal factor solution for FACOM 230-60 computer of the Computer Center of Kyushu University was made by the modification of the program for NEAC 2200 Model 500 computer made by NIITSUMA, et al (1971).

Discussion

NIITSUMA (1968) discussed that MOTOMURA's a and B values of assemblages which are similar in composition and dominated by the same species are plotted on the MOTOMURA's Plane in about the same area. On the occasion of "simple sassemblages" those values are plotted in an area of right upper position, while the plots are in an area of left lower position in case of "complex assemblages".

In the present study, the plots of all the assemblages are under 0.15 concerning *a* value and in an upper and near area concerning the MOTOMURA's Line. This means that these assemblages have very complex structure.

Accordingly the complexity of these assemblages should be attributed to one or more of the following causes, (1) fossil assemblage represents autochthonous one with complex structure, (2) species of different habitats were mixed in an assemblage through the process of transportation and deposition, in other words, the fossil assemblage is not autochthonous, (3) the said assemblage is not represented by a single assemblages but mixture of a few ones because the rock sample might contain several successive thanatocoenoses. The cause (1) is denied by the facts that most of the assemblages are composed of the species of different life habitats and most of the associated molluscan shells are drifted ones.

Q-technique factor analysis

The data matrix for the Q-technique factor analysis consists of 87 species and 31 assemblages of the locality 6968. Simple correlation matrix exhibits relatively high positive correlations of every pair of samples. The first six factors account for 90.57 percent and the first three factors account for 84.27 percent of all informations. Only first ten eigen-values and their percentages are shown in Table 5. The matrix of the factor loadings on the first six factor axes is shown in Table 6.

Most of factor loadings of the factor 1 of Q-technique have considerably large positive values, while some show relatively small values. This is the reflexion of the structure of the assemblages in regard to the dominant species. That is to say, the assemblages showing considerably large positive values of those stations as STAB, STAD, STAF and etc. illustrate high percentages of *Cassidulina carinata, Hyalina balthica* and *Trifarina kokozuraensis,* the cumulative percentage of which accounts about 40 percent or more. The assemblages with relatively large positive values including those stations STAA, STAC, STAE and etc. are also composed mainly of the three species mentioned above, but the percentage of these three species is somewhat smaller and the other species as *Bolivina robusta* at STAA or *Ammonia ketienziensis* and *B. robusta* at STAV

Table 5. The first ten eigen-values and their percentages of Q-technique Factor Analysis.

Factor	Eigen-value	Percentage
1	22.81824	73.61
2	2.10464	6.79
3	1.20000	3.87
4	0.93977	3.03
5	0.57481	1.85
6	0.43973	1.42
7	0.41608	1.34
8	0.26363	0.85
9	0.20207	0.65
10	0.15237	0.49
⋮	⋮	⋮
Sum 31	31.00106	100.00

Table 6. The first six factor loading matrix of Q-technique Factor Analysis

Station name	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
STAA	0.85701	−0.37448	−0.13854	0.03280	0.17632	0.21538
STAB	0.96238	0.10080	0.02933	0.05410	0.05278	0.03823
STAC	0.86445	−0.19194	0.15342	0.11770	−0.27648	0.06594
STAD	0.91707	−0.23096	0.02300	0.18441	−0.11098	−0.10602
STAE	0.77630	−0.33312	0.34261	0.19041	0.02550	−0.07132
STAF	0.93263	0.25983	0.05771	−0.02898	0.02540	0.04579
STAG	0.67934	−0.53820	−0.22458	−0.30485	0.03411	−0.05292
STAH	0.90040	0.08092	0.12173	0.15280	−0.22464	−0.13223
STAI	0.10724	−0.59599	0.52510	−0.23038	0.10319	−0.16939
STAJ	0.89359	0.26704	0.04323	−0.17236	−0.10780	0.16566
STAK	0.91749	0.13151	0.00327	0.08352	0.04501	−0.12831
STAL	0.84337	−0.35902	−0.05676	0.17353	0.18187	−0.01209
STAM	0.89513	0.10556	−0.07189	0.21113	0.17695	0.05308
STAN	0.84248	−0.38002	0.02248	0.10649	−0.08969	0.08740
STAO	0.92943	−0.00902	−0.03320	0.19790	−0.03975	0.14326
STAP	0.93278	−0.18114	−0.07032	0.17527	0.10605	−0.04857
STAQ	0.94659	0.19367	−0.00248	−0.03260	0.16689	0.09645
STAR	0.89553	0.17498	0.10849	0.02763	−0.04704	−0.20863
STAS	0.88457	0.34682	0.03194	−0.20828	0.00791	−0.06883
STAU	0.90841	0.21612	0.04038	−0.02128	−0.12400	−0.15301
STAV	0.79679	−0.04551	0.25560	−0.19125	−0.15322	0.23424
STAW	0.92417	−0.10981	−0.12719	0.05768	−0.04283	−0.04838
STAX	0.80135	−0.10488	−0.35907	−0.12304	−0.04046	−0.22213
STAY	0.90197	−0.10037	−0.13980	0.03394	0.00442	0.19784
STAZ	0.76204	−0.04928	0.36389	−0.40111	0.07518	0.06728
STBA	0.86090	0.31356	0.13123	−0.16407	0.19873	−0.01024
STBB	0.89278	0.34259	0.03481	−0.13785	0.16553	−0.06697
STBC	0.91704	0.06465	−0.19300	0.05667	0.22502	−0.07702
STBD	0.91465	0.21984	−0.02585	0.05578	−0.06334	0.00631
STBE	0.91788	0.14971	−0.02016	0.01037	−0.25017	0.02424
STBF	0.57212	−0.25468	−0.49373	−0.41684	−0.16568	−0.01997

are contained at a remarkable percentage to result smaller value of factor loadings. On the contrary, the assemblages with relatively small values of factor loadings as STAI are dominated by quite different species from those of the preceding assemblages with large values. For example, the assemblage at the station STAI is dominated by *Gyroidina orbicularis, Nonion japonicum* and *Rectobolivina raphana.* Thus the factor 1 of Q-technique is referred to general factor representing the similarity of the benthonic foraminiferal assemblages of all the stations. This conclusion is supported by the fact that the correlation coefficient between the values of factor loadings of factor 1 of Q-technique and cumulative percentage of three species, *C. carinata, T. kokozuraensis* and *H. balthica,* takes a very high significant value at 99 percent confidence level. The fact that most of the stations show relatively large positive values of factor loadings may lead to another conclusion that any drastic environmental change did not occur during the period in question to cause a complete faunal change.

It is predicted concerning the factor 2 of Q-technique that most of the stations yielding assemblages of negative values are of sand facies, while most

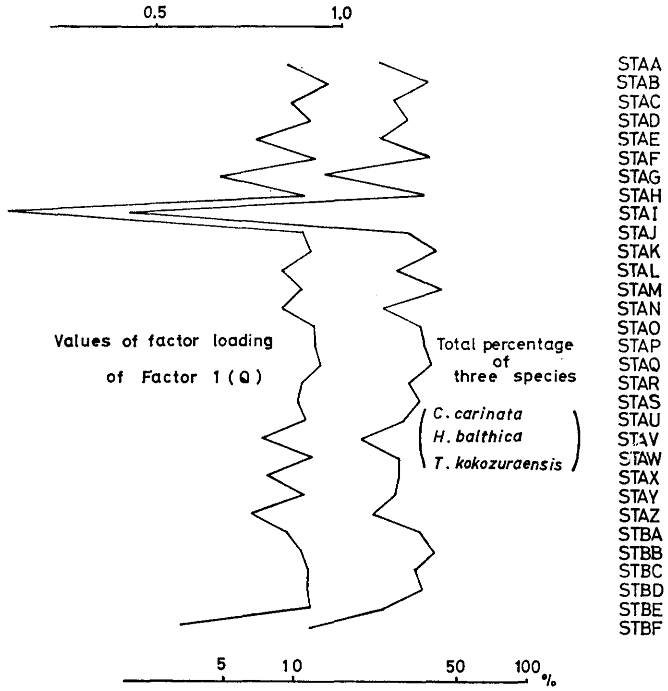

Fig. 6. Fluctuations of factor loadings of factor 1 and cumulative percentages of three dominant species.

of those yielding assemblages of positive values are of muddy facies. Graphs are drawn to compare the factor 2 of Q-technique with such features of the sediments as sand content and sorting. As shown in Text Fig. 7, factor loadings, sand content and sorting change values harmoniously by station. The correlation coefficient between the values of factor loadings of factor 2 of Q-technique and sand content takes a very high significant and negative value at 99 percent confidence level. Furthermore the correlation between the values of factor loadings and cumulative percentage of species with large shells takes significant and negative value at 99 percent confidence level. Generally, the species living in sandy sediment have large shell and the species in muddy sediment have small one, but the correlation coefficient dose not take significant value between the values of factor loadings and ratio of sand-dwellers to mud-dwellers. Thus the factor 2 of Q-technique may be safely concluded to be a factor connected to the grain size of sediments and representing the depositional mechanism.

The following is a comment on the factor 3 of Q-technique. Comparison of the assemblages with relatively large positive values of the factor loadings as STAE, STAI, STAV and STAZ to those with relatively large negative values as STAG, STAX, STBC and STBF clarified the biological difference between them. The assemblages of the former group contain at a remarkable dominancy *Martinottiella communis, Lenticulina calcar, Bolivina* cf. *semicostata, Eponides umbonatus* and *Melonis pompilioides,* which do not or rarely occur in the assem-

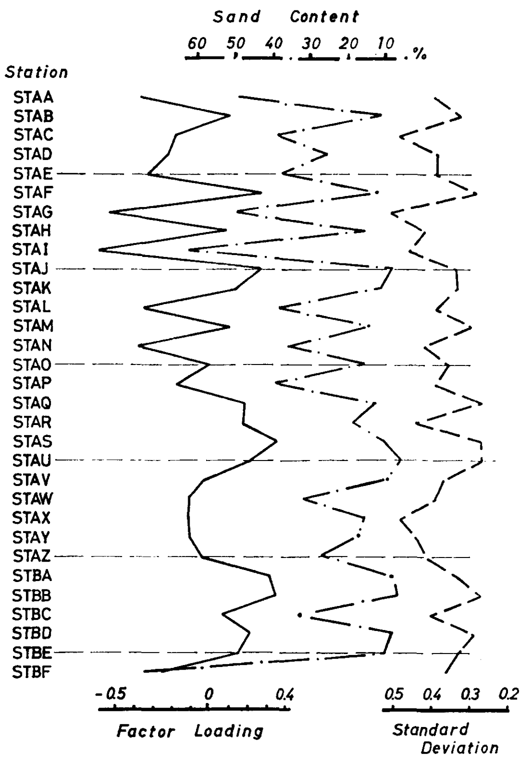

Fig. 7. Fluctuations of factor loadings of factor 2, sand content and standard deviation.

blages of the latter group. These species are confirmed as elements of the muddy sediment. While *Elphidium subarcticum, Planulina wuellerstorfi, Melonis nikoberense* and *B. robusta,* which are elements of sandy sediment, occur in the assemblages with relatively large negative values at notable dominancy.

On the basis of the data mentioned above, the ratio of sand-dwellers to mud-dwellers is calculated and compared with the factor loadings. On that occasion careful distinction of autochthonous and allochthonous elements is needed, because the factor 2 of Q-technique shows that most of the assemblage contain some species transported from the other area after death. Species of sand-dwellers and mud-dwellers were selected for the comparison under the qualifications that they were the elements of outer neritic zone and they had some dominancy in the assemblages. But the species representing sand-dwellers include the species of shallow water elements for the cumulative number of individuals of selected species being not zero in each station. *B. robusta, Uvigerina nitidula, Cibicides aknerianus, Pseudononion japonicum* and *Hanzawaia nipponica* are selected as sand-dwellers and *Bolivinita quadrilatera, E. umbonatus* and *L. calcar* as mud-dwellers.

The correlation coefficient between the values of factor loadings and ratios of sand-dwellers and mud-dwellers takes a significant value at 95 percent con-

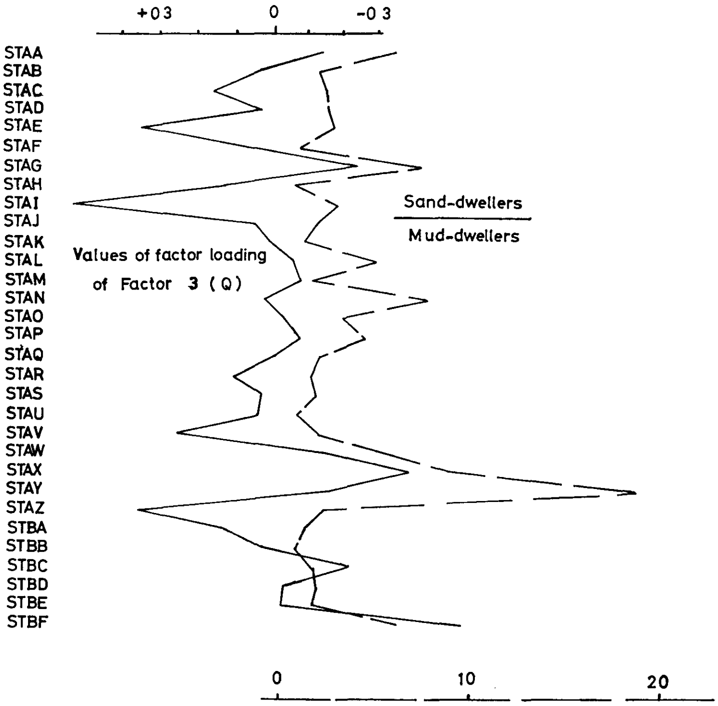

Fig. 8. Fluctuations of factor loadings of factor 3 and ratios of sand-dwellers and mud-dwellers.

fidence level. Thus the factor 3 of Q-technique seems to represent the factor concerning bottom sediments on and in which the benthonic foraminifers lived.

Concerning the factor 4 of Q-technique, the species characterizing the assemblages of stations with relatively large positive values of factor loadings and having some dominancy are as follows; *C. carinata, U. nitidula, B. robusta, Ammonia takanabensis* and *C. aknerianus*. These species are regarded as the elements of lower sublittoral or upper sublittoral zones. While the characteristic species of the assemblages of station with relatively large negative values are as follows; *Bulimina aculeata, B. striata, Uvigerina proboscidea, T. kokozuraensis* and *Melonis pompilioides*, which are elements of bathyal zone. It should be pointed out that *B. aculeata* and *T. kokozuraensis*, according to MATOBA (1967) and AOKI (1968), live in a deeper range than *C. carinata* does. Therefore, the ratio of numbers of individuals of *B. aculeata* plus *T. kokozuraensis* to *C. carinata* is considered to be a measure to estimate the depth of the habitats in a relative sense. The correlation coefficient between the values of factor loadings and ratios takes a high significant value at 99 percent confidence level. Thus the factor 4 of Q-technique seems to be a factor concerned with depth of habitat.

The factors 5 and 6 of Q-technique cannot be predicted to represent any kind of factors at present because of paucity of basic data.

R-technique factor analysis

The R-technique factor analysis was applied to the same data matrix for the

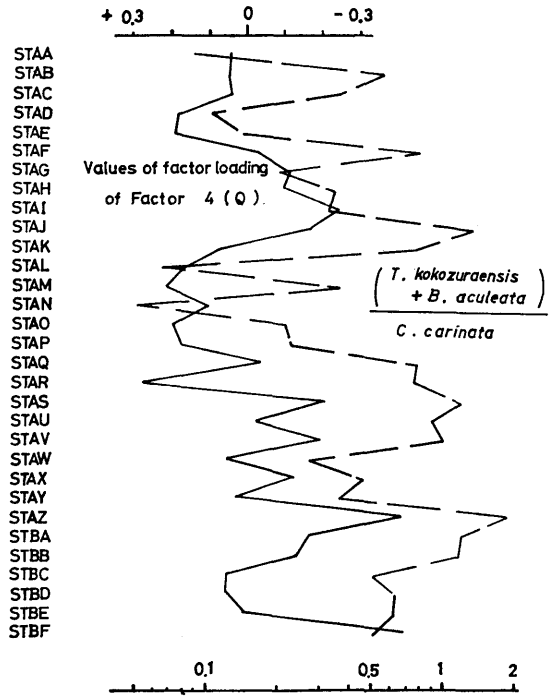

Fig. 9. Fluctuations of factor loadings of factor 4 and ratios of three selected species.

Table 7. The first ten eigen-values and their percentages of R-technique Factor Analysis

Factor	Eigen-value	Percentage
1	17.78693	20.4447
2	14.14937	16.2636
3	7.35756	8.4569
4	5.84918	6.7231
5	4.67569	5.3743
6	3.90357	4.4868
7	3.29840	3.7912
8	3.09658	3.5592
9	2.76164	3.1742
10	2.59335	2.9808
⋮	⋮	⋮
Sum 87	86.99863	100.0000

Q-technique factor analysis in aid of the Q-technique factor analysis for the cause as the characters of each species, constructing the data matrix, being unable to be presented as the numerical values. The eigen-values and their percentages for first ten factors are shown in Table 7. Among those factors, first four ones account for 51.89 percent of all informations. Table 8 shows the first six factor loading matrix for 87 species. It is, however, very difficult to consider

Table 8. The first six factor loading matrix of R-technique Factor Analysis

Species name	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Textularia articulata	0.16572	0.12420	0.24922	−0.00841	0.23732	0.46606
Siphotextularia sp.	0.03395	0.12734	0.03022	−0.17049	0.40026	0.12812
Gaudryina arenaria	−0.77781	−0.45749	0.17889	−0.04602	−0.04356	−0.03949
Martinottiella communis	−0.73048	−0.27233	0.19344	−0.08865	−0.10317	0.08060
Quinqueloculina akneriana	−0.08171	0.00623	−0.21647	−0.01132	0.21285	−0.06024
Q. sawanensis	−0.88029	−0.34689	0.19677	−0.12830	0.04522	0.00114
Q. seminulum	−0.39855	−0.77608	−0.22770	−0.16078	0.07994	0.09143
Sigmoilopsis schlumbergeri	−0.11476	0.24919	−0.03168	−0.00196	−0.01592	0.00902
Amphicorina scalaris	0.28562	−0.38710	−0.31376	−0.34431	−0.30207	−0.35256
Dentalina setanaensis	−0.02393	0.18755	−0.20593	−0.03649	−0.10064	0.01280
D. emaciata	−0.16683	0.06539	−0.07177	0.24066	0.13148	−0.15964
Frondicularia advena	0.13496	0.08549	0.24046	−0.02806	0.19325	0.21162
Lagena laevis	0.31735	−0.75450	−0.37607	−0.14359	0.03248	0.01782
L. striata	0.45270	−0.51675	0.05530	−0.06908	0.24402	0.08375
L. gracillis	0.06816	0.06818	−0.00902	−0.06729	−0.13674	0.01109
Lenticulina abensis	−0.84940	−0.28971	0.19208	−0.15298	0.00567	0.00606
L. calcar	−0.61582	−0.36059	0.50113	0.09968	−0.02373	0.24021
L. nikoberensis	0.06167	0.06021	−0.00757	0.12364	−0.45028	0.25684
L. surugaensis	−0.87038	−0.33420	0.23319	−0.17380	−0.00858	0.04347
Saracenaria angularis	0.02795	0.15105	−0.06581	−0.13062	−0.06370	−0.02592
Plectofrondicularia totomiensis	0.24784	0.08463	0.25910	−0.02834	−0.44436	0.41551
Guttulina sadoensis	−0.57156	−0.28722	0.33955	0.42228	0.02004	−0.17104
Oolina melo	−0.06721	0.14526	−0.23898	0.10516	−0.10635	0.16392
Fissulina cucurbitasema	0.33210	−0.68564	−0.15166	−0.25087	0.30772	0.14815
F. marginata	0.34430	0.13846	0.43675	−0.30962	0.28401	0.00055
Bolivinita quadrilatera	0.51739	−0.03306	0.51696	−0.51212	0.08320	−0.14484
Bolivina nitida	−0.11250	0.15005	−0.25848	0.25731	−0.02641	0.03098
B. robusta	0.38647	−0.41637	0.36202	0.52273	0.07870	−0.14052
B. spissa	0.29565	−0.61344	0.02921	0.43779	−0.14359	−0.07065
B. spinescens	0.17658	−0.11258	0.37924	0.34903	−0.37560	−0.10521
B. cf. *semicostata*	−0.87377	−0.36075	0.24790	−0.11856	−0.00112	−0.00006
B. cf. *tokiokai*	0.01242	0.05016	0.33497	−0.23586	0.48535	0.12369
Rectobolivina raphana	−0.61526	−0.54535	−0.05891	0.01461	0.29681	−0.09296
Islandiella sp.	0.13149	−0.01085	0.15917	0.05517	−0.17045	0.51969
Cassidulinoides bradyi	−0.25037	0.04507	0.03825	−0.35769	−0.34539	−0.44883
C. parkerianus	0.08554	0.06656	0.01459	−0.25234	−0.56774	−0.29141
Siphonodosaria oinomikadoi	0.26242	−0.05778	0.12168	0.02788	−0.00477	0.07644
S. japonica	−0.04264	0.09057	0.02846	−0.02195	−0.03931	−0.13909
Stilostimella lepidula	0.44737	−0.32690	0.24261	−0.36576	−0.58681	0.03004
Bulimina aculeata	0.41602	−0.61894	0.19007	−0.24594	−0.25118	−0.17106
B. marginata	0.33030	−0.67082	0.15322	−0.09267	−0.14683	−0.15388
B. striata	−0.08794	−0.61975	0.23534	−0.18049	−0.18658	−0.01221
B. tenuata	0.38941	0.07182	0.50589	−0.10392	0.30057	−0.12621
Reussella pacifica	0.28442	−0.82162	−0.39514	0.06057	0.13305	0.01860
Uvigerina nitidula	0.08491	−0.24476	−0.04324	0.76793	0.03630	−0.17178
U. proboscidea	0.27160	−0.83389	−0.21479	0.02308	0.03018	0.12376
Siphouvigerina asperula	0.30748	0.08678	0.45883	−0.44827	0.39674	−0.21422
Trifarina kokozuraensis	0.50124	−0.03300	0.65392	−0.30616	0.15309	−0.04676
Uvigerinella glabra	0.29673	−0.12156	0.43946	0.03694	−0.21163	0.48975
Discorbinella nitida	0.27968	−0.72181	−0.50108	−0.03625	−0.02037	0.16010

Table 8. continued

Species name	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Epistominella pulchella	0.29523	−0.41759	−0.11629	−0.37009	−0.34137	−0.41025
E. nipponica	0.54447	−0.31417	0.49208	−0.37195	−0.12193	−0.17750
Baggina philippinensis	0.13857	−0.19760	−0.26795	0.02765	0.09456	0.31389
Valvulineria nipponica	0.17936	−0.04546	0.39388	−0.21833	0.45362	0.23554
Patellina corrugata	0.14180	−0.17738	0.38679	0.69251	−0.10166	0.29063
Ammonia beccarii	−0.13120	−0.88853	−0.15447	0.02687	0.19606	−0.00939
A. ketienziensis	−0.70065	−0.18307	0.25643	0.10699	−0.00875	0.06712
A. takanabensis	−0.55021	−0.07481	−0.01305	0.37049	0.00514	−0.36938
Pseudorotalia gaimardii	−0.84820	−0.27244	0.12595	−0.16982	−0.01296	0.07316
Elphidium advenum	−0.34500	−0.83408	−0.21314	0.07763	0.04237	0.14266
E. crispum	−0.78736	−0.42325	0.32355	0.06738	−0.01102	−0.05155
E. subarcticum	0.30850	−0.53233	−0.33158	−0.15226	0.32386	−0.16371
Eponides umbonatus	0.05025	−0.19678	0.29903	−0.19786	−0.13887	0.34406
Planulina wuellerstorfi	0.25984	−0.78120	−0.50556	−0.10540	0.07628	0.06711
Hyalina balthica	0.56384	−0.05988	0.58080	0.17620	−0.08719	−0.10255
Cibicides aknerianus	−0.69561	0.00472	0.11848	−0.10566	−0.02762	−0.01180
C. haidingerii	−0.87976	−0.38631	0.12867	−0.11507	0.02732	−0.00189
C. lobatulus	0.22823	−0.20636	0.48931	0.67526	−0.13062	0.10434
C. reflugens	0.35010	−0.47006	−0.17160	−0.20387	−0.02601	0.13079
"Virgulina" rotundata	0.15941	0.04016	0.02578	−0.16844	0.44462	−0.35400
Loxostomum karrerianum	0.36081	−0.46174	0.28983	0.23255	0.23516	−0.33531
Cassidulina carinata	0.53242	−0.22505	0.49220	0.21197	0.22790	−0.22055
C. yabei	0.43925	−0.37443	0.22706	0.32255	0.21648	−0.42578
C. depressa	0.41876	0.00342	0.48924	−0.09406	0.33393	−0.09620
Globocassidulina subglobosa	0.45884	−0.71779	0.28712	0.07106	−0.18537	−0.08880
Nonion grateloupi	0.15507	0.02156	0.11912	−0.29139	−0.62455	−0.35888
N. japonicum	−0.84384	−0.42569	0.25320	−0.04856	−0.00319	0.03716
N. scaphum	0.32541	−0.46137	0.03844	−0.17363	0.23054	0.46410
Pseudononion japonicum	0.29742	−0.81586	−0.41697	−0.02424	0.10104	0.00156
Gyroidina nipponica	0.51687	−0.63352	−0.01020	0.05248	−0.11202	−0.07836
G. orbicularis	−0.85675	−0.35337	0.25263	−0.20631	−0.07695	−0.00150
G. sp. *A*	0.48279	−0.19481	0.49530	−0.22524	−0.37870	0.34236
Anomalina glabrata	0.06799	−0.21641	0.27304	0.76083	0.00574	−0.31748
Hanzawaia nipponica	−0.85578	−0.28735	0.09338	0.11631	0.00530	−0.12259
Melonis nikoberense	0.43945	−0.52405	−0.07137	0.17824	0.01677	0.14931
M. pompilioides	−0.83398	−0.31594	0.22533	−0.20643	−0.07118	0.00717
Hoeglundina elegans	0.36197	−0.44783	−0.10184	0.22575	−0.34853	0.30120

and express all the factors in the multidimensional space, especially on fossil assemblages without the knowledge on their strict ecological condition in life. In the present study, only first four factors can be expressed. To discuss the meaning of these factors, one must review the original data and compare them with the characters of that data. In this study, the rare species are neglected in the consideration of factors.

Concerning the factor 1 of R-technique, the species expressed by the relatively large positive values of factor loadings are *H. balthica, Epistominella nipponica, C. carinata, Gyroidina nipponica, T. kokozuraensis, Gyroidina* sp. A, and etc. The common character of these species is small volume of shells. While the species having a relatively large negative values of the factor loadings are *Quinqueloculina sawanensis, Cibicides haidingerii, B.* cf. *semicostata, G. orbicularis, Lenticulina abensis, Pseudorotalia gaimardii,* and etc. The large shell volume is the common character of these species. Thus the factor 1 of R-technique seems to be concerned with the shell volume of the benthonic foraminifers, and the positive and negative values means relatively small and large shell volume.

It is apparent, concerning the factor 2 of R-technique, that large negative value has relation to the species with nearly circular and relatively small sized shell as *Ammonia beccarii, U. proboscidea, Globocassidulina subglobossa* and *P. japonicum* and that relatively large negative values are related to the species with nearly circular and large shells as *Ammonia ketienziensis, B. striata, Cibicides* spp., *Lenticulina* spp., *N. japonicum* and etc. It was also clarified that positive or relatively small negative values are tied to species with cylindrical or platy shell as *Dentalina* spp., *Lagena gracilis, Plectofrondicularia totomiensis, Siphonodosaria* spp., *Bulimina tenuata, H. balthica* and etc. In short the factor 2 of R-technique is estimated as a factor concerning with shell form of the benthonic foraminifers.

The factor 3 of R-technique seems to represent the character of bottom sediments in which the benthonic foraminifers lived. According to the data of recent benthonic foraminifers (ASANO, BRADY, CUSHMAN, PHLEGER, and so on), *Quinqueloculina* spp., *Bolivina nitida, Reussella pacifica, Discorbinella nitida, Elphidium subarcticum, P. wuellerstorfi* and *P. japonicum* are sand-dwellers and they show relatively large negative values of factor loadings. On the contrary, most of mud-dwellers such as *C. carinata, C. depressa, H. balthica, Epistominella nipponica, T. kokozuraensis, B. tenuata* and *L. calcar* have the relatively large positive values. Thus the positive values of the factor 3 of R-technique seem to represent the muddy sediments and the negative one the sandy sediments.

Concerning the factor loadings of the factor 4 of R-technique, relatively large positive values are indicated by such warm water species of common occurrence as *Cibicides lobatulus, Uvigerina nitidula, B. robusta, Ammonia takanabensis, C. carinata,* and *C. yabei,* although rare species do not necessarily fit this tendency. Among these species, *C. lobatulus* and *A. takanabensis* are upper sublittoral elements. Furthermore most of the species of shallow water have the positive values of factor loadings. On the contrary, such species representing the relatively large negative values, except rare species, as *Bolivinita quadrilatera, Siphouvigerina asperula, T. kokozuraensis* and *Nonion grateloupi* are mostly elements of the bathyal zone. The species of cold water fauna also show negative values of factor loadings, but the value is about zero, if they are shallow water elements. According to PHLEGER (1960), depth and temperature of seawater are closely related with each other in the deeper area than certain depth. In the present study, the inferred depositional area of the sampling locality is considered in the lower sublittoral zone, then the depth and the temperature of water need not be taken as independent factors mutually. Thus the factor 4 of R-technique is considered to represent the depth and temperature of benthonic foraminifers, and the positive side means a condition of shallow and/or warm water, on the contrary, the negative side means a condition of deep and/or cool water.

The results of the analysis by the MOTOMURA's formula are examined with the aid of the knowledge on ecological factors clarified by the factor 1 of R-technique. The extreme values of the MOTOMURA's formula can be explained by a presumption that most of the assemblages of stations are not the original autochthonous ones but mixtures of two or more assemblages through the process of sedimentation and/or the procedure of sampling. Besides results of the factor analysis, presence of more shell fragments on the basal planes in sandy strata than in muddy ones and the fluctuation of contents of $CaCO_3$ and organic carbon apparently verify the effect of transportation. According to EMERY (1938), the settling velocity of sand grains is mainly controlled by the grain size. These data inevitably lead to a conclusion that the factor 1 of R-technique is concerned with the depositional mechanism. The large negative value of factor loadings for *Gaudryina arenaria*, although it has a small shell, is attributed to its arenaceous and thick shell.

The factor represented by the factor 2 of R-technique seems to be connected with the threshold velocity of grains. In the species having nearly circular shape, the smaller the shell volume is, the larger the value of factor loading is, and in the species of about same shell volume, the more circular the shape of species is, the larger the value of factor loading is. The smaller values of factor loadings are represented in the positions of species having platy and cylindrical shells. These things mentioned above seems to be connected with the fluctuation of threshold velocity as KRUMBEIN and SLOSS (1953) and KUENEN (1967) claimed. KRUMBEIN and SLOSS also noted that the threshold velocity fluctuated according to the change of specific gravity. But the specific gravities of shells themselves of benthonic foraminifers appear to be the same for most of the shells are made of calcium carbonate, and then the difference of specific gravity may be left out of consideration.

These two conclusions concerning the factor 1 and 2 of R-technique are also supported by the conclusion of factor 2 of Q-technique. And there are no marked contradictions between the results of the factor analysis of R-technique and Q-technique.

Now, we can give a picture of environment during deposition on the basis of the data mentioned in the preceding paragraphs. The factor 1 of Q-technique informs that the bathymetric position of locality 6968 during deposition is in the lower sublittoral to upper bathyal zone, and also that any environmental changes of a large scale did not occur by which the assemblages of benthonic foraminifers were changed completely. The most important factor causing changes of benthonic foraminiferal assemblages is the depositional mechanism, and the most extreme case is shown at the station STAI. The sandy sediments seems to be conveyed through a course expressed in a term "path of transportation", which must have been in the northern part of locality 6968. This is verified by the fact that in each bed the values of factor loadings of factor 2 of Q-technique are correlated more closely with the factor in northern column including the stations STAA, STAB,...., and STAJ than the other columns. A sandy bed including the stations STAV, STAW, STBE and STBF seems to be deposited by one density current according to factor loadings of factor 2 of Q-technique that take more closely connected values with the factor in the station of lower part than upper one in a bed.

On the basis of four factors, it is apparent that the bottom sediments in situ were normally muddy, and most of the sandy ones were occasional trespassers by, for example, density currents. The depth of water, though it is not expressed so definitely, was changed from shallower to deeper and again to shallower successively within the range of lower sublittoral to upper bathyal zones.

Occasional density currents are also suggested by the data, the factor 1 and 2 of R-technique factor analysis, fluctuation of weight contents of calcium carbonate and organic carbon in the beds, and sedimentary features of the outcrop of locality.

Concluding remarks

The following results were obtained from the present study.

The benthonic foraminiferal assemblages of 31 stations at the locality 6968 are divided into four groups and named by the qualitative procedure as *Cassidulina carinata* assemblage, *Rectobolivina raphana* assemblage, *Gyroidina orbicularis–Nonion japonicum* assemblage and *Pseudononion japonicum* assemblage.

25 of 31 stations contain *C. carinata* assemblage and the other six stations are represented by the other three assemblages, which have mixed features of two or more original thanatocoenoses. Under such circumstance as mentioned above, foraminiferal assemblage occurring at the locality 6968 is reasonably called as *C. carinata* assemblage as a whole, and its ecological and depositional environment seems to have been under a condition of the lower sublittoral to upper bathyal zone. However, application of the modified MOTOMURA's formula to analyse complexity of benthonic foraminiferal assemblages clarified that most of the assemblages even of those included in *C. carinata* assemblage do not consist of a single original thanatocoenose but two or more ones by mixing at the time of deposition and/or in the sampling procedure.

The principal factor analysis was applied to infer ecological-depositional factors which determined the structure of respective assemblages. The first four factors of the R-technique factor analysis are interpreted to be related respectively to the depositional mechanism, the threshold velocity of bottom current, the bottom sediments in which the benthonic foraminifers lived and the depth and/or temperature of water. Their percentages occupying in all the information are 20.44%, 16.26%, 8.46% and 6.72%, respectively. While the first four factors of the Q-technique factor analysis are interpreted to be related respectively to the similarity of the assemblages, the mechanism of sedimentation, the bottom sediments in which the benthonic foraminifers lived, and the depth of water. Their percentages in whole information are 73.61%, 6.79%, 3.87% and 3.03%, respectively.

The environment during deposition of sediments of the locality 6968 can be outlined on the basis of the preceding results. That is, the site of deposition seems to be situated at the lower sublittoral to upper bathyal zone, and density flow might have often occurred. Most of the sandy sediments seems to be transported by these density flows through a course being in the northern part of this locality.

The application of the principal factor analysis is, as well known, the most effective when any phenomenon is predicted to be related to several kinds of the known factors, and the weight of each factor is not clarified. Whence the weight of each factor can be quantitatively determined, and this serves as necessary basis for the controlled experiment. Here the factors governing the structure of the benthonic foraminiferal assemblages are only vaguely forecasted at the present case. Consequently the author was able to refer only to a few leading factors. The result is, however, promising enough for him with a perspective, on one hand, for a controlled ecological research of the living foraminifers and, on the other hand, for extracting autochthonous assemblages from several thanatocoenses. Upon these foundations a rigid paleo-ecological study of fossil material should be executed.

Faunal reference list

The following is an alphabetical list of the benthonic foraminiferal species which are shown in systematically arranged plates of this paper. Any detailed taxonomic discussions or complete synonymy of respectie species are not given, but a brief note on *Gyroidina* sp. *A*.

Ammonia beccarii (LINNÉ) Pl. 29, figs. 2a–c.
Rotalia beccarii (LINNÉ), CUSHMAN, (1931): *U. S. Nat. Mus., Bull.* **104**, Pt. 8, 58–60, pl. 12, figs. 1–7, pl. 13, figs. 1, 2.
A. ketienziensis (ISHIZAKI) Pl. 29, figs. 3a–c.
Streblus ketienziensis ISHIZAKI, (1948): *Acta Geol. Taiwan* **2**, (1), 59, pl. 1, figs. 2a–c.
A. takanabensis (ISHIZAKI) Pl. 29, figs. 3a–c.
Streblus takanabensis ISHIZAKI, (1948): ibid, 57, pl. 1, figs. 5a–c.
Amphicorina scalaris (BATCH) Pl. 25, fig. 9.
Nodosaria scalaris (BATCH), BRADY, (1884): Voy. *Challenger Rep., Zool.*, **9**, 510, pl. 63, figs. 28–31.
Anomalina glabrata CUSHMAN Pl. 32, figs. 4a–c.
ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 13, 14, figs. 10–12.
Baggina philippinensis (CUSHMAN) Pl. 28, figs. 15a, b.
Pulvinulina philippinensis CUSHMAN, (1921): *U. S. Nat. Mus., Bull.* **100**, 331, pl. 58, figs. 2a–c.
Bolivina nitida BRADY Pl. 27, fig. 5.
BRADY, (1884): *Voy. Challenger Rep., Zool.*, **9**, 420, pl. 52, figs. 30a, b.
B. robusta BRADY Pl. 27, figs. 6a, 8.
BRADY, (1884): ibid, 421, pl. 53, figs. 7–9.
B. spinescens CUSHMAN Pl. 27, figs. 8a, b.
CUSHMAN, (1911): *U. S. Nat. Mus., Bull.* **71**, Pt. 2, 46, 47, figs. 76a, b.
B. cf. *semicostata* CUSHMAN Pl. 27, figs. 9a, b.
Cf. *Bolivina semicostata* CUSHMAN, (1911): ibid, 43, figs. 70a, b.
B. cf. *spissa* CUSHMAN Pl. 27, fig. 7.

Cf. *Bolivina spissa* CUSHMAN, MATOBA, (1967) : *Sci. Rep. Tohoku Univ., Sendai,* 2nd. ser., 38, (2), 251, pl. 25, figs. 9a, b, 10a, b.

B. cf. *tokiokai* UCHIO Pl. 27, figs. 10a, b.

Cf. *Bolivina tokiokai* UCHIO, (1962) : *Seto Mar. Biol. Lab., Pub.,* **10**, (2), 389, pl. 18, figs. 5a, b.

Bolivinita quadrilatera (SCHWAGER) Pl. 27, fig. 4.

Textularia quadrilatera SCHWAGER, BRADY, (1884): *Voy. Challenger Rep., Zool.,* **9**, 358, pl. 42, figs. 8–12.

Bulimina aculeata D'ORBIGNY Pl. 28, fig. 2.

CUSHMAN and PARKER, (1946) : *U. S. Geol. Surv. Prof. Paper 210-D,* 120, pl. 28, figs. 8–11.

B. marginata D'ORBIGNY Pl. 28, fig. 3.

CUSHMAN and PARKER, (1936) : ibid, 119, pl. 28, figs. 5, 6.

B. striata D'ORBIGNY Pl. 4, fig. 4.

CUSHMAN and PARKER, (1946) : ibid, 119, pl. 28, figs. 1–3.

B. tenuata (CUSHMAN) Pl. 28, fig. 5.

Bulimina exilis BRADY var. *tenuata* (CUSHMAN), CUSHMAN and PARKER, (1946) : ibid, 124, pl. 28, fig. 29.

Cassidulina carinata SILVESTRI Pl. 31, figs. 3a, b.

BARKER, (1960) : *Taxonomic Notes, Soc. Econ. Paleont. Mineral., Spec. Pub.,* (9), 110, pl. 54, figs. 2, 3.

C. depressa ASANO and NAKAMURA Pl. 31, fig. 4.

Cassidulina subglobosa depressa ASANO and NAKAMURA, (1937) : *Japan. Jour. Geol. Geogr.,* **14**, (3, 4) 148, pl. 13, figs. 8a–c.

C. yabei ASANO and NAKAMURA Pl. 31, figs. 5a, b.

ASANO and NAKAMURA, (1937) : ibid, 147, pl. 14, figs. 1a, b.

Cassidulinoides bradyi (NORMAN) Pl. 27, fig. 12.

Cassidulina bradyi NORMAN, BRADY (1884) : *Voy. Challenger Rep., Zool.,* **9**, 431, pl. 54, figs. 6–9.

C. parkerianus (BRADY) Pl. 27, figs. 13a, b.

Cassidulina parkeriana BRADY, (1884) : ibid, 432, pl. 54, figs. 11–16.

Cibicides aknerianus (D'ORBIGNY) Pl. 30, figs. 6a–c.

Truncatulina akneriana CUSHMAN, (1921) : *U. S. Nat. Mus., Bull.* **100**, Pt. 4, 316, pl. 63, fig. 3.

C. haidingerii (D'ORBIGNY) Pl. 30, figs. 7a–c.

Eponides haidingerii (D'ORBIGNY), ASANO, (1951) : *Illust. Cat. Japan. Tert. Small. Foram.,* Pt. 14, 10, figs. 71–73.

C. lobatulus (WALKER and JACOB) Pl. 30, figs. 8a–c.

CUSHMAN, (1931) : *U. S. Nat. Mus., Bull.* **104**, Pt. 8, 118, pl. 21, figs. 3a–c.

C. reflugens MONTFORT Pl. 30, figs. 9a–c.

CUSHMAN, (1931) : ibid, 116, pl. 21, figs. 2a–c.

Dentalina emaciata REUSS Pl. 25, fig. 11.

ASANO, (1938) : *Sci. Rep. Tohoku Univ., 2nd. ser.,* **19**, (2), 215, pl. 25, figs. 13, 20–23, pl. 27, figs. 17, 19, pl. 28, figs. 21, 28, pl. 29, figs. 14, 24.

D. setanaensis ASANO Pl. 25, fig. 10.

ASANO, (1938) : ibid, 215, pl. 30, figs. 9–12, 30–32.

Discorbinella nitida (WILLIAMSON) Pl. 28, figs. 12a–c.

Discopulvinulina nitida (WILLIAMSON), ASANO, (1951) : *Illust. Cat. Japan. Tert. Small. Foram.,* Pt. 14, 6, figs. 38–40.

Elphidium advenum (CUSHMAN) Pl. 29, figs. 6a, b.

ASANO, (1938) : *Jour. Geol. Soc. Japan,* **45**, (538), 587, pl. 14, figs. 3a, b.

E. crispum (LINNÉ) Pl. 30, figs. 1a, b.

CUSHMAN, (1939) : *U. S. Geol. Surv., Prof. Paper 191,* 50, 51, pl. 13, figs. 17–21.

E. subarcticum ASANO Pl. 30, figs. 2a, b.

ASANO, (1950) : *Illust. Cat. Japan. Tert. Small. Foram.,* Pt. 1, 10, figs. 56, 57.

Epistominella nipponica KUWANO Pl. 28, figs| 14a c.

MATOBA, (1967) : *Sci. Rep. Tohoku Univ., 2nd, ser.*, **38**, (2), 254, figs. 8a–f, pl. 26, figs. 13a–c.

E. pulchella HUSEZIMA and MURUHASI Pl. 28, figs. 13a–c.

ASANO, (1951) : *Illust. Cat. Japan .Tert. Small. Foram.*, Pt. 7, 7, figs. 37–39.

Eponides umbonatus (REUSS) Pl. 30, figs. 3a–c.

CUSHMAN, (1931) : *U. S. Nat. Mus., Bull.* **104**, Pt. 8, 52, pl. 11, figs. 1–3.

Fissulina cucurbitasema LOEBLICH and TAPPAN Pl. 27, fig. 2.

MATOBA, (1970): *Sci. Rep. Tohoku Univ., 2nd. ser.*, **42**, (1), 54, pl. 3, figs. 22a, b.

F. marginata (MONTAGU) Pl. 27, fig. 3.

Lagena marginata (MONTAGU), CUSHMAN, (1913) : *U. S. Nat. Mus., Bull.* **71**, Pt. 3, 37, pl. 22, figs. 1–7.

Frondicularia advena CUSHMAN Pl. 25, fig. 12.

CUSHMAN, (1923) : *U. S. Nat. Mus., Bull.* **104**, Pt. 4, 141, pl. 20, figs. 1, 2.

Gaudryina arenaria GALLOWAY and WISSLER Pl. 25, fig. 3.

GALLOWAY and WISSLER, (1927) : *Jour. Paleont.*, **1**, 68, pl. 11, fig. 5.

Globocassidulina subglobosa (BRADY) Pl. 31, fig. 6.

Cassidulina subglobosa BRADY, (1884) : *Voy. Challenger Rep., Zool.*, **9**, 430, pl. 54, figs. 17a–c.

Guttulina sadoensis (CUSHMAN and OZAWA) Pl. 26, fig. 10.

ASANO, (1951) : *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. **8**, 4, figs. 16–18.

Gyroidina nipponica ISHIZAKI Pl. 32, figs. 1a–c.

ASANO, (1951) : ibid, Pt. 14, 8, figs. 55–57.

G. orbicularis D'ORBIGNY Pl. 32, figs. 2a–c.

CUSHMAN, (1915): *U. S. Nat. Mus., Bull.*, **71**, Pt. 5, 69, pl. 29, fig. 30.

G. sp. *A* Pl. 32, figs. 3a–c.

Test is small, subcircular in outline and biconvex, and is composed of about 3 whorls all of which are visible on dorsal side, but only last whorl is visible on ventral side, periphery is slightly lobulate in outline; chambers are distinct, 6 to 8 in last whorl and increasing slightly in size as added; suture is distinct, and straight on dorsal side and nearly sigmoidal on ventral side; wall is smooth; aperture is a narrow and elongate slit at base of apertural face. Diameter becomes up to 0.2 mm.

Hanzawaia nipponica ASANO Pl. 32, figs. 5a–c.

ASANO, (1944): *Jour. Geol. Soc. Japan*, **51**, (606), 99, pl. 4, figs. 1a, b, 2a, b.

Hoeglundina elegans (D'ORBIGNY) Pl. 32, figs. 10a–c.

BARKER, (1960): *Taxonomic Note, Soc. Econ. Paleont. Mineral., Spec. Pub.*, (9), 216, pl. 105, figs. 3–6.

Hyalina balthica (SCHROETER) Pl. 30, figs. 5a, b.

Anomalina balthica (SCHROETER), CUSHMAN, (1931): *U. S. Nat. Mus., Bull.* **104**, Pt. 8, 108, pl. 19, figs. 3a–c.

Lagena gracilis WILLIAMSON Pl. 26, fig. 3.

ASANO, (1951) : *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. **15**, 30, fig. 133.

L. laevis (MONTAGUQ Pl. 26, fig. 1.

CUSHMAN, (1913): *U. S. Nat. Mus., Bull.* **71**, Pt. 3, 5, pl. 1, fig. 3, pl. 38, fig. 5.

L. striata (D'ORBIGNY) Pl. 26, fig. 2.

ASANO, (1938): *Sci. Rep. Tohoku Univ., 2nd. ser.*, **19**, (2), 217, pl. 27, fig. 26, pl. 29, fig. 28.

Lenticlina abensis (ASANO) Pl. 26, figs. 4a, b.

Robulus abensis ASANO, (1936) : *Japan. Jour. Geol. Geogr.*, **13**, (3, 4), 327, pl. 37, figs. 5, 10.

L. calcar (LINNÉ) Pl. 26, figs. 5a, b.

Cristellaria calcar (LINNÉ), CUSHMAN, (1913) :: *U. S. Nat. Mus., Bull.* **71**, Pt. 3, 72, pl. 31, fig. 4.

L. nikoberensis (SCHWAGER) Pl. 26, figs. 6a, b.

Robulus nikoberensis (SCHWAGER), ASANO, (1938) : *Sci. Rep. Tohoku Univ., 2nd. ser.*, **19**, (2), 204, pl. 28, figs. 5, 6, pl. 29, fig. 8.

L. surugaensis (ASANO) Pl. 26, fig. 7a, b.

Robulus surugaensis ASANO, (1936): *Japan. Jour. Geol. Geogr.*, **13**, (3, 4), 328, pl. 37, figs. 4a, b.

Loxostomum karrerianum (BRADY) Pl. 31, fig. 2.
Bolivina karreriana BRADY, (1884): *Voy. Challenger Rep., Zool.*, **9**, 424, pl. 53, figs. 19–21.

Martinotiella communis (D'ORBIGNY) Pl. 25, figs. 4a, b.
Listerella communis (D'ORBIGNY), CUSHMAN, (1937): *Cushman Lab. Foram. Res., Spec. Pub.*, (8), 148, pl. 17, figs. 4–9.

Melonis nikoberensis (CUSHMAN) Pl. 32, figs. 6a, b.
Nonion nikoberense CUSHMAN, (1939): *U. S. Geol. Surv., Prof. Paper 191*, 17, pl. 4, fig. 16.

M. pompilioides (FICHTEL and MOLL) Pl. 32, figs. 7a, b.
Nonion pompilioides (FICHTEL and MOLL), CUSHMAN, (1939): ibid, 19, pl. 5, figs. 9–12.

Nonion grateloupi (D'ORBIGNY) Pl. 31, figs. 7a, b.
CUSHMAN, (1939): ibid, 21, 22, pl. 6, figs. 1–7.

N. japonicum ASANO Pl. 31, figs. 8a, b.
ASANO, (1938): *Jour. Geol. Soc. Japan*, **45**, (538), 593, pl. 15, figs. 1a, b, 2a, b.

N. scaphum (FICHTEL and MOLL) Pl. 31, figs. 9a, b.
CUSHMAN, (1930): *U. S. Nat. Mus., Bull.*, **104**, Pt. 7, 5, pl. 2, figs. 3, 4.

Oolina melo D'ORBIGNY Pl. 27, figs. 1a, b.
ASANO, (1956): *Sci. Rep. Tohoku Univ., 2nd. ser.*, **27**, Pt. 1, 43, 44, pl. 5, figs. 44–50.

Patellina corrugata WILLIAMSON Pl. 29, figs. 1a–c.
BRADY, (1884): *Voy. Challenger Rep., Zool.*, **9**, 634, pl. 86, figs. 1–7.

Planulina wuellerstorfi (SCHWAGER) Pl. 30, figs. 4a–c.
ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 13, 15, figs. 13–15.

Plectofrondicularia totomiensis MAKIYAMA Pl. 26, fig. 9.
ASANO, (1951): ibid, Pt. 15, 39, fig. 165.

Pseudononion japonicum ASANO Pl. 31, figs. 10a–c.
ASANO, (1936): *Jour. Geol. Soc. Japan*, **43**, (512), 347, figs. a–c.

Pseudorotalia gaimardii (D'ORBIGNY) Pl. 29, figs. 5a–c.
Streblus gaimardii (D'ORBIGNY), BARKER, (1960): *Taxonomic Note, Soc. Econ. Paleont, Mineral., Spec. Pub.*, (9), 218, pl. 106, fig. 9.

Quinqueloculina akneriana D'ORBIGNY Pl. 25, figs. 5a–c.
ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 6, 2, figs. 6–8.

Q. sawanensis ASANO Pl. 25, figs. 6a–c.
ASANO, (1951): ibid, Pt. 6, 6, figs. 40–42.

Q. seminulum (LINNÉ) Pl. 25, figs. 7a, b.
ASANO, (1951): ibid, Pt. 6, 7, figs. 43–45

Rectobolivina raphana (PARKER and JACOBS) Pl. 27, fig. 11.
Siphogenerina raphana (PARKER and JACOBS), MATHEWS, (1945): *Jour. Paleont.*, **19**, (6), 588, pl. 81, figs. 16, 17, 21–23.

Reusella pacifica CUSHMAN and MCCULLOCH Pl. 28, fig. 6.
ASANO, (1950): *Ill. Cat. Jap. Tert. Small. Foram.*, Pt. 2, 13, fig. 52.

Saracenaria angularis NATLAND Pl. 26, figs. 8a, b.
ASANO, (1951): ibid, Pt. 15, 13, fig. 66.

Sigmoilopsis schlumbergeri (SILVESTRI) Pl. 25, fig. 8.
BARKER, (1960): *Taxonomic Note, Soc. Econ. Paleont. Mineral., Spec. Pub.*, (9), 16, pl. 8, figs. 1 4.

Siphonodosaria janonica (ISHIZAKI) Pl. 27, fig. 15.
Ellipsonodosaria japonica ISHIZAKI, ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 15, 27, figs. 119, 120.

S. oinomikadoi (ISHIZAKI) Pl. 27, fig. 14.
Ellipsonodosaria oinomikadoi ISHIZAKI, ASANO, (1951): ibid, Pt. 15, 28, figs. 125, 126.

Siphouvigerina asperula (CZJZEK) Pl. 28, fig. 9.

Uvigerina asperula CZJZEK, BARKER, (1960): *Taxonomic Note, Soc. Econ. Paleont. Mineral., Spec. Pub.*, (9), 156, pl. 75, figs. 6–9.

Stilostimella lepidula (SCHWAGER) Pl. 28, fig. 1.
Ellipsonodosaria lepidula (SCHWAGER), ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 15, 28, figs. 123, 124.

Textularia articulata D'ORBIGNY Pl. 25, figs. 1a, b.
ASANO, (1950): ibid, Pt. 3, 3, figs. 9, 10.

Trifarina kokozuraensis (ASANO) Pl. 28, fig. 10.
Angulogerina kokozuraensis ASANO, (1949): *Jour. Paleont.*, **23**, (4), 428, fig. 1.

Uvigerina nitidula SCHWAGER Pl. 28, fig. 7.
CUSHMAN, (1939): *Jour. Geol. Soc. Japan*, **46**, (546), 151, pl. 10, fig. 12.

U. proboscidea SCHWAGER Pl. 31, fig. 8.
CUSHMAN, (1939): ibid, **46**, (546), 151, pl. 10, fig. 13.

Uvigerinella glabra (MILLETT) Pl. 28, fig. 11.
Hopkinsina glabra (MILLETT), AOKI, (1965): *Saitama Univ., Sci. Rep., ser. B*, **5**, (1), 59, pl. 7, fig. 2.

Valvulineria nipponica ISHIZAKI Pl. 28, figs. 16a–c.
ASANO, (1951): *Illust. Cat. Japan. Tert. Small. Foram.*, Pt. 14, 7, figs. 52–54.

"Virgulina" rotundata PARR Pl. 31, figs. 1a, b.
BARKER, (1960): *Taxonomic Note, Soc. Econ. Paleont. Mineral., Spec. Pub.*, (9), 106, pl. 52, figs. 10, 11.

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Tokuhiko KAMEYAMA

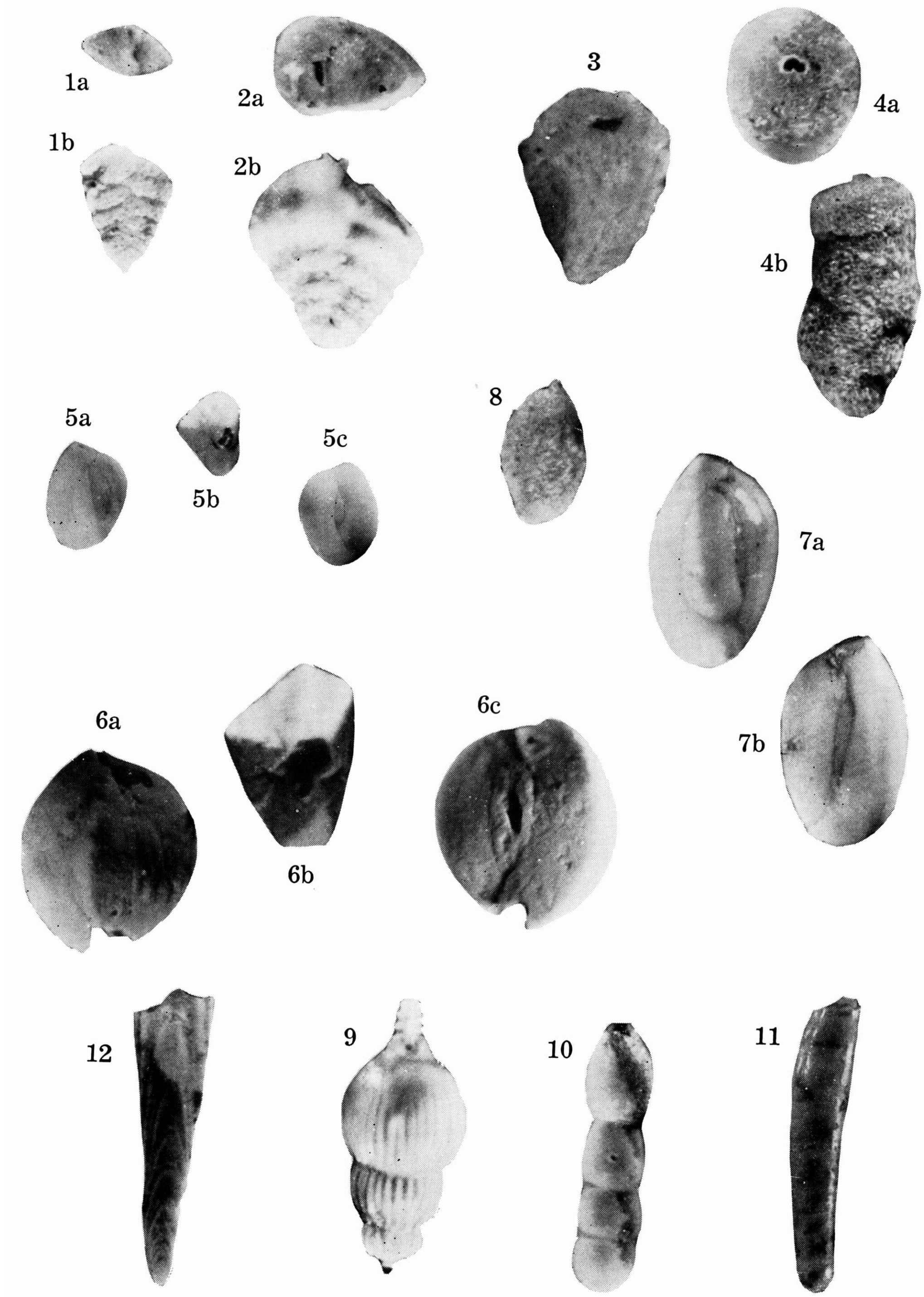
An Application of Quantitative Method for the Analysis of Fossil Benthonic Foraminiferal Assemblage

Plates 25～32

Plate 25

Explanation of Plate 25.

Fig. 1a, b. *Textularia articulata* D'ORBIGNY ×60
Fig. 2a, b. *Siphotextularia* sp. ×60
Fig. 3. *Gaudryina arenaria* GALLOWAY and WISSLER ×100
Fig. 4a, b. *Martinottiella communis* D'ORBIGNY ×50
Fig. 5a–c. *Quinqueloculina akneriana* D'ORBIGNY ×60
Fig. 6a–c. *Q. sawanensis* ASANO ×60
Fig. 7a, b. *Q. seminulum* (LINNÉ) ×60
Fig. 8. *Sigmoilopsis schlumbergeri* (SILVESTRI) ×50
Fig. 9. *Amphicorina scalaris* (BATCH) ×60
Fig. 10. *Dentalina setanaensis* ASANO ×80
Fig. 11. *D. emaciata* REUSS ×50
Fig. 12. *Frondicularia advena* CUSHMAN ×60



T. KAMEYAMA: Analysis of foramimiferal assemblage

Plate 26

Explanation of Plate 26.

Fig. 1.	*Lagena laevis* (MONTAGU) ×80
Fig. 2.	*L. striata* (D'ORBIGNY) ×100
Fig. 3.	*L. gracillis* WILLIAMSON ×100
Fig. 4a, b.	*Lenticulina abensis* ASANO ×60
Fig. 5a, b.	*L. calcar* (LINNÉ) ×50
Fig. 6a, b.	*L. nikoberensis* (SCHWAGER) ×50
Fig. 7a, b.	*L. surugaensis* (ASANO) ×50
Fig. 8a, b.	*Saracenaria angularis* NATLAND ×60
Fig. 9.	*Plectofrondicularia totomiensis* MAKIYAMA ×50
Fig. 10.	*Guttulina sadoensis* (CUSHMAN and OZAWA) ×50

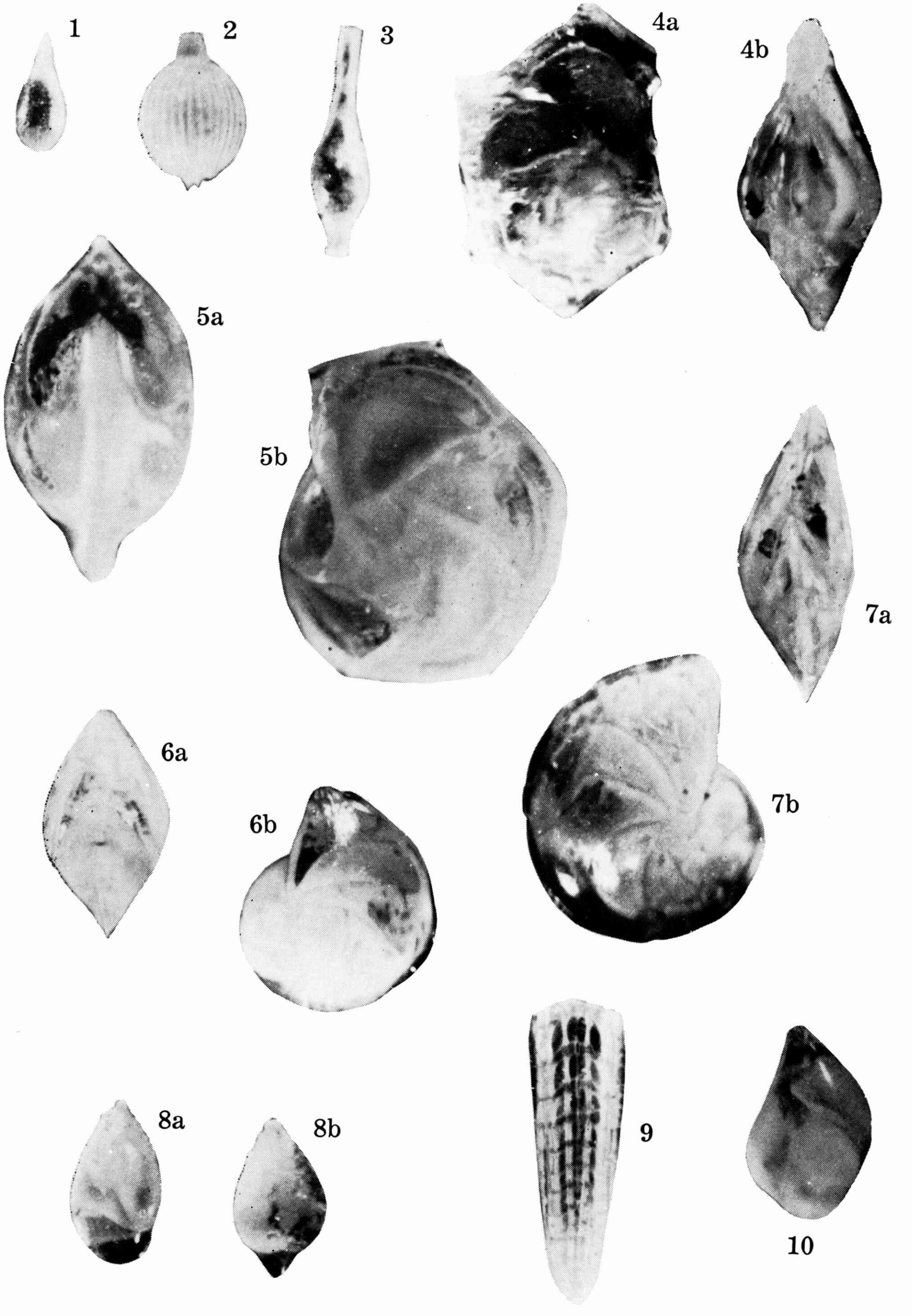

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Plate 27

Explanation of Plate 27.

Fig. 1.	*Oolina melo* D'ORBIGNY ×100
Fig. 2.	*Fissulina cucurbitasema* LOEBLICH and TAPPAN ×150
Fig. 3.	*F. marginata* (MONTAGU) ×150
Fig. 4.	*Bolivinita quadrilatera* (SCHWAGER) ×50
Fig. 5.	*Bolivina nitida* BRADY ×100
Fig. 6a. b.	*B. robusta* BRADY ×100
Fig. 7.	*B. spissa* CUSHMAN ×100
Fig. 8a, b.	*B. spinescens* CUSHMAN ×100
Fig. 9a, b.	*B.* cf. *semicostata* CUSHMAN ×60
Fig. 10a, b.	*B.* cf. *tokiokai* UCHIO ×100
Fig. 11.	*Rectobolivina raphana* (PARKER and JONES) ×60
Fig. 12.	*Cassidulinoides bradyi* (NORMAN) ×100
Fig. 13a, b.	*C. parkerianus* (BRADY) ×150
Fig. 14.	*Siphonodosaria oinomikadoi* (ISHIZAKI) ×60
Fig. 15.	*S. japonica* (ISHIZAKI) ×100

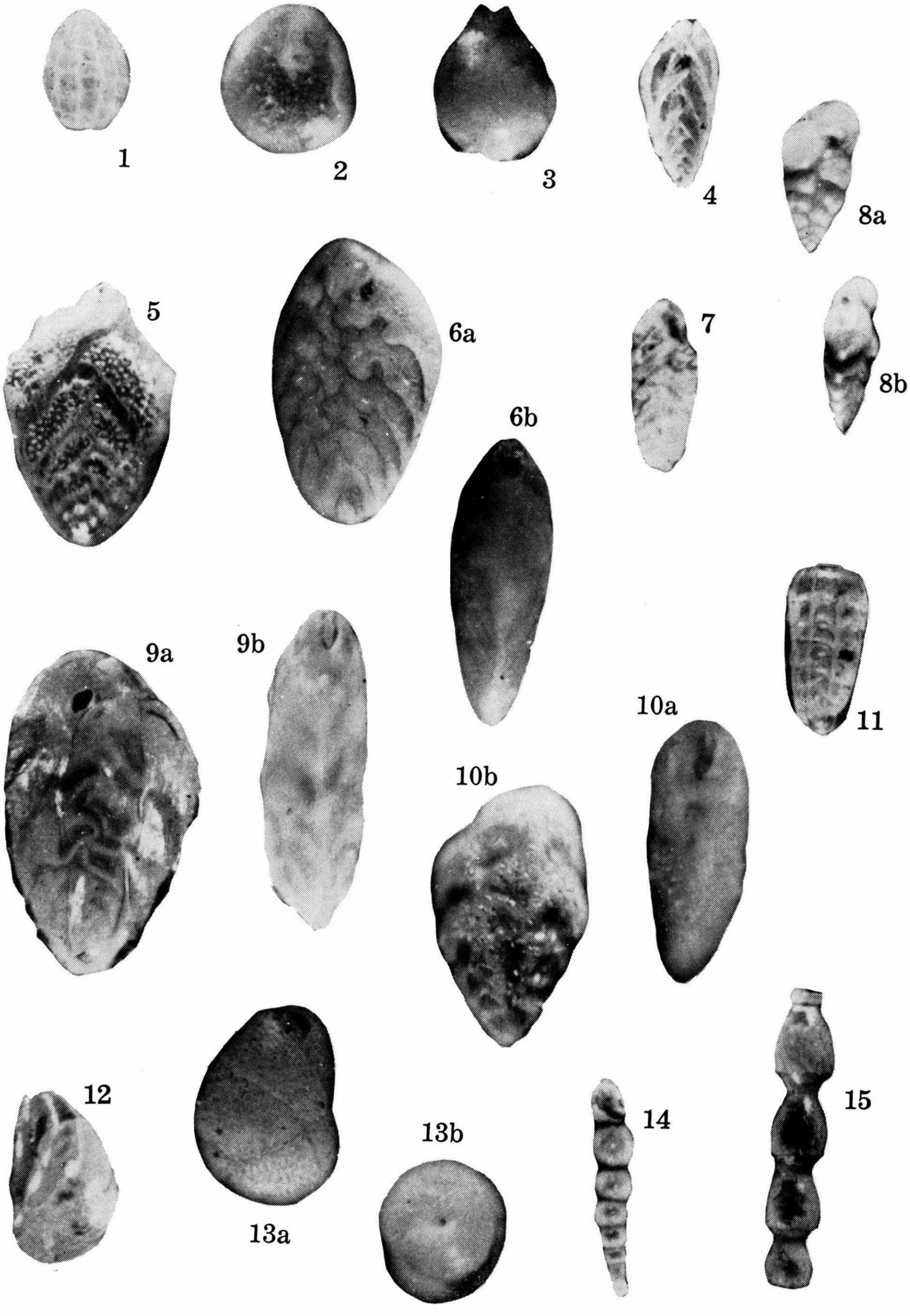
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Plate 28

Explanation of Plate 28.

Fig. 1.	*Stilostimella lepidula* (SCHWAGER) ×80
Fig. 2.	*Bulimina aculeata* D'ORBIGNY ×100
Fig. 3.	*B. marginata* D'ORBIGNY ×100
Fig. 4.	*B. striata* D'ORBIGNY ×60
Fig. 5.	*B. tenuata* (CUSHMAN) ×80
Fig. 6.	*Reussella pacifica* CUSHMAN and MCCULLOCH ×100
Fig. 7.	*Uvigerina nitidula* SCHWAGER ×100
Fig. 8.	*U. proboscidea* SCHWAGER ×100
Fig. 9.	*Siphouvigerina asperula* (CZJZEK) ×100
Fig. 10.	*Trifarina kokozuraensis* (ASANO) ×100
Fig. 11.	*Uvigerinella glabra* (MILLETT) ×100
Fig. 12a–c.	*Discorbinella nitida* (WILLIAMSON) ×100
Fig. 13a–c.	*Epistominella pulchella* HUSEZIMA and MARUHASHI ×100
Fig. 14a–c.	*E. nipponica* KUWANO ×120
Fig. 15a, b.	*Baggina phillippinensis* (CUSHMAN) ×100
Fig. 16a–c.	*Valvulineria nipponica* ISHIZAKI ×120

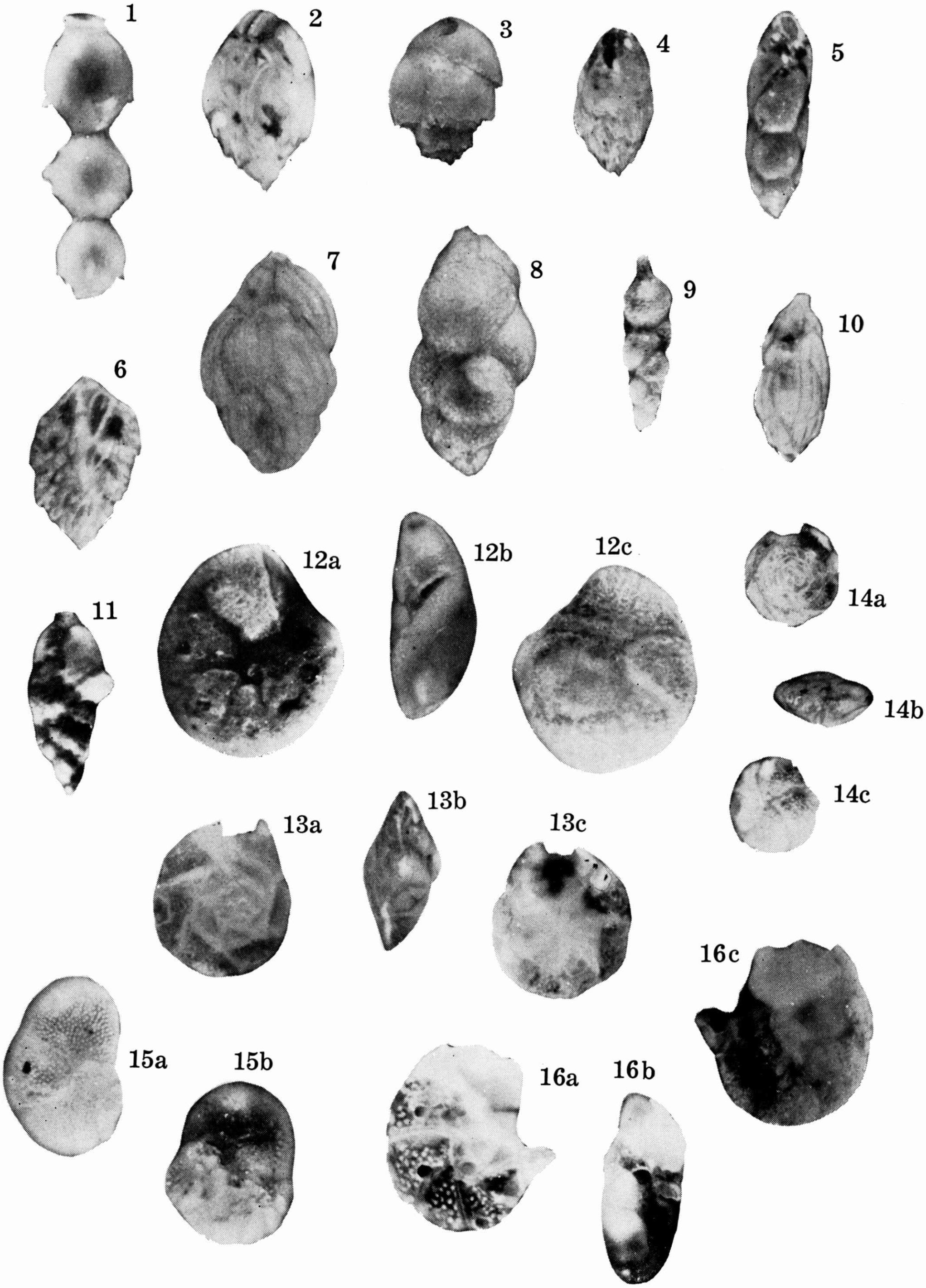

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Plate 29

Explanation of Plate 29.

Fig. 1a–c. *Patellina corrugata* WILLIAMSON ×100
Fig. 2a–c. *Ammonia beccarii* (LINNÉ) ×100
Fig. 3a–c. *A. ketienziensis* KUWANO ×60
Fig. 4a–c. *A. takanabensis* (ISHIZAKI) ×60
Fig. 5a–c. *Pseudorotalia gaimardii* (D'ORBIGNY) ×50
Fig. 6a, b. *Elphidium advenum* (CUSHMAN) ×60

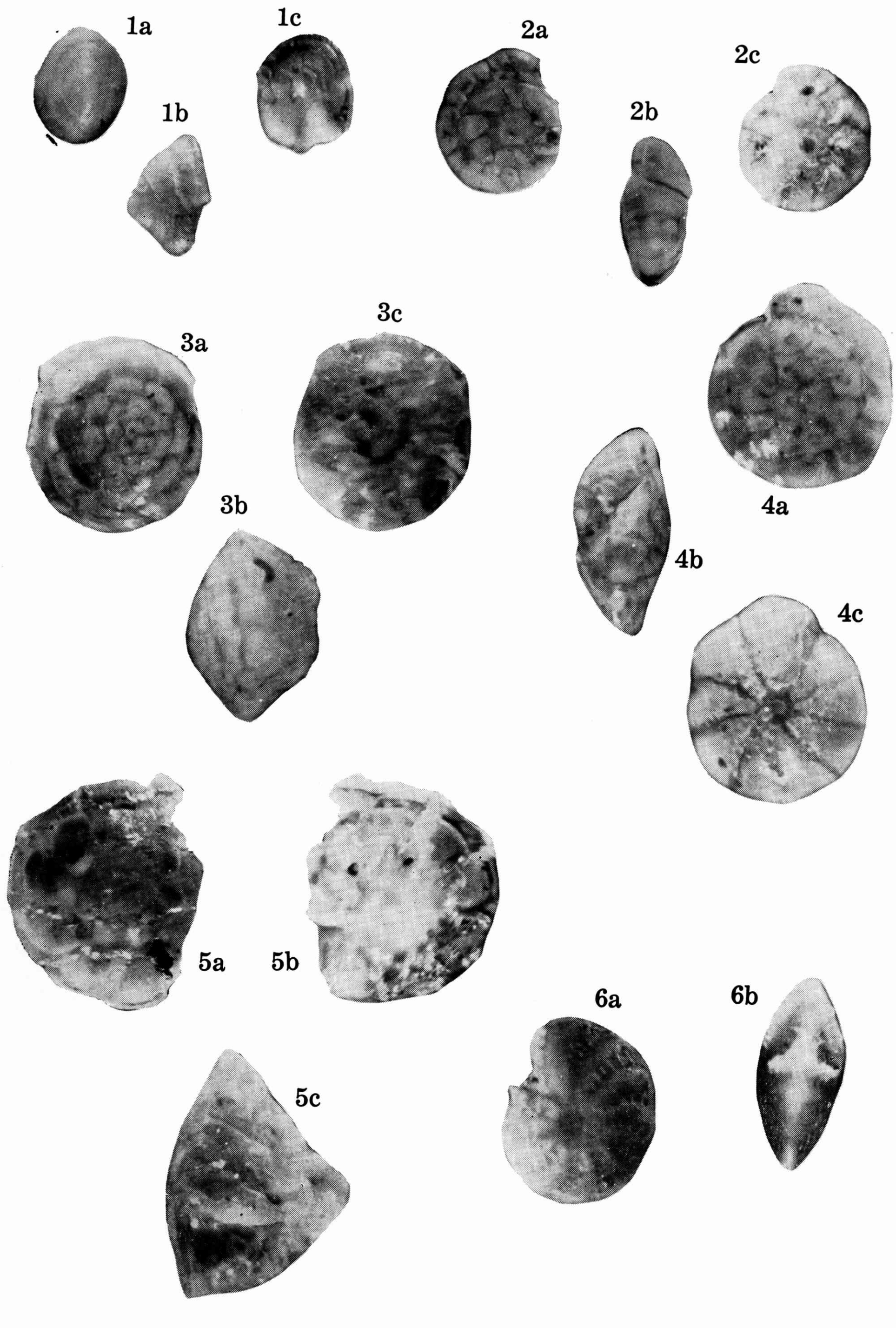

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Plate 30

Explanation of Plate 30.

Fig. 1a, b. *Elphidium crispum* (LINNÉ) ×60
Fig. 2a, b. *E. subarcticum* CUSHMAN ×100
Fig. 3a–c. *Eponides umbonatus* (REUSS) ×100
Fig. 4a–c. *Planulina wuellerstorfi* (SCHWAGER) ×100
Fig. 5a, b. *Hyalina balthica* (SCHRÖTER) ×100
Fig. 6a–c. *Cibicides aknerianus* (D'ORBIGNY) ×60
Fig. 7a–c. *C. haidingerii* (D'ORBIGNY) ×50
Fig. 8a–c. *C. lobatulus* (WARKER & JACOB) ×60
Fig. 9a–c. *C. reflugens* MONTFORT ×60

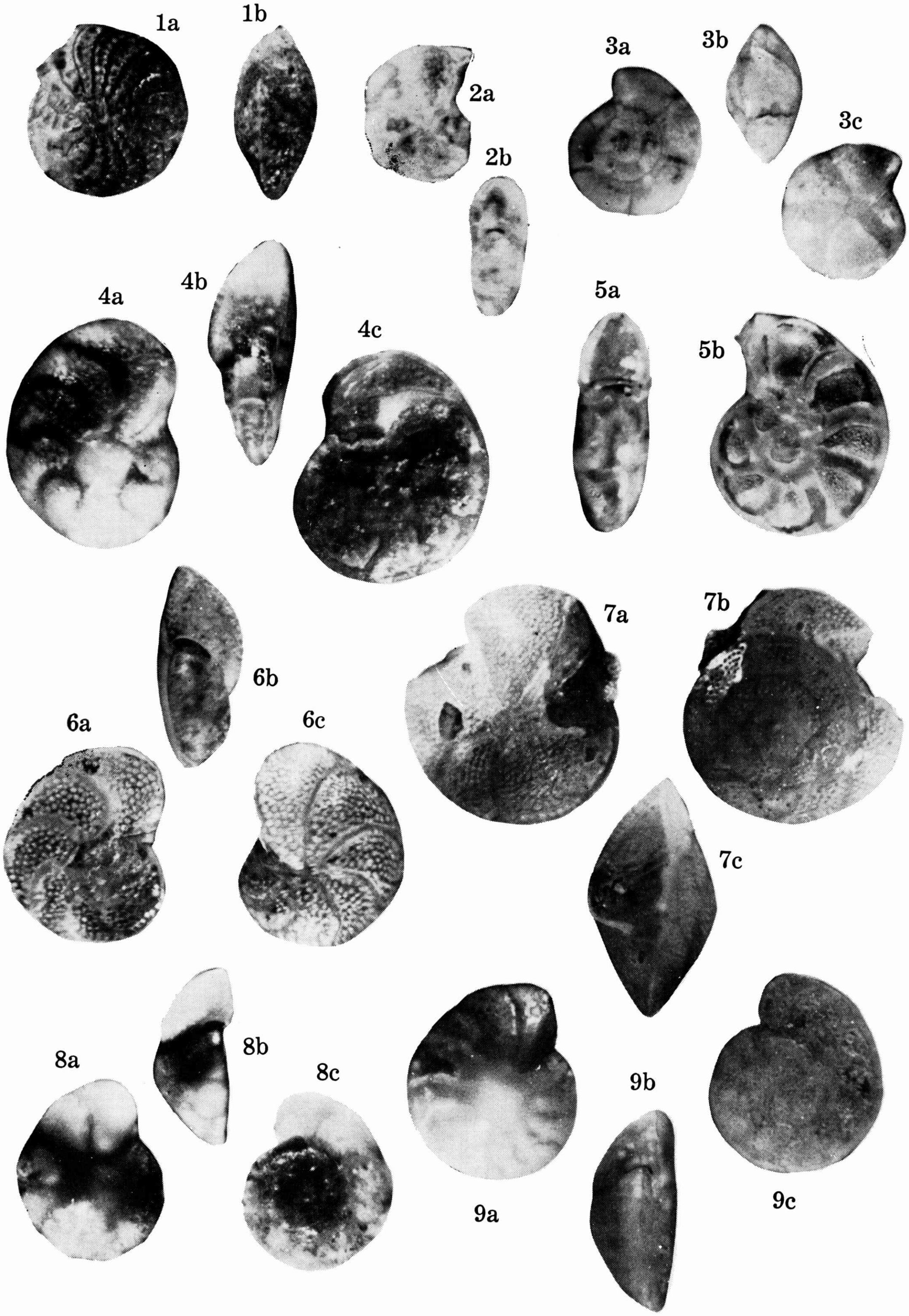
1a
1b
2a
2b
3a
3b
3c
4a
4b
4c
5a
5b
6a
6b
6c
7a
7b
7c
8a
8b
8c
9a
9b
9c

Plate 31

Explanation of Plate 31.

Fig. 1a, b.	*"Virgulina" rotundata* PARR ×100
Fig. 2.	*Loxostomum karrerianum* (BRADY) ×100
Fig. 3a, b.	*Cassidulina carinata* SILVESTRI ×120
Fig. 4.	*C. depressa* ASANO ×120
Fig. 5a, b.	*C. yabei* ASANO ×120
Fig. 6a, b.	*Globocassidulina subglobosa* (BRADY) ×120
Fig. 7a, b.	*Nonion grateloupi* (D'ORBIGNY) ×100
Fig. 8a, b.	*N. japonicum* ASANO ×60
Fig. 9a, b.	*N. scaphum* (FICHTEL and MOLL) ×100
Fig. 10a–c.	*Pseudononion japonicum* ASANO ×100

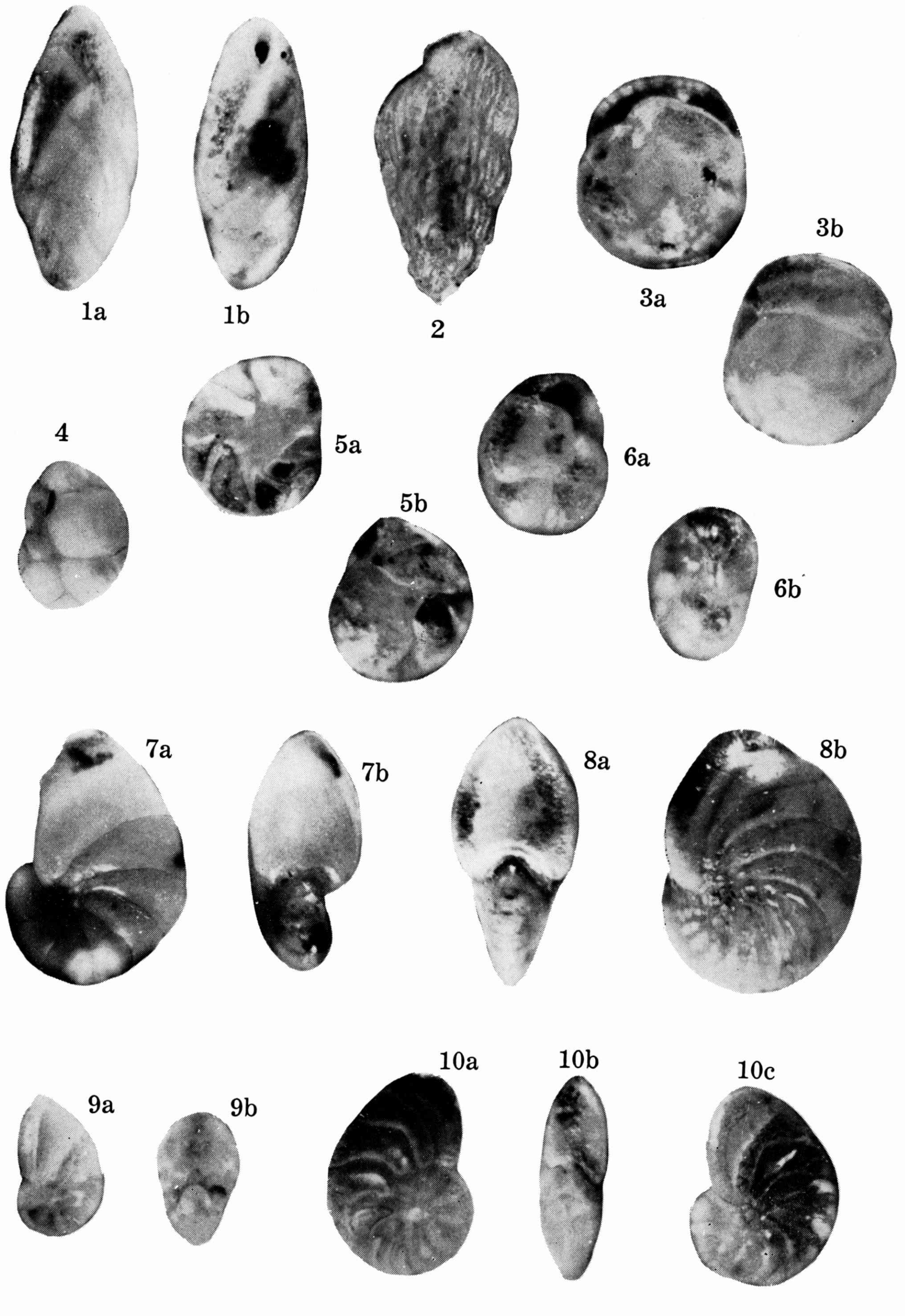

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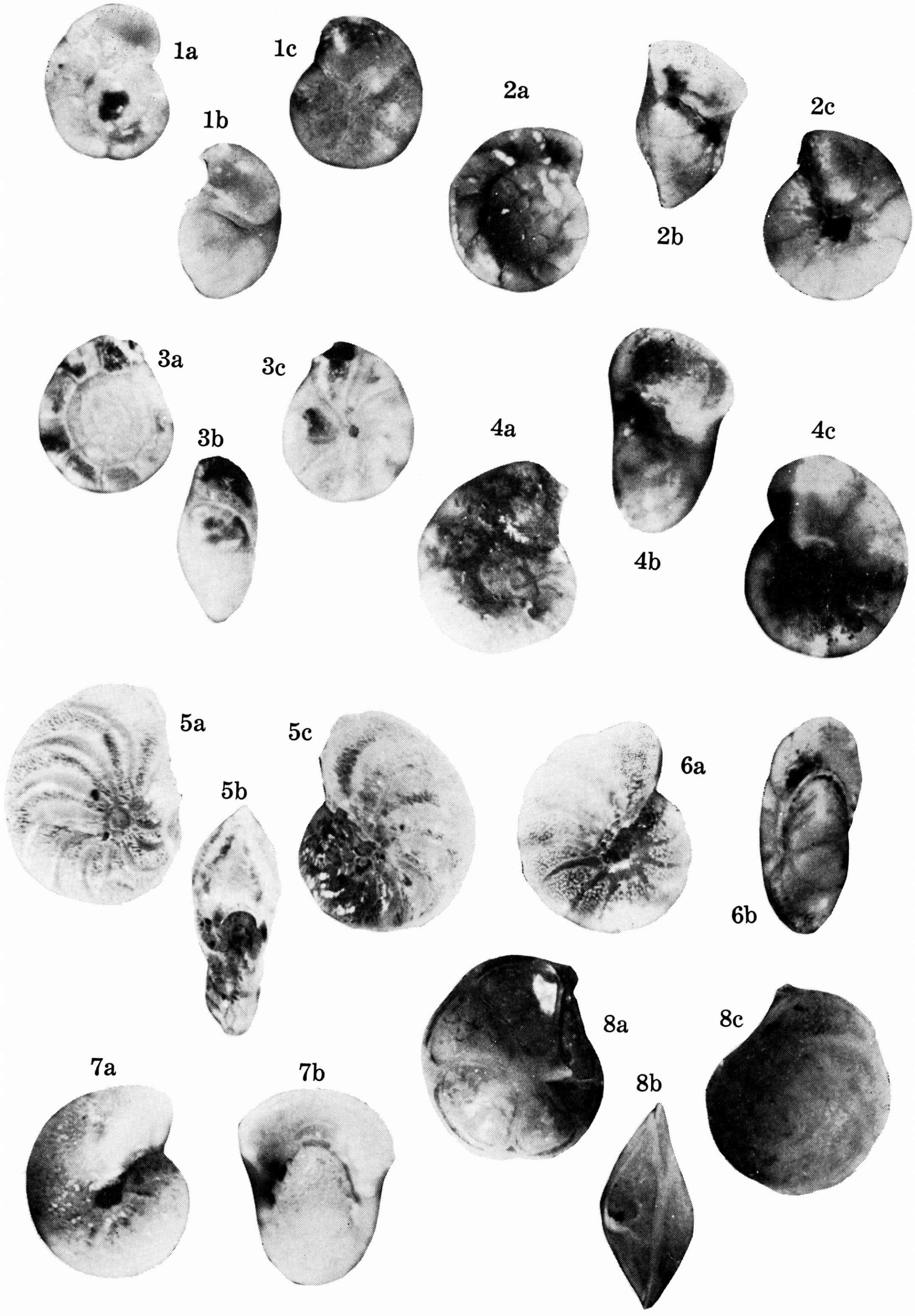
Plate 32

Explanation of Plate 32.

Fig. 1a–c. *Gyroidina nipponica* ISHIZAKI ×100
Fig. 2a–c. *G. orbicularis* D'ORBIGNY ×60
Fig. 3a–c. *G.* sp. A ×120
Fig. 4a–c. *Anomalina glabrata* CUSHMAN ×100
Fig. 5a–c. *Hanzawaia nipponica* ASANO ×60
Fig. 6a, b. *Melonis nikoberensis* (KUSHMAN) ×60
Fig. 7a, b. *M. pompilioides* (FICHTEL and MOLL) ×60
Fig. 8a–c. *Hoeglundina elegans* (D'ORBIGNY) ×60



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