Shallow-Marine Ostracods from the Lower Pleistocene Kazusa Group in the Tama Hills, Central Japan, with Their Biogeographical Significance in the Northwest Pacific Ocean

Authors: Ozawa, Hirokazu, and Ishii, Tohru

Source: Paleontological Research, 18(4) : 189-210

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2014PR018

Paleontological Research, vol. 18, no. 4, pp. 189–210, October 1, 2014

doi:10.2517/2014PR018

Shallow-marine ostracods from the lower Pleistocene Kazusa Group in the Tama Hills, central Japan, with their biogeographical significance in the Northwest Pacific Ocean

HIROKAZU OZAWA[1] AND TOHRU ISHII[2]

[1]*Earth Sciences Laboratory, College of Bioresource Sciences, Nihon University, Fujisawa, Kanagawa 252-0880, Japan (e-mail: ozawa.hirokazu@nihon-u.ac.jp)*
[2]*1409 Yamazaki, Oshima-cho, Fukui, Fukui 918-8018, Japan*

Received August 6, 2013; Revised manuscript accepted April 4, 2014

Abstract. This study investigated an early Pleistocene ostracod fauna from the Kazusa Group in the Tama Hills (*ca.* 1.7–1.4 Ma) along the western side of Tokyo Bay, central Japan. We report for the first time an early Pleistocene ostracod fauna from the Kanto District. This fauna consists of 56 species, with three assemblages defined by Q-mode cluster analysis. The two most abundant species are *Bicornucythere bisanensis* and *Spinileberis quadriaculeata* in the assemblage BS, *Pontocythere subjaponica* and *Buntonia hanaii* in the assemblage PB, and *Loxoconcha ikeyai* and *Pontocythere subjaponica* in the assemblage LP. These assemblages indicate the following depositional environments: (1) the innermost to central area of an inner bay having relatively low salinity (assemblage BS); (2) the outer area of the inner bay and upper-shelf area influenced by open sea water with relatively high salinity (assemblage LP); and (3) the central to outer area of the inner bay having salinity intermediate between that of (1) and (2) (assemblage PB). We also report first occurrences on the Pacific side of Japan near Tokyo Bay for two cryophilic taxa, *Laperousecythere robusta* and *Pectocythere* sp. *Laperousecythere robusta* moved southward from the Japan Sea coast, probably through the Tsugaru Strait before reaching central Japan near Tokyo Bay by 1.6 Ma. *Pectocythere* sp. might have first appeared around Tokyo Bay during the early Pleistocene by 1.6 Ma. The species content of the assemblage BS suggests that *Bicornucythere* and *Spinileberis* commonly inhabited inner-bay areas near Tokyo Bay by 1.6–1.4 Ma at the latest. This fossil fauna does not include inner-bay species of the genera *Neomonoceratina* and *Sinocytheridea*. Their absence near Tokyo Bay in the early Pleistocene is consistent with previous palaeobiogeographical findings regarding Japanese bay-dwelling ostracods. These data provide information about the route and timing of the northward or southward migrations of shallow-marine benthos along the Northwest Pacific margin during the late Cenozoic.

Key words: early Pleistocene, Kazusa Group, Northwest Pacific Ocean, ostracods, palaeobiogeography, Tama Hills

Introduction

Shallow-marine benthic faunas along the Northwest Pacific margin, in both warm and cold waters, changed dramatically during the late Cenozoic in response to events such as marine climatic fluctuations relating to glacio-eustatic cycles (e.g. Chinzei, 1991; Ogasawara, 1994; Irizuki *et al.*, 2009). Benthic ostracods provide useful clues for understanding the relationship between environmental fluctuations and faunal changes because they are sensitive to environmental changes and have high endemism owing to their lack of planktonic stages (e.g. Horne *et al.*, 2002; Boomer *et al.*, 2003; Ozawa, 2010a). However, there are few records of shallow-marine ostracods with detailed age data from the lower Pleistocene of Northwest Pacific margins, especially for cold-water taxa.

The Kazusa Group in central Japan (Figure 1) is the only deposit in the North Pacific Ocean containing early Pleistocene fossils both of warm- and cold-water benthos in shallow-marine areas. The study area lies near the boundary area of the warm Kuroshio and cold Oyashio currents (e.g. Chinzei, 1991; Igarashi, 1994; Figure 1). This group is well known for containing in exposures on the Miura and Boso peninsulas and various open-sea calcareous fossils from lower-shelf to continental-slope

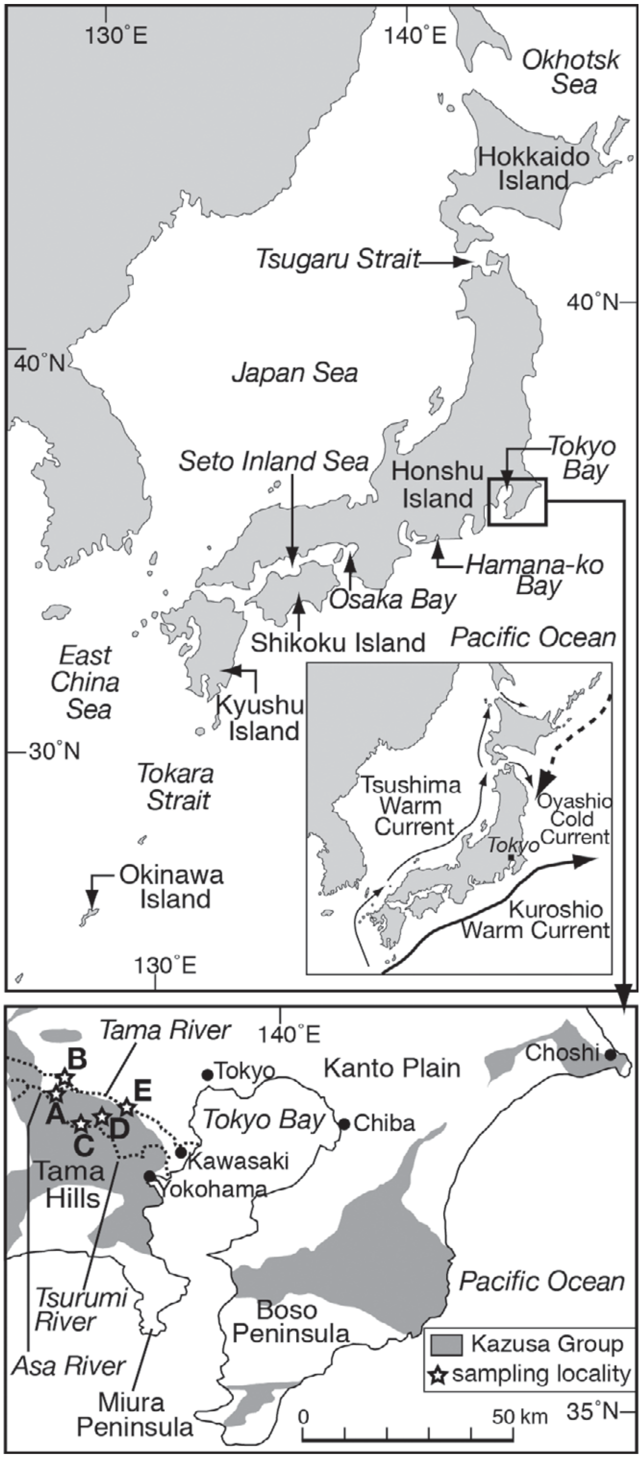

Figure 1. Map showing sampling localities for fossil ostracods and distribution of the Kazusa Group, central Japan, showing localities described in the text, modified from Mitsunashi *et al.* (1979), with map of major ocean currents around modern Japan. Letters A–E correspond to use in Figures 4, 5 and 7.

environments (e.g. Oyama, 1973; Kitazato, 1977; Oda, 1977; Kitazaki and Majima, 2003). Abundant calcareous fossils of shallow-marine species such as mollusks and foraminifers of inner-bay and upper-shelf areas are found in this group in the Tama Hills on the western side of Tokyo Bay (Tokunaga *et al.*, 1949; Fujimoto *et al.*, 1961; Oka *et al.*, 1984). However, no ostracods have been reported from the Kazusa Group in the Tama Hills. Today, this area is a commuter town near the central part of Tokyo, and investigation has been hampered by the destruction of most outcrops by residential development over the last half century.

In the present study, we investigated shallow-marine ostracods from the Kazusa Group in the Tama Hills. Our aim was to better understand this important area in the history of faunas in Northwest Pacific margins. Specifically, we revealed the taxonomic composition and diversity in ostracod faunas and inferred the nature of the palaeoenvironment. In this paper, we discuss the palaeobiogeographical relevance of selected ostracod taxa in shallow-water areas, comparing their occurrence with that in other coastal regions of the Japanese Islands during the late Cenozoic.

Stratigraphy and geological ages

The Kazusa Group in the Tama Hills is exposed along the west side of Tokyo Bay, in the Kanto District of central Japan (e.g. Otuka, 1932; Tokunaga *et al.*, 1949; Oka *et al.*, 1984; Figure 1). According to Takano (1994), this group unconformably overlies the Cretaceous Kobotoke Group and the Neogene Tate Formation, and is overlain by the Middle–Upper Pleistocene Sagami Group and Pleistocene terrace deposits with alluvium. In its western area, the Kazusa Group is composed of seven formations (Figure 2). Except for the lowermost Terada Formation, the six formations express a collective cyclicity, with conglomerates in the lower part of each formation, siltstone in the middle part, and sandstone in the upper part, betraying cyclic sea-level changes corresponding to the Pleistocene glacioeustasy (Takano, 1994). In its eastern area, this group is composed of siltstone and alternations of sandstone and siltstone, and is divided into five formations, with no recognizable cyclic changes in lithology. This character reflects differences in the subsidence rate between the two areas in this sedimentary basin, i.e., a higher rate in the eastern than that the western area (Takano, 1994; Suzuki and Murata, 2011).

Many researchers have presented various views on the geological ages of the Kazusa Group in the Tama Hills during the last 40 years (e.g. Mitsunashi *et al.*, 1979; Takano, 1994; Suzuki, 2008). Recent studies correlating tuff layers and nannofossil biostratigraphy for the Kazusa

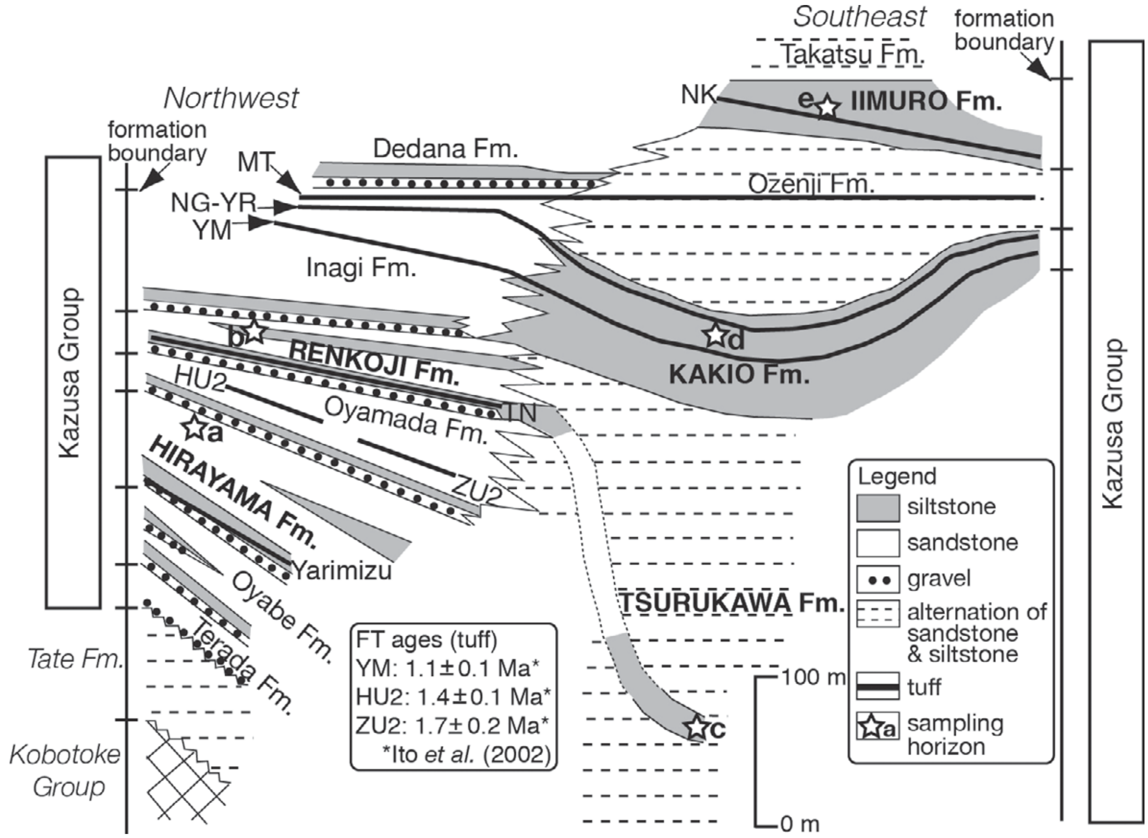

Figure 2. Schematic geological cross sections for the Kazusa Group in the Tama Hills, central Japan, showing the stratigraphic distribution of sampling horizons for fossil ostracods with FT age data, drawn by the fixed horizon at the MT tuff, modified from Takano (1994). Formation names in bold denote the strata examined in this study. Names of two tuff layers in the Inagi and Kakio formations (YM and NG-YR) are after Suzuki and Murata (2011). The scale for width of this schematic sections is *ca.* 40 km. Letters a–e correspond to use in Figure 3.

Group in the Tama Hills, Tokyo (subsurface, from drill cores), the Boso Peninsula and the Choshi districts (Fujioka and Kameo, 2004; Suzuki and Murata, 2011) have estimated that the geological age from the Hirayama to Renkoji formations in the western area is *ca.* 1.7–1.4 Ma, and that of the Tsurukawa to Iimuro formations in the eastern area is *ca.* 1.5–1.4 Ma (Figure 3). Ito *et al.* (2002) dated three tuff layers (YM, HU2 and ZU2 in Figure 1) to *ca.* 1.7–1.1 Ma using the fission-track method (Figure 3). These studies indicate that the depositional period of the Kazusa Group in the Tama Hills is the early Pleistocene (Calabrian).

Materials and methods

We analyzed nine samples of siltstone and silty fine-grained sandstone from the five formations (Figures 2–5; Table 1). In the western area, three samples (a1–a3) were collected from the Hirayama Formation, and two samples (b1 and b2) from the Renkoji Formation. In the eastern area, one sample (c) was obtained from the Tsurukawa Formation, two samples (d1 and d2) were from the Kakio Formation, and one sample (e) was from the Iimuro Formation. Samples c, d1 and d2 were collected by Dr. Y. Kuwano in the 1940s for the research of Tokunaga *et al.* (1949). We cannot observe outcrops for samples a1–a3, c, d1 and d2 at present, because of conservancy work or residential development during the last half century.

Sediment samples of 70–2,000 g dry weight were washed through a 63-μm (250-mesh) sieve, and dried at 80°C in an oven. We picked ostracod specimens from fractions between 0.125–1.0 mm for each sample split. The number of ostracod specimens refers to both valves and carapaces. All the identified adult and juvenile valves (left and right) were counted, and each carapace was counted as one individual. The species diversity was calculated by the Shannon-Wiener function for samples

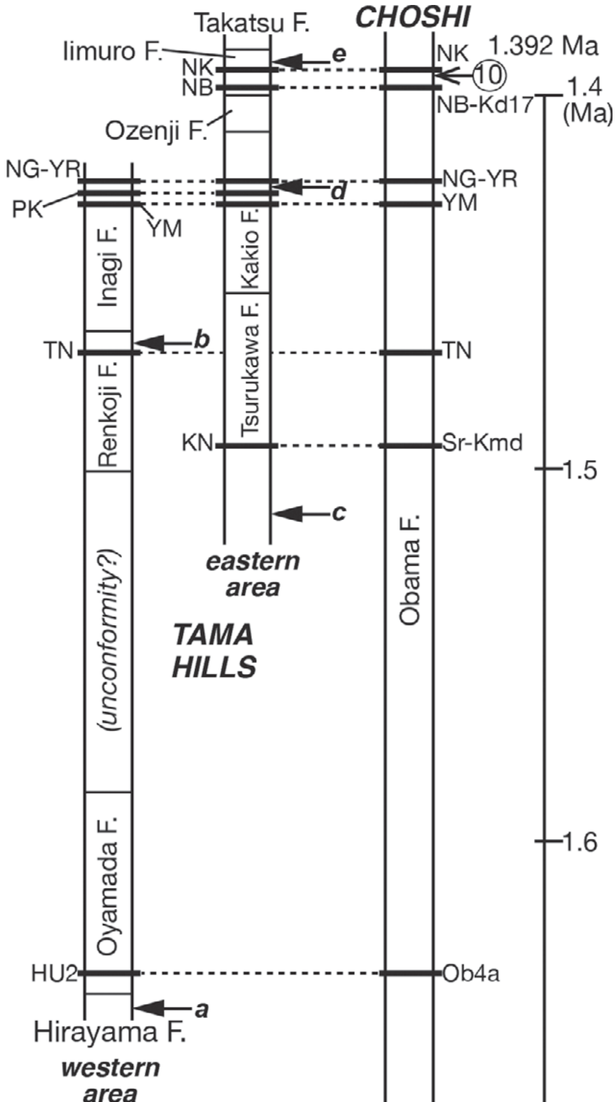

Figure 3. Chronology of tuff layers in the Kazusa Group between Tama Hills (western and eastern areas) and Choshi districts, central Japan, showing stratigraphic positions for horizons of samples a–e in this study, simplified from Suzuki and Murata (2011). Ages of nannofossil datum plains are cited from Sato *et al.* (2009). Letters a–e correspond to use in Figure 2. F.: Formation.

yielding more than 30 specimens.

We determined fossil ostracod assemblages using Q-mode cluster analysis. In the analysis, the Horn's modification of Morishita's overlap index (Morishita, 1959; Horn, 1966) and the unweighed pair-group average (UPGMA) were used as a similarity index and a linkage method, respectively. We used the free software package PAleontological STatistics (PAST) provided by Hammer (2013) for the cluster analysis. Samples containing at least 30 specimens were subjected to cluster analysis. Species represented by less than three individuals in any sample examined were discarded from the present analysis.

All the specimens examined were deposited at the Earth Sciences Laboratory, College of Bioresource Sciences, Nihon University, Fujisawa, Japan. All the sediment samples studied here were stored at the National Museum of Nature and Science, Tsukuba, Japan, identified by register numbers with the prefix RM (Raw Material Collection for microfossil analysis; Table 1).

Results

Occurrence of ostracods

Fifty-six ostracod species belonging to 30 genera were identified in the Kazusa Group (Figures 5–7; Table 2). Eight samples included more than 30 individuals, except for one sample (b2) that yielded less than 20 individuals in total even though all the ostracod specimens were picked from the rest of the fractions. The total number of species for each sample ranged from 2 to 39 species. The Shannon-Wiener index for species diversity ranged from *ca.* 0.7 to 2.8. The absolute abundance (= number of individuals per 100 g sediment) for each sample ranged from *ca.* 4 to 580 (Table 2).

The five top-ranked species in these samples are *Bicornucythere bisanensis*, *Spinileberis quadriaculeata*, *Pontocythere subjaponica*, *Loxoconcha ikeyai* and *Buntonia hanaii* (Table 3), accounting for 72%. Ten other species, *Callistocythere* cf. *subjaponica*, *Cytheropteron* sp., *Hanaiborchella miurensis*, *Hanaiborchella triangularis*, *Loxoconcha tamakazura*, *Pectocythere* sp., *Pontocythere miurensis*, *Pontocythere* sp. 1, *Trachyleberis scabrocuneata* and *Xestoleberis sagamiensis*, are commonly or rarely found from several samples (Table 2). These 15 species accounted for *ca.* 90% of the total of individuals (Table 3). Many of these species currently inhabit shallow-water areas with sandy and muddy sediments in or around Tokyo Bay (Frydl, 1982; Abe, 1983; Kamiya, 1988; Ikeya and Shiozaki, 1993; Nakao and Tsukagoshi, 2002, 2008).

There are common or rare occurrences of *Loxocorniculum mutsuense* with species of the three genera *Xestoleberis*, *Cythere* and *Robustaurila* from three horizons (Table 2). These species are all phytal dwellers, living on sea plants, e.g. the seagrass *Zostera* in sandy substrates

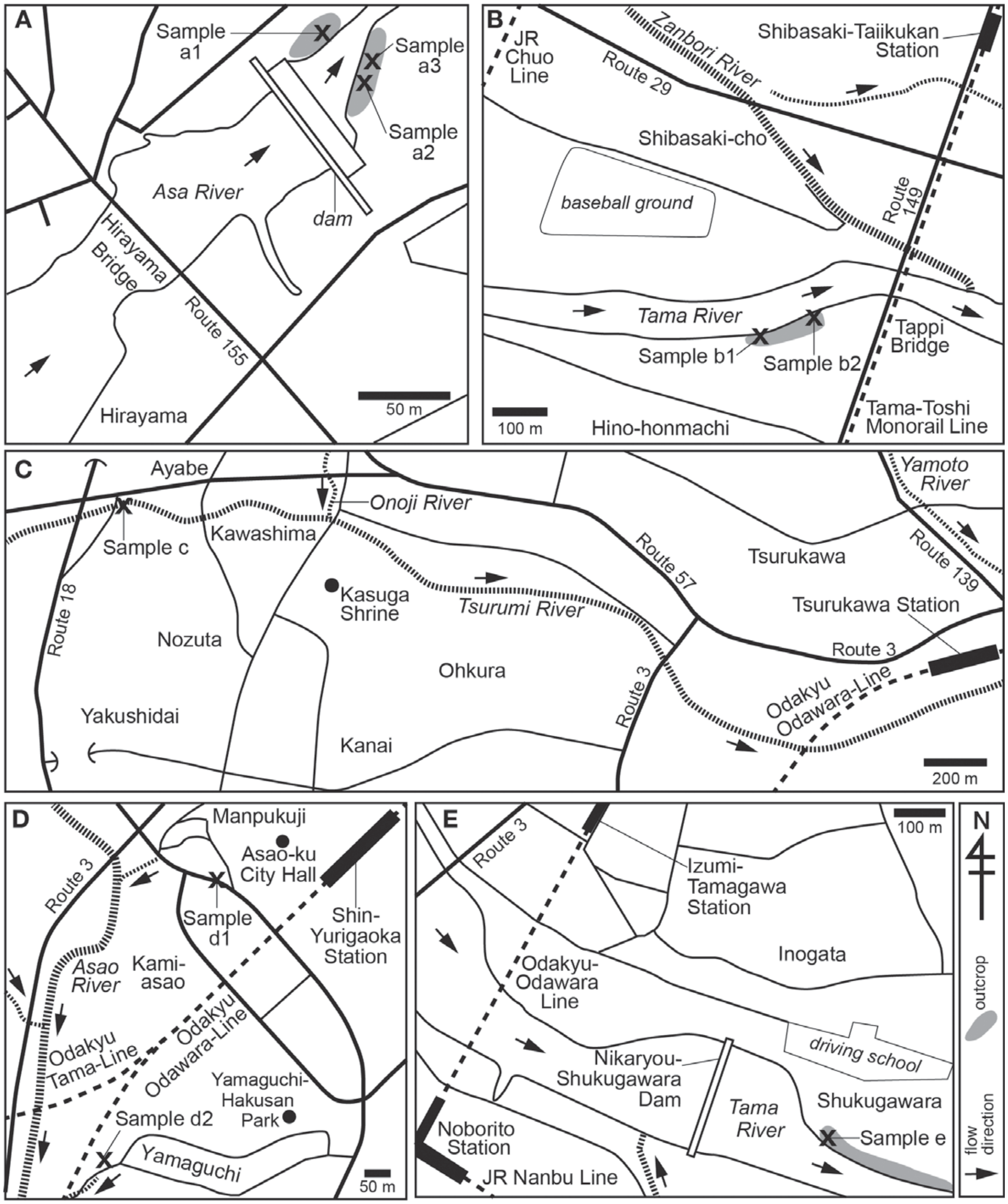

Figure 4. Map showing sampling localities for fossil ostracods from the Kazusa Group, central Japan. Letters A–E correspond to Figures 1, 5 and 7. Samples a1–e correspond to use in Figures 5 and 7 and Tables 1 and 2.

and calcareous algae on rocky shores, along the present-day Japanese coast (e.g. Kamiya, 1988; Tsukagoshi, 1990; Kamiya *et al.*, 2001; Sato and Kamiya, 2007).

Ostracod assemblage

Using the Q-mode cluster analyses for 31 species and eight samples, we identified three assemblages BS, PB and LP (Figure 8). The two most dominant species of

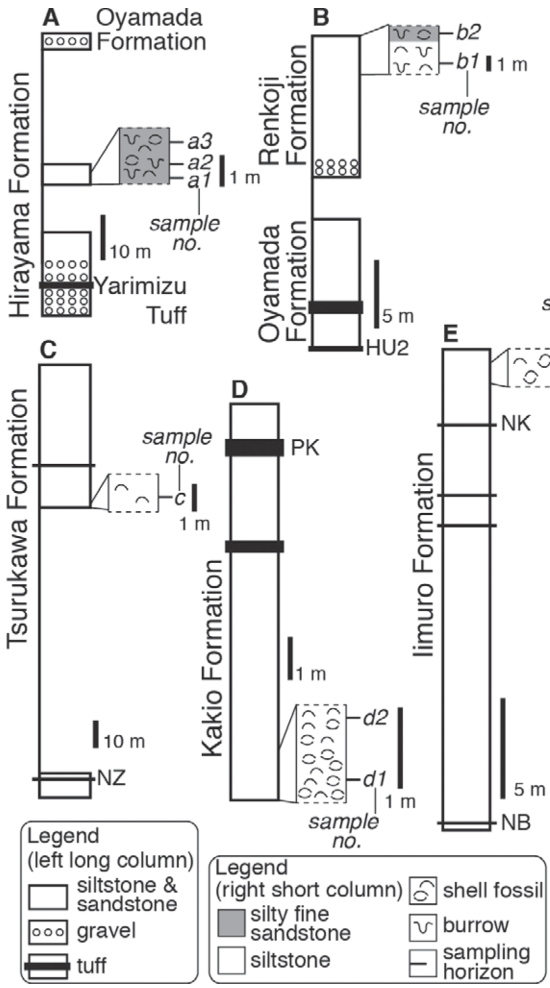

Figure 5. Columnar sections with sample horizons at study sites (right short columns) with schematic columnar sections (left long columns) for the five formations. Schematic columnar sections are modified from Tokunaga *et al.* (1949), Masaoka (1978), Baba *et al.* (1986), Takano (1994), Sekimoto and Ban (1994), Mukaiyama and Matsuda (1998) and Ito *et al.* (2002). Letters A–E correspond to Figures 1, 4 and 7. Samples a1–e correspond to use in Figures 4 and 7 and Tables 1 and 2.

each assemblage are *Bicornucythere bisanensis* and *Spinileberis quadriaculeata* in the assemblage BS, *Pontocythere subjaponica* and *Buntonia hanaii* in the assemblage PB, and *Loxoconcha ikeyai* and *Pontocythere subjaponica* in the assemblage LP (Table 4).

B. bisanensis is a representative of the ostracodal bay fauna of Japan, and dominantly inhabits muddy sediments of the innermost to central areas of the inner bay of Japan at 5–9 m water depths in the low salinity range of 20–30, influenced by fresh water, and wide seasonal fluctuations in dissolved oxygen (DO) conditions that

Table 1. Sample localities for fossil ostracods from the Kazusa Group, with their registration numbers for the National Museum of Nature and Science, Tsukuba, Japan.

No.	Formation	Latitude (N)	Longitude (E)	Registration No.
a1	Hirayama	35°39′07″	139°22′56″	RM-016722
a2	Hirayama	35°39′06″	139°22′58″	RM-016723
a3	Hirayama	35°39′07″	139°22′58″	RM-016724
b1	Renkoji	35°40′54″	139°24′17″	RM-016726
b2	Renkoji	35°41′07″	139°24′18″	RM-016727
c	Tsurukawa	35°35′17″	139°27′07″	RM-016728
d1	Kakio	35°35′59″	139°30′27″	RM-016730
d2	Kakio	35°35′42″	139°30′19″	RM-016729
e	Iimuro	35°37′17″	139°34′45″	RM-016731

can vary from *ca.* 6 ml/l in winter to less than 1 ml/l in summer (e.g. Ikeya and Shiozaki, 1993; Irizuki *et al.*, 2003). *S. quadriaculeata* is another representative species of the ostracodal bay fauna of Japan, and dominantly inhabits muddy sediments of the innermost to central areas of the inner bay of Japan at 2–7 m water depths in almost the same range of conditions of salinity and DO range as *B. bisanensis* (e.g. Ikeya and Shiozaki, 1993; Irizuki *et al.*, 2003).

P. subjaponica and *B. hanaii* are commonly reported from the present-day central to outer parts of shallow-bay areas in less than 40–50 m water depths with sandy (*P. subjaponica*) and muddy-sandy (*B. hanaii*) sediments along the Pacific coast of central and northeastern Japan (e.g. Frydl, 1982; Irizuki *et al.*, 1999; Zhou, unpublished data). Both species were found in this depth range in Sendai and Otsuchi bays along the Pacific coast of northeastern Japan (Ikeya and Itoh, 1991; Ikeya *et al.*, 1992) under conditions of salinity between *ca.* 31 and 34 and DO from *ca.* 1 to 6 ml/l (Terazaki and Shikama, 1979; Iwai, 2008).

L. ikeyai is commonly found from sandy sediments with mud along the modern Pacific coast of southwestern Japan (Zhou, 1995) on the upper shelf area at around 100 m water depth under the influence of the warm Kuroshio Current, such as 106 m depth south of Shikoku Island (*ca.* 8% for the ratio against all individuals of one sample in Loc. 33 of Zhou, 1995) in Tosa Bay, and 110 m depth southeast of Kyushu (5–6% in Locs. 365 and MZ-19 of Zhou, 1995) in the Hyuga-nada (Zhou, unpublished data).

Assemblage BS (sample b1) is dominated by *B. bisanensis* with the maximum percentage in a single sample (RM) exceeding 60%. (Figure 7; Table 4). It is accom-

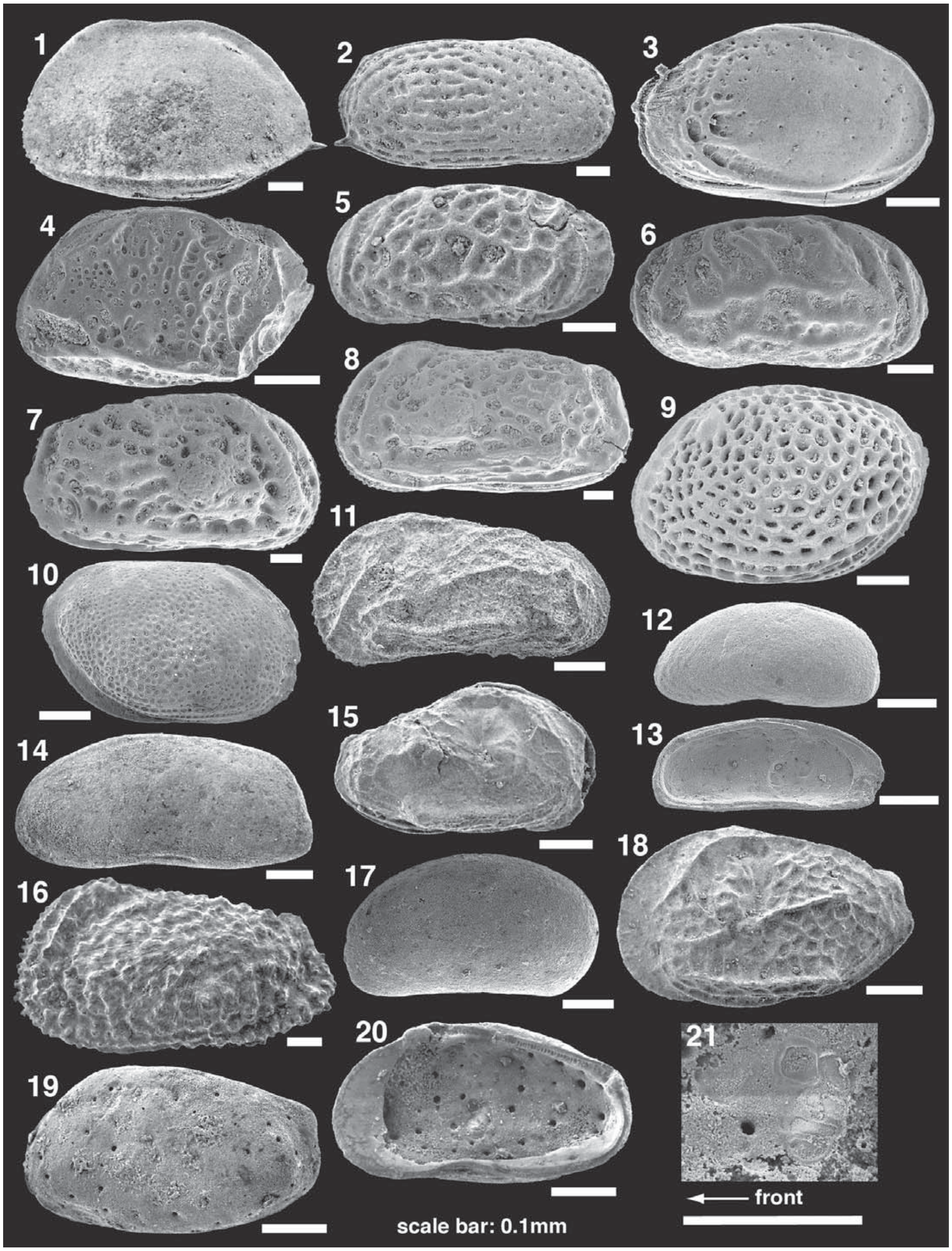

Figure 6. SEM images of fossil ostracods from the Kazusa Group. LV: left valve, RV: right valve, CA: carapace. **1,** *Amphileberis nipponica* (Yajima, 1978), LV; **2,** *Bicornucythere bisanensis* (Okubo, 1975), RV; **3,** *Buntonia hanaii* Yajima, 1978, CA right side; **4,** *Cytheropteron* sp., LV; **5,** *Callistocythere* cf. *subjaponica* Hanai, 1957, LV; **6,** *Callistocythere japonica* Hanai, 1957, RV; **7,** *Laperousecythere robusta* (Tabuki, 1986), RV; **8,** *Laperousecythere robusta* (Tabuki, 1986), CA left side; **9,** *Loxoconcha ikeyai* Zhou, 1995, LV; **10,** *Loxoconcha ikeyai* Zhou, 1995, RV; **11,** *Paracathaycythere costaereticulata* Whatley and Zhao, 1991, LV; **12, 13,** *Pontocythere* sp. 1; 12, CA left side; 13, LV inside; **14,** *Pontocythere subjaponica* (Hanai, 1959), LV; **15,** *Spinileberis furuyaensis* Ishizaki and Kato, 1976, CA right side; **16,** *Trachyleberis scabrocuneata* (Brady, 1880), CA left side; **17,** *Xestoleberis* cf. *dentata* Schornikov, 1975, LV; **18,** *Spinileberis quadriaculeata* (Brady, 1880), LV; **19–21,** *Pectocythere* sp.; 19, LV; 20, RV inside; 21, close-up view of muscle scars in RV. All specimens are adult, except for 7, 8, 10, which are of A-1 juveniles. Specimens of 1, 3, 5, 15, 16, 17 from sample e, 2, 11, 14, 18 from sample b1, 4, 6, 9, 10 from sample d2, 7, 8 from sample a1, 12, 13 from sample c, and 19–21 from sample a3.

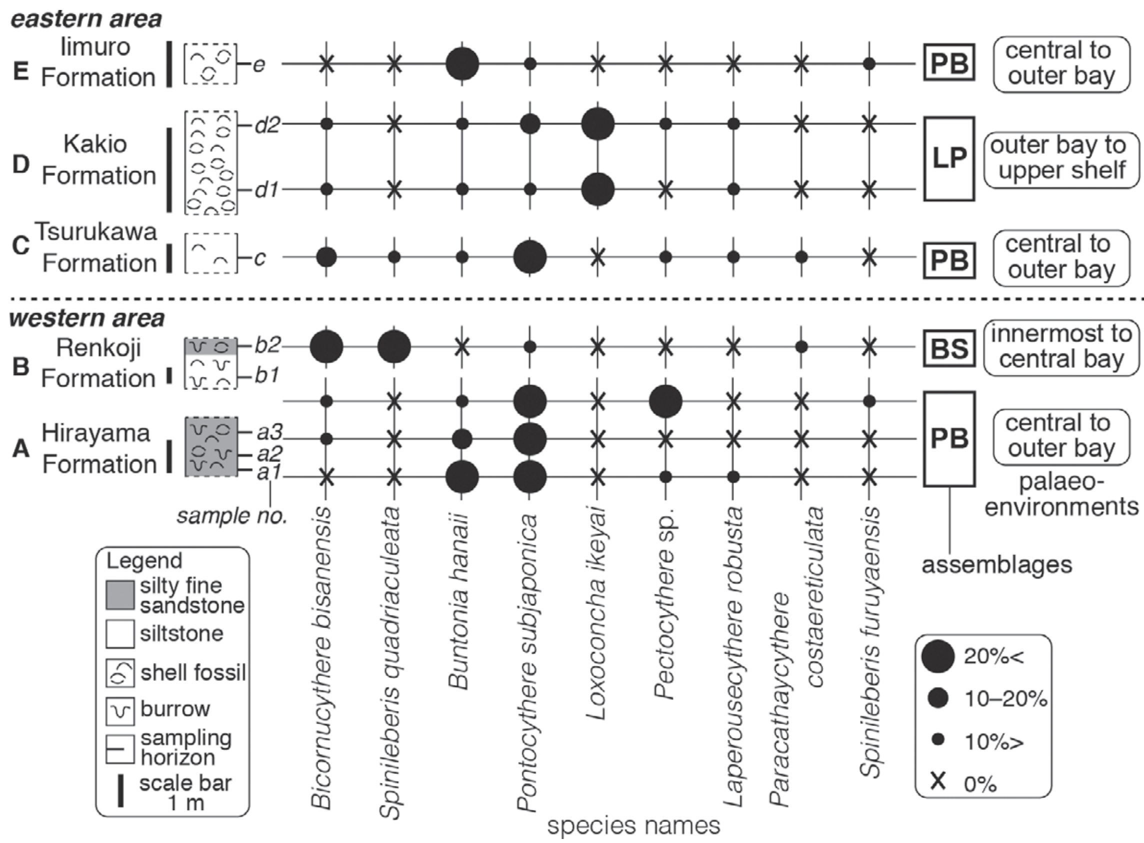

Figure 7. Columnar sections, frequencies of ostracod species, ostracod assemblages and inferred palaeoenvironment at studied sites. Assemblage names are the same as those in Figure 8 and Table 4. Letters A–E correspond to use in Figures 1, 4 and 5. Samples a1–e correspond to use in Figures 4 and 5 and Tables 1 and 2.

panied by abundant *S. quadriaculeata* (RM > 40%). This assemblage is found in one siltstone sample, b1, from the Renkoji Formation (Figures 7 and 8; Tables 1 and 4). This is characterized by a relatively low number of species (4) and highest absolute abundance (more than 570 specimens) with lowest species diversity of *ca.* 0.7 (Tables 2 and 4).

Assemblage PB (samples a1–a3, c and e) contains two common species *P. subjaponica* and *B. hanaii* (RM > 50%) (Figure 7; Table 4). There are common or rare occurrences of *Ambtonia obai*, *Amphileberis nipponica*, *B. bisanensis*, *Callistocythere* cf. *subjaponica*, *Finmarchinella uranipponica*, *Hanaiborchella triangularis*, *Pectocythere* sp., *Pontocythere miurensis*, *Pontocythere* sp. 1 and two species of the genus *Trachyleberis*. This assemblage occurs in samples of silty fine-grained sandstone and siltstone from the three strata, i.e., the Hirayama, Tsurukawa and Iimuro formations (Figures 7 and 8; Tables 1 and 4). It is characterized by wide differences in numbers of species (7–39), in absolute abundance (*ca.* 4–380) and in species diversity of *ca.* 1.0–2.8 (Tables 2 and 4).

Assemblage LP (samples d1 and d2) dominantly includes *L. ikeyai* (RM = *ca.* 60%) (Figure 7; Table 4). This species is accompanied by common *P. subjaponica* and *L. tamakazura* (RM = *ca.* 7%). There are common or rare occurrences of five species of the genus *Callistocythere*, *Cytheropteron miurense*, *Cytheropteron subuchioi* and *Paracytheridea neolongicaudata*. This assemblage occurs in two samples of siltstone from the Kakio Formation (Figures 7 and 8; Tables 1 and 4). It is characterized by middle-range numbers of species (around 20), absolute abundance (*ca.* 110–140) and species diversity of *ca.* 1.7–2.0 (Tables 2 and 4).

Discussion

Depositional environment

The palaeoenvironment of one sample, b1, based on assemblage BS, is the innermost to central area of an

Table 2. List of fossil ostracods from the Kazusa Group.

Species names/Sample no.	Western area					Eastern area				
	a1	a2	a3	b1	b2	c	d1	d2	e	Total
Ambtonia obai (Ishizaki, 1971)	2					3				5
Amphileberis nipponica (Yajima, 1978)						2		2	2	6
Aurila sp.								2		2
Australimoosella tomokoae (Ishizaki, 1968)									1	1
Bicornucythere bisanensis (Okubo, 1975)		3	6	346	1	81	2	7		446
Buntonia hanaii Yajima, 1978	27	4	9			36	1	8	55	140
Bythoceratina sp.								1		1
Callistocythere alata Hanai, 1957b								1		1
Callistocythere japonica Hanai, 1957b						5		7		12
Callistocythere reticulata Hanai, 1957b								1		1
Callistocythere cf. *subjaponica* Hanai, 1957b	7	2	18			17	3		2	49
Coquimba ishizakii Yajima, 1978						5				5
Coquimba sp.						3				3
Cythere sp.						4				4
Cytherois sp.							1			1
Cytheropteron cf. *hanaii* Ishizaki, 1981							1			1
Cytheropteron miurense Hanai, 1957c								1		1
Cytheropteron subuchioi Zhao, 1988						6		1		7
Cytheropteron sp.	1					6	3	14	1	25
Cytherura? sp.						5				5
Eucythere? sp.						2				2
Finmarchinella uranipponica Ishizaki, 1969						3	1			4
Finmarchinella cf. *uranipponica* Ishizaki, 1969						1				1
Hanaiborchella miurensis (Hanai, 1970)						31				31
Hanaiborchella triangularis (Hanai, 1970)	4		10			28				42
Hemicytherura cuneata Hanai, 1957c						1		3		4
Laperousecythere robusta (Tabuki, 1986)	3					1	1	2		7
Loxoconcha epeterseni Ishizaki, 1981						7				7
Loxoconcha ikeyai Zhou, 1995							46	148		194
Loxoconcha optima Ishizaki, 1968						14		1		15
Loxoconcha tamakazura Yajima, 1982							5	21		26
Loxocorniculum mutsuense Ishizaki, 1971						1				1
Munseyella cf. *japonica* (Hanai, 1957a)						1				1
Munseyella sp.							2			2
Paracathaycythere costaereticulata Whatley & Zhao, 1991				1		2				3
Paracytheridea neolongicaudata Ishizaki, 1966								1		1
Pectocythere sp.	7		33			12		4		56
Perissocytheridea sp. 1	1	2				1				4
Perissocytheridea sp. 2						2				2
Pistocythereis bradyformis (Ishizaki, 1968)								1		1
Pontocythere japonica (Hanai, 1959)						4			2	6
Pontocythere miurensis (Hanai, 1959)						26		1		27
Pontocythere subjaponica (Hanai, 1959)	17	21	56	4		101	4	29	2	234
Pontocythere sp. 1	3	4	7			14		1		29
Pontocythere sp. 2						4				4
Pontocythere sp. 3						1				1
Pontocythere sp. 4						2				2
Pontocythere sp. 5									1	1
Robustaurila ishizakii (Okubo, 1980)						1				1
Spinileberis furuyaensis Ishizaki & Kato, 1976			2						1	3
Spinileberis quadriaculeata (Brady, 1880)				224	11	3				238
Trachyleberis niitsumai Ishizaki, 1971	1	1	2			5		7		16
Trachyleberis scabrocuneata (Brady, 1880)							6	10	3	19
Xestoleberis cf. *dentata* Schornikov, 1975						16				16
Xestoleberis sagamiensis Kajiyama, 1913							3	14		17
Gen. et. sp. indet.						1				1
Number of total individuals	73	37	143	575	12	458	79	288	70	1735
Number of total species	11	7	9	4	2	39	14	25	10	56
Species-diversity index	1.85	1.42	1.73	0.72	–	2.77	1.67	1.95	0.97	
Sample weight (g)	310	310	390	100	100	120	70	200	2000	
Individual number / 100 g	23.5	11.9	36.7	575.0	12.0	381.7	112.9	144.0	3.5	

Table 3. Fifteen-ranked ostracod species, their individual numbers (I. No.) and their percentages against all individuals from the Kazusa Group (%).

Species name	I. No.	%
Bicornucythere bisanensis	446	25.7
Spinileberis quadriaculeata	238	13.7
Pontocythere subjaponica	234	13.5
Loxoconcha ikeyai	194	11.2
Buntonia hanaii	140	8.1
Pectocythere sp.	56	3.2
Callistocythere cf. *subjaponica*	49	2.8
Hanaiborchella triangularis	42	2.4
Hanaiborchella miurensis	31	1.8
Pontocythere sp. 1	29	1.7
Pontocythere miurensis	27	1.6
Loxoconcha tamakazura	26	1.5
Cytheropteron sp.	25	1.4
Trachyleberis scabrocuneata	19	1.1
Xestoleberis sagamiensis	17	1.0
Total	1573	90.7

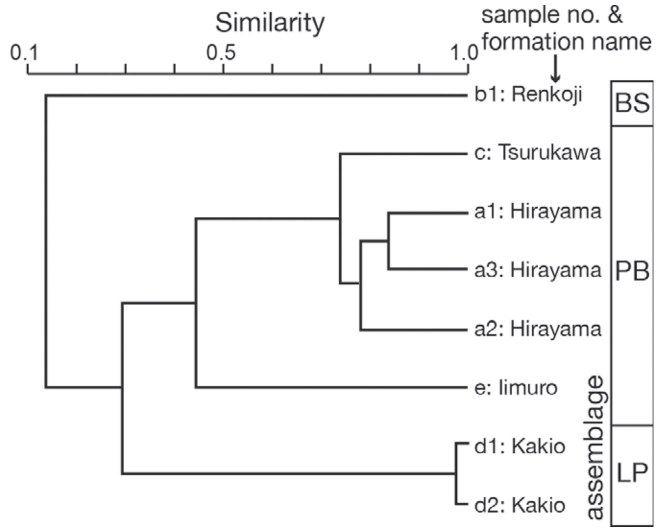

Figure 8. Dendrogram showing the result of Q-mode cluster analysis. Assemblage names correspond to use in Figure 7 and Table 4.

inner bay (Figure 7; Table 4) with water depths shallower than 10 m, relatively low salinity within the range of 20–30 owing to freshwater influences, and wide-ranging DO conditions (e.g. approximately 6 ml/l in winter and less than 1 ml/l in summer). The highest absolute ostracod abundance and the lowest species diversity index (Tables 2 and 4) were found in horizon b1. The low species diversity and high abundance of ostracod fossils can be explained by a depositional environment with very weak water currents and with little ostracod transportation, located in the innermost to central part of an inner bay. The two dominant species of this assemblage inhabit Tokyo Bay and adjacent areas (Abe, 1983; Ikeya and Shiozaki, 1993; Nakao and Tsukagoshi, 2002, 2008), so the palaeo-water temperature range during this period would be similar to that of the present Tokyo Bay.

Several previous studies for fossils of other taxa from the same horizon as our sample b1 (Baba *et al.*, 1986; Tanimura *et al.*, 2005) reported dominant occurrences of molluscan species *Potamocorbula amurensis* with *Theora lubrica*, one benthic foraminifer species, *Ammonia beccarii*, and one diatom species, *Arachnoidiscus ornatus*. These species inhabit shallow marine-water areas in the inner bay, influenced by fresh water, in present-day central Japan (Baba *et al.*, 1986; Sunazawa *et al.*, 2009). According to Akimoto and Hasegawa (1989), the depth range of the distribution for *Ammonia beccarii* is shallower than 50 m on the Japanese coast. These fossil occurrences support our inference for the palaeoenvironment of the assemblage BS. Considering the age of the horizon of sample b1 (Suzuki and Murata, 2011) in terms of the sedimentary cycles in this region formed by Pleistocene glacio-eustatic sea-level changes (Takano, 1994), this depositional period possibly coincides with interglacials between 1.5 and 1.4 Ma, possibly in MIS 49 or 47 (MIS age from Sato *et al*., 2009).

The assemblage PB (a1–a3, c, and e) indicates the central to outer area of the inner bay (Figure 7; Table 4), with intermediate water depths (shallower than 40–50 m), salinity between *ca.* 31 and 34 and DO ranging from *ca.* 1 to 6 ml/l (e.g. Terazaki and Shikama, 1979; Iwai, 2008), between the innermost to central areas of the inner-bay (inferred by assemblage BS) and upper-shelf (estimated by assemblage LP) environments. The second highest absolute abundance of ostracods, with highest species diversity, was seen in the horizon of sample c (Tables 2 and 4). Sample c of the Tsurukawa Formation is characterized by common or rare occurrences of phytal species of four genera, namely, *Cythere*, *Loxocorniculum*, *Robustaurila* and *Xestoleberis* (Table 2). This indicates the existence of beds of calcareous algae on the rocky shore and *Zostera* seagrass on sandy substrates around the intertidal zone (Kamiya *et al.*, 2001; Ishii *et al.*, 2005; Ozawa and Ishii, 2008) near the site of sample

Table 4. Five-ranked species of each assemblage from the Kazusa Group, their average percentages in all samples of each assemblage (RA), their maximum percentage in a single sample (RM), species diversity index (Diversity) and species number (Spp. no.) with palaeoenvironment. Assemblage names (Ass.) correspond to use in Figures 7 and 8.

Ass.	Five-ranked species	RA (%)	RM (%)	Diversity	Spp. no.	Palaeo-environment
BS	*Bicornucythere bisanensis*	–	60.2			
	Spinileberis quadriaculeata	–	39.0			
	Pontocythere subjaponica	–	0.7	0.72	4	innermost to central area of inner-bay
	Paracathaycythere costaereticulta	–	0.2			
	–	–	–			
PB	*Pontocythere subjaponica*	28.8	56.8			
	Buntonia hanaii	28.1	78.6			
	Pectocythere sp.	7.1	23.1	0.97–2.77	7–39	central to outer area of inner-bay
	Callistocythere cf. *subjaponica*	6.8	12.6	(Av: 1.75)	(Av: 16)	
	Bicornucythere bisanensis	6.0	17.7			
LP	*Loxoconcha ikeyai*	54.8	58.2			
	Pontocythere subjaponica	7.6	10.1			
	Loxoconcha tamakazura	6.8	7.3	1.67–1.95	14–25	outer area of inner-bay to upper shelf area
	Trachyleberis scabrocuneata	5.6	7.6	(Av: 1.81)	(Av: 20)	
	Cytheropteron sp.	4.4	4.9			
	Xestoleberis sagamiensis	4.4	4.9			

c. The fact that the depositional environment has relatively strong water currents at the site of sample c might explain the high abundance of ostracod fossils and the high occurrence of phytal species, which were probably transported from near the intertidal zone to the central area of the inner bay. The occurrences of two cryophilic taxa at higher latitudes than Tokyo Bay, *Laperousecythere* and *Pectocythere* (Figure 7; Table 4; e.g. Ozawa *et al*., 2004a, b) from the Hirayama and Tsurukawa formations suggest that palaeotemperatures during these periods might be lower than those of the modern coast around Tokyo.

Plural previous studies reported fossil occurrences of other taxa from horizons of our assemblage PB. From the western area, Mukaiyama and Matsuda (1998) identified 99 molluscan species from horizons of our samples a1–a3 in the Hirayama Formation. Most of them inhabit water depths shallower than 50 m in the inner-bay environment at latitudes 38–39°N along the Japanese coast, i.e., at lower temperature conditions than prevailing in present-day Tokyo Bay at 35–36°N (Mukaiyama and Matsuda, 1998).

In the eastern area, from the horizon of sample c of the Tsurukawa Formation, Fujimoto *et al.* (1961) and Masaoka *et al.* (1990) recognized three molluscan species, namely, *Patinopecten yessoensis*, *Cyclocardia ferruginea* and *Macoma tokyoensis*. These species inhabit the shallow-marine environment of less than 50 m depth in Japan and adjacent areas at latitudes 35–39°N (Oyama, 1973; Masaoka *et al.*, 1990; Okutani, 2000). Fujimoto *et al.* (1961) also reported one dominant species of benthic foraminifer, *Pseudononion* cf. *japonicum*. Its related species *Pseudononion japonicum* inhabits innermost to outer areas of the inner bay at depths shallower than 50 m along the Japanese coast (Akimoto and Hasegawa, 1989; Takata *et al.*, 2006).

From the Iimuro Formation in the eastern area, several researchers reported fossil occurrences of various taxa from and near the horizon of our sample e. Molluscan species *Dosinia japonica* and *Clementia vatheleti*, inhabiting waters shallower than 50–60 m depth in Japan and adjacent areas (e.g. Nobuhara, 1993), dominantly occurred (Koizumi, 1990; Matsukawa *et al.*, 2001). Masubuchi *et al.* (1995) identified two dominant species of benthic foraminifera *Ammonia japonica* and *Pseudorotalia gaimardii*. These species live in the central to outer part of Tokyo Bay and adjacent areas (Kosugi *et al.*, 1991; Sekimoto *et al.*, 2008). Water depth range of their distribution is 20–76 m (*A. japonica*) and shallower than 50 m (*P. gaimardii*) (Akimoto and Hasegawa, 1989). One diatom species, *Paralia sulcata*, is also dominantly found (Masubuchi, 1995). This species inhabits the inner-bay environment of Japan and adjacent areas under salinity conditions of around 34 (Tanimura *et al.*, 2002). Furthermore, fossils of three decapod species, e.g. *Ovalipes punctatus*, living at 30–100 m depth in the inner-bay environment of Japan and adjacent areas, were also reported (Takeda and Masubuchi, 1984, 1985).

These fossil findings support our inference for the palaeoenvironment, based on the assemblage PB. Considering the age of horizons for samples a1–a3 in the Hirayama Formation at the western area (Suzuki and Murata, 2011) with sedimentary cycles formed by Pleistocene glacial eustasy (Takano, 1994), this depositional period possibly coincides with interglacial intervals between 1.7 and 1.6 Ma (Suzuki and Murata, 2011) around MIS 59 (MIS age from Lisiecki and Raymo, 2005).

Finally, the palaeoenvironment in samples d1 and d2 (assemblage LP) was the outer area of a shallow bay to the upper continental shelf (Figure 7; Table 4) with water depths shallower than 100 m, influenced by a warm water current similar to the present-day warm Kuroshio Current, with relatively high salinity (around 35) and high DO levels (5–6 ml/l) throughout the year (e.g. Zhou, 1995). In assemblage LP, *Loxoconcha ikeyai* dominates. This species is commonly found on the modern Pacific coast of southwestern Japan (latitudes 30–34°N; Figure 11) on the upper shelf at around 100 m water depth under the influence of the warm Kuroshio Current (Zhou, 1995). *P. subjaponica* is commonly reported from the central to outer part of the shallow bay at less than 40–50 m water depth with sandy sediments along the present Pacific coast of Japan (e.g. Frydl, 1982; Irizuki *et al.*, 1999; Zhou, unpublished data). These two species are commonly found at 110 m depth on the upper shelf to the southeast of Kyushu Island in the Hyuga-nada (*ca*. 5% of *L. ikeyai* and *ca*. 8% of *P. subjaponica* in Loc. MZ-19 of Zhou, 1995; Zhou, unpublished data). Therefore, its palaeotemperature would be slightly higher than that of the modern coast near Tokyo at latitudes 35–36°N.

The range of species diversity of the assemblage LP is *ca.* 1.7–2.0 (Tables 2 and 4). Several examples of a modern ostracod Japanese coastal assemblage with species-diversity index less than 2.0 were reported from outer bay to upper shelf areas at *ca.* 40–100 m water depth (Ikeya and Shiozaki, 1993; Tsukawaki *et al.*, 1998). Such an assemblage is known from the outer area of Sendai Bay at 60–100 m depth (index 1.5–2.0; Ikeya and Itoh, 1991), St. 25 of the outer area of Otsuchi Bay at *ca.* 60 m depth (index 1.36; Ikeya *et al.*, 1992), St. 11 of the outer area of Tateyama Bay at *ca.* 40 m depth (index 1.71; based on data of Frydl, 1982) and St. G-6 of the upper shelf area off Oki Island in 79 m depth along the Japan Sea coast (index 1.95; based on data of Tsukawaki *et al.*, 1998).

Previous studies reported fossil molluscs from the Kakio Formation (e.g. Takano, 1994). Masaoka (1978) recognized 54 molluscan species from and near horizons of our sample d1, and inferred that this fossil assemblage indicates a palaeoenvironment of an inner bay area with a wide bay mouth influenced by the open sea. These facts support our inference for the palaeoenvironment of the assemblage LP.

We inferred three types of palaeoenvironments based on ostracod occurrences from five formations in the Kazusa Group in the Tama Hills. The western area between *ca.* 1.7 and 1.4 Ma shows two types of environments: the innermost to central areas of an inner bay, and the central to outer areas of a shallow bay. The eastern area during *ca.* 1.5–1.4 Ma also shows evidence of two types of environments: the central to outer areas of a shallow bay, and the outer area of a shallow bay to the upper continental shelf.

Significant occurrence of *Laperousecythere robusta*

Brouwers (1993) established the genus *Laperousecythere* based on specimens from modern coastal surface sediments in the Gulf of Alaska, in the Northeast Pacific. This species is endemic in the North Pacific region, including two marginal areas (Figure 9). Yamaguchi *et al*. (2005) reported the oldest fossil of this genus from an upper Eocene stratum in Japan, thus placing its origin in the Northwest Pacific Ocean around Japan.

Laperousecythere robusta first appeared in the Japan Sea in the early Pleistocene (Figure 9; 2 Ma; age from Yamada *et al*., 2002) and subsequently migrated to the Northeast Pacific during the Pleistocene (Brouwers, 1993). Its modern and fossil occurrences are also known from the Japan Sea, Okhotsk Sea, and Northeast Pacific (Ozawa *et al*., 2004a), but there was no record from the Pacific coast of the Japanese Islands. The fossils found in the Kazusa Group (Figures 6.7 and 6.8) are the first record of *L. robusta* from the Northwest Pacific Ocean

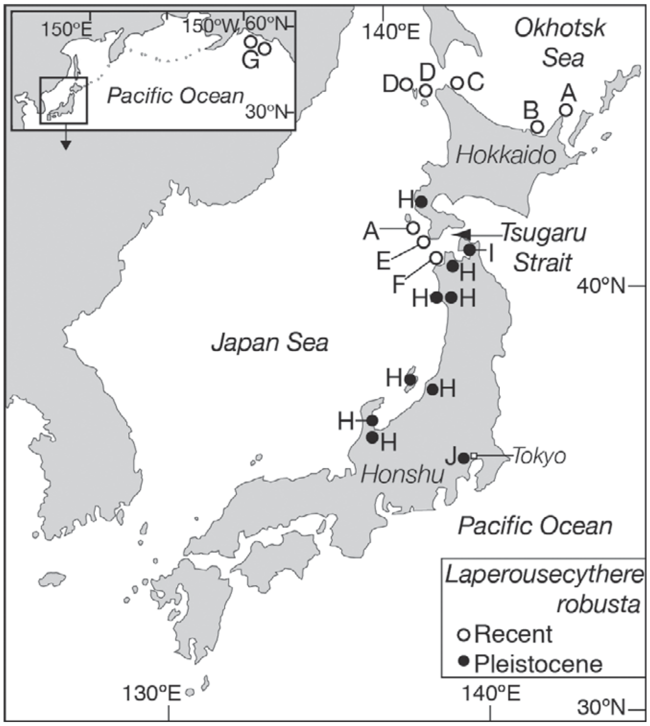

Figure 9. Geographical and geological occurrences of *Laperousecythere robusta*. **A**, Ozawa and Tsukawaki (2008); **B**, Ozawa *et al.* (2004b); **C**, Ikeya and Cronin (1993); **D**, Ozawa *et al.* (1999); **E**, Tsukawaki *et al.* (2001); **F**, Tsukawaki *et al.* (1999); **G**, Brouwers (1993); **H**, Ozawa and Kamiya (2005); **I**, Ozawa and Domitsu (2010); **J**, this study.

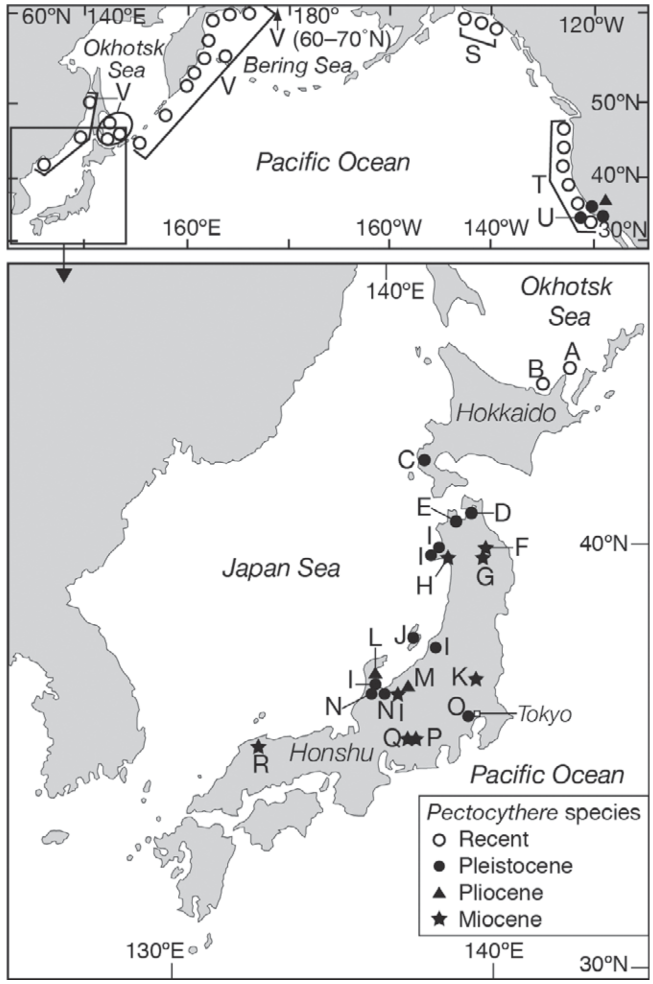

Figure 10. Geographical and geological occurrences of species in the genus *Pectocythere* in North Pacific region. **A**, Ozawa and Tsukawaki (2008); **B**, Ozawa *et al.* (2004b); **C**, Hanai (1957a); **D**, Ozawa and Domitsu (2010); **E**, Tabuki (1986); **F**, Irizuki and Matsubara (1994); **G**, Irizuki and Matsubara (1995); **H**, Irizuki (1994); **I**, Ozawa (unpublished data); **J**, Ozawa (2010b); **K**, Irizuki *et al.* (1998); **L**, Cronin *et al.* (1994); **M**, Ozawa *et al.* (2008); **N**, Ozawa (1996); **O**, this study; **P**, Yamada *et al.* (2001); **Q**, Irizuki *et al.* (2004); **R**, Matsuura *et al.* (2013); **S**, Brouwers (1990); **T**, Valentine (1976); **U**, Whatley and Boomer (1995); **V**, Schornikov (2013).

(Figure 9) and fill substantial gaps of its regional distribution. This occurrence is important for understanding the route and timing of the migration of *L. robusta* from the Japan Sea to the Pacific. *Laperousecythere robusta* must have reached the Northwest Pacific Ocean after 2 Ma, probably through the Tsugaru Strait from the Japan Sea. It likely moved southward to central Japan, reaching Tokyo Bay around 1.6 Ma. The colder temperatures during the glacial intervals would have allowed for this movement because *L. robusta* favors cold water of less than 5°C in winter (Ozawa *et al*., 2004a; Ozawa, 2006).

The genus *Laperousecythere* had the highest species diversity in early Pleistocene Japan Sea with a total of six species (*L. robusta*, *L.* cf. *ishizakii*, *L.* sp. A, *L.* sp. B., *L.* sp. C, and *L.* sp. D; Ozawa and Kamiya, 2005; Ozawa, 2007). Five of these species (all except *L. robusta*) were once endemic in the Pleistocene Japan Sea. However, these five species became extinct within this semiclosed marginal sea during the Pleistocene, due to environmental fluctuations related to glacio-eustatic sea-level changes, particularly the influx of low-salinity water during glacial intervals (Ozawa, 2007; Ishida *et al.*, 2012). One possible reason for the survival of *L. robusta* could be the fact that it was present outside the Japan Sea (for example, in the Northwest Pacific Ocean; Figure 9) from the early Pleistocene, whereas the other five species were present only within the Japan Sea.

Significant occurrence of *Pectocythere* sp.

Hanai (1957a) established the genus *Pectocythere*

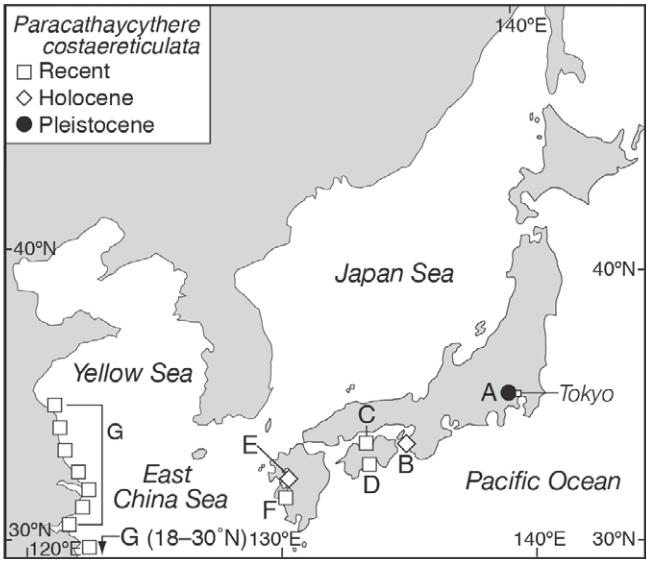

Figure 11. Geographical and geological occurrences of *Paracathaycythere costaereticulata*. **A**, this study; **B**, Yasuhara *et al.* (2002); **C**, Yamane (1998); **D**, Irizuki *et al.* (2008); **E**, Iwasaki (1992); **F**, Yumoto (1995); **G**, Whatley and Zhao (1991).

from specimens in Upper Pleistocene strata on the Japan Sea coast of the Japanese Islands. Most species of this genus are endemic in the North Pacific region, which contains two marginal areas (Figure 10), except for one European species, *Pectocythere hollowayae* from the North Sea, whose temporal range is late Miocene to early Pleistocene (Wood, 2009). Irizuki *et al*. (2004) reported the oldest fossil of this genus from lower Miocene strata in Japan (Figure 10). Therefore, this genus originated in the Pacific coast of Japan, and has migrated to the Northeast Pacific and North Sea since the early Miocene.

Species of this genus, except for *P. hollowayae*, must have diversified independently in both marginal areas of the Pacific since the late Pliocene (Figure 10) because no common species is found on both sides. Species appearing since the late Pliocene are as follows: *Pectocythere daishakaensis*, *P. pseudoamphidonta*, *P.* cf. *pseudoamphidonta* of Schornikov (2013), *P. quadrangulata*, *P.* sp. of Ozawa *et al.* (2004b), *P.* sp. 1 of Schornikov (2013) and *P.* sp. of this study in the Northwest Pacific Ocean and its marginal areas (e.g. Hanai, 1957a; Schornikov, 2013); and *P. clavata*, *P. janae*, *P. kiklukhensis*, *P. marincovichi*, *P. parkerae*, *P. tomalensis*, and *P. tsinensis* with several unnamed *Pectocythere* species from the Northeast Pacific (Triebel, 1957; Watling, 1970; Valentine, 1976; Brouwers, 1990). Only the Kazusa Group yielded *Pectocythere* sp. in our study (*ca.* 1.6–1.4 Ma; Figures 6.19–6.21), suggesting that it speciated in the Pacific coast of Japan by 1.6 Ma at the latest. This species is an example of the diversification of *Pectocythere* since the late Pliocene in the North Pacific.

This genus shows the highest species diversity in the high latitudes (e.g. in the modern Gulf of Alaska; Brouwers, 1990) and is commonly associated with other cryophilic ostracod taxa since the late Miocene (Irizuki, 1994; Ozawa and Kamiya, 2005). Therefore, we assume that *Pectocythere* is cryophilic, and the *P.* sp. of our study might have first appeared on the Pacific coast around Tokyo during glacial intervals in the early Pleistocene before 1.6 Ma.

Significant occurrences of bay species

The ostracod fauna from the Kazusa Group include species of representative inner-bay ostracods of present-day Japan, i.e., *Bicornucythere bisanensis* and *Spinileberis quadriaculeata*, together with *Spinileberis furuyaensis* and *Paracathaycythere costaereticulata* (Figures 6.2, 6.11, 6.15, 6.18; Table 2). The fossil occurrences of these four species (Figure 7) are the oldest records of these inner-bay species near the Tokyo Bay area (e.g. Figure 11). Previous research has not shown any fossil occurrences of these species from the early Pleistocene near Tokyo (e.g. Yumoto, 1995; Ozawa, 2010a; Ozawa and Domitsu, 2010; Irizuki *et al.*, 2011; Tanaka *et al.*, 2011). Many studies indicated that these inner-bay species have migrated from their original southern habitats, such as Okinawa Island, southwestern Japan in the East China Sea, along the Pacific coast of Japan since the late Pliocene (Ishizaki, 1990a, b; Yumoto, 1995; Ikeya *et al.*, 1995; Irizuki *et al.*, 2005, 2009, 2011; Ozawa, 2009, 2010b; Ozawa and Domitsu, 2010; Tanaka *et al.*, 2011). Occurrences of the above four species from the Kazusa Group clearly indicate that these species had already inhabited inner-bay areas near Tokyo Bay by 1.6 Ma (*Bicornucythere bisanensis* and *Spinileberis furuyaensis*) based on occurrences from the Hirayama Formation and by 1.5 Ma (*Paracathaycythere costaereticulata* and *Spinileberis quadriaculeata*) on the basis of occurrences from the Tsurukawa Formation at the latest.

However, the assemblages do not include two inner-bay species, *Neomonoceratina delicata* and *Sinocytheridea impressa*, in the Kazusa Group (Table 2). Irizuki *et al*. (2009) discussed the palaeobiogeography of *N. delicata* in Southeast and East Asia in detail. Two dominant species of the Kazusa Group, *B. bisanensis* and *S. quadriaculeata*, are commonly found with *N. delicata* in the Middle Pleistocene inner-bay fauna from central Japan (Irizuki and Seto, 2004; Irizuki *et al.*, 2011). According to Irizuki *et al*. (2009), *N. delicata* migrated from south of the Tokara Strait (Watase's line) by *ca.* 0.4 Ma (MIS 11) in the Middle Pleistocene through southern Japan and reached Tokyo Bay by *ca.* 0.3 Ma (MIS 9) at the latest.

Irizuki *et al*. (2005) also discussed the palaeobiogeography of *S. impressa* in Southeast and East Asia in detail, describing its migration from the South China Sea coast to Honshu locations such as Osaka and Hamana-ko bays. They stated that this species did not reach Tokyo Bay from the southern coast. It became regionally extinct in the two bays around 0.4 Ma and presently lives only south of the Seto Inland Sea. One of the dominant species from the Kazusa Group, *S. quadriaculeata*, is commonly found with *S. impressa* from a Middle Pleistocene inner-bay fauna near Osaka Bay in southwestern Japan (Irizuki *et al.*, 2005). The fact that *N. delicata* and *S. impressa* were not found in the early Pleistocene Kazusa Group near Tokyo Bay is consistent with previous studies. The absence of the above two species near Tokyo in deposits from 1.7 to 1.4 Ma could be due to the distance from their original southern habitats and the timing of the species' northward migration.

The occurrence or absence of these six inner-bay species in the early Pleistocene Kazusa Group could help to clarify the timing of northward migration by shallow-marine benthic organisms from their original southern habitats along the margin of the Northwest Pacific Ocean during the late Cenozoic.

Conclusions

(1) Nine samples from the early Pleistocene Kazusa Group (*ca.* 1.7–1.4 Ma) of the Tama Hills near Tokyo Bay, central Japan, contained 56 species of ostrcaods. This study is the first to report an ostracod fauna in the early Pleistocene from the Kanto District.

(2) Q-mode cluster analysis distinguished three assemblages. The depositional environment of each assemblage can be inferred as (a) the innermost to middle area of an inner bay influenced by fresh water with relatively low salinity, (b) an outer area of an inner-bay to upper-shelf area influenced by open sea water with relatively high salinity, and (c) a central to outer area of the inner bay with salinity intermediate between that of (a) and (b).

(3) This study is the first to report occurrences of two cryophilic taxa, *Laperousecythere robusta* and *Pectocythere* sp., from the Northwest Pacific Ocean. *Laperousecythere robusta* travelled southward from the Japan Sea probably through the Tsugaru Strait to central Japan near Tokyo Bay during glacial intervals prior to 1.6 Ma. *Pectocythere* sp. might have first appeared around Tokyo Bay in glacial intervals before 1.6 Ma.

(4) Assemblages BS and PB predominantly or commonly contain *Bicornucythere bisanensis* and *Spinileberis quadriaculeata*, with *Spinileberis furuyaensis* and *Paracathaycythere costaereticulata*. This clearly indicates that these four species had already inhabited inner-bay areas near Tokyo Bay by 1.6–1.4 Ma at the latest. Their occurrences are the oldest record of inner-bay species around Tokyo Bay for each species.

(5) This fauna does not include two inner-bay species, *Neomonoceratina delicata* and *Sinocytheridea impressa*, currently distributed south of the Japanese Islands. Their absence near Tokyo Bay in the early Pleistocene is consistent with findings of previous palaeobiogeographical studies.

Taxonomic notes

We briefly described the morphology of the six species below, by using the following measurements in the text: *L*: carapace length (mm), *H*: carapace height (mm).

Order Podocopida Sars, 1866
Superfamily Cytheroidea Baird, 1850
Family Eucytheridae Puri, 1954
Subfamily Pectocytherinae Hanai, 1957
(in Hanai, 1957a)
Genus ***Pectocythere*** Hanai, 1957 (in Hanai, 1957a)
Pectocythere sp.

Figures 6.19–6.21

Remarks.—This species is similar to *Pectocythere quadrangulata* Hanai, 1957 (in Hanai, 1957a) from Plio-Pleistocene sediments of the Japan Sea coast in general external morphology and both the shape and number of muscle scars. However, it differs from *P. quadrangulata* in its weak reticulation in the postero-median area and the outline of the anterior and dorsal margins, with its small-sized carapace (L = 0.43–0.44, H = 0.24–0.25; based on Figures 6.19–6.20) in comparison with the type specimens (L = 0.60–0.64, H = 0.35–0.37 in types; Hanai, 1957a). The present species is also similar to *Pectocythere tsiuensis* Brouwers, 1990 from modern surface sediments in the Northeast Pacific in the general external morphology of the carapace and both the shape and number of muscle scars with one prominent fulcral point. However, the present species differs from *P. tsiuensis* in its weak reticulation in the upper half of the carapace and round outline of the anterior and dorsal margins. The present species is smaller than *P. tsiuensis* (L = 0.60–0.65, H = 0.33–0.36 in types; Brouwers, 1990).

Family Cytheridae Baird, 1850
Subfamily Leptocytherinae Hanai, 1957
(in Hanai, 1957b)
Genus ***Callistocythere*** Ruggieri, 1953
Callistocythere cf. ***subjaponica*** Hanai, 1957
(in Hanai, 1957b)

Figure 6.5

Remarks.—This species is very similar to *Callistocythere subjaponica* Hanai, 1957 (in Hanai, 1957b) from modern beach sand of the Miura Peninsula of central Japan's Pacific coast in lateral outline and size of carapace, and in having a second posterior marginal ridge that is parallel to the posterior margin. However, it differs from *C. subjaponica* in having a lower anterocardinal angle and weaker ridges over the entire area of the carapace. The present species is similar to *Callistocythere japonica* Hanai, 1957 (in Hanai, 1957b) from Recent coastal sand of the Miura Peninsula in carapace outline, general external morphology and size. However, it differs from *C. japonica* in its weak reticulation between ridges in the entire area of carapace, and in the outline of the posteroventral margin, which has a distinct second posterior marginal ridge parallel to it. This species also resembles *Callistocythere alata* Hanai, 1957 (in Hanai, 1957b) from modern beach sand of the Izu Peninsula of central Japan's Pacific coast in the reticulation pattern over the entire carapace and the carapace size. However, this species differs from *C. alata* both in having weaker ridges and finer reticulation between ridges over the entire carapace.

Family Cushmanideidae Puri, 1974
(in Hartmann and Puri, 1974)
Genus ***Pontocythere*** Dubowsky, 1939
Pontocythere sp. 1

Figures 6.12–6.13

Remarks.—This species resembles *Pontocythere miurensis* Hanai, 1959 from the modern beach sand of the Miura Peninsula of central Japan's Pacific coast, but it differs from *P. miurensis* in its narrow anterior outline and its much smaller carapace even in the adult stage (L = 0.38–0.42, H = 0.16–0.18; based on Figure 6.12–6.13) than the type specimens of *P. miurensis* (L = 0.67–0.74, H = 0.30–0.35 in types; Hanai, 1959). This species also resembles *Pontocythere* sp. 1 of Yajima (1982) from the Upper Pleistocene sediments of the Boso Peninsula of central Japan's Pacific coast in carapace length and height. However, it differs from *Pontocythere* sp. 1 of Yajima (1982) (L = 0.43, H = 0.16; Yajima, 1982) in lateral carapace outline posteriorly and a rounder outline than *P.* sp. 1 has.

Family Trachyleberididae Sylvester-Bradley, 1948
Subfamily Pterygocytheridinae Puri, 1957
Genus ***Bicornucythere*** Schornikov and Shaitarov, 1979
Bicornucythere bisanensis (Okubo, 1975)

Figure 6.2

Remarks.—Abe (1988) and Abe and Choe (1988) divided *B. bisanensis* into four forms based on carapace morphology. Carapace outline, length and height, and length-height ratio (*ca.* 2.0) indicate that all specimens of *B. bisanensis* from the Kazusa Group belong to their 'form A'. This form has the same morphological characters as the holotype specimen of *B. bisanensis* described by Okubo (1975) from the modern coast of the Seto Inland Sea, southwestern Japan (e.g., Irizuki and Seto, 2004; Irizuki *et al.*, 2011), and first appeared around Japan in the late Cenozoic (Abe, 1988).

Family Cytheruridae Müller, 1894
Genus ***Cytheropteron*** Sars, 1866
Cytheropteron sp.

Figure 6.4

Remarks.—This species resembles *Cytheropteron miurense* Hanai, 1957 (in Hanai, 1957c) from modern beach sand of the Miura Peninsula of central Japan's Pacific coast on the general external morphology. However it differs from *C. miurense* in strong ridges and large reticulation on the entire carapace, with narrow ventral ala and its smaller-sized carapace (L = 0.45, H = 0.27; based on Figure 6.4) than the type specimens (L = 0.49, H = 0.32 in holotype; Hanai, 1957c). The present species is similar to *Cytheropteron sawanense* Hanai, 1957 (in Hanai, 1957c) from Middle Pleistocene deposits on Sado Island in the Japan Sea in general external morphology. However, this species differs from *C. sawanense* in having robust reticulation on entire carapace and coarser reticulation in the central area, a deep fossa in the posterior area, and a smaller carapace than the type specimens (L = 0.59–0.62, H = 0.35–0.39 in types; Hanai, 1957c).

Family Xestoleberididae Sars, 1928
Genus ***Xestoleberis*** Sars, 1928
Xestoleberis cf. ***dentata*** Schornikov, 1975

Figure 6.17

Remarks.—This species is very similar to *Xestoleberis dentata* Schornikov, 1975 from modern rocky shores of the Seto Inland Sea, of southwestern Japan in the general shape and size of the carapace. However it differs from *X. dentata* in the anterior and posterior ends of the carapace being bluntly pointed. This species also resembles *Xestoleberis ikeyai* Sato and Kamiya, 2007 from modern beach sand at Sesoko Island, just off Motobu, Okinawa Island, southwestern Japan in the East China Sea in general shape and size of the carapace. However this species differs from *X. ikeyai* in having an oval-shaped carapace and a more rounded anterior end.

Acknowledgments

We extend our thanks to Y. Tanimura, K. Uemura, M. Saito (National Museum of Nature and Science, Japan) and the late Y. Kuwano for assisting in preparation for the manuscript and for giving sediment samples with information on fossil localities of the Kazusa Group at the Tama Hills. We also would like to thank B.-C. Zhou (China) for presenting the unpublished data of modern ostracod occurrences from the Pacific coast of southwestern Japan with Otsuchi Bay and Y. Nakao (Nihon University, Japan) for reading an early draft and helping in the identification of ostracod species. We wish to thank T. Irizuki (Shimane University, Japan), M. Yasuhara (Hong Kong University, China) and an anonymous reviewer for constructive reviews. For using by scanning electron microscopes, we thank the National Museum of Nature and Science, Tsukuba, Japan and General Research Institute of College of Bioresource Sciences, Nihon University, Fujisawa, Japan.

References

Abe, K., 1983: Population structure of *Keijella bisanensis* (Okubo) (Ostracoda, Crustacea)—an inquiry into how far the population structure will be preserved in the fossil record. *The University Museum*, *the University of Tokyo*, *Bulletin*, no. 20, p. 443–488.

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

Abe, K. and Choe, K.-L., 1988: Variation of *Pistocythereis* and *Keijella* species in Gamagyang Bay, south coast of Korea. *In*, Hanai, T., Ikeya, N. and Ishizaki, K. *eds.*, *Evolutionary Biology of Ostracoda—Its Fundamentals and Applications*, p. 367–373. Kodansha, Tokyo and Elsevier, Amsterdam.

Akimoto, K. and Hasegawa, S., 1989: Bathymetric distribution of the Recent benthic foraminifers around Japan: As a contribution to the new paleobathymetric scale. *Memoirs of the Geological Society of Japan*, no. 32, p. 229–240. (*in Japanese with English abstract*)

Baba, K., Matsukawa, M., Hayashi, A., Fujii, E., Miyashita, O. and Aiba, H., 1986: A plan for education in geology using strata locally cropped out: an example for the bed of Tama River in the southern Tachikawa City. *Education of Earth Science*, vol. 39, p. 193–201. (*in Japanese*; *original title translated*)

Baird, W., 1850: *The Natural History of the British Entomostraca*, 364 p. The Ray Society, London.

Boomer, I., Horne, D. J. and Slipper, I. J., 2003: The use of ostracodes in paleoenvironmental studies or what can you do with an ostracode shell? *In*, Park, L. E. and Smith, A. J. *eds*., *Bridging the Gap*: *Trends in the Ostracode Biological and Geological Sciences*. The Paleontological Society Papers 9, p. 153–179.

Brady, G. S., 1880: Report on the Ostracoda dredged by H.M.S. Challenger during the years 1873–76. *In*, *Report of the Scientific Results of the Voyage of H.M.S. Challenger during the years 1873–76*, *Zoology*, vol. 1, p. 1–184.

Brouwers, E. M., 1990: Systematic paleontology of Quaternary ostracode assemblages from the Gulf of Alaska, Part 1: Families Cytherellidae, Bairdiidae, Leptocytheridae, Eucytheridae, Krithidae, Cushmanideidae. *U.S. Geological Survey Professional Paper*, vol. 1510, p. 1–43.

Brouwers, E. M., 1993: Systematic paleontology of Quaternary ostracode assemblages from the Gulf of Alaska, Part 2: Families Trachyleberididae, Hemicytheridae, Loxoconchidae, Paracytheridae. *U.S. Geological Survey Professional Paper*, vol. 1531, p. 1–47.

Chinzei, K., 1991: Late Cenozoic zoogeography of the Sea of Japan area. *Episodes*, vol. 14, p. 231–235.

Cronin, T. M., Kitamura, A., Ikeya, N., Watanabe, M. and Kamiya, T., 1994: Late Pliocene climate change 3.4–2.3 Ma: paleoceanographic record from the Yabuta Formation, Sea of Japan. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, vol. 108, p. 437–455.

Dubowsky, N. V., 1939: Materialy k poznaniyu fauny Ostracoda Chernogo morya [Contributions to the knowledge of the ostracod fauna of the Black Sea]. *Trudy Karadagskoy Biologicheskoy Stantsii*, vol. 5, 1-68. (*in Russian*)

Frydl, P. M., 1982: Holocene ostracods in the southern Boso Peninsula. *The University Museum*, *the University of Tokyo*, *Bulletin*, no. 20, p. 61–140.

Fujimoto, H., Juen, S. and Hatori, K., 1961: Geology of the Tama Hills. *Research Report of Cultural Property in Tokyo Metropolitan Area*, *Tokyo Metropolitan Board of Education*, no. 10, p. 1–23. (*in Japanese*; *original title translated*)

Fujioka, M. and Kameo, K., 2004: Correlation between the Obama Formation of the Inubou Group in the Choshi district and the Kiwada, Otadai and Umegase Formations of the Kazusa Group in the Boso Peninsula, central Japan, based on key tephra layers. *Journal of the Geological Society of Japan*, vol. 110, p. 480–496. (*in Japanese with English abstract*)

Hammer, Ø., 2013: PAST: PAleontological STatistics Version 3.01. Available from: http://folk.uio.no/ohammer/past/.

Hanai, T., 1957a: Studies on the Ostracoda from Japan: 2. Subfamilies Pectocytherinae, new subfamily. *Journal of the Faculty of Science*, *the University of Tokyo*, *Section 2*, vol. 10, p. 469–482.

Hanai, T., 1957b: Studies on the Ostracoda from Japan: 1. Subfamilies Leptocytherinae, new subfamily. *Journal of the Faculty of Science*, *the University of Tokyo*, *Section 2*, vol. 10, p. 431–468.

Hanai, T., 1957c: Studies on the Ostracoda from Japan: 3. Subfamilies Cytherurinae G. W. Müller (emend. G. O. Sars, 1925) and Cytheropterinae, new subfamily. *Journal of the Faculty of Science*, *the University of Tokyo*, *Section 2*, vol. 11, p. 11–36.

Hanai, T., 1959: Studies on the Ostracoda from Japan. 4. Family Cytherideidae Sars 1925. *Journal of the Faculty of Science*, *the University of Tokyo*, *Section 2*, vol. 11, p. 291–308.

Hanai, T., 1970: Studies on the ostracod subfamily Schizocytherinae Mandelstam. *Journal of Paleontology*, vol. 44, p. 693–729.

Hartmann, G. and Puri, H. S., 1974: Summary of neontological and paleontological classification of Ostracoda. *Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut*, vol. 70, p. 7–73.

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

Horne, D. J., Cohen, A. and Martens, K., 2002: Taxonomy, morphology and biology of Quaternary and living Ostracoda. *In*, Holmes, J. A. and Chivas A. *eds*., *The Ostracoda: Applications in Quaternary Research*. Geophysical Monograph Series 131, p. 5–36. American Geophysical Union, Washington, D. C.

Igarashi, M., 1994: Paleoceanographic changes during the deposition of the middle Pleistocene Kazusa Group, central Japan: Estimation based on the principal components analysis of planktonic foraminifera. *Journal of the Geological Society of Japan*, vol. 100, p. 348–359. (*in Japanese with English abstract*)

Ikeya, N. and Cronin, T. M., 1993: Quantitative analysis of Ostracoda and water masses around Japan: Application to Pliocene and Pleistocene paleoceanography. *Micropalaeontology*, vol. 39, p. 263–281.

Ikeya, N. and Itoh, H., 1991: Recent Ostracoda from the Sendai Bay region, Pacific coast of northeastern Japan. *Reports of the Faculty of Science*, *Shizuoka University*, vol. 25, p. 93–141.

Ikeya, N., Shimura, K. and Iwasaki, Y., 1995: Ecology and adaptation of the genus *Spinileberis* in the North Pacific. *In*, Riha, J. *ed*., *Ostracoda and Biostratigraphy*, p. 389–397. Balkema, Rotterdam.

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

Ikeya, N., Zhou, B.-C. and Sakamoto, J., 1992: Modern ostracode fauna from Otsuchi Bay, the Pacific coast of Northeastern Japan. *In*, Ishizaki, K. and Saito, T. *eds*., *Centenary of Japanese Micropaleontology*, p. 339–354. Terra Scientific Publishing Company, Tokyo.

Irizuki, T., 1994: Late Miocene ostracods from the Fujikotogawa Formation, northern Japan—with reference to cold water species involved with trans-Arctic interchange. *Journal of Micropalaeontology*, vol. 13, p. 3–15.

Irizuki, T., Fujiwara, O. and Fuse, K., 1999: Taphonomy of fossil ostracode assemblages in Holocene deposits on the Miura Peninsula, central Japan. *Memoirs of the Geological Society of Japan*, no. 54, p. 99–116. (*in Japanese with English abstract*)

Irizuki, T., Ishizaki, K., Takahashi, M. and Usami, M., 1998: Ostracode faunal changes after the mid-Neogene climatic optimum elucidated in the middle Miocene Kobana Formation, Tochigi Prefecture, central Japan. *Transactions and Proceedings of the Palaeontological Society of Japan*, no. 131, p. 65–78.

Irizuki, T. and Matsubara, T., 1994: Vertical changes of depositional environments of the Lower to Middle Miocene Kadonosawa Formation based on analyses of fossil ostracode faunas. *Journal of the Geological Society of Japan*, vol. 100, p. 136–149. (*in Japanese with English abstract*)

Irizuki, T. and Matsubara, T., 1995: Early Middle Miocene ostracodes from the Suenomatsuyama Formation, Ninohe City, northeast Japan and their palaeoenvironmental significance. *Paleontological Research*, vol. 2, p. 30–46.

Irizuki, T., Matsubara, T. and Matsumoto, H., 2005: Middle Pleistocene Ostracoda from the Takatsukayama Member of the Meimi Formation, Hyogo Prefecture, western Japan: significance of the occurrence of *Sinocytheridea impressa*. *Paleontological Research*, vol. 9, p. 37–54.

Irizuki, T., Nakamura, Y., Takayasu, K. and Sakai, S., 2003: Faunal changes in Ostracoda (Crustacea) in Lake Nakaumi, southwest Japan, over the last 40 years. *Geoscience Reports of Shimane University*, no. 22, p. 149–160. (*in Japanese with English abstract*)

Irizuki, T., Naya, T., Yamaguchi, M. and Mizuno, K., 2011: Temporal changes in the paleoenvironment of the inner part of paleo-Tokyo Bay during the middle Pleistocene (MIS 11 and MIS 9): Analysis of fossil ostracode assemblages from the Shimosa Group in the Shobu core, Saitama Prefecture, Central Japan. *Journal of the Geological Society of Japan*, vol. 117, p. 35–52. (*in Japanese with English abstract*)

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. *Journal of the Geological Society of Japan*, vol. 110, p. 309–324. (*in Japanese with English abstract*)

Irizuki, T., Seto, K. and Nomura, R., 2008: The impact of fish farming and bank construction on Ostracoda in Uranouchi Bay on the Pacific coast of southwest Japan—Faunal changes between 1954 and 2002/2005. *Paleontological Research*, vol. 12, p. 283–302.

Irizuki, T., Taru, H., Taguchi, K. and Matsushima, Y., 2009: Paleobiogeographical implications of inner bay ostracodes during the Late Pleistocene Shimosueyoshi transgression, central Japan, with significance of its migration and disappearance in eastern Asia. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, vol. 271, p. 316–328.

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

Ishida, K., Yoshida, K. and Matsuoka, A., 2012: Fossil ostracode assemblages in the Middle Pleistocene upper part of the Sawane Formation on Sado Island, Niigata Prefecture, central Japan and surface water freshening of the Sea of Japan. *Journal of the Geological Society of Japan*, vol. 118, p. 476–492. (*in Japanese with English abstract*)

Ishii, T., Kamiya, T. and Tsukagoshi, A., 2005: Phylogeny and evolution of Loxoconcha (Ostracoda, Crustacea) species around Japan. *Hydrobiologia*, vol. 538, p. 81–94.

Ishizaki, K., 1966: Miocene and Pliocene Ostracodes from the Sendai area, Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 37, p. 131–163.

Ishizaki, K., 1968: Ostracodes from Uranouchi Bay, Kochi Prefecture, Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 40, p. 1–45.

Ishizaki, K. 1969: Ostracodes from Shinjiko and Nakanoumi, Shimane Prefecture, western Honshu, Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 41, p. 197–224.

Ishizaki, K., 1971: Ostracodes from Aomori Bay, Aomori Prefecture, Northeast Honshu, Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 43, p. 59–97.

Ishizaki, K., 1981: Ostracoda from the East China Sea. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 51, p. 37–65.

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

Ishizaki, K., 1990b: 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. 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: Selected Papers in Honor of Prof. Kiyoshi Asano*, p. 118–143. Micropaleontology Press, The American Museum of Natural History, New York.

Ito, H., Taniguchi, T., Shinohara, K. and Eto, T., 2002: Fission-track ages of the early Pleistocene tephras in the Kazusa Group in Tama Hills, central Japan. *The Quaternary Research (Daiyonki-Kenkyu)*,

vol. 41, p. 421–426. (*in Japanese with English abstract*)
Iwai, T., 2008: Examination for occurred cause of oxygen-deficient water at middle-southern district area along the shore in Sendai Bay. *Miyagi Prefectural Report of Fisheries Science*, no. 8, p. 5–13. (*in Japanese*)
Iwasaki, Y., 1992: Ostracod assemblages from the Holocene deposits of Kumamoto, Kyusyu. *Kumamoto Journal of Sciences (Geology)*, vol. 13, p. 1–12. (*in Japanese with English abstract*)
Kajiyama, E., 1913: The Ostracoda from Misaki, part 3. *Zoological Magazine of Tokyo (Doubutsugaku-zassi)*, vol. 25, p. 1–16. (*in Japanese*)
Kamiya, T., 1988: Morphological and ethological adaptations of Ostracoda to microhabitats in *Zostera* beds. *In*, Hanai, T., Ikeya, N. and Ishizaki, K. *eds.*, *Evolutionary Biology of Ostracoda—Its Fundamentals and Applications*, p. 303–318. Kodansha, Tokyo and Elsevier, Amsterdam.
Kamiya, T., Ozawa, H. and Obata, M., 2001: Quaternary and Recent marine Ostracoda in Hokuriku district, the Japan Sea coast. *In*, Ikeya, N. *ed.*, *Field Excursion Guidebook; 14th International Symposium of Ostracoda*, *Shizuoka*, p. 73–106. Organising Committee of 14th ISO, Shizuoka.
Kitazaki, T. and Majima, R., 2003: A cold-seep assemblage in a slope to outer-shelf environment in the Plio-Pleistocene Kazusa Group, Pacific side of central Japan. *Paleontological Research*, vol. 7, p. 279–296.
Kitazato, H., 1977: Vertical and lateral distributions of benthic foraminiferal fauna and the fluctuation of warm and cold waters in the middle Pleistocene of the Boso Peninsula, Central Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 47, p. 7–41.
Koizumi, A., 1990: Early Pleistocene Otariidae from Iimuro Formation, Kawasaki, Kanagawa Prefecture, Japan. *Bulletin of Kanagawa Prefecture Museum*, vol. 19, p. 45–66. (*in Japanese with English abstract*)
Kosugi, M., Kataoka, H. and Hasegawa, S., 1991: Classification of foraminifer communities as indicators of environments in an inner bay and its application to reconstruction of paleoenvironments. *Fossils (Palaeontological Society of Japan)*, no. 50, p. 37–55. (*in Japanese with English abstract*)
Lisiecki, L. E. and Raymo, M. E., 2005: A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoceanography*, vol. 20, p. 1–17.
Masaoka, E., 1978: Outcrop and molluscan fossils from the type locality of the Kakio Mudstone (Loc. Kakio-M of Otuka, 1932) at the Tama Hills. *Geological Survey Report of Land Readjustment Project for the Shin-Yurigaoka Station*, p. 1–11. (*in Japanese*; *original title translated*)
Masaoka, E., Takano, S. and Masubuchi, K., 1990: Summary for molluscan fossils from the Lower Pleistocene Kazusa Group at the Tama Hills (1). *Bulletin of the Kyodo-no-Mori Museum*, *Fuchu City*, *Tokyo*, no. 3, p. 11–18. (*in Japanese*; *original title translated*)
Masubuchi, K., 1995: Diatom assemblages from carbonate concretion in the Lower Pleistocene Kazusa Group, Iimuro Formation in the Tama Hills, central Japan. *Bulletin of Kawasaki Municipal Science Museum for Youth*, vol. 6, p. 1–6. (*in Japanese*)
Masubuchi, K., Sekimoto, K., Sato, T., Kikkawa, M. and Itoda, T., 1995: Stratigraphy of microfossils and paleomagnetism in the Lower Pleistocene Kazusa Group, Iimuro Formation in the Tama Hills, central Japan. *Bulletin of Kawasaki Municipal Science Museum for Youth*, vol. 6, p. 7–39. (*in Japanese*; *original title translated*)
Matsukawa, M., Shinkai, T., Hayashi, K., Mitsugi, T. and Baba, K., 2001: Let's walk on ancient marine bottom based on the Quaternary Kazusa Group at the Tamagawa River floor in South Tokyo. *Education of Earth Science*, vol. 54, p. 193–201. (*in Japanese*; *original title translated*)
Matsuura, Y., Irizuki, T. and Hayashi, H., 2013: Microfossil assemblages associated with argonaut fossils fron the Middle Miocene Fujina Formation, Shimane Prefecture, southwestern Honshu, Japan. *Journal of the Geological Society of Japan*, vol. 119, p. 312–320. (*in Japanese with English abstract*)
Mitsunashi, T., Kikuchi, T., Suzuki, Y., Hirayama, J., Nakajima, T., Oka, S., Kodama, K., Moriguchi, M., Katsurajima, S., Miyashita, M., Yazaki, K. and Kageyama, K., 1979: Chapter 1: Surface geology. *Explanatory Text of the Geological Map of Tokyo Bay and Adjacent Areas*. *Miscellaneous Map Series*, *Scale 1:100,000*, no. 20, 72 p. Geological Survey of Japan, Kawasaki. (*in Japanese with English abstract*)
Morishita, M., 1959: Measuring of interspecific association and similarity between communities. *Memoirs of the Faculty of Science*, *Kyushu University*, *Series E (Biology)*, vol. 3, p. 65–80.
Mukaiyama, T. and Matsuda, T., 1998: Fossil molluscan assemblage and its palaeoenvironment collected from the riverbed of Asa-kawa, along the Northeast of Tama Hills, Tokyo. *Bulletin of Association of Kanto Quaternary Research*, vol. 21, p. 19–39. (*in Japanese*; *original title translated*)
Müller, G. W., 1894: Die Ostracoden des Golfes von Neapel und der angrenzenden Meeresabschnitte. *Fauna und Flora des Golfes von Neapel*, *Monographie*, vol. 21, p. 1–404.
Nakao, Y. and Tsukagoshi, A., 2002: Brackish-water Ostracoda (Crustacea) from the Obitsu River estuary, central Japan. *Species Diversity*, vol. 7, p. 67–115.
Nakao, Y. and Tsukagoshi, A., 2008: Seasonal and decadal changes in distribution and abundance of Ostracoda (Crustacea) in the brackish-water environments. *Proceedings of the Institute of Natural Sciences*, *Nihon University*, no. 43, p. 249–275. (*in Japanese with English abstract*)
Nobuhara, T., 1993: The relationship between bathymetric depth and climate change and its effect on molluscan faunas of the Kakegawa Group, central Japan. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 170, p. 159–185.
Oda, M., 1977: Planktonic foraminiferal biostratigraphy of the Late Cenozoic sedimentary sequence, central Honshu, Japan. *Science Reports of the Tohoku University*, *Second Series (Geology)*, vol. 48, p. 1–72.
Ogasawara, K., 1994: Neogene paleogeography and marine climate of the Japanese Islands based on shallow-marine molluscs. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, vol. 108, p. 335–351.
Oka, S., Kikuchi, T. and Katsurajima, S., 1984: *Geology of the Tokyo-Seinanbu District*, *Quadrangle Series (1: 50,000)*, 148 p. Geological Survey of Japan, Tsukuba. (*in Japanese with English abstract*)
Okubo, I., 1975: *Callistocythere pumila* Hanai, 1957 and *Leguminocythereis bisanensis* sp. nov. in the Inland Sea, Japan. *Proceedings of the Japanese Society of Systematic Zoology*, vol. 11, p. 23–31.
Okubo, I., 1980: Taxonomic studies on Recent marine podocopid Ostracoda from the Inland Sea of Seto. *Publications of the Seto Marine Biological Laboratory*, vol. 25, p. 389–443.
Okutani, T., 2000: *Marine Mollusks in Japan*, 1173 p. Tokai University Press, Tokyo. (*in Japanese*)
Otuka, Y., 1932: Geology of the Tama Hills (Part 1). *Journal of the Geological Society of Japan*, vol. 39, p. 641–655. (*in Japanese*; *original title translated*)
Oyama, K., 1973: Revision of Matajiro Yokoyama's type Mollusca

from the Tertiary and Quaternary of the Kanto area. *Palaeontological Society of Japan, Special Papers*, no. 17, 1–148.

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

Ozawa, H., 2006: An overview of the geographical distribution and ecological significance of species in the three families of cryophilic ostracods (Crustacea: Ostracoda) in and around the Japan Sea–with special reference to distribution of species in relation to water temperature–salinity ranges. *Taxa, Proceedings of the Japanese Society of Systematic Zoology*, vol. 20, p. 26–40. (*in Japanese with English abstract*)

Ozawa, H., 2007: Faunal changes of cryophilic ostracods (Crustacea) in the Japan Sea, in relation to oceanographic environment: an overview. *Fossils (Palaeontological Society of Japan)*, no. 82, p. 22–30. (*in Japanese with English abstract*)

Ozawa, H., 2009: Middle Pleistocene ostracods from the Naganuma Formation in the Sagami Group, Kanagawa Prefecture, central Japan: palaeo-biogeographical significance of the bay fauna in Northwest Pacific margin. *Paleontological Research*, vol. 13, p. 231–244.

Ozawa, H., 2010a: Extinction of cytheroidean ostracodes (Crustacea) in shallow-water around Japan in relation to environmental fluctuations since the early Pleistocene. *In*, Tepper, G. H. *ed.*, *Species Diversity and Extinction*, p. 61–109. Nova Science Publishers, New York.

Ozawa, H., 2010b: Preliminary report on occurrences of the middle Pleistocene ostracods from the Shichiba Formation on Sado Island at the eastern Japan Sea, central Japan. *Nihon–Kaiiki Kenkyu, Kanazawa University*, vol. 41, p, 15–36.

Ozawa, H. and Domitsu, H., 2010: Early Pleistocene ostracods from the Hamada Formation in the Shimokita Peninsula, northeastern Japan: palaeo-biogeographic significance of the occurrence for the shallow-water fauna. *Paleontological Research*, vol. 14, p. 1–18.

Ozawa, H., Ikehara, K. and Katayama, H., 1999: Recent ostracode fauna in the northeastern part of the Japan Sea, off northwestern Hokkaido. *In*, Ikehara, K. and Okamura, Y. *eds.*, *Comprehensive Study on Environmental Changes in the Western Hokkaido Coastal Area and Study on Evaluation of Marine Active Faults*, p. 103–117. Geological Survey of Japan, Tsukuba. (*in Japanese, original title translated*)

Ozawa, H. and Ishii, T., 2008: Taxonomy and sexual dimorphism of a new species of *Loxoconcha* (Podocopida: Ostracoda) from the Pleistocene of the Japan Sea. *Zoological Journal of the Linnean Society*, vol. 153, p. 239–251.

Ozawa, H. and Kamiya, T., 2005: The effects of glacio-eustatic sea-level change on Pleistocene cold-water ostracod assemblages from the Japan Sea. *Marine Micropaleontology*, vol. 54, p. 167–189.

Ozawa, H., Kamiya, T., Itoh, H. and Tsukawaki, S., 2004a: Water temperature, salinity ranges and ecological significance of the three families of Recent cold-water ostracods in and around the Japan Sea. *Paleontological Research*, vol. 8, p. 11–28.

Ozawa, H., Kamiya, T., Kato, M. and Tsukawaki, S., 2004b: A preliminary report on the Recent ostracodes in sediment samples from the R. V. *Tansei-maru* Cruise KT01-14 in the southwestern Okhotsk Sea and the northeastern Japan Sea off Hokkaido. *Bulletin of the Japan Sea Research Institute*, vol. 35, p. 33–46.

Ozawa, H., Nagamori, H. and Tanabe, T., 2008: Pliocene ostracods (Crustacea) from the Togakushi area, central Japan; palaeobiogeography of trans-Arctic taxa and Japan Sea endemic species. *Journal of Micropalaeontology*, vol. 27, p. 161–175.

Ozawa, H. and Tsukawaki, S., 2008: Preliminary report on modern ostracods in surface sediment samples collected during R. V. *Tansei-maru* Cruise KT04-20 in the southwestern Okhotsk Sea and the northeastern Japan Sea off Hokkaido, north Japan. *Bulletin of the Japan Sea Research Institute*, vol. 39, p. 31–48.

Puri, H. S., 1954: Contribution to the study of the Miocene of the Florida Panhandle, Part 3, Ostracoda. *Geological Bulletin, State Board of Conservation, Florida Geological Survey*, vol. 36, p. 217–309.

Puri, H. S., 1957: Notes on the ostracode subfamily Cytherideinae Puri. *Journal of the Washington Academy of Sciences*, vol. 47, p. 305–306.

Ruggieri, G., 1953: Età e faune di un terrazzo marino sulla costa ionica della Calabria. *Giornale di Geologia, Annali del Museo Geologico di Bologna, Serie 2a*, vol. 23, p. 17–168.

Sars, G. O., 1866: Oversigt af Norges marine Ostracoder. *Forhandlinger i Videnskabs-Selskabet i Kristiania*, vol. 1865, p. 1–130.

Sars, G. O., 1928: *An account of the Crustacea of Norway. Volume 9. Ostracoda. Parts 15, 16. Cytheridae (concluded)*, p. 241–277. Bergen Museum, Bergen.

Sato, T., Chiyonobu, S. and Hodell, D. A., 2009: Quaternary calcareous nannofossils datums and biochronology in the North Atlantic Ocean, IODP Site U1308. *Proceedings of the Integrated Ocean Drilling Program*, vol. 303/306: doi: 10.2204/iodp/proc.303306.210.2009.

Sato, T. and Kamiya, T., 2007: Taxonomy and geographical distribution of recent *Xestoleberis* species (Cytheroidea, Ostracoda, Crustacea) from Japan. *Paleontological Research*, vol. 11, p. 183–227.

Schornikov, E. I., 1975: Ostracod fauna of the intertidal zone in the vicinity of the Seto Marine Biological Laboratory. *Publications of the Seto Marine Biological Laboratory*, vol. 22, p. 1–30.

Schornikov, E. I., 2013: Subclass Podocopa. *In*, Pugachev, O. N. *ed.*, *Check-list of Species of Free-Living Invertebrates of the Russian Far Eastern Seas. Issledovaniya Fauny Morei* (Investigations of the Fauna of Seas), vol. 75, p. 92–111, Russian Academy of Sciences, Zoological Institute, St. Petersburg. (*in Russian with English abstract*)

Schornikov, E. I. and Shaitarov, S. V., 1979: A new genus of ostracods from Far-Eastern Seas. *Biologiya Morya*, vol. 2, p. 41–47. (*in Russian with English abstract*)

Sekimoto, K. and Ban, M., 1994: Foraminiferal assemblages of Iimuro Formation in Ikuta Ryokuchi Park, Kawasaki City, Central Japan. *Report of Kawasaki Nature Survey*, no. 3, p. 1–8. (*in Japanese*)

Sekimoto, K., Endo, K. and Shimizu, K., 2008: Holocene deposits and the paleoenvironments in the Tokyo International Airport (Haneda), northwest part of Tokyo Bay, Central Japan. *Proceedings of the Institute of Natural Sciences, Nihon University, Section 2, Department of Geosystem Sciences*, vol. 43, p. 337–345. (*in Japanese with English abstract*)

Sunazawa, Y., Suzuki, H., Notoya, M. and Fujita, D., 2009: Occurrence of *Arachnoidiscus ornatus* in *Gelidium* beds of Himi City, Toyama Bay. *Diatom*, vol. 25, p. 79–85. (*in Japanese with English abstract*)

Suzuki, T., 2008: Stratigraphy of the Kazusa Group in the Tama Hills. *In*, Geological Society of Japan *ed.*, *Monograph Geology of Japan vol. 3: Kanto District*, p. 292–299. Asakura Publishing Company, Tokyo. (*in Japanese*; *original title translated*)

Suzuki, T. and Murata, M., 2011: Stratigraphy and correlation of tephras in the Lower Pleistocene Kiwada Formation and its correlative beds, Kanto, Central Japan. *Journal of the Geological Society of Japan*, vol. 117, p. 379–397. (*in Japanese with English abstract*)

Sylvester-Bradley, P. C., 1948: The ostracod genus *Cythereis*. *Journal*

of Paleontology, vol. 22, p. 792–797.
Tabuki, R., 1986: Plio-Pleistocene Ostracoda from the Tsugaru Basin, North Honshu, Japan. *Bulletin of College of Education*, *University of the Ryukyus*, vol. 29, p. 27–160.
Takano, S., 1994: Stratigraphy of the lower Pleistocene Kazusa Group in the Tama Hills, Central Japan. *Journal of the Geological Society of Japan*, vol. 100, p. 675–691. (*in Japanese with English abstract*)
Takata, H., Irizuki, T. and Ishida, K., 2006: Living benthic foraminifera from Urauchi Bay, Kamikoshiki-jima Island, Kagoshima Prefecture, southern Japan. *Laguna*, no. 13, p. 99–107. (*in Japanese*)
Takeda, M. and Masubuchi, K., 1984: On a fossils of *Cancer japonicus* from the Iimuro Formation (Kazusa Group) in the Tama River. *Annual Report of the Kawasaki Municipal Science Museum for Youth*, no. 2, p. 27. (*in Japanese*)
Takeda, M. and Masubuchi, K., 1985: Crab fossils of *Ovalipes punctatus* (de Haan) and *Carcinoplax lingimana* (de Haan) from the Iimuro Formation (Kazusa Group) in the Tama River. *Bulletin of the Kawasaki Municipal Science Museum for Youth*, no. 3, p. 35–38. (*in Japanese*)
Tanaka, G., Kuroda, S. and Ikeya, N., 2011: Taxonomy and microhabitats of the genus *Spinileberis* (Ostracoda, Crustacea) from Japan. *Paleontological Research*, vol. 15, p. 213–232.
Tanimura, Y., Kato, M., Nagumo, T., Kobayashi, A. and Yokoyama, K., 2005: An exceptionally well preserved Middle Pleistocene epiphytic diatom *Arachnoidiscus ornatus*, from Japan: A possible taphonomic process. *Bulletin of the National Science Museum*, *Tokyo*, *Series C (Geology & Paleontology)*, vol. 31, p. 7–12.
Tanimura, Y., Shimada, C. and Haga, M., 2002: Migration of continental mixed-waters preserved in abundance of a diatom species *Paralia sulcata*: Paleoceanography of the northeastern East China Sea from the last glacial through the postglacial. *The Quaternary Research (Daiyonki-Kenkyu)*, vol. 41, p. 85–93. (*in Japanese with English abstract*)
Terazaki, M. and Shikama, N., 1979: Monthly variation of water temperature and salinity in Otsuchi Bay. *Report of Otsuchi Marine Research Center*, no. 5, p. 9–14. (*in Japanese*)
Tokunaga, S., Gohara, Y. and Kuwano, Y., 1949: Geology of Tama Hills in the western vicinity of Tokyo. *Miscellaneous Reports of the Research Institute for Natural Resources*, vol. 14, p. 43–60. (*in Japanese with English abstract*)
Triebel, E., 1957: Neue Ostracoden aus dem Pleistozän von Kalifornien. *Senckenbergiana Lethaea*, vol. 38, p. 291–309.
Tsukagoshi, A., 1990: Ontogenetic change of distributional patterns of pore systems in *Cythere* species and its phylogenetic significance. *Lethaia*, vol. 23, p. 225–241.
Tsukawaki, S., Kamiya, T., Ozawa, H. and Kato, M., 1998: Preliminary results on the sediment samplings during the R. V. *Tansei-Maru* Cruise KT96-17 Leg 2 in the southwestern part of the Japan Sea–sediments, benthic foraminifers and ostracodes. *Bulletin of the Japan Sea Research Institute*, no. 29, p. 67–89.
Tsukawaki, S., Ozawa, H., Domitsu, H., Hirano, K., Maeda, T., Tomii, Y., Xu, X., Saito, S., Kamiya, T., Kato, M. and Oda, M., 2001: Preliminary results from the R. V. *Tansei-Maru* Cruise KT99-14 in the central and northeastern marginal part of the Japan Sea–sediments, benthic and planktonic foraminifers, and ostracodes (part 1: surface sediments). *Bulletin of the Japan Sea Research Institute*, no. 32, p. 1–28.
Tsukawaki, S., Ozawa, H., Domitsu, H., Tanaka, Y., Kamiya, T., Kato, M. and Oda, M., 1999: Preliminary results from the R. V. *Tansei-Maru* Cruise KT97-15 in the eastern marginal part of the Japan Sea off Tsugaru Peninsula, Northeast Japan–sediments, benthic and planktonic foraminifers and ostracodes. *Bulletin of Japan Sea Research Institute*, no. 30, p. 99–140.
Valentine, P. C., 1976: Zoogeography of Holocene Ostracoda off western North America and paleoclimatic implications. *U.S. Geological Survey Professional Paper*, vol. 916, p. 1–47.
Watling, L., 1970: Two new species of Cytherinae (Ostracoda) from central California. *Crustaceana*, vol. 19, p. 251–263.
Whatley, R. C. and Boomer, I., 1995: Autochthonous and allochthonous Quaternary Ostracoda from Site 893, Santa Barbara Basin. *Proceeding of the Ocean Drilling Program*, *Scientific Results*, vol. 146, p. 251–255.
Whatley, R. C. and Zhao, Q., 1991: On *Paracathaycythere costaereticulata* Whatley & Zhao gen. et sp. nov. *Stereo-Atlas of Ostracod Shells*, vol. 18, p. 93–96.
Wood, A. M., 2009: The phylogeny and palaeozoogeography of cold-water species of ostracod (Crustacea). *Paleontological Research*, vol. 13, p. 345–366.
Yajima, M., 1978: Quaternary Ostracoda from Kisarazu near Tokyo. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 112, p. 371–409.
Yajima, M., 1982: Late Pleistocene Ostracoda from the Boso Peninsula, Central Japan. *The University Museum*, *the University of Tokyo*, *Bulletin*, no. 20, p. 141–227.
Yamada, K., Irizuki, T. and Nakajima, Y., 2001: Spatial and temporal distribution of fossil ostracode assemblages and sedimentary facies in the Lower Miocene Arakida Formation, Tomikusa Group, Nagano Prefecture, central Japan. *Journal of the Geological Society of Japan*, vol. 107, p. 1–13. (*in Japanese with English abstract*)
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, central Japan. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, vol. 185, p. 115–132.
Yamaguchi, T., Matsubara, T. and Kamiya, T., 2005: Eocene ostracods from the Iwaya Formation on Awajishima Island, southwestern Japan. *Paleontological Research*, vol. 9, p. 305–318.
Yamane, K., 1998: Recent ostracode assemblages from Hiuchi-nada Bay, Seto Inland Sea of Japan. *Bulletin of Ehime Prefectural Science Museum*, no. 3, p. 9–59. (*in Japanese with English abstract*)
Yasuhara, M., Irizuki, T., Yoshikawa, S. and Nanayama, F., 2002: Changes in Holocene ostracode faunas and depositional environments in the Kitan Strait, southwestern Japan. *Paleontological Research*, vol. 6, p. 85–99.
Yumoto, M., 1995: A redescription of *Paracathaycythere costaereticulata* Whatley and Zhao, 1991 (Ostracoda, Crustacea). *Kumamoto Journal of Science*, *Geology*, vol. 14, p. 27–38.
Zhao, Q., 1988: Ostracoda. *In*, Wang, P.-X., Zhang, J., Zhao, Q.-H., Min, Q., Bian, Y., Zheng, L., Cheng, X. and Chen, R. *eds.*, *Foraminifera and Ostracoda in Bottom Sediments of the East China Sea*, p. 181–280. China Ocean Press, Beijing. (*in Chinese with English abstract*)
Zhou, B.-C., 1995: Recent ostracode fauna in the Pacific off Southwest Japan. *Memoirs of the Faculty of Science*, *Kyoto University*, *Series of Geology and Mineralogy*, vol. 57, p. 21–98.

Appendix

List of locations for samples in Figures 4, 5 and 7 with Tables 1 and 2, correlated to previous studies.

Sample a1: Loc. 1C of Mukaiyama and Matsuda (1998), left bank of Asakawa River, 130 m downstream from Hirayama Bridge in Hino City, Tokyo.

Samples a2: around Loc. 1B of Mukaiyama and Matsuda (1998), sand bank in Asakawa River, 140 m downstream from Hirayama Bridge in Hino City, Tokyo.

Sample a3: around Loc. 1D of Mukaiyama and Matsuda (1998), sand bank in Asakawa River, 160 m downstream from Hirayama Bridge in Hino City, Tokyo.

Sample b1: around Loc. 9 of Baba *et al.* (1986), right bank of Tama River in Sakae-machi, Hino City, Tokyo.

Sample b2: around Loc. 10 of Baba *et al.* (1986), right bank of Tama River in Sakae-machi, Hino City, Tokyo.

Sample c: Loc. 19 of Masaoka *et al.* (1990), bed of Tsurumi River west of Kawashima, Nozuta-machi, Machida City, Tokyo.

Sample d1: Loc. M of Otuka (1932), outcrop in Manpukuji, Asao-ku, Kawasaki City, Kanagawa.

Sample d2: Loc. “Yamaguchi” of Otuka (1932), bed of small river in Yamaguchi, Asao-ku, Kawasaki City, Kanagawa.

Sample e: Loc. 1 of Koizumi (1990), left bank of Tama River, 150 m downstream from Shukugawara-seki Dam in Igata, Komae City, Tokyo.