Holocene foraminiferal fauna and sedimentary environment in the Shirone area, Echigo Plain, central Japan

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Abstract

Foraminiferal assemblages of a drilling core in the Shirone area, Echigo Plain, central Japan are analyzed, and the stratigraphical change of the Holocene sedimentary environment of this area is discussed on the basis of the change of lithological facies and the foraminiferal assemblages. The geologic profile of the core is divided into four sedimentary units, U-1 to U-Ⅳ in descending order. Moreover, U-Ⅲ is subdivided into SU-Ⅲ-1 and –2. U-Ⅱ, U-Ⅲ and U-Ⅳ contain foraminifers. Foraminiferal fauna is divided into four divisions, Foraminiferal Divisin (F.D.)-A to -D. F.D. -A, -B, -C and- D correspond to U-Ⅱ, SU-Ⅲ-1, SU-Ⅲ-2 and U-Ⅳ respectively. The F.D.-A consists of *Ammonia beccarii* Assemblage. The F.D.-B does mainly *Ammonia beccarii-Quinqueloculina akneriana* Assemblage. The F.D.-C does mainly *Ammonia beccarii- Elphidium etigoense* Assemblage. The F.D.-D does *Ammonia beccarii* Assemblage. Sedimentary environments have successively been changed oligohaline to mesohaline water of innermost bay in U-Ⅳ, polyhaline to mesohaline water of inner to outer bay in SU-Ⅲ-2, and oligohaline to mesohaline water of lagoon in SU-Ⅲ-1 to U-Ⅱ, from 10,000 to 6,000 years ago. The sea expansion in the Echigo Plain corresponded to the age of Holocene transgression. And it is noticeable that a lagoonal environment had been took the place of bay's one, or that a lagoonal environment appeared about 7,000 years ago. It may be caused by the formation of sand barrier situated in the coastal area of the Echigo Plain.

Key words: Assemblage, foraminifera, holocene, sedimentary environment.

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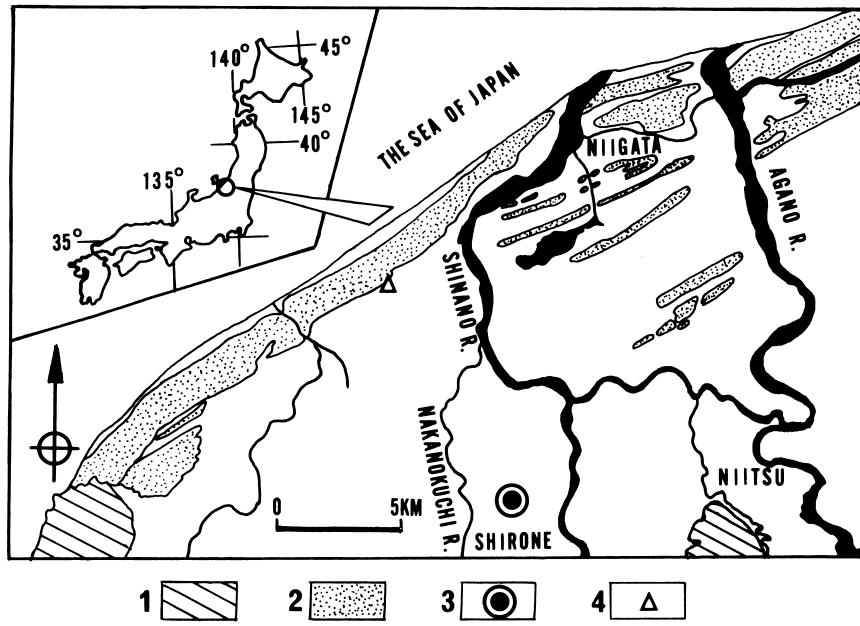

Fig.1. Location map of the Shirone 9-4 1. Mountain and hill, 2. Dune, 3. Location of the Shirone 9-4 core site, 4. Location of the Sakaiwa K-1 core site (Kobayashi et al., 1976) (Distribution of dunes is after Niigata Ancient Dune Reserch Group, 1974).

Introduction

The Echigo Plain is one of wide alluvial plains in the coastal area along the Sea of Japan. The maximum thickness of the latest Pleistocene and Holocene (Alluvium) in the Echigo Plain is more than 150m (Minato et al., 1967 ; Wada, 1972). The deposits yield rare marine fossils (Fukuda et al., 1966 ; Kobayashi et al., 1976 ; Niigata Diatom Research Group , 1976)

The Shirone area is situated on the inside of the Niigata dune along the sea coast (Fig. 1). Several stratigraphical and environmental studies have been carried out for the countermeasure of land subsidence (Hasegawa et al., 1967; Wada, 1972; Niigata Quaternary Research Group, 1972). Hasegawa et al. (1967) represented that thick fossiliferous clay beds were distributed 20 m to 30 m below the ground in the Shirone area. Wada (1972) suggested that these clay beds were formed under lagoonal environment which was caused by the Holocene transgression, so-called the Jomon transgression. In these reports, detailed analyses of fauna and sedimentary environment were not carried out.

The authors fortunately have a chance to study sedimentary facies and foraminifers of one

core which was drilled in the Shirone area. The core contains many molluscan fossils and microfossils such as foraminifers, ostracods and radiolarians. In this paper, the stratigraphical change of foraminiferal assemblages and Holocene sedimentary environments is discussed on the basis of the analysis of this core from the Shirone area.

Outline of geology

The alluvium in the Echigo Plain was stratigraphically divided into two formations, Shirone and Kurotori Formations by Aoki and Nakagawa (1980). Recently, the geologic section between Shirone and Niigata Cities and the ^{14}C data were reported by Yasui et al. (1998). The ages of Shirone and Kurotori Formations were dated from 20,000 to 4,500 y.B.P., and younger than 4,500 y.B.P. respectively.

The geologic section from Niigata to Shirone Cities around the studied area is shown in Fig. 2. The alluvium in the Shirone area ranges from 100 m to 125 m in thickness, and unconformably overlies the Upper Pleistocene buried terrace gravels and firmed peats.

The lower part of the Shirone Formation is composed of massive silts and alternating beds of sand and silt, which were deposited in fresh water environment, because these beds contain vivianites and plant fragments. The middle part of the Shirone Formation consists of soft marine clay facies which changes to fine sand facies toward the north. The upper part of the Shirone Formation is composed of alternating beds of sand and silt which were deposited in marine or brackish water environment. The Kurotori Formation is composed of alternating beds of medium or fine sand, silt and humus, and these beds indicate fluvial strata. It ranges from 10 m to 15 m in thickness.

The unconformity between Pleistocene and Holocene strata has not be seen yet in the Shirone area.

Material and method

The drilling site (Shirone 9-4) is in Negishi, Shirone City, Niigata Prefecture (N37° 47' 29", E139° 2' 2"). The site is located in a coastal plain between Shinano and Nakanokuchi Rivers in the northern part of the Echigo Plain (Figs. 1 and 2). The depth of the drilling hole is 70.0 m, and the altitude is 0.2 m below the sea level.

Samples for foraminiferal analysis are prepared by the following process. The upper half of one meter core was taken by split spoon sampler, and the lower half was by double core tube. Clayey and silty sediments were cut every 10 cm intervals. The weight of one wet sample taken by split spoon sampler is 10 g to 30 g, and the weight by double core tube is 70 g to 100 g. The analyzed samples were picked up all in 18.5 m to 35.9 m, and each 20 cm to 30 cm interval in 35.9 m to 63.9 m. The samples were washed by the use of a sieve of 75 μ m openings. The remained samples on the sieve were dried. Moreover, they were passed through a sieve of

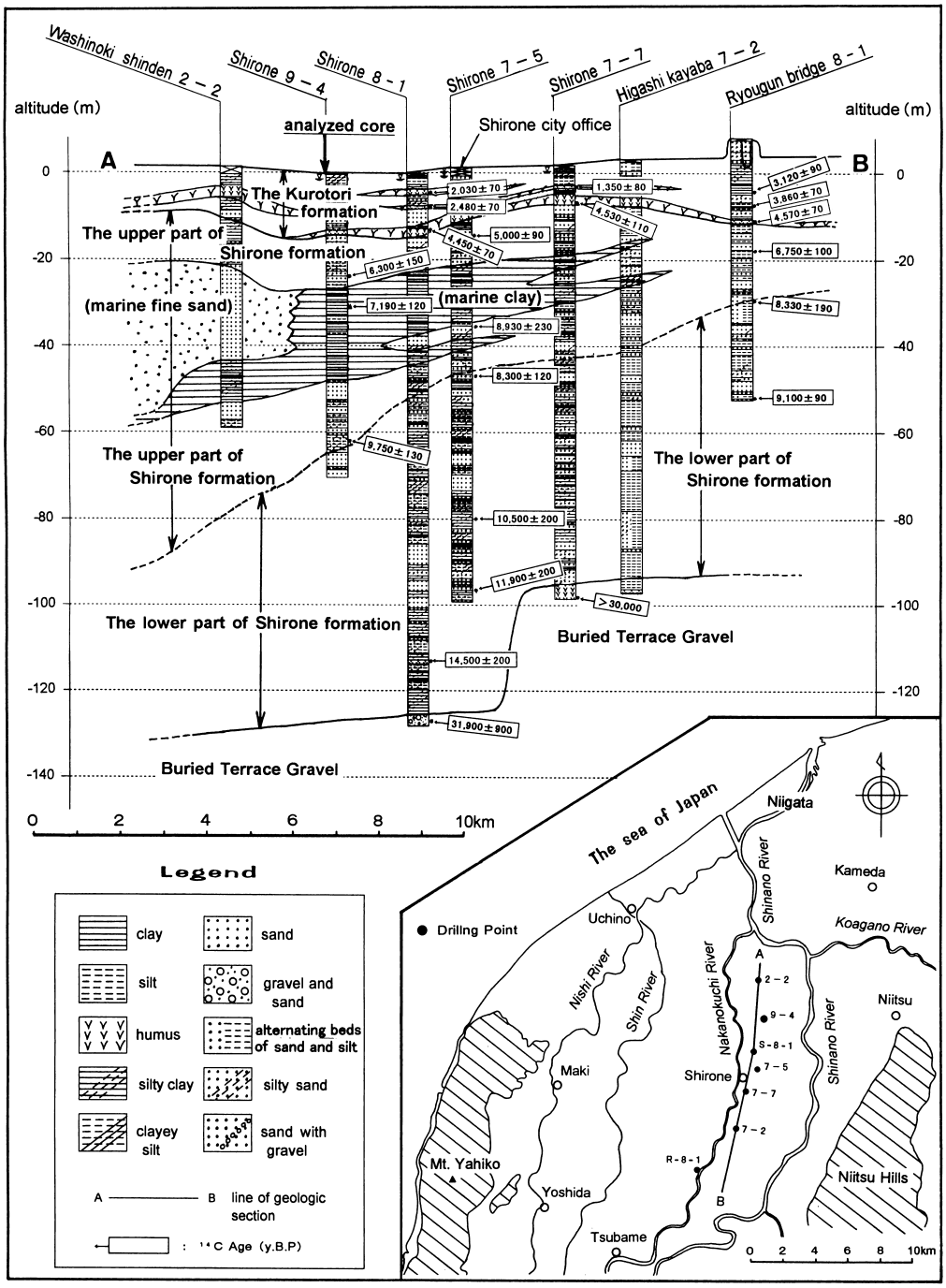

Fig. 2. The geologic section of Shirone area (modified from Yasui et al., 1998)

125 μ m openings. The passed samples were used for foraminiferal analysis. Most of samples were divided by a splitter to get 200 odd individuals, and all specimens were picked up from each sample.

Division of sedimentary unit

The profile of the core is divided into four sedimentary units, U- Ⅰ to U-Ⅳ from sedimentary facies in descending order (Fig. 3).

U- Ⅰ (0.7 m - 14.3 m) is composed of alternating beds of silt and very fine to fine sand, with two distinctive humus layers. Silt layers include abundant plant fragments.

U- Ⅱ (14.3 m - 25.9 m) is composed of very fine to fine sands , and fine alternating beds of silt and very fine sand. The uppermost part consists of pumiceous sands. Shells of *Potamocorbula amurensis* and *Corbicula japonica* are found between 18.0 m and 20.0 m below the ground.

U- Ⅲ (25.9 m - 47.7 m) is composed mainly of clays, and subdivided into two subunits by a slight difference of facies, namely SU- Ⅲ -1 and SU- Ⅲ -2. SU- Ⅲ -1 (25.9 m - 32.9 m) is composed of dark greenish gray massive silty clays with many small molluscan shells. SU- Ⅲ - 2 (32.9 m - 47.7 m) is composed of dark gray to black laminated silty clays and intercalated sandy silts in two layers which contain abundant plant fragments in 32.9 m to 34.2 m and 35.9 m to 37.4 m below the ground.

U-Ⅳ (47.7 m -70.0 m) is composed of alternating beds of silt and very fine to fine sand at 0.2 m to 1m intervals with several layers of medium sands. Silt layers include abundant plant fragments. Fine alternating beds of sand and silt at intervals of 0.2 cm to 1cm are intercalated at several horizons. Shells of *Corbicula japonica* are found at 63.0 m below the ground.

U- Ⅰ is corresponded to the Kurotori Formation and U- Ⅱ to Ⅳ are correlated with the Shirone Formation. The ^{14}C ages (Yasui et al., 1998) in Fig. 3 are dated in the Shirone 9-1 core which is located about 170 m away from the Shirone 9-4 core.

Characteristics of foraminiferal occurrence

The samples collected from 37 horizons of the Kurotori formation contain some radiolarians in several horizons, but no foraminifera. The occurrence of a few specimens of Thecamoebina (Testacea) is noticeable at 1.8 m to 1.9 m below the ground. The morphological feature of the family is similar to foraminifera. Thecamoebina is a fresh water species, but sometimes is found from shallow marine sediments which was deposited in marine bottoms under the influence of fresh water.

The samples collected from 142 horizons of the Shirone formation are analyzed, and 112 samples of them contain many fossils such as molluscs, foraminifers, radiolarians, ostracods and diatoms. The distributional chart of foraminifers in this formation is shown in Table 1. It

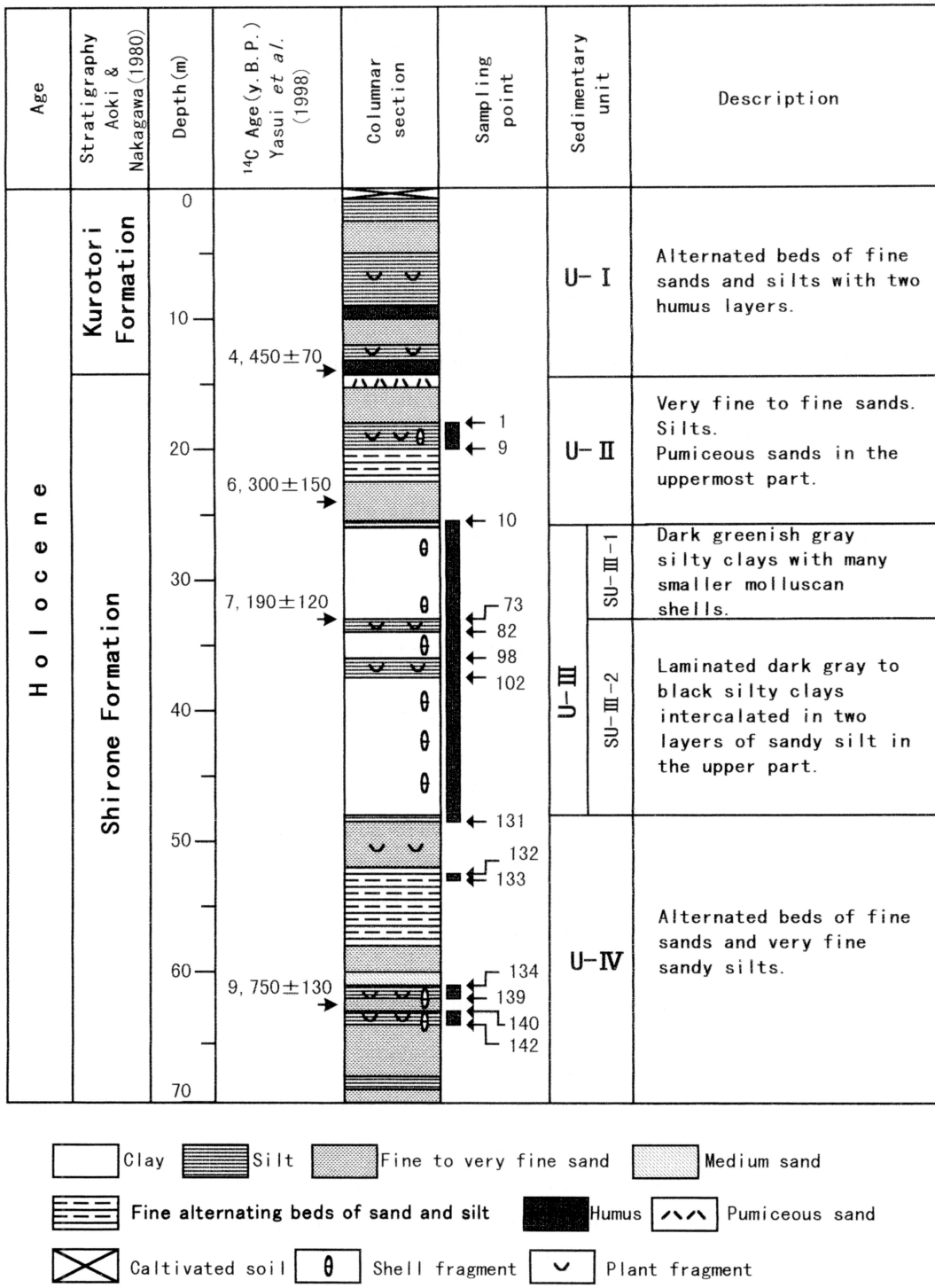

Fig. 3. The geological column of Shirone 9-4 core, and sampling points.

Table 1(1). Distributional chart of foraminifers in the Shirone formation

	Sample number	1	2	3	4	5	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	34	35	36	37	38	39
	Depth(m) / Species	18.50–18.60	18.60–18.70	18.70–18.80	18.90–19.00	19.50–19.60	19.60–19.70	25.50–25.60	25.60–25.70	25.70–25.80	25.80–25.90	25.90–26.00	26.10–26.20	26.20–26.30	26.30–26.40	26.40–26.50	26.50–26.60	26.60–26.70	26.70–26.80	26.80–26.90	26.90–27.00	27.20–27.30	27.40–27.50	27.50–27.60	27.60–27.70	27.70–27.80	27.80–27.90	27.90–28.00	28.10–28.20	28.20–28.30	28.40–28.50	28.50–28.60	28.60–28.70	28.70–28.80	28.80–28.90	28.90–29.00
	Planktonic foraminifera																																			
1	*Globigerina bulloides* d'Orbigny																																			
2	*G.* cf. *brady* Wisnet																																			
3	*G. falconensis* Blow																																			
4	*G. foliata* Bolli																																			
5	*G. pachiderma* (Ehrenberg)																																			
6	*G. quinqueloba* Natland																																			
7	*G.* cf. *woodi* Jenkins																																			
8	*G.* sp. A																																			
9	*G.* spp.																												1							
10	*Globigerinita glutinata* (Egger)																																			
11	*G.* spp.																																			
12	*Globigerinoides ruber* (d'Orbigny)																																			
13	*Globorotalia ungulata* Bermudez																																			
	Benthic calcareous foraminifera																																			
14	*Ammonia beccarii* (Linne)	10	1	9	11	301	103	126	192	273	347	155	14	161	4	20	1010	135	231	48	46	1		114	38	39	414	177	538	1	5	167	4	137	206	330
15	*A. beccarii* forma B						5		4	5								5	6							4		3	15				1	2		7
16	*A. beccarii* forma C								1																									1	2	
17	*A. beccarii* forma L								57	4		1							3															5	3
18	*A. inflata* (Seguenza)									2												1	1													
19	*A. japonica* Hada							5			3						15							4			1					4				
20	*A.* spp.												1																							
21	*Bolivina* spp.																																			
22	*Buccella frigida carida* Cushman & Uchio																																			
23	*Bulimina* spp.																																			
24	Buliminidae? gen. et sp. indet.																																			
25	*Bussella frigida* (Cushman)																																			
26	*B. inusitata* Andersen																																			
27	*Cassidulina* sp.																																			
28	*Cibicides ungerianus* (d'Orbigny)																																			
29	*Discopulvinulina* cf. *isabelleana* (d'Orbigny)																																			
30	*D.* sp.																																			
31	*Elphidium clavatum* Cushman																																			
32	*E. etigoense* Husezima & Maruhasi																																			
33	*E.* cf. *hanzawai* Asano																																			
34	*E. poeyanum* (d'Orbigny)																																			
35	*E. subarcticum* Cushman																																			
36	*E.* cf. *subgranulosum* Asano																																			
37	*E.* sp. A																																			
38	*E.* spp.	1				1																		1							1				

Table 1(2). Distributional chart of foraminifers in the Shirone formation (Continue)

39	*Epistominella tamana* (Kuwano)																																						
40	*E.* sp.																																						
41	*Eponides* cf. *procerus* (Brady)																																						
42	*E.* cf. *subornatus* (Cushuman)																																						
43	*Fissurina* cf. *semimarginata* (Reuss)																																						
44	*Glomospirella* sp.																																						
45	*Guttulina* sp.																																						
46	*Hauerina fragilissima* (Brady)																																						
47	*Melonis* sp.																																						
48	*Miliolinella* spp.								1									4																				1		
49	*Murraynella globosa* Millett																																						
50	*Nonion* spp.																																						
51	*Oolina* sp.																																						
52	*Pseudononion grateloupi* (d'Orbigny)																																						
53	*P.* *japonica* Asano																																						
54	*Quinqueloculina akneriana* d'Orbigny								6																				1		17			2	1		14		
55	*Q.* *elongata* (Natland)									4																			1										
56	*Q.* cf. *hasimotoi* Asano																																						
57	*Q.* *seminula* (Linnaeus)											1																			8								
58	*Q.* sp. A																																						
59	*Q.* spp.								2									15								10			1		3			4			3		
60	*Reussella atlantica* Cushman																																						
61	*R.* sp.																																						
62	*Robulus sasai* Asano																														1								
63	*Spiroloculina* cf. *communis* Cushman & Todd																																						
64	*S.* cf. *corrugata* Cushman & Todd																																						
65	*Triloculina trigonula* (Lamarck)																																						
66	*T.* sp.																																						
67	*Uvigerina akitaensis* Asano																																						
Benthic agglutinated foraminifera																																							
68	*Haplophragmoides* sp. A																																						
69	*H.* spp.																																						
70	*Sigmoilina* sp. A																																						
71	*Trochammina* cf. *pygmaea* Hoglund																																						
72	*T.* spp.																																						
Total number		11	1	9	11	302	108	131	263	288	350	157	15	161	4	20	1044	140	240	48	46	2	1	129	38	43	418	180	583	1	5	178	6	140	231	340		
Individual number(/100g)		20	6	13	21	310	124	137	383	331	350	206	90	603	32	69	3492	150	583	51	54	31	11	133	97	109	496	329	2370	6	18	1359	36	312	321	418		
Radiolaria									○	○	○	○	○	○	○	○		○	○	○	○		○	○	○	○	○	○	○	○			○	○	○	○			
Ostracod										○		○		○				○	○				○		○	○	○	○	○		○		○	○		○			

Table 1(3). Distributional chart of foraminifers in the Shirone formation (Continue)

	40	42	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	61	62	63	64	65	67	69	70	71	72	84	85	86	87	88	89	90	92	93	94	95	96	97
	29.10–29.20	29.30–29.40	29.50–29.60	29.60–29.70	29.70–29.80	29.80–29.90	29.90–30.00	30.15–30.25	30.35–30.45	30.50–30.60	30.60–30.70	30.70–30.80	30.80–30.90	30.90–31.00	31.10–31.20	31.20–31.30	31.30–31.40	31.50–31.60	31.60–31.70	31.70–31.80	31.80–31.90	31.90–32.00	32.20–32.30	32.40–32.50	32.50–32.60	32.70–32.80	32.80–32.90	34.20–34.30	34.30–34.40	34.50–34.60	34.60–34.70	34.70–34.80	34.80–34.90	34.90–35.00	35.25–35.35	35.35–35.45	35.50–35.60	35.60–35.70	35.70–35.80	35.80–35.90
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14	32	1	736	271	637	286	145	40	9	480	74	5			1	2	92	19	213	60	84	41	1	5	1	14	8	5	8	44	73	21	29	1	6	67	65	200	39	1
15	2	1		10	18	3		6		17			5	12			6	2	8	5	5	3		3		1		1		2	3					4	3		6	
16										5	1																			1									
17	3			7	49	11				3									33	4	24			1				1	1	20		63		2	7	5	37		
18				2															3	1		1								2					3			1	
19			10							9							2			3	6																		
20					13					13		1									7							1				8	6		2		5	
21						1																		1													19		
22																												1	2	3	8	6	15			19	6	22	8	
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34																																					1			
35																			1									2	2	39	1	3	1			2				
36																					1									9									99	
37																			2																					
38			6																1											52			7			1	3			

Table 1(4). Distributional chart of foraminifers in the Shirone formation (Continue)

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54	2		54	5	29	16	15	1		14	2								16	8	37			5		2		1	1	40	2		5	1	1	16	3	30		
55				4	4	4															26																	5		
56																																								
57				16	36	18				1									2	1		7					1			8							1	3	3	
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	39	2	818	315	792	339	160	47	9	554	82	6	5	17	1	2	100	30	294	84	243	58	1	15	1	17	9	19	16	221	131	44	161	2	9	146	100	375	161	1
	179	8	5346	1324	3718	6780	2963	475	69	584	70	9	8	29	9	10	352	84	838	223	504	112	11	62	16	36	24	57	176	342	224	66	846	42	46	1947	138	2799	240	10
	○	○		○	○	○				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○		○	○			○	○	○	○								○	○	○	○		○		○	○	○	○	○	○	○	○	○		○	○		○	

Table 1(5). Distributional chart of foraminifers in the Shirone formation (Continue)

		98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	134	136	137	139	142
		36.20–36.30	36.50–36.60	36.80–36.90	36.90–37.00	37.40–37.50	37.50–37.60	37.60–37.70	37.70–37.80	37.80–37.90	38.20–38.30	38.50–38.60	38.80–38.90	39.40–39.50	39.90–40.00	40.40–40.50	40.70–40.80	41.20–41.30	41.50–41.60	41.80–41.90	42.20–42.30	42.50–42.60	42.80–42.90	43.20–43.30	43.50–43.60	43.80–43.90	44.20–44.30	44.50–44.60	44.80–44.90	45.20–45.30	45.90–46.00	46.20–46.30	46.60–46.70	60.60–60.70	61.10–61.20	61.30–61.40	61.70–61.80	63.80–63.90
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14		58	110	50	1	16	31	108	8	38	35	28	414	222	64	108	24	35	100	45	33	66	2	74	109	71		16	5		87	1	80	11	2	16	1	
15			2										2		1																								
16																									6	4												
17		6	12	6				5			1	3	3		4			4	3	1		2		2		8					2							
18			5	1				6	3	10	9	3	9	1	5			1	1			2		13	26													
19			15			6	4	4		12	3		2		3	3				3				2	12													
20						2		3	2					5	3								1	9	5			3	1	1									
21															2																								
22			7				6	12	1	6	2	7	70	4	7			1	12	7		36		3	60	19												
23																																						
24																																						
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32			24	15		13	35	490	130	32	33		165	4	53	2		2	26	113	1	64		88	80	14		7	1			1						
33																																						
34				7	1			7	6							1																		4					
35			1	13				10		17		8	5			3		1	13	51	1	26		24	60	8		5										
36			12	3			6	4		2			3	2	9	3		3	6	13	1	18		1	9	14		7			1				1			1
37			6	6	1														21					13													
38																																						

Table 1(6). Distributional chart of foraminifers in the Shirone formation (Continue)

39			1										1																												
40																											1														
41		1																																							
42							1						3																												
43							1																																		
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52		19	7		3													2																						
53		2													30																										
54		9	1		2	1	19			6		54	3		36		3	22	70		43		30	32			1				12								
55		2									1	4		5	4			8	3				1	12	2		1									13			
56									1																															
57		2							12		6		1		28	4	1	9	6					51	32		1				152								
58												2																				2								
59		3	3		1	1	7	1	3	5	1	1	1	11	5		3	10	10		17	1	10		19		1						1						
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	64	245	124	4	47	84	678	158	142	94	64	737	252	207	195	30	55	255	327	37	277	4	285	460	209	1	42	7	2	256	7	82	15	3	29	1	1			
	257	4712	192	108	1516	125	705	237	180	324	102	1971	451	4225	214	46	104	659	424	97	287	4	1623	1029	239	4	54	7	14	1391	16	66	20	15	94	7	77			
	○	○		○	○	○	○		○					○		○	○				○	○			○	○							○	○		○	○			
		○	○		○	○	○	○	○	○	○	○	○	○	○	○		○			○		○	○	○	○	○			○	○								

also shows the individual number of foraminifers in each dry 100g material with the occurrence of radiolarians and ostracods.

34 genera and 58 species are identified and they are composed of 11 species of planktons and 47 of benthos. Individual number, species number and frequency of several distinct species are shown in Fig. 4. The most of fauna is composed of benthic calcareous species, while planktonic and agglutinated species are rare. Individual number of a 100g material is diversified from 4 to 6,780 specimens and is largely fluctuating between 25.5 m and 35.8 m below the ground. Planktonic species occur 2.4 % to 5.1 % and 0.6 % to 3.8 %, at 31.8 m to 32.0 m (SU-Ⅲ-1) and 34.3 m to 43.3 m (SU-Ⅲ-2) below the ground respectively.

Foraminiferal assemblage

Five benthic foraminiferal assemblages are discriminated, namely *Ammonia beccarii*, *Ammonia beccarii - Quinqueloculina akneriana* and *Ammonia beccarii - Haplophragmoides* spp., and *Ammonia beccarii - Elphidium etigoense* and *Elphidium etigoense - Trochammina* cf. *pygmaea* Assemblages. The three former assemblages are characterized by the combination of *Ammonia, Quinqueloculina* and *Haplophragmoides*. The two latter assemblages are by the combination of *Ammonia*, *Elphidium* and *Trochammina*.

In this chapter, the species composition and environment of each assemblage are described as the following. Distribution data of living foraminifers in an inner bay (Hada, 1939 ; Ishiwada, 1958 ; Matoba, 1970 ; Inoue, 1980 ; Kosugi et al., 1991; Nomura and Seto,1992) and fossil assemblages in Japanese Neogene to Quaternary strata (Chiji, 1984 ; Inoue, 1989 ; Matoba, 1990) are mainly referred in order to determine environments of several assemblages.

(1) *Ammonia beccarii* Assemblage (Ab As.) : *Ammonia beccarii* occupies about 100 %. Some subordinate species over 2 % to 3 % is *Quinqueloculina* spp.. This assemblage is characterized by *Ammonia beccarii* as an indicator of innermost bay, and indicates oligohaline to mesohaline water environment of innermost bay.

(2) *Ammonia beccarii - Quinqueloculina akneriana* Assemblage (A-Q As.) : *Ammonia beccarii* is abundant and occupies about 90 %, accompanying commonly with 5 % to 10 % *Quinqueloculina* spp. , *Q. akneriana* , *Q. seminula* and *Q. elongata*. This assemblage contains *Quinqueloculina* spp. as an indicator of inner bay. It shows mesohaline water environment of inner bay.

(3) *Ammonia beccarii - Haplophragmoides* spp. Assemblage (A-H As.) : This assemblage is composed of the same specific composition to the A-Q As., but characteristically including 2 % to 30 % *Haplophragmoides* spp. and *Trochammina* spp.. They are agglutinated genera of innermost bay. Therefore, this assemblage indicates oligohaline to mesohaline water environment of inner to innermost bay.

(4) *Ammonia beccarii - Elphidium etigoense* Assemblage (A-E As.) : This assemblage is composed of 25 % to 80 % *Ammonia beccarii*, 10 % to 50 % *Elphidium*, such as *E. etigoense*,

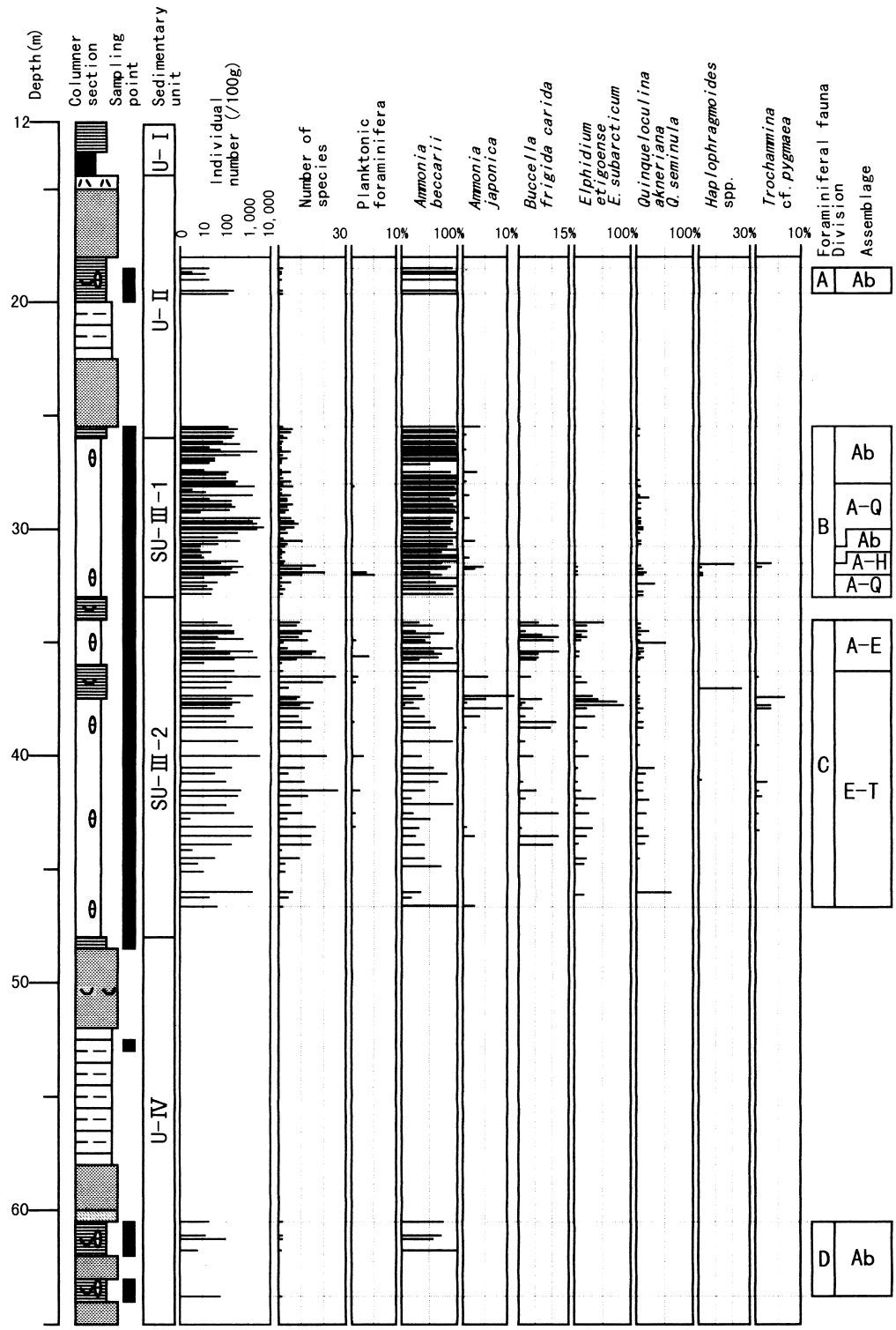

Fig. 4. Stratigraphic distribution of individual number, number of species and frequency of some distinctive species. Captions of columner section are explained in Fig. 2. Assemblage, Ab: *Ammonia beccarii*, A-Q: *Ammonia beccarii- Quinqueloculina akneriana*, A-H: *Ammonia beccarii- Haplophragmoides* spp., A-E: *Ammonia beccarii- Elphidium etigoense*, E-T: *Elphidium etigoense- Trochammina* cf. *pygmaea*.

E. subarcticum and *E.* cf. *subgranulosum*. In some samples, *Elphidium* is abundant, occupying 61 %. *Buccella fridiga carida, Quinqueloculina akneriana* and *Q. seminula* are accompanied. This assemblage contains *Elphidium* as an indicator of inner bay, and *Buccella frigida carida*, indicating polyhaline water of inner to outer bay. Therefore, this assemblage indicates polyhaline water environment of inner to outer bay.

(5) *Elphidium etigoense - Trochammina* cf. *pygmaea* Assemblage (E-T As.) : The specific composition of this assemblage is similar to the A-E As., but including 1 % to 7 % *Trochammina* cf. *pygmaea*. This assemblage indicates mesohaline to polyhaline water environment of inner to outer bay.

The stratigraphical change of foraminiferal fauna

On the basis of above-mentioned assemblages , the change of foraminiferal fauna in the Shirone 9-4 core is mainly divided into four divisions, Foraminiferal Division-A, -B,-C and -D in descending order (Fig. 4).

(1) Foraminiferal Division A (18.5 m to 19.7 m, sample nos. 1 to 6) is composed of Ab As.. It corresponds to a part of the U-Ⅱ. This division indicates oligohaline to mesohaline water environment of innermost bay by Ab As..

(2) Foraminiferal Division B (25.5 m to 32.9 m, sample nos. 10 to 72) is composed of Ab As. in 25.5 m to 28.0 m and 30.7 m to 31.5 m, A-Q As. in 28.0 m to 30.7 m and 32.0 m to 32.9 m, and A-H As. in 31.5 m to 32.0 m. Planktonic species such as *Globigerinoides ruber* are occurred in 31.5 m to 32.0 m. This division corresponds to SU-Ⅲ-1. In this division, *Ammonia* and *Quinqueloculina* is dominated, indicating oligohaline to mesohaline water environment of innermost to inner bay. But, Ab As. and A-Q As. are occurred repeatedly. Therefore, the fluctuation of salinity may have been larger. The occurrence of planctonic species also suggests that warm surface water flowed temporarily.

(3) Foraminiferal Division C (34.2 m to 46.7 m, sample nos. 84 to 129) is composed of A-E As. in 34.2 m to 36.3 m, and E-T As. in 36.3 m to 46.7 m respectively. Planktonic species, *Globigerinoides ruber* and *Globigerina* cf. *brady* yield at several horizons. This division corresponds to SU-Ⅲ-2. The assemblages indicate polyhaline to mesohaline water of inner to outer bay. The occurrence of planktonic species suggests that warm surface water flowed sporadically.

(4) Foraminiferal Division D (60.6 m to 63.9 m, sample nos. 134 to 142) is composed of Ab As.. It corresponds to a part of the U-Ⅳ. Ab As. indicates oligohaline to mesohaline water environment of innermost bay.

Sedimentary environment

The foraminiferal fauna of the Shirone 9-4 core is characterized by species whose environment indicated oligohaline to polyhaline brackish water. On the basis of sedimentary facies and foraminiferal assemblages, the environmental change of strata is inferred in ascending order as follows (Fig. 5).

(1) Unit Ⅳ (10,000 to 8,000 years ago)

U-Ⅳ which consists of alternating beds of silt and sand yields foraminifers from silty layers with *Corbicula japonica*, of brackish water mollusca, and correspond to Foraminiferal Division D which is characterized by Ab As.. It is probable that this unit was mainly deposited under brackish, oligohaline to mesohaline, water environment.

(2) Unit Ⅲ

U-Ⅲ is subdivided into two subunits, SU-Ⅲ-2 and SU-Ⅲ-1 in ascending order.

① Subunit-Ⅲ-2 (8,000 to 7,000 years ago)

This subdivision consists of dark gray to black laminated silty clays, and corresponds to Foraminiferal Division C which is characterized by A-E and E-T Ass.. They indicate polyhaline to mesohaline water of inner to outer bay. Therefore, this subunit was deposited under polyhaline to mesohaline water environment. And the occurrence of *Globigerinoides ruber* and *Globigerina* cf. *brady* in several horizons may indicate the flowing of warm water in the surface of sea into an inlet or a bay sporadically.

② Subunit-Ⅲ-1 (7,000 to 6,000 years ago)

This subdivision consists of dark greenish gray massive or laminated silty clays with many small molluscan shells, and corresponds to Foraminiferal Division B which is characterized by Ab, A-Q and A-H Ass.. These assemblages are characterized by *Ammonia* and *Quinqueloculina* , indicate oligohaline to mesohaline water of inner to innermost bay. It is noticeable that the main faunal change took place at the horizon between SU-Ⅲ-1 and SU-Ⅲ-2 . In SU-Ⅲ-1, polyhaline to mesohaline water elements such as *Elphidium* and *Buccella* were very rare. The fluctuation of individual number in SU-Ⅲ-1 was larger than in SU-Ⅲ-2. As mentioned after, the paleogeographical feature was inferred to be a lagoon rather than an embayment. The occurrence of *Globigerinoides ruber* suggests that warm water in the surface of sea flowed into again temporarily.

(3) Unit Ⅱ (6,000 to 5,000 years ago)

U-Ⅱ consists of alternating beds of silt and sand. Foraminifers occur from silty layers with brackish water molluscs such as *Corbicula japonica* and *Potamocorbula amurensis*. U-Ⅱ corresponds to Foraminiferal Division A which is characterized by Ab As.. It is probable that this unit was mainly deposited under the environment of brackish, oligohaline to mesohaline, water environment.

(4) Unit Ⅰ (younger than 4,500 years ago)

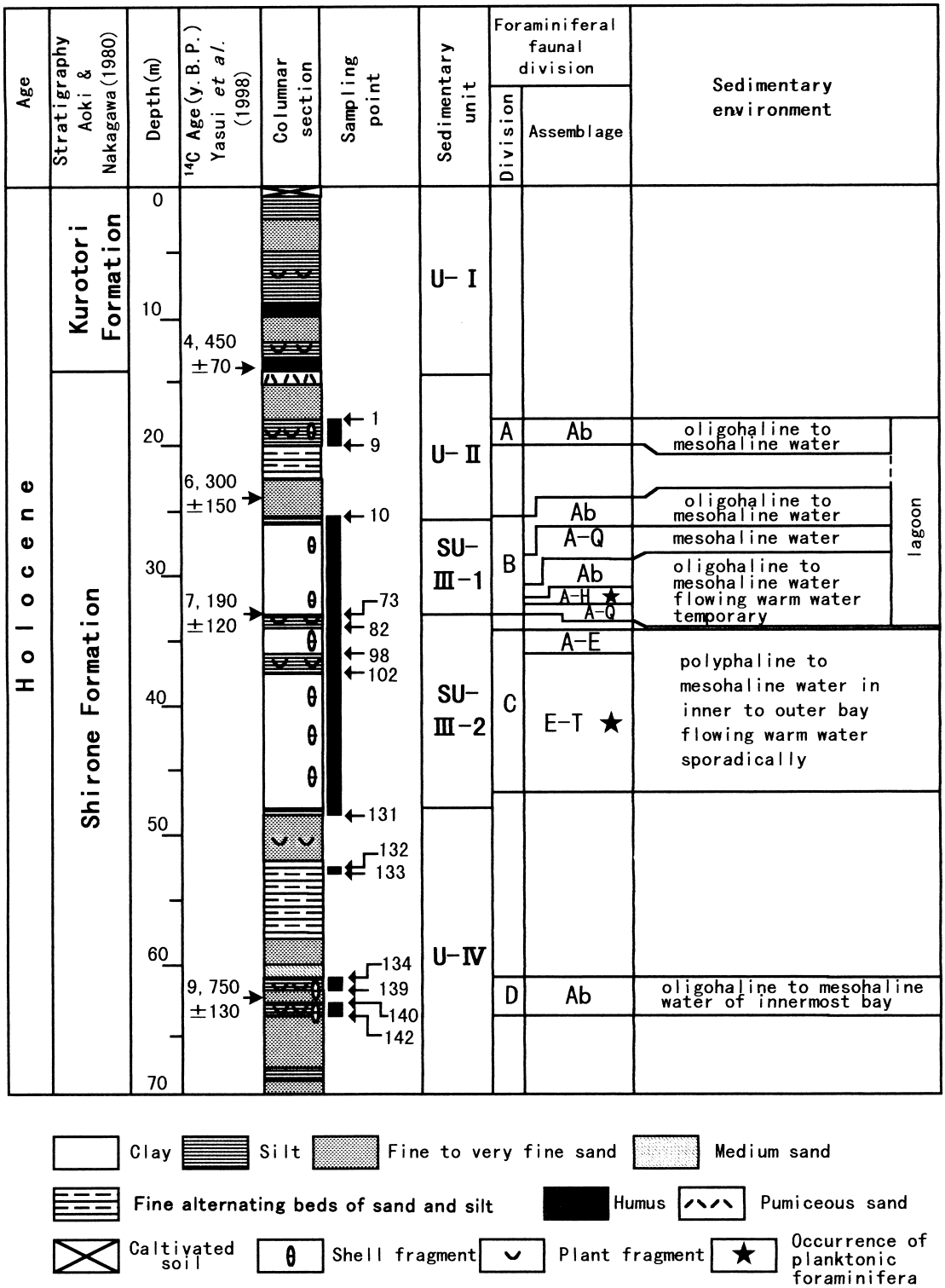

Fig. 5. Change of inferred sedimentary environment

U- Ⅰ consists of alternating beds of silt and sand with humus layers. Foraminifers are absent, indicating that this unit may have been mainly formed under fresh water condition.

Holocene transgression of the Echigo Plain

Foraminiferal assemblages have significantly changed in composition between SU-Ⅲ-2 and SU-Ⅲ-1 . The fluctuation of individual number in SU-Ⅲ-1 was larger than in SU-Ⅲ-2. Moreover, the color of sediments changs from dark greenish gray to black colors upwards. It indicates that the marine environment was changed about 7,000 years ago. There is a large possibility that a lagoonal environment with a sand barrier in the northern area appeared instead of paleo-bay at that time. The sand body consists of well compacted fine sands (N value $\geqq$50) and was buried under Niigata City (Fig. 2). It may be related with the appearance of lagoonal environment in the Shirone area.

As a result, it is inferred that the sedimentary environment in the Shirone area was changed from innermost bay with oligohaline to mesohaline water (U-Ⅳ) and with polyhaline to mesohaline water (SU-Ⅲ-2), to a lagoon with oligohaline to mesohaline water (SU-Ⅲ-1) and again with oligohaline to mesohaline water (U-Ⅱ) upwards. Considering the ^{14}C data (Yasui et al., 1998) of U-Ⅱ to U-Ⅳ, this sea expansion was caused by Holocene transgression.

The sedimentary environment of thick clayey sediments in the Shirone area has been considered to be a brackish lagoon on the basis of sedimentary facies and some marine diatoms (Wada, 1972 ; Niigata Quaternary Research Group, 1972). They argued that the absence of distinctive marine fauna and flora in the Holocene transgression age was caused to be closed by sand barriers or dunes existed in a bay mouth. But, the occurrence of polyhaline water fauna in SU-Ⅲ-2 suggests that the marine condition had been spread temporalily in the Shirone area, and the appearance of lagoonal environment may be took place about 7,000 years ago.

Kobayashi et al. (1976) analyzed the Sakaiwa K-1 core (Fig. 1) which was drilled in the coastal area apart from 10 km northwest of the Shirone 9-4 core. The clayey bed of 105 m to 114 m below the ground, dated 8,020$\pm$115 y.B.P., contains abundant *Ammonia beccarii*. The silty bed of 30.5 m to 83.1 m is also characterized by the predomination of *Ammonia japonica* and *Pseudorotalia gaimardii* , with *Elphidium subincertum*, *Buccella frigida* and *Nonion manpukujiense*. Some planktonic species were detected from the silty bed. Therefore, outer bay or coastal environment was estimated by them. It is considered that the silty bed of 30.5 m to 83.1 m below the ground of the Sakaiwa K-1 core corresponds to that of Unit Ⅲ at the Shirone 9-4 core, which is corresponded to about 8,000 to 6,500 years ago. At that time, the site of Sakaiwa K-1 core was coastal marine, probably outside of the sand body.

Conclusion

The findings of this study support the following conclusions:

(1) The Shirone area of the Echigo Plain is underlain by marine strata in 18 m to 65 m below the ground, which contained many foraminifers. By the ^{14}C data of this strata, the marine deposits were formed by the Holocene transgression.

(2) Poor evidence of marine condition has been shown in the Shirone area, inside of the Echigo Plain by several previous studies. But, by the analysis in detail, polyhaline water foraminiferal assemblage is found in 35 m to 48 m below the ground. This suggests that the distinctive marine condition had been spread at first in the Shirone area at 7,000 to 8,000 years ago.

(3) The embaymental environment had been situated at the first stage of the Holocene transgression. The appearance of lagoonal environment with a sand barrier may be took place about 7,000 years ago. In the lagoonal condition, the fluctuation of salinity by influence of sea water or fresh water was larger than in embaymental one.

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Explanation of Plates

Plate 1

1a,b: *Ammonia beccarii* (Linne)
2a,b: *Ammonia beccarii* forma B
3a,b: *Ammonia beccarii* forma L
4a,b: *Ammonia beccarii* forma C
5a,b,c: *Quinqueloculina akneriana* d'Orbigny
6: *Quinqueloculina elongata* (Natland)
7: *Epistominella tamana* (Kuwano)
8: *Quinqueloculina* cf. *hasimotoi* Asano
9a,b: *Quinqueloculina* sp. A
10: *Spiroloculina* cf. *corrugata* Cushman & Todd
11: *Triloculina trigonula* (Lamarck)
12: *Miliolinella* sp.
13: *Buccella frigida carida* Cushman & Uchio

Plate 2

14a,b: *Elphidium* cf. *subgranulosum* Asano
15a.b: *Elphidium etigoense* Husezima & Maruhasi
16: *Pseudononion grateloupi* (d'Orbigny)
17a,b: *Elphidium clavatum* Cushman
18: *Elphidium* cf. *hanzawai* Asano
19: *Bolivina* sp.
20: *Sigmoilina* sp. A
21a,b,c: Buliminidae? gen. et sp. indet.
22: *Haplophragmoides* sp. A
23a,b: *Reussella atlantica* Cushman
24a,b: *Trochammina* cf. *pygmaea* Hoglund
25a,b: *Globigerina* cf. *brady* Wisnet
26: *Globigerina pachiderma* (Ehrenberg)
27a,b: *Globigerinoides ruber* (d'Orbigny)
28: *Globigerina bulloides* d'Orbigny
29: *Globorotalia ungulata* Bermudez

Plate 1

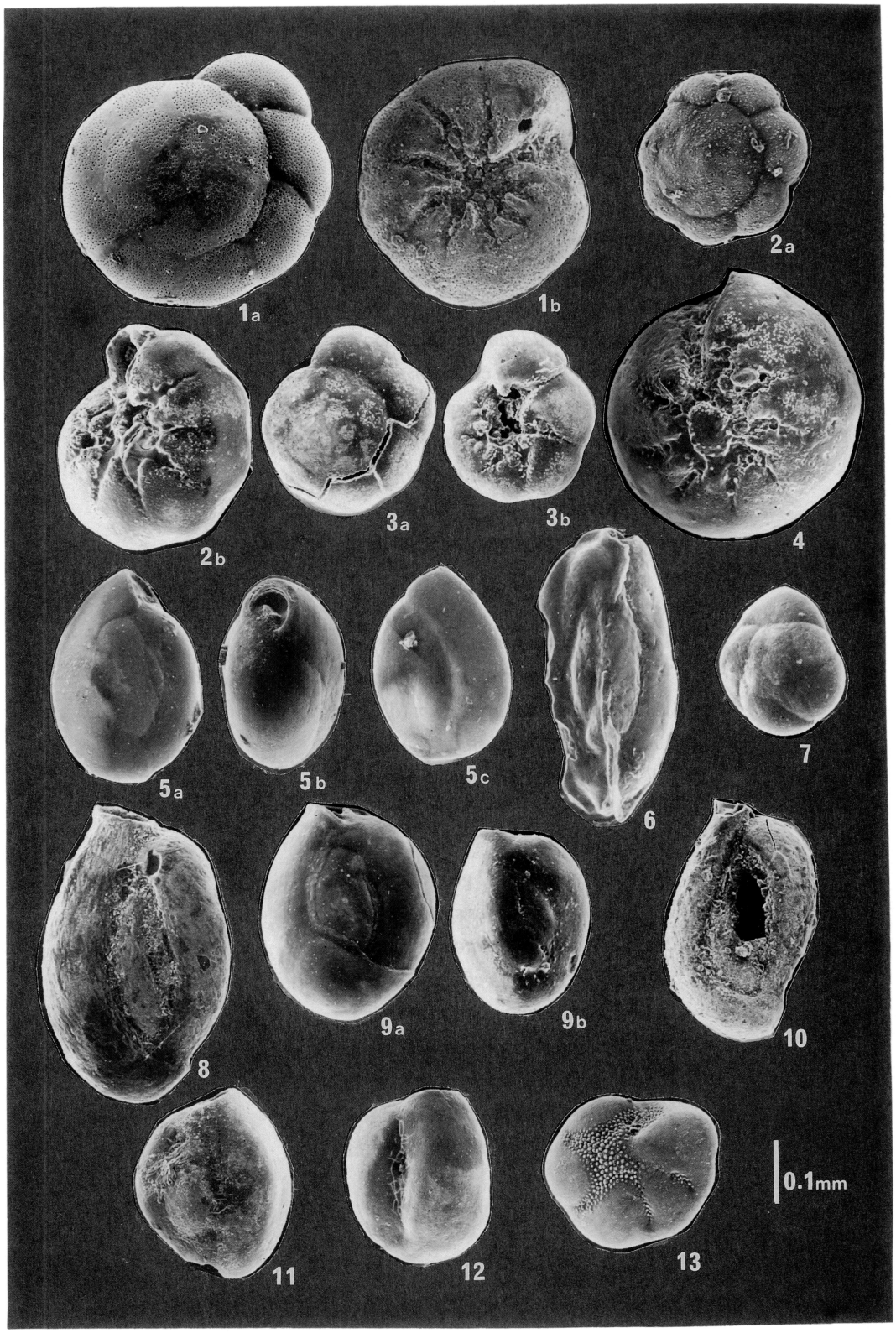
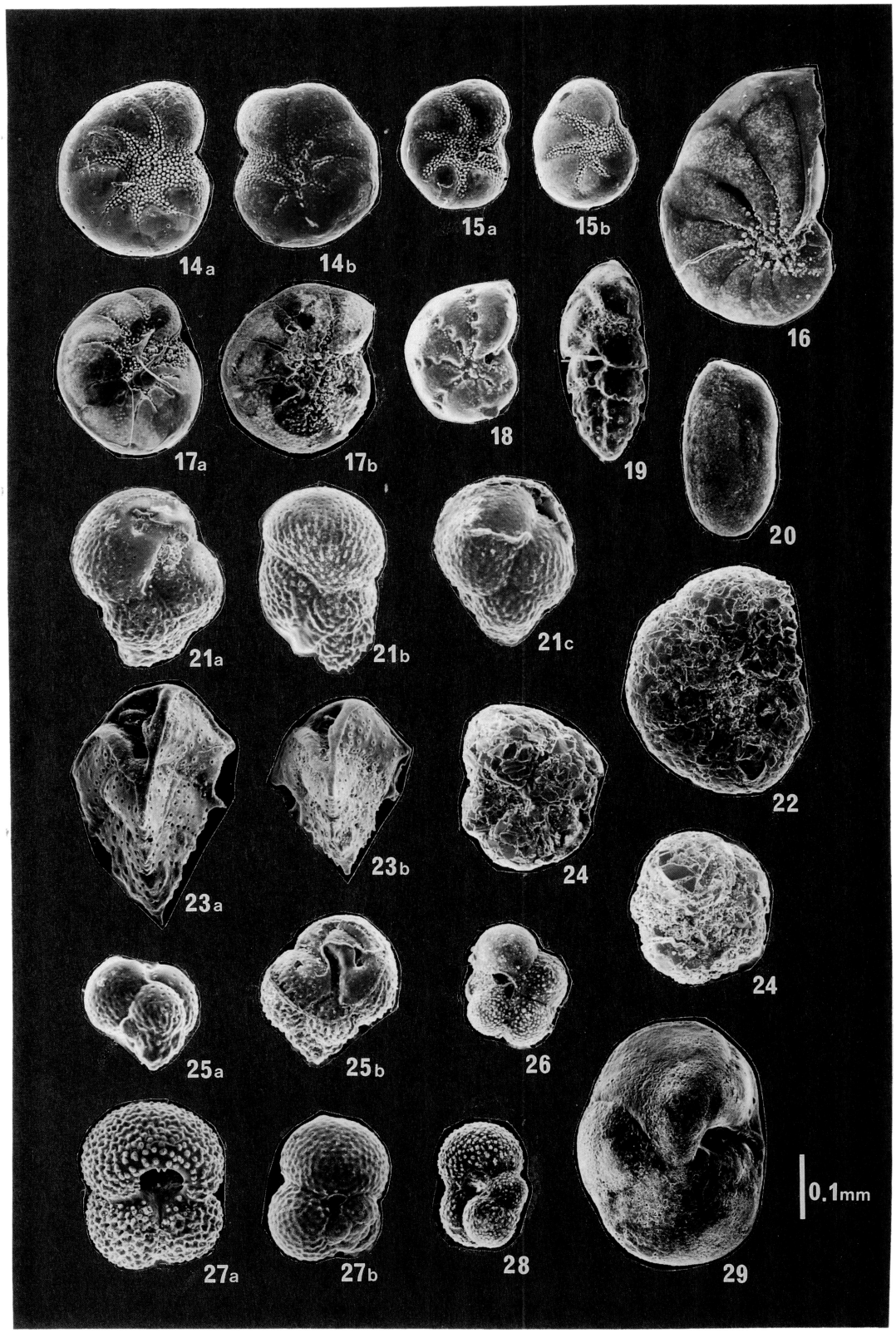


Plate 2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