Middle Pleistocene Ostracoda from the Takatsukayama Member of the Meimi Formation, Hyogo Prefecture, western Japan: significance of the occurrence of Sinocytheridea impressa

Authors: IRIZUKI, TOSHIAKI, MATSUBARA, TAKASHI, and MATSUMOTO, HIROMI

Source: Paleontological Research, 9(1) : 37-54

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/prpsj.9.37

Paleontological Research, vol. 9, no. 1, pp. 37–54, April 30, 2005

Middle Pleistocene Ostracoda from the Takatsukayama Member of the Meimi Formation, Hyogo Prefecture, western Japan: significance of the occurrence of *Sinocytheridea impressa*

TOSHIAKI IRIZUKI[1], TAKASHI MATSUBARA[2] AND HIROMI MATSUMOTO[3]

[1]*Department of Geoscience, Interdisciplinary Faculty of Science and Engineering, Shimane University: 1060 Nishikawatsu, Matsue Shimane 690-8504, Japan (e-mail: irizuki@riko.shimane-u.ac.jp)*

[2]*Division of Natural History, Museum of Nature and Human Activities, Hyogo: 6 Yayoigawa, Sanda Hyogo 669-1546, Japan (e-mail: matsu@nat-museum.sanda.hyogo.jp)*

[3]*Department of Geoscience, Interdisciplinary Faculty of Science and Engineering, Shimane University: 1060 Nishikawatsu, Matsue Shimane 690-8504, Japan*

Received October 23, 2004; Revised manuscript accepted January 11, 2005

Abstract. Thirty-seven ostracode species are identified from 15 samples from lithological Units II and III at the type locality of the middle Pleistocene (Marine Isotope Stage 11: ca. 0.41 Ma) Takatsukayama Member of the Meimi Formation, Hyogo Prefecture, western Japan. Three ostracode biofacies are distinguished on the basis of Q-mode cluster analysis. The depositional environments of each biofacies can be inferred as bay sandy coast (BC), enclosed inner bay (IB) and middle bay influenced by freshwater inflows from rivers on the Harima Plain (CB). A rapid increase in water depth from bay coast to middle bay occurred at the deposition of the middle part of Unit II of the Takatsukayama Member. *Sinocytheridea impressa* (Brady), which probably disappeared or rapidly decreased from paleo-Osaka Bay at about 0.3–0.35 Ma, is abundant at the study site. One of the reasons for the disappearance or rapid decrease of this species is likely that paleo-Osaka Bay changed from a low-salinity, enclosed nutrient-rich and highly turbid bay to a moderate salinity, ventilated bay with good circulation, together with the vicariance event suggested by previous studies. This change was probably linked with both widespread inundation in the neighboring paleo-Harima-nada Bay and the development of large-scale tidal currents from the Akashi Strait connecting both bays. Thereafter, *Neomonoceratina delicata* Ishizaki and Kato replaced *S. impressa* and became the dominant taxon in paleo-Osaka Bay. *Sinocytheridea impressa* which lived in paleo-Osaka and Harima-nada Bays has larger valves than any specimens of this species from Recent seas. The cause of this large size in the past might have been an abundant food supply or dissolved chemicals from freshwater inflows into paleo-Osaka and Harima-nada Bays. Alternatively, whether large-valve populations occurred as a result of genetic changes in relation to the geographical isolation or not, natural selection operated in favor of increased valve size in paleo-Osaka and Harima Bays for reasons that are as yet uncertain.

Key words: MIS 11, Ostracoda, paleo-Osaka and Harima-nada Bays, Pleistocene, *Sinocytheridea*, Takatsukayama Member

Introduction

A major global climatic oscillation of the order of ca. 100,000 years developed after the middle Pleistocene. In eastern Asia, land bridges formed between the Eurasian Continent and the Japanese Islands during the intervals of glacial maxima (e.g., Ujiié and Ujiié, 1999; Konishi and Yoshikawa, 1999; Ujiié *et al.*, 2003).

At that time, terrestrial animals migrated from the continent to the islands (e.g., Kawamura, 1991; Konishi and Yoshikawa, 1999; Kimura, 2002). On the other hand, many straits arose between the continental mainland and the islands during interglacial periods. Those animals were then isolated and their populations diminished or evolved. Ostracodes are an abundant and practically ubiquitous group of minute crustaceans. Most benthic marine ostracode species have a hard calcareous bivalved carapace that is easily fossilized. The benthic ostracodes have no planktonic period in their life cycle. Therefore, it seems that ostracode species inhabiting shallow enclosed muddy bay bottoms find it difficult to migrate rapidly to other shallow bays if deep straits are present between bays. As a result, migration, extinction, and evolution of shallow embayment species have been strongly influenced by cyclic changes in glacial and interglacial climates during the late Quaternary period (Ishizaki, 1987, 1990a, b). Osaka Bay is situated in the eastern part of the Seto Inland Sea, western Japan. Its paleogeography has changed cyclically under the influence of glacio-eustasy during the Pleistocene to Holocene. Embayment ostracode faunas from Holocene deposits in the Osaka Bay region have recently been studied in detail (e.g., Irizuki *et al.*, 2001; Masuda *et al.*, 2002; Yasuhara *et al.*, 2002a, b, 2004) (Figure 1). These studies correlated the dynamics of ostracode faunas in Osaka Bay with relative sea-level changes during the Holocene (the Jomon Transgression). However, only a few studies of Pleistocene ostracodes from paleo-Osaka Bay have been conducted (Ishizaki, 1984, 1990a). Ishizaki (1984, 1990a) studied temporal changes in ostracodes from middle Pleistocene to Holocene borehole cores excavated in Osaka Bay off Senshu, which is situated in the southern part of paleo-Osaka Bay. In the present study, we report in detail middle Pleistocene ostracodes from the Takatsukayama Member of the Meimi Formation, Hyogo Prefecture, which is situated to the north of the Akashi Strait, in the northern part of paleo-Osaka Bay (Figure 1), and was deposited in paleo-Harima-nada Bay. Hashimoto and Maeda (1989) reported a preliminary study of the fossil ostracodes from the member. However, the vertical changes that they reported have not been quantified. Here, we reconstruct the depositional environment of the Takatsukayama Member and discuss ostracode faunal changes in paleo-Osaka and Harima-nada Bays during the Pleistocene.

Geological setting and age

Plio–Pleistocene deposits are widely developed in the eastern Harima Plain, in the south–central part of Hyogo Prefecture (e.g., Itihara *et al.*, 1960; Huzita and Maeda, 1984; Hashimoto and Maeda, 1989; Igawa and Itihara, 1993). They are divided, in ascending order, into the Osaka Group and terrace deposits (Huzita and Maeda, 1984; Hashimoto and Maeda, 1989; Igawa and Itihara, 1993). The Osaka Group in the eastern Harima Plain is composed, in ascending order, of the Akashi and Meimi Formations (Huzita and Kasama, 1983; Huzita and Maeda, 1984; Hashimoto and Maeda, 1989). The Meimi Formation is subdivided in ascending order into three members: the Asagiri, Takatsukayama and Iwaoka (Hashimoto and Maeda, 1989). The Takatsukayama Member, which is the object of the present study, unconformably overlies the Akashi Formation at the type locality. Katoh *et al.* (1999) subdivided the Takatsukayama Member into four units (Units I to IV) at the type locality, which is an outcrop to the south of Wakaba-gakuen Special School, Kozukayama, Tamon-cho, Tarumi Ward, Kobe City (Latitude: 34°40′18″N; Longitude: 135°3′35″E; Figures 1 and 2).

Unit I unconformably covers the Akashi Formation and is composed mainly of gravel overlain by silt (Huzita and Kasama, 1983; Huzita and Maeda, 1984; Hashimoto and Maeda, 1989; Igawa and Itihara, 1993; Sato *et al.*, 1997; Katoh *et al.*, 1999). The thickness of this unit is about 6.5 m (Hashimoto and Maeda, 1989), but only the upper half is now exposed. A fine tuff layer (10–20 cm thick), called the "Takatsukayama Volcanic Ash Layer" (Suzuki, 1988; Hashimoto and Maeda, 1989; Igawa and Itihara, 1993; Kato *et al.*, 1999), is intercalated near the uppermost part of this unit.

Unit II consists of a 1.2-m-thick, dark gray clay, rich in shells of such molluscs as *Crassostrea pestigris* (Hanley), *C. gigas* (Thunberg), and "*Volachlamys yagurai* (Makiyama)". Ueji (1937) and Fukuda and Ando (1951) called this unit the "Takatsukayama Shell Bed". *Thalassinoides*-like sand pipes are densely developed in the basal part of the unit and penetrate into Unit I. The boundary between Units I and II is probably an erosional surface because the uppermost part of Unit I, including the "Takatsukayama Volcanic Ash Layer", is eroded westward.

Unit III is composed first of pale gray to yellowish gray bioturbated clayey silt (2.7 m thick), followed by a yellowish gray to yellowish brown silty sand (0.7 m thick), and then a light gray fine- to medium-grained sand (1.2 m thick) rich in cylindrical sand pipes, and shows a coarsening-upward sequence. The molluscan fossils are contained only in the lower 2 m interval; they are abundant in the lowest part and tend to decrease upward in the sequence. Fossil cones of conifers are also found sporadically in the upper part of the unit. The "Takatsukayama Clay Bed" of Itihara *et al.* (1960) corresponds to Unit II and the lower part of Unit III.

Unit IV comprises, in ascending order, an orange-to-brown parallel-laminated medium- to coarse-grained sand (0.3–5 m thick) and gravelly me-

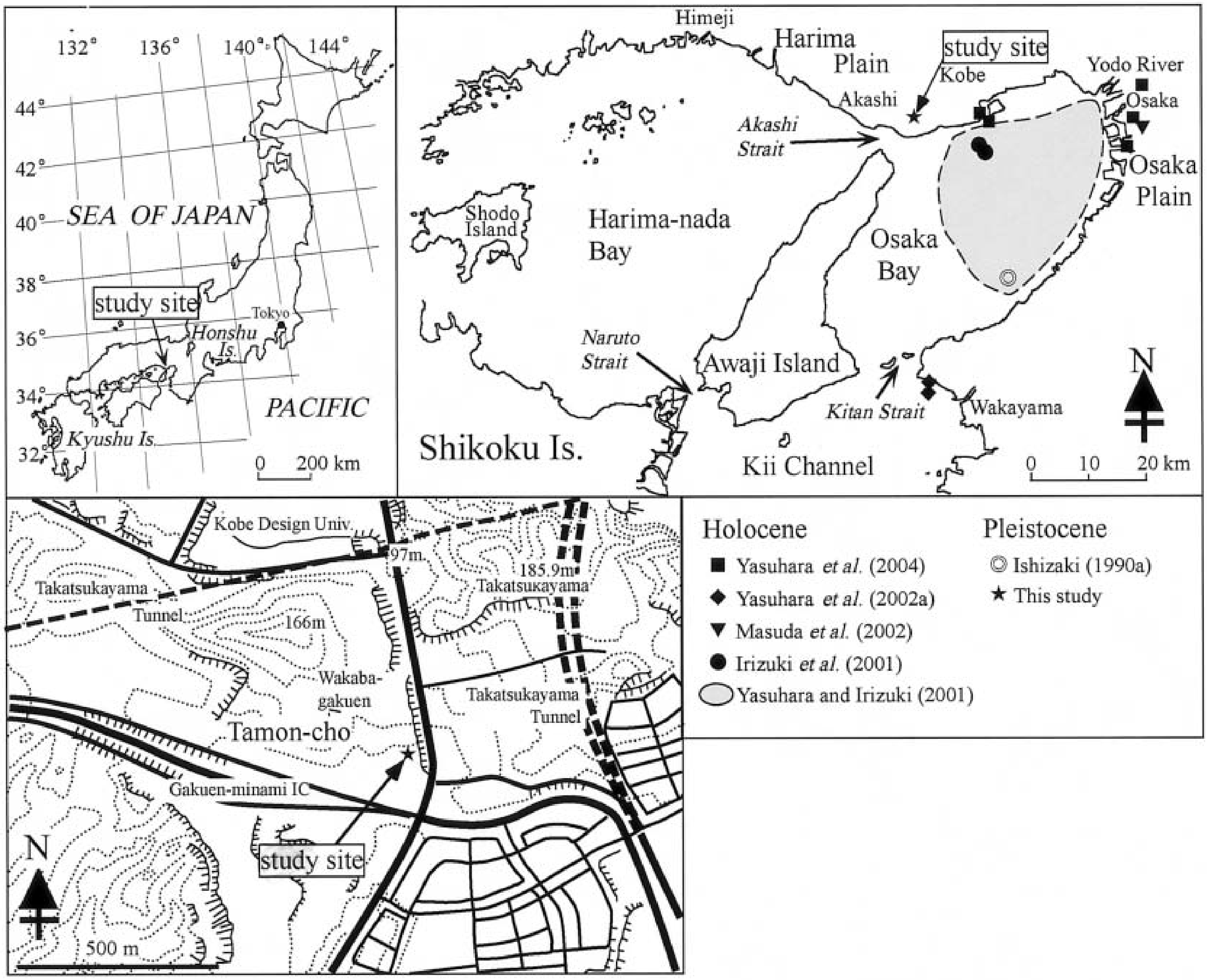


Figure 1. Index and the location maps of the study site. Base map: 1:25,000 topographical maps ''Zenkai'' and ''Suma'' by the Geographical Survey Institute of Japan.

dium- to coarse-grained sand (more than 4.5 m thick) including thin lenticular granule layers showing foreset cross-stratification. The original thickness of this unit was about 20 m (Hashimoto and Maeda, 1989), but most of it was removed during development of the land in the 1980s.

Kato *et al.* (1999) dated the ''Takatsukayama Volcanic Ash Layer'' at 0.41 $\pm$ 0.12 Ma (error, 1σ) using the fission-track method. On the basis of the petrological characteristics, they also correlated this layer with the Minatojima II Volcanic Ash Layer (Miyagawa *et al.*, 1996) intercalated in marine clay layer Ma 9 in the upper part of the Osaka Group. Kato *et al.* (2000) referred Unit II to the calcareous nannofossil zone CN14b of Okada and Bukry (1980). Therefore, the Takatsukayama Member of the Meimi Formation is correlated with Marine Isotope Stage (MIS) 11.

Materials and methods

We selected two sections (A and B) situated 3 m apart at the outcrop at the type locality. Six samples (TAK-1 to 6) were collected from section A and ten samples (TAK-7 to 16) from section B. Samples TAK-1 to 11 were from Unit II and samples TAK-12 to 16 were from the lower part of Unit III.

Dried samples of 80 g were weighed, boiled in a beaker for one hour on a hot plate, and washed with water on a 200-mesh sieve screen (opening, 0.075 mm). The samples were dried, then soaked in naphtha so-

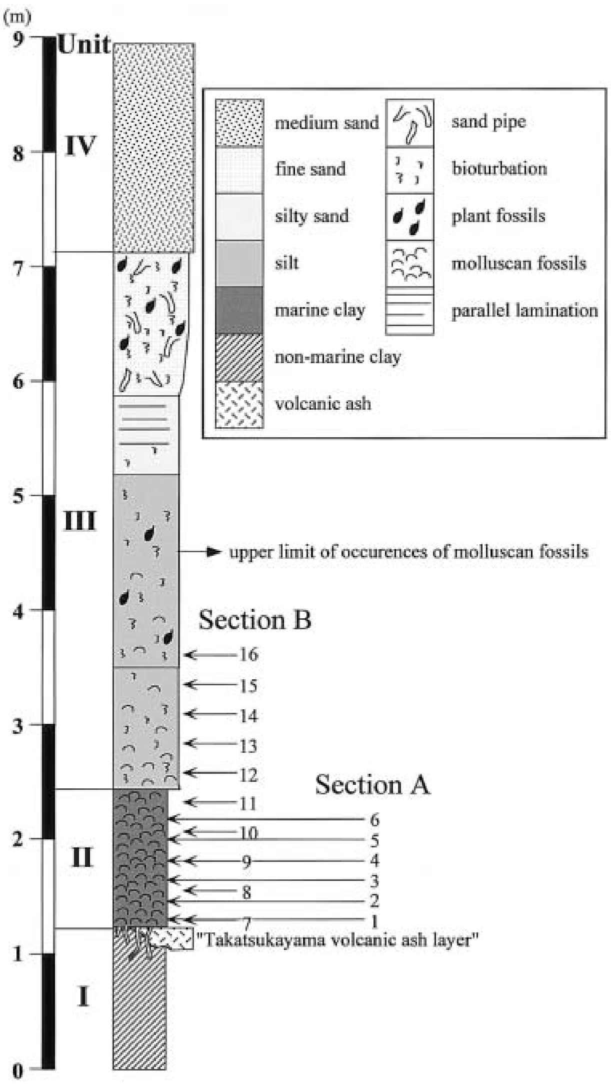


Figure 2. A columnar section with sample horizons at the study site.

lution for about one hour. After the remaining naphtha was removed, the samples were boiled again for about two hours and washed with water on a 200-mesh sieve screen. As far as possible, 200 ostracode specimens were picked from the dried fractions on a 115-mesh sieve screen (0.125 mm) under a binocular microscope. The number of specimens refers to both valves and carapaces.

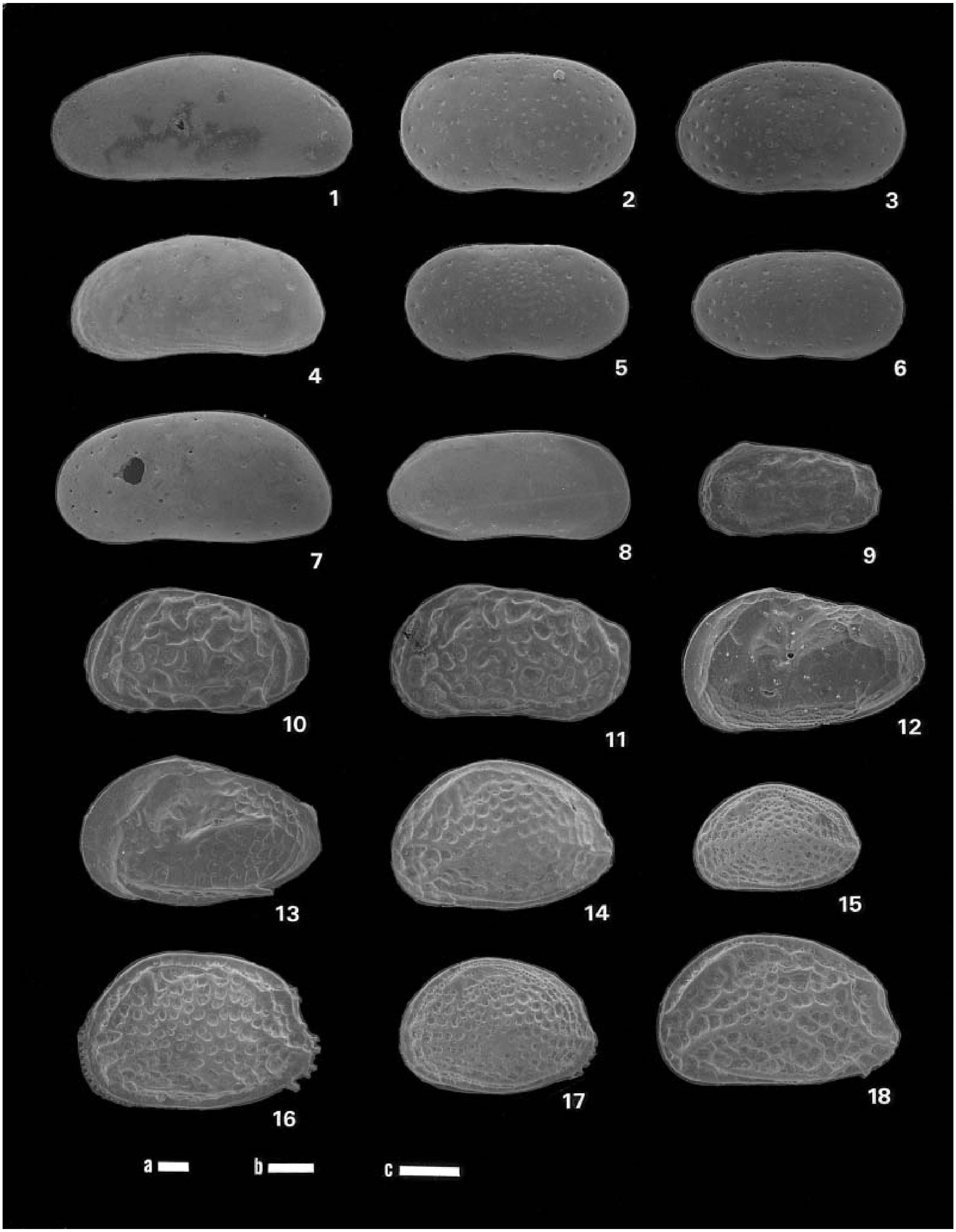
Results

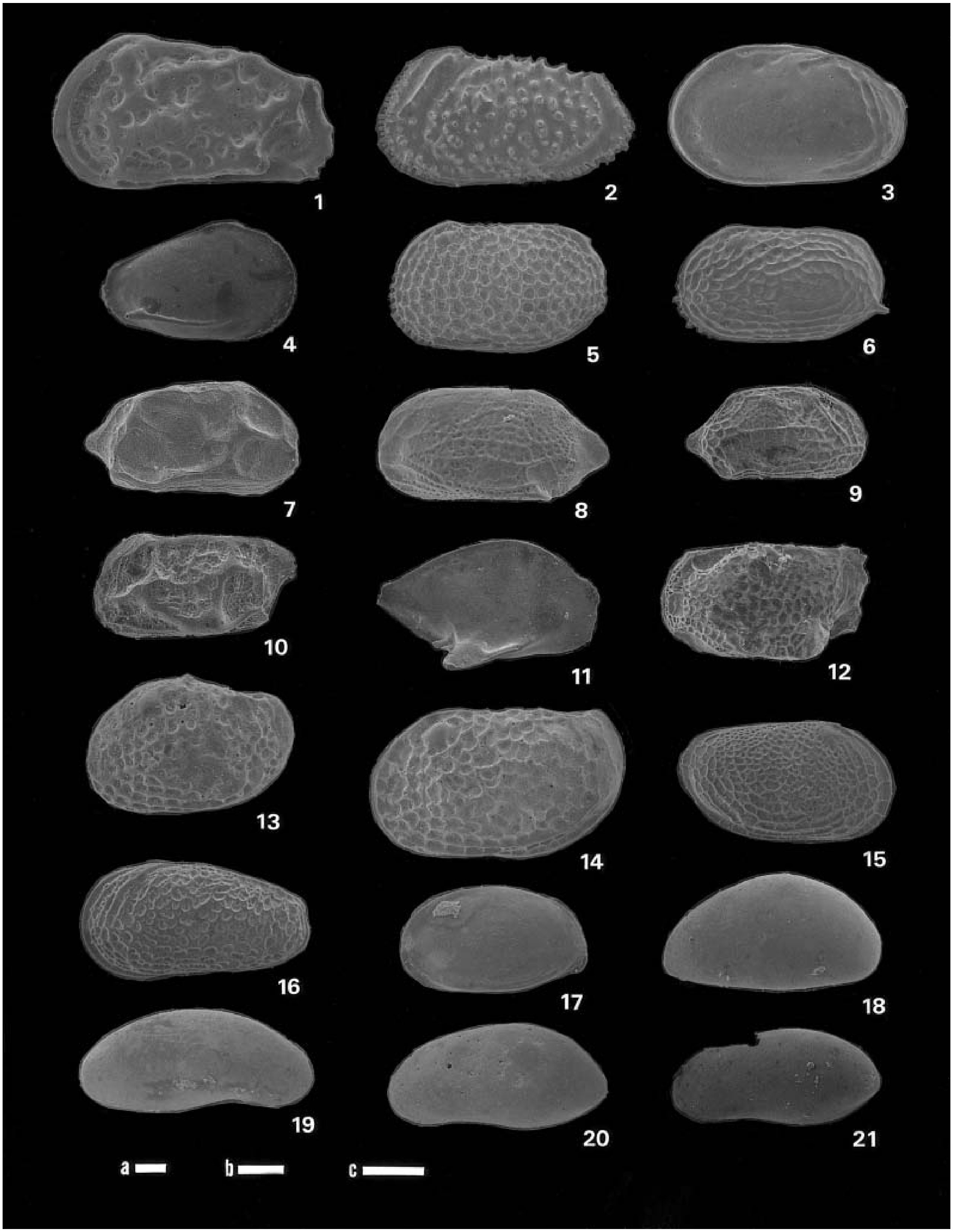
Occurrence of ostracodes

Thirty-seven ostracode species were identified in 15 samples, but not in sample TAK-16. All species, except *Xestoleberis hanaii* Ishizaki and *X. suetsumuhana* Yajima, the valves of which were broken or badly preserved, are presented in Figures 3 and 4. Species numbers in each sample ranged from 14 to 23 and the species diversity index (Shannon-Wiener function: $H(S) = -\Sigma p_i \ln p_i$, where p_i means the proportion of the ith species) ranged between ca. 1.82 and 2.51 (Table 1). The dominant species was *Sinocytheridea impressa* (Brady). Living specimens of the genus *Sinocytheridea* have only been observed in inner brackish areas of Ariake Bay, Kyushu Island, southwestern Japan (*Sinocytheridea* sp. of Iwasaki, 1992) and only one valve has been recovered from Hiuchi-nada Bay in the Seto Inland Sea, southwestern Japan (*Sinocytheridea* sp. of Yamane, 1998) (Figure 5). *Sinocytheridea* has not been reported from other recent Japanese bays. *Sinocytheridea impressa* is dominant in oligohaline to euhaline, supratidal to upper-shelf waters less than 20 m deep along the Chinese coasts and is especially abundant in the brackish waters influenced by freshwater inflows (e.g., Zhao, 1984, 1987; Zhao and Wang, 1988; Wang and Zhao, 1991) (Figure 5). The subordinate species were *Trachyleberis scabrocuneata* (Brady) and *Callistocythere undulatifacialis* Hanai.

➡ **Figure 3.** Selected ostracode species from the middle Pleistocene Takatsukayama Member of the Meimi Formation (Part 1). All figures were taken by the scanning electron microscope (SEM). All specimens are stored in the Department of Geoscience, Interdisciplinary Faculty of Science and Engineering, Shimane University (DGSU). Scale bars indicate 0.1 mm (a for 2, 3, 5, 6, 14–17; b for 1, 4, 7, 9–11, 13 and 18; c for 8 and 12). LV: left valve, RV: right valve.

1. *Aglaiocypris* sp., adult LV, sample TAK-1, DGSU no. CO0155. **2, 3, 5, 6.** *Sinocytheridea impressa* (Brady); 2. female LV, sample TAK-3, DGSU no. CO0156; 3. female RV, sample TAK-3, DGSU no. CO0157; 5. male LV, sample TAK-3, DGSU no. CO0158; 6. male RV, sample TAK-3, DGSU no. CO0159. **4.** *Pontocythere miurensis* (Hanai), female LV, sample TAK-12, DGSU no. CO0160. **7.** *Parakrithella pseudadonta* (Hanai), female LV, sample TAK-3, DGSU no. CO0161. **8.** *Pseudopsammocythere tokyoensis* Yajima, female RV, sample TAK-5, DGSU no. CO0162. **9.** *Munseyella japonica* (Hanai), male LV, sample TAK-2, DGSU no. CO0163. **10.** *Callistocythere alata* Hanai, female LV, sample TAK-13, DGSU no. CO0164. **11.** *Callistocythere undulatifacialis* Hanai, female LV, sample TAK-3, DGSU no. CO0165. **12.** *Spinileberis furuyaensis* Ishizaki and Kato, female LV, sample TAK-4, DGSU no. CO0166. **13.** *Spinileberis quadriaculeata* (Brady), female LV, sample TAK-1, DGSU no. CO0167. **14.** *Aurila cymba* (Brady), female LV, sample TAK-5, DGSU no. CO0168. **15.** *Aurila disparata* Okubo, female LV, sample TAK-4, DGSU no. CO0169. **16.** *Aurila spinifera* s.l. Schornikov and Tsareva, female LV, sample TAK-5, DGSU no. CO0170. **17.** *Aurila uranouchiensis* Ishizaki, female LV, sample TAK-6, DGSU no. CO0171. **18.** *Robustaurila ishizakii* (Okubo), female LV, sample TAK-1, DGSU no. CO0172.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
a
b
c


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
a
b
c

The former is widely distributed in enclosed bays in eastern Asia and the latter lives in sandy bay coasts (e.g., Hanai *et al.*, 1977). *Aurila spinifera* s.l. Schornikov and Tsareva is also dominant and is reported abundant in Holocene deposits in Osaka Bay off Kobe (Irizuki *et al.*, 2001) and Hiuchi-nada Bay in the Seto Inland Sea (Yamane, 1998), and also from middle Pleistocene deposits in central Japan (Irizuki *et al.*, 2002).

Sinocytheridea impressa occurs in the middle part of Unit II and increases in abundance moving upwards in the sequence (Figure 6). Vertical changes in the relative frequency of *T. scabrocuneata* and *A. spinifera* s.l. are similar to that of *S. impressa*. Frequency peaks of the three species are situated in the upper part of Unit II to the lower part of Unit III (Figure 6). On the other hand, relative frequencies of *C. undulatifacialis*, and such inner bay species as *Spinileberis quadriaculeata* (Brady) and *Bicornucythere* sp., decrease upwards in Unit II and are rare in the lower part of Unit III (Figure 6). *Spinileberis quadriaculeata* is dominant in the inner part of enclosed muddy bays at a water depth of 2–7 m (Ikeya and Shiozaki, 1993). *Bicornucythere* sp. is taxonomically identical with *Leguminocythereis hodgii* (Brady) of Ishizaki (1968), *Bicornucythere bisanensis* (Okubo) of Irizuki and Hosoyama (2000), and *Bicornucythere bisanensis* form M of Irizuki *et al.* (2001), Yasuhara and Irizuki (2001), and Yasuhara *et al.*, (2002a, b). This species is very similar to the types of *B. bisanensis* which correspond to *B. bisanensis* "form A" of Abe (1988). The former differs from the latter in having more slender and smaller valves especially in males and juveniles. It is also very similar to *B. bisanensis* "form M" of Abe (1988) but the latter has a more rectangular valve shape, especially in juveniles. *Bicornucythere* sp. has also been observed in middle Pleistocene deposits in the Tokai region, central Japan (Irizuki and Hosoyama, 2000; Irizuki *et al.*, 2002; Irizuki and Seto, 2004) and Holocene deposits in the Osaka Bay region (Irizuki *et al.*, 2001; Yasuhara and Irizuki, 2001; Yasuhara *et al.*, 2002a, b, 2004). There is no clear tendency for the relative frequencies of such bay species as *Cytheromorpha acupunctata* (Brady) and *Pistocythereis bradyi* (Ishizaki) to change vertically throughout the sequences.

Compared with ostracode assemblages from the Holocene borehole core deposits excavated in Osaka Bay and on the Osaka Plain (Irizuki *et al.*, 2001; Yasuhara *et al.*, 2002a, b, 2004), and those from present-day Osaka Bay (Yasuhara and Irizuki, 2001) and Hiuchi-nada Bay (Yamane, 1998), the Takatsukayama Member is especially characterized by the presence of *S. impressa* and by the absence of *B. bisanensis*, which is widely and abundantly distributed in Japanese enclosed bays (Ikeya and Shiozaki, 1993).

Faunal analysis

Q-mode cluster analysis based on Horn's (1966) overlap index and the group average method was undertaken for 15 samples from the Takatsukayama Member to identify biofacies. Three biofacies (IB, BC and CB) were delineated (Figure 7) and are explained as follows:

Biofacies IB (Inner Bay) is composed of only one sample (TAK-7) from the lowest part of Unit II in section A. The species number is only 14. *Spinileberis quadriaculeata* is the dominant species. Others are such sandy bay coastal species as *Aurila cymba* (Brady) and *Munseyella japonica* (Hanai). The depo-

← **Figure 4.** Selected ostracode species from the middle Pleistocene Takatsukayama Member of the Meimi Formation (Part 2). All figures were taken by the scanning electron microscope (SEM). All specimens are stored in the Department of Geoscience, Interdisciplinary Faculty of Science and Engineering, Shimane University (DGSU). Scale bars indicate 0.1 mm (a for 2, 5 and 6; b for 1, 3, 11, 13, 14, 16, 17, 19–21; c for 4, 7–10, 12, 15 and 18). LV: left valve, RV: right valve.

1. *Cornucoquimba tosaensis* (Ishizaki), female LV, sample TAK-2, DGSU no. CO0173. **2.** *Trachyleberis scabrocuneata* (Brady), female LV, sample TAK-3, DGSU no. CO0174. **3.** *Falsobuntonia hanaii* (Yajima), female LV, sample TAK-5, DGSU no. CO0175. **4.** *Pistocythereis bradyformis* (Ishizaki), juvenile RV, sample TAK-1, DGSU no. CO0176. **5.** *Pistocythereis bradyi* (Ishizaki), female LV, sample TAK-3, DGSU no. CO0177. **6.** *Bicornucythere* sp. female LV, sample TAK-5, DGSU no. CO0178. **7.** *Semicytherura* sp., female RV, sample TAK-4, DGSU no. CO0179. **8.** *Semicytherura mukaishimensis* Okubo, female LV, sample TAK-5, DGSU no. CO0180. **9.** *Semicytherura polygonoreticulate* Ishizaki and Kato, female RV, sample TAK-2, DGSU no. CO0181. **10.** *Semicytherura* cf. *yajimae* Ikeya and Zhou, adult LV, sample TAK-12, DGSU no. CO0182. **11.** *Cytheropteron donghaiense* (Zhao), adult RV, sample TAK-5, DGSU no. CO0183. **12.** *Bythoceratina*? sp., adult LV, sample TAK-5, DGSU no. CO0184. **13.** *Loxoconcha hattorii* Ishizaki, female LV, sample TAK-1, DGSU no. CO0185. **14.** *Loxoconcha tosaensis* Ishizaki, male LV, sample TAK-7, DGSU no. CO0186. **15.** *Loxoconcha uranouchiensis* Ishizaki, juvenile RV, sample TAK-1, DGSU no. CO0187. **16.** *Cytheromorpha acupunctata* (Brady), female LV, sample TAK-3, DGSU no. CO0188. **17.** *Nipponocythere bicarinata* (Brady), female LV, sample TAK-3, DGSU no. CO0189. **18.** *Xestoleberis* sp. juvenile LV, sample TAK-7, DGSU no. CO0190. **19.** *Sclerochilus* sp. adult RV, sample TAK-3, DGSU no. CO0191. **20, 21.** *Paracytheroma* sp.; 20. female LV, sample TAK-4, DGSU no. CO0192; 21. male LV, sample TAK-6, DGSU no. CO0193.

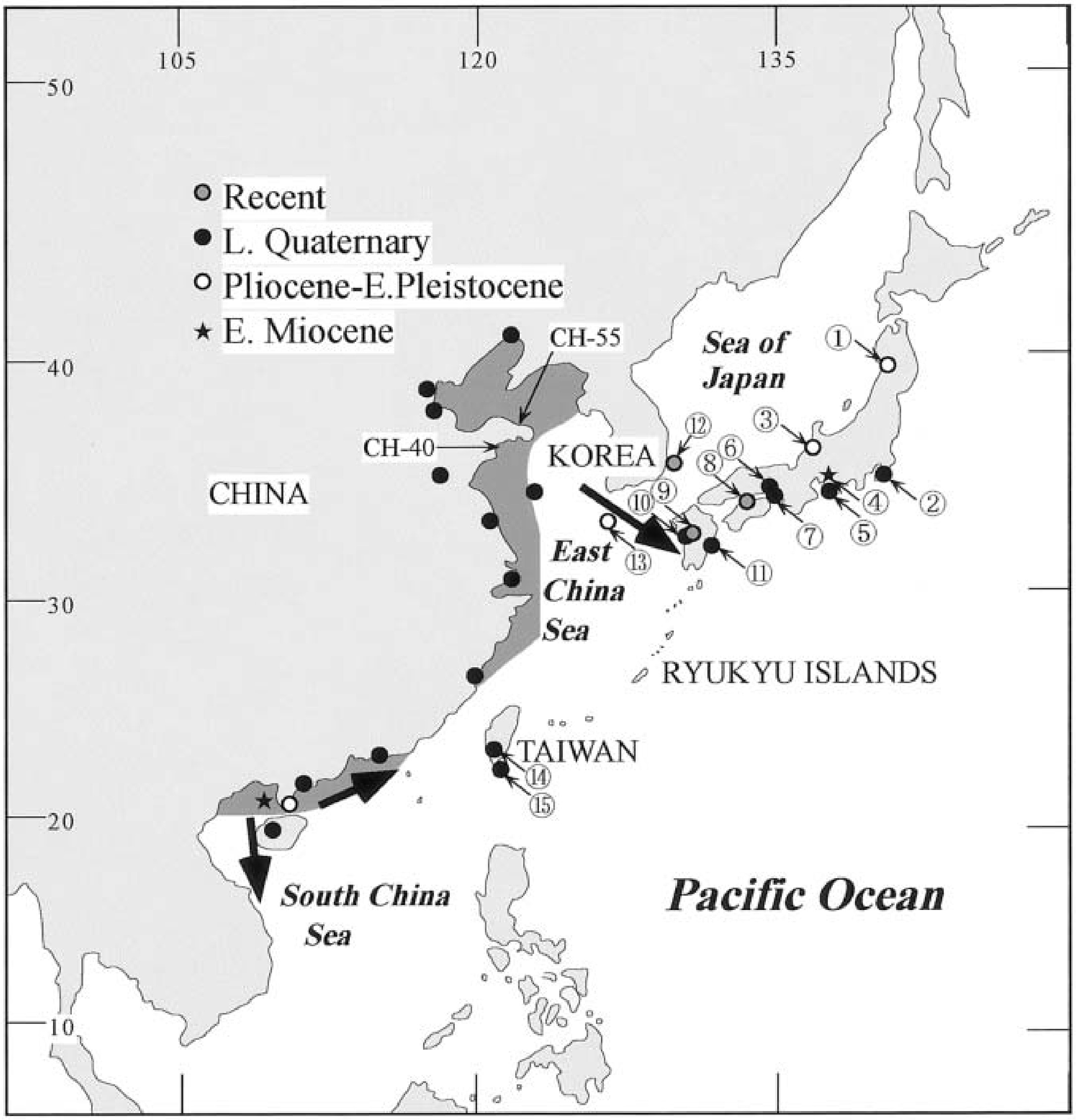
Table 1. Occurrence list of fossil ostracodes from the middle Pleistocene Takatsukayama Member of the Meimi Formation.

Takatsukayama (TAK)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**sum.**
Aglaiocypris sp.	2															2
Aurila cymba (Brady)	16	18	4	1	7		11	9	14	5			3	1	1	90
Aurila disparata Okubo	8	6	2	10	3	4		6	10	3	7	5	14	6		84
Aurila spinifera Schornikov & Tsareva s.l.			7	9	24	22				19	15	24	62	52	40	274
Aurila uranouchiensis Ishizaki				1		1			1	1	3					7
Bicornucythere sp.	23	19	8	12	7	3	8	12	10	13	5	6	2		1	129
Bythoceratina ? sp.					1											1
Callistocythere alata Hanai			2		6	6					4	2	17	11	1	49
Callistocythere undulatifacialis Hanai	43	45	22	24	21	13	5	72	102	23	29	8	27	14	9	457
Cornucoquimba tosaensis (Ishizaki)	5	10	11	18	13	17		18	44	17	5	16	18	10	5	207
Cytheromorpha acupunctata (Brady)	29	16	12	11	23	23	8	13	16	11	11	9	34	13	2	231
Cytheropteron donghaiense (Zhao)					1							1				2
Falsobuntonia hanaii Yajima			3		2	1					1		5	1	4	17
Loxoconcha hattorii Ishizaki	8	12				1	3	1		1			1			27
Loxoconcha tosaensis Ishizaki	5	7		1			7	4		1	1		1			27
Loxoconcha uranouchiensis Ishizaki	1		1	2			3									7
Munseyella japonica (Hanai)	15	21		2		1	11	10	3	1			1			65
Nipponocythere bicarinata (Brady)	1	1	8	8	11	20		1	1		1	1	1			54
Paracytheroma sp.				1	1	1							1			4
Parakrithella pseudadonta (Hanai)		1	4	2	4	1		2		2	2	1	3		1	23
Pistocythereis bradyformis (Ishizaki)	2		1													3
Pistocythereis bradyi (Ishizaki)	16	17	14	9	5	11		13	6	5	6	3	10	6	4	125
Pontocythere miurensis (Hanai)				1							1	2	1	2		7
Pseudopsammocythere tokyoensis Yajima	2	1	2	4	1			1			1		1			13
Robustaurila ishizakii (Okubo)	2						1	2								5
Sclerochilus sp.			1													1
Semicytherura mukaishimensis Okubo			1		1	1					1					4
Semicytherura polygonoreticulata Ishizaki & Kato		1			1											2
Semicytherura cf. *yajimae* Ikeya & Zhou						1						1				2
Semicytherura sp.	1			3		1	1		1				4	1		12
Sinocytheridea impressa (Brady)			41	79	72	75			2	43	40	68	112	62	43	637
Spinileberis furuyaensis Ishizaki & Kato		3		1			1							1		6
Spinileberis quadriaculeata (Brady)	17	19	11	6	16	8	35	15	13	3	6	10	30	17	4	210
Trachyleberis scabrocuneata (Brady)	3	7	43	39	57	35	3	17	36	40	38	42	71	60	41	532
Xestoleberis hanaii Ishizaki	1											1	1			3
Xestoleberis suetsumuhana Yajima														1		1
Xestoleberis sp.	4	1		1			4			1			1	1	1	14
Number of species	21	18	20	23	21	21	14	16	14	17	19	17	24	17	14	37
Species diversity	2.51	2.47	2.42	2.34	2.34	2.28	2.16	2.18	1.91	2.23	2.28	2.05	2.29	2.09	1.82	
Equitability	0.59	0.65	0.57	0.45	0.49	0.47	0.62	0.55	0.48	0.55	0.52	0.46	0.41	0.48	0.44	
Number of specimens	204	205	198	245	277	246	101	196	259	189	177	200	421	259	157	3334
Individual No. / 1g sedeiment	5.08	5.11	9.86	12.2	13.8	24.5	2.52	3.92	6.5	4.72	4.41	10	21	8.63	1.95	6.53
Sample weight (g)	40.2	40.1	20.1	20.1	20	10	40.1	50	39.9	40.1	40.1	20	20	30	80.4	511

sitional environment of this biofacies is typical of enclosed inner sandy and muddy bays at water depths of around 5 m.

Biofacies BC (Bay Coast) is composed of four samples (TAK-1, 2, 8, and 9) from the lowest part of Unit II in section B and the lower part of Unit II in section A. It contains many *C. undulatifacialis*, with subordinate numbers of *Cornucoquimba tosaensis* (Ishizaki) and *C. acupunctata*. Moreover, such inner muddy bay species as *Bicornucythere* sp. and *S. quadriaculeata* are included. The depositional environment of this biofacies was inner sandy bay coast.

Biofacies CB (Central Bay) is composed of six samples (TAK-3 to 6, 10, and 11) from the middle to upper part of Unit II in both sections A and B and four samples (TAK-12 to 15) from the lower part of Unit III in section B. *Sinocytheridea impressa* is the dominant species. Subordinate species are *T. scabrocuneata* and *A. spinifera* s.l. Co-occurrences of many specimens of *A. spinifera* s.l. and *T. scabrocuneata* are observed in samples from northwestern Osaka Bay off Kobe at the peak of transgression (ca. 6,000 to 5,000 cal. yr BP) during the Holocene (Irizuki *et al.*, 2001). At that time, tidal currents from the Akashi Strait



① Sasaoka Fm.; Yamada *et al.* (2002)
② Yabu Fm.; Ozawa *et al.* (1995)
③ Omma Fm.; Ozawa (1996)
④ Toyama Fm.; Irizuki *et al.* (2004)
⑤ Atsumi Gr.; Ishizaki (1987)
⑥ Takatsukayama Mb. ; This study
⑦ Osaka Bay; Ishizaki (1990a)
⑧ Hiuchi-nada Bay; Yamane (1998)
⑨ Ariake Bay; Iwasaki (1992)
⑩ Kitaarima Fm.; original data
⑪ Toriyamahama Fm.; Nakao (1993)
⑫ off Ulsan; Cheong (1986)
⑬ Sogwipo Fm.; Lee and Paik (1992)
⑭ Ssukou Fm.; Hu and Yeh (1978)
⑮ Hengchun Limestone; Hu (1982, 1984)

Figure 5. Temporal and spatial distributions of the genus *Sinocytheridea* in East Asia. Data from the mainland in China are based on Wang and Zhao (1991). References in other areas (Japan, Korea and Taiwan) are listed in the figure. CH-40 and CH-55 mean the sample localities of specimens for the analysis of measurements of valve size in this study. Solid large arrows indicate possible ways of migration and dissemination (Wang and Zhao, 1991).

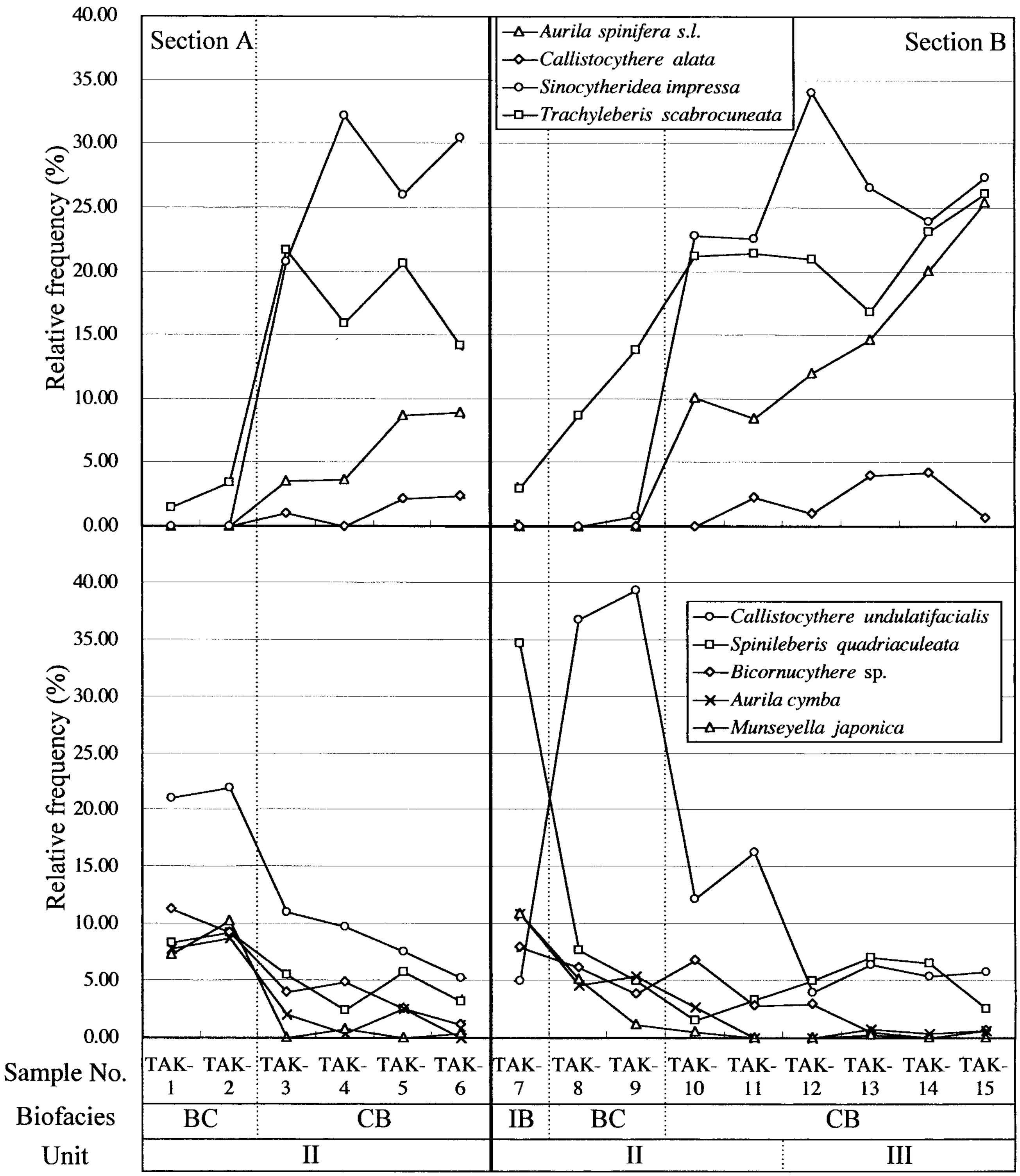


Figure 6. Vertical changes of relative frequencies of selected species from the Takatsukayama Member.

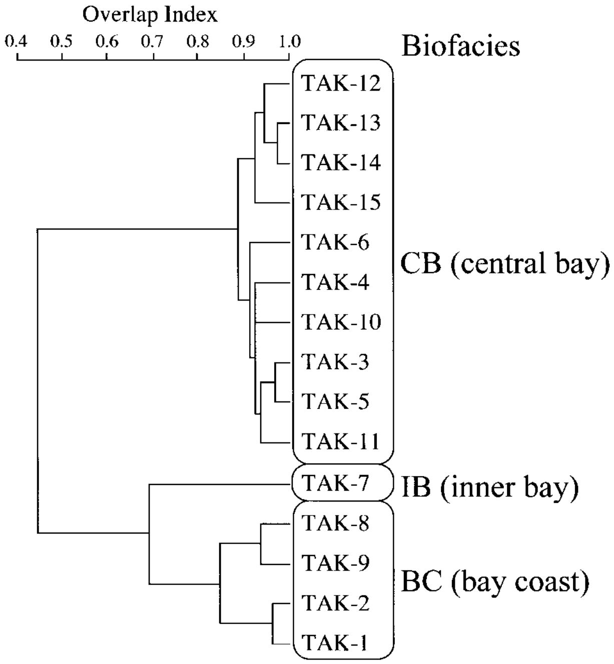


Figure 7. Dendrogram showing the result of Q-mode cluster analysis.

connecting Osaka Bay and Harima-nada Bay were intensified and sandy sediments were supplied to Osaka Bay off Kobe (Masuda *et al.*, 2000, 2002). Very rare species, such as *Cytheropteron donghaiense* (Zhao) and *Falsobuntonia hanaii* (Yajima), that are important as environmental indicators, are also found. The former mainly lives at water depths of more than about 15 m and the latter is distributed under the influence of the warm Kuroshio Current or in an open shelf area. Therefore, the depositional environment of this biofacies was middle bay, where sandy sediments were supplied by currents under the influence of freshwater inflows.

Size of *Sinocytheridea impressa*

We measured the valve size (length and height of left valves) of *S. impressa* to investigate size variation. We also measured the valve size of *S. impressa* from samples T144 and T144′ in the N8 clay layer off Senshu, which are the same samples as those reported by Ishizaki (1990a), and also from two Recent surface sediment samples (CH-40 and CH-55) along the Shangton Peninsula in northeastern China (Figure 5). Sample CH-40 is composed of mud containing shell fragments and was collected on August 14, 1999, from the Yellow Sea, 10 km SSE of Wangchun, on the southern coast of the Shangton Peninsula (Latitude: 36°26′N, Longitude: 120°56′E). The water depth is about 4–5 m and salinity 28‰. Sample CH-55 was collected on August 20, 1999, from the Bohai Gulf, east of Weihai on the northern coast of the Shangton Peninsula (Latitude: 37°31′N, Longitude: 122°09′E). The water depth there is 13 m and salinity is 29‰. Valve length/height diagram is shown in Figure 8. Specimens from the Takatsukayama Member are all plotted in areas dominated by those from samples T144 and T144′. The lengths of the left valves of adult specimens from the Takatsukayama Member range from 0.76–0.88 mm in females and 0.73–0.83 mm in males. A Mann–Whitney U-test of the measured valve lengths was performed (Table 2). The valve size of specimens from the Takatsukayama Member is the same as that for specimens from the N8 clay layer, with a 95% confidence level. Specimens from the

Table 2. Calculated probability values by a Mann-Whitney's U-test of valve length in *Sinocytheridea impressa*. Values less than 0.01 are taken in significant difference between samples compared.

Male	TAK	T-144	CH-55	CH-40
TAK		0.1489	<0.01	<0.01
T-144			<0.01	<0.01
CH-55				0.5224
CH-40				

Female	TAK	T-144	CH-55	CH-40
TAK		0.052	<0.01	<0.01
T-144			<0.01	<0.01
CH-55				0.968
CH-40				

A-1	TAK	T-144	CH-55	CH-40
TAK		0.276	<0.01	<0.01
T-144			<0.01	<0.01
CH-55				0.417
CH-40				

A-2	TAK	T-144	CH-55	CH-40
TAK		0.9365	<0.01	<0.01
T-144			<0.01	<0.01
CH-55				0.88
CH-40				

A-3	TAK	T-144	CH-55	CH-40
TAK		0.012	<0.01	<0.01
T-144			<0.01	<0.01
CH-55				0.817
CH-40				

Shangton Peninsula are all smaller than the Japanese Pleistocene specimens, with a 95% confidence level. According to the size data for *S. impressa*, including those of type specimens from some references (Hou *et al.*, 1982; Gou *et al.*, 1983; Whatley and Zhao, 1988 and so on), the length of female valves ranges from about 0.67–0.77 mm. Therefore, the specimens from paleo-Osaka and Harima-nada Bays are larger than any other *S. impressa* samples.

Discussion

Vertical changes in the depositional environment

A few authors (Ando, 1953, 1954; Huzita and Maeda, 1984; Hashimoto and Maeda, 1989; Sato *et al.*, 1997) have previously considered the reconstruction of the depositional environment of the Takatsukayama Member. Hashimoto and Maeda (1989) suggested, on the basis mainly of molluscan fossils, that the member was formed in a shallow inner bay and they reconstructed the signature of a bay coastal line. Sato *et al.* (1997) studied fossil diatoms and analyzed the chemistry of the sediments from the member in detail. In their study, Unit I was inferred to have been freshwater in origin, with the sediments deposited in a swamp or lake. Water depth gradually increased upwards in the sequence. Unit II was thought to have been deposited in a bay environment, whereas Unit III was of shallow marine origin with water depth decreasing upwards in the sequence.

Our study has used new data from ostracodes to refine the depositional environments represented in the member. The stratigraphical distribution of three ostracode biofacies in the member is shown in Figure 9. Vertical changes in the depositional environment are reconstructed on the basis of the fossil ostracodes as follows. The lowermost part of Unit II was deposited in a shallow inner muddy bay (biofacies IB) or inner bay sandy coast (biofacies BC) during an early transgression. Thereafter, the bay was rapidly enlarged and deepened, and the study site became brackish, in an enclosed nutrient-rich and highly turbid middle bay under the influence of freshwater inflow from many rivers. The water depth around this interval probably reached at least 15 m. The maximum flooding surface was at the horizon above the interval of ostracode-bearing samples because *Aurila spinifera* s.l. increases upwards in the sequence and is most abundant in the uppermost sample (sample TAK-15). Therefore, the results of the present study are consistent with those of previous studies except that we define the water depth as rapidly increasing at the deposition of the middle part of Unit II, which corresponds to the boundary between biofacies BC and CB.

Occurrence of *Sinocytheridea impressa*

The genus *Sinocytheridea* was proposed by Hou (Hou *et al.*, 1982) with two referred species, the type species *S. latiovata* Hou and Chen and *S. longa* Hou and Chen. Whatley and Zhao (1988) taxonomically examined the type species and other related species, and concluded that *S. latiovata*, *Cyprideis yehi* Hu and Yeh, *S. longa*, and *Eucytheridea sinobesani* Hu are synonyms of *S. impressa*. The former two are female and the latter two are males of *S. impressa*. Thus, the genus *Sinocytheridea* has been reduced to a single species, *S. impressa*. Nevertheless, there are some other morphological variations (e.g., *Sinocytheridea* sp. of Irizuki *et al.*, 2004) and new species might be described in the future. The specimens of *S. impressa* from the Takatsukayama Member have almost the same valve morphology as the type specimens designated by Whatley and Zhao (1988; plate 1, figs. 8–10). Figure 5 shows the localities at which the genus *Sinocytheridea* has been reported in the literature. The oldest *Sinocytheridea* is from lower Miocene deposits of the Beibu Gulf, South China Sea (Wang and Zhao, 1991), and central Japan (Irizuki *et al.*, 2004). Wang and Zhao (1991) thought that *S. impressa* migrated from the Beibu Gulf area to the north and south, and came to Japan through the East China Sea. Ishizaki (1990a) mentioned that this species migrated to Japan pre-0.44 Ma when the East China Sea was a shallow sea and thus came to Japan. Recently, *S. impressa*, reported as *S. latiovata*, was recognized in the upper Pliocene Sasaoka Formation in the Tohoku district, on the Japan Sea coast of northern Japan (the Sasaoka Formation; Yamada *et al.*, 2002) (Figure 5). Ozawa (1996) reported it also from the lower Pleistocene Omma Formation in the Hokuriku district on the Japan Sea coast, central Japan (Figure 5). Therefore, *S. impressa* lived commonly along the Japan Sea coast during the late Pliocene to early Pleistocene.

Ishizaki (1984, 1990a) studied middle Pleistocene to Holocene ostracodes from borehole core samples excavated in the eastern part of Osaka Bay, off Senshu (Figure 1). Ostracodes were abundant in samples from marine clay layers N8, N6, N5, N2, and N1 (in ascending order) studied by Okamura and Yamauchi (1984). Ishizaki (1990a) recognized that *S. impressa* was present only in samples from the N8 and N6 clay layers, with none in the other younger samples. Ishizaki (1990a, b) thought that the cause of this disappearance was the splitting of the *S. impressa* population (vicariance event) because of deepened shelf

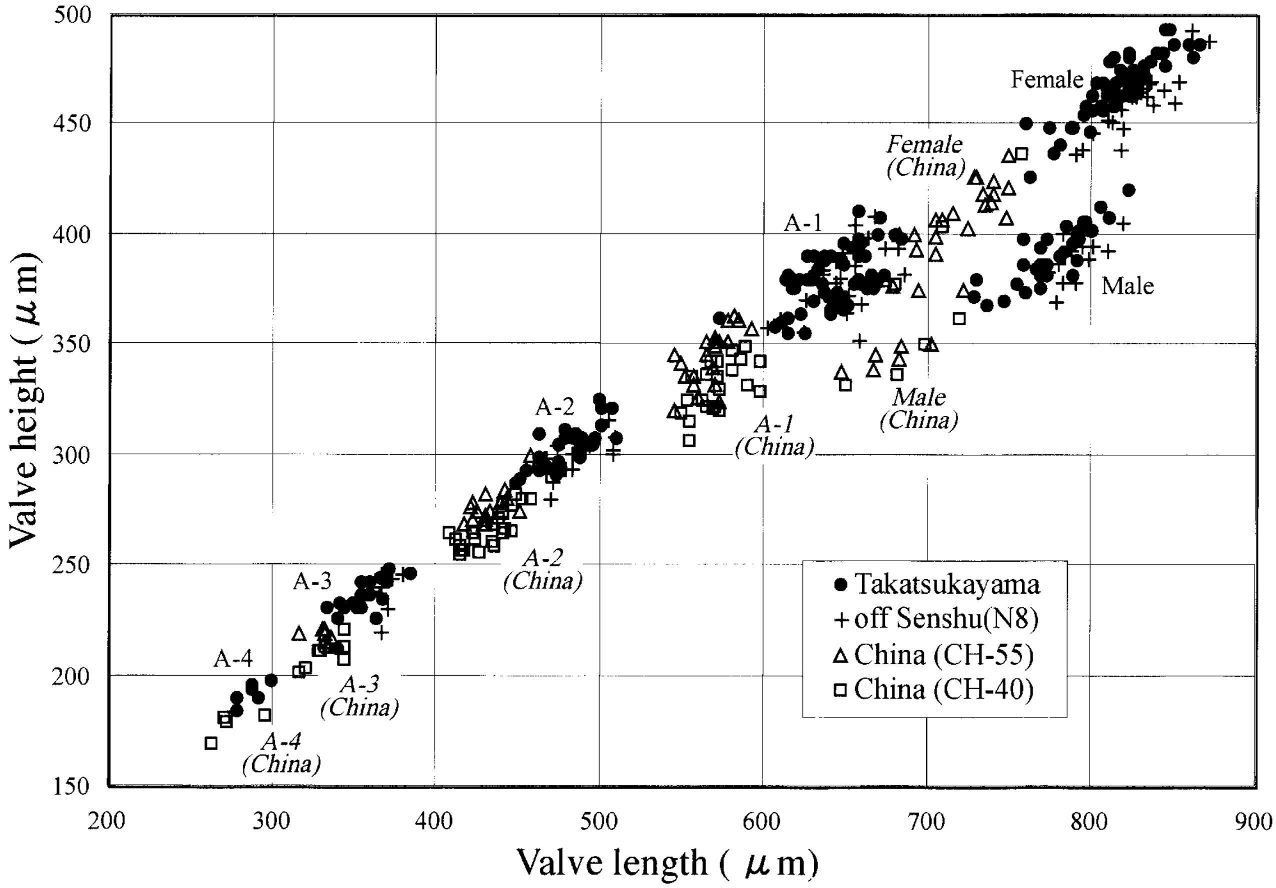


Figure 8. Diagram showing the relationship between valve length and height, A-1 to A-4 mean juvenile stages.

areas between China and Japan that resulted from the transgression at the time of deposition of the N5 clay layer, and that this species was replaced by *Spinileberis quadriaculeata*. The ages of the marine clay layers off Senshu are controversial. Masuda (1993) proposed two possible correlations between oxygen isotope curves and marine clay layers. Clay layers N8, N6, N5, N2, and N1 were assigned to MIS 15, 11, 9, 5, and 1, respectively, or MIS 13, 9, 7, 5 and 1, respectively. However, he noted that the former is more probable. Correlations reported by Yoshikawa and Mitamura (1999) are the same as those of Masuda. If this hypothesis is correct, *S. impressa* was living off Senshu until MIS 11. In the present study, many specimens of *S. impressa* occurred from the middle to the upper part of Unit II and the lower part of Unit III. This study supports the proposition that *S. impressa* lived in paleo-Harima-nada and Osaka Bays until at least MIS 11. As the study site was situated under the stronger influence of freshwater inflows than areas off Senshu, *S. impressa* is abundantly found in the Takatsukayama Member.

Ozawa *et al.* (1995) reported a few specimens of *Sinocytheridea* sp. from the middle Pleistocene Yabu Formation, Chiba Prefecture, central Japan, which is assigned to MIS 9. It is uncertain whether or not this species is conspecific with *S. impressa*, but *Sinocytheridea* might have survived until at least MIS 9 in other areas besides Kyushu Island (the inner part of Ariake Bay), where *Sinocytheridea* sp. is extant. *Sinocytheridea impressa* now lives widely in the Bohai Gulf, Yellow Sea, East China Sea, and South China Sea along the Chinese coast. It particularly dominates the mouths of rivers and estuaries in which salinity is lower, nutrients from rivers are abundant, and waters are highly turbid.

According to the paleogeographical map around the Akashi Strait drawn by Hashimoto and Maeda (1989), paleo-Harima-nada Bay was distributed only around Kobe City at the deposition of the Takatsukayama

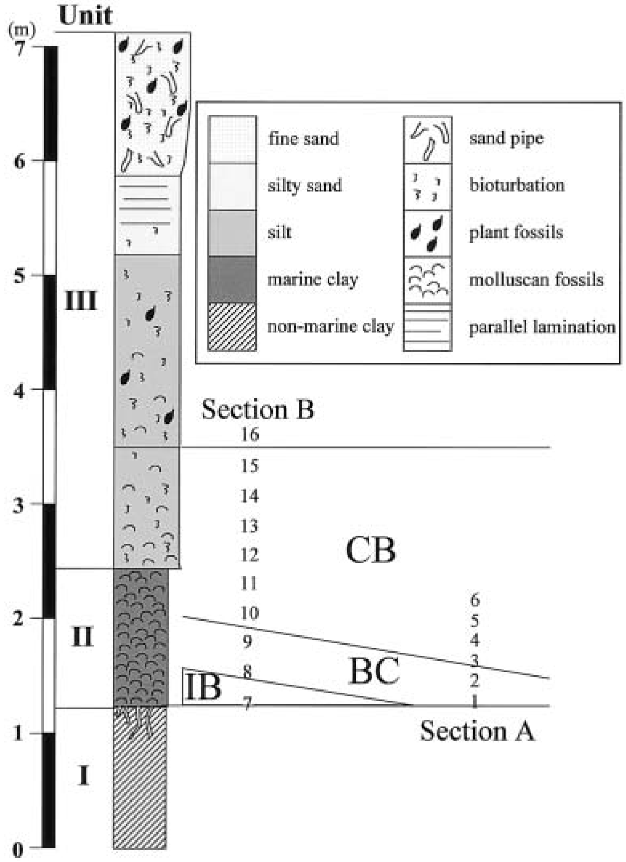


Figure 9. Vertical distribution of biofacies with a columnar section.

Member and seawater did not invade most of the present-day Harima-nada Bay. Paleo-Harima-nada Bay was connected to paleo-Osaka Bay only through the Akashi Strait. Thus, terrigenous sand and mud were supplied abundantly to paleo-Osaka Bay not only from the Yodo River but also from rivers on the Harima Plain. The conditions of paleo-Osaka and Harima-nada Bays were inferred to have been similar to those of the present-day inner part of Ariake Bay, the Yellow Sea, or Bohai Sea. Miyahara and Masuda (1999) investigated the sedimentology of borehole core deposits in the Osaka Bay region. This study suggested that sandy sediments from the Akashi Strait reached eastern Osaka Bay from MIS 9. Therefore, tidal currents through the Akashi Strait strengthened from MIS 9, and seawater circulation in Osaka Bay also intensified. Moreover, the coastline at the deposition of the Iwaoka Member (MIS 7.3; Sato *et al.*, 1999) is inferred to have been more westward in Harima-nada Bay than that at the deposition of the Takatsukayama Member (Hashimoto and Maeda, 1989). The evidence suggests that paleo-Harima-nada Bay was larger at MIS 9 and MIS 7.3 than at MIS 11. We think that one of the reasons for the disappearance or rapid decrease of *S. impressa* from paleo-Osaka Bay was that the bay changed from a low-salinity, enclosed nutrient-rich and highly turbid bay to a moderate salinity, ventilated bay, which is closely linked with the paleogeographical changes around paleo-Osaka Bay, together with the vicariance event suggested by Ishizaki (1990a, b).

According to the ostracode occurrence list of Ishizaki (1984, 1990a), *Neomonoceratina delicata* Ishizaki and Kato was abundant at intervals MIS 9 and MIS 5 in paleo-Osaka Bay off Senshu after *S. impressa* disappeared or rapidly decreased. This species has been reported as abundant in deposits at MIS 7 and MIS 5 in central to eastern Japan (e.g., Ishizaki and Kato, 1976; Yajima, 1982; Ishizaki and Matoba, 1985; Irizuki and Hosoyama, 2000; Kamiya *et al.*, 2001; Irizuki and Seto, 2004). Therefore, we infer that *N. delicata* and not *S. quadriaculeata* might have replaced *S. impressa* after MIS 9. Other species have been recognized based on specimens described as *Bicornucythere bisanensis* (Abe, 1988; Irizuki and Seto, 2004). For example, the first author of the present study investigated specimens referred to *Bicornucythere bisanensis* by Ishizaki (1984, 1990a) in samples collected off Senshu. As a result, both *B. bisanensis* and *Bicornucythere* sp. were identified. *Bicornucythere* sp. occurred in all samples except T102, but *B. bisanensis* only occurred in samples above sample T39, which is in the lowest part of the N2 layer of Ishizaki (1984, 1990a), suggesting that *B. bisanensis* was dominant at least from MIS 5 to the present day. Therefore, three characteristic bay species (*S. impressa*, *N. delicata* and *B. bisanensis*) have lived for a limited time in paleo-Osaka and Harima-nada Bays, although *S. quadriaculeata* and *Bicornucythere* sp. possibly lived there in interglacial periods during the middle to late Pleistocene and Recent (Figure 10).

Sinocytheridea impressa, as recognized in the present study, occurred with such bay taxa as *A. spinifera* s.l., *T. scabrocuneata*, *Bicornucythere* sp., *S. quadriaculeata*, and so on. In the East China Sea, *S. impressa* occurs widely from oligohaline supratidal areas to euhaline seas (Zhao, 1984, 1987; Zhao and Wang, 1988). However, living specimens from Ariake Bay occur with such low-salinity species as *Loxoconcha ocellata* Hou and *Spinileberis furuyaensis* Ishizaki and Kato in the innermost part of the bay (Iwasaki, 1992). Therefore, it seems that most of the turbid and nutrient-rich bays, in which *S. impressa* prefers to live, have diminished in the Japanese islands since the mid-Pleistocene.

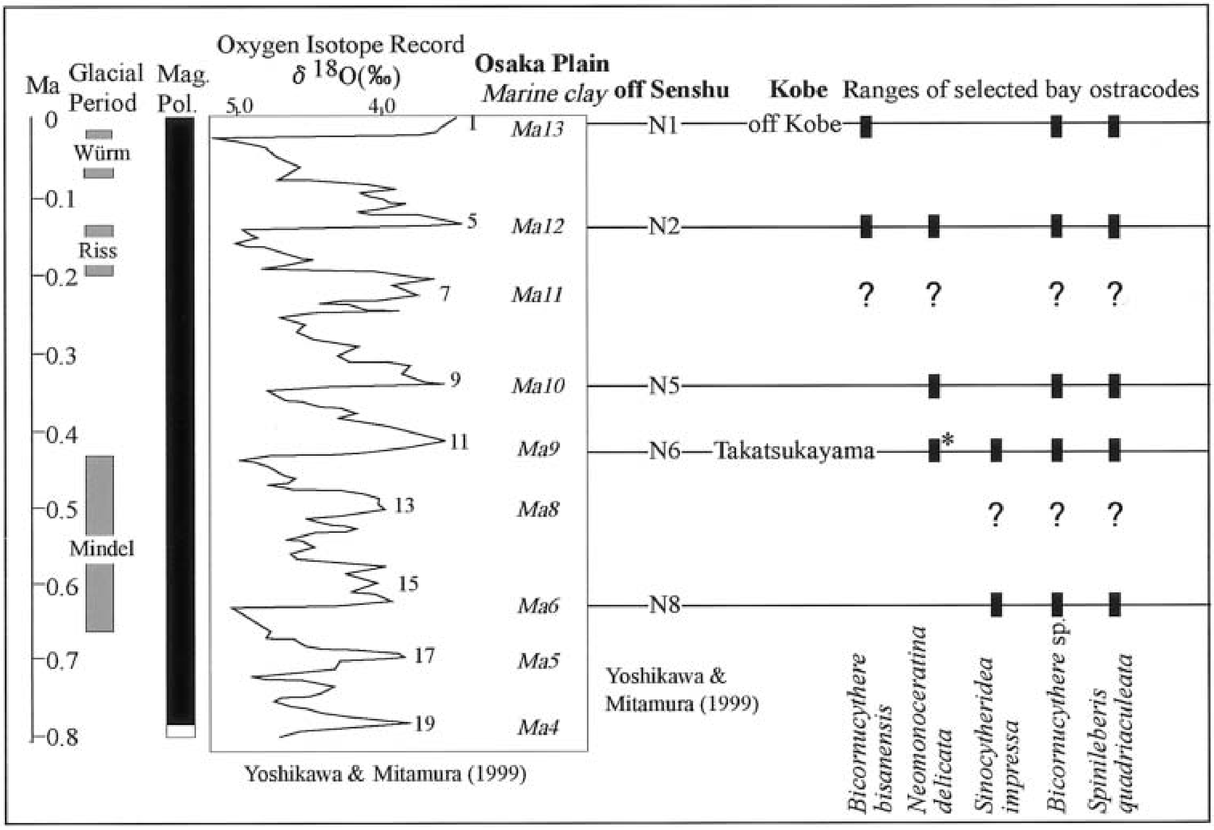


Figure 10. Temporal changes of selected five bay ostracode species in paleo-Osaka and Harima-nada Bays based on Ishizaki (1984, 1990a) and this study. **Neomonoceratina delicata* is not found in the Takatsukayama Member but rarely found in the N6 marine clay layer (Ishizaki, 1984, 1990a). Oxygen isotope stratigraphy and lithostratigraphy in the Osaka Plain were based on Yoshikawa and Mitamura (1999).

Cause of size variations in *S. impressa*

Ishizaki (1990a) recognized that *S. impressa* from the N6 clay layer, which is correlated with the horizon just prior to its disappearance or rapid decrease, has smaller valves than those of specimens from the underlying N8 clay layer, which contains abundant *S. impressa*. He considered that such dwarfing could be caused by environmental constraints severe enough to influence valve size. However, he mentioned that this result is statistically inconclusive because there were only three specimens from the N6 clay layer. Our analysis of *S. impressa* measurements shows that specimens from the Takatsukayama Member (MIS 11) and those from the N8 layer off Senshu (MIS 15) have the same valve sizes. Therefore, the dwarfing (size reduction) suggested by Ishizaki (1990a) did not occur at the study site.

The reasons for the large valve size of *S. impressa* from the paleo-Osaka Bay region are not clear. Valve size depends on environmental factors (ecophenotype) and/or genetic factors (genotype) (e.g., Keen, 1982; Neil, 2000). In the case of the former, a positive relationship between size and food supply has been reported in brackish-water ostracodes (e.g., Keen, 1982). Other examples show that size increase is related to increase in dissolved chemicals, decrease in water temperature and increase in water depth (see Keen, 1982). It is estimated to have been extremely warm during MIS 11 (Howard, 1997). Water temperature is inferred to have been higher at the study site at the time of the deposition of the Takatsukayama Member than in the recent Yellow and Bohai seas, so the large valve size seems independent of water temperature. Water depth is also not an influential factor because the paleo-water-depth of the Takatsukayama Member at the horizon of *S. impressa* abundance is estimated to have been about 15 m. Water depth at the sites of samples CH-40 and CH-55 is about 4–5 m and 13 m, respectively. Therefore, if valve size depends only on environmental factors, food supply or dissolved chemicals from freshwater inflows into the paleo-Osaka and Harima-nada Bays most likely influenced valve size. Alternatively, whether large-valve populations occurred as a result of genetic changes in relation to geographical isolation or not, natural selection operated in favor of increased valve size in paleo-Osaka and Harima-nada Bays for reasons that are as yet uncertain. This has not been clarified in the present study and further assessment is required to determine which of these hypotheses is most likely.

Conclusions

1. Thirty-seven ostracode species were identified in 15 samples from lithological Units II and III at the type locality of the middle Pleistocene (MIS 11) Takatsukayama Member of the Meimi Formation.
2. Three ostracode biofacies (BC, IB, and CB) are distinguished on the basis of Q-mode cluster analysis. The depositional environments of each biofacies can be inferred as bay sandy coast (BC), enclosed inner bay (IB), and middle bay influenced by freshwater inflows from rivers on the Harima Plain (CB).
3. Rapid increase of water depth from bay coastal to middle bay occurred at the horizon in the middle part of Unit II of the Takatsukayama Member.
4. *Sinocytheridea impressa*, which probably disappeared or rapidly decreased from paleo-Osaka Bay about 0.3–0.35 Ma, is abundant at the study sites. One of the reasons for the disappearance or rapid decrease of this species from paleo-Osaka Bay is that the bay changed from a low-salinity, enclosed nutrient-rich and highly turbid bay to a moderate salinity, ventilated bay with good circulation. Thereafter, *Neomonoceratina delicata* replaced it and increased in paleo-Osaka Bay.
5. The valve size of *S. impressa* in paleo-Osaka and Harima-nada Bays is larger than that of any other specimens from Recent seas, including the East China Sea. The cause of this large size in the past might have been an abundant food supply or dissolved chemicals from freshwater inflows into paleo-Osaka and Harima-nada Bays. Alternatively, natural selection operated in favor of increased valve size in paleo-Osaka and Harima-nada Bays for reasons that are as yet uncertain.

Acknowledgments

We thank K. Ishizaki for lending samples from Osaka Bay off Senshu and discussing Pleistocene ostracodes. We are also indebted to N. Ikeya, Q. Zhao, B.C. Zhou, G. Tanaka and K. Tangiku for their help in collecting samples from Chinese coasts. Acknowledgments are also due to H. Sato and S. Katoh for their discussing stratigraphy and depositional environments of the Meimi Formation. The manuscript has benefited from reviews by Q. Zhao and R. Tabuki. This study was supported by a Grant-in-Aid for Scientific Research (C) from the Japan Society for the Promotion of Sciences (No. 15540451 to T. Irizuki). Sampling in China was supported by a Grant-in-Aid for Scientific Research (B) from the Japan Society for the Promotion of Sciences (No. 11691182 to N. Ikeya).

References

Abe, K., 1988: Speciation completed? *In*, Hanai, T., Ikeya, N. and Ishizaki, K., *eds.*, *Evolutionary Biology of Ostracoda: Its Fundamentals and Applications*, p. 919–925. Kodansha and Elsevier, Tokyo and Amsterdam.

Ando, Y., 1953: Molluscan fossils from Maiko and Takatsukayama. *Hyogo Biology*, vol. 2, p. 141–144. (*in Japanese*)

Ando, Y., 1954: Foraminiferal assemblages in the Maiko and Takatsukayama Shell-Beds. *Hyogo Biology*, vol. 2, p. 192–195. (*in Japanese*)

Cheong, H. K., Lee, E. H., Paik, K. H. and Chang, S. K., 1986: Recent ostracodes from the southwestern slope of the Ulleung Basin, East Sea, Korea. *Journal of the Paleontological Society of Korea*, vol. 2, p. 38–53.

Fukuda, O. and Ando, Y., 1951: The Takatsuka-yama Shell-Bed. *The Journal of the Geological Society of Japan*, vol. 57, p. 415. (*in Japanese*)

Gou, Y. S., Zheng, S. Y. and Huang, B. R., 1983: Pliocene ostracode fauna of Leizhou Peninsula and northern Hainan Island, Guangdong Province. *Palaeontologia Sinica, Whole No. 162, New Series B*, no. 18, p. 1–117. (*in Chinese with English abstract*)

Hanai, T., Ikeya, N., Ishizaki, K., Sekiguchi, Y. and Yajima, M., 1977: *Checklist of Ostracoda from Japan and Its Adjacent Seas.* 119 p. University of Tokyo Press, Tokyo.

Hashimoto, I. and Maeda, Y., 1989: *Reading Strata in Kobe, Part 2—Natural History of Kobe During the Past 2 Million Years.* 119 + 12 p. Kobe Shizen Shuppan-Kai [Kobe Nature Publishing Association], Kobe. (*in Japanese*) [available from website at http://www.kobe-c.ed.jp/shizen/sitemap/strbooks.html]

Horn, H. S., 1966: Measurement of "overlap" in comparative ecological studies. *The American Naturalist*, vol. 100, p. 419–424.

Howard, W. R., 1997: A warm future in the past. *Nature*, vol. 388, p. 418–419.

Hou, Y., Yang, H., Chen, T., Ho, J., Zhou, Q. and Tian, M., 1982: *Cretaceous–Quaternary Ostracode Fauna from Jiangsu.* 386 p. Geological Publishing House, Beijing. (*in Chinese with English abstract*)

Hu, C. H., 1982: Studies on ostracode faunas from the Hengchun Limestone (Pleistocene), Hengchun area, southern Taiwan. *Quarterly Journal of the Taiwan Museum*, vol. 35, p. 171–195.

Hu, C. H., 1984: New fossil ostracod faunas from Hengchun Peninsula, southern Taiwan. *Quarterly Journal of the Taiwan Museum*, vol. 37, p. 65–129.

Hu, C. H. and Yeh, K. Y., 1978: Ostracod faunas from the Pleistocene Liushuang Formation in the Tainan area, Taiwan. *Proceedings of the Geological Society of China*, no. 21, p. 151–162.

Huzita, K. and Kasama, T., 1983: *Geology of the Kôbe District.* 115 p., 5 pls., 1 quadrangle map (1:50,000-scale). Geological Survey of Japan, Tsukuba. (*in Japanese with English abstract*)

Huzita, K. and Maeda, Y., 1984: *Geology of the Suma District*. 101 p., 5 pls., 1 quadrangle map (1:50,000-scale). Geological Survey of Japan, Tsukuba. (*in Japanese with English abstract*)

Igawa, N. and Itihara, M., 1993: The Harima Basin—with special reference to the Akashi area—. *In*, Itihara, M., *ed.*, *The Osaka Group*, p. 110–126. Sogensha, Tokyo. (*in Japanese*)

Ikeya, N. and Shiozaki, M., 1993: Characteristics of the inner bay ostracodes around the Japanese Islands—The use of ostracodes to reconstruct paleoenvironments—. *The Memoirs of the Geological Society of Japan*, no. 39, p. 15–32. (*in Japanese with English abstract*)

Irizuki, T. and Hosoyama, M., 2000: Fossil ostracodes (Crustacea) from the Pleistocene Noma Formation, Aichi Prefecture, central Japan. *Bulletin of Aichi University of Education* (*Natural Science*), vol. 49, p. 9–15. (*in Japanese with English abstract*)

Irizuki, T., Kamiya, M. and Ueta, K., 2002: Temporal and spatial distribution of fossil ostracode assemblages and sedimentary facies in the Middle Pleistocene Tahara Formation, Atsumi Peninsula, central Japan. *Geoscience Report of Shimane University*, no. 21, p. 31–39. (*in Japanese with English abstract*)

Irizuki, T., Masuda, F., Miyahara, B., Hirotsu, A., Ueda, S. and Yoshikawa, S., 2001: 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. *The Quaternary Research*, vol. 40, p. 105–120.

Irizuki, T. and Seto, K., 2004: Temporal and spatial variations of paleoenvironments of Paleo-Hamana Bay, central Japan, during the Middle Pleistocene—Analyses of fossil ostracode assemblages, and total organic carbon, total nitrogen and total sulfur contents—. *The Journal of the Geological Society of Japan*, vol. 110, p. 309–324. (*in Japanese with English abstract*)

Irizuki, T., Yamada, K., Maruyama, T. and Ito, H., 2004: Paleoecology and taxonomy of Early Miocene Ostracoda from the eastern Setouchi Province, central Japan. *Micropaleontology*, vol. 50, p. 105–147.

Ishizaki, K., 1968: Ostracodes from Uranouchi Bay, Kochi Prefecuture, western Honshu, Japan. *Science Reports of the Tohoku University, Sendai, Japan, Second Series*, vol. 40, p. 1–45.

Ishizaki, K., 1984: Detailed survey on ostracods in the drilling no. 56-9 core samples at the Kansai International Airport in Osaka Bay. *In*, Nakaseko, K., *ed.*, *Geological Survey of the Submarine Strata at the Kansai International Airport in Osaka Bay, Central Japan*, p. 37–43, Calamity Science Institute, Osaka. (*in Japanese*)

Ishizaki, K., 1987: The crocodile *Tomistoma machikanense* and ostracodes from Southwest Japan in the Middle Pleistocene. *Fossils* (*Palaeontological Society of Japan*), no. 43, p. 35–38. (*in Japanese*)

Ishizaki, K., 1990a: A setback for the genus *Sinocytheridea* in the Japanese mid-Pleistocene and its implications for a vicariance event. *In*, Whatley, R. and Maybury, C., *eds.*, *Ostracoda and Global Events*, p. 139–152. Chapman and Hall, London.

Ishizaki, K., 1990b: Sea level change in mid-Pleistocene time and effects on Japanese ostracode faunas. *Bulletin of Marine Science*, vol. 47, p. 213–220.

Ishizaki, K. and Kato, M., 1976: The basin development of the Diluvium Furuya Mud Basin, Shizuoka Prefecture, Japan, based on faunal analysis of fossil ostracodes. *In*, Takayanagi, Y. and Saito, T., *eds.*, *Progress in Micropaleontology*, p. 118–143. Micropaleontology Press, New York.

Ishizaki, K. and Matoba, Y., 1985: Akita (Early Pleistocene cold shallow water Ostracoda). *In, Guidebook of Excursions for the 9th International Symposium on Ostracoda, Excursion 5*, p. 1–12. Organizing Committee, 9th International Symposium on Ostracoda, Shizuoka.

Itihara, M., Oguro, J. and Kinugasa, H., 1960: On the Akasi Group and the Harima Group (Part 2). *The Journal of the Geological Society of Japan*, vol. 66, p. 605–615. (*in Japanese with English abstract*)

Iwasaki, Y., 1992: Ostracod assemblages from the Holocene deposits of Kumamoto, Kyushu. *Kumamoto Journal of Science* (*Geology*), vol. 13, p. 1–12. (*in Japanese with English abstract*)

Kamiya, T., Ozawa, H. and Obata, M., 2001: Quaternary and Recent marine Ostracoda in Hokuriku district, the Japan Sea coast. *In, ISO* (*International Symposium on Ostracoda*) *2001, Field Excursion Guidebook*, p. 73–106. Organizing Committee of ISO (International Symposium on Ostracoda) 2001, Shizuoka.

Katoh, S., Horiuchi, S., Sato, H., Matsubara, T. and Furutani, H., 2000: Calcareous nannofossils of the Takatsukayama Member of the Meimi Formation in the eastern part of the Harima Plain, western Japan. *Humans and Nature*, no. 11, p. 61–67. (*in Japanese with English abstract*)

Katoh, S., Sato, H., Matsubara, T., Hyodo, M. and Danhara, T., 1999: Fission-track age and correlation of the Takatsukayama Volcanic Ash Layer distributed at the western foothills of the Rokko Mountains, western Japan. *The Quaternary Research*, vol. 38, p. 411–417. (*in Japanese with English abstract*)

Kawamura, Y., 1991: Quaternary mammalian faunas in the Japanese Islands. *The Quaternary Research*, vol. 30, p. 213–220.

Keen, M. C., 1982: Intraspecific variation in Tertiary ostracods. *In*, Bate, R. H., Robinson, E. and Sheppard, L. M., *eds.*, *Fossil and Recent Ostracods*, p. 381–405. Wllis Horwood, Chichester.

Kimura, M. *ed.*, 2002: *The Formation of the Ryukyu Arc and Migrations of Biota to the Arc*. 206 p. Okinawa Times, Naha. (*in Japanese*)

Konishi, S. and Yoshikawa, S., 1999: Immigration times of the two proboscidean species *Stegodon orientalis* and *Palaeoloxodon naumanni*, into the Japanese Islands and the formation of land bridge. *Earth Science* (*Chikyu Kagaku*), vol. 53, p. 125–134. (*in Japanese with English abstract*)

Lee, E. H. and Paik, K. H., 1992: Late Cenozoic ostracod fauna and paleoenvironments of the marine sedimentary strata in the Cheju Island, Korea. *Palaeontological Society of Korea, Special Publication*, no. 1, p. 121–160.

Masuda, F., 1993: The Osaka Group and relative sea-level changes—Depositional systems of rhythmical alternations of marine and non-marine layers—. *Chikyu Monthly*, no. 8, p. 86–94. (*in Japanese*)

Masuda, F., Irizuki, T., Fujiwara, O., Miyahara, B. and Yoshikawa, S., 2002: A Holocene sea-level curve constructed from a single core at Osaka, Japan (A preliminary note). *Memoirs of the Faculty of Science, Kyoto University, Series of Geology and Mineralogy*, vol. 59, p. 1–8.

Masuda, F., Mihayara, B., Hirotsu, A., Irizuki, T., Iwabuchi, Y. and Yoshikawa, S., 2000: Temporal variation of Holocene Osaka Bay conditions estimated from a core in off-Kobe. *The Journal of the Geological Society of Japan*, vol. 106, p. 482–488. (*in Japanese with English abstract*)

Miyagawa, C., Yoshikawa, S. and Ikeda, Z., 1996: Tephrostratigraphy of Middle to Upper Pleistocene core-sample from the Port Island, Kobe City, Kinki District, Japan. *Earth Science* (*Chikyu Kagaku*), vol. 50, p. 456–465. (*in Japanese with English abstract*)

Miyahara, B. and Masuda, F., 1999: Temporal variation of depositional systems recorded in marine clay intervals recognized in a core from Kitatsumori, Nishinari, Osaka, Japan. *Abstracts, The 106th Annual Meeting of the Geological Society of Japan*, p. 290. (*in Japanese*)

Nakao, K., 1993: Distribution of molluscan associations of the Pleistocene Toriyamahama Formation in the Miyazaki Plain. *The Quaternary Research*, vol. 32, p. 157–170. (*in Japanese with English abstract*)

Neil, J. V., 2000: Factors influencing intraspecific variation and polymorphism in marine podocopid Ostracoda, with particular reference to Tertiary species from southeastern Australia. *Hydrobiologia*, vol. 419, p. 161–180.

Okada, H. and Bukry, D., 1980: Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Marine Micropaleontology*, vol. 5, p. 321–325.

Okamura, M. and Yamauchi, M., 1984: Detailed survey on nannofossils at the Kansai International Airport in Osaka Bay, central Japan. *In*, Nakaseko, K., *ed.*, *Geological Survey of the Submarine Strata at the Kansai International Airport in Osaka Bay, Central Japan*, p. 19–28, Calamity Science Institute, Osaka. (*in Japanese*)

Ozawa, H., 1996: Ostracode fossils from the late Pliocene to early Pleistocene Omma Formation in the Hokuriku district, central Japan. *The Science Reports of Kanazawa University*, vol. 41, p. 77–115.

Ozawa, H., Kamiya, T. and Tsukagoshi, A., 1995: Ostracode evidence for the paleoceanographic change of the middle Pleistocene Jizodo and Yabu Formations in the Boso Peninsula, central Japan. *The Science Reports of Kanazawa University*, vol. 40, p. 9–37.

Sato, H., Hashimoto, I., Chin Kheng, Ng, Matsuura, K. and Maeda, Y., 1997: Paleoenvironmental analysis of the sediments from the Takatsuka-yama Bed, Middle Pleistocene layer in western Kobe City. *Humans and Nature*, no. 8, p. 53–62. (*in Japanese with English abstract*)

Sato, H., Katoh, S., Inoue, H. and Hyogo, M., 1999: Marine transgression equated with oxygen isotope stage 7.3 in the Harima District, Hyogo Prefecture, western Japan. *The Quaternary Research*, vol. 38, no. 5, p. 401–410. (*in Japanese with English abstract*)

Suzuki, M., 1988: Fission track ages of the Quaternary tuff layers. *The Memoirs of the Geological Society of Japan*, no. 30, p. 219–221. (*in Japanese with English abstract*)

Ueji, T., 1937: Geology and structure of the Rokkô Massif. *Journal of Geography*, vol. 49, no. 584, p. 481–497. (*in Japanese*)

Ujiié, H. and Ujiié, Y., 1999: Late Quaternary course changes of the Kuroshio Current in the Ryukyu Arc region, northwestern Pacific Ocean. *Marine Micropaleontology*, vol. 37, p. 23–40.

Ujiié, Y., Ujiié, H., Taira, A., Nakamura, T. and Oguri, K., 2003: Spatial and temporal variability of surface water in the Kuroshio source region, Pacific Ocean, over the past 21,000 years: Evidence from planktonic foraminifera. *Marine Micropaleontology*, vol. 49, p. 335–364.

Wang, P. and Zhao, Q., 1991: Paleobiogeography of Ostracoda and Foraminifera in the China Sea area. *Acta Oceanologia Sinica*, vol. 10, no. 1, p. 93–105.

Whatley, R. and Zhao, Q., 1988: A revision of Brady's 1869 study of the Ostracoda of Hong Kong. *Journal of Micropalaeontology*, vol. 7, p. 21–29.

Yajima, M., 1982: Late Pleistocene Ostracoda from the Boso Peninsula, central Japan. *University Museum, University of Tokyo Bulletin*, no. 20, p. 141–227.

Yamada, K., Irizuki, T. and Tanaka, Y., 2002: Cyclic sea-level changes based on fossil ostracode faunas from the Upper Pliocene Sasaoka Formation, Akita Prefecture, northeast Japan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 185, p. 115–132.

Yamane, K., 1998: Recent ostracode assemblages from Hiuchinada Bay, Seto Inland Sea of Japan. *Bulletin of Ehime Prefectural Science Museum*, no. 3, p. 19–59. (*in Japanese with English abstract*)

Yasuhara, M. and Irizuki, T., 2001: Recent Ostracoda from the northeastern part of Osaka Bay, southwestern Japan. *Journal of Geoscience, Osaka City University*, vol. 44, p. 57–95.

Yasuhara, M., Irizuki, T., Yoshikawa, S. and Nanayama, F., 2002a: Changes in Holocene ostracode faunas and depositional environments in the Kitan Strait, southwestern Japan. *Paleontological Research*, vol. 6, p. 85–99.

Yasuhara, M., Irizuki, T., Yoshikawa, S. and Nanayama, F., 2002b: Holocene sea-level changes in Osaka Bay, western Japan: Ostracode evidence in a frilling core from the southern Osaka Plain. *The Journal of the Geological Society of Japan*, vol. 108, p. 633–643.

Yasuhara, M., Irizuki, T., Yoshikawa, S., Nanayama, F. and Mitamura, M., 2004: Holocene ostracode paleobiogeography in Osaka Bay, southwestern Japan. *Marine Micropaleontology*, vol. 53, p. 11–36.

Yoshikawa, S. and Mitamura, M., 1999: Quaternary stratigraphy of the Osaka Plain, central Japan and its correlation with oxygen isotope record from deep sea cores. *The Journal of the Geological Society of Japan*, vol. 105, p. 332–340. (*in Japanese with English abstract*)

Zhao, Q., 1984: Recent Ostracoda from the coast zone of the East China Sea and Yellow Sea. *Marine Geology and Quaternary Geology*, vol. 4, p. 45–57. (*in Chinese with English abstract*)

Zhao, Q., 1987: A study of the distribution of Recent ostracod faunas from the coastal areas of the East China and Yellow Seas. *Acta Oceanographica Sinica*, vol. 6, p. 413–420.

Zhao, Q. and Wang, P., 1988: Modern Ostracoda in sediments of shelf seas off China: Quantitative and qualitative distributions. *Oceanographica et Limnologica Sinica*, vol. 19, p. 553–561. (*in Chinese with English abstract*)