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Late Pliocene–early Pleistocene paleoceanographic evolution of the Sea of Japan

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Abstract

The stratigraphic distribution and abundance of molluscs and planktonic foraminifera within a sixth-order (41 kyr) depositional sequence of the early Pleistocene Omma Formation in central Japan provide several important information on the Sea of Japan since 2.5 Ma. The sea possibly experienced three substages in the paleoceanographic history since then. During substage I (2.5–1.71 Ma, oxygen isotope stage 60/59), cold northern surface water prevailed due to the closure of the sea's southern entrance. During substage II (1.71–1.52 Ma, stage 51), the warm Tsushima Current flowed into the sea from the south during interglacial highstands. During substage III (1.52–0 Ma), isolation of the Sea of Japan was reinforced by narrowing and/or shallowing of the northern entrance. These changes were caused by some local tectonic movements that affected topography of the southern and northern straits. Inflow of the Tsushima Current resulted in migration of warm-water organisms into the Sea of Japan during interglacial stages, and acted as a barrier to the migration of terrestrial organisms between East Asia and Japanese Islands. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Sea of Japan; Tsushima current; Early Pleistocene; Late Pliocene; Planktonic foraminifera; Molluscs; Depositional sequence

1. Introduction

The Sea of Japan is a semi-enclosed marginal sea with an area of approximately 1,000,000 km² and an average depth of 1350 m. It is connected to the East China Sea through the Tsushima Strait, to the Pacific Ocean through the Tsugaru Strait, and to the Sea of Okhotsk through the Soya and Mamiya Straits (Fig. 1). These straits are narrow and less than 130 m deep. The only current presently flowing into the Sea of Japan is the Tsushima Current. This current, a branch of the warm Kuroshio Current, enters the Sea of Japan

through Tsushima Strait and makes its way northward along the western coast of Honshu Island (Fig. 1). The Tsushima Current supplies a large quantity of heat, and also transports marine organisms, into the Sea of Japan. Moreover, the presence of the Tsushima Current implies that the terrestrial organisms of Japan have been isolated from those of mainland Asia for some time. Therefore, the current likely had a profound influence on Quaternary paleoclimates, ecosystems and organic evolution within and around the Sea of Japan (e.g. Yasuda, 1982; Oba et al., 1991; Dunbar et al., 1992; Tada, 1994; Kitamura et al., 1994, 1997, 2000b; Ishiwatari et al., 1999; Tada et al., 1999).

The history of the Tsushima Current is preserved in

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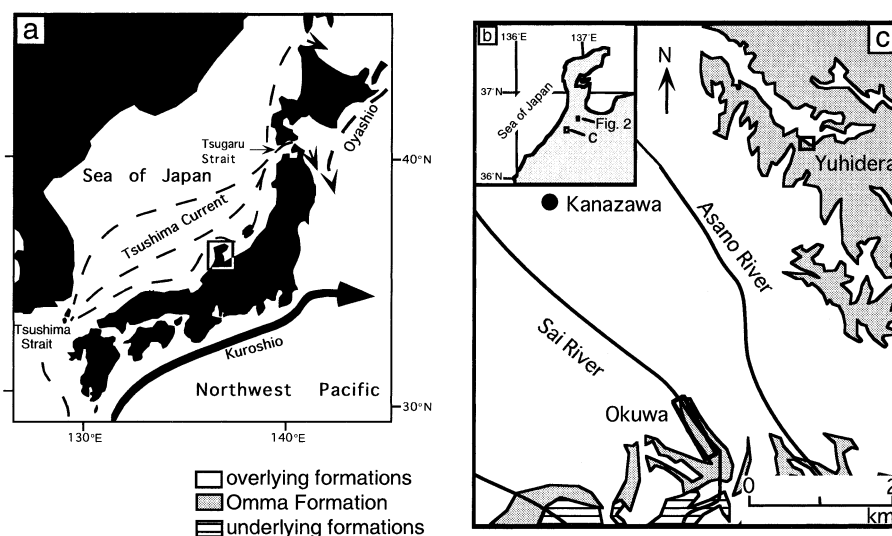


Fig. 1. Map of the Sea of Japan and geologic map of the Omma Formation around Kanazawa City, Central Japan, modified from Imai (1959).

the stratigraphic sequence of warm-water species that were influenced by the warm Kuroshio Current. Warm-water species entered the Sea of Japan along the Tsushima Current, and later were locally exterminated by the succeeding glacial period. Kitamura (1995, 1997) examined the stratigraphic distribution of warm-water molluscan species in the early Pleistocene Omma Formation. The formation is exposed around Kanazawa area, Hokuriku province on the Sea of Japan coast of central Japan. The middle and upper parts at its type section (the Okuwa section) are composed of sixth-order (41 kyr) depositional sequences (Figs. 1 and 2) (Kitamura et al., 1994). These sequences were deposited in inner- to outer-shelf environments and accumulated during oxygen isotope stages 50–25 (Fig. 2). The stratigraphic pattern of warm-water species over the past 1.5 myr has been studied on the basis of compiled fossil records from the Omma Formation, and from upper Quaternary sediments at ODP Site 797 in the Sea of Japan (Koizumi, 1992). The results suggest that the Tsushima Current flowed into the Sea of Japan at all interglacial stages from 49 to 1, except for stage 23. Recently, Arai et al. (1998) and Takata (2000) analyzed the stratigraphy and planktonic foraminiferal assemblages from the very latest Pliocene and early Pleistocene (prior to stage 49) in Hokuriku province. Arai et al. (1998) examined planktonic

foraminiferal assemblages in two sedimentary cycles of the late Pliocene Junicho Formation, in Toyama Prefecture. These cyclothem were deposited in an outer-shelf and resulted from glacio-eustatic sea-level changes during the Olduvai Subchron (Arai et al., 1991). Arai et al. (1998) found one individual of the warm-water planktonic foraminifera *Globigerinoides ruber* in each of two horizons in the upper portion of the lower cycle. In addition, Takata (2000) studied planktonic foraminiferal assemblages in five sixth-order (41 kyr) depositional sequences in the early Pleistocene Omma Formation, Toyama Prefecture (the Oyabe section) (Fig. 2): these sequences are numbered 1–5. The first-appearance datums of *Gephyrocapsa oceanica* and *Gephyrocapsa* (large) are in the middle portion of Cycle 2 and the base of Cycle 5, respectively (Fig. 2). The warm-water planktonic foraminifera *G. ruber* was recognized from Cycles 1, 2 and 3. Using the first appearance of *Gephyrocapsa* (large) as a datum, the Omma Formation in the Oyabe section can be correlated with the lower part of the formation at the Okuwa section. In consequence, the Junicho and Omma Formations record the most complete and undeformed shallow-marine late Pliocene–early Pleistocene history of the Sea of Japan. The accompanying faunas provide an excellent Plio-Pleistocene record of the Sea of Japan, especially of the Tsushima Current. In this study, we

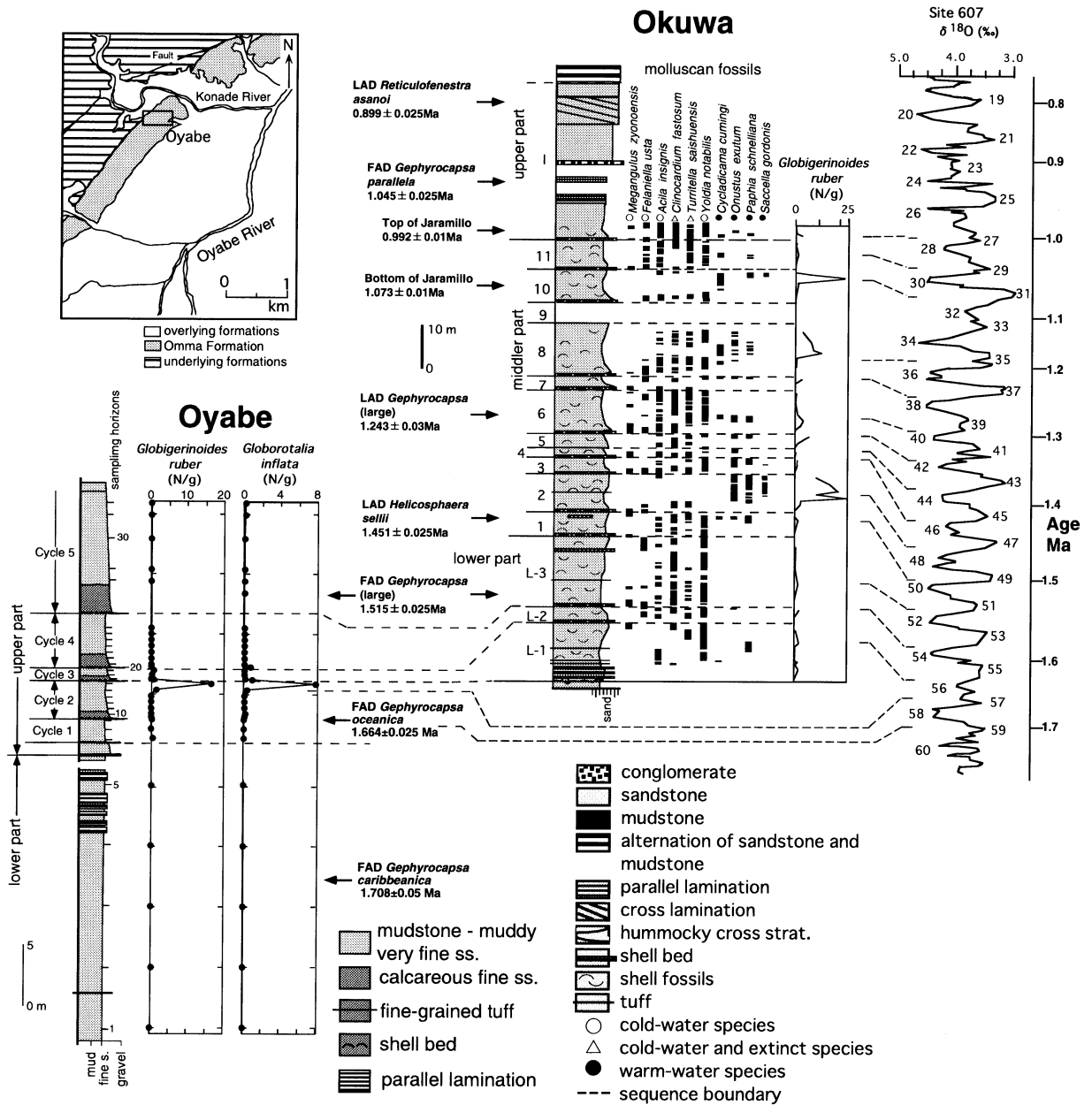


Fig. 2. Columnar sections of the Omma Formation at its type section and the Oyabe section. Biostratigraphic datum horizons are after Takayama et al. (1988), Sato and Takayama (1992) and Takata (2000); magnetostratigraphic data from Ohmura et al. (1989) and Kitamura et al. (1994); time scale for the oxygen isotope record at DSDP Site 607 and ages of biostratigraphic datum horizons and magnetic polarity changes are based on the chronology of Berger et al. (1994). L-1 to L-3, 1–11, I: depositional sequence numbers. Columnar section at the Oyabe area is after Takata (2000). Columnar 1–5: depositional sequence numbers. Geologic map of the Omma Formation around Oyabe is modified from Sumi et al. (1989).

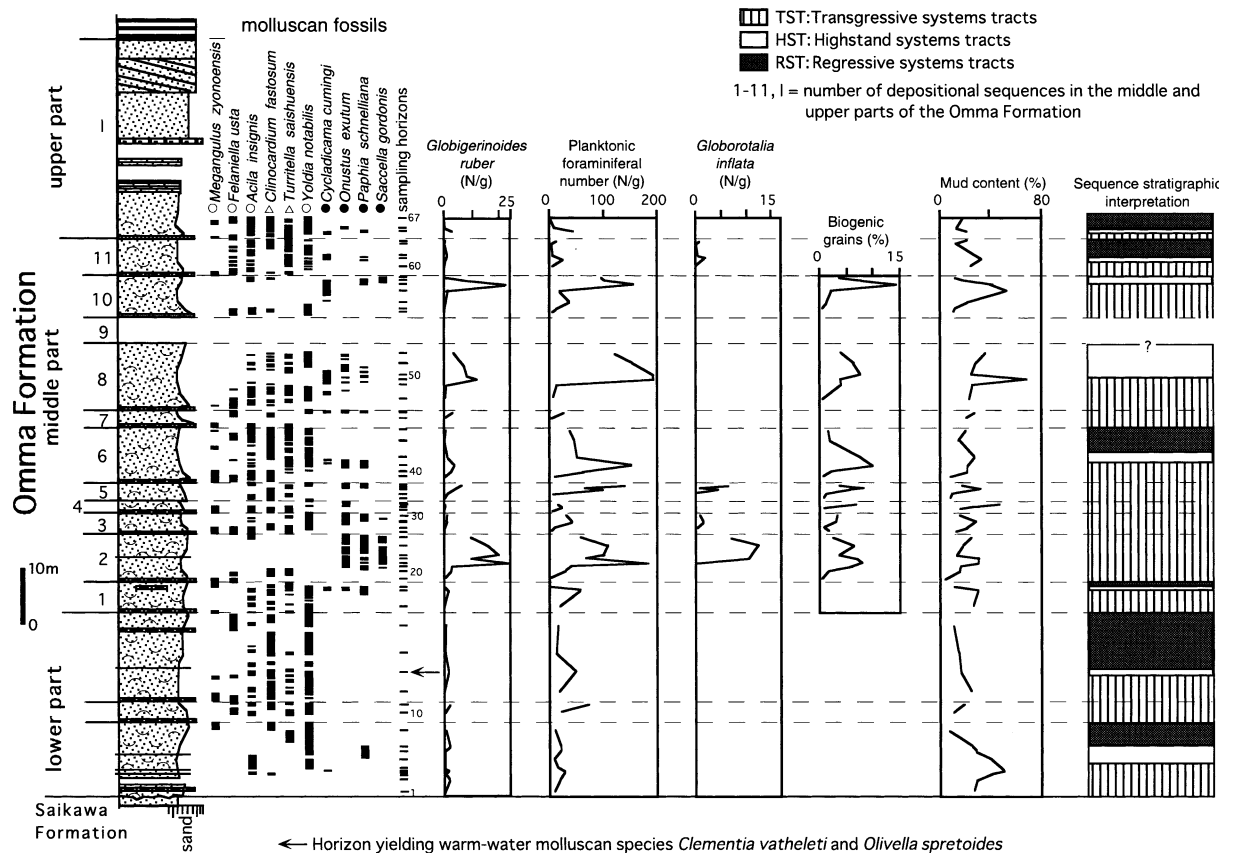


Fig. 3. Stratigraphic distribution of the planktonic foraminifera *G. ruber* (warm-water elements), *G. inflata*, biogenic grains and mud content in the Omma Formation at the Okuwa section.

examined the lithofacies and fossil record of the lower and middle parts of the Omma Formation in the vicinity of its type section at Okuwa, and we discuss the history of the Tsushima Current during late Pliocene to early Pleistocene based on our data and latest information.

2. Geological setting of Omma Formation depositional sequences

The Omma Formation at the Okuwa type section has been divided into lower, middle and upper parts, based on its litho- and biofacies (Kitamura and Kondo, 1990). Its middle part is composed of eleven sixth-order (41 kyr) depositional sequences that were deposited in inner- to outer-shelf depths during

oxygen isotope stages 50–28 (Figs. 2 and 3) (Kitamura et al., 1994). These sequences are numbered in ascending order 1–11. Three depositional sequences in the middle part of the formation are recognized in the Yuhidera area, which is 4 km northeast of Okuwa (Figs. 1 and 4). These sequences include the following elements, in ascending stratigraphic order: (1) a basal sequence boundary that is superposed on the ravinement surface; (2) a TST (2–5 m thick) consisting of a basal shell bed (0.3 m thick) (a condensed onlap shell bed) and overlying fine- to very-fine-grained sandstone; (3) a maximum flooding horizon that coincides with the horizon that has the maximum concentration of sand-size carbonate grains; (4) an HST (2–3 m thick) consisting of fine-grained sandstone and sandy siltstone; and (5) an RST (<1.0 m thick) comprised of a coarsening-upward

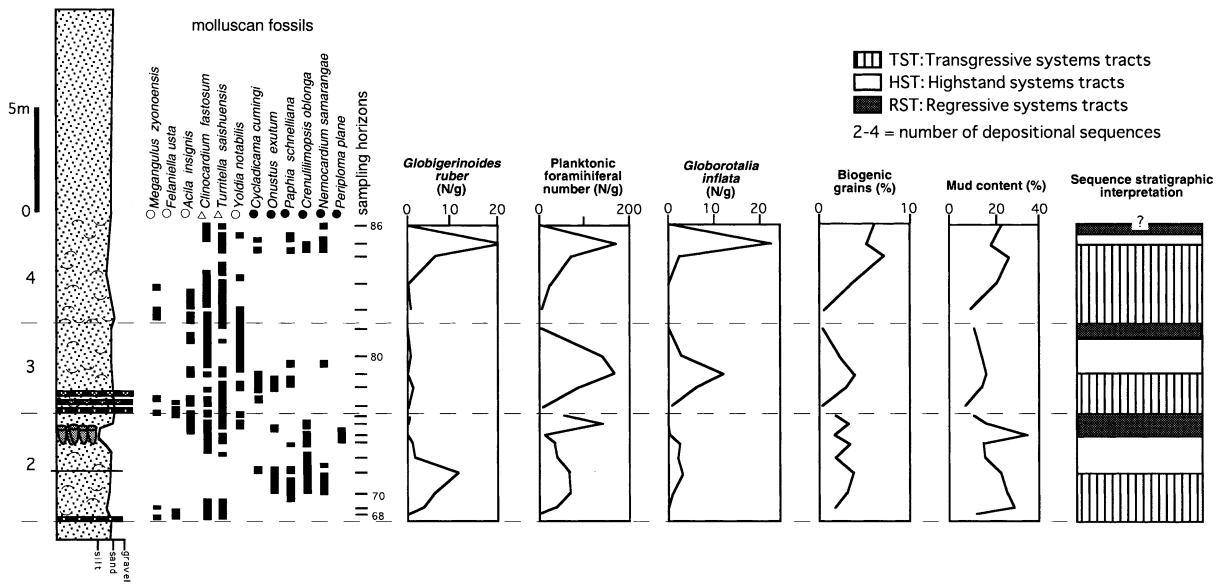


Fig. 4. Stratigraphic distribution of the planktonic foraminifera *G. ruber* (warm-water elements), *G. inflata*, biogenic grains and mud content in the Omma Formation at Yuhidera area.

fine-grained sandstone (Kitamura et al., 2000a). The boundary between the HST and RST has been defined as the last appearance datum of warm-water planktonic foraminifera. Based on the modern distribution of extant molluscan species, the sequence at Yuhidera is inferred to have been deposited in water a few tens of meters deeper than at Okuwa (Kitamura et al., 1997). As a result, preservation of the depositional sequences at Yuhidera is better than at Okuwa. For example, in the depositional sequences at Okuwa, the RST and even HST sediments have been obliterated by shoreface erosion at the superjacent sequence boundary (Figs. 3 and 4) (Kitamura et al., 2000a, 2001).

The 25 m thick lower part of the Omma Formation consists mainly of bluish-gray, fine- to very-fine-grained sandstone with abundant and well-preserved molluscs. The lower unconformity and the molluscan record of the basal part of the formation were recognized recently from new outcrops at the Okuwa section (Kitamura, 1997) (Fig. 3). The paleobathymetric change is estimated at 0–100 m, based on the distribution of living molluscan species (Kitamura, 1991a, 1997). Although two horizons with warm-water molluscs were recognized in the lower part of

the section (sampling horizons 6–8 and 13), systematic changes of lithofacies and molluscan assemblages did not develop in the lower part of the Omma Formation (Kitamura, 1991a).

3. Stratigraphic distribution of warm-water molluscs and planktonic foraminifera within depositional sequences of the Omma Formation

The inflow of the Tsushima Current was the principal factor which affected the stratigraphic distribution of warm-water molluscs within the Omma Formation, although water depth and erosion along an upper sequence boundary also influenced the presence of the molluscs (Kitamura et al., 2000a). According to Kitamura et al. (1999), the rate of change in the depth of the Tsushima Current at the initiation of inflow was 17 ± 9 m per 1000 years. This means that the greater the water depth on the continental shelf, the later was the migration of warm-water molluscs into the site. In addition, the maximum depth of the Tsushima Current during the formation of depositional sequence 2 (oxygen isotope stage 47) has been estimated to be 100 m (Kitamura et al., 1997).

This is because small volume of transport of the current due to the narrow and shallow Tsushima Strait. As a result, the stratigraphic distribution of warm-water molluscs constitutes a wedge within an individual depositional sequence, prior to any shore-face erosion during the subsequent transgression. In summary, even at times when the Tsushima Current flowed into the Sea of Japan, it was possible for warm-water molluscs to be absent from a given depositional sequence on the continental shelf, owing to the thinness of the current and to erosion at the superjacent boundary.

In contrast to molluscs, planktonic foraminifera are strongly controlled by sea water surface temperatures. In addition, foraminifera are short-lived and respond rapidly to environmental changes, in comparison with adult molluscs that are relatively long-lived and may lag behind changes. However, planktonic foraminifera are generally absent in coastal waters. Furthermore microfossils cannot be examined with the unaided eye in the outcrop. Therefore, planktonic and molluscan fossil analyses are complement to each other to reconstruct the history of the Tsushima Current from the shallow marine records.

4. Methods of study

The stratigraphic distribution and abundance of molluscs in the Omma Formation at both the Okuwa and Yuhidera sections have previously been analyzed (Kitamura, 1991a,b, 1997; Kitamura et al., 1994, 1997). The stratigraphic distribution and abundance of planktonic foraminifera in depositional sequence 2 at both sections have also previously been studied (Kitamura et al., 1997, 2000a). In depositional sequences II and III of the upper part of the Omma Formation, calcareous fossils occur in places in the former and do not in the latter (Kitamura et al., 1999, Fig. 2). The planktonic foraminifera studied here were recovered from 69 samples taken from intervals other than those in depositional sequences 2, II and III (Fig. 2). These samples were soaked in hot water for one hour and washed using a sieve with 125 μm diameter openings. The samples were subsequently split into aliquots containing about 200 specimens each. All planktonic foraminiferal specimens were picked and identified. Our defi-

nition of warm-water species follows that of Takemoto and Oda (1997). In addition, we re-examined lithofacies in the lower part of the Omma Formation at Okuwa.

5. Results

5.1. Planktonic foraminifera

Planktonic foraminifera were recovered from all but five of the 69 samples, and the dominant species are *Globigerina bulloides*, *G. quinqueloba* and *Neogloboquadrina pachyderma* (Appendix A). Warm-water taxa are dominated by *G. ruber*, along with a few individuals of *G. sacculifer*, *Orbulina universa* and *Pulleniatina obliquiloculata*. *G. ruber* seems to be the shallowest dwelling species and stay in surface waters during its life cycle (Fairbanks et al., 1982). In addition, among three species *G. ruber*, *G. sacculifer* and *O. universa* which temperature tolerances are known, the lower limit of *G. ruber* (19°C) is highest (*G. sacculifer* and *O. universa* are 14 and 12°C, respectively) (e.g. Hemleben et al., 1989). This means that *G. ruber* is most suitable for index of the warm Tsushima Current.

Within the depositional sequence in the middle part of the Omma Formation, warm taxa occur in the entire HST deposit and only in the upper part of the TST deposit (Figs. 3 and 4). Planktonic foraminiferal abundances range between 0 and 200/g, and change systematically within the depositional sequence in the middle part of the formation. Abundance minima are placed at the fine-grained sandstone just above the basal shell bed (its base corresponds to sequence boundary), whereas abundance peak horizons commonly occur at or close to the horizon that has the maximum concentration of sand-size biogenic grains (Figs. 3 and 4). Such a stratigraphic pattern for planktonic foraminifera is common in depositional sequences resulting from Quaternary glacio-eustasy in temperate regions (e.g. Armentrout, 1996).

Large numbers of *Globorotalia inflata* occur in samples with warm-water species in depositional sequences 2, 3 and 5 at Okuwa and in depositional sequences 2, 3 and 4 at Yuhidera (Figs. 3 and 4). On the basis of ecostratigraphic datums and biogenic

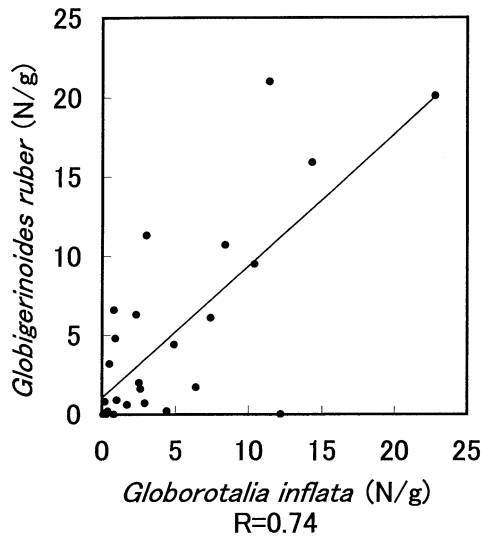


Fig. 5. Correlation of abundances of *G. inflata* with abundances of *G. ruber* at the horizon with *G. inflata*. R = Pearson's correlation coefficient.

grains, Kitamura (1998) has shown that the upper portion of depositional sequence 4 at Okuwa is missing due to truncation at an upper sequence boundary. We think that this missing interval results in the difference in the stratigraphic distribution of *G. inflata* between the two sections. This species appeared at every interglacial stage from stage 47 to 41. Furthermore, there is a positive correlation in abundances for *G. ruber* and *G. inflata* at the horizon with *G. inflata* ($R = 0.74$, $F = 28.57$, $df = 1, 23$, $P < 0.01$) (Fig. 5). This means that the species immigrated with *G. ruber* through the Tsushima Strait during the interglacial sea-level highstand. *G. inflata* has not been reported living in the Sea of Japan (Ichikura and Ujiié, 1976; Park and Shin, 1998). In East China Sea, it is found from recent surface sediments of southeastern area, and not from northwestern part (Xu and Oda, 1995, 1999). The southeastern part is deeper than 200 m and occupied by the open-sea water mass with high temperature and high salinity, due to the influence of Kuroshio. On the other hand, northwestern part is shallower than 200 m and dominated by the coastal water with low temperature and low salinity. From this evidence, we think that the immigration of *G. inflata* implies that the Tsushima Strait and northwestern part of the East

China Sea had geographic and hydrographic conditions similar to those of the present southeastern area of the East China Sea. If this interpretation is correct, *G. inflata* may be used as an indicator of existence of the Tsushima Strait that has water depth more than that of recent.

5.2. Cyclothem in the lower part of the Omma Formation

Based on the present re-examination, three cyclothem are recognized in the lower part of the Omma Formation, and are shown in Figs. 2 and 3. The bases of cyclothem represent either an unconformity or shell beds with erosional bases. The sediments in cyclothem L-1 and L-3 change upward from fine-grained sandstone through very-fine-grained sandstone or siltstone back to fine-grained sandstone. However, cyclothem L-2 lacks the upper fine-grained sandstone unit. There are two horizons with warm-water molluscs within cyclothem L-1. The lower horizon is 0.2 m thick and contains many articulated shells of the warm-water species *Cycladicama cumingi* (see Kitamura, 1997), while many warm-water species (e.g. *Acila divaricata*, *Limopsis crenata*, *Paphia schmelliana*) also are found in the 2 m thick upper horizon (Kitamura, 1991a) (Fig. 3). In cyclothem L-3, the warm-water species *Clementia vatheleti* and *Olivella spretoides* are present in the 25 cm thick horizon that is present 5 m above its base (Kitamura, 1991a). We found one individual of the warm-water *Onustus exutus* in the uppermost part of cyclothem L-2. The planktonic foraminiferal abundance ranges from 0 to 75/g. in the lower part of L-2, and abundance peak horizons within cyclothem L-2 and L-3 correspond to the horizons with warm-water molluscs (Fig. 3). The warm-water planktonic foram *G. ruber* is present in all horizons with warm-water molluscs (Fig. 3). *G. inflata* is not observed in the lower part of the Omma Formation (Fig. 3).

6. Discussion

In our investigation, systematic changes in lithofacies and molluscan and planktonic foraminiferal assemblages for cyclothem L-2 and L-3 in the lower part of the Omma Formation are very similar to those in depositional sequences in the middle part

of the formation. According to Takayama et al. (1988), the first-appearance datum of *Gephyrocapsa* (large), which coincides with oxygen isotope stage 51 (1515 ± 25 ka; Berger et al., 1994), is placed just above the basal shell bed of cyclothem L-3 (Fig. 2). Cyclothem L-1 and L-2 are younger than the first-appearance datums of *G. oceanica* (1664 ± 25 ka; Berger et al., 1994) (Takayama et al., 1988). These data imply that cyclothem L-3 correlates with oxygen isotope stages 51–50, and that the depositional duration of the lower two cyclothem was less than 150,000 yrs. As a consequence, it is evident that cyclothem L-3 is a sixth-order (41 kyr) depositional sequence. We also infer that cyclothem L-2 is a sixth-order depositional sequence, with its upper part (the horizon with warm-water molluscs) having been obliterated by shoreface erosion at the superjacent sequence boundary (Figs. 2 and 3).

It is noteworthy that cyclothem L-1 contains two horizons with warm-water molluscs and planktonic foraminiferal species. There are no significant differences in sediments between the two horizons, and we infer that the sedimentation rate was not different between them. If this was so, then the duration of the warm period in the upper horizon was 10 times as long as that in the lower horizon. Based on these inferences, we regard cyclothem L-1 as a sixth-order depositional sequence, and believe that the relatively short warming phase may have been caused by a millennial-scale climatic change during the early Pleistocene (Raymo et al., 1998). Based on this interpretation, the lowest cyclothem in the lower part of the Omma Formation correlates with oxygen isotope stages 56–54 (Fig. 2).

As mentioned above, five sixth-order (41 kyr) depositional sequences are present in the early Pleistocene Omma Formation at the Oyabe section. The upper part of Cycle 5 consists of brownish fine-grained sandstone that lacks calcareous material of any kind. *G. ruber* and *G. inflata* were recognized in Cycles 1, 2 and 3, and all cycles, respectively (Appendix B) (Fig. 2). The first-appearance datums of *G. oceanica* and *Gephyrocapsa* (large) are in the middle portion of Cycle 1 and at the base of Cycle 5, respectively (Fig. 2). Thus, three cyclothem in the lower part of the Omma Formation at Okuwa correlate with Cycles 3–5 in the Oyabe area (Fig. 2). This implies that the absence of warm-water *G. ruber* in

Cycles 4 and 5 at Oyabe is the result of missing horizons that would have contained them. Our results show that warm-water organisms appeared in interglacial periods beginning with the first-appearance datum of *G. oceanica* (oxygen isotope stage 59).

Many colleagues discuss molluscs and planktonic foraminifera in sediments from the Sea of Japan area between 1.66 and 2.5 Ma in age (e.g. Hasegawa, 1979; Morizumi and Ishigaki, 1981; Takayama et al., 1988; Sato et al., 1988; Kheradyar, 1992; Koizumi, 1992; Cronin et al., 1994; Arai et al., 1991, 1997, 1998; Takata, 2000). However, only two studies of these reported occurrences of warm-water diatoms and planktonic foraminifera. Two individuals of *G. ruber* were found in a 0.5 m thick horizon, representing the Olduvai Subchron in the Junicho Formation, that was deposited on the outer shelf (Arai et al., 1998). In contrast, warm-water diatoms have been recognized from at least three horizons (Koizumi, 1992). However, there is a serious problem with using warm-water diatoms as a proxy for the Tsushima Current, because they are present in sediment representing the later part of stage 2 (Tada et al., 1999). According to Ishiwatari et al. (1999), the alkenone-based sea-surface temperature measured in sediment cores from the Oki Ridge was 18°C at 17.5 ka. This is similar to the modern temperature (19°C) and might have resulted from stable stratification of the water column due to the input of fresh water. We think that such a warming of surface water led to a proliferation of warm-water diatoms that were relicts of the preceding warm interglacials. In contrast, warm-water planktonic foraminifera and molluscs have not been found in sediments of the later glacial periods (e.g. Habe and Kosuge, 1970; Emery et al., 1971; Oba et al., 1991). Based on these observations and inferences, we infer that warm-water planktonic foraminifera and molluscs are better proxies for the Tsushima Current than are diatoms. In summary, the Tsushima Current flowed into the Sea of Japan episodically before stage 60, and then flowed continuously during each interglacial stage.

A general trend of positive shift of $\delta^{18}\text{O}$ of interglacial periods is recognized around stage 59 in many marine isotope records (Ruddiman et al., 1989; Shackleton et al., 1990; Berger et al., 1994). However, in view of the relatively long $\delta^{18}\text{O}$ record over the

interval from 0.8 to 2.5 Ma, there are no significant differences in the $\delta^{18}\text{O}$ values of interglacial stages before and after stage 59 (Raymo et al., 1989; Ruddiman et al., 1989; Shackleton et al., 1990; Berger et al., 1994; Tiedeman et al., 1994). Provided that the oxygen isotope record is regarded as a proxy for the glacio-eustatic sea level record (e.g. Chappell et al., 1996), no significant changes are recognized in sea level between interglacial stages before or after stage 59. Therefore, we think that deepening and/or widening of the Tsushima Strait due to local tectonism caused the onset of cyclical inflow of the Tsushima Current. According to Kamata and Kodama (1999), crustal stretching has occurred in the northern Okinawa Trough since 2 Ma due to a change in the convergence direction of the Philippine Sea plate. Based on its timing and location, we assume that this event led to deepening and/or widening of the Tsushima Strait. The inflow of the Tsushima Current into the Sea of Japan isolated the terrestrial biota of Japan from that of mainland Asia during at least the interglacial sea-level highstands since oxygen isotope stage 59 (ca. 1.7 Ma). This increase of geographical heterogeneity might have contributed to great diversity of species of plants in temperate eastern Asia (Qian and Ricklefs, 2000).

Dunbar et al. (1992) inferred that increased tectonic isolation of the Sea of Japan took place at 1.3 Ma, based on variations in the biogenic opal content of sediments at ODP Site 798 (911 m deep). The age-assignment was deduced from the last-appearance datums of *Helicosphaera sellii* (1.20 Ma) and the top of the Olduvai event (1.66 Ma). Tada (1994) noted oscillations between oxic and anoxic conditions in the period from 2.5 to 1.2 Ma, and between highly oxic and euxinic conditions in the period from 1.2 Ma to the present for bottom water in the Sea of Japan. Estimated age 1.2 Ma by Tada (1994) is based on the first-appearance datum of *G. oceanica* (1.35 Ma) and base of the Jaramillo event (0.98 Ma) at ODP Site 797 (2862 m deep). According to the stratigraphic datums presented by Berger et al. (1994), ages by Dunbar et al. (1992) and Tada (1994) are calculated to be 1.52 Ma (1.3 Ma, fide Dunbar et al., 1992) and 1.42 Ma (1.2 Ma, fide Tada, 1994), respectively. The differences seem to be due to uncertainties in the stratigraphic positions of datum planes, since there are many dissolution zones lacking calcareous fossils in

Pleistocene sediments at both sites (Kheradyar, 1992; Tada et al., 1992). This dissolution was caused by fluctuations of the CCD owing to glacio-eustatic sea-level changes (Oba et al., 1991; Tada, 1994). The greater the water depth, the larger was the influence of CCD fluctuations. We therefore infer that increased isolation of the Sea of Japan took place around 1.52 Ma (stage 51). Tada (1994) implied that this isolation probably was related to narrowing and/or shallowing of the northern strait. Our results strongly support this interpretation, because *G. inflata* dwelled in the Sea of Japan in the period from oxygen isotope stages 47–41 (Figs. 3 and 4), as also recognized in other sediment records (e.g. Sato et al., 1987; Kheradyar, 1992).

Tada (1994) concluded that paleoceanographic evolution of the Sea of Japan since 18 Ma was divided into five stages. During the youngest episode, Stage 5 (2.5–0 Ma), surface water conditions fluctuated between warm and cold, oxygenation levels in the bottom water fluctuated between hyperoxic and euxinic. Our results show that Stage 5 is subdivided into three substages. During substage I (2.5–1.71 Ma (stage 60/59)), cold surface water prevailed in the Sea of Japan owing to closure of the southern strait (Fig. 6). Cold-water organisms dominated in the sea, and terrestrial organisms migrated to and from Asia and Japan. This oceanic conditions were exactly the same as Stage 4 presented by Tada (1994), except for the effects caused by glacio-eustatic sea level oscillations that started approximately at 2.5 Ma. In substage II (1.71–1.52 Ma (stage 51)), the Tsushima Current flowed into the Sea of Japan during interglacial highstands (Fig. 6). This was caused by opening of the Tsushima Strait as the result of crustal stretching in the northern Okinawa Trough. Since the northern strait was wide and/or deep during this substage, almost entire mass of the current probably flowed out through it to the Northwestern Pacific Ocean. Warm-water organisms entered the sea during interglacial periods and were extirpated by the following glacial period. The opening of the Tsushima Strait produced geographic isolation and subsequent speciation of terrestrial organisms in the Japanese Islands. During substage III (1.52–0 Ma), the Tsushima Current flowed continuously into the sea during interglacial highstands, while narrowing and/

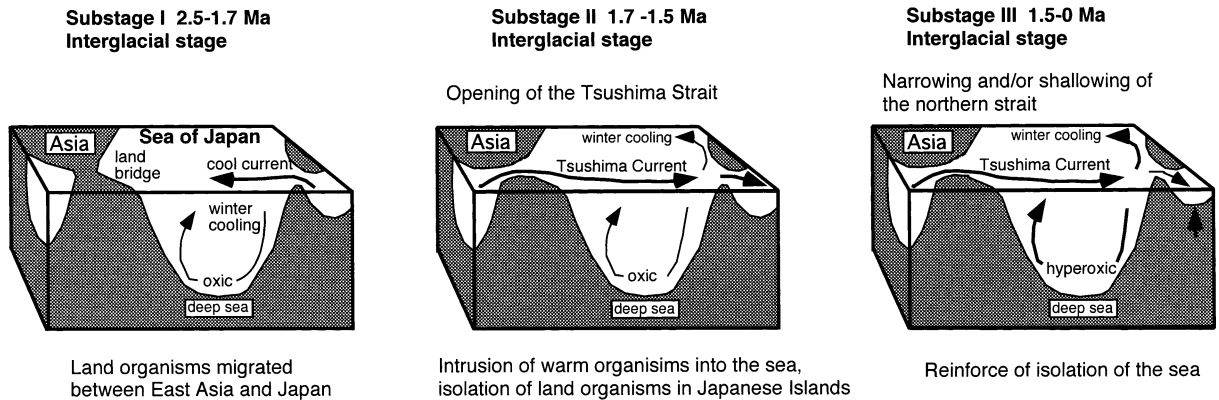


Fig. 6. Paleooceanographic history of the Sea of Japan since 2.5 Ma.

or shallowing of the northern strait reinforced isolation of the Sea of Japan (Fig. 6). The decrease in outflow of the Tsushima Current to the Pacific probably increased the production of Japan Sea Proper Water that ventilated the deeper waters in the sea. Consequently, the oxidation level of the deep sea during the interglacial stages of substage III was higher than during the prior substages. From the stratigraphic distribution of *G. inflata*, the depth of the Tsushima Strait is inferred to have decreased after oxygen isotope stage 41 (1.3 Ma).

Kawamura (1998) thought that a land bridge between mainland Asia and Japanese Islands emerged around 1.2–1.0 Ma, based on the appearance of the elephant *Mammuthus shigensis* in Japan. Despite of the incompleteness of the fossil record of terrestrial mammals, the formation of land bridge coincides with shoaling of the Tsushima Strait inferred on the basis of the stratigraphic distribution of *G. inflata*. The configuration of a land bridge between mainland East Asia and Japanese Islands at 2.0–1.2 Ma has been highly controversial. Kawamura (1998) argue that fossil elephants were not evidence for a land bridge, whereas Koizumi (2000) thought that canine fossils imply that a land bridge was present around the Plio-Pleistocene boundary. Our results provide insights into this contradiction. The diversification and extinction of terrestrial organisms in the Japanese Islands were, in fact, strongly influenced by the formation and shoaling of the Tsushima Strait at 1.7 and 1.3 Ma, respectively.

7. Conclusions

High-resolution analyses of Plio-Pleistocene lithofacies, molluscan fossils and planktonic foraminifera of formations in Hokuriku province support dividing the paleooceanographic history of the Sea of Japan since 2.5 Ma (i.e. Stage 1 of Tada (1994)) into three substages. During substage I (2.5–1.71 Ma (stage 60/59)), cold surface water prevailed in the Sea of Japan, due to closure of the southern strait. During substage II at 1.71–1.52 Ma (stage 51), the Tsushima Current flowed into the sea during each interglacial highstand. During substage III (1.52–0 Ma), isolation of the Sea of Japan was reinforced by narrowing and/or shallowing of the northern strait. These transitions were caused by local tectonic changes that influenced the southern and northern channels. These episodes caused significant changes not only in the paleoenvironment, but also in the geographic distribution of both terrestrial and marine organisms in and around the Sea of Japan.

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Appendix A

Planktic foraminifera identified at studied section of early Pleistocene Omma Formation at the Okuwa and Yuhidera sections.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Locality	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa
Part	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Middle	Middle	Middle
Cycle	1	1	1	1	1	1	1	1	1	2	2	3	3	3	3	1	1	1
Mud content (%)	27.1	30.9	41.7	44.0	51.4	37.3	28.6	24.6	7.3	11.7	17.8	23.1	17.4	15.5	10.7	27.3	30.4	12.5
<i>G. bulloides</i>	2	46	28	22	35	3	15	13	3	29	43	13	78	3	25	95	76	1
<i>G. woodi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. quinqueloba</i>	0	0	0	0	0	0	0	0	0	1	2	1	2	0	0	18	63	0
<i>G. glutinata</i>	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	1	0
<i>G. ruber</i>	0	1	0	3	0	0	0	2	0	2	2	0	3	0	2	0	5	0
<i>G. sacculifer</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>G. tenellus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globigerinoides</i> sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>N. pachyderma</i>	0	5	9	8	8	7	15	17	2	0	4	2	8	0	1	5	59	0
<i>N. pachyderma</i> (s.)	0	5	6	7	6	7	11	14	2	0	1	0	1	0	0	4	34	0
<i>N. pachyderma</i> (d.)	0	0	3	1	2	0	4	3	0	0	3	2	7	0	1	1	25	0
<i>N. dutertrei</i>	0	0	1	0	0	0	1	1	0	0	3	1	2	0	1	2	0	0
<i>N. incompta</i>	0	0	0	0	0	0	2	0	0	0	1	0	3	1	0	0	0	0
<i>O. universa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. inflata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>P. obliquiloculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	13	23	18	16	9	32	40	1	4	27	3	36	8	33	64	136	0
Total	2	65	61	51	59	20	65	73	6	72	85	21	134	12	62	185	340	1
Number of planktonic foraminifera (N/g)	1	15	19	12.4	9	4	12	12	6	21	75	5	44.7	7	13	19	57.6	0.4
Number of <i>G. ruber</i> (N/g)	0.0	0.2	0.0	0.7	0.0	0.0	0.0	0.3	0.0	0.6	1.8	0.0	1.0	0.0	0.4	0.0	0.8	0.0
Number of <i>G. inflata</i> (N/g)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix A (continued)

Sample number	19 ^a	20 ^a	21 ^a	22 ^a	23 ^a	24 ^a	25 ^a	26 ^a	27	28	29	30	31	32	33	34	35
Locality	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa
Part	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle
Cycle	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	5	5
Mud content (%)	6.0	16.0	16.0	30.0	30.0	14.0	20.0	25.0	10.9	19.7	25.7	15.4	13.9	25.6	45.6	7.9	8.2
<i>G. bulloides</i>	0	48	60	66	42	83	30	38	0	16	65	133	7	97	66	2	7
<i>G. woodi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. quinqueloba</i>	0	65	106	61	72	37	73	58	0	0	24	11	2	1	18	0	2
<i>G. glutinata</i>	0	5	21	34	14	4	1	0	0	0	8	1	0	3	4	0	0
<i>G. ruber</i>	0	9	14	27	33	57	29	28	0	0	4	8	0	4	4	0	0
<i>G. sacculifer</i>	0	0	0	2	0	0	2	1	0	1	0	0	1	0	0	0	0
<i>G. tenellus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globigerinoides</i> sp.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0
<i>N. pachyderma</i>	0	0	0	0	0	0	0	0	0	3	22	24	1	16	15	2	1
<i>N. pachyderma</i> (s.)	0	0	0	0	0	0	0	0	0	3	0	13	0	8	0	0	1
<i>N. pachyderma</i> (d.)	0	0	0	0	0	0	0	0	0	0	0	11	1	8	0	2	0
<i>N. dutertrei</i>	0	5	4	4	2	6	7	0	0	0	5	4	0	0	1	0	0
<i>N. incompta</i>	0	4	14	4	9	22	8	3	0	1	0	2	0	1	4	0	1
<i>O. universa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. inflata</i>	0	0	0	0	36	31	26	22	0	0	11	9	0	0	0	0	0
<i>P. obliquiloculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	11	10	12	14	21	19	14	0	10	93	73	2	46	78	0	2
Total	0	147	229	210	222	261	195	164	0	33	232	265	13	168	191	4	13
Number of planktonic foraminifera (N/g)	0	31	43.2	186	64	96	107	62.4	0	2	35	29	2	15	12	2	2
Number of <i>G. ruber</i> (N/g)	0.0	1.9	2.6	23.9	9.5	21.0	15.9	10.7	0.0	0.0	0.6	0.9	0.0	0.4	0.3	0.0	0.0
Number of <i>G. inflata</i> (N/g)	0.0	0.0	0.0	0.0	10.4	11.4	14.3	8.4	0.0	0.0	1.7	1.0	0.0	0.0	0.0	0.0	0.0

Appendix A (continued)

Sample number	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Locality	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa
Part	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle
Cycle	5	5	5	6	6	6	6	6	6	7	7	8	8	8	8	8	8
Mud content (%)	24.2	28.7	19.0	7.5	21.2	21.8	25.4	15.0	19.1	20.7	25.6	23.7	26.5	67.8	25.7	29.0	35.1
<i>G. bulloides</i>	136	75	123	5	99	127	88	105	95	0	5	12	9	93	65	33	21
<i>G. woodi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. quinqueloba</i>	27	26	14	0	15	23	28	12	16	0	0	2	5	13	6	18	8
<i>G. glutinata</i>	6	9	0	0	18	8	27	2	0	0	0	0	0	6	0	0	0
<i>G. ruber</i>	10	11	10	0	7	7	9	0	1	0	6	1	4	18	10	9	4
<i>G. sacculifer</i>	1	1	2	0	0	2	0	0	0	0	0	0	0	1	1	0	0
<i>G. tenellus</i>	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
<i>Globigerinoides</i> sp.	1	0	3	0	0	4	0	0	0	0	0	0	0	1	0	1	1
<i>N. pachyderma</i>	11	10	26	3	14	24	29	39	27	0	19	11	19	37	34	57	44
<i>N. pachyderma</i> (s.)	5	8	14	3	10	15	20	31	13	0	16	9	18	29	26	44	38
<i>N. pachyderma</i> (d.)	6	2	12	0	4	9	9	8	14	0	3	2	1	8	8	13	6
<i>N. dutertrei</i>	0	4	2	0	1	2	0	0	2	0	4	0	0	7	10	0	2
<i>N. incompta</i>	1	1	2	0	0	0	1	0	2	0	0	0	0	2	5	0	0
<i>O. universa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
<i>G. inflata</i>	11	2	12	0	0	1	0	0	0	0	0	0	1	0	0	0	0
<i>P. obliquiloculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	79	107	41	2	49	135	97	98	69	0	16	23	35	123	111	99	82
Total	283	248	235	10	203	333	279	256	212	0	50	49	24	304	244	217	162
Number of planktonic foraminifera (N/g)	126	108	144	4	68	152	47	45	36	0	19	1	5	200	195	174	130
Number of <i>G. ruber</i> (N/g)	4.4	4.8	6.1	0.0	2.3	3.2	1.5	0.0	0.2	0.0	2.3	0.0	0.8	11.8	8.0	7.2	3.2
Number of <i>G. inflata</i> (N/g)	4.9	0.9	7.4	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0

Appendix A (continued)

Sample number	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68 ^a	69 ^a
Locality	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Okuwa	Yuhidera	Yuhidera
Part	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Upper	Upper	Upper	Middle	Middle
Cycle	10	10	10	10	10	10	10	11	11	11	11	11	1	1	1	2	2
Mud content (%)	12.0	13.0	20.0	53.0	37.0	21.0	13.0	24.0	32.9	28.8	14.3	21.4	23.5	15.0	18.3	12.0	28.0
<i>G. bulloides</i>	7	45	44	41	52	24	13	1	9	0	0	1	10	24	1	0	73
<i>G. woodi</i>	4	19	11	11	34	21	19	0	0	0	0	0	0	0	0	0	0
<i>G. quinqueloba</i>	5	19	49	20	27	53	42	0	5	2	1	0	5	17	1	0	58
<i>G. glutinata</i>	0	1	4	6	8	2	0	0	3	0	0	0	0	1	0	0	0
<i>G. ruber</i>	0	0	1	13	45	21	6	0	1	1	0	0	5	8	0	0	32
<i>G. sacculifer</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
<i>G. tenellus</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Globigerinoides</i> sp.	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0
<i>N. pachyderma</i>	1	15	28	18	9	9	23	1	14	4	1	2	10	19	2	0	0
<i>N. pachyderma</i> (s.)	1	13	25	16	8	8	21	1	9	3	1	2	7	10	0	0	0
<i>N. pachyderma</i> (d.)	0	2	3	2	1	1	2	0	5	1	0	0	3	9	2	0	0
<i>N. dutertrei</i>	0	2	4	12	8	2	3	0	1	1	0	1	3	1	0	0	0
<i>N. incompta</i>	2	61	54	41	94	87	35	0	0	0	1	1	1	14	0	0	0
<i>O. universa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. inflata</i>	0	0	0	0	0	0	0	0	22	2	0	1	0	0	0	0	0
<i>P. obliquiloculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	3	18	29	11	27	14	11	2	71	12	1	4	64	113	3	0	131
Total	22	180	225	173	305	234	153	4	126	22	4	10	118	198	7	0	294
Number of planktonic foraminifera (N/g)	4	15	38	19	158	94	91	2	25	4	3	8	49	8.8	1	0	39
Number of <i>G. ruber</i> (N/g)	0.0	0.0	0.2	1.4	23.3	8.4	3.6	0.0	0.2	0.2	0.0	0.0	2.1	0.4	0.0	0.0	4.2
Number of <i>G. inflata</i> (N/g)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0

Appendix A (continued)

Sample number	70 ^a	71 ^a	72 ^a	73 ^a	74 ^a	75 ^a	76 ^a	77	78	79	80	81	82	83	84	85	86
Locality	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera	Yuhidera
Part	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle	Middle
Cycle	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4
Mud content (%)	24.0	23.0	16.0	15.0	34.0	16.0	11.0	7.0	14.0	16.0	14.0	11.0	9.0	21.2	26.0	19.4	23.5
<i>G. bulloides</i>	69	65	68	79	140	149	200	55	72	41	78	7	15	62	115	88	0
<i>G. woodi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. quinqueloba</i>	77	53	120	126	71	77	41	6	5	9	7	0	1	2	20	19	0
<i>G. glutinata</i>	24	0	2	2	1	1	0	2	1	7	0	0	2	2	6	3	0
<i>G. ruber</i>	24	61	13	16	0	0	2	0	4	0	1	0	3	0	27	38	0
<i>G. sacculifer</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
<i>G. tenellus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globigerinoides</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>N. pachyderma</i>	0	0	0	0	0	0	0	5	62	17	25	0	6	6	17	23	0
<i>N. pachyderma</i> (s.)	0	0	0	0	3	10	2	2	45	4	10	0	3	2	9	7	0
<i>N. pachyderma</i> (d.)	1	1	0	4	5	22	5	3	17	13	15	0	3	4	8	16	0
<i>N. dutertrei</i>	48	0	8	38	72	284	32	0	1	0	0	0	2	0	1	3	0
<i>N. incompta</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>O. universa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. inflata</i>	3	16	16	26	1	0	0	2	15	10	4	0	0	0	10	43	0
<i>P. obliquiloculata</i>	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	18	115	32	46	18	66	19	29	49	50	67	1	21	38	72	99	0
Total	263	312	260	333	303	577	294	75	209	134	182	8	51	110	271	317	0
Number of planktonic foraminifera (N/g)	72	58	40	33	17	140	60.7	10	90	164	132	2	10	27	63	168	0
Number of <i>G. ruber</i> (N/g)	6.6	11.3	2.0	1.6	0.0	0.0	0.4	0.0	1.7	0.0	0.7	0.0	0.6	0.0	6.3	20.1	0.0
Number of <i>G. inflata</i> (N/g)	0.8	3.0	2.5	2.6	0.1	0.0	0.0	0.3	6.4	12.2	2.9	0.0	0.0	0.0	2.3	22.8	0.0

Appendix B

Planktic foraminifera identified at studied section of early Pleistocene Omma Formation at the Oyabe section.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Part	Lower	Lower	Lower	Lower	Lower	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper
Cycle						1	1	1	2	2	2	2	2	2	2	3
<i>G. bulloides</i>	38	12	49	91	73	107	60	78	225	72	38	25	96	90	79	80
<i>G. quinqueloba</i>	24	26	10	8	4	12	12	17	34	18	8	15	26	29	45	29
<i>G. cf. quinqueloba</i>	0	0	0	8	0	7	2	7	8	0	5	3	11	5	5	3
<i>N. pachyderma</i>	7	4	1	1	0	4	0	7	50	26	18	22	18	22	42	36
<i>N. incompta</i>	20	19	22	19	14	13	9	36	30	23	16	13	21	46	34	13
<i>N. dutertrei</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
<i>N. kagaensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>G. ruber</i>	0	0	0	0	0	2	0	1	0	0	0	0	0	5	59	9
<i>G. inflata</i>	0	0	0	0	0	0	1	0	0	1	0	0	0	1	28	11
<i>G. uvula</i>	1	0	0	1	2	1	1	0	1	3	2	1	5	5	4	2
sp. indet.	0	0	0	0	0	0	0	0	2	1	4	2	1	0	4	2
Total	90	61	82	120	93	146	84	146	350	144	91	81	178	203	306	185
Number of planktonic foraminifera (N/g)	10.5	40.4	48.5	10.8	8.8	41.5	71.1	40.9	26.1	9.0	24.6	16.5	86.5	56.3	85.9	13.7
Number of <i>G. ruber</i> (N/g)	0	0	0	0	0	0.6	0	0.3	0	0	0	0	0	1.4	16.6306	0.7
Number of <i>G. inflata</i> (N/g)	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0.3	7.9	0.8

Sample number	17	18	19 ^a	20	21	22	23	24	25	26	27	28	29	30	31	32
Part	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper	Upper
Cycle	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5
<i>G. bulloides</i>	51	36	100	119	116	100	132	128	107	143	52	74	70	80	33	54
<i>G. quinqueloba</i>	11	4	38	14	21	15	32	71	42	92	10	37	24	14	16	10
<i>G. cf. quinqueloba</i>	5	7	5	2	5	2	5	2	6	1	4	10	5	0	0	0
<i>N. pachyderma</i>	12	10	15	23	18	22	23	54	35	22	26	32	20	3	4	8
<i>N. incompta</i>	16	12	33	41	61	38	46	33	33	62	8	59	37	20	30	35
<i>N. dutertrei</i>	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
<i>N. kagaensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. ruber</i>	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>G. inflata</i>	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
<i>G. uvula</i>	1	2	1	1	1	1	4	7	0	1	1	5	2	0	1	2
sp. indet.	0	0	0	0	0	1	0	0	0	1	0	0	11	0	0	6
Total	97	72	193	202	222	179	242	295	223	322	102	217	169	117	85	116
Number of planktonic foraminifera (N/g)	13.2	19.4	157.3	135.5	363.7	412.9	203.9	247.6	244.7	1030.4	37.1	98.5	150.2	15.6	11.3	7.7
Number of <i>G. ruber</i> (N/g)	0	0.3	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of <i>G. inflata</i> (N/g)	0.1	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0.1	0.1

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