A Study of Quaternary Paleoenvironments and Paleobiology in Japan

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This article presents that our investigations based on paleobiology have good progress in understanding how environmental conditions changed and fluctuated during Quaternary, of fossils themselves as well, for these ten years. Major results are as follows: (1) Sedimentary facies and molluscan fossil contents of Quaternary sediments were originated from glacio-eustacy with the period of orbital precession and/or obliquity by the Milankovitch cycles. (2) Four stages in warm molluscan and diatom assemblages were recognized during the Holocene in Hokkaido. They can be correlated with the periods of strong northward inflow of the warm Tsushima Current. (3) The rising of averaged temperature by 2–3°C and sea-level by 2–3 m were recognized at the Hyperthermal and Last Interglacial age. (4) Tsunami deposits, which consist of sand and sandy gravel with mixed environmental molluscan shells and wood fragments, generated by earthquakes were found along the Boso and Miura peninsulas. (5) A cold-seep chemosynthetic community, which is composed of the articulated bivalves Conchoecia bica and Lucinoma spectabilis, were found in the lower Pleistocene Koshbia Formation, Yokohama City. (6) Living fossils were observed in seafloor caves, in deep water, or in singular area around spouting thermal spring on the ocean floor.

Key Words: eustatic sea-level changes, Milankovitch cycles, Last Interglacial age, tsunami deposits, chemosynthetic benthic communities, molecular biology, living fossils

I. Ice ages

Quaternary is a key period for scientific investigations to estimate about the Earth in future. Ice ages during Quaternary consist of alternating cold glacial periods and warm interglacial periods. These climatic fluctuations recorded in the environments are continuously focused to investigate and understand. Paleobiological approach is one of important means for it.

1. Sea-level fluctuations

To know about the latest Quaternary when eustatic sea-level fluctuations occurred in the large magnitude and in a shorter time of period, fossilized fauna and microfossils in the sediments on land, as well as on coastal and shallow-water area in the Japanese Islands, have been examined (Igarashi, 1994; Kanisawa and Takeuti, 1997; Kitamura et al., 1997). Nara (1995, 1997, 1998) have analyzed that the Rossetia socialis-crowded beds in the middle Pleistocene Ichinono alternating beds of sand and mud, Kongochi Formation in the Boso Peninsula were formed in a transgressive systems tract of a high-frequency depositional sequence.

2. Milankovitch cycles

Fluctuations in climatic conditions have been understood as some periodicities, Milan-
kovitch cycles, which fossil assemblages recorded (Kitamura, 1991, 1994, 1997b). Kitamura et al. (1994) documented a cyclothemic record based on changes in sedimentary facies and molluscan fossil associations in the middle part of the Omma Formation (early Pleistocene) in Kanazawa City, which has a periodicity of 41,000-years. Kamataki and Kondo (1997) suggested that all the depositional sequence (sedimentary facies and molluscan fossil content) of the Shimosa Group in the Boso Peninsula were originated from glacio-eustasy with the period of orbital precession (20,000-years) or obliquity (40,000-years) by the Milankovitch theory.

3. Pulses of Tsushima current during the Holocene
Four stages, 7,500 yrs BP, 4,000 yrs BP, 2,400–2,300 yrs BP, and 600 yrs BP, of Holocene warm molluscan and diatom assemblages are recognized in Hokkaido (Arakawa and Yamaizaki, 1998; Kito et al., 1998; Sawai and Mishio, 1998). These stages are concordant with the periods of strong northward inflow of the warm Tsushima Current, which had been found in the sediments from the Japan Sea.

4. Last Interglacial age
Now we are anxious about rise of averaged temperature by 2–3°C due to greenhouse effect that comes from increasing CO₂ in the atmosphere, but almost same rise as that is known to have occurred ca. 6,300 years ago (Sato and Katoh, 1998) and the Last Interglacial age (Ishizaka et al., 1995; Kondo et al., 1996). Corresponding to that warm conditions, at ca. 6,300 yrs ago sea level was higher by 2–3 m than the present.

5. Paleoenvironments on coastal area
Fossil assemblages from the coastal area, where salinity of water and sedimentary sequences are greatly diversified, differ greatly from place to place, as in estuaries or inner-bays, and provide the data for reconstructing paleo-environments. Shells are necessary to discriminate three-dimentional distribution of the marine and/or terrestrial strata (Kosugi et al., 1991; Matsuoka, 1992; Nakao, 1993; Nakagawa et al., 1993; Sawa et al., 1994; Sato, 1995; Ichihara et al., 1996; Kobayashi, 1996; Sato et al., 1996; Nara and Kotake, 1997; Inada et al., 1998). For example, Shimoyama (1994) showed the shoreline at the peak of Jomon transgression based on the distribution of the marine shell in northern Kyushu.

6. Paleoenvironments in lake deposits
Analysis of the microfossils in the samples from the boring cores taken from lake floor with higher sedimentation rate allowed to reconstruct even smaller fluctuations of environmental conditions (Sawai and Kashima, 1996; Oshima et al., 1997; Xiao et al., 1997; Nguyen et al., 1998). Kuwae et al. (1997) obtained that the total number of diatom valves increases under warm and wet paleoclimatic conditions, and decreases under cold and dry conditions during the past 400,000 years.

7. Paleoenvironments on land
Paleoenvironmental conditions on land during Quaternary have been reconstructed based on the results from analysis of the fossilized plants and all of microfossils like fossilized pollens (Matsushita, 1992; Nakamura and Yamanaka, 1992; Ooi, 1992; Igarashi et al., 1993; Kiyonaga, 1993; Suzuki et al., 1993; Ohira et al., 1994; Hayashi, 1996; Mori, 1996; Minaki, 1997; Takiya and Hagiwara, 1997; Yan et al., 1997).

II. Tsunami deposits
The Quaternary fossil assemblages occurring shallow sedimentary basins and continental slopes were obviously carried from various environments. They have been classified as a miscellaneous group, but the assemblages which were carried into during a temporary event such as tsunami come to be distinguished from other members in the group (Nara, 1997; Irizuki et al., 1998; Fujiwara et al., 1999). The Holocene marine terraces along the Boso and Miura peninsulas show repeated coseismic uplift, but there is little geologic evidence for inferring paleoseismic events. Fujiwara et al. (1997) first found three tsunami deposits generated by earthquakes in Holocene bay-floor muds of Boso Peninsula. The ages of these tsunami beds agree with the ages of the marine terraces.

III. Chemosynthetic benthic communities
Near the hot spots and the boundary of spreading where seafloor plates are producing heated water called black or white smoker is gushing out into seawater, and there inhabit the rare organisms, like tubewarm which do not depend on solar energy. Around seeping cold water along the subduction zone rare forms like Calyptogena shells inhabit (Akimoto et al., 1996a; Hattori et al., 1996; Kitazato, 1996; Kojima et al., 1996; Majima et al., 1996; Naganuma et al., 1996; Shibasaki and Majima, 1997). Akimoto et al. (1996b) discussed the relationship between the benthic foraminiferal assemblages and the chemical paleoenvironments with the cold seepage during the Late Cenozoic time. Chemical factors which influences the distribution of benthic foraminifers are the hydrogen sulfide contents, methane contents, dissolved oxygen, and alkalinity of the interstitial and bottom waters. According to Tate and Majima (1998), a cold-seep chemosynthetic community, which is composed of the articulated bivalves Conchocela bisecta and Lucinoma spectabilis, occurs in the lower Pleistocene Koshiha Formation, Yokohama City.

IV. Water-pollution

It has been explained that water-pollution is related to abnormal propagation of specific organism: blue and red tides propagate abnormally due to over nutritious water. Matsuoka and Takeuchi (1995) observed that most of the vegetative cells, planozygotes, and hypnozygotes (resting cysts) were produced during a large bloom, but these cells appeared in a very low number in other seasons.

V. Bathymetric index

As regards fossils to reconstruct paleo-water depth, fossils of the invertebrate fauna and benthic foraminifers have been used, and now composition of the microfossil assemblages is known to be useful for reconstruction of the habitats in the depths from continental shelf down to seafloor. Yanagisawa (1996) proposed two diatom bathymetric indices as proxies of water depth in sea bottom. They are defined as follows; \( \text{Bd} 1 = \frac{X_p}{(X_s + X_p)} \) and \( \text{Bd} 2 = \frac{0.5 X_t + X_p}{(X_s + X_t + X_p)} \), where \( X_s \), \( X_t \), and \( X_p \) are frequencies of diatom species characteristic to shelf, transitional, and pelagic regions, respectively.

VI. Statistic analysis of fossil assemblages

Statistic analysis of fossil assemblages of marine plankton provided the development of the Td (Diatom temperature index) and transfer function for reconstruction of salinity and surface temperature during Quaternary. Tanaka (1991) carried out the transfer functions of calcareous nannoplankton thanatocoenoses in surface sediments from seas around Japan. On the other hand, Takemoto and Oda (1997) analyzed planktic foraminiferal transfer functions for the Kuroshio-Oyashio current region off Japan. The sensitivity of diatom temperature index (Td) to temperature is not uniform, but greatly variable geographically; within mixed water region, it is sensitive enough to be used as a reliable thermometer, but the Td value is much insensitive in warm or cold current region, not reflecting a temperature change (Yanagisawa, 1993).

VII. Proxy for water masses

Remains and fossilized assemblages of marine organisms, as well as living ones, are analyzed to get informations about paleo-distributions of waters, paleotemperatures, and organic productions. Hagino (1997) recognized three living coccolithophore assemblages corresponding to distinct water masses; the cold Oyashio current, Tsugaru warm current, and mixed water.

VIII. Biotic microgrowth structure

Fluctuations in environmental conditions are recorded as periodicities in growth of such biotic structures as the shells of bivalve and barnacle, skeltons of corals, otolith of fish, and tree rings. Sato (1997) revealed that the growing season of Phacosoma japonicum is influenced by the annual pattern of food (phytoplankton) abundance, and that shell microgrowth patterns in shells preserve well seasonal changes of phytoplankton abundance.

IX. Biostratigraphy

The first and last appearances in four groups...
of planktic microfossils, foraminifera, calcareous nannofossils, radiolaria, and diatoms, have been compared with the geomagnetic polarity records. Regional sequences have been established within the geographic limitations for extending the isochronous surfaces represented by the biologic events (Shimamoto et al., 1994; Kitamura, 1995, 1997a; Kotake et al., 1995; Okubo et al., 1995; Oishi et al., 1996; Sugawara et al., 1997; Kameo, 1998). Takanaya et al. (1995) recognized 13 calcareous nannofossil datums in the Pleistocene sediments from the North Atlantic, Indian and equatorial Pacific Ocean, and also Japanese Islands.

X. Paleobiology

Paleobiological investigations for Quaternary have such advantageous points that fossil records are complete, that direct application of physiological, ecological, and embryological informations of the present species is available, and that data on age-assignment are abundant. This fact makes it possible to trace morphological developments within single phylogeny and also processes of its diversification.

1. Molecular biology

Analyzing the phylogenetic process in molluscan fauna from morphological and molecular viewpoints revealed evolitional processes from late Pleistocene to Recent. Kusumi et al. (1994) investigated genetic structures of two Japanese populations of brachiopod Lingula anatina and morphology of the shells. An electrophoretic survey of enzyme variations demonstrated that both populations of L. anatina retained a high level of genetic variability. The genetic distance between the two populations is within the value that characterize conspecific populations.

2. Living fossils

Living fossils co-occurring with present species inhabit the peculiar environments, the negative one like seafloor caves, deep water with lesser predatism pressure, or very singular area around spouting thermal spring on the ocean floor. This suggests a possible relationship of the environmental habitats with preservation of the regime (Hayami and Kase, 1992; Kase and Hayami, 1992, 1994; Tabuki and Hanai, 1994; Yamaguchi, 1994).

References

Akimoto, K., Saji, T., Tsutsuim, R. and Yoshihara, E. (1996a) Living and fossil benthic foraminiferal assemblages co-occurred with the Calyptogena communities (I)—Depth distribution of benthic foraminifera in the sediments of the off Hattshima living Calyptogena community. Fossils, 60, 41-47. (J+E)

Akimoto, K., Saga, S. and Yamada, K. (1996b) Recent and fossil benthic foraminiferal assemblages co-occurred with the Calyptogena communities (II)—Benthic foraminiferal assemblages with the late Cenozoic cold seepage—. Fossils, 61, 40-46. (J+E)


Igarashi, Y., Igarashi, T., Daimaru, H., Yamada, O,
Miyagi, T., Matsushima, K. and Hiramatsu, K. (1993) Vegetation history of Kenbuchi basin and Furano basin in Hokkaido, north Japan, since 32,000 yrs BP. 

Inada, A., Ohama, K. and Shimamura, K. (1998) Vegetational history since the latter period of the last glacial age around the lowland along the Shinkawa river in Yachiyo City, Chiba Prefecture, central Japan. The Quat. Res. (Daiyonki-Kenkyu), 37, 283–298. (J+E)


Kiyonaga, J. (1993) Vegetation history during the last half of the Holocene around the lowland along the river Uta in the western part of Sagami Plain, central Japan. The Quat. Res. (Daiyonki-Kenkyu), 32, 31–40. (J+E)


Shibasaki, T. and Majima, R. (1997) A fossil chemosynthetic community from outer shelf envi-


(J+E) in Japanese with English abstract, (J) in Japanese