Vertical Changes of Holocene Ostracodes in Bore Hole Cores from off Kobe, Related to the Opening of Straits and Relative Sea-Level Change in Western Japan

Toshiaki Irizuki^{*1}, Fujio Masuda^{*2}, Basara Miyahara^{*2}, Atsushi Hirotsu^{*3},
Shizuki Ueda^{*3} and Shusaku Yoshikawa^{*3}

Fossil ostracodes were studied in two bore hole cores (OB-1 and OB-2) from Osaka Bay off Kobe in western Japan to examine vertical changes in ostracode faunas. Fifty-two species were identified in 56 sediment samples. Based on numerical analyses of these ostracodes, the samples examined are grouped into five biofacies: BM (brackish mud), SM (shallow mud), SS (shallow sandy mud), DS (deep sandy mud) and DM (deep mud). These biofacies are distributed in upward sequence in both cores. From ca. 11,000–10,000 cal yrs BP, the predominant species living were those dominant in enclosed inner brackish bays at water depths of 2–7 m. Inner to middle, enclosed shallow muddy bay species increased at the study sites after the opening of the Akashi Strait (ca. 9,700 cal yrs BP). Ostracode assemblages changed ca. 8,000 cal yrs BP, when Osaka and Harima-nada Bays were connected with Mizushima-nada Bay. Tidal currents from the Akashi Strait have since been strong. As a result, specimens of intertidal to shoreface species were transported with sandy sediments into deeper Osaka Bay off Kobe. Thus, their individual numbers increased rapidly. A peak in the number of intertidal to shoreface species and deep mud-dwellers occurred around 5,500 cal yrs BP, suggesting that tidal currents from the Akashi Strait and paleo-water depth reached their maxima at this time (ca. 33 m). These species then decreased with time, with the start of a regression. After ca. 2,000–1,600 cal yrs BP, mud-dwellers inhabiting enclosed, organic matter-rich bays were abundant. Their numbers increased further as coarse materials from the Akashi Strait decreased and the Yodo River began to bring flood clays into the study sites. Both “form A” and “form M” of *Bicornucythere bisanensis* are present in both core samples. “Form M” first invaded the study sites through the Kitan Strait to the south. “Form A” came to Osaka Bay off Kobe, ca. 8,350–8,000 cal yrs BP, and has since become the dominant of the two forms.

Key Words : Ostracoda, Osaka Bay, Holocene, Akashi Strait, sea-level change

I. Introduction

Eustatic rise in sea level occurred after the last glacial maximum at about 20,000 years ago. Sea level reached its maximum height

(higher than it is at present) in Japan ca. 6,500–5,000 years before present, as estimated by carbon isotope dating (¹⁴C yrs BP) (Ota *et al.*, 1990). This transgression is called the Jomon transgression. During this period, seawater

Received May 29, 2000. Accepted October 28, 2000.

*1 Department of Earth Sciences, Aichi University of Education. 1 Hirosawa, Igaya-cho, Kariya, 448-8542, Japan.
E-mail : [REDACTED]

*2 Department of Geology and Mineralogy, Graduate School of Science, Kyoto University. Kitashirakawa oiwake-cho, Sakyo-ku, Kyoto, 606-8502, Japan.

*3 Department of Geosciences, Faculty of Science, Osaka City University. 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka, 558-8585, Japan.

inundated basins that were formed by erosion during the last glacial period. Drowned valleys and small enclosed bays developed inland. Many straits opened around the Japanese islands (Ota *et al.*, 1990).

Many authors have reported the developmental history of the Osaka Plain and its adjacent areas during the Holocene period (e.g., Kajiya and Itihara, 1972; Maeda, 1976, 1978). Maeda (1976, 1978) surmised that the maximum height of sea level was about 3 m above present level. Kawachi Bay formed to the east of Osaka Bay at the height of the Jomon transgression (Kajiya and Itihara, 1972). Recently, Miyahara *et al.* (1999) studied sedimentary facies and fossil ostracode faunas. They also conducted high density radiocarbon dating of molluscan shells, downcore in a single bore hole core at Kitatsumori in the Osaka Plain. Masuda *et al.* (2000) suggested that a peak in sea level occurred in Osaka Bay at ca. 5,300–5,000 cal yrs BP. Onodera and Oshima (1983) described the geomorphological history of the eastern Seto Inland Sea through analyses of continuous seismic reflection records, bottom core samples, radiocarbon dates and surface topography. Masuda *et al.* (2000) studied sedimentary facies and performed stratigraphical, high density radiocarbon dating at the same bore holes as those examined in the present study in Osaka Bay off Kobe.

Holocene marine events have strongly influenced the composition and structure of shallow marine invertebrate assemblages, including those of molluscs, foraminifers and ostracodes. Ostracoda, which is the subject of this study, is small and bivalved Crustacea. Some authors have investigated temporal changes of Holocene ostracode assemblages in Japan (Frydl, 1982; Ota *et al.*, 1985; Ikeya *et al.*, 1990; Iwasaki, 1992; Kamiya and Nakagawa, 1993; Irizuki *et al.*, 1998, 1999; Miyahara *et al.*, 1999; Yasuhara *et al.*, 1999b). Many of these studies involve ostracode assemblages in small drowned valleys, facing open coastal seas during the Jomon transgression. Similar vertical changes of ostracode assemblages are reported. Miyahara *et al.* (1999) and Yasuhara *et al.* (1999b) studied Holocene ostracodes from bore hole cores in the Osaka Plain. On the

other hand, we have examined bore hole cores drilled from the surface of the seabed off Kobe. These regions have been influenced by tidal currents from the west and fresh water from rivers to the east. Therefore, temporal sequences of ostracodes in Osaka Bay off Kobe are assumed to be different from those in the Osaka Plain and from other small drowned valleys.

The aim of this study is to elucidate the intricate relationships among temporal sequences of ostracodes, the opening of straits and the relative sea-level changes during the Holocene period in Osaka Bay off Kobe.

II. Materials and methods

Osaka Bay is a large enclosed bay in western Japan, connected with the Pacific Ocean (Kii Channel) through the Kitan Strait to the south, and with Harima-nada Bay through the Akashi Strait to the west (Fig. 1). Harima-nada Bay is linked with the western Seto Inland Sea (Mizushima-nada and Hiuchi-nada Bays) through the Bisan-Seto Strait to the west, and with the Pacific Ocean (Kii Channel) through the Naruto Strait to the south. The bottom of

Fig. 1 Index and locality maps

eastern Osaka Bay slopes gently westward, beneath water extending to depths of 10–20 m. It is covered with flood clay derived from the Yodo River and other small rivers at the eastern margin (Fig. 1–3). In the western half of the bay, sand to sandy mud is transported from the Akashi Strait at the western margin and from the Kitan Strait lying to the south. Some cardons have developed around those straits (e.g., Onodera and Oshima, 1983), where deposits range from sand to sandy gravel. We used two bore hole cores (OB-1 and OB-2) drilled by Japan Coast Guard in the western part of Osaka Bay (Fig. 1–3). Masuda *et al.* (2000) reported briefly on the ostracodes from the OB-1 core. This core is situated at a water depth of 21.72 m, 4 km off Kobe (34°36'18.3"N, 135°9'20.7"E). The OB-2 core is situated at a water depth of 21.91 m, 5 km off Kobe (34°35'48"N, 135°9'29.1"E). Bottom surfaces at both sites are covered mainly with mud, derived from the Yodo and other rivers, flowing through eastern regions of Osaka Bay. We collected 36 samples from the marine sediments above 29.5-m core depth in OB-1 and 32 samples from the marine sediments above 32.17-m core depth in OB-2 (Fig. 2). An interval between samples is typically one meter, though sample spacing is reduced for selected horizons.

We initially measured the water content of all samples. We then collected 30 g of wet sediments and washed them with water on three piled mesh sieve screens (opening is 25 μm (500 mesh), 63 μm (250 mesh) and 250 μm (60 mesh)). We divided samples containing excessive ostracodes into workable aliquots using a sample splitter. After that, we picked about 200 specimens on each assemblage slide from samples coarser than 250 μm . The number of specimens refers to the sum of either right or left valves of each species.

III. Sedimentary facies and ages of study cores

Masuda *et al.* (2000) described in detail the Holocene marine sediments above the transgressive surface (29.5-m core depth) within the OB-1 core and divided them into four sedimentary facies (Fig. 2). We briefly mention those facies here and correlate them to those of the

Fig. 2 Columnar sections of OB-1 and OB-2 cores and horizons of ostracode bearing samples. Numerals with underline show samples less than 50 individuals. Numerals in parentheses mean radiocarbon age (calendar yrs BP) of each sample of OB-1 core as estimated from depositional curve of Masuda *et al.* (2000). Sedimentary facies of OB-1 core are based on Masuda *et al.* (2000).

OB-2 core as follows :

1. Lower Mud (LM)

Lower Mud at depths of 29.5–21.0 m in OB-1 and 32.17–22.0 m in OB-2 consists mainly of clean clay, partly intercalating silt layers. Bioturbation and shells are common. The lowermost part of LM is composed of organic matter-rich, sandy silt. Brackish molluscs (*Potamocorbula amurensis*) and diatoms (*Hydo-*

rosera triquetra) occur at depths of 26.0–24.4 m and ca. 28.5 m in OB-1, respectively.

2. Middle Sandy Mud (MS)

Middle Sandy Mud at depths of 21.0–13.0 m in OB-1 and 22.0–15.0 m in OB-2 consists mainly of massive well-sorted, very fine sand and intercalating silt layers. Intensive bioturbation is apparent, especially in the uppermost part. Mud content decreases upward.

3. Upper Sandy Mud (US)

Upper Sandy Mud is distributed at depths of 13.0–4.0 m in OB-1 and 15.0–5.0 m in OB-2. The lower part of US is composed of silt and intercalating graded bedding intervals of fine to very fine sand, whereas the upper part (at depths of 7.0–4.0 m in OB-1) is entirely silt. Volcanic glasses are concentrated at depths of 11.5–10.5 m in OB-1. Masuda *et al.* (2000) suggest that these volcanic glasses correlate with the Kikai-Akahoya volcanic ash (K-Ah), dated at 7,300 cal yrs BP (Fukusawa, 1995). Some molluscan species that characteristically inhabit water depths from ca. 20–250 m (including *Zeuxis siquijorensis*, *Microcirce dilecta*, and *Myadora fluctuosa*) are found at depths of 12.0–6.5 m in OB-1.

4. Uppermost Clay (UC)

Uppermost Clay at depths of 4.0–0 m in OB-1 and 5.0–0 m in OB-2 is composed of clean clay with bioturbation. Shallow-water molluscan shells (such as *Theol fragilis*, *Solen strictus* and *Veremorpa micra*) are recognizable in OB-1.

The lower (LM) and upper (UC) strata are mainly comprised of clay, derived from the Yodo and other rivers flowing through the eastern regions of Osaka Bay. On the other hand, the middle (MS and US) strata are com-

posed of relatively coarse-grained sediments (well-sorted coarse silt to fine sand), discharged from the Akashi Strait to the west.

Using the AMS method, Masuda *et al.* (2000) conducted radiocarbon dating of molluscan shell fragments, collected at 32 horizons of the marine section in the OB-1 core. From these data, they constructed a depositional curve for OB-1. Their results indicate that depositional rates are high in LM (ca. 8 mm/yr), MS (ca. 7 mm/yr) and UC (4 mm/yr) facies and low in the US facies (0.9–1.8 mm/yr). Ages in calendar years before present are given for all ostracode-bearing samples from OB-1 (Fig. 2), as calculated on the basis of the depositional curve constructed by Masuda *et al.* (2000). We have no data on radiocarbon dating in the OB-2 core.

IV. Biofacies based on ostracode assemblages

We identified 52 ostracode species in 56 samples (27 samples in OB-1 and 29 samples in OB-2; Table 1). Figure 3 shows scanning electron micrographs of selected ostracodes. All ostracodes are commonly found around Japan today except *Neomonoceratina delicata*, which has never been reported from contemporary Japanese bays. We carried out a conventional multivariate analysis (Q-mode cluster analysis) to group samples quantitatively. We adopted the group average method based on the overlap index of Horn (1966) (Fig. 4). We used 31 species, each represented by more than three specimens, in any of the 39 samples containing more than 50 specimens. By this means, five clusters were distinguished (Fig. 4). These clusters are referred to as biofacies. Biofacies

Fig. 3 Scanning electron micrographs of fossil ostracodes from boring core in Osaka Bay off Kobe

Scale bars=0.5 mm (A for 1–4, 15–17; b for 5–14, 18). All specimens are right valves. 1. *Krithe japonica* Ishizaki (sample no. 1–5), 2. *Spinileberis quadriaculeata* (Brady) (sample no. 2–197), 3. *Cythere nishinipponica* Okubo (sample no. 2–144), 4. *Schizocythere asagao* Yajima (sample no. 2–96), 5. *Aurila spinifera* s.l. Schornikov and Tsareva (fine reticulation form) (sample no. 1–12), 6. *Aurila spinifera* s.l. Schornikov and Tsareva (coarse reticulation form) (sample no. 1–101), 7. *Trachyleberis scabrocuneata* (Brady) (sample no. 2–144), 8. *Trachyleberis* sp. (sample no. 2–144), 9. *Amphileberis nipponica* (Yajima) (sample no. 1–6), 10. *Bicornucythere bisanensis* (Okubo) (Form A, adult female) (sample no. 1–12), 11. *Bicornucythere bisanensis* (Okubo) (Form A, A-1 instar) (sample no. 1–12), 12. *Pistocythereis bradyi* (Ishizaki) (sample no. 2–197), 13. *Bicornucythere bisanensis* (Okubo) (Form M, adult female) (sample no. 1–103), 14. *Bicornucythere bisanensis* (Okubo) (Form M, A-1 instar) (sample no. 1–103), 15. *Cytheropteron uchioi* Hanai (sample no. 2–106), 16. *Loxoconcha viva* Ishizaki (sample no. 1–7), 17. *Cytheromorpha acupunctata* (Brady) (sample no. 1–10), 18. *Kobayshiina donghaiensis* Zhao (sample no. 1–8)

BM is situated in the lower part of the OB-2 core (sedimentary facies LM). The other four biofacies, SM, SS, DS and DM, are located in upper sections in both cores. Figures 5 and 6 show vertical changes in the percentage of selected ostracodes, numbers of species and biofacies of OB-1 and OB-2, respectively.

Figure 7 illustrates temporal changes in the numbers of individual ostracodes per 10-g sediment sample (referred to herein as "ostracode number") at OB-1, for the selected species and biofacies.

1. Biofacies BM (brackish mud)

Biofacies BM comprises only one sample

Table 1 List of ostracodes from OB-1 and OB-2 cores

OB-1	1	2	3	4	5	6	7	8	9	10	101	11	12	102	13	14	15	16	17	103	18	19	20	21	104	22	25				
<i>Ambtonia obai</i> (Ishizaki)					1				3																						
<i>Amphileberis nipponica</i> (Yajima)		1	2	2	1	3																									
<i>Aurila corniculata</i> Okubo						1			2																						
<i>Aurila cymba</i> (Brady)		1							3	2		2	1			2															
<i>Aurila dispallata</i> Okubo									1	2	1					3									1						
<i>Aurila hatai</i> Ishizaki						1																									
<i>Aurila spinifera</i> s.l. Schornikov & Tsareva		2	1	4	8	5	23	25	40	40		29	47	27	6	9	5														
<i>Aurila tosaensis</i> Ishizaki				1	1				3	3	1	3	1	2	1	2		1													
<i>Australimacella tomokoae</i> (Ishizaki)																															
<i>Bicornucythere bisanensis</i> (Okubo) ("form A")		2	8	19	39	55	12	28	17	37	33	47	29	76	11	1															
<i>Bicornucythere bisanensis</i> (Okubo) ("form M")		4	8	10	16	7	3	3	4	2	6	4	3	1	1	4	3	2	17	19	36		14	34	34	21	3	1			
<i>Callistocythere alata</i> Hanai									1	1	2		4	13	10	2	1														
<i>Callistocythere reticulata</i> Hanai									1	1	1																				
<i>Callistocythere undulatifacialis</i> Hanai									1	1	3	1	1	1	4	1	2														
<i>Cletocythereis</i> sp.																															
<i>Cornucoquimba tosaensis</i> (Ishizaki)									2	2	2	2	3	1																	
<i>Cythere nishinipponica</i> Okubo		1			2	1	2	7	8	5	1	7	6	3	4	2	2	1													
<i>Cythere otenipponica</i> Hanai									2	2	1		3			2	1								1						
<i>Cytheromorpha acupunctata</i> (Brady)		3	1	1	3	1	3	5	7	8		12	7	7	1	4	4	1	1	1					2	4					
<i>Cytheropteron miurense</i> Hanai					3		2			1																					
<i>Cytheropteron uchioi</i> Hanai								1	2	2																					
<i>Cytherura</i> sp.												1																			
<i>Finnarchinella uranipponica</i> Ishizaki														1																	
<i>Kobayashina donghaiensis</i> Zhao		1	1			1	1	1	5	2	4		2																		
<i>Kritha japonica</i> Ishizaki			1	4	2		2	1	1	1		1	2																		
<i>Loxoconcha epeterseni</i> Ishizaki							1	2	1	3			3																		
<i>Loxoconcha harimensis</i> Okubo									1	1																					
<i>Loxoconcha hattori</i> Ishizaki						1	1						1																		
<i>Loxoconcha japonica</i> Ishizaki																															
<i>Loxoconcha pulchra</i> Ishizaki											2		1	1																	
<i>Loxoconcha tamakazura</i> Yajima										1																					
<i>Loxoconcha tosaensis</i> Ishizaki		1	2			1				1	1		2																		
<i>Loxoconcha uranouchiensis</i> Ishizaki										1			1			1	1			1											
<i>Loxoconcha viva</i> Ishizaki		4	13	10	18	16	11	16	12	16	13		25	18	18	8															
<i>Neomonocerotina delicata</i> Ishizaki & Kato										1			1																		
<i>Neonesidea oligodentata</i> (Kajiyama)																															
<i>Pistocythereis bradyformis</i> (Ishizaki)									1	4	5	2	3												1	2	2				
<i>Pistocythereis bradyi</i> (Ishizaki)		5	11	9	12	23	13	24	25	14	10		12	12	13	7	5	1	5	4	1	2			1	9	22	10	3	1	
<i>Pontocythere miurense</i> (Hanai)													1																		
<i>Robustaurilla ishizakii</i> (Okubo)						1			2	3		1	1																		
<i>Schizocythere asagao</i> Yajima						2	3	5	2	8	4		1	4																	
<i>Schizocythere kishinouyei</i> (Kajiyama)						1	4	1																							
<i>Semicytherura</i> sp.																															
<i>Spinileberis quadriaculeata</i> (Brady)		4	7	6	14	12	6	17	8	9	12		11	14	20	15	9	11	13	20	12	18		20	20	25	33	4	1	2	
<i>Trachyleberis scabrolineata</i> (Brady)		1	4	7	13	10	6	9	13	17	41		48	36	28	7	10	2	5	8	5	5		11	20	21	22	8			
<i>Trachyleberis</i> sp.			1	4	3	5	12	12	26	29		18	22	19	6	4	2														
<i>Xestoleberis hanaii</i> Ishizaki																															
No. of specimens	22	62	67	133	152	75	165	158	216	229	238	242	232	71	59	36	28	50	38	63	46	84	107	92	19	3	2				
No. of species	8	13	11	16	20	19	19	26	31	29	22	29	17	14	16	12	7	5	5	6	4	5	7	6	5	3	1				
OB-2	5	18	27	35	45	54	63	74	85	96	106	116	124	134	144	156	164	175	186	197	207	216	224	236	246	265	285	293	309		
<i>Ambtonia obai</i> (Ishizaki)																															
<i>Amphileberis nipponica</i> (Yajima)		2		1	3	3	5	3	1																						
<i>Anchistrocheles yamaguchii</i> Yajima																2		1													
<i>Aurila corniculata</i> Okubo									2	2	3	1																			
<i>Aurila cymba</i> (Brady)				1					3	1	4		3	1	1	1	9	2		1	1										
<i>Aurila dispallata</i> Okubo				1	1									1	1	3	1														
<i>Aurila hatai</i> Ishizaki																															
<i>Aurila spinifera</i> s.l. Schornikov & Tsareva		1	4	3	2	6	11	19	24	33	46		41	31	34	15	26	7	1												
<i>Aurila tosaensis</i> Ishizaki									3	1	5		3	2		2	3														
<i>Aurila uranouchiensis</i> Ishizaki																															
<i>Bicornucythere bisanensis</i> (Okubo) ("form A")		5	15	14	60	63	94	71	31	35	34		48	41	34	1	5														
<i>Bicornucythere bisanensis</i> (Okubo) ("form M")		14	23	13	20	14	15	13	6	3	2		3	3	1	3	9	3	3	46	41	35		6	13	7	19	3	4	2	1
<i>Bythoceratina hanaii</i> Ishizaki									1	1	1																				
<i>Callistocythere alata</i> Hanai																															
<i>Callistocythere reticulata</i> Hanai																															
<i>Cletocythereis</i> sp.																															
<i>Cornucoquimba tosaensis</i> (Ishizaki)																															
<i>Cythere nishinipponica</i> Okubo		1	1		2	2	3	4	9	8	8		3	2			1														
<i>Cythere otenipponica</i> Hanai									1	1	2	1																			
<i>Cytheromorpha acupunctata</i> (Brady)				1																											
<i>Cytheropteron miurense</i> Hanai		1	3			2	2	3	5	2	1																				
<i>Cytheropteron uchioi</i> Hanai																															
<i>Cytherura</i> sp.		1							1	1																					
<i>Kobayashina donghaiensis</i> Zhao																															
<i>Kritha japonica</i> Ishizaki		7			1	1	6		1	1	1		1	1																	
<i>Loxoconcha epeterseni</i> Ishizaki																															
<i>Loxoconcha hattori</i> Ishizaki	</

Fig. 4 Dendrogram of Q-mode cluster analysis
BM, SM, SS, DS and DM refer to biofacies.

(number 285) from the middle part of LM in OB-2. It is characterized by an overwhelming preponderance (about 89%) of the species *Spinileberis quadriaculeata*. Of the four constituent species, the other three are "form M" of *Bicornucythere bisanensis* (Abe and Choe, 1988), *Pistocythereis bradyformis* and *P. bradyi*.

Spinileberis quadriaculeata has been reported as a dominant species at water depths of 2–14 m. it is, however, more abundant on muddy substrates ($Md=5$ to 8ϕ) in inner brackish bays (where salinity reaches 20–30‰) at water depths of 2–7 m (Ikeya and Shiozaki, 1993). It is not a dominant species in these environments in contemporary Osaka Bay, which is deeper than 8.8 m (Yasuhara *et al.*, 1999a). *Bicornucythere bisanensis* has been reported to be common at water depths ranging from 2–16 m. It is more abundant on muddy substrates ($Md=5$ to 7ϕ) in inner to middle brack-

ish bays (where salinity is 20–30‰) at depths of 5–9 m (Ikeya and Shiozaki, 1993). This biofacies is interpreted as a deposit formed in an inner brackish muddy bay, shallower than about 10 m during an early transgression.

2. Biofacies SM (shallow mud)

Biofacies SM is composed of 11 samples. It lies in the MS facies of OB-1, and in the interval between the upper part of LM and the middle to upper part of MS in OB-2. This biofacies is characterized by the dominance of "form M" of *B. bisanensis*, *S. quadriaculeata*, *P. bradyi* and *Trachyleberis scabrocuneata*. The relative abundance of *S. quadriaculeata* is 23–40% in OB-1 and 11–37% in OB-2. It decreases upward in OB-2. The number of species is small: four to nine.

Trachyleberis scabrocuneata and *P. bradyi* are commonly found in the shallow muds of enclosed bays (e.g., Ishizaki, 1968; Yasuhara *et al.*, 1999a). The decrease in relative abundance of *S. quadriaculeata* and the increase in abundance of *B. bisanensis* possibly indicate an increase in water depth. This biofacies is interpreted as a deposit in an inner to middle, enclosed shallow muddy bay deeper than biofacies BM.

3. Biofacies SS (shallow sandy mud)

Biofacies SS is composed of three samples (number 13 in OB-1, and numbers 134 and 144 in OB-2). This biofacies is present in the lowermost part of the US facies in both cores. Biofacies SS is characterized by the occurrence of *Aurila spinifera* s.l. and *Trachyleberis* sp., both of which are never found in underlying biofacies DM and SM. *Spinileberis quadriaculeata* and *T. scabrocuneata* are also common in this biofacies. There is a moderate number of species in SS: 16 to 22.

Aurila spinifera s.l. in this study corresponds to both forms of *Aurila cymba* (fine reticulate form) described by Yamane (1998) and to *Aurila* cf. *kiritsubo* (coarse reticulate form). The latter conforms to *A. spinifera* described by Schornikov and Tsareva (1995). The adult specimens in the present study show the gradation from fine to coarse reticulation. Thus, we tentatively assign them to *A. spinifera* s.l. *Aurila spinifera* s.l. is reported from sand to sandy bottoms in Hiuchi-nada Bay near the

Fig. 5 Columnar section of OB-1 core, sample horizons, percentages of dominant species, number of species and biofacies

Deep mud species are *Ambtonia obai*, *Amphileberis nipponica*, *Cytheropteron uchioi*, *Kobayashiina donghaiensis* and *Krithe japonica*. Intertidal and phytal species are *Aurila* spp. except for *A. spinifera* s.l., *Cornucoquimba tosaensis*, *Cythere* spp., *Loxoconcha* spp. except for *L. pulchra*, *L. tosaensis* and *L. viva*, *Neonesidea oligodentata*, *Robustaurila ishizakii* and *Xestoleberis hanaii*.

Kurushima Strait (Yamane, 1998) and in Osaka Bay, where the influence of tidal currents from the Akashi Strait is felt (Yasuhara *et al.*, 1999a). Moreover, "form A" of *B. bisanensis* (Abe and Choe, 1988) occurs in this biofacies in OB-1. It is represented only by a single juvenile valve in underlying biofacies SM (sample number 236) in OB-2. *Trachyleberis* sp., often confused with *T. scabrocuneata*, is also a characteristic species in Osaka Bay near the Akashi Strait (Yasuhara *et al.*, 1999a). This biofacies is interpreted as a deposit formed in a sandy shallow bay under the mild influence of tidal currents.

4. Biofacies DS (deep sandy mud)

Biofacies DS consists of 15 samples and covers almost the whole interval of US facies. It is characterized by a high relative abundance of *A. spinifera* s.l., "form A" of *B. bisanensis*

and *Trachyleberis* sp. *Cythere* and *Schizocythere* species are also common in this biofacies. The ostracode number is high, especially for *A. spinifera* s.l. and *Trachyleberis* spp. The number of species reaches its maximum in this biofacies: 14-31 in OB-1 and 17-27 in OB-2. *Cytheropteron uchioi* is present in the middle part of this biofacies (sample numbers 8-10 in OB-1; sample numbers 74-116 in OB-2) (Table 1).

The ostracode number of such sand-dwellers as *A. spinifera* s.l., *Trachyleberis* sp. and "form A" of *B. bisanensis* increases in this biofacies. *Cythere* and *Schizocythere* are reported from *Zostera* beds in the intertidal zones and on the open sandy shorefaces, respectively (Hanai *et al.*, 1977). *Cytheropteron uchioi* is reported at water depths of more than 20 m around central

Fig. 6 Columnar section of OB-2 core, sample horizons, percentages of dominant species, number of species and biofacies
For intertidal and phytal species and deep mud species, see Figure 5.

to southwestern Japan and China (e.g., Frydl, 1982; Zhao and Wang, 1988; Iwasaki, 1992; Yamane, 1998), but is recognized commonly at water depths exceeding 30 m (Zhao and Wang, 1988). Thus, phytal species, sand- and mud-dwellers, or deep and shallow species mix in this biofacies. Yamane (1998) investigated the distribution patterns of recent ostracodes from Hiuchi-nada Bay, southern Japan (Fig. 1-2). The ostracode "association A" of Yamane (1998) is similar to biofacies DS of the present study. It is distributed in silty sand to sand at about 16–33 m in water depth near the Kurushima Strait in the western part of Hiuchi-nada Bay (Fig. 1-2). "Association A" is composed mainly of dead specimens of sandy and phytal species. The specimens are thought to have been trans-

ported from intertidal and sandy shorefaces around the Kurushima Strait by tidal currents and to have accumulated in deeper regions (Yamane, 1998). Therefore, it is possible that phytal species and sand-dwellers in biofacies DS were transported with sand from intertidal zones and shorefaces around the Akashi Strait, to the seabed at water depths of 20–30 m or more, by strong tidal currents.

5. Biofacies DM (deep mud)

Biofacies DM is composed of 10 samples and is present in the uppermost part of the US and UC facies. It is characterized by the dominance of "form A" and "form M" of *B. bisanensis*, *P. bradyi*, and *Loxoconcha viva*. *Amphileberis nipponica*, *Kobayashiina donghaiensis* and *Krithe japonica* also occur in some samples.

Fig. 7 Temporal changes of biofacies and individual number per 10-g sediment sample for each species in OB-1 core

A horizontal scale shows the number of individuals. Arrows show the first occurrences.

Minor constituents of this biofacies include *A. spinifera* s.l., *Trachyleberis* sp. and phytal species, all of which are characteristic of the underlying biofacies SS and DS. There is a moderate number of species: 11–20 in OB-1, and 14–18 in OB-2.

All dominant species in biofacies DM have been reported from muddy bottoms. *Amphileberis nipponica*, *Ko. donghaiensis* and *K. japonica* are common at water depths of more than 15–20 m around Japan (e.g., Frydl, 1982; Bodergat and Ikeya, 1988; Iwasaki, 1992; Yamane, 1998). Yasuhara *et al.* (1999a) reported these ostracodes as characteristic species of muddy bottoms at water depths of 17.2–37.2 m in middle Osaka Bay. Then, this biofacies is interpreted as a deposit formed in an enclosed, middle muddy bay at water depths of more than 15–20 m.

V. Relationships among temporal changes of ostracodes, the opening of straits and relative sea-level changes

Onodera and Oshima (1983) constructed structure contour maps to show the boundary between Holocene marine sediments and underlying deposits in Harima-nada Bay, Kii Channel and Osaka Bay (Fig. 1–3). They inferred that the Kitan, Naruto and Akashi Straits had opened when sea level reached about -60 ± 5 m, -50 m, and -35 m, respectively. Masuda *et al.* (2000) dated the base of the LM facies (i.e., the transgressive surface) of OB-1 at ca. 11,000 cal yrs BP (event ① in Fig. 8) and placed it about 51.0 m below the present sea level. At this horizon, seawater reached to the study area (OB-1). Ostracodes appear in the

Fig. 8 Summary of geological (sedimentological) and ostracode events detected in OB-1 core off Kobe. Relative sea-level curve (A) and depositional curve (B) are after by Masuda *et al.* (2000). C means the maximum flooding surface.

lowermost part of the LM facies in OB-2 (sample number 309). The LM facies is flood clay derived from rivers and accumulated in study sites during an early transgression (ca. 11,000–9,700 cal yrs BP in OB-1). One sample taken from the LM facies belongs to biofacies BM, characterized by inner brackish muddy bay species (Fig. 6).

Based on the analysis of sedimentary facies and the seismic profile in Osaka Bay, Masuda *et al.* (2000) suggested that the MS facies is a tidal delta deposit. Moreover, they indicated that the base of MS represents the advent of tidal currents passing through the Akashi Strait at OB-1 (ca. 9,700 cal yrs BP) (event ② in Fig. 8). Coarser grained silt then flowed from the west

into the study sites in Osaka Bay, with the opening of the Akashi Strait. The ostracode number of inner to middle, enclosed shallow muddy bay species, characterizing biofacies SM, increased around the boundary between the LM and MS facies in OB-1 (Fig. 6). On the other hand, the base of biofacies SM in OB-2 is situated in the upper part of the LM facies (Fig. 6). Thus, the first deposition of coarser grained silt transported from the Akashi Strait at OB-2 is thought to have been later than that at OB-1. This may be ascribed in part to the farther position of OB-2 from the Akashi Strait.

There are slight changes to the ostracode faunas at the horizon uppermost in the MS facies, which may correspond to the lower part of biofacies SS. *Aurila spinifera* s.l. and *Trachyleberis* sp., characterizing biofacies SS and DS, first occur in sample number 14 in OB-1 (Fig. 5 and Table 1). They increase with height in the section (Figs. 5 and 8). "Form A" of *B. bisanensis* and *Callistocythere* spp. first occur in sample number 13 in OB-1 (Fig. 5 and Table 1).

The Bisan-Seto Strait, situated between Harima-nada Bay and Mizushima-nada Bay (Fig. 1-2), is one of the shallowest straits in the Seto Inland Sea with water depths of less than 20 m in many areas. At the time of the accumulation of the US facies (ca. 8,000 cal yrs BP), sea level rose sufficiently for seawater to inundate the Bisan-Seto area (Masuda *et al.*, 2000). As a consequence, Osaka and Harima-nada Bays are thought to have been connected with Mizushima-nada Bay through the Bisan-Seto Strait (event ③ in Fig. 8). The ostracode number of *A. spinifera* s.l. and *Trachyleberis* sp. increases at the base of biofacies DS (Fig. 7). As mentioned above, these ostracodes in biofacies DS are found only in those regions of contemporary Osaka Bay that are influenced by tidal currents from the Akashi Strait (Yasuhara *et al.*, 1999a). They are dominant in present-day Hiuchi-nada Bay near the Kurushima Strait (Yamane, 1998). Therefore, we infer that the study sites were affected by tidal currents from the western Seto Inland Sea, at the time represented by the base of biofacies DS (ca. 8,000 cal yrs BP) (Fig. 8).

After the opening of the Bisan-Seto Strait,

the tidal currents from the Akashi Strait intensified with time, as the Jomon transgression continued. Such phytal genera as *Aurila*, *Cythere* and *Loxoconcha*, and open sandy shoreface species such as *Schizocythere* spp., are common in biofacies DS. There is a rapid increase in ostracode number for *A. spinifera* s.l. and *Trachyleberis* sp. at sample number 11 in OB-1 (ca. 6,600 cal yrs BP), which reaches a maximum at sample number 10 in OB-1 (ca. 5,470 cal yrs BP). The percentages of these species in assemblages also peak around the horizon represented by sample number 10. The largest number of species occurs around sample number 9 (ca. 4,460 cal yrs BP) (Fig. 5 and Table 1). The influence of tidal currents from the Akashi Strait reached its maximum around sample number 10 in OB-1. The maximum flooding surface occurred around the time represented by sample number 10 (C in Fig. 8). Many specimens of sandy and phytal ostracodes, which lived in the intertidal zone and shorefaces around the Akashi Strait, were transported with sandy sediments to deeper muddy bottoms. In this way, a mixture of ostracode faunas gave rise to the maximum ostracode numbers and species numbers. The presence of such middle sublittoral species as *C. uchioi* and a peak in the ostracode number of deep mud species in sample number 10 also support this conclusion. Masuda *et al.* (2000) suggested that a peak in sea level occurred at ca. 5,300–5,000 cal yrs BP in Osaka Bay. Therefore, the age and paleo-water depth of the maximum sea level estimated in our study, correspond well with the results from the depositional curve of OB-1 (B in Fig. 8), and to the sea-level curve on the Osaka Plain (A in Fig. 8). Vertical changes in the structure and composition of ostracode assemblages at OB-2 are similar to those at OB-1. For example, the number of open water species increases upwards and reaches its maximum at sample number 106 (Fig. 6).

The boundary between biofacies DS and DM (ca. 2,000–1,600 cal yrs BP in OB-1) is situated between the horizon of the last deposition of sand derived through the Akashi Strait (event ⑤ in Fig. 8) and the starting horizon of intense deposition of flood clay from the Yodo River at

the eastern margin of Osaka Bay (event ⑥ in Fig. 8). Such sand-dwellers as *A. spinifera* s.l., *Trachyleberis* sp. and *Schizocythere* spp. decrease in this interval, suggesting a decrease in tidal currents from the Akashi Strait. Both "form A" and "form M" of *B. bisanensis* increase in biofacies DM. A decrease in species number from the upper biofacies DS to DM also suggests that depositional environments changed, becoming enclosed organic matter-rich bays with time.

The extent of tidal currents flowing from the Akashi Strait and that of the inflow of flood clay from the Yodo River have influenced the composition and structure of ostracode assemblages in Osaka Bay off Kobe.

VI. Brief comments on the distributional pattern of *Bicornucythere*

One of the representative species inhabiting Japanese enclosed muddy bays is *B. bisanensis* (Ikeya and Shiozaki, 1993). Ishizaki (1972) first recognized a size variation in Japanese *B. bisanensis* and assumed that the difference of valve size was due to the mode of reproduction. Abe and Choe (1988) and Abe (1988) distinguished four different forms ("forms A", "M", "P" and "G") within the eastern Asian *B. bisanensis* populations on the basis of carapace size and shape. Of these, "form A" and "form M" have been identified in Japan (Fig. 3). "Form A" has a larger and thicker carapace

than "form M" in the corresponding juvenile and adult stages. "Form A" has been reported widely from Japanese enclosed bays. Its fossil record suggests it is the oldest of the four forms, extending into the Pliocene in western Japan (Abe, 1988). Only three reports have so far been published on the distribution of "form M" from Japan (Ishizaki, 1968; Iwasaki, 1992; Yasuhara *et al.*, 1999a). Only "form M" is extant in Uranouchi Bay in southern Shikoku, which faces the Pacific Ocean (Ishizaki, 1968; Abe, 1988). Iwasaki (1992) found that "form M" predominates over "form A" in the shallower areas of contemporary Ariake Bay off Shirakawa, western Kyushu and in the lower- and uppermost samples from Holocene bore hole cores in the Kumamoto Plain near Ariake Bay. Conversely, Yasuhara *et al.* (1999a) reported that both forms are abundant in Osaka Bay at water depths of 8.8–37.2 m. They did not recognize a trend comparable in distribution to that reported in Ariake Bay. "Form M" has so far been reported from enclosed bays in western Japan.

We investigated temporal changes in individual numbers of both "form A" and "form M" of *B. bisanensis* from a Holocene bore hole core at Kitatsumori in the Osaka Plain (34°38'49"N, 135°29'09"E) to correlate with those from off Kobe (Table 2). This core is the same as that used by Miyahara *et al.* (1999). Table 2 gives the age, in calendar years before the present,

Table 2 Sample horizon, radiocarbon age (calendar yrs BP), sample weight (g) and individual number of "form A" and "form M" of *Bicornucythere bisanensis* from Kitatsumori

horizon(m)	cal yrs BP	weight(g)	"form A"	"form M"	horizon(m)	cal yrs BP	weight(g)	"form A"	"form M"
8.50	1160	80.00		1	14.50	3800	57.59	52	2
9.00	1220	76.90		4	14.95	5270	77.38	41	
9.50	1300	80.00		4	15.00	5390	80.00	32	
10.00	1410	60.00	44	17	15.40	5630	75.44	29	
10.50	1510	23.59	34	9	16.00	5930	40.00	42	
11.00	1620	80.00	31		16.50	6110	80.00	58	
11.50	1730	40.00	37	1	17.00	7110	29.42	78	1
11.70	1800	64.70	32		17.50	7620	73.72	54	
12.00	1900	73.00	20		18.00	7860	80.00	1	
12.35	1970	33.00	24	15	18.50	7980	77.23		1
12.50	2020	38.86	20	9	19.00	8130	60.00	68	
13.00	2300	80.00	18		19.50	8310	80.00		2
13.38	2600	20.00	23		19.70	8390	80.00		5
14.00	3170	20.00	21	3					

Radiocarbon ages were estimated from depositional curve of Miyahara *et al.* (1999).

of all ostracode-bearing samples from Kitatsumori as calculated on the basis of the depositional curve constructed by Miyahara *et al.* (1999). Specimens from samples in OB-1 older than ca. 8,350 cal yrs BP are all "form M" (Fig. 7). All specimens in biofacies BM and SM in OB-2 are also "form M" except for one juvenile from sample number 236 (Fig. 6). Furthermore, until ca. 8,310 cal yrs BP, only "form M" was present at Kitatsumori (Table 2). "Form A" first occurred in the period between 8,310–8,130 cal yrs BP in Kitatsumori and between 8,350–8,020 in OB-1 off Kobe, respectively. "Form A" subsequently dominated over "form M" in both Kitatsumori and off Kobe. After ca. 1,600–1,500 cal yrs BP, the relative abundance of "form M" increased again. Only "form M" was present after 1,300 cal yrs BP in Kitatsumori. Yasuhara *et al.* (1999b) also reported similar temporal changes of both forms from a Holocene bore hole core in Sakai City in the Osaka Plain. According to these authors, "form A" was first occurred around $7,132 \pm 68$ ^{14}C yrs BP. Whereas "form M" was present from around $1,079 \pm 68$ ^{14}C yrs BP after which time it predominated over "form A". We have drawn certain conclusions on the migration of these forms of *Bicornucythere* in Osaka Bay on the basis of the above-mentioned observations. "Form M" first invaded Osaka Bay from the Kitan Strait, following the invasion of *S. quadriculeata* during an early transgression, when the Akashi Strait was not yet established. The presence of one juvenile specimen of "form A" in the upper part of the LM facies in OB-2, however, suggests that "form A" was already living in Osaka Bay around the opening of the Akashi Strait. As the increase in relative sea level accelerated around ca. 8,000 cal yrs BP (Fig. 8), water depth increased rapidly in Osaka Bay. Therefore, "form A" invaded around Kobe and Kitatsumori. Inland areas were subsequently inundated with seawater. One of the reasons for the absence or scarcity of "form M" in Kitatsumori, Sakai City and off Kobe, during the time interval between ca. 8,000 and 1,600 cal yrs BP, may be that "form M" migrated to interior bays such as Kawachi Bay to the east of Kitatsumori. After ca. 2,000–1,600 cal yrs BP, these interior bays disappeared and "form

M" returned to Kitatsumori and Kobe. Both forms occur widely in the present Osaka Bay in equal proportions (Yasuhara *et al.*, 1999a).

VII. Conclusions

1. An enclosed inner brackish bay existed off Kobe during the early Holocene transgression.
2. The Akashi Strait opened at ca. 9,700 cal yrs BP and inner to middle, enclosed shallow muddy bay species increased.
3. The number of individual of sand-dwellers increased rapidly at ca. 8,000 cal yrs BP, when the Bisan-Seto Strait opened. Osaka, Harima-nada and Mizushima-nada Bays were interconnected and the Seto-Inland Sea has been formed.
4. "Form M" of *B. bisanensis* (Abe and Choe, 1988) was dominant in Osaka Bay off Kobe before the opening of the Bisan-Seto Strait. "Form A" subsequently invaded the region at ca. 8,350–8,000 cal yrs BP and outnumbered "form M" for several thousand years. "Form M" predominates over "form A" in the uppermost part of cores off Kobe and in the Osaka Plain.
5. The ostracode number, both of deep mud- and sand-dwellers, reached its maximum at around 9.5-m core depth of OB-1, which accumulated at the time of maximum flooding (ca. 5,500 cal yrs BP).
6. Open marine sand-dwellers decreased after maximum flooding, suggesting a decrease in the influence of tidal currents through the Akashi Strait.
7. From ca. 1,600 to 1,100 cal yrs BP, organic matter-rich middle bay ostracodes again predominated throughout Osaka Bay off Kobe. This reflects a decrease in sandy sediment inflow from the Akashi Strait and an increased flood clay inflow from the Yodo River and other rivers.

Acknowledgments

We would like to thank Dr. Kunihiro Ishizaki of Ishinomaki Senshu University for critical reading of the manuscript. We also thank Dr. Yo Iwabuchi of Japan Coast Guard for his supply of core samples and Mr. Moriaki Yasuhara of Osaka City University for discussing ostracode assemblages from recent Osaka

Bay. This study was supported by the Grant-in-Aid for Encouragement of Young Scientist from the Japanese Ministry of Education, Science and Culture (No. 10740246).

References

- Abe, K. (1988) Speciation completed? In *Keijella bisanensis* species group. Hanai, T., Ikeya, N. and Ishizaki, K. (eds.) *Evolutionary biology of Ostracoda : Its fundamentals and applications* : 919–925, Kodansha and Elsevier.
- Abe, K. and Choe, K.-L. (1988) Variation of *Pistocythereis* and *Keijella* species in Gamagyang Bay, south coast of Korea. Hanai, T., Ikeya, N. and Ishizaki, K. (eds.) *Evolutionary biology of Ostracoda : Its fundamentals and applications* : 367–373, Kodansha and Elsevier.
- Bodergat, A.M. and Ikeya, N. (1988) Distribution of Recent Ostracoda in Ise and Mikawa Bays, Pacific coast of Central Japan. Hanai, T., Ikeya, N. and Ishizaki, K. (eds.) *Evolutionary biology of Ostracoda : Its fundamentals and applications* : 413–428, Kodansha and Elsevier.
- Frydl, P. (1982) Holocene ostracods in the southern Boso Peninsula. Hanai, T. (ed.) *Studies on Japanese Ostracoda* : 61–140, Bull. Univ. Mus., Univ. Tokyo, 20.
- Fukusawa, H. (1995) Non-glacial varved lake sediment as a natural timekeeper and detection on environmental changes. *The Quat. Res. (Daiyonki-Kenkyu)*, 34, 135–149. (J+E)
- Hanai, T., Ikeya, N., Ishizaki, K., Sekiguchi, Y. and Yajima, M. (1977) *Checklist of Ostracoda from Japan and its adjacent seas*. 119 p, Univ. Tokyo Press.
- Horn, H.S. (1966) Measure of "overlap" in comparative ecological studies. *Amer. Natur.*, 100, 419–424.
- Ikeya, N. and Shiozaki, M. (1993) Characteristics of the inner bay ostracodes around the Japanese islands—The use of ostracodes to reconstruct paleoenvironments—. *Mem. Geol. Soc. Japan*, 39, 15–32. (J+E)
- Ikeya, N., Wada, H., Akutsu, H. and Takahashi, M. (1990) Origin and sedimentary history of Hamana-ko Bay, Pacific coast of central Japan. *Mem. Geol. Soc. Japan*, 36, 129–150. (J+E)
- Irizuki, T., Fujiwara, O., Fuse, K. and Masuda, F. (1998) Paleoenvironmental changes during the last post glacial period on the western coast of the Miura Peninsula, Kanagawa Prefecture, Central Japan : Fossil ostracode fauna and event deposits in bore hole cores. *Fossils (Palaeont. Soc. Japan)*, 64, 1–22. (J+E)
- Irizuki, T., Fujiwara, O. and Fuse, K. (1999) Taphonomy of fossil ostracode assemblages in Holocene deposits on the Miura Peninsula, central Japan. *Mem. Geol. Soc. Japan*, 54, 66–116. (J+E)
- Ishizaki, K. (1968) Ostracodes from Uranouchi Bay, Kochi Prefecture, Japan. *Sci. Rept. Tohoku Univ.*, 2nd Ser. (Geol.), 40, 1–45.
- Ishizaki, K. (1972) Morphological variation in *Leguminocythereis hodgii* (Brady), Ostracoda (Crustacea) from Japan. *Professor Jun-ichi Iwai Memorial Volume* : 697–707.
- Iwasaki, Y. (1992) Ostracod assemblages from the Holocene deposits of Kumamoto, Kyushu. *Kumamoto Jour. Sci. (Geol.)*, 12, 1–12. (J+E)
- Kajiyama, H. and Itihara, M. (1972) The developmental history of the Osaka Plain with references to the radio-carbon dates. *Mem. Geol. Soc. Japan*, 7, 101–112. (J+E)
- Kamiya, T. and Nakagawa, T. (1993) Ostracode fossil assemblages in the Holocene shell bed found in Takahama-cho, Fukui Prefecture, Central Japan. *Bull. Dept. Nat. His. Fukui City Mus.*, 1, 115–133. (J+E)
- Maeda, Y. (1976) The sea level changes of Osaka Bay from 12,000 BP to 6,000 BP, environmental changes in the Osaka Bay area during the Holocene Part-I. *Jour. Geosci., Osaka City Univ.*, 20, 43–58.
- Maeda, Y. (1978) Holocene transgression in Osaka Bay, environmental changes in the Osaka Bay area during the Holocene Part-III. *Jour. Geosci., Osaka City Univ.*, 21, 53–63.
- Masuda, F., Miyahara, B., Hirotsu, A., Irizuki, T., Yoshikawa, S. and Iwabuchi, Y. (2000) Temporal variation of Holocene Osaka Bay condition estimated from a core in off-Kobe, Japan. *Jour. Geol. Soc. Japan*, 106, 482–488. (J+E)
- Miyahara, B., Masuda, F., Irizuki, T., Fujiwara, O. and Yoshikawa, S. (1999) Holocene sea level curve and paleoenvironments reconstructed from a core in Osaka, Japan. Saito, Y., Ikehara, K. and Katayama, H. (eds.) *Land-sea link in Asia : "Prof. Kenneth O. Emery Commemorative International Workshop"* : 415–420, Proceedings of an international workshop on sediment transport and storage in coastal sea-ocean system, STA (JISTEC) and Geol. Surv. Japan.
- Onodera, K. and Ohshima, K. (1983) Geomorphological development in the eastern Seto Inland Sea. *Bull. Geol. Surv. Japan*, 34, 217–239. (J+E)
- Ota, Y., Matsushima, Y., Miyoshi, M., Kashima, K., Maeda, Y. and Moriwaki, H. (1985) Holocene environmental changes in the Choshi Peninsula and its surroundings, easternmost Kanto, central Japan. *The Quat. Res. (Daiyonki-Kenkyu)*, 24, 13–29. (J+E)
- Ota, Y., Umitsu, M. and Matsushima, Y. (1990) Recent Japanese research on relative sea level changes in the Holocene and related problems. *The Quat. Res. (Daiyonki-Kenkyu)*, 29, 31–48. (J+E)
- Schornikov, E. I. and Tsareva, O. A. (1995) New Ostracoda of the genus *Aurila* from the N.W. Pacific. *Mitt. Hamb. Zool. Mus. Inst.*, 92, 237–253.
- Yamane, K. (1998) Recent ostracode assemblages from Hiuchi-nada Bay, Seto Inland Sea of Japan. *Bull. Dept. Nat. His. Ehime Pref. Sci. Mus.*, 3, 19–59.

(J+E)

Yasuhara, M., Yoshikawa, S. and Irizuki, T. (1999a) Recent Ostracoda from Osaka Bay, southwestern Japan. *Proc. 9th Symp. Geo-environments and Geotechnics*, 167-172. (J+E)

Yasuhara, M., Yoshikawa, S., Irizuki, T. and Nanayama, F. (1999b) Analyses of depositional environments of the Holocene Namba Formation, Central Japan, based on fossil ostracode fauna. *Abstracts*,

the 106th Annual Meeting of the Geological Society of Japan, 43. (J)

Zhao, Q. and Wang, P. (1988) Modern Ostracoda in sediments of shelf seas off China : quantitative and qualitative distributions. *Oceanologia et Limnologia Sinica*, 19, 553-561. (C+E)

(C+E) in Chinese with English abstract, (J) in Japanese, (J+E) in Japanese with English abstract

神戸沖ボーリングコアにおける完新世貝形虫群集の垂直変化

—西日本の海峡の開口と相対的海水準変動に関連して—

入月俊明^{*1}・増田富士雄^{*2}・宮原伐折羅^{*2}・広津淳司^{*3}・
植田静喜^{*3}・吉川周作^{*3}

(要 旨)

神戸沖の大阪湾で掘削された2本のボーリングコア(OB-1とOB-2)を用いて貝形虫化石を調査した。56試料から52種の貝形虫類が同定された。これらの貝形虫化石群集は数量解析に基づき、5つの化石相に分けられた。すなわち、下位から化石相はBM(湾汽水泥底相)、SM(湾奥泥底相)、SS(湾奥砂質泥底相)、DS(湾中央砂質泥底相)、DM(湾中央泥底相)に変化する。約11,000～10,000年以前は閉鎖的内湾奥(水深2～7m)に優占する汽水性種が多産する。約9,700年前に明石海峡が開口し、湾奥から湾中央部の浅海泥底種が増加した。貝形虫群集は大阪湾と播磨灘が水島灘と通じた約8,000年前に変化しはじめた。明石海峡からの潮流が強くなるにつれて、潮間帯や外浜の種が砂質堆積物とともに多量に深い神戸沖の大阪湾に運搬された。潮間帯から外浜に生息す

る種と湾中央部の深海泥底種の産出個体数が最大になる時期は5,500年前前後である。このことは神戸沖が明石海峡からの潮流の影響を強く受けるとともに、古水深が最大になったことを意味している(最大古水深は約33m)。その後、2,000～1,600年前頃からの海退により、これらの外洋性の種は減少し、閉鎖的で有機物の多い湾の泥底に生息する種が増加しはじめた。これらの内湾性種は、明石海峡からの粗粒堆積物の運搬が減り、淀川からの洪水性粘土の供給が増加することにより、さらに増加した。本試料中には、日本の内湾に普遍的に生息する *Bicornucythere bisanensis* が含まれ、その中でM型が大阪湾の南の紀淡海峡から最初に侵入し、その後、約8,350～8,000年前になってA型が優占するようになった。

*1 愛知教育大学教育学部理科教育講座地学領域 〒448-8542 刈谷市井ヶ谷町広沢1. E-mail : [REDACTED]

*2 京都大学大学院理学研究科地質学鉱物学教室 〒606-8542 京都市左京区北白川追分町。

*3 大阪市立大学理学部地球学科 〒558-8585 大阪市住吉区杉本3-3-138。