

Early to Middle Miocene Ostracods from the Yatsuo Group, Central Japan: Significance for the Bathyal Fauna between Japan Sea and Northwest Pacific Ocean During the Back-Arc Spreading

Author: Ozawa, Hirokazu

Source: Paleontological Research, 20(2): 121-144

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2015PR028

The BioOne Digital Library (<u>https://bioone.org/</u>) 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 (<u>https://bioone.org/subscribe</u>), the BioOne Complete Archive (<u>https://bioone.org/archive</u>), and the BioOne eBooks program offerings ESA eBook Collection (<u>https://bioone.org/esa-ebooks</u>) and CSIRO Publishing BioSelect Collection (<u>https://bioone.org/csiro-ebooks</u>).

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 <u>www.bioone.org/terms-of-use</u>.

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 to middle Miocene ostracods from the Yatsuo Group, central Japan: Significance for the bathyal fauna between Japan Sea and Northwest Pacific Ocean during the back-arc spreading

HIROKAZU OZAWA

Earth Sciences Laboratory, College of Bioresource Sciences, Nihon University, Fujisawa, Kanagawa 252-0880, Japan (e-mail: ozawa.hirokazu@nihon-u.ac.jp)

Received February 14, 2015; Revised manuscript accepted September 17, 2015

Abstract. This study investigated early to middle Miocene ostracods from the Yatsuo Group (ca. 17-15 Ma), located on the Japan Sea coast of central Japan. Ostracods from this area consist of 100 species in 60 genera, with two assemblages defined by Q-mode cluster analysis. The five most abundant genera of each assemblage are Krithe, Propontocypris?, Cytherella, Argilloecia, and Falsobuntonia in assemblage A, and Schizocythere, Cornucoquimba, Callistocythere, Neomonoceratina, and Paracytheridea in assemblage B. The depositional environment of each assemblage can be defined as (1) outer-shelf to bathyal areas (assemblage A) and (2) inner-shelf areas (assemblage B). Stratigraphic changes in the faunal composition, with changes in lithofacies, suggest a shallowing-upward phase in this sedimentary basin. These assemblages contain the same species or genera as corresponding Pacific faunas in the early to middle Miocene. The assemblage containing bathyal genera such as Cytherella and Krithe from Yatsuo at 17-16 Ma is the oldest record from the entire Japan Sea coast, and their fossil records are common to Cenozoic bathyal genera among the Pacific fauna. This fact indicates that these genera could migrate from the Pacific Ocean through the deep-sea passageway to the Japan Sea since at least around 17 Ma during the early Miocene. The shallow-water assemblage of the inner-shelf area around 15.7 Ma has only a small percentage of cold-water genera. The paleo-water temperature in the shallow-sea area around 15.7 Ma in Yatsuo would have been intermediate between warm (subtropical) and cold marine climates around 16 Ma in the Japanese Islands. The ostracod fauna from Yatsuo is significant for the paleogeography and faunal migration of benthos in the Northwest Pacific Ocean during the formation period of the Japan Sea caused by back-arc spreading.

Key words: deep-sea passageway, early to middle Miocene, Japan Sea, Northwest Pacific, ostracods, Yatsuo Group

Introduction

The paleogeography and aquatic environments around the Japanese Islands in the Northwest Pacific region changed greatly during the early to middle Miocene (e.g. Chinzei, 1991; Ogasawara *et al.*, 2008). In the period pre-20 Ma, the Japanese Islands were part of the eastern margin of the Asian Continent, and the Japan Sea still did not exist (Iijima and Tada, 1990; Uemura, 2006; Kano *et al.*, 2007; Tsutsumi, 2014). The Japan Sea began to open as a marginal sea around 20 Ma, caused by back-arc spreading due to pull-apart opening, until 15 Ma (Otofuji *et al.*, 1994; Hoshi and Takahashi, 1999; Hoshi *et al.*, 2006; Baba *et al.*, 2007; Yanai *et al.*, 2010; Sawada *et al.*, 2013). Major geological and tectonic events in this region from the early to middle Miocene led to drastic changes of the aquatic environment from freshwater lakes to shallow seas and deep-sea basins with corresponding changes of benthic faunas (Chinzei, 1991; Tada, 1994; Ogasawara, 1994; Irizuki and Matsubara, 1994; Uemura, 2006).

Benthic ostracods provide good clues to understand the relationship between aquatic environmental fluctuations and faunal changes, because they are sensitive to environmental changes, with high endemism due to no planktic growth stages (Boomer *et al.*, 2003; Ozawa, 2010, 2013). Several studies have documented the ostracod fauna in shallow-water areas of the inner-shelf region in the Japan Sea for the early to middle Miocene during 20-15 Ma (e.g. Ishizaki, 1963; Yajima, 1988; Tanaka et al., 2004). However, to date, few studies have presented accounts of early to middle Miocene (20-15 Ma) deep-water ostracods from outer-shelf to bathyal areas of the Japan Sea. A preliminary report of Irizuki et al. (2006) only touched on this topic. Some studies of shallow- and deep-water ostracods in this sea have been conducted on slightly younger records from the middle to late Miocene (15-7 Ma; Yajima, 1988; Irizuki, 1994; Tanaka et al., 2002; Tanaka, 2003; Tanaka and Nomura, 2009; Matsuura et al., 2013) or shallow-sea assemblages of the early to middle Miocene (17-16 Ma; Ishizaki, 1963; Yajima, 1988; Huh and Paik, 1992; Huh and Whatley, 1997; Tanaka et al., 2004).

The Yatsuo Group comprises the Miocene bathyal stratigraphic unit during 17–16 Ma outcropping in the Japan Sea region. These deposits contain many bathyal calcareous fossils and much chronological data around 16 Ma (Yanagisawa, 1999a; Amano *et al.*, 2004). Kamiya *et al.* (2006) briefly mentioned fossil occurrences of several genera of bathyal ostracods from here, but they did not provide basic details for their specimens such as their geological age, fossil localities or a faunal list with their SEM images. Therefore there are no faunal reports for bathyal ostracods from Yatsuo in detail.

This study investigated ostracods from two formations (Kurosedani and Higashibessho formations) in the Yatsuo Group in order to better understand this important area in the faunal history of the Japan Sea and the Northwest Pacific. Specifically, this study revealed the taxonomic composition and diversity in ostracod faunas, and inferred the nature of the paleo-environment, with representative ostracod faunal lists from this area and their SEM images. The present paper discusses the paleobiogeographical relevance of selected ostracod taxa in bathyal areas, comparing their occurrence with that in other coastal regions of the Japanese Islands during the late Cenozoic. These results allow for inferences regarding the paleogeography of the Japan Sea, an era in which deep-water basins appeared just after the back-arc spreading.

Geological setting and age

The Kurosedani and Higashibessho formations in the Yatsuo Group, along the Toyama Bay coast of the Japan Sea, are well exposed in the Yatsuo area, southwest of Toyama City, central Japan (Figure 1). Sakamoto and Nozawa (1960) and Hayakawa and Takemura (1987) described their geology in detail. The Kurosedani Forma-



Figure 1. Map showing sampling localities for fossil ostracods and distribution of the Kurosedani and Higashibessho formations in the Yatsuo Group, central Japan, showing two studied areas (1 and 2), simplified from Yamada *et al.* (1974) and Kaseno *et al.* (1992). Letters 1 and 2 correspond to use in Figure 4.

tion conformably overlies the Iozen Formation, and is overlain conformably by the Higashibessho Formation (Figure 2). The Higashibessho Formation is unconformably overlain by the Tonami Group.

The Kurosedani Formation is composed mainly of mudstone, accompanied by alternations of mudstone– sandstone. This formation consists of five members including the Fushikidani Mudstone Member with the Yamadanaka Tuff (Figure 2). The Higashibessho Formation is composed mainly of mudstone, accompanied by sandstone and alternations of mudstone and sandstone, and consists of four members (Tochiage Mudstone, Shiotani Sandstone, Asatani Mudstone, and Mitani Mudstone members; Figure 2).

The Kurosedani Formation contains early to middle Miocene planktic microfossils (Tanimura, 1979). Previous studies (e.g. Hasegawa and Takahashi, 1992) had placed microfossils from this formation at the lower part of the planktic foraminifer zone N.8 of Blow (1969; Figure 3) and the lower part of the nannofossil CN3 zone of Okada and Bukry (1980). The andesitic lava in the uppermost part of the Iwaine Formation, which is in the lower part of the Yatsuo Group (Figure 2), has a K–Ar age of 16.4 \pm 0.9 Ma (Shibata, 1973).

The Higashibessho Formation also contains early to middle Miocene planktic microfossils (Tanimura, 1979;



Figure 2. Stratigraphy of the Yatsuo Group in central Japan, after Hayakawa and Takemura (1987), Hasegawa and Takahashi (1992) and Yanagisawa (1999a). Bold-italic letters show the three members examined for ostracods in this study. M: Member.

Figure 3). According to Yanagisawa's (1999a) biochronological summary of the Yatsuo Group (Figure 3), microfossils from here correspond to the diatom NPD 3A, 3B, and 4A zones of Akiba (1986), the planktic foraminifer zone N.8 of Blow (1969) and the calcareous nannofossil CN3 zone of Okada and Bukry (1980) with the radiolarian *Calocyletta costata* zone of Motoyama and Maruyama (1998). Yanagisawa (1999a) recognized six diatom biohorizons from D35 (FO *Denticulopsis praelauta*; 16.4 Ma) to D43 (LO *Denticulopsis okunoi*; 15.4 Ma) in the Higashibessho Formation (Figure 3; age from Berggren *et al.*, 1995; Yanagisawa and Akiba, 1998; Watanabe and Yanagisawa, 2005).

Therefore, the Kurosedani and Higashibessho formations likely date to *ca.* 17–15 Ma, corresponding to the early to middle Miocene, based on planktic microfossil records (Figure 3). These formations were deposited during the mid-Neogene climatic optimum *ca.* 17–15 Ma (e.g. Chinzei, 1991) around the isotope event Mi 2 (16.0 Ma; age from Takahashi, 2004) of Miller *et al.* (1998).

Materials and methods

Twenty-two rock samples were collected for microfossil analysis from the three members of the Kurosedani and Higashibessho formations (Figures 4, 5). Nine samples (F1–F9) were obtained mainly from the mudstone of the Fushikidani Mudstone Member in the Kurosedani Formation along the Yachi River. Seven samples (T1– T7) were collected mainly from the mudstone of the Tochiage Mudstone Member in the Higashibessho For-



Figure 3. Chronology of the Kurosedani and Higashibessho formations in the Yatsuo Group of central Japan related to biochronology and the geomagnetic polarity time scale, modified from Yanagisawa (1999a). Bold-italic letters show the three members studied for ostracods. Ages from Berggren *et al.* (1995), Lourens *et al.* (2004) and Watanabe and Yanagisawa (2005); P: planktic foraminifer zone (Blow, 1969); D: diatom zone (Akiba, 1986; Yanagisawa and Akiba, 1998), CN: nannofossil zone (Okada and Bukry, 1980), Chron and Mp: geomagnetic polarity (Cande and Kent, 1995); Mi2: Miocene oxygen isotope event 2 (Takahashi, 2004). M, Member; Md, Mudstone; S, Sandstone Member; Mi2, event according to Miller *et al.* (1998) and Takahashi (2004).

mation along the Wada and Akae rivers (Figure 4). Six samples (S1–S6) were obtained from sandy mudstone layers within alternations of sandy mudstone and fine sandstone of the Shiotani Sandstone Member in the Higashibessho Formation along the Wada River (Figure 5). These samples were collected in the 1970's by Y. Tanimura for his own research (Tanimura, 1979). We cannot observe outcrops for most of these samples at present, because of conservancy work or residential development since the 1980's.

Dried sediment samples in amounts of 80 g were disaggregated using a saturated sodium sulfate solution and naphtha, washed through a 63-µm (250-mesh) sieve, and dried at 80°C in an oven. This procedure was repeated until the entire sediment sample had disintegrated. Approximately 200 ostracod individuals were picked from six samples (S1–S6) from fractions between 0.125 and 1.0 mm for each sample split. Other samples yielded



Figure 4. Map showing sampling localities for fossil ostracods with distribution of three members in the Yatsuo Group, central Japan, simplified from Sakamoto and Nozawa (1960), Hayakawa and Takemura (1987) and Yanagisawa (1999a). Letters 1 and 2 correspond to use in Figure 1. M: Member.

less than 90 specimens in total, when all specimens that were presented were picked from fractions between 0.125 and 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 yielding more than 30 specimens.

The author determined fossil ostracod assemblages using Q-mode cluster analysis. In the analysis, 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. This study used the free software package PAleontological STatistics (PAST) provided by Hammer (2014) for the cluster analysis. Samples containing at least 30 specimens were subjected to the 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 are stored at the National Museum of Nature and Science, Tsukuba, Japan.

Results

Occurrence of ostracod

In total, 100 ostracod species in 60 genera were identified from the 22 samples. The Fushikidani and Tochiage mudstone members yielded just under 90 individuals and less than 10 species from each sample (F1– F9 and T1–T7; Table 1), even though ostracod specimens were picked from all fractions, except for the sample F5 yielding 14 species and sample T3 yielding 15 species. The total number of species collected from the Fushikidai Mudstone and Tochiage Mudstone members is 25 and 36, respectively. The species diversity in these samples, calculated by the Shannon-Wiener function, was lower than 1.8, except for sample T3 (2.5; Table 1).

The Shiotani Sandstone Member yielded higher numbers of ostracod taxa (80 species; Table 2) than did the Fushikidani and Tochiage mudstone members. Approximately 20–50 species accounted for approximately 170– 300 specimens from each sample of the Shiotani Sandstone Member (S1–S6). The species diversity in these samples, calculated by the Shannon-Wiener function, was approximately 2.4–3.2 (Table 2), which is higher than that for most samples from the Fushikidani and Tochiage mudstone members.

The six samples from the Shiotani Sandstone Member showed an absolute abundance of ostracod fossils (= number of all specimens per 100 g sediment) of approximately 220–740, which is considerably higher than the absolute abundance of approximately 3–110 for the 16 samples from the Fushikidani and Tochiage mudstone members (Tables 1, 2).

The two most abundant species are *Schizocythere* sp. 1 and *Cornucoquimba saitoi* accounting for *ca*. 30% of the total number of specimens (Table 3). Other species in the genera *Cornucoquimba*, *Neomonoceratina*, *Paracytheridea*, *Callistocythere*, and *Neonesidea* are commonly found from many horizons (Figure 5; Table 2). Species in the above six genera accounted for more than 50% of the total number of individuals (Table 3). These genera currently inhabit shallow-water areas with sandy



Figure 5. Columnar sections, frequencies of ostracod species and taxa, ostracod assemblages of the studied area, simplified from Tanimura (1979). YMT, Yamadanaka Tuff; SSM, Shiotani Sandstone Member; MM, Mudstone Member; Fm., Formation. Bold-italic letters show samples used for quantitative analyses. Assemblage names correspond to their use in Figure 6 and Table 4.

Hirokazu Ozawa

 Table 1.
 List of fossil ostracods from the Fushikidani and Tochiage mudstone members in the Yatsuo Group. "Irizuki & Yamada, 2004"

 in this table means Irizuki and Yamada in Irizuki *et al.*, 2004.

Mombor nomo		E,	shikid	oni M	udetor	o M	amh)r		т	achi	ogo M	Indate	no M	lamh	or	
Species nome/Semple number	E1	ГI Е2			E5		ETT	51 E 9	EO	T1	T2	T2		T5		T7	Total
A south a suff and a house of the south of the suff and t	ГІ	ΓZ	гэ	Г4	гэ	го	Г/	го	ГУ	11	12	15	14	13	10	2	Total
Acaninocyinereis koreana Hun & whatey, 1997												1			3	2	5
Acaninocythereis munechikai Isnizaki, 1981												1					1
Acanthocythereis quaarata Irizuki & Yamada, 2004												4					4
Acanthocythereis cf. tsurugasakensis labuki, 1986	•		10	-								2	•				2
Argilloecia cf. toyamaensis Ishizaki & Irizuki, 1990	2		12	1				I					2		I		25
Australimoosella hanaii Yajima, 1992												1					1
Bradleya cf. sendaiensis Ishizaki, 1966				3		1											4
Callistocythere kyongjuensis Huh & Whatley, 1997												2					2
Callistocythere? sp.													1				1
Cornucoquimba cf. kagitoriensis Ishizaki et al., 1996										2							2
Cornucoquimba moniwensis (Ishizaki, 1966)					1												1
Cornucoquimba saitoi (Ishizaki, 1963)								1				1					2
Cornucoquimba sp. 1															1		1
Cythere omotenipponica Hanai, 1959												7					7
Cythere cf. schornikovi Ikeya & Tsukagoshi, 1988												1					1
<i>Cytherella</i> sp.				2	47												49
Cytheropteron uchioi Hanai, 1957					1												1
Cytheropteron cf. sendaiensis Ishizaki. 1966					1									1			2
<i>Cytherura</i> ? sp.					2												2
Falsobuntonia sp.	3	1			3	1	4	1					3			3	19
Hemicytherura? sp.	-	-			-	-		-	1				-			-	1
Henryhowella sp					1								1				2
Hirsutocythere? nozokiensis (Ishizaki 1963)				1	3												4
Hirsutocythere? sp				1	5								1				1
Kritha of antisawanansis Ishizaki 1966	3	1				3					1		2				13
Krithe of ianoniag Ishizoki, 1900	3	4	7		5	3					1		2				13
Krithe of any main Hangi 1050			57	20	12		2	1		2							12
Kriine ci. sawanensis Hanai, 1939			57	39	13		2	1		2 1							114
Legumocymere sp.										1		1					1
Loxoconcha pulchra Isnizaki, 1968					1							1					1
Loxoconcha? sp. 1					I			1									1
Munseyella sp. 1					1			1				•					1
Neonesidea sp.				I	1							2					4
Pacambocythere cf. similis Malz, 1982							I										1
Paijenborchella cf. iocosa Kingma, 1948									1								1
Palmenella limicola (Norman, 1865)											1			1		2	4
Palmoconcha sp. 1								1		1			2				4
Palmoconcha? sp.		1															1
Paracytheridea neolongicaudata Ishizaki, 1966															1		1
Parakrithella? sp.				1													1
Propontocypris? sp. 1			4	10	4					43					1		62
Propontocypris? sp. 2				7	5			1									13
Pseudoaurila ishizakii Irizuki & Yamada, 2004												2					2
Pseudoaurila okumurai (Yajima, 1992)												5					5
Robertsonites reticulatus Irizuki & Yamada, 2004															1		1
Saida? sp.																1	1
Schizocythere sp. 1															1		1
Schizocythere sp. 2																1	1
Sclerochilus? sp.															1		1
Trachyleheris leei Huh & Whatley 1997												2			1		3
Trachyleberis mizunamiensis Vajima 1992												2			1		2
Trachyleberis shukunohoraensis Vajima 1992												2					2
Number of total individuals	Q	6	80	71	00	5	7	7	2	/0	r	25	12	n	11	0	201
Number of total individuals	2	2	4	/ 1	14	2	2	7	2	+7	2	15	12	2	11	۶ ۲	574
Species diversity in few	3	3	4	۲ 1 40	14	3	3	/	2	J	2	13	/	2	9	S	31
Number of individuals (100 -	10.0	-	100.0	1.48	1./1	-	0.0	-	2.5	0.34	25	42.0	15.0	25	12.0	-	_
Number of individuals/ 100 g	10.0	1.5	100.0	ðð.ð	110.0	0.3	ð.ð	ð.ð	2.3	01.3	2.3	43.8	13.0	2.3	13.8	11.5	

Member name		Shiota	ni Sands	tone Me	Member			
Species name/Sample number	S 1	S2	S3	S4	S5	S6	Total	
Acanthocythereis munechikai Ishizaki, 1981					1		1	
Acanthocythereis quadrata Irizuki & Yamada, 2004				1			1	
Acanthocythereis cf. tsurugasakensis Tabuki, 1986		1					1	
Argilloecia cf. toyamensis Ishizaki & Irizuki, 1990	1	1					2	
Bythoceratina? sp.						2	2	
Callistocythere kyongjuensis Huh & Whatley, 1997	20	18	6	2	9	9	64	
Coquimba cf. ishizakii Yajima, 1987					1	1	2	
Cornucoquimba cf. kagitoriensis Ishizaki et al., 1996	17	11	17	14	2	11	72	
Cornucoquimba moniwensis (Ishizaki, 1966)			9	3	28	12	52	
Cornucoquimba saitoi (Ishizaki, 1963)	36	17	50	39	41	42	225	
Cornucoquimba sp. 2	1	1					2	
Cornucoquimba sp. 3				3			3	
Cythere omotenipponica Hanai, 1959	4	8	5	3	9	3	32	
Cythere cf. schornikovi Ikeya & Tsukagoshi, 1988	1	3	3	3	1	1	12	
Cythere cf. uranipponica Hanai, 1959	3		1		2		6	
Cytherella? sp.			1				1	
Cytheroma? sp.		1					1	
Cytheropteron miurense Hanai, 1957		2		2			4	
Cytheropteron cf. sendaiensis Ishizaki, 1966	3	1	3				7	
Cytheropteron subuchioi Zhao, 1988	3	1	2		3		9	
Cytheropteron uchioi Hanai, 1957					1	1	2	
Cytheropteron sp.		5	1		5	7	18	
Falsobuntonia sp.	2	1	1				4	
Finmarchinella hanaii Okada, 1979	9	16				3	28	
Finmarchinella japonica (Ishizaki, 1966)	4	1	1				6	
Finmarchinella cf. japonica (Ishizaki, 1966)			1		1		2	
Hemicythere emarginata (Sars, 1866)	2		1			3	6	
Hemicythere kitanipponica (Tabuki, 1986)		1			1		2	
Hemicytherura clathrata Sars, 1866		2					2	
Hemicytherura cuneata Hanai, 1957	1						1	
Hemicytherura kajiyamai Hanai, 1957		1					1	
Hermanites posterocostata Ishizaki, 1966	3	3			1	1	8	
Kangarina sp.		1			1		2	
Kobayashiina hyalinosa Hanai, 1957	1	1					2	
Kotoracythere cf. abnorma Ishizaki, 1966	2	2	2	11	4	9	30	
Krithe cf. antisawanensis Ishizaki, 1966	3	3					6	
Krithe cf. japonica Ishizaki, 1971						1	1	
Laperousecythere ishizakii Irizuki & Matsubara, 1995						4	4	
Laperousecythere sp.					1		1	
Loxoconcha nozokiensis Ishizaki, 1963	6	5			1		12	

 Table 2.
 List of fossil ostracods from the Shiotani Sandstone Member in the Yatsuo Group. "Irizuki & Yamada, 2004" in this table means Irizuki and Yamada in Irizuki *et al.*, 2004.

Table 2.	Continued.

Member name		Shiota	ani Sand	Sandstone Member			
Species name/Sample number	S1	S2	S3	S4	S 5	S6	Total
Loxoconcha pulchra Ishizaki, 1968	3		1				4
Loxoconcha? sp. 2	1	4			3	7	15
Loxocorniculum kotoraformum Ishizaki, 1966	7	8	1	2	7	6	31
Loxocorniculum sp.	1	1					2
Loxocythere? sp.						1	1
Metacytheropteron sp.					1	2	3
Munseyella sp. 1		2	2	2	1	8	15
Munseyella sp. 2		2					2
Neomonoceratina cf. hatatatensis (Ishizaki, 1966)				2			2
Neomonoceratina ikeyai Irizuki & Yamada, 2004	2		3		2		7
Neomonoceratina japonica (Ishizaki, 1966)	5	9	14	18	9	18	73
Neonesidea sp.	7			5	9	2	23
Paijenborchella cf. hanaii Tabuki, 1986			2		3		5
Palmenella limicola (Norman, 1865)	5	3	6	1	4	4	23
Palmoconcha sp. 1						2	2
Palmoconcha sp. 2	6	5	3		1		15
Paracytheridea neolongicaudata Ishizaki, 1966	17	24	8	7	6	9	71
Paradoxostoma? sp.	2						2
Pectocythere sp.	2	1				4	7
Perissocytheridea sp.	1						1
Pontocythere cf. miurensis (Hanai, 1959)	4	2	1	1	2	1	11
Propontocypris? sp. 1	1					1	2
Pseudoaurila ishizakii Irizuki & Yamada, 2004	23	8			10		41
Pseudoaurila okumurai (Yajima, 1992)	3	2	4	1			10
Pseudoaurila? sp.		1					1
Robertsonites reticulatus Irizuki & Yamada, 2004	11	17	2	2	2	3	37
Schizocythere sp. 1	44	77	59	42	90	79	391
Schizocythere sp. 2		7	2	1	1	4	15
Schizocythere? sp.		1					1
Sclerochilus? sp.	1						1
Semicytherura pseudoundata Irizuki & Yamada, 2004	11	18			1	4	34
Semicytherura cf. miurensis (Hanai, 1957)					1		1
Semicytherura cf. hanaii Ishizaki, 1981		1					1
Spinileberis sp.				3			3
Trachyleberis leei Huh & Whatley, 1997	2						2
Trachyleberis mizunamiensis Yajima, 1992			1		5		6
Urocythereis? gorokuensis Ishizaki, 1966			1				1
Xestoleberis cf. hanaii Ishizaki, 1968	6	6		5	1		18
Xestoleberis cf. setouchiensis Okubo, 1979	7	1					8
Xestoleberis? sp.						2	2
Number of total individuals	294	307	214	173	272	267	1527
Number of total species	44	47	32	24	39	34	80
Species-diversity index	3.18	3.03	2.49	2.43	2.58	2.70	
Number of individuals/ 100 g	735.0	383.8	267.5	216.3	680.0	333.8	

Species name	No.	%
Schizocythere sp. 1	392	20.4
Cornucoquimba saitoi	227	11.8
Krithe cf. sawanensis	114	5.9
Cornucoquimba cf. kagitoriensis	74	3.9
Neomonoceratina japonica	73	3.8
Paracytheridea neolongicaudata	72	3.7
Callistocythere kyongjuensis	66	3.4
Propontocypris? sp. 1	64	3.3
Cornucoquimba moniwensis	52	2.7
Cytherella sp.	49	2.6
Pseudoaurila ishizakii	43	2.2
Cythere omotenipponica	39	2.0
Robertsonites reticulatus	38	2.0
Semicytherura pseudoundata	34	1.8
Loxocorniculum kotoraformum	31	1.6
Kotoracythere cf. abnorma	30	1.6
Finmarchinella hanaii	28	1.5
Neonesidea sp.	27	1.4
Palmenella limicola	27	1.4
Argilloecia cf. toyamaensis	26	1.4
Total	1506	78.4

Table 3. Twenty-ranked ostracod species, their numbers ofindividuals (No.), and their percentages against all individualsfrom the Yatsuo Group.

and muddy sediments around the Japanese Islands (Frydl, 1982; Ikeya and Itoh, 1991; Kamiya *et al.*, 2001; Ozawa, 2003; Tanaka, 2008; Irizuki *et al.*, 2009).

Species in the genera *Krithe, Propontocypris?*, *Cytherella, Falsobuntonia, Acanthocythereis, Robertsonites,* and *Palmenella* are commonly or rarely found from several horizons (Figure 5; Tables 1, 2). These seven genera are found from outer-shelf and bathyal areas with muddy sediments around Japan (Ishizaki and Irizuki, 1990; Ikeya and Suzuki, 1992; Zhou and Ikeya, 1992; Zhou, 1995; Ozawa and Kamiya, 2005; Ozawa and Tsukawaki, 2008; Tanaka *et al.*, 2012a).

There are common or rare occurrences of the genera *Cythere, Loxocorniculum*, and *Xestoleberis* along with *Loxoconcha pulchra* from many horizons (Figure 5; Tables 1, 2). These four taxa are all phytal dwellers, living on sea plants, e.g. the seagrass *Zostera* in sandy substrates, and calcareous algae on rocky shores, along the

present-day Japanese coasts (Kamiya, 1988; Tsukagoshi, 1990; Kamiya *et al.*, 2001; Ishii *et al.*, 2005; Sato and Kamiya, 2007; Ozawa and Ishii, 2008, 2014; Ozawa, 2013). The two species of *Pseudoaurila (P. ishizakii* and *P. okumurai*) occur also from many horizons (Figure 5; Tables 1, 2). Iriziuki *et al.* (2004) stated that these two species probably went extinct during the Miocene, and presumed that they were phytal dwellers on the basis of their carapace shape, which resembles a rugby ball, as a result of adaptation to life on leaves of seagrass or algae (e.g. Kamiya, 1988).

Ostracod assemblage

Two fossil assemblages A and B were defined by the Q-mode cluster analysis (Figure 6) using 52 species and 11 samples. Assemblage A (samples F3-F5 and T1), from the Fushikidani and Tochiage mudstone members mainly in mudstone samples, was mainly composed of five genera, i.e., Krithe, Propontocypris?, Cytherella, Argilloecia, and Falsobuntonia (Figures 5, 6; Table 4). It is enriched by characteristic occurrences of Bradleya, Hirsutocythere?, Henryhowella, Legitimocythere, and Palmoconcha (Figures 5, 7, 8, Table 4). This study allocated the 11 samples from the Fushikidani and Tochiage mudstone members (samples F1, F2, F6-F9, T2, and T4-T7) that yielded less than 15 specimens and were not examined by cluster analysis to assemblage A on the basis of the species composition, because these samples commonly yielded the above genera (Figure 5).

Most of these characteristics and the genus composition are typical of ostracod assemblages in muddy sediments from outer-shelf to bathyal areas of the present Northwest Pacific and Japan Sea (e.g. Ikeya and Suzuki, 1992; Zhou and Ikeya, 1992; Ikeya and Cronin, 1993; Ozawa, 2003; Ozawa and Kamiya, 2005; Tanaka *et al.*, 2012a). Individuals of these ostracod taxa accounted for approximately 80% of ostracod specimens in the 15 samples of assemblage A, which was characterized by a low number of species and low absolute abundance in muddy sediments, and a species diversity index of approximately 1–2 (Tables 1, 4).

In regard to assemblage A, *Krithe* and *Cytherella* were more dominant in the Fushikidani Mudstone Member than in the Tochiage Mudstone Member, and were accompanied by genera such as *Argilloecia*, *Falsobuntonia*, *Henryhowella*, and *Hirsutocythere*? (Figures 5, 6; Tables 1, 4). In contrast, in the Tochiage Mudstone Member, *Propontocypris*? dominated and was accompanied by *Acanthocythereis* and *Robertsonites* (Figures 5, 6; Tables 1, 4). At present along the Pacific and Japan Sea coasts of Japan, the former genera such as *Krithe* are dominant in relatively bathyal areas at approximately 300–1,000 m water depths, while the latter genera such

Hirokazu Ozawa

Table 4. Summary for two ostracod assemblages (Ass.) from the Yatsuo Group. Diversity index (Diversity) in samples used in cluster analysis, number of species (No. spp.) in all samples, paleoenvironments, and five-ranked ostracod species of each assemblages, with their mean percentages in samples used in cluster analysis of each assemblage (RA) and their maximum percentage in a single sample (RM). Assemblage names correspond to use in Figures 5 and 6.

Ass.	Diversity	No. spp.	Paleoenvironment	Five-ranked species	RA (%)	RM (%)
А	0.54-1.71	2-14	outer shelf to	Krithe cf. sawanensis	36.3	71.3
	(mean: 1.12)	(mean: 5)	bathyal area	Propontocypris? sp. 1	27.9	87.8
				Cytherella sp.	14.1	53.4
				Argilloecia cf. toyamaensis	6.2	15.0
				Propontocypris? sp. 2	3.9	9.9
В	2.49-3.18	15–47	inner shelf area	Schizocythere sp. 1	21.9	33.1
	(mean: 2.70) (mean: 34)		Cornucoquimba saitoi	13.9	23.4	
				Neomonoceratina japonica	4.5	10.4
			Cornucoquimba cf. kagitoriensis	4.3	8.1	
				Paracytheridea neolongicaudata	3.9	7.8

Figure 6. Dendrogram showing the result of Q-mode cluster analysis of 11 samples and the relative abundances of the dominant ostracod species in each assemblage. Assemblage names correspond to their use in Figure 5 and Table 4.

Figure 7. SEM images of fossil ostracods from the Yatsuo Group. RV: right valve, LV: left valve, CA: carapace. **1,** *Acanthocythereis koreana* Huh and Whatley, 1997, RV; **2, 3,** *Acanthocythereis quadrata* Irizuki and Yamada in Irizuki *et al.*, 2004; 2, LV; 3, LV; **4,** *Acanthocythereis cf. tsurugasakensis* Tabuki, 1986, CA right side; **5,** *Argilloecia* cf. *toyamaensis* Ishizaki and Irizuki, 1990, CA left side; **6,** *Bradleya* cf. *sendaiensis* Ishizaki, 1966, CA right side; **7,** *Falsobuntonia* sp., CA left side; **8,** *Hirsutocythere*? *nozokiensis* (Ishizaki, 1963), CA left side; **9,** *Hirsutocythere*? sp., CA right side; **10, 11,** *Henryhowella* sp.; 10, CA right side; **11,** CA right side; **12,** *Krithe* cf. *sawanensis* Ishizaki, 1965, CA right side; CA right side; **14,** *Legitimocythere* sp., RV; **15,** *Palmenella limicola* (Norman, 1865), LV; **16,** *Propontocypris*? sp., RV; **17, 18,** *Robertsonites reticulatus* Irizuki and Yamada in Irizuki *et al.*, 2004; 17, LV; 18, RV; **19–21,** *Cytherella* sp.; 19, CA left side; 20, CA left side; 21, CA left side. All specimens are adults, except for 6, 11, 17 and 20 which are juveniles. Scale bars 0.1 mm: A for 9; B for 1, 8, 10, 11, 16; C for 4; D for 2, 3, 6, 7, 12–14, 17–21; E for 5; F for 15. Specimens of 1 from sample T7, 2–4 from sample T2, 5 from sample F4, 6 from sample F4, 7–9 from sample T4, 10–12, 19–21 from sample F5, 13, 15, 17 from sample S1, 14, 16 from sample T1, and 18 from sample T6.

Figure 8. SEM images of fossil ostracods from the Yatsuo Group. CA: carapace. **1–3**, *Palmoconcha* sp. 1; 1, male, CA right side; 2, female, CA right side; 3, female, CA dorsal side; **4–6**, *Palmoconcha* sp. 2; 4, male, CA right side; 5, female, CA right side; 6, female, CA dorsal side. All specimens are adults. Specimens of 1 from sample F8, 2, 3 from sample T4, 4, 6 from sample S1, and 5 from sample S2.

as *Propontocypris* and *Robertsonites* are dominant or common from outer-shelf to bathyal areas at approximately 150–300 m water depths (e.g. Zhou and Ikeya, 1992; Zhou, 1995; Ozawa and Kamiya, 2001, 2005; Ozawa, 2003).

A small number of shallow-sea genera on inner-shelf areas, such as *Schizocythere* and *Cornucoquimba* in the present Japan Sea and Northwest Pacific (e.g. Ikeya and Cronin, 1993; Ozawa, 2003), occurred from the Tochiage Mudstone Member (samples T1 and T5–T7; Table 1). These genera occurred very rarely in the Fushikidani Mudstone Member.

Assemblage B (samples T3 and S1–S6) was dominantly composed of the shallow-sea genera Schizocythere and accompanied by *Callistocythere*, Cornucoquimba, Pseudoaurila, Neomonoceratina, Cythere, Paracytheridea, Loxocorniculum, Neonesidea, Pontocythere, and Xestoleberis (Figures 5, 6, 9, 10; Table 4). This assemblage mainly occurred in sandy mudstone layers within alternations of mudstone and sandstone of the Shiotani Sandstone Member (samples S1-S6) and in part of the Tochiage Mudstone Member (sample T3; Figures 5, 6). Most of these dominant genera inhabit inner-shelf areas of the modern Japan Sea and Northwest Pacific (e.g. Ikeya and Cronin, 1993; Zhou, 1995; Kamiya et al., 2001; Ozawa and Kamiya, 2001; Ozawa, 2003, 2010; Tanaka, 2008; Irizuki et al., 2009). Individuals of species in these genera accounted for approximately 80% of ostracod specimens in this assemblage, which was characterized by a high number of species and absolute abundance in sandy sediments, and a species diversity index of approximately 3 (Tables 1, 2, 4). Assemblage B had a much higher number of species and higher ostracod abundance than did assemblage A from the Fushikidani and Tochiage Mudstone members, except for sample T3 (Tables 1, 2, 4).

Most species found in assemblage B, e.g. *Callisto-cythere kyongjuensis*, *Cornucoquimba saitoi*, *Loxocon-cha nozokiensis*, *Neonesidea* sp., *Pseudoaurila ishizakii*, *P. okumurai*, *Schizocythere* sp. 1, and *Trachyleberis miz-unamiensis* belong to the main species in the ostracod TS (*Trachyleberis mizunamiensis-Schizocythere* sp.) association, defined by Irizuki *et al.* (2004) from the Pacific inner shelf (shallower than 30 m) of the Japanese early Miocene fauna.

Discussion

Water depth of depositional environments

The presence of assemblage A indicates a paleoenvironment in outer-shelf to bathyal areas, while assemblage B suggests an inner-shelf paleo-environment. Further detailed examinations of differences of the genus composition in assemblage A between the two mudstone members suggest a shallowing upwards-phase.

Common or rare occurrences of phytal-dwelling taxa such as *Cythere* and *Xestoleberis* from assemblage B (samples S1–S6) suggest the existence of beds of calcareous algae on the rocky shore and eelgrass *Zostera* on a sandy substrate around the intertidal zone near the site of

Figure 9. SEM images of fossil ostracods from the Yatsuo Group. RV: right valve, LV: left valve, CA: carapace. **1**, **2**, *Callistocythere kyongjuensis* Huh and Whatley, 1997; 1, CA left side; 2. CA left side; **3**, *Cornucoquimba* cf. *kagitoriensis* Ishizaki *et al.*, 1996, CA left side; **4**, *Cornucoquimba moniwensis* (Ishizaki, 1966), RV; **5**, **6**, *Cornucoquimba saitoi* (Ishizaki, 1963); 5, LV; 6. RV; **7**, *Cythere omotenipponica* Hanai, 1959, RV; **8**, *Cytheropteron* cf. *sendaiensis* Ishizaki, 1966, CA right side; **9**, *Cytheropteron* sp., LV; **10**, *Kotoracythere* cf. *abnorma* Ishizaki, 1966, LV; **11**, *Laperousecythere ishizakii* Irizuki and Matsubara, 1995, LV; **12**, *Loxoconcha nozokiensis* Ishizaki, 1963, RV; **13**, *Neomonoceratina japonica* (Ishizaki, 1966), LV; **14**, *Neonesidea* sp., CA left side; **15**, *Paracytheridea neolongicaudata* Ishizaki, 1966, RV; **16**, **17**, *Schizocythere* sp. 1; 16, LV; 17, LV; **18**, *Schizocythere* sp. 2, LV; **19**, *Pseudoaurila ishizaki* Irizuki and Yamada in Irizuki *et al.*, 2004, CA left side; **20**, *Trachyleberis leei* Huh and Whatley, 1997, RV; **21**, *Xestoleberis* cf. *hanaii* Ishizaki, 1968, CA right side. Scale bars are 0.1 mm: A for 3, 4, 14, 19–21; B for 1, 2, 5–8, 10,11, 15–18; C for 9, 12, 13. All specimens are adults, except for 11 and 15 which are juveniles. Specimens of 1, 2 from sample S2, 3, 4, 9, 11, 12 from sample S6, 5, 6, 10, 13, 15–17 from sample S5, 7, 8, 14, 19 from sample S1, 18 from sample S3, 20 from sample T2, and 21 from sample S4.

Figure 10. Relative frequency (%) of dominant ostracod genera from the Shiotani Sandstone Member (samples S1–S6; assemblage B).

these samples. The fact that the depositional environment has relatively strong water currents at the site of these samples can 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 inner-shelf area, also considering that samples S1–S6 were composed of sandstone, which is evidence for some sorting influence.

Stratigraphic changes in these genera or species composition for the assemblages A and B, with lithofacies from mudstone to alternation of mudstone and sandstone in the study area (Figure 5), suggest a shallowing-upward phase of the paleo-setting for this sedimentary basin. The paleo-environment changed from bathyal to inner-shelf as a whole between *ca.* 17 and 15.7 Ma.

Temperature of bathyal water

Numerous paleo-environmental studies, including those based on molluscan analyses, have suggested that a warm tropical-subtropical aquatic environment appeared in shallow- and deep-sea areas of Japan during the mid-Neogene climatic optimum at *ca.* 17–15 Ma, except for the cooling event Mi 2 around 16 Ma (e.g. Chinzei, 1991; Ogasawara, 1994; Amano *et al.*, 2004; Irizuki *et al.*, 2004). The deep-water ostracod genera found in the assemblage A from the Fushikidani and Tochiage mudstone members (*ca.* 17–16 Ma; Figures 3, 5), e.g. *Cytherella, Bradleya*, and *Hirsutocythere*? (e.g. Figure 7), are distributed together in the present Kuroshio Warm Current area in the outer-shelf to bathyal

regions off southern Japan on the Pacific and East China Sea coasts (Ishizaki, 1983; Zhou, 1995). Therefore, during the depositional period of the two mudstone members, a relatively warm-water environment of 5–10°C like that created by the present Kuroshio Current (Ikeya and Cronin, 1993) would have been found in the outershelf to bathyal areas at Yatsuo.

This condition was different from the relatively coldwater environment prevailing in the outer-shelf to bathyal areas in the present Japan Sea (Japan Sea Intermediate–Proper Water; Ozawa, 2003), less than 2°C (e.g. Ikeya and Cronin, 1993; Ozawa and Kamiya, 2001, 2005). The depositional period of the two mudstone members in Yatsuo, with bathyal ostracods, correlates to the appearance period of warm-water shallow-sea ostracods in the Mizunami, Kanazawa, Tomioka and Ota areas and lower horizons of the Ninohe area (lower part of the Kadonosawa Formation), with numerous subtropical warm-water ostracod and molluscan assemblages characteristic of Japan (Figure 11; e.g. Irizuki and Matsubara, 1994; Amano *et al.*, 2004; Tanaka *et al.*, 2013).

Previous studies have proposed a global cooling period, i.e., the Miocene oxygen isotope event Mi2 around 16.0 Ma (e.g. Miller *et al.*, 1998; age from Takahashi, 2004; Figure 11). In Yatsuo, the Mi2 event correlates to the depositional period of the Tochiage Mudstone Member (Figure 11), but samples from this member contain no cold-water genera such as *Finmarchinella* (Table 1). According to Irizuki *et al.* (2004), the rapid and dominant appearance of shallow-dwelling cold-water ostracods around 16.4 Ma at Ninohe in northeastern Japan could reflect a cold marine climate influenced by this cooling event. Evidence of this event was not recorded in the ostracod fauna from the Tochiage Mudstone Member at Yatsuo, probably due to the deepwater environment.

Paleobiogeography of bathyal fauna between 17–16 Ma

The assemblage A from Yatsuo contains in conjunction with *Cytherella* species of *Henryhowella* and *Legitimocythere* (Figures 5, 6). All these are common bathyal genera that have lived since the Paleogene in many such regions of the Pacific and other oceans (e.g. Cronin and Compton-Goodin, 1987; Cronin *et al.*, 2002; Yamaguchi, 2004; Bergue and Nicoladis, 2012). Modern and Eocene–Pleistocene sediments from the Pacific coasts of Japan and Southeast Asia include these genera as well as *Krithe* (Figures 7, 12–15) (e.g. Hanai *et al.*, 1980; Ishizaki, 1983; Zhou, 1995; Yamaguchi, 2004). However, up to now, considering the entire coastline of the Japan Sea, from the early Miocene to the present there

Figure 11. Stratigraphic correlation of the early-middle Miocene (17–15 Ma) strata in Yatsuo and seven areas of Japan referred in the text. P, planktic foraminiferal zone of Blow (1969); D, diatom zone of Barron and Gladenkov (1995); Mi2 event according to Miller *et al.* (1998) and Takahashi (2004). Age data; **a**, Irizuki and Matsubara (1994, 1995); **b**, Takahashi and Yanagisawa (2003); **c**, Takahashi and Hayashi (2004); **d**, Yanagisawa (1999a); **e**, Yanagisawa (1999b); **f**, Irizuki *et al.* (2004); **g**, Irizuki (2003); **h**, Irizuki *et al.* (2006, 2014). S. M.: Sandstone Member.

has been just one preliminary report of the genus *Cytherella*, which was found at the coastline's southwestern end in the middle Miocene Yasuda Formation of the Masuda Group (Irizuki *et al.*, 2006; shown as G in Figure 12). Moreover, the geological age of this formation is still vague, because previous studies have presented several different ages, such as the foraminifer Zone N.9 of Blow (1969; Nomura *et al.*, 1993; 14.7–14.2 Ma) and ca. 16– 15 Ma (e.g. Irizuki *et al.*, 2014). So the bathyal ostracod assemblage containing the several genera *Cytherella*, *Henryhowella*, and *Legitimocythere* from Yatsuo, which is below D35 (FO *D. praelauta*; 16.4 Ma), is the oldest fossil record from the entire Japan Sea coast.

This study also found two *Palmoconcha* species from Yatsuo (Figures 5, 8; Tables 1, 2), constituting the oldest fossil record of this genus from the entire Japan Sea coast. Yamaguchi and Kamiya (2007) divided *Palmoconcha* species from the North Pacific (latitude 20°–60°N) into two groups by the carapace morphology. One is the *P. parapontica* group, characterized by distinct posterodorsal muri with no prominent eye spots. The other is the *P. laevimarginata* group, which have no postero-dorsal muri and a distinct eye spots. The former group is distributed only in the Northwest Pacific around Japan from the Oligocene to the present, being endemic to this area, and the latter group is found on the Northwest and Northeast Pacific coasts (Yamaguchi and Kamiya, 2007). Zhou (1995) reported common occurrences of this genus from outer-shelf to bathyal areas around present-day Japan.

The author considers that *Palmoconcha* sp. 1 from Yatsuo belongs to the *P. parapontica* group, and *Palmoconcha* sp. 2 from the same locale belongs to the *P. laevimarginata* group, based on the existence or absence of the postero-dorsal muri and eye spot (Figure 8). The occurrence of *Palmoconcha* sp. 2 from Yatsuo is the oldest and sole record of the *P. laevimarginata* group from the entire Japan Sea, and that of *Palmoconcha* sp. 1 is the oldest record of this genus from the Japan Sea.

The genus *Falsobuntonia* also has been reported only from the Northwest Pacific (latitude 20°–60°N), and is known as one of the endemic genera in this region from the Oligocene to the present (Yamaguchi and Kamiya, 2007). Previous studies (Ikeya and Suzuki, 1992; Zhou, 1995; Ozawa *et al.*, 2004) reported common occurrences of this genus from outer-shelf to bathyal areas around present-day Japan. *Bradleya*, *Krithe*, and *Pacambocythere* are also bathyal genera, and are commonly reported from outer-shelf to bathyal areas around present-day Japan (e.g. Ikeya and Suzuki, 1992; Zhou and Ikeya, 1992;

Figure 12. Geographical and geological occurrences of the genus *Cytherella* in and around the Japanese Islands from the Eocene to Recent. A, This study; B, Nakao *et al.* (2001); C, Irizuki (2003); D, Yamaguchi *et al.* (2005); E, Zhou (1995); F, Ishizaki (1983); G, Irizuki *et al.* (2006); H, Yamaguchi *et al.* (2006); I, Yamaguchi (2004); J, Yamaguchi (2006); K, Iwatani and Irizuki (2008); L, Iwatani *et al.* (2011); M, Yamaguchi *et al.* (2012); N, Nohara (1987).

Ozawa, 2003).

The occurrence of the last-named three genera from Yatsuo is their oldest record from the entire Japan Sea. These ostracod genera from Yatsuo are significant for the origin, evolution and extinction of the bathyal benthos during the Cenozoic in and around the Japan Sea.

Faunal interchange and deep-sea passageway

A Miocene fossil assemblage around 17 Ma containing *Cytherella* and *Pacambocythere* was reported also from the Pacific side of Japan in the Makino Formation of the Awa area, Mie Prefecture (Irizuki, 2003; Figures 11, 12, 14). Therefore, occurrences of outer-shelf and bathyal ostracods in the Yatsuo Group strongly indicate faunal interchange between Northwest Pacific and Japan Sea

Figure 13. Geographical and geological occurrences of the genus *Krithe* in and around the Japanese Islands from the Eocene to middle Miocene. A, This study; B, Irizuki *et al.* (1998); C, Tanaka and Hasegawa (2013); D, Tanaka *et al.* (2002); E, Tanaka (2003), Tanaka and Nomura (2009); F, Yamaguchi and Kamiya (2007); G, Yamaguchi *et al.* (2006); H, Yamaguchi (2004); I, Yamaguchi (2006). Fossil occurrence of *Krithe* from the Miocene Yasuda Formation, southwestern Japan Sea coast (Irizuki *et al.*, 2006; the same locality shown as G in Figure 12) is not presented here, because of its vague age.

faunas and the existence of a deep-sea passageway, connected to both areas around 17–16 Ma.

Amano et al. (2004) have also suggested the existence of Miocene deep-sea passageways connecting to the Pacific, based on molluscan analysis from Yatsuo. They represented occurrences of deep-sea molluscan fossils containing taxa of outer shelf and bathyal areas, from a horizon that is *ca*. 75 m lower than the Yamadanaka Tuff, correlated to the uppermost part of the Kurosedani Formation. The depositional periods of the Yamadanaka Tuff and the sampling horizon of Amano et al. (2004) are approximately 16.6 Ma and 16.8 Ma, respectively, based on the diatom biohorizons of Yanagisawa (1999a) as dated by Watanabe and Yanagisawa (2005) (Figure 3), if the rate of sediment accumulation of the Kurosedani Formation is the same as that of the lower horizons of the overlying Higashibessho Formation, i.e., ca. 3.3 cm/1,000 years between two diatom biohorizons D35 and D40.

A precise age for the beginning of the formation of the

Figure 14. Maps for the Japanese Islands of three Cenozoic periods showing with occurrences of the genus *Cytherella*. **1**, early Miocene; **2**, early to middle Miocene; **3**, middle to late Miocene. Map 1 is simplified from Uemura (2006), and maps 2 and 3 are simplified from Chinzei (1991). Names of paleo-troughs are from Iijima and Tada (1990). Arrows with dotted lines in map 2 indicate the inferred invasion routes of bathyal ostracods from the Pacific to the Japan Sea. Area names in map 2; **a**, Ninohe; **b**, Ota; **c**, Tomioka; **d**, Yatsuo; **e**, Kanazawa; **f**, Mizunami; **g**, Awa. Area names in map 3; **h**, Matsue; **i**, Izumo; **j**, Tanegashima. Occurrence data of the genus *Cytherella* in maps 2 and 3; **d**, this study; **g**, Irizuki (2003); **j**, Yamaguchi *et al.* (2012). Occurrence data of *Cytherella* from the Miocene Yasuda Formation, southwestern Japan Sea coast (Irizuki *et al.*, 2006; shown as **G** in Figure 12) is not presented here, because of its vague age.

Figure 15. Maps for the Japanese Islands of three Cenozoic periods showing with occurrences of the genus *Krithe.* **1**, early Miocene; **2**, early to middle Miocene; **3**, middle to late Miocene. Map 1 is simplified from Uemura (2006), and maps 2 and 3 are simplified from Chinzei (1991). Names of paleo-troughs are from Iijima and Tada (1990). Arrows with dotted lines in map 2 indicate the inferred invasion routes of bathyal ostracods from the Pacific to the Japan Sea. Area names **a**–**j** in maps 2 and 3 correspond to their use in Figure 14, area names in map 3 are **k**, Tanagura; **l**, Karasuyama. Occurrence data of the genus *Krithe* in maps 2 and 3; **a**, Irizuki and Matsubara (1994, 1995), **b**, Tanaka *et al.* (2013), **d**, this study; **h**, Tanaka *et al.* (2002); **i**, Tanaka (2003), Tanaka and Nomura (2009); **k**, Irizuki *et al.* (1998); **l**, Tanaka and Hasegawa (2013). Occurrence data of *Krithe* from the Miocene Yasuda Formation, southwestern Japan Sea coast (Irizuki *et al.*, 2006; shown as **G** in Figure 12) is not presented here, because of its vague age.

deep-sea basin in the Japan Sea and the time during which deep-sea passageways existed to the Pacific are still vague, because the starting age of the deposition for the Kurosedani Formation is unclear. However, *Cytherella* is found from the sample F3 in the Kurosedani Formation, and this sample is from *ca*. 500 m lower than the Yamadanaka Tuff (Tanimura, 1979; Figure 5). If the sedimentation rate of the Kurosedani Formation (Fushikidani Mudstone Member) is equal to that of the lower horizons of the Tochiage Mudstone Member (ca. 3.3 cm/1,000 years; Yanagisawa, 1999a), the age of the horizon F4 is estimated to be much older than 17 Ma, i.e.. ca. 18.2 Ma. Considering the age of lava from the uppermost part of the underlying Iwaine Formation (Figure 2; 16.4 ± 0.9 Ma; Shibata, 1973), this estimated age (ca. 18.2 Ma) for the horizon F4 would be much older than this lava age. So the time when these tectonic and faunal-migration events would have started has to be at least around 17.0 Ma, which is slightly older than the age estimated from the molluscan study of Amano et al. (2004). Thus, the deep-water basin of the Japan Sea at central Japan had been formed by ca. 17 Ma at least, considering these facts. These bathyal ostracods would have passed through the "Paleo-Sanin-Hokuriku Trough" or "Paleo-Fossa Magna Trough", named by Iijima and Tada (1990), connected to the Pacific around 16 Ma (Figures 14, 15).

The modern shallow-depth limit of several bathyal genera, such as *Krithe*, *Legitimocythere*, and *Henryhow-ella*, was reported on the basis of researches for grab and coretop samples to be under 1,000 m in the Northwest and Southwest Pacific (e.g. Zhou, 1995; Ayress *et al.*, 1997). Based on these data, the paleo-water-depth of this deep-water passageway might have been shallower than 1,000 m at least.

Water temperature of shallow water

According to previous studies for many regions shown in Figure 11, shallow-sea ostracod species dominated during 17.0-16.2 Ma, e.g. Pseudoaurila ishizakii, Cornucoquimba saitoi, and Schizocythere sp. 1 (e.g. Yajima, 1992; Irizuki and Matsubara, 1994; Irizuki, 2003; Tanaka et al., 2004, 2012b, 2013). These were warm-subtropical species during the Miocene (Irizuki, 2003; Goto et al., 2013). Among these shallow-sea ostracods, species of Schizocythere and Cornucoquimba are dominant also in the Shiotani Sandstone Member (15.7 Ma) of Yatsuo with small percentages of species of Trachyleberis and Loxoconcha (Figures 5, 6, 10, 11). Three shallow coldwater genera, Finmarchinella, Hemicythere and Kotoracythere, defined by Irizuki and Matsubara (1994, 1995), also occurred in this sandstone (Figure 10; Table 2). However, these three taxa were not found in assemblages from Mizunami–Kanazawa (17.0–16.7 Ma), Tomioka-Ota (16.7–16.2 Ma) or the lower horizons of Ninohe (17.0– 16.4 Ma) during 17.0-16.2 Ma (Yajima, 1992; Irizuki and Matsubara, 1994; Tanaka et al., 2004, 2012b, 2013). These genera were dominant in the upper horizons of Ninohe during 16.4-15.0 Ma (in the NPD3B and 4A zones) in the upper part of the Kadonosawa and

Suenomatsuyama formations (Irizuki and Matsubara, 1994, 1995; Figure 11). Thus, dominant occurrences of these cold-water genera indicate a cooling event in the shallow-marine environment of the Ninohe area (since 16.4 Ma; Irizuki and Matsubara, 1994, 1995).

However, deposits of the Shiotani Sandstone Member in Yatsuo around 15.7 Ma have quite small ratios of the three genera *Finmarchinella*, *Hemicythere*, and *Kotoracythere* (ca. 5% of the total number of specimens of samples S1–6; ca. 2–7% in each sample; Figures 6, 10). These numbers were much lower than at Ninohe since 16.4 Ma (e.g. Clusters D and E of Irizuki and Matsubara, 1994). There the ratio in total specimens of their two clusters (consisting of 42 samples) at Ninohe around 16.0 Ma was more than 20%, and the maximum ratio of one sample was ca. 70% (Irizuki and Matsubara, 1994). For these horizons, it is inferred that the paleo-environment of Ninohe since 16.4 Ma was under cold-marine climate condition (Irizuki and Matsubara, 1994, 1995; Figure 11).

The shallow-sea water temperature during the period of deposition of the Shiotani Sandstone Member (15.7 Ma) in Yatsuo differed from both the warm subtropical condition during 17.0–16.2 Ma in Mizunami–Kanazawa, Tomioka–Ota and Ninohe (17.0–16.4 Ma) and the cold condition since 16.4 Ma at Ninohe. The shallow-sea water temperature of Yatsuo at 15.7 Ma suggest an intermediate environment between those of the warmsubtropical and cold conditions around 16 Ma for Japan. The cause of the difference in the faunal composition of shallow-water environments between Yatsuo and other areas in this cooling period, e.g. differences in latitudes or geographical settings, is not clear. We have to examine more examples of ostracod faunas around 16 Ma from many areas in Japan and its adjacent areas.

Conclusions

- (1) Twenty-two samples from the lower to middle Miocene Yatsuo Group in central Japan on the Japan Sea coast contained 100 species of ostracods in 60 genera.
- (2) Q-mode cluster analysis distinguished two assemblages. The depositional environment of each assemblage can be inferred as (a) the outer-shelf to bathyal area and (b) the inner-shelf area. Both assemblages contain the same species or genera as respective Pacific faunas in the early to middle Miocene during 17–16 Ma. Stratigraphic changes in the taxonomic composition and lithofacies suggest a shallowing-upward phase in this sedimentary basin, from bathyal to inner-shelf depths.
- (3) This study represents the oldest record of the bathyal

benthonic ostracod fauna (17–16 Ma) from the entire Japan Sea coast. This ostracod fauna is significant for its origin, evolution, and extinction during the Cenozoic in the Japan Sea and its adjacent areas. The assemblage includes bathyal genera, e.g. *Krithe*, *Propontocypris*?, *Cytherella*, *Argilloecia*, and *Falsobuntonia*, that are common to Pacific faunas and those of the Japan Sea coast. This result indicates that these ostracods migrated from the Pacific coast through a deep-sea passageway to the Japan Sea since the early Miocene at least *ca*. 17 Ma.

(4) The shallow-water assemblage of the inner-shelf area around 15.7 Ma has just small percentages of cold-water genera. This result suggests that the paleo-water temperature at the shallow sea around 15.7 Ma in this region was in an intermediate condition between warm (subtropical) and cold marine climates found around 16 Ma in the Japanese Islands.

Taxonomic notes

The author briefly describes the morphology of six species below, using the following measurements in the text: L: carapace length (mm), H: carapace height (mm). This study follows the classification of ostracod orders in Horne *et al.* (2002).

Subclass Podocopa Sars, 1866 Order Platycopida Sars, 1866 Superfamily Cytherelloidea Sars, 1866 Family Cytherellidae Sars, 1866 Genus *Cytherella* Jones, 1849

Cytherella sp.

Figures 7.19-7.21

Remarks.--Specimens from Yatsuo are similar to Cytherella japonica Ishizaki, 1983, described from Late Pliocene sediments of Shikoku, southwestern Japan in the Northwest Pacific realm, having faint subparallel costae along the anterior margin and granular elements in the posterior margin, with similar carapace length and height. However, they differ in having large and distinct granular elements in the posterior margin with a straight outline of the dorsal and ventral margins. This genus is one of the representative bathyal genera that have been found from the Paleogene to the present in many bathyal regions of the Pacific (Figures 12, 14) and along oceanic coasts elsewhere (e.g. Cronin et al., 2002; Bergue and Nicoladis, 2012). Specimens of Figure 7.19 and 7.21 are adult male and female, and a specimen of Figure 7.20 is juvenile.

Order Podocopida Sars, 1866 Superfamily Cytheroidea Baird, 1850 Family Cytheridae Baird, 1850 Subfamily Schizocytherinae Mandelstam, 1960 Genus *Schizocythere* Triebel, 1950

Schizocythere sp. 1

Figures 9.16, 9.17

Remarks.-The present species is similar to Schizocythere okhotskensis Hanai, 1970 (L = 0.79-0.89, H =0.47-0.53 in types; Hanai, 1970) from modern surface sediments obtained east of Sova Cape, Hokkaido, northern Japan on the southwest coast of the Okhotsk Sea. However, it is distinguished from S. okhotskensis in having weaker ridges in the anterior marginal, mid-central, postero-dorsal and postero-ventral areas, a different pattern of ridges in the posterior half, and a smaller carapace even in the adult stage (L = 0.60, H = 0.32; based on Figure 9.16). This species is different from Schizocythere kishinouyei (Kajiyama, 1913) from modern surface sediments of the Miura Peninsula, central Japan in the Northwest Pacific realm, in having weaker ridges in the mid-central, ventral marginal and dorsal marginal areas, and different distributional patterns of ridges and reticulations in the postero-ventral and postero-dorsal areas.

Schizocythere sp. 2

Figure 9.18

Remarks.—This species is similar to *Schizocythere ikeyai* Tsukagoshi and Briggs, 1998 described from modern surface sediments of Akkeshi Bay, Pacific coast of Hokkaido, northern Japan. However, the present species differs from *S. ikeyai* in having much weaker ridges in the mid-central, antero-dorsal, and postero-dorsal areas, a different distributional patterns of ridges and reticulations in the mid-central and postero-ventral areas, and a different outline of the anterior and posterior ends of the carapace. This species is different from *Schizocythere* sp. 1 of this study in having less developed reticulations and ridges on the entire carapace, a different distributional patterns of ridges in the posterior half, and a different outline at the posterior end.

Family Trachyleberididae Sylvester-Bradley, 1948 Genus *Falsobuntonia* Malz, 1982

Falsobuntonia sp.

Figure 7.7

Remarks.—Specimens from Yatsuo are similar to Falsobuntonia hayamii (Tabuki, 1986), from Pleistocene sediments of the Tsugaru Peninsula, on the Japan Sea coast of northeastern Japan, in general outline, but they differ in having well developed reticulation and ridges in the posterior area with a larger valve size (L = 0.76). This genus is endemic to the Northwest Pacific coastal regions from the Oligocene to the present (Yamaguchi and Kamiya, 2007).

Family Loxoconchidae Sars, 1925 Genus *Palmoconcha* Swain and Gilby, 1974

Palmoconcha sp. 1

Figures 8.1-8.3

Remarks.—Specimens from Yatsuo are very similar to *Palmoconcha parapontica* (Zhou, 1995) from modern surface sediments off southwestern Japan in the Northwest Pacific realm, but they slightly differ by the wide area of the secondary reticulation on the carapace surface. The author considers that this species belongs to the *Palmoconcha parapontica* group defined by Yamaguchi and Kamiya (2007), from the existence of distinct posterodorsal muri and lack of distinct eye spots. This group is one of two morphological groups of this genus around the Pacific coastal region, and is endemic around Japan from the Oligocene to the present (Yamaguchi and Kamiya, 2007). Specimen of Figure 8.1 is an adult male, and specimens of Figure 8.2 and 8.3 are adult females.

Palmoconcha sp. 2

Figures 8.4-8.6

Remarks.—Specimens from Yatsuo are very similar to *Palmoconcha propontica* (Hu, 1983) described from Plio-Pleistocene deposits of southern Taiwan in the Northwest Pacific realm, but they slightly differ by the fine reticulation in the anterior area and angular posterior margin. The author considers that this species belongs to the *Palmoconcha laevimarginata* group of Yamaguchi and Kamiya (2007), based on the absence of distinct postero-dorsal muri and existence of eye spots. This group is found in the Northwest and Northeast Pacific margins, and is present in Japan from the Eocene to the present (Yamaguchi and Kamiya, 2007). Specimen of Figure 8.4 is an adult male, specimens of Figure 8.5 and 8.6 are adult females.

Acknowledgements

I extend my thank to Y. Tanimura, M. Saito (National Museum of Nature and Science, Tsukuba, Japan), T. Kamiya (Kanazawa University, Japan) and H. Ohama (Toyama City, Japan) for assisting in various aspects of

manuscript preparation and for giving the author the opportunity to use sediment samples and the information on fossil localities of the Yatsuo Group. I wish to thank B.-C. Zhou (Shanghai Science and Technology Museum, China) and T. Irizuki (Shimane University, Japan) for presenting the unpublished data of ostracod occurrences from the Pacific and Japan Sea coasts of southwestern Japan. I would like to thank T.M. Cronin (United States Geological Survey, USA) and K. Yamada (Shinshu University, Japan) for their constructive review and many useful suggestions. For use of their scanning electron microscopes, I thank the National Museum of Nature and Science, Tsukuba, Japan. This research was financially supported in part by a Grant-in-Aid from the Japan Society for the Promotion Science (No. 15K07199 to H. Ozawa).

References

- Akiba, F., 1986: Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified Lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the North Pacific. *In*, Whallen, E. *ed.*, *Initial Reports of the Deep Sea Drilling Project*, vol. 87, p. 393–480. U. S. Government Printing Office, Washington D. C.
- Amano, K., Hamuro, T. and Hamuro, M., 2004: Latest early–earliest middle Miocene deep-sea molluscs in the Japan Sea borderland– the warm-water Higashibessho fauna in Toyama Prefecture, central Japan. *Paleontological Research*, vol. 8, p. 29–42.
- Ayress, M., Neil, H., Passlow, V. and Swanson, K., 1997: Benthonic ostracods and deep watermasses: A qualitative comparison of Southwest Pacific, Southern and Atlantic Oceans. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 131, 287–302.
- Baba, K. A., Matsuda, T., Itaya, T., Wada, Y., Hori, N., Yokoyama, M., Eto, N., Kamei, R., Zaman, H., Kidane, T. and Otofuji, Y., 2007: New age constraints on counter-clockwise rotation of NE Japan. *Geophysical Journal International*, vol. 171, p. 1325–1341.
- Baird, W., 1850: The Natural History of the British Entomostraca, 364 p. The Ray Society, London.
- Barron, J. A. and Gladenkov, A. Y., 1995: Early Miocene to Pleistocene diatom biostratigraphy of Leg. 145. *In*, Rea, D. K., Basov, I. A., Scholl, D. W. and Allan, J. F. *eds.*, *Proceedings of the Ocean Drilling Program, Scientific Results*, vol. 145, p. 3–19. College Station, Texas (Ocean Drilling Program).
- Berggren, W. A., Kent, D. V., Swisher, C. C. III. and Aubry, M. -P., 1995: A revised Cenozoic geochronology and chronostratigraphy. *Society for Sedimentary Geology, Special Publication*, vol. 54, p. 129–212.
- Bergue, C. T. and Nicoladis, D. D., 2012: The Paleocene-Oligocene ostracodes from DSDP Site 329 (Falkland Plateau): Taxonomy and paleozoogeographical remarks. *Paleontological Research*, vol. 16, p. 47–58.
- Blow, W. H., 1969: Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In, Brönniman, P. and Renz, H. H. eds., Proceedings of the First International Conference on Planktonic Microfossils (Geneva, 1967), vol. 1, p. 199–421. E. J. Brill, Leiden.
- Boomer, I., Horne, D. J. and Slipper, I. J., 2003: The use of ostracods in paleoenvironmental studies, or what can you do with an ostracod shell? *In*, Park, L. E. and Smith, A. J. *eds.*, *Bridging the Gap:*

Trends in the Ostracode Biological and Geological Sciences. Paleontological Society Papers, vol. 9, p. 153–179.

- Cande, S. C. and Kent, D. V., 1995: Revised calibration of geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, vol. 100, p. 6093–6095.
- Chinzei, K., 1991: Late Cenozoic zoogeography of the Sea of Japan area. *Episodes*, vol. 14, p. 231–235.
- Cronin, T. M., Boomer, I., Dwyer, G. S. and Rodriguez-Lazaro, J., 2002: Ostracoda and paleoceanography. *In*, Holmes, J. A. and Chivas, A. eds., *The Ostracoda: Applications in Quaternary Research*, p. 99–119. AGU Geophysical Monograph Series 131.
- Cronin, T. M. and Compton-Goodin, E., 1987: Cenozoic Ostracoda from deep sea drilling project Leg 95 off New Jersey (Sites 612 and 613). *In*, Turner, K. L. *ed.*, *Initial Reports of the Deep Sea Drilling Project*, vol. 95, p. 439–451. U. S. Government Printing Office, Washington, D. C.
- Frydl, P. M., 1982: Holocene ostracods in the southern Boso Peninsula. University Museum, the University of Tokyo, Bulletin, no. 20, p. 61–140.
- Goto, T., Irizuki, T., Hayashi, H., Tanaka, Y., Matsuyama, K. and Iwatani, H., 2013: Stratigraphy and depositional environment of the Miocene in the Tajibe area, Okayama Prefecture, southwest Japan. Journal of the Geological Society of Japan, vol. 119, p. 321–333. (in Japanese with English abstract)
- Hammer, Ø., 2014: PAST: PAleontological STatistics Version 3.02 [online]. [Cited 19 January 2015]. Available from: http:// folk.uio.no/ohammer/past/.
- Hanai, T., 1957: 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.
- Hanai, T., Ikeya, N. and Yajima, M., 1980: Checklist of Ostracoda from Southeast Asia. *The University Museum, the University of Tokyo, Bulletin*, no. 17, p. 1–242.
- Hasegawa, S. and Takahashi, H., 1992: Faunal succession of benthic foraminifera in the upper Yatsuo Group of the Hokuriku district, central Japan–A temporal faunal trend during an early–middle Miocene transgression in Japan. *In*, Ishizaki, K. and Saito, T. *eds.*, *Centenary of Japanese Micropaleontology*, p. 51–66. Terra Scientific Publishing Company, Tokyo.
- Hayakawa, H. and Takemura, A., 1987: The Neogene system in the Yatsuo area, Toyama Prefecture, central Japan. *Journal of the Geological Society of Japan*, vol. 93, p. 717–732. (*in Japanese with English abstract*)
- Horn, H. S., 1966: Measurement of "overlap" in comparative ecological studies. *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*, p. 5–36. *AGU Geophysical Monograph Series* 131.
- Hoshi, H., Iwano, H. and Danhara, T., 2006: New age constraints on the Miocene tectonic evolution of southwestern Japan: fission track ages from the Shitara district, Aichi Prefecture. *Journal of the Geological Society of Japan*, vol. 112, p. 153–165. (*in Japanese* with English abstract)
- Hoshi, H. and Takahashi, M., 1999: Miocene counterclockwise rotation of Northeast Japan: a review and new model. *Bulletin of the*

Geological Survey of Japan, vol. 50, p. 3-16.

- Hu, C., 1983: Ostracods from the Maanshan Mudstone, Hengchun Peninsula, Southern Taiwan. *Petroleum Geology of Taiwan*, vol. 19, p. 149–178.
- Huh, M. and Paik, K. H., 1992: Miocene Ostracoda from the Seojeongri Area, Pohang Basin, Korea. *Journal of the Geological Society* of Korea, vol. 28, p. 273–283.
- Huh, M. and Whatley, R., 1997: New species of Miocene cytheracean Ostracoda from the Pohang Basin, SE Korea. *Journal of Micropaleontology*, vol. 16, p. 31–40.
- Iijima, A. and Tada, R., 1990: Evolution of Tertiary sedimentary basins of Japan in reference to opening of the Japan Sea. *Journal* of Faculty of Sciences, the University of Tokyo, vol. 22, p. 121– 171.
- 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. *Reports of the Faculty* of Science, Shizuoka University, vol. 25, p. 93–141.
- Ikeya, N. and Suzuki, C., 1992: Distributional patterns of modern ostracodes off Shimane Peninsula, southwestern Japan Sea. *Report of the Faculty of Sciences, Shizuoka University*, vol. 26, p. 91–137.
- Ikeya, N. and Tsukagoshi, A., 1988: The interspecific relations between three close species of the genus *Cythere* O. F. Müller. *In*, Hanai, T., Ikeya, N. and Ishizaki, K. *eds.*, *Evolutionary Biology* of Ostracoda–Its Fundamentals and Applications, p. 891–917. Kodansha, Tokyo and Elsevier, Amsterdam.
- 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., 2003: Miocene stratigraphy and microfossils from the eastern Setouchi Province. *Shimane-ken Chigaku-kaishi*, vol. 18, p. 1–5. (*in Japanese*; original title translated)
- 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, Central Japan. *Paleontological Research*, vol. 2, p. 30–46.
- Irizuki, T., Iwatani, H., Takeshi, K. and Hoshino, K., 2006: Geology and fossil ostracode assemblages from the Middle Miocene Masuda Group, Shimane Prefecture. *Abstracts, the 113th Annual Meeting of the Geological Society of Japan*, p. 115. (*in Japanese*)
- 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 paleoenvironmental significance. *Transactions* and Proceedings of the Palaeontological Society of Japan, New Series, no. 177, p. 65–78.
- 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., Tsukimata, K., Matsuura, Y., Goto, T., Iwatani, H. and Kawano, S., 2014: Temporal changes of ostracode faunas in the

Chugoku district during the Miocene. Abstracts with Programs, the 160th Regular Meeting, the Palaeontological Society of Japan, p. 51. (in Japanese)

- 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. *Micropaleontol*ogy, vol. 50, p. 105–147.
- 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., 1963: Japanese Miocene ostracodes from the Sunakosaka Member of the Yatsuo Formation, east of Kanazawa City, Ishikawa Prefecture. *Japanese Journal of the Geology and Geog*raphy, vol. 34, p. 19–34.
- 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, Western Honshu, Japan. Science Reports of the Tohoku University, Second Series (Geology), vol. 40, p. 1–45.
- 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., 1983: Ostracoda from the Pliocene Ananai Formation, Shikoku, Japan – Description. *Transactions and Proceedings of* the Palaeontological Society of Japan, New Series, no. 131, p. 135–158.
- Ishizaki, K., Fujiwara, O. and Irizuki, T., 1996: Ostracod faunas from the upper Miocene Tsunaki Formation near the southern border of Sendai City, northeast Japan. *Proceedings of the 2nd European Ostracodologists Meeting*, p. 113–120.
- Ishizaki, K. and Irizuki, T., 1990: Distribution of bathyal ostracodes in sediments of Toyama Bay, Central Japan. *Courier Forschun*gsinstitut Senckenberg, vol. 123, p. 53–67.
- 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)
- Iwatani, H., Irizuki, T. and Goto, T., 2011: Temporal changes of Plio– Pleistocene Ostracoda from the Takanabe Formation, Miyazaki Group, Southwest Japan. *Paleontological Research*, vol. 15, p. 269–289.
- Jones, T. R., 1849: A monograph of the Entomostraca of the Cretaceous formation of England. *Annual Volumes (Monographs) of the Palaeontographical Society*, vol. 3, p. 1–40.
- Kajiyama, E., 1913: The Ostracoda from Misaki, part 3. Zoological Magazine of Tokyo (Doubutsugaku-zassi), vol. 25, p. 1–16. (in Japanese; original title translated)
- 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.
- Kamiya, T., Sato, T. and Kumakiri, M., 2006: Evolution of the Ostra-

coda and the environmental changes of the Japan Sea. In, Hayakawa, K. ed., Past, Present and Future Environments of Pan-Japan Sea Region, p. 109–125. Maruzen, Tokyo.

- Kano, K., Uto, K. and Ohguchi, T., 2007: Stratigraphic review of Eocene to Oligocene successions along the eastern Japan Sea: implication for early opening of the Japan Sea, *Journal of Asian Earth Sciences*, vol. 30, p. 20–32.
- Kaseno, Y., Miura, S. and Fujii, S., 1992: Weather condition, geomorphology and geology of Hokuriku district. Urban Kubota, Osaka, no. 31, p. 2–15. (in Japanese; original title translated)
- Kingma, J. T., 1948: Contributions to the knowledge of the young-Caenozoic Ostracoda from the Malayan Region. *Proefschrift*, *Rijks-Universiteit Utrecht*, p. 1–118.
- Lourens, L. J., Hilgen, F. J., Laskar, J., Shackleton, N. J. and Wilson, D., 2004: The Neogene period. *In*, Gradstein, F. M., Ogg, J. G. and Smith, A. G. *eds.*, *A Geologic Time Scale 2004*, p. 404–420. Cambridge University Press, Cambridge.
- Malz, H., 1982: Plio-Pleistozäne Buntoniini von SW-Taiwan (Ostracoda). Senckenbergiana Lethaea, vol. 63, p. 377–411.
- Mandelstam, M. J., 1960: Ostracoda. In, Tschernysheva, E. N. ed., Fundamentals of Paleontology, Arthropoda Volume, p. 264–421. State Scientific Technological Publishing House, Moscow. (in Russian)
- Matsuura, Y., Irizuki, T. and Hayashi, H., 2013: Microfossil assemblages associated with argonaut fossils from 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*)
- Miller, K. G., Mountain, G. S., Browning, J. V., Kominz, M., Sugarman, P. J., Christie-Blick, N., Katz, M. E. and Wright, J. D., 1998: Cenozoic global sea-level, sequences, and the New Jersey transect: Results from coastal plain and slope drilling. *Reviews of Geophysics*, vol. 36, p. 569–601.
- 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.
- Motoyama, I. and Maruyama, T., 1998: Neogene diatom and radiolarian biochronology for the middle-to-high latitudes of the Northwest Pacific region: Calibration to the Cande and Kent's geomagnetic polarity time scales (CK92 and CK95). Journal of the Geological Society of Japan, vol. 104, p. 171–183. (in Japanese with English abstract)
- Nakao, Y., Tanaka, G. and Yamada, S., 2001: Pleistocene and living marine Ostracoda in Shizuoka district, Japan. In, Ikeya, N. ed., Field Excursion Guidebook for the 14th International Symposium of Ostracoda, Shizuoka, p. 127–147. Organising Committee of 14th ISO, Shizuoka.
- Nohara, T., 1987: Cenozoic ostracodes of Okinawa-jima. Bulletin of College of Education, University of the Ryukyus, vol. 30, p. 1–105.
- Nomura, R., Fukuhama, M. and Tabara, H., 1993: Discovery of Palaega sp. (Isopoda) from the Miocene Masuda Group, Shimane Prefecture, Japan, and its geological age. Journal of the Geological Society of Japan, vol. 99, p. 871–876. (in Japanese with English abstract)
- Norman, A. M., 1865: Report on the Crustacea. In, Brady, G. S. ed., Deep-sea Dredging on the Coasts of Northumberland and Durham in 1864, p. 189–193. Report of the 34th Meeting of the British Association for the Advancement of Science.
- 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.
- Ogasawara, K., Takano, M., Nagato, H. and Nakano, T., 2008: Ceno-

zoic molluscan faunas and climatic changes in the northern Pacific related to Pacific gateways: review and perspective. *Bulletin of the Geological Survey of Japan*, vol. 59, p. 355–364.

- Okada, H. and Bukry, D., 1980: Supplementary modification and introduction of code numbers to the low latitude coccolith biostratigraphic zonation (Bukry, 1973, 1975). *Marine Micropaleontology*, vol. 5, p. 319–328.
- Okada, Y., 1979: Stratigraphy and Ostracoda from the Late Cenozoic strata of the Oga Peninsula, Akita Prefecture. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 115, p. 143–173.
- Okubo, I., 1979: Three species of *Xestoleberis* (Ostracoda) from the Inland Sea of Japan. *Proceedings of the Japanese Society of Systematic Zoology*, no. 16, p. 9–16.
- Otofuji, Y., Kambara, A., Matsuda, T. and Nohdam, S., 1994: Counterclockwise rotation of Northeast Japan: Paleomagnetic evidence for regional extent and timing of rotation. *Earth and Planetary Science Letters*, vol. 121, p. 503–518.
- 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., 2010: 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., 2013: The history of sexual dimorphism in Ostracoda (Arthropoda, Crustacea) since the Palaeozoic. *In*, Moriyama, H. *ed.*, *Sexual Dimorphism*, p. 51–80. InTech Open Access Company, Rijeka.
- 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 Ishii, T., 2014: Shallow-marine ostracods from the Lower Pleistocene Kazusa Group in the Tama Hills, central Japan, with their biogeographical significance in the Northwest Pacific Ocean. *Paleontological Research*, vol. 18, p. 189–210.
- Ozawa, H. and Kamiya, T., 2001: Palaeoceanographic records related to glacio-eustatic sea-level 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., 2005: 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. 54, p. 255–276.
- Ozawa, H., Kamiya, T., Kato, M. and Tsukawaki, S., 2004: 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. 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.
- Sakamoto, T. and Nozawa, T., 1960: *Geological Map of the Yatsuo District, Quadrangle Series (1: 50,000),* 77 p. Geological Survey of Japan, Kawasaki. (*in Japanese with English abstract*)
- Sars, G. O., 1866: Oversigt af Norges marine Ostracoder. Forhandlinger i Videnskabs-Selskabet i Kristiania, vol. 1865, p. 1–130.
- Sars, G. O., 1925: An Account of the Crustacea of Norway. Volume 9.

Ostracoda. Parts 11, 12. Cytheridae (continued), p. 177–208. Bergen Museum, Bergen.

- 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.
- Sawada, Y., Mishiro, Y., Imaoka, T., Yoshida, K., Inada, R., Hisai, K., Kondo, H. and Hyodo, M., 2013: K-Ar ages and paleomagnetism of the Miocene in the Izumo Basin, Shimane Prefecture. *Journal* of the Geological Society of Japan, vol. 119, p. 267–284. (in Japanese with English abstract)
- Shibata, K., 1973: K-Ar ages of volcanic rocks from the Hokuriku Group. Memoirs of the Geological Society of Japan, no. 8, p. 143–149. (in Japanese with English abstract)
- Swain, F. M. and Gilby, J. M., 1974: Marine Holocene Ostracoda from the Pacific coast of North and Central America. *Micropaleontol*ogy, vol. 20, p. 257–352.
- 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, Part 2, no. 29, p. 27–160.
- Tada, R., 1994: Paleoceanographic evolution of the Japan Sea. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 108, p. 487– 508.
- Takahashi, M., 2004: Oxygen isotope fluctuation pattern between 19 and 8 Ma re-calculated on the basis of Cande and Kent's (1995) geomagnetic polarity time scale. *Journal of the Japanese Association for Petroleum Technology*, vol. 69, p. 83–93. (*in Japanese with English abstract*)
- Takahashi, M. and Hayashi, H., 2004: Geology and integrated chronostratigraphy of the Miocene marine sequence in the Tomioka area, Gunma Prefecture, central Japan. *Journal of the Geological Society of Japan*, vol. 110, p. 175–194. (*in Japanese with English abstract*)
- Takahashi, M. and Yanagisawa, Y., 2003: Stratigraphy and geochronology of the Miocene marine sequences in the Ota area, Gunma Prefecture, central Japan. Journal of the Geological Society of Japan, vol. 109, p. 648–660. (in Japanese with English abstract)
- Tanaka, G., 2003: Middle Miocene ostracods from the Omori Formation, Izumo City, Southwest Japan—Its implications for paleoenvironment of the Proto-Japan Sea. *Earth Science (Chikyu-Kagaku)*, vol. 57, p. 111–127.
- Tanaka, G., 2008: Recent benthonic ostracod assemblages as indicators of the Tsushima Warm Current in the southwestern Sea of Japan. *Hydrobiologia*, vol. 598, p. 271–284.
- Tanaka, G. and Hasegawa, Y., 2013: Miocene ostracods from the Itahana Formation in the Tomioka District, Gunma Prefecture, Central Japan: Palaeoenvironmental significance and systematics. *Paleontological Research*, vol. 17, p. 138–172.
- Tanaka, G., Itami, M., Kurosawa, S., Yoshioka, A., Yokota, M., Arai, R., Idehara, Y. and Hayashi, H., 2013: The depositional environment of the singular Middle Miocene strata from southwestern Tomioka City, Gunma Prefecture, central Japan, from the view point of fossil ostracod assemblage. *Journal of the Geological Society of Japan*, vol. 119, p. 17–24. (*in Japanese with English abstract*)
- Tanaka, G. and Nomura, R., 2009: Middle Miocene ostracods from the Furue Formation, Shimane Prefecture, Southwest Japan. *Journal* of the Geological Society of Japan, vol. 115, p. 261–265. (in Japanese with English abstract)
- Tanaka, G., Nomura, S. and Hasegawa, Y., 2012b: Miocene ostracods from the Midorimachi Formation, Ota City, Gunma Prefecture,

central Japan. Bulletin of Gunma Museum of Natural History, no. 16, p. 31-40.

- Tanaka, G., Seto, K., Mukuda, T. and Nakano, Y., 2002: Middle Miocene ostracods from the Fujina Formation, Southwest Japan and their paleoenvironmental significance. *Paleontological Research*, vol. 6, p. 1–22.
- Tanaka, G., Tsukawaki, S. and Ooji, A., 2004: Preliminary report on ostracodes from the Miocene Sunagozaka Formation, southern part of Kanazawa City, Ishikawa Prefecture, central Japan. Bulletin of the Japan Sea Research Institute, vol. 35, p. 53–63. (in Japanese with English abstract)
- Tanaka, G., Zhou, B.-C., Ikeya, N. and Hasegawa, Y., 2012a: Recent ostracod assemblages from Suruga Bay, central Japan. *Bulletin of Gunma Museum of Natural History*, no. 16, p. 1–30.
- Tanimura, Y., 1979: Yatsuo area, Toyama Prefecture (2). In, Tsuchi, R. ed., Fundamental Data on Japanese Neogene Bio- and Chronostratigraphy, p. 83–84. Working Group "Japanese Neogene Bioand Chronostratigraphy", Shizuoka. (in Japanese; original title translated)
- Triebel, E., 1950: Homöomorphe Ostracoden-Gattungen. Senckenbergiana, vol. 31, p. 313–330.
- Tsukagoshi, A., 1990: Ontogenetic change of distributional patterns of pore systems in *Cythere* species and its phylogenetic significance. *Lethaia*, vol. 23, p. 225–241.
- Tsukagoshi, A. and Briggs, W. M., Jr., 1998: On Schizocythere ikeyai Tsukagoshi & Briggs sp. nov. Stereo-Atlas of Ostracod Shells, vol. 25, p. 43–52.
- Tsutsumi, Y., 2014: An Illustrated Guide to Birth of the Japanese Islands, 181 p. Kodansha, Tokyo. (in Japanese)
- Uemura, K., 2006: Chapter 2.2. The formation process of the Japanese Islands. In, National Science Museum ed., Natural History of the Japanese Islands, p. 23–40. Tokai University Press, Hadano. (in Japanese; original title translated)
- Watanabe, M. and Yanagisawa, Y., 2005: Refined early to middle Miocene diatom biochronology for the middle- to high-latitude North Pacific. *Island Arc*, vol. 14, p. 91–101.
- Yajima, M., 1987: Pleistocene Ostracoda from the Atsumi Peninsula, central Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New Series, no. 145, p. 49–76.
- Yajima, M., 1988: Preliminary notes on the Japanese Miocene Ostracoda. In, Hanai, T., Ikeya, N. and Ishizaki, K. eds., Evolutionary Biology of Ostracoda—Its Fundamentals and Applications, p. 1073–1085. Kodansha, Tokyo and Elsevier, Amsterdam.
- Yajima, M., 1992: Early Miocene Ostracoda from Mizunami, central Japan. Bulletin of the Mizunami Fossil Museum, no. 19, p. 247– 267.
- Yamada, N., Sakamoto, T., Nozawa, T. and Enda, T., 1974: Geological Map of the Kanazawa District (1: 500,000; 2nd Edition). Geological Survey of Japan, Kawasaki. (in Japanese)

- Yamaguchi, T., 2004: Oligocene ostracode assemblages from the Itanoura Formation, Nishisonogi Group, Nagasaki Prefecture, southwestern Japan. *Paleontological Research*, vol. 8, p. 53–70.
- Yamaguchi, T., 2006: Eocene ostracodes from the Iojima Group, Nagasaki Prefecture, southwestern Japan. *Journal of Paleontol*ogy, vol. 80, p. 902–918.
- Yamaguchi, T. and Kamiya, T., 2007: Oligocene–Miocene ostracode assemblages with the genus *Palmoconcha* from Japan. *Journal of Paleontology*, vol. 81, p. 632–642.
- Yamaguchi, T., Mashiba, H. and Kamiya, T., 2012: Miocene Ostracodes from the Osaki Formation, Kukinaga Group, Tanegashima, Southwest Japan, and their significance for the biogeography of the Indo-West Pacific. *Paleontological Research*, vol. 16, p. 107– 123.
- 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.
- Yamaguchi, T., Nagao, R. and Kamiya, T., 2006: Paleogene ostracodes from the Kishima Formation, Kishima Group, southwestern Japan. Bulletin of the Mizunami Fossil Museum, no. 33, p. 87– 101.
- Yanagisawa, Y., 1999a: Diatom biostratigraphy of the lower to middle Miocene sequence in the Yatsuo area, Toyama Prefecture, central Japan. Bulletin of the Geological Survey of Japan, vol. 50, p. 139– 165. (in Japanese with English abstract)
- Yanagisawa, Y., 1999b: Diatom biostratigraphy of the Miocene sequence in the southern Kanazawa area, Ishikawa Prefecture, central Japan. Bulletin of the Geological Survey of Japan, vol. 50, p. 49–65. (in Japanese with English abstract)
- Yanagisawa, Y. and Akiba, F., 1998: Revised Neogene diatom biostratigraphy for the northwest Pacific around Japan, with an introduction of code numbers for selected diatom biohorizons. *Journal* of the Geological Society of Japan, vol. 106, p. 395–414.
- Yanai, S., Aoki, K. and Akahori, Y., 2010: Opening of Japan Sea and major tectonic lines of Japan: MTL, TTL and Fossa Magna. Journal of Geography (Chigaku Zassi), vol. 119, p. 1079–1124. (in Japanese with English abstract)
- 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.
- Zhou, B. -C. and Ikeya, N., 1992: Three species of Krithe (Crustacea: Ostracoda) from Suruga Bay, central Japan. Transactions and Proceedings of the Palaeontological Society of Japan, New Series, no. 166, p. 1097–1115.