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Article

Paleoenvironmental analysis from fossil ostracod assemblages of the Middle Pleistocene Naganuma Formation in the Sagami Group, central Japan

Hirokazu Ozawa[1,*] and Gengo Tanaka[2]

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Abstract: This study estimates paleoenvironmental changes in water depths and temperatures from approximately 0.6 Ma during the marine oxygen isotope stage (MIS) 15 of the Middle Pleistocene along coastal Japan. We used the modern analog technique (MAT), which is based on ostracod assemblages from the Naganuma Formation in the Sagami Group of Kanagawa Prefecture in central Japan. The analysis revealed that the Naganuma Formation was deposited in the shallow-marine environment at paleo-water depths of 25–41 m, similar to current depths of southwestern Japan coastal areas such as the Setonaikai Sea. The estimated summer paleo-water temperature (ca. 28℃) was approximately 2℃ higher than current Sagami Bay water temperatures at depths of shallower than 30 m. The estimated temperatures were also similar to or slightly lower (~2℃) than current summer temperatures in Sagami Bay at depths of 40 m. The estimated winter paleo-water temperatures (6–11℃) were slightly lower (~2℃) than current Sagami Bay temperatures at depths of shallower than 40 m. This study reports for the first time fluctuations in paleo-water temperature estimates quantitatively from 0.6 Ma during the MIS 15 along coastal Japan.

Keywords: osracods, Middle Pleistocene, Naganuma Formation, MIS 15, modern analog technique, paleo-water temperature, Sagami Bay, Kanagawa Prefecture, central Japan

1. Introduction

The paleoenvironment and invertebrate faunas fluctuated drastically during the Pleistocene in response to marine climatic changes and glacioeustacy in shallow seas of the northwest Pacific Ocean margin near the Japanese Islands (Chinzei, 1991; Tada, 1994; Amano, 2004; Ozawa and Kamiya, 2005; Ozawa and Ishii, 2014). Because of the mid-Pleistocene transition (MPT; e.g. Berger and Jansen, 1994) and a shift in the glacioeustatic climatic cycle periodicity from 41 kyr to 100 kyr, the Middle Pleistocene represents an important paleoclimate period.

Benthic ostracods provide clues for understanding paleoenvironments, because they lack a planktic growth stage and are endemic, making them sensitive to environmental changes (e.g. Boomer *et al.*, 2003). Previous Japanese studies of ostracods have documented environmental changes since the Middle Pleistocene, evidenced by fossils in shallow seas along the Pacific coasts of the Osaka Bay, Lake Hamana, and Tokyo Bay (Yajima, 1978, 1982; Ishizaki, 1990a, b; Ozawa *et al.*, 1995; Yasuhara and Kumai, 2003; Irizuki and Seto, 2004; Irizuki *et al.*, 2002, 2005, 2011) from 0.4 Ma in the MIS 11 (MIS age from e.g. Lisiecki and Raymo, 2005). However, details of the Middle Pleistocene paleoenvironment prior to 0.4 Ma along the Japanese coast remain unknown.

The Middle Pleistocene Naganuma Formation (ca. 0.6 Ma, MIS 15; Machida, 2010) of the Sagami Group is exposed on the northern side of Sagami Bay (Fig. 1; Ujiie and Kagawa, 1963) and is known for its shallow marine calcareous fossils, including molluscs (Yabe, 1906; Oyama, 1973). There are no reports of fluctuations in paleo-water temperatures from 0.6 Ma in the MIS 15 for coasts of Japan and adjacent regions. This study reports, for the first time, fluctuations in paleo-water temperatures of coastal Japan from 0.6 Ma (MIS 15) using modern analog technique (MAT) methods.

[1] Earth Sciences Laboratory, College of Bioresource Sciences, Nihon University, Kameino 1866, Fujisawa, Kanagawa 252-0880, Japan
[2] General Education Courses, Institute of Liberal Arts and Science, Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan
[*] Corresponding author: H. Ozawa, Email: ozawa.hirokazu@nihon-u.ac.jp

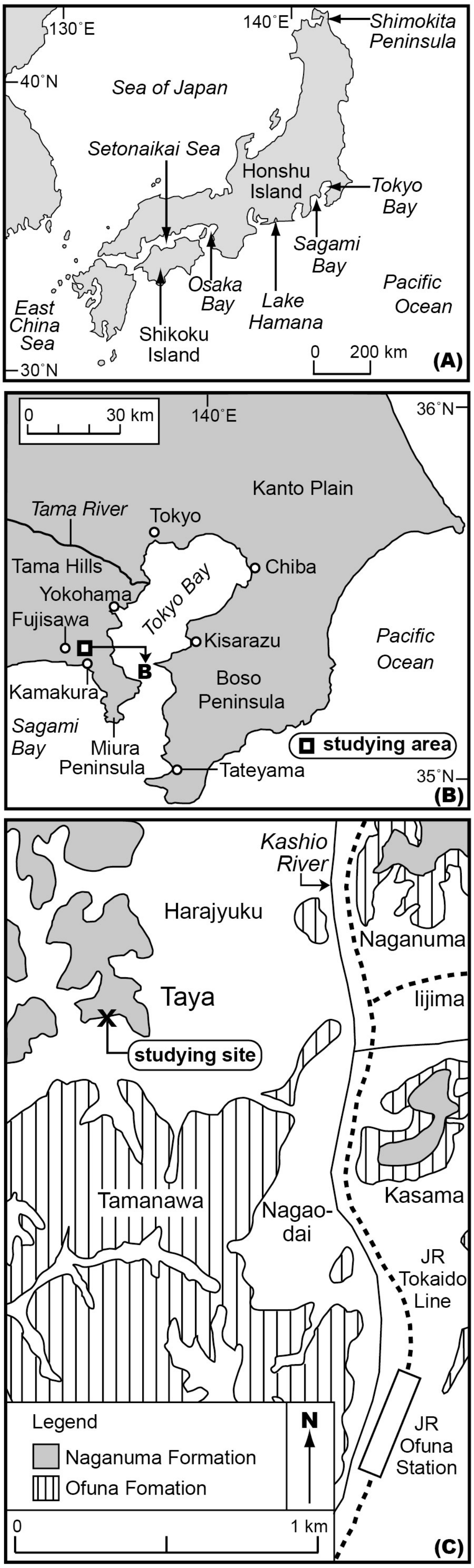

Fig. 1 (A) A map of locations described in the text. (B) A map of the study area. (C) A map of the distribution of the Naganuma Formation of central Japan, with the study site, modified from Ujiie and Kagawa (1963). (A)–(C) are modified from Ozawa (2009).

2. Geological setting

The Naganuma Formation in the Sagami Group is exposed at the base of the Miura Peninsula in the southernmost region of Yokohama City and in the northeastern region of Fujisawa City, Kanagawa Prefecture, central Japan (Fig. 1). The geology and fossils of this formation have been studied (e.g. Otuka, 1937; Ujiie and Kagawa, 1963; Oyama, 1973; Mitsukoka *et al.*, 1977; Mitsunashi and Kikuchi, 1982) since 1906 (Yabe, 1906). This stratum unconformably overlies the Lower Pleistocene Ofuna Formation in the Kazusa Group (age from Fujioka *et al.*, 2003), and the unconformable surface is known as the "Naganuma Unconformity" (Machida, 2010; Fig. 2). The Middle Pleistocene Byobugaura Formation in the Sagami Group unconformably overlies the Naganuma Formation (Osada *et al.*, 1982; age from Machida, 2010). The Naganuma Formation primarily consists of silt and fine- to medium-grained sand, and contains calcareous fossils accompanied by layers of tuff (Otsuka, 1937; Ujiie and Kagawa, 1963; Fig. 2). Fossil ostracods have also been found in the Naganuma Formation (Ozawa, 2009).

The chronology of tuff layers suggests that the Naganuma and Byoubugaura formations in the Sagami Group of the Miura Peninsula are correlated with the lower and upper parts, respectively, of the Kasamori Formation in the Kazusa Group of the Boso Peninsula in central Japan (Machida, 2010; Fig. 2). The two unconformities of the Naganuma Formation in the study area (Fig. 2) are also seen in the Kazusa Group of the Boso Peninsula. Based on the chronology of the Ks18 tuff layer of the lower part of Kasamori Formation (Machida, 2010), the Naganuma Unconformity is estimated to have been formed while the sea-level was low during a glacial period (MIS 16). Similarly, the Byobugaura Formation is correlated with the upper part of the Kasamori Formation (Fig. 2). Based on estimations from the Ks11 tuff layer chronology in the Kasamori Formation, previous researches (Machida *et al.*, 1980; Machida, 2010) determined that another unconformity between the Naganuma and Byobugaura formations was also formed while sea-level was low during a glacial period (MIS 14). The Naganuma Formation is thought to have formed from deposits during the high sea-level period of the interglacial period between MIS 16 and 14, and therefore to be correlated with MIS 15, approximately 0.6 Ma (Machida, 2010; MIS age from Lisiecki and Raymo, 2005), although Ozawa (2009) referred previous studies of nannofossils and tuff layers pre-2009 to estimate that the formation was deposited in ca. 0.5 Ma (MIS 13).

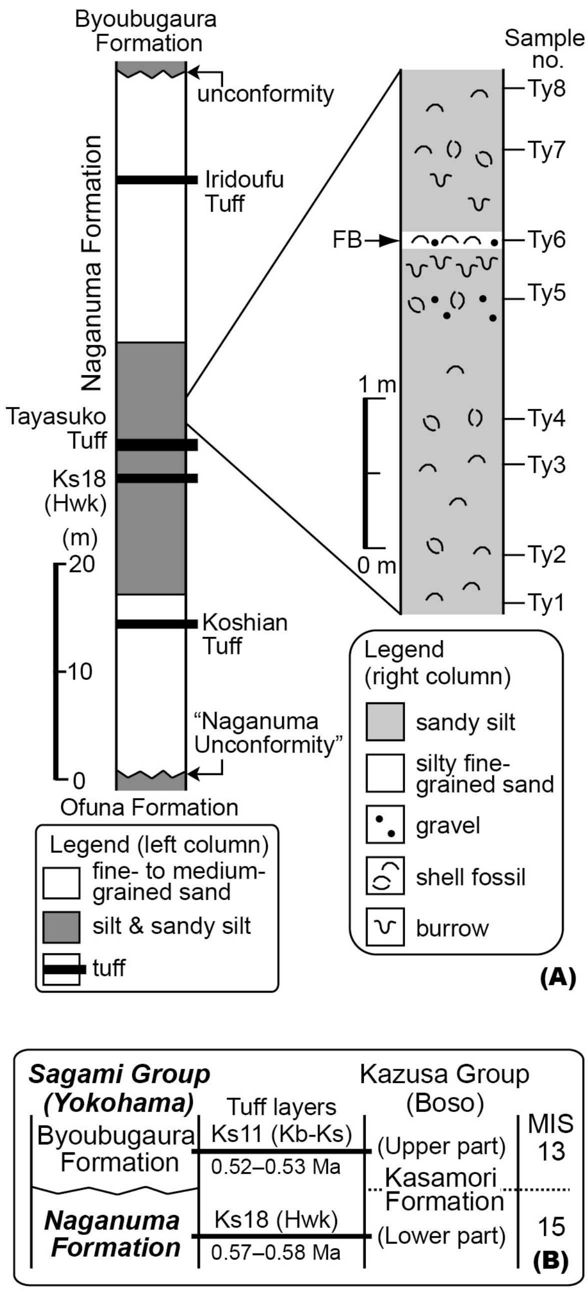

Fig. 2 (A) A columnar section of the Naganuma Formation with sample horizons, modified from Osada *et al.* (1982) and Ozawa (2009). FB: dominant occurrences of fragments of barnacles. (B) Schematic stratigraphic correlation for the Naganuma, Byoubugaura and Kasamori formations between Yokohama and Boso areas. Data for tuff layers in (A) and (B) referred from Mitsuoka *et al.* (1977), Mitsunashi and Kikuchi (1982), Osada *et al.* (1982), Machida and Arai (2003), and Machida (2010). MIS (Marine oxygen Isotope Stage) nos. are referred from Machida (2010).

3. Materials and methods

We used the modern analog technique (MAT) to analyze the Naganuma Formation fossil ostracod assemblage dataset found in Table 1 of Ozawa (2009). Ozawa (2009) described fossil ostracod assemblages from eight sediment samples (Ty1–Ty8) collected from the Naganuma Formation outcrop, which is exposed in the Taya area of Sakae-ku, Yokohama City, Kanagawa Prefecture, central Japan (latitude: 35º 21.77' N, longitude: 139º 31.42' E; Figs. 1 and 2). Then a total of 58 ostracod species were identified.

The MAT is a method for estimating paleoenvironmental conditions, such as the water depth and temperature, by comparing similar recent environmental data to fossil assemblages (Overpeck *et al.*, 1985). The degree of nonsimilarity between objective fossil assemblages and recent assemblages is determined by the formula as follows;

$$\mathrm{SCD} = \sum_{i=1}^{n} (\mathrm{Fpi}^{1/2} - \mathrm{Mpi}^{1/2})^2$$

(SCD: square chord distance; Fpi: proportion of the i-th fossil species; Mpi: proportion of the i-th modern species). Ikeya and Cronin (1993) first employed MAT to fossil ostracod assemblages in order to estimate Pliocene and Pleistocene paleoenvironments of Japan, based on 273 recent samples from Japan and adjacent areas. In the current study, we summarized data from 419 recent samples (including 367 species) from Japan and adjacent areas (Zhou, 1993; Tsukawaki *et al.*, 1997, 1998, 1999, 2000; Yamane, 1998, Ozawa *et al.*, 1999; Yasuhara and Irizuki, 2001; Nakao and Tsukagoshi, 2002; Irizuki *et al.*, 2006; Tanaka, 2008) using the modern analog data matrix of the United States Geological Survey (Ikeya and Cronin, 1993). Squared-chord distances (SCDs) were computed using Microsoft Excel 2007 in the Visual Basics for Applications (VBA) environment, following methods described by Tanaka and Nomura (2009).

The SCD is a value between 0 and 2. When the SCD is 0, the objective fossil assemblage is completely concordant with recent assemblages. To obtain the minimum and maximum bottom water temperatures for each recent ostracod sample, temperatures for the sites used in our study were obtained from the sectioned squares of the Japan Oceanographic Data Center (JODC) database within one degree of latitude and longitude (JODC, 2017; http://www.jodc.go.jp/jodcweb/index_j.html). We estimated paleo-water temperatures in both summer and winter at paleo-water depths for eight Naganuma Formation samples described by Ozawa (2009).

4. Results

The MAT results for changes in the paleo-water depth and temperature in summer and winter based on the ostracod assemblage dateset from the Naganuma

Table 1 Results of modern analog area based on the MAT (modern analog technique) for each fossil ostracod sample from the Naganuma Formation. From left to right: sample number from Ozawa (2009); estimated water depth (WD); summer bottom water temperature (SBT); winter bottom water temperature (WBT); square chord distance (SCD); longitude (Long.) and latitude (Lat.) of the most similar modern site in terms of the ostracod assemblage; reference for the recent ostracod assemblage of a modern analog area. N: northern; C.: central; SW: southwestern.

Sample no.	WD (m)	SBT (℃)	WBT (℃)	SCD	Long. (ºN)	Lat. (ºE)	Modern analog area	Reference
Ty1	41	16.0	11.0	1.06	127.09	34.16	N East China Sea	Choe (1985)
Ty2	25	28.4	6.3	0.87	133.25	34.13	C. Setonaikai Sea	Yamane (1998)
Ty3	25	28.4	6.3	0.71	133.25	34.13	C. Setonaikai Sea	Yamane (1998)
Ty4	35	30.6	10.3	1.22	131.37	34.43	SW Sea of Japan	Tsukawaki *et al.* (2000)
Ty5	25	28.4	6.3	0.81	133.25	34.13	C. Setonaikai Sea	Yamane (1998)
Ty6	31	28.4	6.3	0.89	133.20	34.08	C. Setonaikai Sea	Yamane (1998)
Ty7	31	28.4	6.3	0.72	133.20	34.08	C. Setonaikai Sea	Yamane (1998)
Ty8	25	28.4	6.3	0.58	133.25	34.13	C. Setonaikai Sea	Yamane (1998)

Table 2 MAT (modern analog technique) method results (SCD analysis; SCD means square chord distance) for the three ostracod assemblages (A–C) from the Naganuma Formation (Ozawa, 2009). From left to right: assemblage names; five dominant species from Ozawa (2009); assemblage (Ass.); estimated water depth (WD) range; summer bottom water temperature (SBT) range; winter bottom temperature (WBT) range; square chord distance (SCD) range; modern analog area based on the modern analog technique (MAT). C.: central; SW: southwestern; N: northern.

Ass.	Five dominant species	WD range (m)	SBT range (°C)	WBT range (°C)	SCD range	Modern analog areas
A	*Krithe japonica* *Amphileberis nipponica* *Buntonia hanaii* *Bicornucythere bisanensis* *Krithe surugensis*	25–41	16.0–30.6	6.3–11.0	0.71–1.22	C. Setonaikai Sea SW Sea of Japan, N East China Sea
B	*Amphileberis nipponica* *Bicornucythere bisanensis* *Nipponocythere bicarinata* *Krithe japonica* *Loxoconcha tosaensis*	25–31	28.4	6.3	0.72–0.81	C. Setonaikai Sea
C	*Bicornucythere bisanensis* *Amphileberis nipponica* *Trachyleberis scabrocuneata* *Loxoconcha tosaensis* *Nipponocythere bicarinata*	25	28.4	6.3	0.58	C. Setonaikai Sea

Formation (Ozawa, 2009) are shown in Table 1 and Fig. 3. Species compositions of fossil ostracod assemblages from eight Naganuma Formation samples are similar to modern assemblages found in present-day shallow seas surrounding southwestern Japanese Islands, such as the central Setonaikai Sea (Hiuchinada Sea), the southwestern Sea of Japan, and the northern East China Sea (Tables 1 and 2).

Our results suggest that paleo-water depths fluctuated between 25 and 41 m (Fig. 3; Table 1). These water depths are slightly shallower for Ty1 through Ty8 (41–25 m). The paleo-water temperatures in summer are estimated to be approximately 16ºC for the one lower horizons (Ty1), and 28–31ºC for the seven upper horizons (Ty2–Ty8). Winter paleo-water temperatures are estimated to be approximately 10–11ºC for the two lower horizons (Ty1 and Ty4) and 6ºC for the six upper horizons (Ty2, Ty3 and Ty5–Ty8).

Our results showing a realtively wide SCD range (0.71–1.22; Fig. 3 and Table 2) suggest that the modern analog areas of the assemblage A of Ozawa (2009) are the central Setonaikai Sea (Hiuchinada Sea), the southwestern Sea of Japan, and the northern East China Sea, from longitudes 127–134ºE and latitudes 34–36ºN and at water depths ranging from 25–41 m. The modern analog area for the assemblage B is the central Setonaikai Sea (Hiuchinada

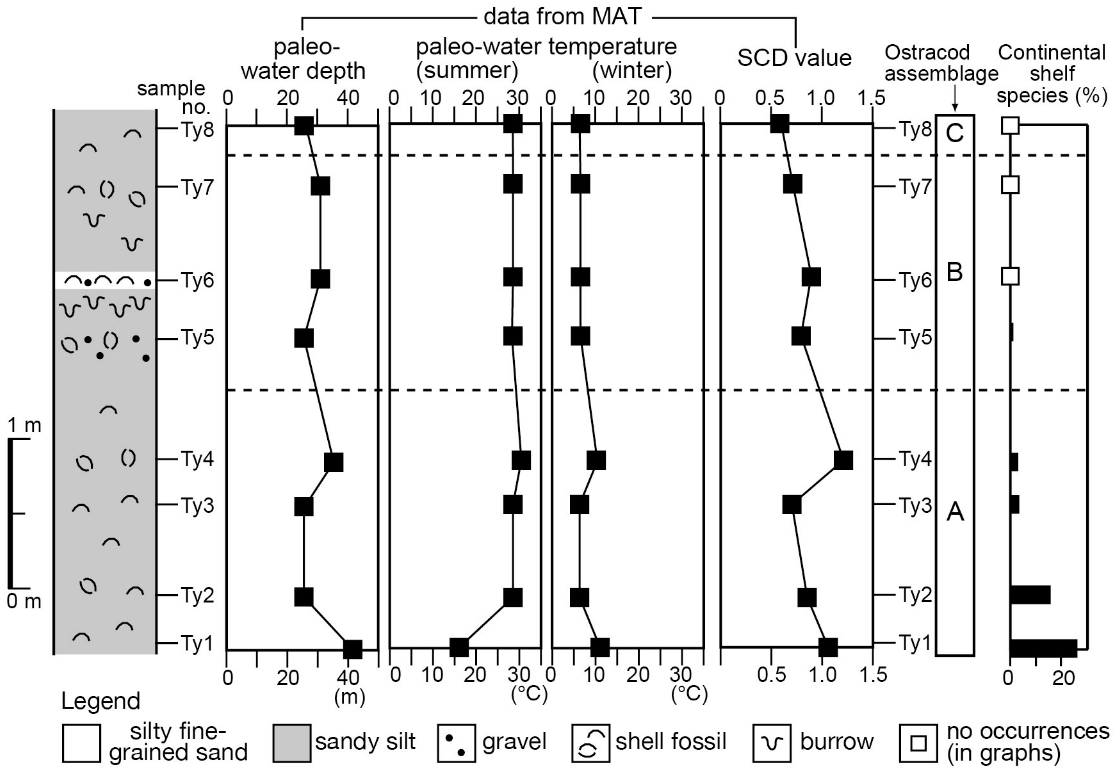

Fig. 3 Vertical changes in results from the MAT (modern analog technique) method (SCD analysis; SCD means square chord distance) for each sample in the Naganuma Formation within a columnar section, with sample horizons. Ostracod assemblages A–C and Continental shelf species are the same as in Ozawa (2009). Data for appearance horizons of the assemblages A–C and percentages for Continental shelf species are referred from Ozawa (2009). Continental shelf species: *Abrocythereis guangdongensis*, *Actinocythereis kisarazuensis*, *Bradleya japonica*, *Bradleya* sp., *Hirsutocythere? hanaii*, *Krithe surugensis* and *Loxoconcha tamakazura*. Columnar section is modified from Ozawa (2009).

Sea) from longitudes 133–134ºE and latitudes 34–35ºN at water depths of 25–31 m, as evidenced by a realtively low SCD range (0.72–0.81). The modern analog area of the assemblage C has the lowest SCD score (0.58), and it is also the central Setonaikai Sea (Hiuchinada Sea) at longitude 133ºE and latitude 34ºN at a water depth of 25 m.

5. Discussion

5. 1 Paleo-water depth

The paleo-water depth of the Naganuma Formation was reconstructed by several previous studies of molluscan fossils. Osada *et al.* (1982) reported the detailed species composition of the molluscan fossils from the two upper horizons above the Tayasuko tuff layer at the same location as the current study. They recognized one molluscan fossil assemblage, which was dominated by *Acila divaricata* (Hinds) in the two horizons, and reported that the paleoenvironment in their lower horizon (near sample Ty1 of Ozawa (2009)) was the inner bay area influenced by the open sea with 20–60 m water depths. They estimated that the water depth of their upper horizon (near sample Ty6 of Ozawa (2009)), was slightly shallower than that of the lower horizon.

The three steps of the water-depth decrease during the depositional periods of the horizons Ty1–Ty8 were defined from the ostracod assemblages A–C (Fig. 3), which include dominantly *Amphileberis nipponica*, *Bicornucythere bisanenesis* and *Krithe japonica* (Fig. 4; Table2) by Ozawa (2009). That study stated that the water depth decreased upwards in the studied sequence from around 40 m water depth to 10–15 m water depths, and that the influence of the open-sea water was weaker during depositional periods of the upper six horizons of Ty3–Ty8, compared with the lower two horizons Ty1–Ty2, based on the ratio of continental species of Ozawa (2009); i.e., *Abrocythereis guangdongensis*, *Actinocythereis kisarazuensis*, *Bradleya japonica*, *Bradleya* sp., *Hirsutocythere? hanaii*, *Krithe surugensis* and *Loxoconcha tamakazura* (Figs. 3 and 4). These species are reported from modern continental shelf area around Japan (e.g. Ikeya and Suzuki, 1992; Zhou and Ikeya, 1992; Zhou, 1995; Tsukawaki *et al.*, 1998, 2000; Tanaka, 2008, 2012).

Therefore paleo-water depths reconstructed from MAT

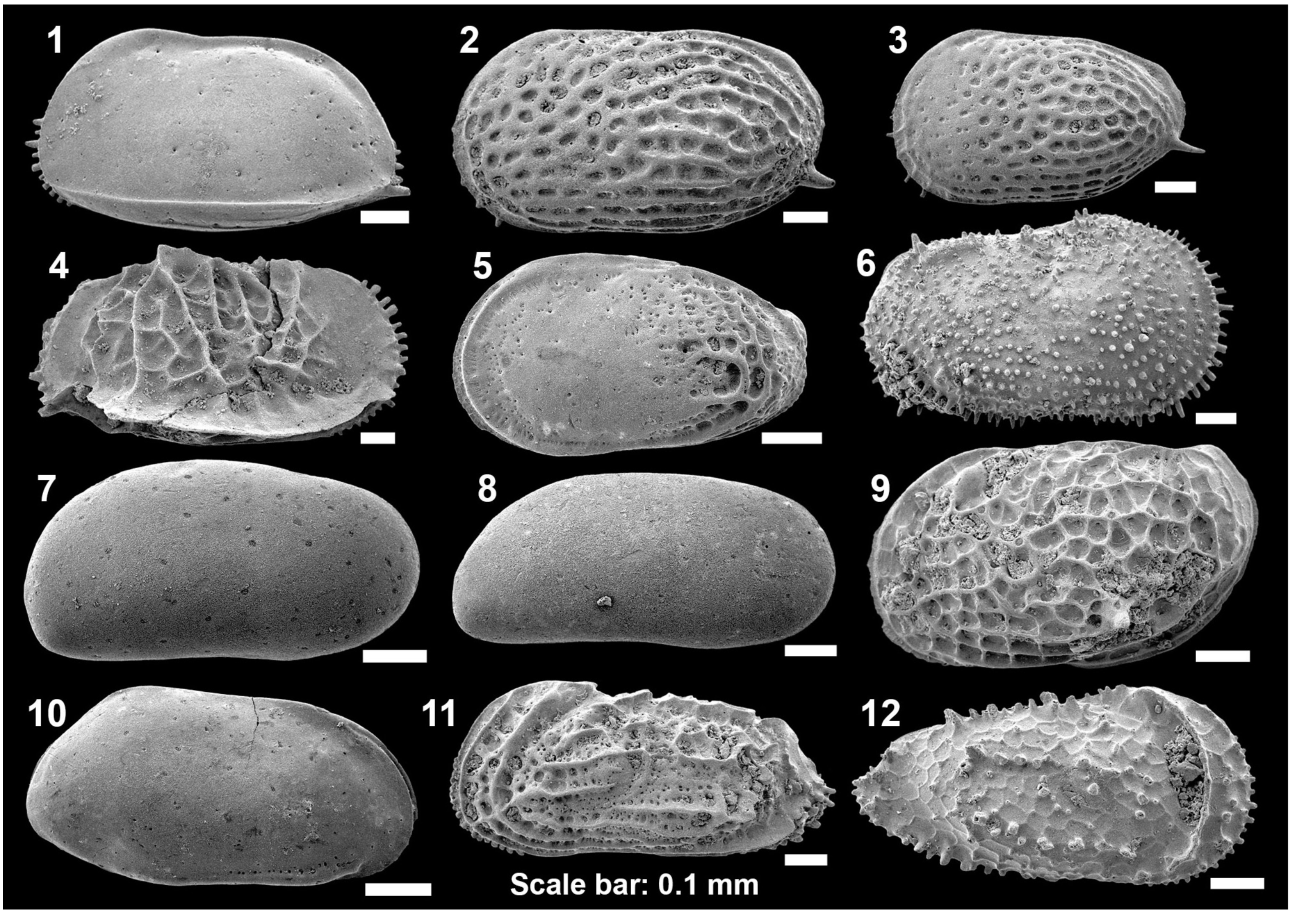

Fig. 4 SEM images of fossil ostracods from the Naganuma Formation, modified from Ozawa (2009). LV: left valve, RV: right valve, CA: carapace. **1**: *Amphileberis nipponica* (Yajima), male LV, sample no. Ty6, **2–3**: *Bicornucythere bisanensis* (Okubo), **2**: female LV, Ty7, **3**: A-1 juvenile LV, Ty1, **4**: *Bradleya japonica* Benson, female RV, Ty1, **5**: *Buntonia hanaii* Yajima, male LV, Ty3, **6**: *Hirsutocythere? hanaii* Ishizaki, A-1 juvenile RV, Ty5, **7**: *Krithe japonica* Ishizaki, female RV, Ty6, **8**: *Krithe surugensis* Zhou and Ikeya, male RV, Ty7, **9**: *Loxoconcha tosaensis* Ishizaki, male LV, Ty7, **10**: *Nipponocythere bicarinata* (Brady), male RV, Ty6, **11**: *Sinoleberis tosaensis* (Ishizaki), female CA left side, Ty5., **12**: *Trachyleberis scabrocuneata* (Brady), A-1 juvenile RV, Ty5. All scale bars are equal to 0.1 mm.

in our study (Fig. 3; Tables 1 and 2) are mostly consistent with results from previous molluscan and ostracod studies.

5. 2 Paleo-water temperature

The SCD scores (0.58–1.22) for paleotempeartures based on ostracods and the MAT were fairly high (Fig. 3; Tables 1 and 2). Ikeya and Cronin (1993) demonstrated that a SCD value below 0.5 indicates analogs at a faunal provincial level, although we could obtain only these SCD scores herein. However we had tried to attempt to compare paleotemperatures to average modern data, including the minimum and maximum water temperature in and around Sagami Bay (Table 3), in an effort to reconstruct the Japanese paleoenvironment from 0.6 Ma, because this study reported for the first time fluctuations in paleo-water temperature estimates quantitatively during the MIS 15 along coastal Japan.

We compared the estimated Naganuma Formation paleotemperatures (Figs. 3 and 5; Tables 1 and 2) to modern water temperatures in and around Sagami Bay, located within latitude 35–36˚N and longitude 139–140˚E (Table 3). We utilized data for this region from Japan Oceanographic Data Center (2017)'s website (http://www.jodc.go.jp/jodcweb/JDOSS/index_j.html), as this is the area closest to the Naganuma Formation sampling site. Modern water temperatures are presented as averages with maximum and minimum values for 97 years between 1906 and 2003. Data are given for latitude 35–36˚N and longitude 139–140˚E (within one degree of latitude and longitude for a given site) at water depths of 20, 30, and 50 m in summer (August) and winter (February) (Table 3). The water depths are not the same as the estimated paleo-water depths, so comparisons were made between similar water depths. For example, a paleo-water depth of

Table 3 Modern average, maximum, and minimum water temperatures from 1906 to 2003 for latitude 35–36˚N and longitude 139–140˚E (within one degree of latitude and longitude for a given site) at three water depths (20, 30, and 50 m) in summer (August) and winter (February). From the J-DOSS database of Japan Oceanographic Data Center (2017).

Water	Summer temperature (°C)			Winter temperature (°C)		
depth (m)	average	maximum	minimum	average	maximum	minimum
20	21.6	26.6	15.5	13.9	17.5	8.6
30	20.0	26.1	14.0	14.4	17.4	10.9
50	17.5	23.2	12.7	14.5	17.3	11.5

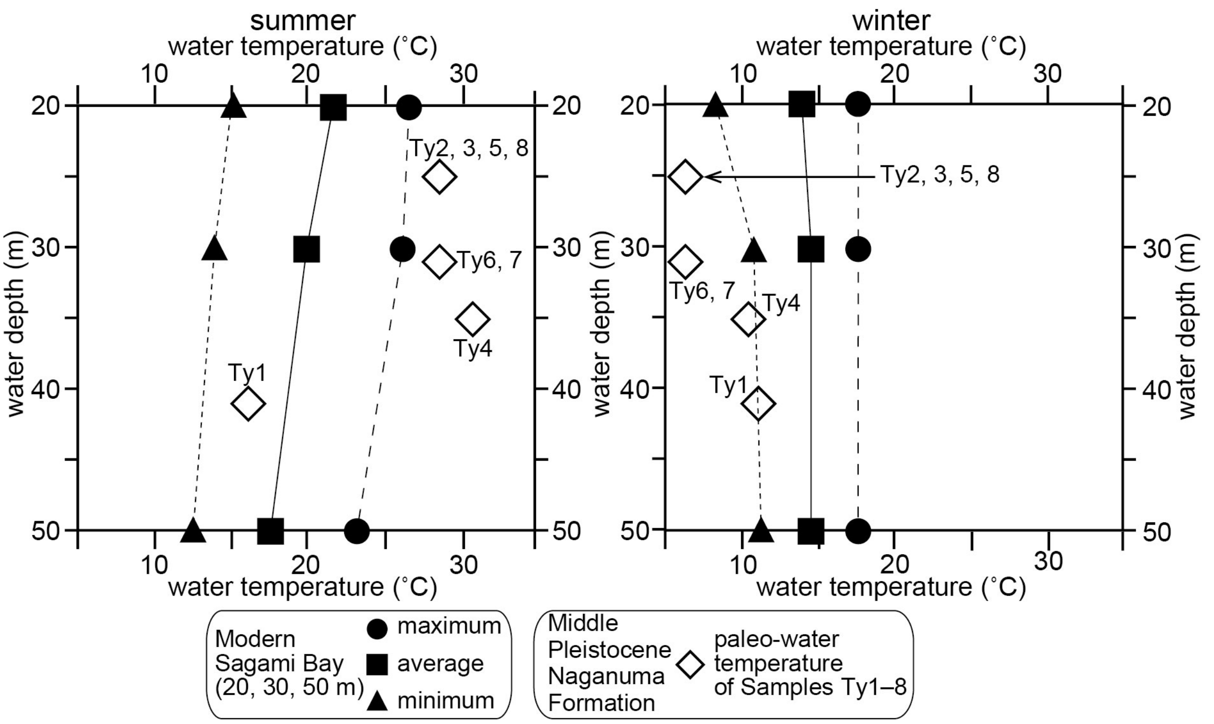

Fig. 5 Results for the paleo-water depth and water tempearature in summer and winter from the MAT (modern analog technique) method (SCD analysis; SCD means square chord distance) for each sample in the Naganuma Formation, and modern average, maximum, and minimum water temperatures from 1906 to 2003 for latitude 35–36˚N and longitude 139–140˚E (within one degree of latitude and longitude for a given site) at three water depths (20, 30, and 50 m) in summer (August) and winter (February). Data of the modern water temperature are referred from the J-DOSS database of Japan Oceanographic Data Center (2017).

31 m was compared to average values at the 30 m depth in modern seas.

Results from these comparisons suggest that estimated paleo-water temperatures at depths of 25–35 m (16–31℃; Fig. 5, Tables 1 and 2) were slightly higher than those in and around the present-day Sagami Bay (ca. 18–22℃ of 20–50 m; Fig. 5; Table 2) in summer for seven of eight samples. For the assemblage A samples (Ozawa, 2009), the summer estimated temperatures at 25 m and 35 m for three samples (28.4℃ for samples Ty2 and Ty4, and 30.6℃ for Ty3, respectively; Fig. 5; Table 2) were 7–10℃ higher than present-day average temperatures at depths of 20 m and 30 m (21.6℃ and 20.0℃; Fig. 5; Table 3). These estimated temperatures are approximately 2–4℃ higher than the modern maximum temperatures in this region (26.6℃ and 26.1℃). Estimated summer temperatures at depths of 41 m for another sample in the assemblage A (16.0℃ for Ty1) were 2–4℃ lower than the modern average temperatures at 30 and 50 m in Sagami Bay (17.5℃ and 20.0℃). This value is also 2–3℃ higher than modern minimum temperatures in this area (12.7℃ and 14.0℃). Estimated summer temperatures of the assemblages B and C at 25 m and 31 m (28.4℃ for Ty5–Ty8) were 7–8℃ higher than average temperatures at 20 m and 30 m (20.0℃ and 21.6℃; Table 3), and are 2℃ higher than recent maximum Sagami Bay temperatures (26.1℃ and 26.6℃).

Estimated winter water temperatures (6–11℃) were lower than recent Sagami Bay water temperatures at depths of 20–50 m (14–15℃; Fig. 5; Table 2) for all samples. Estimated winter temperatures of the assemblage A at 25 m, 35 m, and 41 m (6.3℃ for Ty2 and Ty3, 10.3℃ for Ty4, 11.0℃ for Ty1) were 4–8℃ lower than recent average temperatures at 20 m, 30 m, and 50 m (13.9℃, 14.4℃, and 14.5℃, respectively; Table 3), and 1–2℃ lower than modern minimum temperatures (8.6℃, 10.9℃, and 11.5℃, respectively). Estimated temperatures of the assemblages B and C at 25 m and 31 m (6.3℃ for Ty5–8) were 8℃ lower than average temperatures at depths of 20 m and 30 m (13.9℃ and 14.4℃, respectively), and were 2–5℃ lower than modern minimum temperatures in and around Sagami Bay (8.6℃ and 10.9℃).

The estimated summer water temperature for depths of 25–35 m was slightly higher (~2℃) than that in present-day Sagami Bay at depths of 20–30 m, although the estimated summer temperature at 41 m depths was similar to or slightly lower (~3℃) than current temperatures at 30–50 m depths (Fig. 5). The estimated winter temperatures were slightly lower (~2℃) than those recorded recently in Sagami Bay at depths of 30–50 m.

The ostracod species *Sinoleberis tosaensis* (Fig. 4) was found in assmblage B of the Naganuma Formation (Ozawa, 2009). This shallow-marine species has been mainly found along the Pacific coast of southwestern Japan (south of 35ºN) from Lake Hamana of Honshu Island to Uranouchi Bay of Shikoku Island (water depths of less than 15 m, and in the Taiwan Strait of the southern East China Sea (Ishizaki, 1968; Malz and Ikeya, 1982). This species is not found around modern Tokyo Bay (e.g. Frydl, 1982; Zhou, 1995). *S. tosaensis* fossils are found in Pliocene deposits in southwestern Taiwan along the coast of the northern South China Sea and in Plio-Pleistocene deposits in Taiwan and Japan along the Pacific Ocean coasts (Malz and Ikeya, 1982). Modern-day and fossil distributions of this species suggest that it favors warm envinronments influenced by warm Kuroshio Current along the Pacific Ocean coast (Ozawa, 2009). Therefore, the presence of this species in the Naganuma Formation might suggest that paleo-water temperatures in shallow marine areas were slightly higher 0.6 Ma compared to those in the present-day Sagami Bay, especially in summer.

5. 3 Comparison with results of Ozawa (2009)

Based on the species compositions of three ostracod fossil assemblages from the Naganuma Formation, as determined through Q-mode cluster analysis, Ozawa (2009) described three types of paleoenvironments with three stepwise changes during the depositional period of the horizons Ty1–Ty8; i.e., the outer bay (assemblage A), central bay (assemblage B), and inner bay (assemblage C) (Fig. 3; Table 2). In our MAT analysis, the species composition of the fossil assemblages B and C, described by Ozawa (2009), is most similar to the assemblages from the modern area of the Setonaikai Sea (Hiuchinada Sea) (Tables 1, 2 and 4). The fossil assemblage A is correlated with the three modern assemblages from three different areas; i.e., the Setonaikai Sea, Sea of Japan, and East China Sea (Tables 1, 2 and 4). Fossil assemblages from six samples (Ty2, Ty3, and Ty5–Ty8) out of a total of eight samples collected from the Naganuma Formation are most similar to those from the modern Setonaikai Sea (Hiuchinada Sea) (Tables 2 and 4). Ozawa (2009) identified the paleoenvironment of the assemblage A as the outer bay area. The SCD scores for two (Ty1 and Ty4) out of four samples of the assemblage A have the highest range in our study, ca. 1.1–1.2 (Fig. 3; Tables 1 and 4). Thus, our results reflect the utility of relatively small datasets for MAT analysis by including assemblages from just four localities in outer bay areas of the Setonaikai Sea (Hiuchinada Sea).

Comparing the results of Ozawa (2009) with those from our MAT study (Table 4), their paleoenvironments align well with bay areas, with the assemblage A as outer bay (samples Ty1 and Ty4) and B as central bay (Ty5–Ty7), and differ slightly for the assemblages A (Ty2 and Ty3) and C (Ty8). The SCD scores of these three samples (Ty2, Ty3 and Ty8) were greater than 0.5; i.e., 0.6–0.9 (Fig. 3; Tables 1 and 4). Therefore, our data may not yet support a detailed comparison between paleoenvironments and modern sea environments around Japan, especially for these three samples. On the other hand, Ozawa (2009) might have regarded the percentages of *Amphileberis nipponica* and *Loxoconcha tosaensis*, which are often reported from outer and central bay areas (e.g. Yamane, 1998; Tsukawaki *et al.*, 2000), in assemblages A (Ty2, Ty3) and C (Ty8; Table 4) as more important in paleoenvironments. However, our MAT results show a similar tendency with regard to paleoenvironmental fluctuations to those reported by Ozawa (2009), with the water depth decreasing upwards in this sequence from around 40 m to 20 m, and a weaker influence from open-sea water in the upper horizons, as compared to the lower horizons.

5. 4 Paleoenvironment of 0.6 Ma in and around Japan

Several recent studies of other microfossils were used to generate new details of the Japanese paleoenvironment around 0.6 Ma. Radiolarian fossils from 0.74 Ma were present in a drill core that was obtained from the bottom of the sea at a depth of 1,200 m from east of the Shimokita Peninsula in northeastern Japan (Matsuzaki *et al.*, 2014). This study determined that the influenece of the warm Tsugaru Current (a branch of the Tsushima and Kuroshio Currents) significantly increased from 0.62 Ma to 0.48 Ma (from MIS 15 to MIS 13). Based on the fossil radiolarian assemblages, researchers estimated that sea surface water temperatures 0.6 Ma were slightly higher than modern-day temperatures off the Shimokita Peninsula. They hypothesized that warm Kuroshio Current, which flows along the northwest margin of the Pacific Ocean near the Japanese Islands, became more influential for central and southwestern Japan during this time.

Table 4 Comparisons for MAT (modern analog technique) method results (SCD analysis; SCD means square chord distance) for the three ostracod assemblages (A–C) from the Naganuma Formation (Ozawa, 2009). From left to right: sample no., modern analog area (outer bay and central bay are referred from Choe, 1985; Yamane, 1998, Tsukawaki *et al.*, 2000) and square chord distance (SCD) based on the modern analog technique (MAT), paleoenvironment and assemblage names of Ozawa (2009). C.: central; SW: southwestern; N: northern.

	This study		Ozawa (2009)	
Sample no.	Modern analog area	SCD	paleoenvironment	assemblages
Ty1	N East China Sea (outer bay)	1.06	outer bay	A
Ty2	C. Setonaikai Sea (central bay)	0.87	outer bay	A
Ty3	C. Setonaikai Sea (central bay)	0.71	outer bay	A
Ty4	SW Sea of Japan (outer bay)	1.22	outer bay	A
Ty5	C. Setonaikai Sea (central bay)	0.81	central bay	B
Ty6	C. Setonaikai Sea (central bay)	0.89	central bay	B
Ty7	C. Setonaikai Sea (central bay)	0.72	central bay	B
Ty8	C. Setonaikai Sea (central bay)	0.58	inner bay	C

Compared to estimates from radioralian and ostracod studies, Japanese Middle Pleistocene pollen studies (Hongo, 2009; Hongo and Mizuno, 2009; Nirei, 2017) differed in paleoclimate estimations for present-day central Japan. Based on the assemblages of the dominant genera *Cryptomeria* and *Fagus* in boring core samples from inland areas near Tokyo and Osaka bays, results from the pollen studies determined that the paleo-air temperatures in inland areas of the Kanto and Osaka plains during MIS 15 were slightly lower than present-day temperatures.

Results from the current study and other micropaleontological studies of 0.6 Ma demonstrate evidence of both warmer and cooler paleotemperatures compared to present temperatures among inland, coastal, and offshore regions of Japan. The SCD scores from our ostracod MAT analysis were relatively high (Fig. 3; Tables 1 and 2). So yet, our study could not address a detailed comparison of paleotemperatures and modern-day sea water temperatures.

The paleotemperatures of the Northwest Pacific margin of the Japanese Islands during the MPT remain unknown. Research on paleoclimates in marine and inland regions during the MPT will clarify changes related to glacioeustacy in both the paleoenvironment and in invertebrate faunas in shallow marine regions along the Northwest Pacific margin. Further paleoenvironmental research on the Middle Pleistocene is needed in Japan and adjacent regions.

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相模層群長沼層（中部更新統）産の介形虫化石群に基づく古環境解析

小沢広和・田中源吾

要　旨

本研究は，神奈川県に分布する相模層群長沼層産の海生介形虫化石群に基づき，海洋酸素同位体ステージ15（MIS 15）の約60万年前の古環境（水深，水温）を現生アナログ法（MAT）を用いて推定した．その結果，長沼層の古環境は，現在の瀬戸内海などの西南日本沿岸の水深25～41 mの海域に，最も類似することが明らかになった．これらの西南日本沿岸域の水温値（夏：16～28℃，冬：6～11℃）を，現在の相模湾の水温データと比較したところ，夏の水温は水深30 m以浅では少なくとも2℃ほど高いが，40 m付近では現在とほぼ同じか2℃ほど低く，冬の水温は40 m以浅で少なくとも2℃ほど低いことが明らかになった．本研究は約60万年前（MIS 15）の日本列島沿岸浅海域における古水温の変動を，定量的に推定した初の研究例である．