

Early Pleistocene Ostracods from the Hamada Formation in the Shimokita Peninsula, Northeastern Japan: the Palaeobiogeographic Significance of their Occurrence for the Shallow-Water Fauna

Authors: Ozawa, Hirokazu, and Domitsu, Hanako

Source: Paleontological Research, 14(1) : 1-18

Published By: The Palaeontological Society of Japan

URL: <https://doi.org/10.2517/1342-8144-14.1.001>

The BioOne Digital Library (<https://bioone.org/>) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (<https://bioone.org/subscribe>), the BioOne Complete Archive (<https://bioone.org/archive>), and the BioOne eBooks program offerings ESA eBook Collection (<https://bioone.org/esa-ebooks>) and CSIRO Publishing BioSelect Collection (<https://bioone.org/csiro-ebooks>).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Early Pleistocene ostracods from the Hamada Formation in the Shimokita Peninsula, northeastern Japan: the palaeobiogeographic significance of their occurrence for the shallow-water fauna

HIROKAZU OZAWA¹ AND HANAKO DOMITSU²

¹Department of Geology, National Museum of Nature and Science, Tokyo, 3-23-1 Hyakunin-cho, Shinjuku-ku, Tokyo 169-0073, Japan (e-mail: ozawahi@kahaku.go.jp)

²Department of Ecosystem Studies, School of Environmental Science, The University of Shiga Prefecture, 2500 Hassaka-cho, Hikone, Shiga 522-8533, Japan (e-mail: domitsu.h@ses.usp.ac.jp)

Received February 17, 2009; Revised manuscript accepted October 20, 2009

Abstract. The early Pleistocene ostracod fauna from the Hamada Formation (ca. 1.5–1.2 Ma) was investigated in the Shimokita Peninsula, northeastern Japan. Twelve samples of this fossil fauna yielded 184 species, many of which are representative upper-shelf ostracods in the modern northeastern Japan Sea. Three biofacies were defined by Q-mode cluster analysis. The two most abundant species for each biofacies are *Neonesidea* sp. and *Schizocythere kishinouyei* in biofacies N, *Buntonia hanaii* and *Yezocythere hayashii* in biofacies B, and *Laperousecythere robusta* and *Finmarchinella daishakaensis* in biofacies L. The depositional environment of the individual biofacies can be defined as (1) upper-shelf area under open-sea influence in relatively high salinity (biofacies N), (2) inner–central-bay area, with relatively low salinity (biofacies B), and (3) bay-mouth area with intermediate salinity levels between those of (1) and (2) (biofacies L). Water depth decreased from the upper-shelf area through to the bay-mouth and then to the inner–central-bay areas during the depositional period of the studied horizons. The palaeoceanographic setting during most of the depositional period was estimated as the conditions of a water mass similar to the present Japan Sea Central Water, while surface waters were influenced by currents similar to the modern Tsugaru Warm and Oyashio Cold Currents. Based on the species content of biofacies B, *Buntonia* and *Yezocythere* commonly inhabited shallow inner-bay areas around 1.2 Ma in this region, instead of the modern representative inner-bay taxa of Japan which first appeared in the northernmost Honshu region after 1.0 Ma. The occurrence mode for extant and now-extinct species of the families Hemicytheridae, Cytheruridae and Eucytheridae suggests that the ostracod fauna in the upper-shelf environment from the Hamada Formation was similar to those from the southwestern to northeastern Japan Sea coast during the same period, even though it is situated at the easternmost extremity of the Japan Sea coastline (ca. 141°E) near the Pacific.

Key words: Early Pleistocene, extinct species, Hamada Formation, Japan Sea, ostracods, palaeo-biogeography

Introduction

The shallow-water benthic faunas at the Northwest Pacific margin of the Japanese Islands including the Japan Sea changed drastically during the Pleistocene in response to marine climatic fluctuations (e.g., Cronin and Ikeya, 1987; Chinzei, 1991; Amano, 2004). Benthic ostracods provide good clues to understanding the relationship between environmental fluctuations and faunal changes because they are sensitive to environmental changes and have a high rate of

endemism due to the lack of planktic growth stages in their life cycle (e.g., Boomer *et al.*, 2003; Cronin and Dwyer, 2003).

Previous studies have documented the changes that have occurred since the late Pliocene in the shallow-marine ostracod faunas on the Japanese side of the Japan Sea coast (e.g., Ozawa *et al.*, 2004a, 2008; Ozawa and Kamiya, 2005a, b). These studies discussed in detail the occurrence during the Pleistocene of selected shallow-water species from the Japan Sea coast in relation to coastal environmental fluctu-

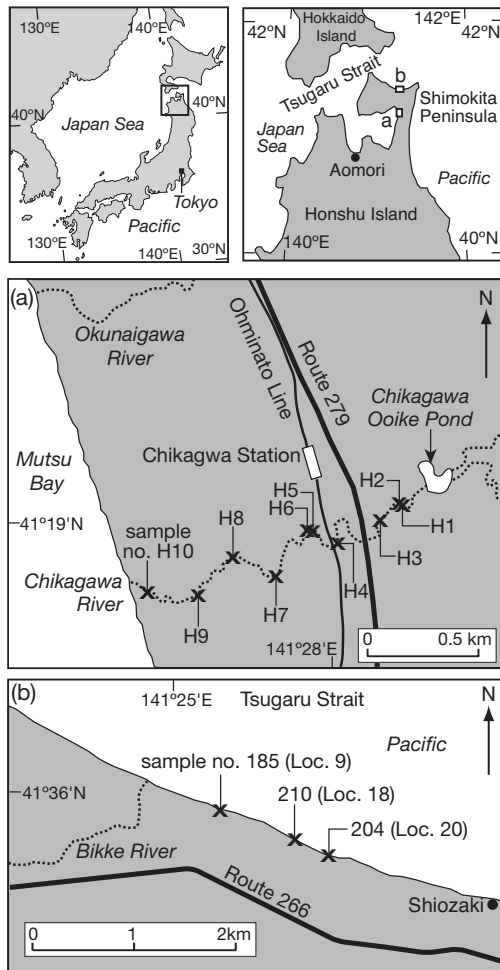


Figure 1. Location maps showing the study area and sample localities for fossil ostracods of the Hamada Formation in northeastern Japan. (a): Chikagawa area, (b): Tanabu Lowland area.

ations. However, there are no such detailed reports for the early Pleistocene ostracod fauna during the interval 1.5 to 1.0 Ma in the shallow-water area from the easternmost coast of the Japan Sea (ca. 141°E) in northeastern Japan around the Tsugaru Strait, which connects the Japan Sea and Pacific Ocean. To date, one detailed study has given an account of the early Pleistocene ostracod fauna around this area for the interval 1.0–0.8 Ma (Tabuki, 1986; age data from Nemoto, 1997), but the faunal composition of this region during the interval 1.5–1.0 Ma is uncertain.

The early Pleistocene Hamada Formation exposed in the Shimokita Peninsula near the Tsugaru Strait (Figure 1) is well known to contain many shallow-water, calcareous fossils representing the interval ca. 1.5–1.2 Ma (e.g., Kanazawa, 1990; Sugawara *et al.*, 1997). However, there exists just one preliminary report by Hanai and Yamaguchi (1987) for its ostracod fauna, which revealed ca. 20 taxa. This report

investigated the palaeo-biogeography of these taxa and the palaeo-environment of this sequence, but did not present a species list or SEM images of the pertinent ostracods. Since the latter half of the 1980's, many new species in the Plio-Pleistocene ostracod fauna of northeastern Japan have been described and placed in palaeo-biogeographical context (e.g., Tabuki, 1986; Tsukagoshi and Ikeya, 1987; Hanai and Ikeya, 1991; Irizuki, 1993, 1996; Ozawa and Ishii, 2008; Ozawa and Kamiya, 2008, 2009), including several occurrence reports for a small number of particular species from this stratum (e.g., Ozawa and Kamiya, 2005a). Based on previous studies alone, we are unable to produce a precise overview of the species composition of the Hamada Formation.

This study aims to fill in the gaps in the knowledge of this important area for the history of the Japan Sea with a detailed ostracod faunal list, estimates of palaeo-environment, and SEM images of many of the species. Furthermore, we discuss the palaeo-biogeographical relevance for selected ostracod species in shallow-water areas, comparing their occurrence with other coastal regions along the Japanese Islands during the Plio-Pleistocene.

Geological setting and age

The Hamada Formation is exposed in the northeastern part of the Shimokita Peninsula, northeastern Japan (Figure 1). Since this formational name was introduced by Hanzawa (1954), many authors have described its geology and calcareous fossil fauna (e.g., Kuwano, 1956; Aoki and Kuwano, 1959; Yamaguchi, 1970; Hanai and Yamaguchi, 1987). According to Haga and Yamaguchi (1990), the Hamada Formation unconformably overlies the early Miocene Tomari Formation and the middle–late Miocene Gamanosawa Formation, and is overlain unconformably by the late Pleistocene Tanabu Formation.

The Hamada Formation is mainly composed of sandstone, calcareous sandstone, silty sandstone and siltstone, intercalated with many thin layers of pumice tuff (e.g., Kanazawa, 1990). Kanazawa and Yamaguchi (1988) divided this formation into five members by lithofacies and key tuff layers in and around the type locality at the eastern coast of Mutsu Bay, i.e., the Shijimisawa Sandstone, Sakaigawa Alternation, Hatazawagawa Sandstone, Chikagawa Silty Sandstone and Okunaigawa Siltstone Members. The geological age of the Chikagawa Silty Sandstone and Okunaigawa Siltstone Members of the Hamada Formation in and around the type locality was estimated at between 1.45 and 1.21 Ma based on calcareous-nannofossil biostratigraphy (Sugawara *et al.*, 1997; age from Sato *et al.*, 1999). Therefore these two members date to ca. 1.5–1.2 Ma on the basis of planktic microfossil records.

According to Kuwano (1957), a part of the Hamada Formation mainly consisting of sandy siltstone is also exposed

at a seaside cliff in the Tanabu Lowland area on the northernmost side of the Shimokita Peninsula (Figure 1b). This is correlated to the uppermost part of the same facies in and around the type locality based on lithology, although there are presently no age data for these strata in the Tanabu area. The late Pleistocene Tanabu Formation and terrace deposits unconformably overlie the Hamada Formation in the Tanabu area, but there are no exposures showing their contact with it. No calcareous fossils occurred in the outcrops, and only casts of molluscan fossils and burrows were found. Only siltstone fragments found around the coastal cliff, which probably originated from outcrops of the Hamada Formation in this area, contained fossils with preserved calcareous parts. Kuwano (1957) examined several siltstone fragments and briefly reported occurrences of molluscan and foraminifer fossils.

Materials and methods

Ten sediment samples H1–H10 of the Hamada Formation in the Chikagawa area near its type locality were collected for microfossil analysis from outcrops along the lower reaches of the Chikagawa River, on the eastern coast of Mutsu Bay, northern Shimokita Peninsula, Aomori Prefecture, northeastern Japan (Figures 1a and 2). These samples were obtained from the calcareous fine–medium sandstone and silty sandstone in the Chikagawa Silty Sandstone Member and the siltstone in the Okunaigawa Siltstone Member.

We also examined for ostracods (Figure 1b) three samples (nos. 185, 210 and 204) from the Tanabu Lowland area that were numbered and studied by Kuwano (1957). These consist of sandy silt sediments that infilled burrow fossils; these sediments probably were supplied by outcrops of the Hamada Formation near the seaside cliff of three localities (nos. 9, 18 and 20, respectively) of Kuwano (1957).

Dried samples of about 20 g weight were washed through a 63- μm (250-mesh) sieve, and then oven-dried. Approximately 200 ostracod individuals were picked from these samples in fractions between 0.25–1.0 mm for each sample split, under a binocular microscope. All the specimens examined here were deposited at the Department of Geology, National Museum of Nature and Science, Tokyo, Japan.

Q-mode cluster analysis was conducted to determine the fossil ostracod biofacies on the basis of similarities between samples with respect to ostracod species composition, based on the Pearson correlation coefficient and the unweighed pair-group average (UPGMA) using the free software PAST (Paleontological Statistics) version 1.82 (<http://folk.uio.no/ohammer/past/>; Hammer *et al.*, 2001). Samples containing more than ca. 200 specimens were used for this study. Within these samples, only specimens that were represented by more than three specimens in any one sample were utilized for this analysis.

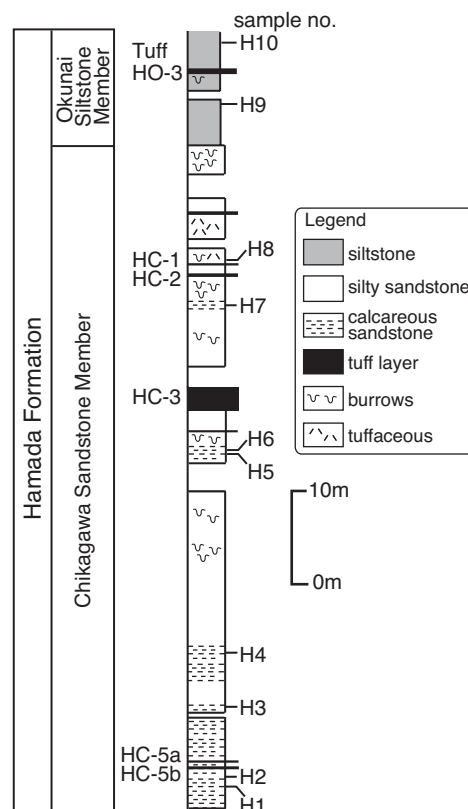


Figure 2. A columnar section with sample horizons of the Chikagawa area. Names of six tuff layers represent key tuff layers of Kanazawa and Yamaguchi (1988).

Results

Occurrence of ostracods

In total, 184 ostracod species (Figures 3–5; Table 1) were identified from the 12 samples. Ten samples H1–H9 from the Chikagawa area and no. 204 from the Tanabu Lowland area include more than ca. 200 individuals. Two samples nos. 185 and 210 contain small numbers of ostracods, less than 20 individuals, and one sample H10 yielded no ostracods. The total number of species for each sample, including more than ca. 200 individuals, ranged from 50 to 75 (Figure 6; Table 1). The range of species diversity in these samples, calculated by the Shannon–Weaver function, was ca. 3.15–3.85, and the absolute abundance (=number of individuals per 10 gram sediment) for each sample was 180–1,660 (Figure 6) except for the two aforementioned samples nos. 185 and 210 from the Tanabu area which each yielded very few individuals (Table 1).

The eleven most abundant species are *Neonesidea* sp., *Finmarchinella daishakaensis*, *Cythere sanrikuensis*, *Laprousecythere robusta*, *Schizocythere kishinouyei*, *Aurila tsukawakii*, *Cythere urupensis*, *Johnnealella nopporensis*,

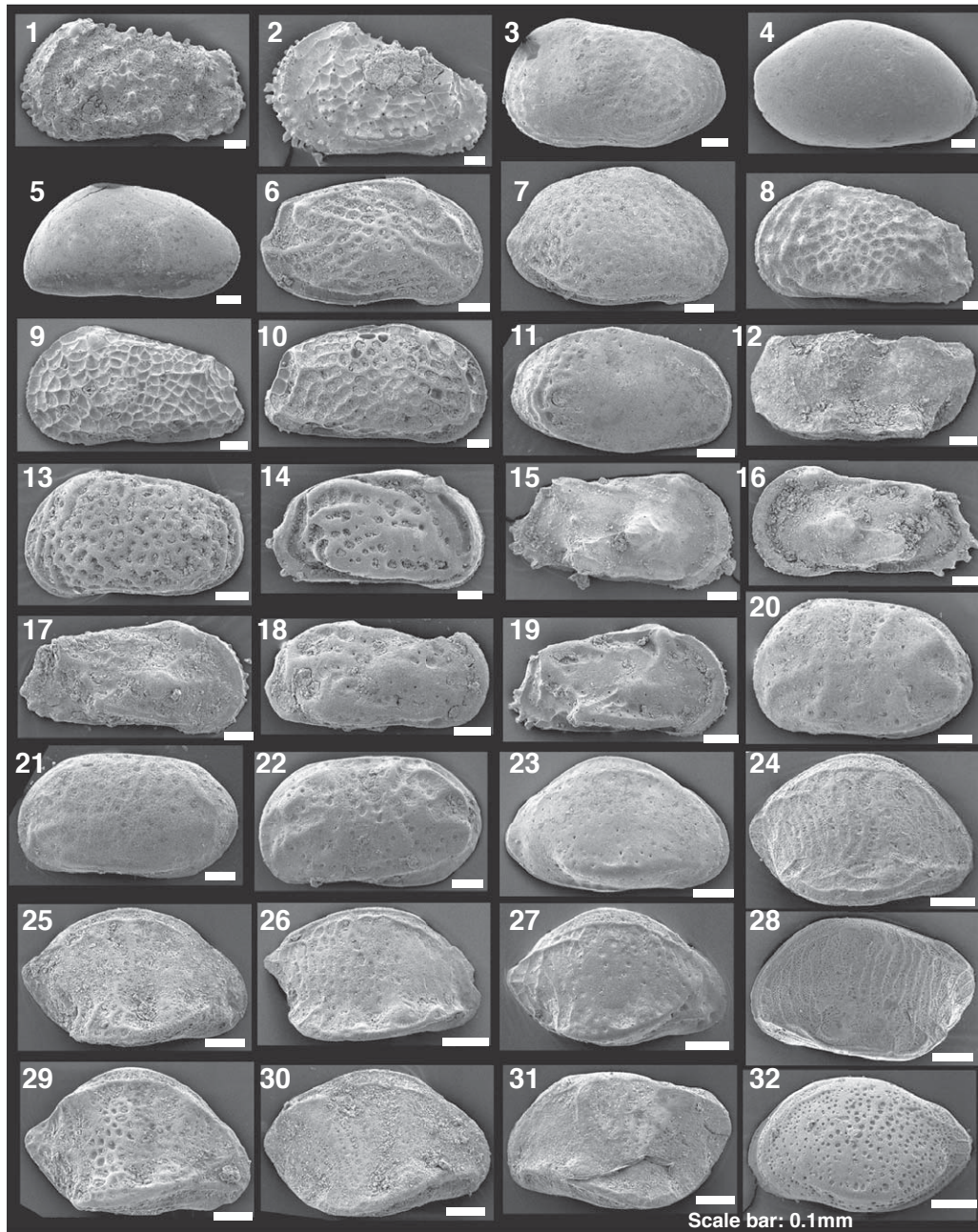


Figure 3. SEM images of fossil ostracods from the Hamada Formation (Part 1). LV: left valve, RV: right valve. **1.** *Acanthocythereis dunelmensis* s.l. (Norman, 1865), male LV, from H9. **2.** *Acanthocythereis tsurugasakensis* Tabuki, 1986, juvenile LV, from H3. **3.** *Acuticythereis?* sp., juvenile LV, from H4. **4.** *Aponesidea?* sp., juvenile LV, from H2. **5.** *Argilloecia* sp., female RV, from H8. **6.** *Aurila hataii* Ishizaki, 1968, female RV, from H7. **7.** *Aurila tsukawakii*, female RV, from H7. **8.** *Baffinicythere ishizakii* Irizuki, 1996, juvenile LV, from H2. **9.** *Baffinicythere reticulata* Irizuki, 1996, juvenile LV, from H8. **10.** *Baffinicythere robusticostata* Irizuki, 1996, female RV, from 204. **11.** *Buntonia hanaii* Yajima, 1978, male RV, from H8. **12.** *Bythoceratina* sp. 1, female LV, from H1. **13.** *Callistocythere setanensis* Hanai, 1957, female LV, from H7. **14.** *Cornucoquimba alata* (Tabuki, 1986), female RV, from H4. **15.** *Cornucoquimba* sp. cf. *C. moniwensis* (Ishizaki, 1966), female RV, from H4. **16.** *Cornucoquimba moniwensis* (Ishizaki, 1966), male LV, from H4. **17.** *Cornucoquimba saitoi* (Ishizaki, 1963), male RV, from H2. **18.** *Cornucoquimba* sp. 1, female antero-dorsally broken RV, from H8. **19.** *Cornucoquimba* sp. 2, male RV, from H7. **20.** *Cythere hanaii* Tsukagoshi & Ikeya, 1987, female LV, from H1. **21.** *Cythere sanrikuensis* Tsukagoshi & Ikeya, 1987, female LV, from H6. **22.** *Cythere urupensis* Schornikov, 1974, female LV, from H7. **23.** *Cytheropteron* sp. cf. *C. arcuatum* Brady *et al.*, 1874, female RV, from 204. **24.** *Cytheropteron* sp. 1, female RV, from 204. **25.** *Cytheropteron* sp. cf. *C. eremitum* Hanai, 1957, female RV, from H6. **26.** *Cytheropteron* sp. 2, female RV, from 204. **27.** *Cytheropteron* sp. 8, female RV, from 204. **28.** *Cytheropteron* sp. 6, female LV, from 204. **29.** *Cytheropteron* sp. 3, female RV, from H4. **30.** *Cytheropteron* sp. 4, female RV, from H4. **31.** *Cytheropteron* sp. 7, female LV, from H4. **32.** *Cytheropteron yajimai* Tabuki, 1986, female LV, from H3.

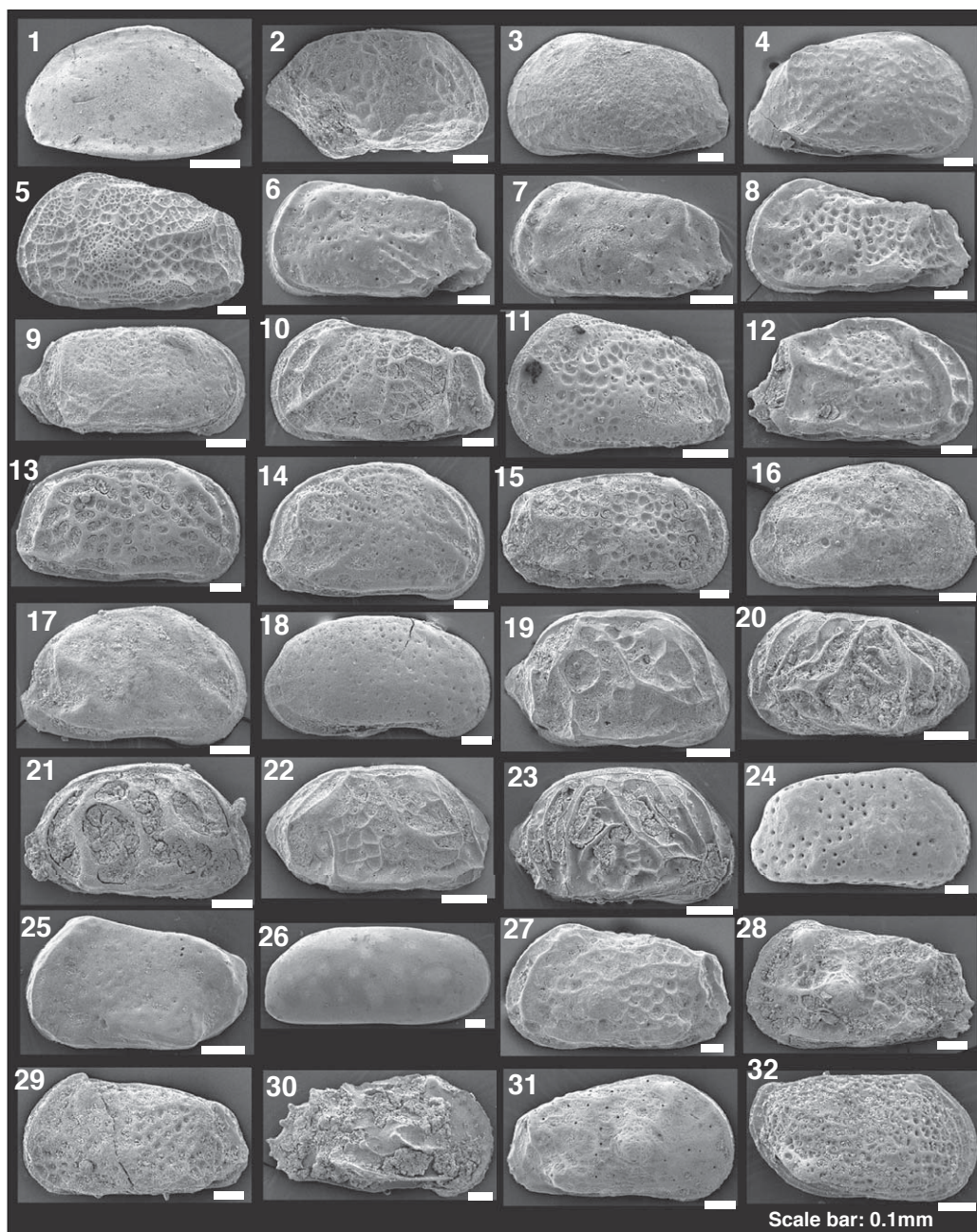


Figure 4. SEM images of fossil ostracods from the Hamada Formation (Part 2). LV: left valve, RV: right valve. **1.** *Cytheropteron?* sp. 1, female posteriorly broken LV, from H8. **2.** *Cytherura?* sp. 1, female RV, from H8. **3.** *Daishakacythere abei* (Tabuki, 1986), juvenile LV, from H7. **4.** *Daishakacythere posterocostata* (Tabuki, 1986), juvenile RV, from H8. **5.** *Elofsonella* sp. cf. *E. concinna* (Jones, 1857), female LV, from H8. **6.** *Finnarchinella daishakaensis* Tabuki, 1986, male LV, from H8. **7.** *Finnarchinella hanaii* Okada, 1979, male LV, from H1. **8.** *Finnarchinella japonica* s.l. Ishizaki, 1966, male LV, from 204. **9.** *Finnarchinella rectangulata* Tabuki, 1986, female RV, from H2. **10.** *Hemicythere emarginata* (Sars, 1865), male LV, from H7. **11.** *Hemicythere* sp. 1, juvenile LV, from H3. **12.** *Hemicythere kitanipponica* (Tabuki, 1986), female RV, from H8. **13.** *Hemicythere orientalis* Schornikov, 1974, female RV, from H4. **14.** *Hemicythere* sp. cf. *H. orientalis* Schornikov, 1974, female RV, from H8. **15.** *Hemicythere ochotensis* Schornikov, 1974, female RV, from H7. **16.** *Hemicythere quadrinodosa* Schornikov, 1974, juvenile RV, from H8. **17.** *Hemicythere* sp. 2, juvenile RV, from H3. **18.** *Hemicythere?* sp. 1, male RV, from H6. **19.** *Howeina* sp. 4, female RV, from H8. **20.** *Howeina* sp. 1, male LV, from H9. **21.** *Howeina leptocytheroidea* (Hanai, 1957), female RV, from H7. **22.** *Howeina* sp. 3, male RV, from H8. **23.** *Howeina* sp. 2, female RV, from H8. **24.** *Johnmealella nopporensis* Hanai & Ikeya, 1991, female RV, from 204. **25.** *Kotoracythere* sp. 1, female LV, from H3. **26.** *Krithe* sp., male RV, from H3. **27.** *Laperousecythere robusta* (Tabuki, 1986), female LV, from 204. **28.** *Laperousecythere* sp. 4, juvenile LV, from H4. **29.** *Laperousecythere sasaakensis* (Irizuki, 1993), female LV, from H5. **30.** *Laperousecythere* sp. 2, juvenile RV, from H4. **31.** *Laperousecythere* sp. 3, male RV, from H3. **32.** *Loxoconcha* sp. cf. *L. kitanipponica* Ishizaki, 1971, male RV, from H6.

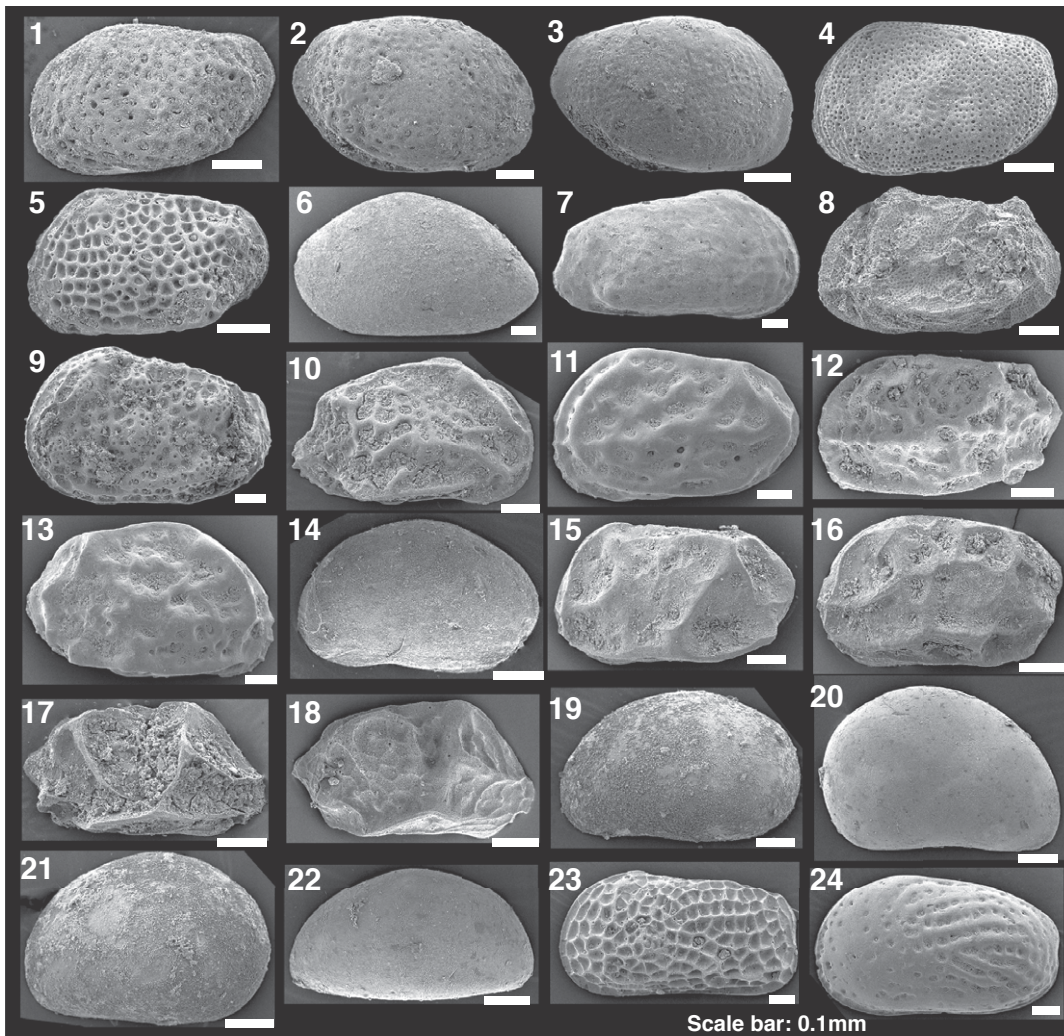


Figure 5. SEM images of fossil ostracods from the Hamada Formation (Part 3). LV: left valve, RV: right valve. **1.** *Loxoconcha epeterseni* Ishizaki, 1981, female LV, from H6. **2.** *Loxoconcha kamiyai* Ozawa & Ishii, 2008, female RV, from H7. **3.** *Loxoconcha kamiyai* Ozawa & Ishii, 2008, juvenile RV, from H8. **4.** *Loxoconcha ozawai* Tabuki, 1986, juvenile LV, from H8. **5.** *Loxoconcha subkotoriforma* Ishizaki, 1966, female LV, from H8. **6.** *Neonesidea* sp., female LV, from H5. **7.** *Normanicypthere japonica* Tabuki, 1986, male RV, from H1. **8.** *Palmenella limicola* (Norman, 1865), female LV, from H9. **9.** *Robertsonites reticuliformis* (Ishizaki, 1966), juvenile LV, from H9. **10.** *Robustaurila* sp. cf. *R. salebrosa* (Brady, 1869), female RV, from H4. **11.** *Schizocythere ikeyai* Tsukagoshi & Briggs, 1998, female LV, from 204. **12.** *Schizocythere kishinouyei* (Kajiyama, 1913), female LV, from H7. **13.** *Schizocythere okhotskensis* Hanai, 1970, female RV, from 204. **14.** *Semicytherura hiberna* Okubo, 1980, male LV, from H2. **15.** *Semicytherura subundata* (Hanai, 1957), female LV, from H1. **16.** *Semicytherura robustundata* Ozawa & Kamiya, 2008, female LV, from H1. **17.** *Semicytherura* sp. 2, female RV, from H1. **18.** *Semicytherura tanimurai* Ozawa & Kamiya, 2008, female RV, from H8. **19.** *Xestoleberis hanaii* Ishizaki, 1968, female LV, from H6. **20.** *Xestoleberis iturupica* Schornikov, 1974, female RV, from H3. **21.** *Xestoleberis sagamiensis* Kajiyama, 1913, female LV, from H7. **22.** *Xestoleberis setouchiensis* Okubo, 1979, female LV, from H7. **23.** *Yezocythere hayashii* Hanai & Ikeya, 1991, female LV, from H8. **24.** *Yezocythere* sp., female LV, from 204.

Semicytherura subundata, *Schizocythere okhotskensis* and *Yezocythere hayashii* (Figure 6; Tables 1 and 2). They accounted for 45.6% of the total population. Another nine species, *Aurila hataii*, *Baffnicypthere ishizakii*, *Buntonia hanaii*, *Cytheropteron sawanense*, *Daishakacythere posterocostata*, *Finmarchinella japonica* s.l., *Hemicythere emarginata*, *Howeina* sp. 2 and *Yezocythere* sp., are commonly found from many horizons (Tables 1 and 2). These

twenty species accounted for ca. 60% of the total individuals. The rest of the other 164 species accounted for 40% of the total population.

Most of these species are found together in sandy and calcareous sandy sediments on the present-day upper shelf in the northeastern Japan Sea off Hokkaido (e.g., Ozawa *et al.*, 1999, 2004a; Ozawa, 2003). Species of two genera, *Cythere* and *Xestoleberis*, commonly occur in all horizons

Table 1. Occurrence list of fossil ostracods from the Hamada Formation.

Species name/Sample number	185	204	210	H1	H2	H3	H4	H5	H6	H7	H8	H9	Total
<i>Acanthocythereis dunelmensis</i> s.l. (Norman, 1865)		4			2	5	2	1	1		6	7	28
<i>Acanthocythereis mutsuensis</i> Ishizaki, 1971											1		1
<i>Acanthocythereis tsurugasakensis</i> Tabuki, 1986						6							6
<i>Acanthocythereis</i> sp.		2				1							3
<i>Acuticythereis?</i> sp.		2			2		1	1				1	7
<i>Ambtonia obai</i> (Ishizaki, 1971)												3	3
<i>Amphileberis nipponica</i> (Yajima, 1978)												8	8
<i>Aponesidea?</i> sp.		2			2		2		2	4			12
<i>Argilloecia toyamaensis</i> Ishizaki & Irizuki, 1990	3	1					1						5
<i>Argilloecia</i> sp.		1									6		7
<i>Aurila cymba</i> (Brady, 1869)											1		1
<i>Aurila hataii</i> Ishizaki, 1968				5	8	1	12	8	5	12	12	4	67
<i>Aurila spinifera</i> Schornikov & Tsareva, 1995										1	3		4
<i>Aurila tsukawakii</i> Ozawa & Kamiya, 2009		2		7	11	3	19	43	16	2	15		118
<i>Baffinicythere ishizakii</i> Irizuki, 1996	2	6		4	5	5	3	3	6	6			40
<i>Baffinicythere reticulata</i> Irizuki, 1996		5		1	3	3	1	3	2	2	5		25
<i>Baffinicythere robusticostata</i> Irizuki, 1996		10		3	2	3	1	1	3	2	4		29
<i>Buntonia hanaii</i> Yajima, 1978						1					3	43	47
<i>Bythoceratina hanaii</i> Ishizaki, 1968								4	5	1			10
<i>Bythoceratina</i> sp. 1		1		3	2				2				8
<i>Bythoceratina</i> sp. 2										1			1
<i>Bythoceratina</i> sp. 3									1				1
<i>Bythocythere</i> sp.		2		1	4		1			1	2		11
<i>Callistocythere setanensis</i> Hanai, 1957		1		2		1	2		3	2			11
<i>Callistocythere undata</i> Hanai, 1957										1	3		4
<i>Callistocythere undulatifacialis</i> Hanai, 1957				1							1		2
<i>Coquimba ishizakii</i> Yajima, 1978							3	1			1		5
<i>Cornucoquimba alata</i> (Tabuki, 1986)				3	2	2	5	2	2	10		1	27
<i>Cornucoquimba moniwiensis</i> (Ishizaki, 1966)							5						5
<i>Cornucoquimba saitoi</i> (Ishizaki, 1963)				3	3			4	3	2			15
<i>Cornucoquimba tosaensis</i> Ishizaki, 1968								1		1	6	1	9
<i>Cornucoquimba</i> sp. cf. <i>C. moniwiensis</i> (Ishizaki, 1966)				5	6	4	2						17
<i>Cornucoquimba</i> sp. 1											2		2
<i>Cornucoquimba</i> sp. 2										1			1
<i>Cornucoquimba</i> sp. 3										2			2
<i>Cornucoquimba?</i> sp.								1					1
<i>Cythere hanaii</i> Tsukagoshi & Ikeya, 1987				1		4	1	4	5	3	5		23
<i>Cythere japonica</i> Hanai, 1959							1					3	4
<i>Cythere sanrikuensis</i> Tsukagoshi & Ikeya, 1987	2			2	8	19	12	9	9	25	31	15	132
<i>Cythere urupensis</i> Schornikov, 1974	6			11	8	13	5	18	25	10	4	14	114
<i>Cythereis asamushiensis</i> Ishizaki, 1971					1								1
<i>Cytheroma?</i> sp.						1							1
<i>Cytheropteron miurense</i> Hanai, 1957				1	2		1	1		1	7		13
<i>Cytheropteron sawanense</i> Hanai, 1957	2			5	11	2	4	1	3	7	1	2	38
<i>Cytheropteron yajimai</i> Tabuki, 1986	2			2	7	1	3	5			1		21
<i>Cytheropteron</i> sp. cf. <i>C. arcuatum</i> Brady <i>et al.</i> , 1874	2												2
<i>Cytheropteron</i> sp. cf. <i>C. elaei</i> Cronin, 1988						1							1
<i>Cytheropteron</i> sp. cf. <i>C. eremitum</i> Hanai, 1957				1	3		1		4	2			11
<i>Cytheropteron</i> sp. 1		4											4
<i>Cytheropteron</i> sp. 2		6		2			2		3	1	1		15
<i>Cytheropteron</i> sp. 3				1			1		1	2			5
<i>Cytheropteron</i> sp. 4				1					3		1		5
<i>Cytheropteron</i> sp. 5									1	1			2
<i>Cytheropteron</i> sp. 6		4		2		1	3			2			12
<i>Cytheropteron</i> sp. 7						1	1			1			3
<i>Cytheropteron</i> sp. 8		3											3
<i>Cytheropteron?</i> sp. 1										1	2		3
<i>Cytheropteron?</i> sp. 2				1						1			2
<i>Cytherura miii</i>					1						1		2
<i>Cytherura?</i> sp. 1											3	1	4
<i>Cytherura?</i> sp. 2											1		1
<i>Daishakacythere abei</i> (Tabuki, 1986)	2			1	2	4	3	3	6	2		1	24
<i>Daishakacythere posterocostata</i> (Tabuki, 1986)	10					4	1	12	12	15	12	2	68
<i>Daishakacythere</i> sp.	3			1		2							6
<i>Elofsonella</i> sp. cf. <i>E. concinna</i> (Jones, 1856)					1	2					4		7
<i>Eucythere</i> sp.				1		2			1				4
<i>Falsobuntonia</i> sp.												2	2
<i>Finmarchinella daishakaensis</i> Tabuki, 1986	19			12	8	5	11	22	15	11	36		139
<i>Finmarchinella hanaii</i> Okada, 1979				5	5		5	1					16
<i>Finmarchinella japonica</i> s.l. (Ishizaki, 1966)	11			6	7	15	6	1	9	7	2		64
<i>Finmarchinella nealei</i> Okada, 1979	4			4	5	5	2	1	2		1	1	25
<i>Finmarchinella rectangularata</i> Tabuki, 1986	2			3	2	2		1	1				11
<i>Finmarchinella uranipponica</i> Ishizaki, 1969					1		1		1	6	1	2	12
<i>Finmarchinella</i> sp. cf. <i>F. hanaii</i> Okada, 1979						3							3
<i>Finmarchinella</i> sp. cf. <i>uranipponica</i> Ishizaki, 1971								3	1				4

Table 1. (continued)

Species name/Sample number	185	204	210	H1	H2	H3	H4	H5	H6	H7	H8	H9	Total
<i>Fimmarchinella</i> sp.		6						1					7
<i>Hanaiborchella miurensis</i> (Hanai, 1970)											1		1
<i>Hanaiborchella triangularis</i> (Hanai, 1970)								1					1
<i>Hemicythere emarginata</i> (Sars, 1865)		3		4	4	9	2	11	9	15	1	2	60
<i>Hemicythere kitanipponica</i> (Tabuki, 1986)										9	6	1	16
<i>Hemicythere ochotensis</i> Schornikov, 1974										12	2	1	15
<i>Hemicythere orientalis</i> Schornikov, 1974		2		5	3	6	6	8			1	2	33
<i>Hemicythere quadrinodosa</i> Schornikov, 1974		1		3	3	15	2	1	6				31
<i>Hemicythere</i> sp. cf. <i>H. orientalis</i> Schornikov, 1974											3		3
<i>Hemicythere</i> sp. 1		1		1	2	5	1	4	4	2	2		22
<i>Hemicythere</i> sp. 2						4							4
<i>Hemicythere?</i> <i>miii</i> (Ishizaki, 1969)											1		1
<i>Hemicythere?</i> sp. 1				1	1	1		1	4				8
<i>Hemicythere?</i> sp. 2										1			1
<i>Hemicytherura kajiyamai</i> Hanai, 1957										1			1
<i>Howeina camptocytheroidea</i> Hanai, 1957		2		1						1	4	1	9
<i>Howeina leptocytheroidea</i> Hanai, 1957									2	2			4
<i>Howeina</i> sp. 1		3		2	1						1	5	12
<i>Howeina</i> sp. 2		5		3			1	2	1	6	13	5	36
<i>Howeina</i> sp. 3					1					2	3		6
<i>Howeina</i> sp. 4		3			1			1	1	2	5	1	14
<i>Howeina?</i> sp. 1						1							1
<i>Howeina?</i> sp. 2		1											1
<i>Howeina?</i> sp. 3								1					1
<i>Johnnealella nopporensis</i> Hanai & Ikeya, 1991		34		3	4	7	9	19	15	1	2	8	102
<i>Kotoracythere</i> sp. 1		5				1	1	1	1				9
<i>Kotoracythere</i> sp. 2									1				1
<i>Krithe antisawanensis</i> Ishizaki, 1966		1											1
<i>Krithe</i> sp.						3							3
<i>Laperousecythere robusta</i> (Tabuki, 1986)		69		2	5	5		12	9	2	18	3	125
<i>Laperousecythere sasaokensis</i> (Irizuki, 1993)								2					2
<i>Laperousecythere</i> sp. 1							1						1
<i>Laperousecythere</i> sp. 2							1	1					2
<i>Laperousecythere</i> sp. 3						2					1		3
<i>Laperousecythere</i> sp. 4		1			1		1						3
<i>Laperousecythere</i> sp. 5		6							1				7
<i>Loxococoncha epeterseni</i> Ishizaki, 1981							2	4	7	1			14
<i>Loxococoncha harimensis</i> Okubo, 1980								1		2			4
<i>Loxococoncha hattorii</i> Ishizaki, 1971				1							1	1	2
<i>Loxococoncha japonica</i> Ishizaki, 1968									1		1		2
<i>Loxococoncha kamiyai</i> Ozawa & Ishii, 2008										6	5	6	17
<i>Loxococoncha optima</i> Ishizaki, 1968		1		1				1	1			1	5
<i>Loxococoncha ozawai</i> Tabuki, 1986											3		3
<i>Loxococoncha subkotorajorma</i> Ishizaki, 1966					2	3					3	1	9
<i>Loxococoncha tosaensis</i> Ishizaki, 1968										1	1		2
<i>Loxococoncha</i> sp. cf. <i>L. kitanipponica</i> Ishizaki, 1971		1					1	1	1				4
<i>Loxocorniculum mutsuense</i> Ishizaki, 1971				1			4			3	5	1	14
<i>Loxocythere inflata</i> Hanai, 1959										2	2	4	8
<i>Munseyella hatatensis</i> Ishizaki, 1966		2				1			1		1		5
<i>Munseyella</i> sp. 1												1	1
<i>Munseyella</i> sp. 2				1									1
<i>Munseyella</i> sp. 3		1		1				1					3
<i>Munseyella?</i> sp.		1											1
<i>Neonesidea</i> sp.		1			53	4	45	82	75	40	3		303
<i>Normanicythere japonica</i> Tabuki, 1986		2	12	1	3	2		3					23
<i>Normanicythere?</i> sp.					1								1
<i>Paijenborchella hanaii</i> Tabuki, 1986				1							9	3	13
<i>Paijenborchella tsurugasakensis</i> Tabuki, 1986												5	5
<i>Paijenborchella</i> sp.											1		1
<i>Palmenella limicola</i> (Norman, 1865)				1	1	2		1		1	1	13	20
<i>Palmoconcha</i> sp.						2			1			1	4
<i>Paracypris?</i> sp. 1						2							2
<i>Paracypris?</i> sp. 2						1							1
<i>Paracypris?</i> sp. 3									1				1
<i>Paracypris?</i> sp. 4					1								1
<i>Paracytheridea bosoensis</i> Yajima, 1978								1	2				3
<i>Paracytheridea neolongicaudata</i> Ishizaki, 1966						2		3		2		2	9
<i>Pectocythere daishakaensis</i> Tabuki, 1986				1				1					2
<i>Pontocythere miurensis</i> (Hanai, 1959)					1					1	2		4
<i>Pontocythere subjaponica</i> (Hanai, 1959)				2	1		1		3				7
<i>Pontocythere?</i> sp.						1							1
<i>Propontocypris?</i> sp. 1							1						1
<i>Propontocypris?</i> sp. 2								3					3
<i>Pseudocythere</i> sp.					1		1						2
<i>Pseudocythere?</i> sp.		2											2

Table 1. (continued)

Species name/Sample number	185	204	210	H1	H2	H3	H4	H5	H6	H7	H8	H9	Total
<i>Robertsonites hanaii</i> Tabuki, 1986		3			1	1		5					10
<i>Robertsonites reticuliformis</i> (Ishizaki, 1966)												16	16
<i>Robertsonites?</i> sp.						1							1
<i>Robustaurila</i> sp. cf. <i>R. salebrosa</i> (Brady, 1869)				1	2		6	4	1				14
<i>Schizocythere ikeyai</i> Tsukagoshi & Briggs, 1998		3		1									4
<i>Schizocythere kishinouyei</i> (Kajiyama, 1913)		3		17	9	7	5	18	23	29	11	2	124
<i>Schizocythere okhotskensis</i> Hanai, 1970		26		3	10	5	9	6	3	4	5	2	73
<i>Sclerochilus</i> sp. 1				1									1
<i>Sclerochilus</i> sp. 2						2				3			5
<i>Sclerochilus</i> sp. 3							1	2	2	3	1		9
<i>Sclerochilus</i> sp. 4								1					1
<i>Sclerochilus</i> sp. 5								1					1
<i>Sclerochilus</i> sp. 6									2				2
<i>Sclerochilus</i> sp. 7		2		2	7	2	7	3	1	5			29
<i>Sclerochilus?</i> sp.					1								1
<i>Semicytherura hiberna</i> Okubo, 1980				1	1	1					1	2	6
<i>Semicytherura robustundata</i> Ozawa & Kamiya, 2008		1		5	3	4		1	1				15
<i>Semicytherura subundata</i> (Hanai, 1957)		2		21	12	4	14	4	7	10		1	75
<i>Semicytherura tanimurai</i> Ozawa & Kamiya, 2008				2	3		1		1	1	2		10
<i>Semicytherura</i> sp. cf. <i>S. henryhowei</i> Hanai & Ikeya, 1977										1			1
<i>Semicytherura</i> sp. cf. <i>S. miurensis</i> (Hanai, 1957)										2			2
<i>Semicytherura</i> sp. 1				1		2				3			6
<i>Semicytherura</i> sp. 2				1									1
<i>Semicytherura?</i> sp.										3			3
<i>Sinocytheridea</i> sp.		1								1			2
<i>Sinoleberis tosaensis</i> (Ishizaki, 1968)												1	1
<i>Trachyleberis niitsumai</i> (Ishizaki, 1971)										1	2		3
<i>Xestoleberis hanaii</i> Ishizaki, 1968				1	4	4		8	6	3		1	27
<i>Xestoleberis iturupica</i> Schornikov, 1974					1	7	5	2	10	4	2		31
<i>Xestoleberis sagamiensis</i> Kajiyama, 1913										7		1	8
<i>Xestoleberis setouchiensis</i> Okubo, 1979		1			2	2	2	1	3	2			13
<i>Xestoleberis suetsumuhana</i> Yajima, 1982											1		1
<i>Yezocythere hayashii</i> Hanai & Ikeya, 1991		7		1			1	2			21	41	73
<i>Yezocythere</i> sp.	11	33	5								1	7	57
Number of total individuals	18	365	6	192	265	249	253	380	365	347	332	253	3025
Number of total species	4	64	2	63	62	66	62	69	66	75	74	50	184
Species-diversity index	—	3.36	—	3.69	3.53	3.85	3.49	3.30	3.45	3.71	3.69	3.15	
Sample weight (g)	20	20	20	2	3	5	4	14	7	4	2	8	
Individual number/10 g	9	183	3	960	877	496	640	271	521	868	1660	316	

Table 2. 20 most abundant ostracod species, their individual numbers and their percentages against all individuals from the Hamada Formation.

Species name	%	I. No.
<i>Neonesidea</i> sp.	10.0	303
<i>Finnarchinella daishakaensis</i>	4.6	139
<i>Cythere sanrikuensis</i>	4.4	132
<i>Laperousecythere robusta</i>	4.1	125
<i>Schizocythere kishinouyei</i>	4.1	124
<i>Aurila tsukawakii</i>	3.9	118
<i>Cythere urupensis</i>	3.8	114
<i>Johnnealella nopporensis</i>	3.4	102
<i>Semicytherura subundata</i>	2.5	75
<i>Schizocythere okhotskensis</i>	2.4	73
<i>Yezocythere hayashii</i>	2.4	73
<i>Daishakacythere posterocostata</i>	2.2	68
<i>Aurila hataii</i>	2.2	67
<i>Finnarchinella japonica</i> s.l.	2.1	64
<i>Hemicythere emarginata</i>	2.0	60
<i>Yezocythere</i> sp.	1.9	57
<i>Buntonia hanaii</i>	1.6	47
<i>Baffinicythere ishizakii</i>	1.3	40
<i>Cytheropteron sawanense</i>	1.3	38
<i>Howeina</i> sp. 2	1.2	36
Total	61.3	1855

(the graph of phytal species in Figure 6; Table 1). Species of these genera are phytal dwellers on calcareous algae of rocky shores and on the eelgrass *Zostera* in the sandy substrate near the intertidal zone along the modern Japanese coast (e.g., Tsukagoshi and Ikeya, 1987; Kamiya, 1988; Sato and Kamiya, 2007).

Ostracod biofacies

Three fossil biofacies N, L and B were defined by the Q-mode cluster analysis using 104 species based on a ca. 0.2 level (Figure 7). The three most abundant species of each biofacies are *Neonesidea* sp., *Laperousecythere robusta* and *Buntonia hanaii* (Table 3).

The most abundant species in biofacies N is *Neonesidea* sp., which forms ca. 16% on average of the seven samples (Table 3). It is commonly accompanied by *Schizocythere kishinouyei*, *Aurila tsukawakii*, *Cythere sanrikuensis* and *Finnarchinella daishakaensis* with common or rare occurrences for *Aurila hataii*, *Baffinicythere* spp., *Cornucoquimba alata*, *Cytheropteron sawanense*, *Daishakacythere* spp., *Finnarchinella japonica*, *Hemicythere orientalis*, *Johnnealella nopporensis*, *Laperousecythere robusta*, *Schizo-*

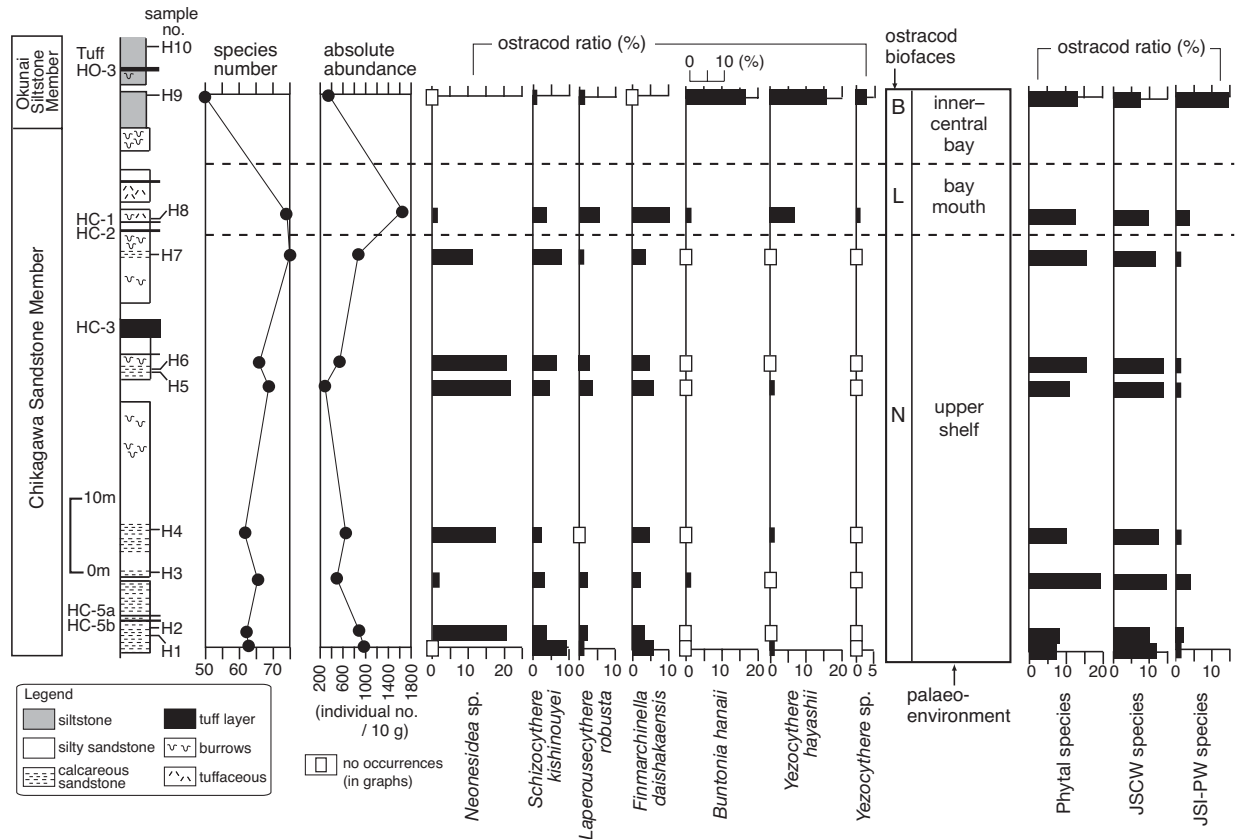


Figure 6. Vertical changes of the relative frequency (%) of selected ostracod taxa from the Hamada Formation (Chikagawa area) of each sample and data of the species number and absolute abundance (=ostracod individual number per 10 g sediment) of each sample, with a columnar section and sample horizons. Phytal species: *Cythere* spp. and *Xestoleberis* spp. JSCW (Japan Sea Central Water) species: *Baffinicythere ishizakii*, *Baffinicythere robusticostata*, *Cornucoquimba alata*, *Daishakacythere abei*, *Daishakacythere posterocostata*, *Finnarchinella nealei*, *Hemicythere orientalis*, *Howeina campotytheroidea*, *Howeina leptocytheroidea*, *Johnnealella nopporensis* and *Munseyella hatatensis*. JSI-PW (Japan Sea Intermediate–Proper Water) species: *Acanthocythereis dunelmensis*, *Elofsonella* sp. cf. *E. concinna*, *Palmenella limicola* and *Robertsonites reticuliforma*. Biofacies N, L and B are the same as those in Figure 7.

cythere okhotskensis and *Xestoleberis iturupica* (Figure 6; Tables 1 and 3). This biofacies characterizes the seven lower to middle horizons H1–H7 of the Chikagawa area in calcareous fine- to medium-grained sandstone (Figures 6 and 7).

Neonesidea sp. has been mainly reported in calcareous sandy sediments on the present-day upper shelf in the northeastern Japan Sea off Hokkaido (e.g., Ozawa *et al.*, 1999; Tsukawaki *et al.*, 2001). Most of the other 15 taxa are typical of biofacies from the upper shelf under the influence of the open sea at a water depth of 50–100 m in calcareous sandy and sandy sediments in the northeastern Japan Sea. This area is under the influence of the Japan Sea Central Water mass, which has a water temperature of around 10°C in summer and less than 5°C in winter, salinity of around 34 psu, and a high dissolved oxygen content of 6–9 ml/l (e.g., Kuwahara, 1990; Ikeya and Cronin, 1993; Ozawa, 2003). Biofacies N is characterized by relatively high numbers of species (62–75) and a high species diversity of ca. 3.30–3.85 (Figure 6;

Table 2).

The most abundant species of Biofacies L is *Laperousecythere robusta*, making up more than 12% on average of the two samples (Table 3). It is accompanied by *Finnarchinella daishakaensis*, *Johnnealella nopporensis*, *Yezocythere* sp., *Cythere sanrikuensis*, *Baffinicythere* spp., *Daishakacythere posterocostata* and *Yezocythere hayashii* in common to rare occurrences (Figure 6; Tables 1 and 3). This biofacies is found from the upper horizon H8 of the Chikagawa area in the silty sandstone sample and no. 204 of the Tanabu area in the sandy siltstone sample (Figures 6 and 7). Another two samples from the Tanabu area (nos. 185 and 210), which include just small numbers of ostracod individuals, have a similar species composition to biofacies L (Table 1).

Laperousecythere robusta, *Johnnealella nopporensis*, *Baffinicythere* spp. and *Daishakacythere posterocostata* are mainly reported from the Recent upper shelf at 50–100 m water depth in sandy sediments in the northeastern Japan

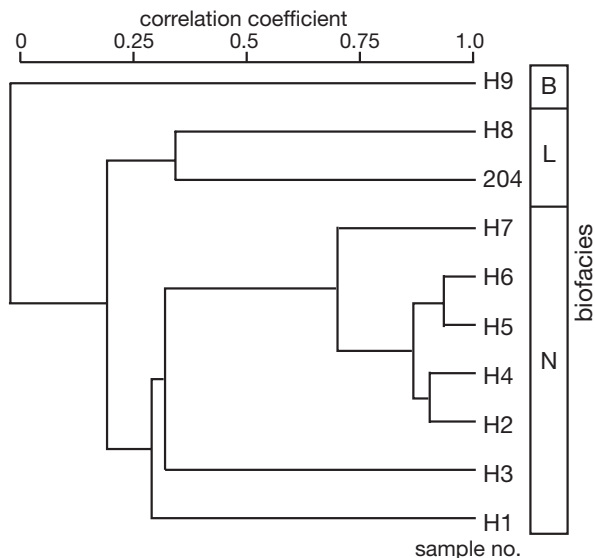


Figure 7. Dendrogram showing the result of the Q-mode cluster analysis. H1–H9, 204: sample number. Biofacies N, L and B are the same as those in Figure 6.

Sea off Hokkaido (e.g., Ozawa *et al.*, 1999; Ozawa, 2003). *Finmarchinella daishakaensis* is an extinct species, which appears to have inhabited the upper-shelf area of the Japan Sea until the middle Pleistocene (e.g., Ozawa and Kamiya, 2005a). *Yezocythere* sp. is probably an extinct species, but often occurs in the fossil biofacies of shallow inner-central-bay areas from the early Pleistocene in and around the Japan Sea coasts (Paik and Lee, 1988; Ozawa, 1996; Ozawa and Kamiya, 2001). *Cythere* species inhabit calcareous algae near the intertidal zone (e.g., Tsukagoshi and Ikeya, 1987), and their carapaces are often found from central-bay and bay-mouth areas (e.g., Kamiya *et al.*, 2001).

Most of these extant species are commonly distributed in sandy sediments on the upper shelf in open sea areas at a present water depth of 50–100 m in the northeastern Japan Sea off Hokkaido. This area is under the prevailing conditions of the Japan Sea Central Water mass, which has a water temperature of around 10°C in summer and less than 5°C in winter, a salinity of around 34 psu, and a high dissolved oxygen content of 6–9 ml/l (e.g., Ozawa, 2003). Biofacies L is characterized by relatively high numbers of species (64–74) and a high species diversity, ca. 3.36–3.69 (Figure 6; Table 2).

Biofacies B is dominated by *Buntonia hanaii*, at 17 % of the total number of specimens (Figure 6; Table 3). It is accompanied by *Yezocythere hayashii*, *Robertsonites reticuliformis*, *Cythere sanrikuensis*, *Cythere urupensis*, *Yezocythere* sp., *Palmenella limicola*, *Amphileberis nipponica* and *Acanthocythereis dunelmensis* in common occurrences (Figure 6; Tables 1 and 3). This biofacies was found just from the up-

Table 3. Five dominant species of each biofacies, their average percentages in all samples of each assemblage, their maximum percentage in a single sample, and the range of species number and species diversity index from the Hamada Formation.

	Species names	RA (%)	RM(%)	Diversity	Spp. no.
B	<i>Buntonia hanaii</i>	17.0	17.0		
	<i>Yezocythere hayashii</i>	16.2	16.2	3.15	50
	<i>Robertsonites reticuliformis</i>	6.3	6.3	(Av: 3.15)	(Av: 50)
	<i>Cythere sanrikuensis</i>	5.9	5.9		
	<i>Cythere urupensis</i>	5.5	5.5		
L	<i>Laperousecythere robusta</i>	12.4	18.8		
	<i>Finmarchinella daishakaensis</i>	6.9	10.8	3.36–3.69	64–74
	<i>Johnnealella nopporensis</i>	5.2	9.3	(Av: 3.53)	(Av: 69)
	<i>Yezocythere</i> sp.	4.9	9.0		
	<i>Cythere sanrikuensis</i>	4.7	9.3		
N	<i>Neonesidea</i> sp.	16.1	21.6		
	<i>Schizocythere kishinouyei</i>	5.3	8.9	3.30–3.85	62–75
	<i>Aurila tsukawakii</i>	4.9	11.3	(Av: 3.57)	(Av: 66)
	<i>Cythere sanrikuensis</i>	4.1	7.7		
	<i>Finmarchinella daishakaensis</i>	3.9	5.8		

permost horizon H9 of the Chikagawa area in one siltstone sample (Figures 6 and 7).

Buntonia hanaii is dominantly reported from present-day inner-central-bay areas in 30–10 m water depth from silty and sandy sediments in the northeastern Japan Sea, accompanied by *Amphileberis nipponica* (e.g., Ikeya *et al.*, 1992). Water conditions consist of a temperature of around 20°C in summer and around 5°C in winter, a salinity of around 33 psu, and a dissolved oxygen content of 3–6 ml/l (e.g., Terazaki and Shikama, 1979; Nagamine *et al.*, 1982; Ikeya and Itoh, 1991; Ikeya *et al.*, 1992). *Yezocythere hayashii* is often found from the Recent upper shelf under open-water conditions in the Japan Sea off Hokkaido (e.g., Ozawa *et al.*, 1999). However, it also dominantly inhabits central-bay areas, such as the modern Aomori Bay, at 20–50 m water depth (Ishizaki, 1971) near the Chikagawa area. In this area the water temperature is around 15°C in summer and less than 5°C in winter, salinity is around 33 psu due to a slight freshwater influence, and dissolved oxygen is relatively low at 3–6 ml/l (e.g., Nagamine *et al.*, 1982; Ozawa *et al.*, 2004a). *Yezocythere* sp., which is the same species as *Yezocythere* sp. in Biofacies L (Table 1), is possibly now extinct, but often occurs in the fossil biofacies of the inner central bay together with *Yezocythere hayashii* from early Pleistocene strata on the Japan Sea coast (e.g., Ozawa, 1996; Ozawa and Kamiya, 2001). *Cythere* species inhabit calcareous algae near the intertidal zone (e.g., Tsukagoshi and Ikeya, 1987), and their carapaces are often found from shallow central-bay and bay-mouth areas (e.g., Kamiya *et al.*, 2001). *Robertsonites reticuliformis*, *Palmenella limicola* and *Acanthocythereis dunelmensis* are dominantly or commonly distributed in the Japan Sea in silty sediments on the lower shelf and continental slope in the deep-water region under the influence of the Japan Sea Intermediate-

Proper Water mass (e.g., Ikeya and Suzuki, 1992; Ozawa, 2003, 2004). This water mass has a temperature of around or less than 5°C throughout the year, a salinity of around 34 psu, and relatively high dissolved oxygen levels of 5–6 ml/l (e.g., Ikeya and Cronin, 1993; Ozawa *et al.*, 2004b; Ozawa and Kamiya, 2005b). This biofacies is characterized by the lowest number of species, 50, and lowest species diversity, ca. 3.15, among the studied samples (Figure 6; Tables 1 and 3).

Discussion

Stratigraphical changes in the depositional environment in the Chikagawa area

The palaeo-environment for the seven lower to middle horizons H1–H7 based on the occurrence of biofacies N is the upper shelf at 50–100 m water depth influenced by the open sea (Figure 6) similar to the modern Japan Sea Central Water under conditions of relatively high salinity of around 34 psu and high dissolved oxygen levels of 6–9 ml/l. The palaeo-environment in the uppermost horizon of H9 (biofacies B) is the shallow inner–central–bay area (Figure 6) in 10–50 m water depth, under conditions of relatively low salinity of around 33 psu, slightly influenced by freshwater, and dissolved oxygen levels of 3–6 ml/l. The surmised water depth decreased upwards in the sequence during the depositional period in the studied horizons, from 50–100 m to 10–50 m. The influence of the open sea in this area became weaker during the time of deposition of the uppermost horizon H9 compared with the lower to middle horizons H1–H7.

Biofacies L, found in only one horizon, H8, indicates a bay–mouth palaeo-environment (Figure 6) in intermediate conditions of water depth, salinity and dissolved oxygen, between upper-shelf and inner–central–bay environments, i.e., around 50 m depth, salinity 33–34 psu, and dissolved oxygen level around 6 ml/l, estimated from biofacies N and B respectively.

The horizon H8 is characterized by a mixture of ostracod species characteristic of the inner–central–bay and upper shelf of the Japan Sea, with the highest absolute abundance of ostracods and the second highest number of species. One dominant species, *Finnarchinella daishakaensis*, probably is extinct, but is judged to have dwelled in shallow open-sea water, because it occurs in shallow open-sea assemblages of the early Pleistocene (e.g., Tabuki, 1986; Ozawa and Kamiya, 2005a). The horizon H8 is thus inferred to have been deposited during a regressive period based on changes in the ostracod assemblages (Figure 6).

The ostracods in this silty sandstone might signify a relatively low rate of deposition, due to a period of reduced sediment supply (e.g., Kamataki, 1999; Ozawa and Kamiya, 2005b), at least in part during the regressive phase from upper-shelf to inner–central–bay environments. A regressive

phase could induce a period of relatively increased concentration of fossils due at least in part to reworking of upper-shelf species, e.g., *Neonesidea* sp. and *Schizocythere kishinouyei*, from strata exposed during the regression.

Species such as *Buntonia hanaii*, *Yezocythere hayashii* and *Yezocythere* sp. in the H8 horizon, however, cannot have been all reworked from the directly underlying strata, because they are absent or very rare in those layers (Figure 6). This implies that they lived at or around the site during the time of deposition of H8, although the relative abundance of *Buntonia hanaii* was similar to an earlier period (H3 horizon).

The palaeo-water temperature conditions for the two biofacies N and L in horizons H1–H8 are similar to those in the upper-shelf environment of the northeastern Japan Sea off Hokkaido based on the species composition of ostracods.

Biofacies B is characterized by a unique mixture of shallow inner–central–bay species (*Buntonia hanaii* and *Amphileberis nipponica*) and Japan Sea Intermediate–Proper Water (JSI–PW) species of the lower shelf and slope (*Robertsonites reticuliformis*, *Palmenella limicola* and *Acanthocythereis dunelmensis*) with species also inhabiting the central bay such as Aomori Bay (*Yezocythere hayashii*) and probable inner-bay species (*Yezocythere* sp.). The state of fossil preservation of the species listed above in biofacies B is almost the same (Figures 3–5). This type of biofacies is not known along the present coast of Japan, but a similar combination of ostracod species from these two different habitats was also reported from late Pliocene–early Pleistocene biofacies in other areas of the Japan Sea coast (e.g., Omma Formation, ca. 2.1–1.7 Ma; Ozawa and Kamiya, 2001).

In the modern Arctic region, *Robertsonites reticuliformis*, *Palmenella limicola* and *Acanthocythereis dunelmensis* are distributed in waters shallower than 50 m with a temperature of less than 6°C (Ikeya and Cronin, 1993). The latter two species are mainly found in the northern Pacific in waters 20–100 m in depth with a temperature of around 5°C, dissolved oxygen levels of 2–7 ml/l and salinity less than 33 psu (Brouwers, 1988, 1990, 1993). Athersuch *et al.* (1989) recorded *Acanthocythereis dunelmensis* from the shallow sea (at depths around 50 m) in the northern Atlantic and Arctic Oceans. Robinson (1978) reported characteristic occurrences of *Acanthocythereis dunelmensis* with shallow-water species from late Pleistocene strata in England, and inferred that this species occurred in shallower inshore environments in the cold periods of the Pleistocene. *Buntonia hanaii* mainly inhabits the shallow inner–central–bay area with a wide geographical range from the coasts of eastern China to northeastern Japan (e.g., Zhao and Wang, 1988; Ikeya *et al.*, 1992). Therefore, the only environment where we could expect to see abundant occurrences of these species in biofacies B would be shallow inner–central–bay areas under conditions of lower temperatures in summer (around 5°C) than is the case in the present bays of northeastern Japan.

Common occurrences of phytal species of two genera, *Cythere* and *Xestoleberis*, from all the horizons H1–H9 (Figure 6) indicate the existence of abundant beds of the seaweed *Zostera* on the sandy bottom and calcareous algae on the rocky shore near the intertidal zone in this area throughout the depositional period.

Several studies have previously reconstructed the palaeo-environment of the Hamada Formation, based on benthic ostracod, molluscan and foraminifer fossils. For example, Hanai and Yamaguchi (1987) preliminarily represented the occurrence data of ca. 20 ostracod taxa between our horizons H1–H10 from the same section (their horizons C33–C4). Generally, the faunal compositions of dominant/common species and estimates of palaeo-environments they arrived at are similar to those of our study. However, they reported one biofacies dominantly consisting of species that indicate a lower-shelf to upper continental slope area under the conditions of the JSI-PW (species of genera *Acanthocythereis*, *Robertsonites* and *Elofsonella*) from their samples C22 and C24. We have not found a similar type of biofacies, but our sample H3 shows a small peak in the percentage (ca. 5%) for species of these three genera (JSI-PW species in Figure 6). So, our sample H3 is the most similar to their samples C22 or C24 including the deep-water biofacies of Hanai and Yamaguchi (1987), although their and our samples were collected from slightly different horizons.

Kanazawa (1990) reported the species composition of the molluscan fauna between our horizons H5–H10 at the same section in detail (his horizons C20–C1). He judged the palaeo-environment for our horizons H5–H8 of the Chikagawa Sandstone Member as the upper-shelf area under open-water conditions. In the Okunaigawa Siltstone Member (our horizon H9), the palaeo-environment was inferred to be a shallow bay.

Nemoto and Yoshimoto (2001) reported the species composition of the benthic foraminifer fauna between our horizons H1–H10 at the same section in detail, and recognized three fossil biofacies of benthic foraminifers (their horizons CHI19–CHI1). Two of their biofacies from the Chikagawa Sandstone Member consist of many upper-shelf species, while the third one, from the Okunaigawa Siltstone Member, includes many shallow inner-bay species.

The palaeo-environmental change reconstructed from our new ostracod data of the Chikagawa area is almost consistent with that of previous ostracod, molluscan and benthic foraminifer studies. Furthermore, our ostracod study estimates three types of environments (Figure 6) with more detailed information on the water depth, salinity and dissolved oxygen levels than previous studies. We define three periods of decreasing water depth during the depositional period of the studied horizons (Figure 6), and the existence of a period of relatively low rate of sedimentation around horizon H8. Our ostracod data also reconstruct occurrences of calcareous

algae on the rocky shore and beds of the seaweed *Zostera* on the sandy bottom near the intertidal zone in this area throughout the depositional period.

Palaeoceanographic conditions of surface water

Hanai and Yamaguchi (1987) reported the fossil occurrence of *Cythere omotenipponica* from this formation. They estimated a shallow-marine environment influenced by a warm-water current based on its occurrence from two localities (their horizons C18 and C12). However, our study has found no specimens of this species (Table 1), possibly because we studied fewer samples than they did. Instead of *Cythere omotenipponica*, we found many individuals of *Cythere sanrikuensis* and *Cythere urupensis* from all the horizons (Table 1). Hanai and Yamaguchi (1987) also reported the occurrences of these two species from here.

According to Tsukagoshi (1996), Recent specimens of *Cythere sanrikuensis* only inhabit the intertidal zone of the Pacific coast of northern Honshu and southern Hokkaido in areas influenced by the Tsugaru Warm Current, a branch of the Tsushima Warm Current. Recent specimens of *Cythere urupensis* are only found in the intertidal zone of the Pacific coast of eastern Hokkaido under the influence of the Oyashio Cold Current. So, these fossil occurrences indicate that the surface water environment during the interval 1.5 to 1.2 Ma in the study area was influenced by currents similar to both the Tsugaru Warm and Oyashio Cold Currents, like the modern oceanographic setting around the Shimokita Peninsula. Therefore, in the shallow-marine environment of this area, a water mass similar to the present Japan Sea Central Water existed under two kinds of surface waters, similar to the modern Tsugaru Warm and Oyashio Cold Currents.

In regard to the palaeoceanography of the surface water in the northwestern Pacific margin since the late Pliocene, Koya (1995) analyzed diatom assemblages from deep-sea cores of DSDP Sites 436, 438 and 440 off the Sanriku region of northern Honshu Island. His study concluded that the surface-water environment in the northwestern Pacific off northern Honshu had shifted to an oceanographic setting resembling the modern water-current conditions ca. 2 Ma (age scale cited from Motoyama *et al.*, 2004), probably related to the climatic cooling in the Northern Hemisphere since the late Pliocene.

Furthermore, in relation to the Japan Sea coast, Ozawa and Kamiya (2001) studied early Pleistocene ostracod assemblages from central Japan. According to their study, the influx during interglacials of the Tsushima Warm Current from the East China Sea into the Japan Sea at a volume comparable to the present began 1.5 Ma at the latest. Thus, the volume of the Tsugaru Warm Current, which is a branch of the Tsushima Warm Current, through the Tsugaru Strait from the Japan Sea to the northwestern Pacific margin, has been similar to modern conditions since 1.5 Ma.

Therefore our results for ostracod occurrences in the

Hamada Formation (ca. 1.5–1.2 Ma) for two *Cythere* species (Table 1), inhabiting intertidal areas under the influence of both the Tsugaru Warm and Oyashio Cold Currents, respectively, are concordant with previous palaeoceanographic studies around northern Honshu during this period.

Age and depositional environment of the fragment samples from the Tanabu area

From three samples of sandy siltstone fragments (nos. 185, 204 and 210 of Kuwano, 1957) in the Tanabu Lowland area, planktic foraminifer fossils of *Neogloboquadrina pachyderma*, which first appeared at 1.25 ± 0.04 Ma (Domitsu and Oda, 2008), were obtained in sediment fractions between 0.125–1.0 mm for each sample, by one of the authors in this study (H. Domitsu). Additionally, *Neogloboquadrina inglei*, which has a last occurrence age of 0.73 ± 0.05 Ma (Domitsu and Oda, 2008), was obtained from one of these samples (no. 204). No calcareous nannofossils were found from these samples. Therefore, these Tanabu samples were dated to younger than ca. 1.3 Ma at the latest based on the occurrence of *Neogloboquadrina pachyderma*. Furthermore, one of the three samples (no. 204) was dated to ca. 1.3–0.7 Ma, based on the cooccurrence of the above two planktic foraminifer species and biostratigraphy of ODP Site 1150 (located at 39°11'N, 143°20'E and 2,681 m water depth) in the Pacific off northeastern Japan (Domitsu and Oda, 2008).

In the biofacies L of the Tanabu area in sample no. 204, *Laperousecythere robusta*, *Yezocythere* sp. and *Yezocythere hayashii* are dominantly or commonly found (Table 1). So the palaeo-environment there during a restricted period between ca. 1.3–0.7 Ma is judged to have been a bay-mouth area around 50 m depth, salinity 33–34 psu, and dissolved oxygen level around 6 ml/l, based on occurrences both of upper-shelf species, e.g., *Laperousecythere robusta* (50–100 m water depths in the Japan Sea off Hokkaido; e.g., Ozawa *et al.*, 1999) and central-bay species *Yezocythere hayashii* (20–50 m in Aomori Bay; Ishizaki, 1971) with the probable inner-central-bay species *Yezocythere* sp. (e.g., Ozawa, 1996).

Significant occurrences of bay species

The biofacies B in the siltstone from the Chikagawa area commonly includes several inner-central-bay species such as *Buntonia hanaii*, *Yezocythere* spp. and *Amphileberis nipponica*. However, it contains no individuals of the taxa which today dominate silty sediments in the shallow inner-bay environment around Japan as reported by Ikeya and Shiozaki (1993), i.e., the *Bicornucythere* species group and *Spinileberis quadriaculeata* (Figure 6; Tables 1 and 3). At present, *Buntonia hanaii* and *Yezocythere hayashii* dominantly or commonly inhabit the inner-central-bay environments in northern Honshu (ca. 40–41°N), such as Aomori and Otsuchi Bays, alongside the above taxa (e.g., Ishizaki,

	Epochs															
	A		B		C		D		E		F					
	Strata	Sasaoka	Junicho	Omma	Hamada	Haizume	Kawachi	Kaidate	Kitaura	Daishaka	Setana	Wakimoto	Shichiba	Shibikawa	Anden	
Now-extinct spp.																
<i>Cornucoquimba</i> sp. C		f														
<i>Laperousecythere</i> cf. <i>ishizakii</i>																
<i>Laperousecythere</i> sp. D																
<i>Laperousecythere</i> sp. A																
<i>Semicytherura leptosubundata</i>																
<i>Semicytherura robustundata</i>																
<i>Laperousecythere</i> sp. 2												b				
<i>Laperousecythere</i> sp. 4																
<i>Normaniccythere japonica</i>																
<i>Pectocythere daishakaensis</i>																
<i>Laperousecythere sasaakensis</i>																
<i>Cornucoquimba</i> sp. 2																
<i>Cornucoquimba</i> sp. 1																
<i>Cornucoquimba</i> sp. B																
<i>Hemicythere kitanipponica</i>																
<i>Johnnealella?</i> sp.																
<i>Semicytherura subslipperi</i>																
<i>Urocyclythere?</i> <i>gorokuensis</i>																
<i>Daishakacythere</i> sp.																
<i>Finnarchinella daishakaensis</i>																
<i>Finnarchinella rectangulata</i>																
<i>Semicytherura tanimurai</i>																
<i>Semicytherura subundata</i>																
Extant spp.																
<i>Baffinicythere ishizakii</i>																
<i>Baffinicythere robusticostata</i>																
<i>Cornucoquimba alata</i>																
<i>Finnarchinella nealei</i>																
<i>Hemicythere orientalis</i>																
<i>Johnnealella nopporensis</i>																
<i>Laperousecythere robusta</i>																
<i>Yezocythere hayashii</i>																
<i>Howeina campitocytheroidea</i>																
<i>Howeina higashimeyaensis</i>																
<i>Howeina leptocytheroidea</i>																
<i>Munseyella hatatensis</i>																
<i>Daishakacythere abei</i>																
<i>Daishakacythere posterocostata</i>																



Figure 8. Temporal changes of occurrences of the selected now-extinct ostracod species at the Japan Sea coast, modified from Ozawa and Kamiya (2005a) and Ozawa (2007), with the location map of strata. Cited literature for ostracod occurrences; a: Ishizaki and Matoba (1985), b: Tabuki (1986), c: Cronin and Ikeya (1987), d: Irizuki (1993), e: Irizuki (1996), f: Ishida (unpubl. data), g: Irizuki and Ishida (2007), h: Ozawa and Kamiya (2008), i: this study (Chikagawa area). Cited literature for age data; Takayama *et al.* (1988), Kato *et al.* (1995), Okubo *et al.* (1995), Nemoto (1997), Shirai *et al.* (1997), Sugawara *et al.* (1997), Nojo *et al.* (1999), Sato *et al.* (1999), Takata (2000), and Yamada *et al.* (2002). Age of epochs; (A): –1.5 Ma, (B): 1.2–1.0 Ma, (C): 0.9 Ma, (D): 0.8–0.5 Ma, (E): 0.4–0.25 Ma, (F): 0.1 Ma.

Table 4. Synonym list of ostracod species from the Hamada Formation.

Ozawa (1996)	Ozawa & Kamiya (2005a)	This study
<i>Ambostracon?</i> sp.	—	<i>Laperousecythere</i> sp. 1
<i>Aurila</i> cf. <i>uranouchiensis</i>	—	<i>Aurila tsukawakii</i>
<i>Cornucoquimba</i> cf. <i>saitoi</i>	—	<i>Cornucoquimba</i> sp. cf. <i>C. saitoi</i>
<i>Cornucoquimba</i> sp. 1, <i>C.</i> sp. 2	<i>Cornucoquimba</i> sp. A	<i>Cornucoquimba</i> sp. 1
<i>Cornucoquimba</i> sp. 7	<i>Cornucoquimba</i> sp. D	<i>Cornucoquimba</i> sp. 2
<i>Cytheropteron</i> cf. <i>arcuatum</i>	—	<i>Cytheropteron</i> sp. cf. <i>C. arcuatum</i>
<i>Cytheropteron</i> cf. <i>elaeni</i>	—	<i>Cytheropteron</i> sp. cf. <i>C. elaeni</i>
<i>Elofonella</i> cf. <i>concinna</i>	—	<i>Elofonella</i> sp. cf. <i>E. concinna</i>
<i>Laperousecythere</i> sp. 1	<i>Laperousecythere</i> sp. B	<i>Laperousecythere</i> sp. 4
<i>Laperousecythere</i> sp. 2	<i>Laperousecythere</i> sp. C	<i>Laperousecythere</i> sp. 2
<i>Loxoconcha</i> sp. 1	—	<i>Loxoconcha kamiyai</i>
<i>Patagonacythere</i> sp. 1	—	<i>Laperousecythere</i> sp. 3
<i>Semicytherura</i> cf. <i>undata</i>	<i>Semicytherura</i> cf. <i>undata</i>	<i>Semicytherura robustundata</i>
<i>Semicytherura</i> sp. 6	—	<i>Semicytherura tanimurai</i>
<i>Yezocythere</i> sp.	—	<i>Yezocythere</i> sp.

1971; Ikeya *et al.*, 1992).

Fossils of the *Bicornucythere* species group and *Spinileberis quadriaculeata* are mainly found from deposits dating from the late Pliocene (ca. 3 Ma) onwards along the Pacific and Japan Sea coasts of central Honshu-Kyushu (south of ca. 36°N) (Abe, 1983; Ishizaki, 1983; Cronin *et al.*, 1994; Kamiya *et al.*, 2001; Nakao *et al.*, 2001; Iwatani and Irizuki, 2008). Many individuals of *Yezocythere hayashii*, *Yezocythere* sp. and the *Bicornucythere* species group are found together in the shallow-bay biofacies between 2.1–1.2 Ma from the Japan Sea coast, central Honshu (Ozawa, 1996; Ozawa and Kamiya, 2001). *Buntonia hanaii*, the *Bicornucythere* species group and *Spinileberis quadriaculeata* are found together in a shallow-bay biofacies sample taken from a Lower Pleistocene formation (ca. 1.4 Ma) of the Kazusa Group in the Tama Hills, central Honshu (Ozawa, unpubl. data).

Therefore *Buntonia hanaii* and *Yezocythere* spp. commonly inhabited the inner–central-bay environment in the Shimokita area around 1.2 Ma, instead of the *Bicornucythere* species group and *Spinileberis quadriaculeata*. The latter taxa must have migrated from south to northernmost Honshu (41°N) after ca. 1.0 Ma, based on their fossil occurrences from south of Aomori City near the Shimokita area (Daishaka Formation, 1.0–0.8 Ma; Tabuki, 1986; age from Nemoto, 1997). Fossil records of *Spinileberis quadriaculeata* during or before 1.5–1.2 Ma are reported just from south of 36°N, i.e., central Honshu and the Okinawa Islands (e.g., Nohara, 1987; Ozawa, unpubl. data). So its late appearance in northernmost Honshu might simply be a function of the migration distance from southern Japan to central and then to northernmost Honshu. The reasons are still uncertain for the late appearance in northernmost Honshu of the *Bicor-*

nucythere species group, which had already colonized north-eastern Japan (ca. 40°N) by around 2 Ma along the Japan Sea coast (Ishizaki and Matoba, 1985). Thus the late appearance of this genus in northernmost Honshu might be caused by other factors.

Significant occurrences of now-extinct species

Temporal changes of now-extinct species of the three ostracod families Hemicytheridae, Cytheruridae and Eucytheridae from the southwestern to northeastern Japan Sea coast of Japan since the late Pliocene (ca. 2 Ma) have previously been reported in detail (Figure 8, Table 4; Ozawa and Kamiya, 2005a; Ozawa, 2006, 2007). According to Ozawa and Kamiya (2008), *Semicytherura tanimurai* is also a now-extinct species of Cytheruridae, and has a pattern of fossil occurrence similar to that of other now-extinct species as indicated by Ozawa and Kamiya (2005a) and Ozawa (2006, 2007). Their data are added to Figure 8 of this study, which shows occurrences of now-extinct species of the three families. According to previous studies (Ozawa and Kamiya, 2005a; Ozawa, 2006, 2007), these species were present until 2 Ma at the latest along the Japan Sea coast, and then most of them became extinct during the middle Pleistocene within this isolated marginal sea, probably due to the appearance of low-salinity environments, especially during glacial low-stands.

The ostracod fauna from the Hamada Formation in the Chikagawa area includes 15 now-extinct species of the above three families (Figure 8) from shallow-water sediments. However, this fauna lacks several now-extinct species of two genera in these three families, i.e., *Laperousecythere* sp. cf. *L. ishizakii*, *Laperousecythere* sp. A, *Laperousecythere* sp. D and *Cornucoquimba* sp. C (Figure 8). This occurrence mode

of now-extinct species with extant species in the three ostracod families during the interval 1.5 to 1.2 Ma is similar to that observed in coastal deposits from the southwestern to north-eastern Japan Sea (Figure 8) during the same period. These facts suggest that the ostracod fauna living under open sea conditions of the upper-shelf regions in the Chikagawa area was similar to those of other areas of the Japan Sea during this period, even though the Chikagawa area is located at the easternmost part of the Japan Sea near the Pacific, ca. 141°E.

Conclusions

(1) The ostracod fauna from the early Pleistocene Hamada Formation in the Chikagawa and Tanabu Lowland areas of the Shimokita Peninsula, northeastern Japan, consists of 184 species, based on the examination of a total of twelve samples.

(2) Three biofacies were recognized by Q-mode cluster analysis. The depositional environment of each biofacies can be defined as (a) upper-shelf area under the influence of the open sea in relatively high salinity (biofacies N), (b) inner-central-bay area with relatively low salinity (biofacies B) and (c) bay-mouth area with intermediate salinity level between those of (a) and (b) (biofacies L).

(3) The palaeo-environment changed during the depositional period in the Chikagawa area with a decrease in water depth, from the upper shelf through the bay mouth to the inner central bay. It is estimated that the palaeoceanographic setting of this area was a water mass similar to the present Japan Sea Central Water mass under surface water influenced by currents similar to the modern Tsugaru Warm and Oyashio Cold Currents.

(4) Based on planktic foraminifers, the probable geological age of the Hamada Formation in the Tanabu Lowland area is ca. 1.3–0.7 Ma. During a restricted period of 1.3–0.7 Ma the palaeo-environment was a bay-mouth area there.

(5) The occurrence of *Buntonia hanaii* and *Yezocythere* spp. in biofacies B of the Chikagawa area indicates that they commonly inhabited the inner-central-bay environment along the coast of northernmost Honshu around 1.2 Ma, instead of modern representative inner-bay taxa, e.g., *Spiniliberis quadriculeata*, that first appeared in northernmost Honshu after 1.0 Ma.

(6) The fossil ostracod fauna from the Chikagawa area of 1.5–1.2 Ma contains in the upper-shelf region 15 now-extinct species and 14 extant species of Hemicytheridae, Cytheruridae and Eucytheridae, but lacks several now-extinct species of *Laperousecythere* and *Cornucoquimba*. These results suggest that the ostracod fauna of the upper-shelf environment in this area was similar to those from southwestern to north-eastern Japan Sea coasts during the same period, even though this area is located at the easternmost extremity of the Japan Sea coast (ca. 141°E) near the Pacific.

Acknowledgments

We wish to thank Y. Tanimura (National Museum of Nature and Science, Tokyo) and the late Y. Kuwano for kind assistance in various aspects of preparing the manuscript and in examination for sediment samples. Thanks are also due to A. Tsukagoshi (Shizuoka University) and M. Oda (Tohoku University) for giving valuable advice concerning the species identification of ostracods and planktic foraminifers. We thank T. M. Cronin (United States Geological Survey), K. Ishida (Shinshu University) and R. J. Smith (Lake Biwa Museum) for critically reviewing the manuscript and providing much helpful advice. This research was partly supported by a Grant-in-Aid for Young Scientists (B) from MEXT, No. 20740291 to H. Domitsu.

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. *Journal of the Faculty of Science, University of Tokyo Bulletin*, vol. 20, p. 443–488.
- Amano, K., 2004: Biogeography and the Pleistocene extinction of neogastropods in the Japan Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 202, p. 245–252.
- Aoki, S. and Kuwano, Y., 1959: Neogene molluscan fauna of Shimokita Peninsula, northern Honshu, Japan (preliminary report). *Miscellaneous Reports of the Research Institute for Natural Resources*, no. 50, p. 30–34. (in Japanese with English abstract)
- Athersuch, J., Horne, D. J. and Whittaker, J. E., 1989: *Marine and Brackish Water Ostracods (Superfamilies Cypridacea and Cytheracea)*, 359 p. E. J. Brill, Leiden.
- 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.
- Brouwers, E. M., 1988: Palaeobathymetry on the continental shelf based on examples using ostracods from the Gulf of Alaska. In: De Deckker, P. D., Colin, J.-P. and Peypouquet, J.-P. eds., *Ostracoda in the Earth Sciences*, p. 55–76. Elsevier, Amsterdam.
- Brouwers, E. M., 1990: Systematic paleontology of Quaternary ostracode assemblages from the Gulf of Alaska, Part 1: Families Cytherellidae, Bairdiidae, Cytheridae, Leptocytheridae, Limnocytheridae, Eucytheridae, Krithidae, Cushmaniidae. *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. and Dwyer, G. S., 2003: Deep-sea ostracodes and climate change. 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. 247–264.
- Cronin, T. M. and Ikeya, N., 1987: The Omma Manganji ostracode fauna (Plio-Pleistocene) of Japan and the zoogeography of circumpolar species. *Journal of Micropalaeontology*, vol. 6, p. 65–88.
- 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.

- Domitsu, H. and Oda, M., 2008: Pleistocene planktic foraminifer events in the northwest Pacific near Japan. *The Open Paleontology Journal*, vol. 1, p. 1–6.
- Haga, M. and Yamaguchi, T., 1990: Stratigraphy and fossil diatoms of the Neogene to Quaternary formations in the eastern Shimokita Peninsula, Aomori Prefecture. *Bulletin of National Science Museum, Tokyo, Series C*, vol. 16, p. 55–78. (in Japanese with English abstract)
- Hammer, Ø., Harper, D. A. T. and Ryan, P. D., 2001: PAST: Paleontological statistics software package for education and data analysis. *Palaeontologica Electronica*, vol. 4, 9 p. [available from website at <http://palaeo-electronica.org/2001.1/past/issue1.01.htm>]
- Hanai, T. and Ikeya, N., 1991: Two new genera from the Omma-Manganji ostracode fauna (Plio–Pleistocene) of Japan—with a discussion of theoretical versus purely descriptive ostracode nomenclature. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 163, p. 861–878.
- Hanai, T. and Yamaguchi, T., 1987: Plio-Pleistocene ostracod fauna of Shimokita, Aomori Prefecture (preliminary report). *Memoirs of National Science Museum, Tokyo*, no. 20, p. 45–51. (in Japanese with English abstract)
- Hanzawa, S., 1954: *Regional Geology of Japan: Tohoku Region*, 344 p. Asakura-Shoten Co., Tokyo. (in Japanese)
- Ikeya, N. and Cronin, T. M., 1993: Quantitative analysis of Ostracoda and water masses around Japan: Application to Pliocene and Pleistocene paleoceanography. *Micropaleontology*, vol. 39, p. 263–281.
- Ikeya, N. and Itoh, H., 1991: Recent Ostracoda from the Sendai Bay region, Pacific coast of northeastern Japan. *Report of Faculty of Science, Shizuoka University*, vol. 25, p. 93–141.
- 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. and Suzuki, C., 1992: Distributional patterns of modern ostracodes off Shimane, southwestern Japan Sea. *Report of Faculty of Science, Shizuoka University*, vol. 26, p. 91–137.
- 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. 1993: Morphology and taxonomy of some Japanese hemicytherin Ostracoda—with particular reference to ontogenetic changes of marginal pores. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 170, p. 186–211.
- Irizuki, T., 1996: Ontogenetic change in valve characters in three new species of *Baffinicythere* (Ostracoda, Crustacea) from Northern Japan. *Journal of Paleontology*, vol. 70, p. 450–462.
- Irizuki, T. and Ishida, K., 2007: Relationship between Pliocene ostracode assemblages and marine environments along the Japan Sea side regions in Japan. *Fossils (Palaeontological Society of Japan)*, no. 82, p. 13–20. (in Japanese with English abstract)
- Ishizaki, K., 1971: Ostracodes from Aomori Bay, Aomori Prefecture, Northeast Honshu, Japan. *Tohoku University, Science Report, 2nd Series (Geology)* vol. 43, p. 59–97.
- Ishizaki, K., 1983: Ostracoda from the Pliocene Ananai Formation, Shikoku, Japan—Description. *Transactions and Proceedings of the Palaeontological Society of Japan*, no. 131, p. 135–158.
- Ishizaki, K. and Matoba, Y., 1985: Early Pleistocene cold, shallow water Ostracoda. *Guidebook of Excursions, Excursion 5: Akita International Symposium of Ostracoda, Shizuoka*, p. 1–12.
- Iwatani, H. and Irizuki, T., 2008: Geology and fossil ostracode assemblages from the Pliocene Miyazaki Group in the northern part of the Miyazaki Plain, Southwest Japan. *Fossils (Palaeontological Society of Japan)*, no. 84, p. 61–73. (in Japanese with English abstract)
- Kamatani, T., 1999: Molluscan shell assemblage under the influence of depositional rate: An example of the middle Pleistocene Yabu Formation, Shimosa Group, central Japan. *Memoirs of the Geological Society of Japan*, no. 54, p. 175–184. (in Japanese with English abstract)
- 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.
- Kanazawa, K., 1990: Early Pleistocene glacio-eustatic sea-level fluctuations as deduced from periodic changes in cold- and warm-water molluscan associations in the Shimokita Peninsula, northeast Japan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 79, p. 263–273.
- Kanazawa, K. and Yamaguchi, T., 1988: Geology of the Plio-Pleistocene Hamada Formation in the Shimokita Peninsula, Aomori Prefecture. *Bulletin of the National Science Museum, Tokyo, Series C*, vol. 14, p. 45–57. (in Japanese with English abstract)
- Kato, M., Akada, K., Takayama, T., Goto, T., Sato, T. and Kameo, K., 1995: Calcareous microfossil biostratigraphy of the uppermost Cenozoic Formation distributed in the coast of the Japan Sea—“Sawane Formation”. *Annals of Science, College of Liberal Arts, Kanazawa University*, vol. 32, p. 21–38. (in Japanese with English abstract)
- Koya, K., 1995: Marine environmental changes since late Pliocene, recorded in the diatom fossil assemblage of the DSDP cores off Sanriku, Northeast Japan. *The Journal of the Geological Society of Japan*, vol. 101, p. 148–161. (in Japanese with English abstract)
- Kuwahara, A., 1990: Chemical features of coastal area of Sanin region (Chapter 34-III). In, Coastal Oceanography Research Committee, Oceanographical Society of Japan ed., *Coastal Oceanography of Japanese Islands/ Supplementary Volume*, p. 768–771. Tokai University Press, Tokyo. (in Japanese)
- Kuwano, Y., 1956: Quaternary system in the environs of Tanabu-Machi, Aomori Prefecture, Japan. *Miscellaneous Reports of the Research Institute for Natural Resources*, no. 40, p. 29–40. (in Japanese with English abstract)
- Kuwano, Y., 1957: Quaternary system of the northern part of Tanabu Lowland area, Aomori Prefecture, Japan. *Miscellaneous Reports of the Research Institute for Natural Resources*, nos. 43–44, p. 178–194. (in Japanese with English abstract)
- Motoyama, I., Niitsuma, N., Maruyama, T., Hayashi, H., Kamikuri, S., Shiono, M., Kanamatsu, T., Morishita, C., Aoki, K., Hagino, K., Nishi, H. and Oda, M., 2004: Middle Miocene to Pleistocene magneto-biostratigraphy of ODP Sites 1150 and 1151, northwest Pacific: sedimentation rate and updated regional geologic time scale. *The Island Arc*, vol. 13, p. 289–305.
- Nagamine, F., Mitsuya, T., Amano, K., Takabayashi, N., Nara, Y., Shiratori, T., Yamamoto, M., Hamada, K., Fukikoshi, H. and Kindaichi, H., 1982: Report of the result for the research on the shallow sea survey lines (Mutsu Bay), Fiscal year report of the preliminary project on the fishery and marine condition. *Report of Aomori Prefectural Fishery and Aquaculture Center*, p. 1–24. (in Japanese)
- Nakao, Y., Tanaka, G. and Yamada, S., 2001: Pleistocene and living marine Ostracoda in Shizuoka district, Japan. In, Ikeya, N. ed., *Field Excursion Guidebook; 14th International Symposium of Ostracoda, Shizuoka*, p. 127–147. Organising Committee of 14th ISO, Shizuoka.
- Nemoto, N., 1997: Palaeoenvironment around Tsugaru Strait in the early Quaternary based on the foraminifer fossils. *Oshimanography*, vol. 4, p. 22–27. (in Japanese)
- Nemoto, N. and Yoshimoto, N., 2001: Foraminiferal fossils from the Pleistocene Hamada Formation in the Chikagawa area, eastern Shimokita Peninsula, Northeast Japan. *Fossils (Palaeontological Society of Japan)*, no. 69, p. 1–24. (in Japanese with English abstract)
- Nohara, T., 1987: Cenozoic ostracodes of Okinawa-jima. *Bulletin of College of Education, Ryukyu University*, no. 30, p. 1–105.
- Nojo, A., Hasegawa, S., Okada, H., Togo, Y., Suzuki, A. and Matsuda, T., 1999: Interregional lithostratigraphy and biostratigraphy of the Pleistocene Setana Formation, southwestern Hokkaido, Japan. *The Journal*

- of the *Geological Society of Japan*, vol. 105, p. 370–388. (in Japanese with English abstract)
- Okubo, R., Oda, H., Takayama, T. and Kitamura, A., 1995: Paleomagnetic polarity and calcareous nannofossil biostratigraphy of the Pleistocene Sawane Formation on Sado-Island, Niigata Prefecture, central Japan. *The Journal of the Geological Society of Japan*, vol. 101, p. 443–450. (in Japanese with English abstract)
- Ozawa, H., 1996: Ostracode fossils from the late Pliocene to early Pleistocene Omma Formation in the Hokuriku district, central Japan. *Science Report of Kanazawa University*, vol. 41, p. 77–115.
- Ozawa, H., 2003: Japan Sea ostracod assemblages in surface sediments: their distribution and relationships to water mass properties. *Paleontological Research*, vol. 7, p. 257–274.
- Ozawa, H., 2004: Okhotsk Sea ostracods in surface sediments: depth distribution of cryophilic species relative to oceanic environment. *Marine Micropaleontology*, vol. 53, p. 245–260.
- 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., Ikehara, K. and Katayama, H., 1999: Recent ostracod fauna in the northeastern part of the Japan Sea, off northwestern Hokkaido. In, Ikehara, K. and Okamura, Y. eds., *Preliminary report on researches in the 1998 Fiscal year, GSJ Interim Report, no. MG/99/1*, p. 103–117. Geological Survey of Japan, Tsukuba. (in Japanese)
- Ozawa, H. and Ishii, T., 2008: Taxonomy and sexual dimorphism of a new species of *Loxocoelcha* (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., 2001: Palaeoceanographic records related to glacio-eustatic fluctuations in the Pleistocene Japan Sea coast based on ostracods from the Omma Formation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 170, p. 27–48.
- Ozawa, H. and Kamiya, T., 2005a: 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. and Kamiya, T., 2005b: Ecological analysis of benthic ostracods in the northern Japan Sea, based on water properties of modern habitats and late Cenozoic fossil records. *Marine Micropaleontology*, vol. 55, p. 255–276.
- Ozawa, H. and Kamiya, T., 2008: Taxonomy and palaeobiogeographical significance for four new species of *Semicytherura* (Ostracoda, Crustacea) from the Early Pleistocene Omma Formation at the Japan Sea coast. *Journal of Micropaleontology*, vol. 27, p. 135–146.
- Ozawa, H. and Kamiya, T., 2009: A new species of *Aurila* (Crustacea: Ostracoda: Cytheroidea: Hemicytheridae) from the Pleistocene Omma Formation on the coast of the Sea of Japan. *Species Diversity*, vol. 14, p. 27–39.
- 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, T. 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*, no. 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 Micropaleontology*, vol. 27, p. 161–175.
- Paik, K. H. and Lee, E. H., 1988: Plio-Pleistocene ostracods from the Sogwipo Formation, Cheju Island, Korea. In, Hanai, T., Ikeya, N. and Ishizaki, K. eds., *Evolutionary Biology of Ostracoda—Its Fundamentals and Applications*, p. 541–556. Kodansha, Tokyo and Elsevier, Amsterdam.
- Robinson, E., 1978: The Pleistocene. In, Bate, R. and Robinson, E. eds., *A stratigraphic index of British Ostracoda*. Geological Journal Special Issue 8, p. 451–472.
- Sato, T., Kameo, K. and Mita, I., 1999: Validity of the latest Cenozoic calcareous nannofossil datums and its implication to the tephrochronology. *Earth Science (Chikyu-Kagaku)*, vol. 53, p. 265–274. (in Japanese with English abstract)
- 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.
- Shirai, M., Tada, R. and Fujioka, K., 1997: Identification and chronostratigraphy of Middle to Upper Quaternary marker tephra occurring in the Anden coast based on comparison with ODP cores in the Japan Sea. *Quaternary Research (Daiyonki-Kenkyu)*, vol. 36, p. 183–196. (in Japanese with English abstract)
- Sugawara, H., Yamaguchi, T. and Kawabe, T., 1997: Geological age of the Hamada Formation in the eastern Shimokita Peninsula, Aomori Prefecture. *Fossils (Palaeontological Society of Japan)*, no. 62, p. 15–23. (in Japanese with English abstract)
- Tabuki, R., 1986: Plio-Pleistocene Ostracoda from the Tsugaru Basin, North Honshu, Japan. *Bulletin of College of Education, University of Ryukyus*, vol. 29, p. 27–160.
- Takata, H., 2000: Palaeoenvironmental changes during the deposition of the Omma Formation (late Pliocene to early Pleistocene) in Oyabe area, Toyama Prefecture based on the analysis of benthic and planktonic foraminiferal assemblages. *Fossils (Palaeontological Society of Japan)*, no. 67, p. 1–18. (in Japanese with English abstract)
- Takayama, T., Kato, M., Kudo, T. and Kameo, K., 1988: Calcareous microfossil biostratigraphy of the uppermost Cenozoic Formations distributed in the coast of the Japan Sea—part 2: Hokuriku Sedimentary Basin. *Journal of Japanese Association of Petroleum Technology*, vol. 53, p. 9–27. (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)
- Tsukagoshi, A., 1996: Recommendation of paleontology–phylogeny demonstrated fossils. In, Iwatsuki, K. and Mawatari, S. eds., *Species Diversity, Biodiversity Series 1*, p. 173–187. Shokabo, Tokyo. (in Japanese, title translated)
- Tsukagoshi, A. and Ikeya, N., 1987: The ostracod genus *Cythere* O. F. Müller, 1785 and its species. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 148, p. 197–222.
- Tsukawaki, S., Ozawa, H., Domitsu, H., Hirano, K., Maeda, T., Tomii, Y., Saito, S., Xu, X., 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 parts of the Japan Sea—Sediments, benthic and planktonic foraminifers and ostracodes (Part I: Surface sediments). *Bulletin of the Japan Sea Research Institute*, no. 32, p. 1–28.
- 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., 1970: The Neogene of the northeastern part of the Shimokita Peninsula, northeast Honshu, Japan. *The Journal of the Geological Society of Japan*, vol. 76, p. 185–197. (in Japanese with English abstract)
- Zhao, Q. and Wang, P., 1988: Distribution of modern Ostracoda in the shelf seas off China. In, Hanai, T., Ikeya, N. and Ishizaki, K. eds., *Evolutionary Biology of Ostracoda—Its Fundamentals and Applications*, p. 805–821. Kodansha, Tokyo and Elsevier, Amsterdam.