by Kiyotaka Chinzei

Late Cenozoic zoogeography of the Sea of Japan area

The zoogeographic history of the Sea of Japan can be summarized as follows. From 17 to 15 Ma, before the spreading of the sea, tropical and subtropical mollusks invaded the area. The benthic and planktonic faunas changed sharply into temperate faunas at about 15 Ma, an event associated with the rotation of Japan and the opening of the Sea of Japan. From about 10 to 5 Ma, sedimentary deposits formed that were barren of benthic mollusks as a result of the stagnation of the Sea of Japan basin. Cold-water molluscan fauna reappeared in the coastal areas at about 5 Ma. This has been followed by a period of marked cyclicity of cold- and warm-water faunas since about 1.3 Ma.

Introduction

The Sea of Japan is a young marginal basin located between Japan and the Asian continent and probably was formed in middle Miocene time. Since then, the sea has experienced drastic changes in oceanography and biogeography, which are due to both regional tectonic development and global climatic changes. Here, I will summarize the Neogene and Quaternary zoogeography of the Sea of Japan, and I will give a general picture of the biogeographic changes of this area.

Remanent magnetism of Japanese rocks of early Miocene and older ages shows a large deviation from the magnetism of later rocks and the present-day geomagnetic field. This deviation has been explained by the hypothesis that the Japanese islands were located closer to the Asian continent before the middle Miocene and then rotated, clockwise in southwestern Japan and counterclockwise in northeastern Japan, into their current position (for example, see Otofujii and Matsuda, 1984; Hirooka, 1988). The Sea of Japan basin developed as a consequence of this rotation. The rotation is thought to have occurred within a very short interval between 15 and 14 Ma for southwestern Japan and between 20 and 15 Ma for northeastern Japan. The rotation might have had a drastic effect on the marine faunas of the Sea of Japan region if it did occur in such a short time interval.

Oscillatory change in the environment of the Sea of Japan was remarkable during the Quaternary. Cold and warm currents alternatively flowed into the sea through four narrow and shallow straits, and during the glacial maximum, the sea became isolated and the bottom stagnated. Recent work on onland sediments and analyses of basin deposits of the Sea of Japan have revealed these spectacular changes in this area during the Quaternary.

Details of the faunal history in the Sea of Japan area during the Neogene Subperiod and Quaternary Period, as well as the associated

literature, have been given in several synthetic papers and in numerous descriptive works (for example, see Kotaka, 1986; Chinzei, 1978, 1986; and other publications).

Early middle Miocene invasion of tropical fauna

The oldest known marine Cenozoic deposits in the area of the Sea of Japan belong to the lowest middle Miocene and are assigned to the N.8 planktonic foraminiferal zone of Blow (1969) at about 17 Ma. This is also the case for deposits of the Sea of Japan basin, where recent Ocean Drilling Program (ODP) drilling revealed the existence of shallow-marine sandstone beds of about the same age (Tamaki and others, 1990; Kaneoka and others, 1991).

The shallow-marine deposits of the N.8 zone of early middle Miocene age are distributed widely over the Japanese islands, as well as in the Korean peninsula, which indicates a regional and rapid transgression. Muddy sediments containing bathyal foraminifers are also known in troughs along the coast of the Sea of Japan. These are the deposits of the Sea of Japan before it spread, according to recent magnetic geochronology. The sea was probably relatively narrow, as reconstructed from paleomagnetic studies. The main stream of the warm Paleo-Kuroshio Current of this age flowed in all likelihood into the Sea of Japan area because of the distribution we find of tropical mollusks that are limited to this area.

The fauna in these transgressive deposits is remarkable in its tropical and subtropical nature (fig. 1). The molluscan associations in southwestern Japan include strictly tropical mangrove-swamp elements and subtidal forms, of which congeneric species are now living in the Philippines and Indonesian waters (for example, see Ozawa and others, 1986). Larger foraminifers, common in the calcareous sediments, also indicate the tropical nature of the marine climate (Matsumaru, 1981). However, no true reef facies are found, probably because of frequent clastic influxes from the surrounding lands.

Predominance of an extremely warm climate in this relatively short time interval was a global phenomenon, as is seen on the west coast of North America and in other places, as well as in the deep-sea sediments (Armentrout and others, 1984; Shackleton and Kennett, 1975; Woodruff and others, 1981).

Whereas the strictly tropical mollusks are limited to southwestern Japan, many of the other constituent species extend northward to northeastern Japan, and some species reach central Hokkaido. A latitudinal gradient of the diversity (that is, a gradual disappearance of the species toward the north in northeastern Japan) is also a characteristic feature of the present-day subtropical region.

Changeover of faunal characteristics at about 15 Ma

At about 15 Ma in the upper part of the N.9 foraminiferal zone, the tropical mollusks and larger foraminifers disappeared. Microbio-

stratigraphy shows that the disappearance was nearly contemporaneous throughout Japan. In places, the shallow-marine sediments containing tropical fauna are covered with diatomaceous shale of an offshore type that is poor in benthic fossils. In others places, the fauna was replaced by a different shallow-water molluscan fauna of the temperate type. The temperate nature of this new fauna is shown by the geographic distribution of the constituent species (fig. 2). Most of these are found in the Sea of Japan coastal area and to the north, some extending as far north as Sakhalin island and the Kamchatka peninsula of the USSR (Gladenkov and Sinelnikova, 1990). The compositions of the molluscan fauna do not show any geographic gradient through most parts of the area of the Sea of Japan, in contrast to the northward reduction of the early middle Miocene fauna discussed earlier. This temperate fauna is hard to explain simply by a global tendency toward climatic deterioration during the middle Miocene, and the fauna suggests a drastic geographic change in the Sea of Japan area.

An abrupt change in the benthic foraminiferal fauna is also known in the Sea of Japan area at about the boundary between foraminiferal zones N.9 and N.10 in the middle Miocene. This change is very close to the horizon in which the change in molluscan fauna occurs. The faunal character changes from a highly diverse, warm-water type to a limited arenaceous assemblage. The arenaceous foraminiferal assemblage suggests an environment of relatively deep, cold, and stagnant conditions. The planktonic foraminiferal fauna also decreased from this horizon upward and was replaced within foraminiferal zone N.11 by cold-water species (Maiya and Inoue, 1981; Maiya, 1988).

Siliceous sediments composed mainly of planktonic diatom valves started to accumulate also at about 15 Ma in the Sea of Japan basin and along the coastal areas. The sediments, which are lithologically similar to the Miocene Monterey Formation of California, USA, are barren of benthic megafossils and are considered to be the deposits of an isolated and stagnant marine basin.

All these changes in molluscan and foraminiferal faunas, as well as in the sedimentary facies, most probably were related to the rapid rotation of the Japanese islands and the resultant opening of the Sea of Japan basin.

The molluscan fauna living in the newly created Sea of Japan included both shallow- and deep-water associations. The shallow-water associations are composed dominantly of the genera that were common to the fauna of the early middle Miocene prior to spreading of the Sea of Japan, but they are different in species level (Chinzei, 1984). These species had newly appeared and were mostly endemic to the area (fig. 3). This particular change in species composition can be explained as follows. The fauna may have been isolated from the southern parental populations as the waterway, the Tsushima Strait that connects the Sea of Japan and the East China Sea, closed from the south as a result of the clockwise rotation of southwestern Japan. The constituents that invaded the region during the preceding period of marked warming might then have undergone speciation in order to adapt to the cooler new conditions.

The deep-water mollusks were mostly new to the Sea of Japan region, and many of the genera that appeared in the middle Miocene are now living in the subarctic region of the Northwest Pacific. The shallow-water associations also contain species that probably originated from the north.

Figure 1.— Distribution of early middle Miocene benthic mollusks (modified from Chinzei, 1986) and paleoposition of Japan as restored on the basis of paleomagnetism (Hirooka, 1988). Abbreviations: w., water; assoc., association.

Figure 2.— Distribution of benthic molluscan associations during the middle Miocene (modified from Chinzei, 1986) and presumed paleogeography of the Sea of Japan. See figure 1 for explanation.

Figure 3.—Geographic distribution of principal shallow-water molluscan species in the Sea of Japan and adjacent areas during the middle Miocene. Two localities are off the map: locality K, Myonchon on the northern Korean peninsula, and locality 17, Rumoi area on Hokkaido.

Late Miocene stagnation of the Sea of Japan basin

The deposits in the Sea of Japan area during the late Miocene from about 10 to 5 Ma are dominated by diatomaceous mudstone. The shallow-marine sediments that are contemporaneous with the mudstone are scarcely found in the area. The deposits are barren of benthic mollusks and contain only a very limited, arenaceous, foraminiferal fauna. This suggests that the Sea of Japan floor was likely to have been stagnant and that most of the coastal areas were submerged into quiet waters. The planktonic diatom flora is comparable to that of the Northwest Pacific, which indicates the presence of a main water connection toward the north (Kanaya, 1959).

Revival of the Sea of Japan benthic fauna in the Pliocene

The emergence of the Japanese islands became pronounced in Pliocene and early Pleistocene time from 5 to 1 Ma, during which time

the areas of marine sedimentation were reduced to the coastal belt and basin of the Sea of Japan. Shallow-marine mollusks and other biota reappeared in the deposits of the coastal belt, whereas diatomaceous sediments barren in megafossils continued to accumulate on the basin floor.

Because the Pliocene and lower Pleistocene strata in the Sea of Japan coastal area accumulated in the last stage of the reclamation of the Neogene onland basin, the offshore fauna tends to occur in the lower horizon and is replaced upward by the shallow-water associations (fig. 4). Offshore mollusks found in the muddy deposits are mostly conspecific with or very closely related to the present-day offshore muddy bottom dwellers of the temperate and subarctic regions around Hokkaido and the Sea of Okhotsk north of Japan. However, some warm-water foraminifers also are intermingled with the cold-water fauna, which suggests that a sea connection existed to the south (Maiya, 1988).

The shallow-marine molluscan fauna consists mainly of species now living in the temperate and subarctic regions, and it is associated with some extinct species. The extinct species were mostly endemic to the Sea of Japan area, some of which were common or were related closely to the endemic species in the middle Miocene fauna, as noted above. This shows a faunal continuity beyond the late Miocene stagnation event in the Sea of Japan.

▲ Figure 4.—Distribution of benthic molluscan associations in the Pliocene and early Pleistocene (modified from Chinzei, 1986) and presumed paleogeography of the Sea of Japan. See figure 1 for explanation.

Faunal change caused by Pleistocene climatic fluctuation

Cyclic changes in shallow-marine fauna began at about 1.3 Ma in the Sea of Japan coastal area. The cyclicity apparently is climatic and eustatic in origin. This cyclicity is exhibited by the alternation of beds containing cold- and shallow-water mollusks and beds rich in warm- and deeper water mollusks (Kitamura and Kondo, 1990; Kanazawa, 1990). The interval of a cycle was about 10,000 to 30,000 years, and the amplitude of the depth change was a maximum of 50 m, as inferred from benthic mollusks (fig. 5).

This is the first appearance of warm-water benthic mollusks in the Sea of Japan area since the spreading of the basin. The appearance of the warm-water forms indicates the existence of a connection through Tsushima Strait, the southwestern gateway to the Pacific Ocean, during high stands of sea level. The proportion of warm-water components decreases toward the northeast from the strait.

The Pleistocene deposits in the Sea of Japan basin are characterized by their light and dark banding, as observed in the deep-sea cores obtained from ODP Leg 127 (Tada and others, 1991). The dark bands consist of parallel laminated mud that has a high content of pyrite and organic matter but is poor in biogenic particles. This represents a deep-basin deposit formed during the time of reduced water circulation. The band has a high $\delta^{18}\text{O}$ value, which indicates

Figure 5.—Change in molluscan associations as seen in a unit of sediment (Cycle 9 of Kitamura and Kondo, 1990) from the early Pleistocene at about 1 Ma in the middle Omma Formation of Kanazawa, central Japan. Also shown are presumed changes in water depth and water regime (modified from Kitamura and Kondo, 1990).

low sea level and relatively cold conditions (Oba, 1984). The alternating appearance of the dark and light banding is particularly conspicuous in sediments younger than 1.3 Ma (Tada and others, 1991), the age corresponding to the reappearance of the warm-water benthic species in the onland sections.

Sea of Japan as experimental field for paleozoogeography

The Sea of Japan and the surrounding area can be regarded as an ideal experimental field for marine paleozoogeography. The origin and history of the Sea of Japan basin have become increasingly clear, and both the stratigraphy and chronology have been established for the fossiliferous strata. By using this as an example, we can delve into and describe details of the replacement and development of marine benthic faunas, as well as their speciation processes, and we can discuss these problems on the firm basis of an environmental reconstruction. The influence of climatic and glacio-eustatic oscillations is also very distinct in this area because of the unique physiography of the Sea of Japan.

Acknowledgment

Dr. Simon R. Wallis of Kyoto University kindly read the manuscript.

References

- Armentrout, J.M., Chinzei, K., and Gladenkov, Yu.B., 1984, Correlation of North Pacific Neogene molluscan biostratigraphic frameworks, in Ikebe, N., and Tsuchi, R., eds., *Pacific Neogene datum planes; contributions to biostratigraphy and chronology*: Tokyo, University of Tokyo Press, p. 245–254.
- Blow, W.H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy: International Conference on Planktonic Microfossils, 1st, Proceedings, v. 1, p. 199–421.
- Chinzei, K., 1978, Neogene molluscan faunas in the Japanese Islands: An ecologic and zoogeographic synthesis: *The Veliger*, v. 21, no. 2, p. 155–170.
- 1984, Ecological parallelism in shallow marine benthic associations of Neogene molluscan faunas in Japan, in David, L., and Gall, J.-C., eds., *First international congress of paleoecology: Géobios, Mémoire Spécial*, no. 8, p. 135–143.
- 1986, Faunal succession and geographic distribution of Neogene molluscan faunas in Japan, in Kotaka, T., ed., *Japanese Cenozoic molluscs—Their origin and migration*: Palaeontological Society of Japan, Special Papers, no. 29, p. 17–32.
- Gladenkov, Yu.B., and Sinelnikova, V.N., 1990, Miocene mollusks and climatic in Kamchatka: Academy of Sciences of the USSR, Geological Institute, Transaction, no. 453, p. 1–172. [In Russian.]
- Hirooka, K., 1988, Neogene paleoposition of the Japanese Islands inferred from paleomagnetic studies, in Tsuchi, R., Chiji, M., and Takayanagi, Y., eds., *IGCP Project 246—Pacific Neogene Events in Time and Space*: Osaka Museum of Natural History, Special Publication, p. 3–16. [In Japanese, English abstract.]
- Kanaya, T., 1959, Miocene diatom assemblages from the Onnagawa Formation and their distribution in the correlative formations in Northeast Japan: *Science Reports of the Tohoku University*, 2nd series, Geology, v. 30, p. 1–130.
- Kanazawa, Ken'ichi, 1990, Early Pleistocene glacio-eustatic sea-level fluctuations as deduced from periodic changes in cold- and warm-water molluscan associations in the Shimokita Peninsula, Northeast Japan: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 79, no. 3–4, p. 263–273.
- Kaneoka, I., Takigami, Y., Takaoka, N., Yamashita, S., and Tamaki, K., 1991, ⁴⁰Ar–³⁹Ar analyses of volcanic rocks recovered from the Japan Sea floor by Leg 127/128: Constraint of the formation age of the Japan Sea: *Proceedings of the Ocean Drilling Program, scientific results*, v. 127: College Station, Texas, Texas A&M University [in press].
- Kitamura, A., and Kondo, Y., 1990, Cyclic changes of sediments and molluscan fossil associations caused by glacio-eustatic sea level changes during the early Pleistocene: *Journal of the Geological Society of Japan*, v. 96, no. 1, p. 19–36. [In Japanese and English.]
- Kotaka, T., ed., 1986, *Japanese Cenozoic molluscs—Their origin and migration*: Palaeontological Society of Japan, Special Papers, no. 29, 255 p.
- Leg 127 and Leg 128 shipboard scientific parties, 1990, *Evolution of the Japan Sea*: *Nature*, v. 346, p. 18–20.
- Maiya, S., 1988, Neogene events as revealed by changes of foraminiferal assemblages from central and northern Japan, in Tsuchi, R., Chiji, M., and Takayanagi, Y., eds., *IGCP Project 246—Pacific Neogene Events in Time and Space*: Osaka Museum of Natural History, Special Publication, p. 31–48. [In Japanese, English abstract.]
- Maiya, S., and Inoue, Y., 1981, Historical changes of Lower-Middle Miocene foraminiferal assemblages and paleogeography in Niigata Basin: *Fossils*, Palaeontological Society of Japan, no. 30, p. 73–78. [In Japanese.]
- Matsumaru, K., 1981, Consideration concerning larger foraminiferal zoogeography and ecology in Late Early Miocene to Early Middle Miocene: *Fossils*, Palaeontological Society of Japan, no. 30, p. 59–66. [In Japanese.]
- Oba, T., 1984, Oxygen and carbon isotope analyses in the cores KH79–3–C3, the Japan Sea since the last glacial age: *Monthly Chikyu (The Earth)*, v. 6, p. 558–575. [In Japanese.]
- Otofui, Y., and Matsuda, T., 1984, Timing of rotational motion of southwest Japan inferred from paleomagnetism: *Earth and Planetary Science Letters*, v. 70, p. 373–382.
- Ozawa, T., Nakagawa, T., and Takeyama, K., 1986, Middle Miocene molluscan fauna of the Uchiura Group, Wakasa Province, Southwest Japan, in Kotaka, T., ed., *Japanese Cenozoic molluscs—Their origin and migration*: Palaeontological Society of Japan, Special Papers, no. 29, p. 135–148.
- Shackleton, N.J., and Kennett, J.P., 1975, Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation; oxygen and carbon isotope analyses in DSDP Sites 277, 279, and 281: *Initial reports of the Deep Sea Drilling Project*, v. 29: Washington, D.C., National Science Foundation, p. 743–756.
- Tada, R., Koizumi, I., Brunner, C.A., Rahman, A., and Cramp, A., 1991, Correlation of dark and light layers, and origin of their cyclicity in the Quaternary sediments from the Japan Sea: *Proceedings of the Ocean Drilling Program, scientific results*, v. 127: College Station, Texas, Texas A&M University [in press].
- Tamaki, K., Psicotto, K., and others, 1990, *Proceedings of the Ocean Drilling Program, initial reports*, v. 127: College Station, Texas, Texas A&M University, p. 1–844.
- Woodruff, F., Savin, S.M., and Douglas, R.G., 1981, Miocene stable isotope record: A detailed deep Pacific Ocean study and its paleoclimatic implications: *Science*, v. 212, p. 665–668. □

Dr. Kiyotaka Chinzei is a Professor of Geology at Kyoto University in Kyoto, Japan. He has interests in the faunal history of Cenozoic and Mesozoic mollusks, particularly in community ecology and functional morphology. Dr. Chinzei graduated from Yokohama National University and received his master's and doctoral degrees in geology from the University of Tokyo.