Revista Mexicana de Ciencias Geológicas, v. 19, núm. 3, 2002, p. 190-205

Planktonic foraminiferal biostratigraphy of the Miocene Arakawa Group in central Japan

Hiroki Hayashi[1*] and Masaki Takahashi[2]

[1] Solid Earth Division, National Institute for Earth Sciences and Disaster Prevention, 3-1, Tennodai, Tsukuba, Ibaraki 305-0006, Japan.
[2] Institute of Geoscience, National Institute of Advanced Industrial Science and Technology, C-7, 1-1-1, Higashi, Tsukuba City, Ibaraki 305-08567 Japan.
** email: rin@hiroba.org*

ABSTRACT

We examined a planktonic foraminiferal biostratigraphy in the middle to upper Miocene Arakawa Group in central Japan. Chronostratigraphy has been already established for this sequence based on K-Ar ages of intercalated volcaniclastic layers. The studied section corresponds to planktonic foraminiferal zones N.8 to N.14 of the standard zonation. We detected fifteen biohorizons including a new one and estimated their numerical ages based on the K-Ar chronostratigraphy. The comparison of our ages with data from elsewhere suggest that four of our ages (the last occurrence of Praeorbulina sicana, the first occurrence of Orbulina suturalis, the first occurrence of Globigerina nepenthes, and the last occurrence of Neogloboquadrina mayeri) would coincide with those of the standard time scale, that is to say that these four shows better reproducibility for sites between low- and mid-latitude regions. In addition, five of those, namely, the last occurrence of Globorotalia bykovae, the last occurrence of Tenuitella clemenciae, the first occurrence of Gna. nepenthes, the last occurrence of Globorotalia ichinosekiensis, and the last occurrence of Globorotalia iwaiensis, have a good potential for correlating marine strata in Japan.

Keywords: biostratigraphy, planktonic foraminifera, Miocene, central Japan.

RESUMEN

Se estudia la bioestratigrafia planctónica foraminífera en el Grupo Arakawa correspondiente al Mioceno medio al superior localizado en el centro de Japón. La cronoestratigrafia de esta secuencia ya ha sido establecida con base en las edades K-Ar de capas volcanoclásticas intercaladas. La sección estudiada corresponde a las zonas planctónicas foraminíferas N.8 a N.14 de la zonación estándar. Detectamos 15 bio-horizontes, incluyendo uno nuevo, y estimamos sus edades basados en la cronoestratigrafía K-Ar. La comparación de estas edades con datos publicados sugieren que cuatro de dichas edades (la última ocurrencia de Praeorbulina sicana, la primera ocurrencia de Orbulina suturalis, la primera ocurrencia de Globigerina nepenthes, y la última ocurrencia de Neogloboquadrina mayeri) coinciden con aquéllas de la escala del tiempo estándar, es decir, que estas cuatro muestran mejor reproducibilidad para los sitios localizados entre las regiones de baja y mediana latitud. Además, cinco de éstas, que corresponden a la última ocurrencia Globorotalia bykovae, la última ocurrencia Tenuitella clemenciae, la primera ocurrencia de Gna. nepenthes, la última ocurrencia de Globorotalia ichinosekiensis, y la última ocurrencia de Globorotalia iwaiensis, tienen un buen potencial para la correlación de estratos marinos en Japón.

Palabras clave: bioestratigrafia, foraminíferos planctónicos, Mioceno, Japón central.

INTRODUCTION

During the Miocene, mid-latitude planktonic foraminiferal assemblages were different from those in the tropics (Saito, 1977) precluding the application of the identical zonal schemes (Blow, 1969; Berggren *et al.*, 1995). A separate zonation might therefore be established for this part of the ocean. Unfortunately, detailed Miocene magneto-biostratigraphy for mid-latitude northwestern Pacific has never been established because of discontinuous occurrence of calcareous microfossils in deep-sea cores from this area. Instead, the biostratigraphy of this area is based on examination of marine strata exposed on land.

Oda (1977) divided the Neogene in Japan into eleven planktonic foraminiferal biozones based on the biostratigraphic studies in central to northeast Japan. Maiya (1978) established a zonation for the "oil-field-region", the Sea of Japan side of northeast Japan, dividing the Neogene into nine zones. However, geochronologic and/or magnetostratigraphic constraints on those biohorizons in Japan are still poor and synchrony and biogeographical limitation of some biohorizons remain obscure (Oda *et al.*, 1984).

The middle to upper Miocene Arakawa Group distributed in the Karasuyama area, central Japan, yields abundant marine microfossils. In addition, this marine sequence is intercalated with many volcaniclastic layers, some of which are datable. Thus, the Arakawa Group is one of the most suitable sequences for carrying out an integrated stratigraphic study, which would enables us to establish a zonation useful for correlation of middle to upper Miocene marine strata in northwestern Pacific. The purpose of this study is to develop a planktonic foraminiferal biostratigraphy for the lower half of the Arakawa Group and to estimate numerical ages of recognized biohorizons, and discuss their synchrony and geographic extent.

GEOLOGICAL SETTING

The Karasuyama area is located in the northern part of central Japan (Figure 1). The late Cenozoic sequences in the study area can be divided into two groups (Kawada, 1948): the Nakagawa (mainly consisting of terrestrial pyroclastic rocks) and Arakawa (marine sedimentary rocks) Groups. The marine sequence of the Arakawa Group overlies the lower Miocene Nakagawa Group unconformably. The Arakawa Group is divided into four formations by Sakai (1986); the Kobana, Ogane, Tanokura and Irieno Formations (Figure 1). The Kobana Formation consists mainly of calcareous fine- to coarse-grained sandstone with a basal conglomerate layer. The Ogane Formation includes sandy siltstone and siltstone with frequent intercalations of volcaniclastics. The Tanokura Formation is composed of diatomaceous siltstone. The Irieno Formation consists of sandy siltstone. The stratigraphic relationship between each of these formations is all conformable, except for the base of the Tanokura Formation where submarine erosion is suggested. The total thickness of the Arakawa Group is more than 700 meters.

All of these formations are intercalated by a large number of volcaniclastic layers which are useful as key beds (more than 100 sets were described by Sakai, 1986), and about 20 of them include minerals such as biotite and/or hornblende useful for K-Ar dating and zircon for fission track dating. Kasuya (1987) reported fission track ages of two tuff beds in the Ogane Formation. K-Ar ages of eight tuff layers in the Kobana and Ogane Formations were determined by Takahashi *et al.* (1999, 2000).

The Kobana and Ogane Formations yield calcareous microfossils including foraminifers, ostracods and calcareous nannofossils. The overlying Tanokura and Irieno Formations yield mainly siliceous microfossils such as diatoms and radiolarians. Previous some biostratigraphic studies of this sequence include those on radiolarians and diatoms by Sugie (1993), calcareous nannofossils by Honda (1981) and Tanaka and Takahashi (1998), and planktonic foraminifers by Usami *et al.* (1995, 1996).

Paleoenvironmental reconstruction of the studied area has been undertaken on the basis of ostracods (Irizuki *et al*., 1998), benthic foraminifers (Aoshima, 1987), radiolarians (Sugie, 1993), and diatoms (Yanagisawa *et al.,* 2000). The results of such studies can be summarized as follows: (1) Ostracod fossils from the Kobana Formation suggest that the formation was deposited under the influence of subtropical to warm-temperate waters in a sublittoral environment (Irizuki *et al.*, 1998). (2) Abundant occurrences of planktonic foraminifers from the Kobana and the lower half of the Ogane Formations (Aoshima, 1987, Figure 3) indicate an open-ocean paleoenvironment. (3) According to the diatom flora from the upper half of the Ogane and the Irieno Formations, paleodepth of depositional environments of the upper part of the Ogane through the lower half of the Tanokura is considered to be middle bathyal, and those of the upper half of the Tanokura and the Irieno to be as upper bathyal to outer sublittoral (Yanagisawa *et al.*, 2000). (4) Such results from planktonic fossil evidence suggest that the paleoceanographic conditions prevailed through the depositional time period of these formations were open-sea, not in an enclosed basin.

MATERIAL AND METHODS

We made 1/100 columnar sections of the Kobana and Ogane Formations from ten routes in the central part of this area (Figure 2). Each columnar section is jointed by the correlating of key beds when each two is at some distance. The total thickness of the studied sequence is about 200 meters. Then, we collected 269 rock samples

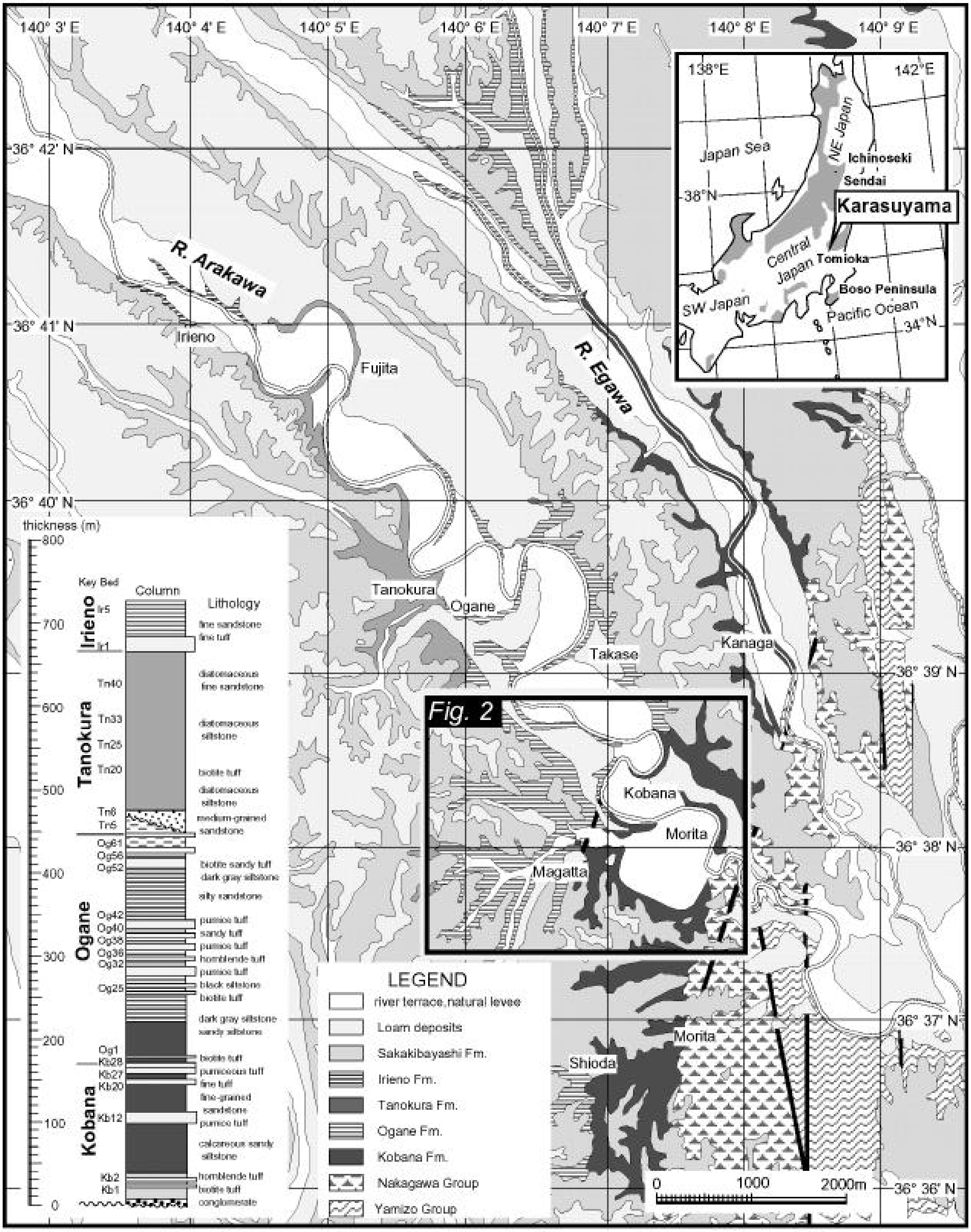

Figure 1. Geological map and a schematic stratigraphic column of the Miocene marine sequence of the Arakawa Group in the Karasuyama area.

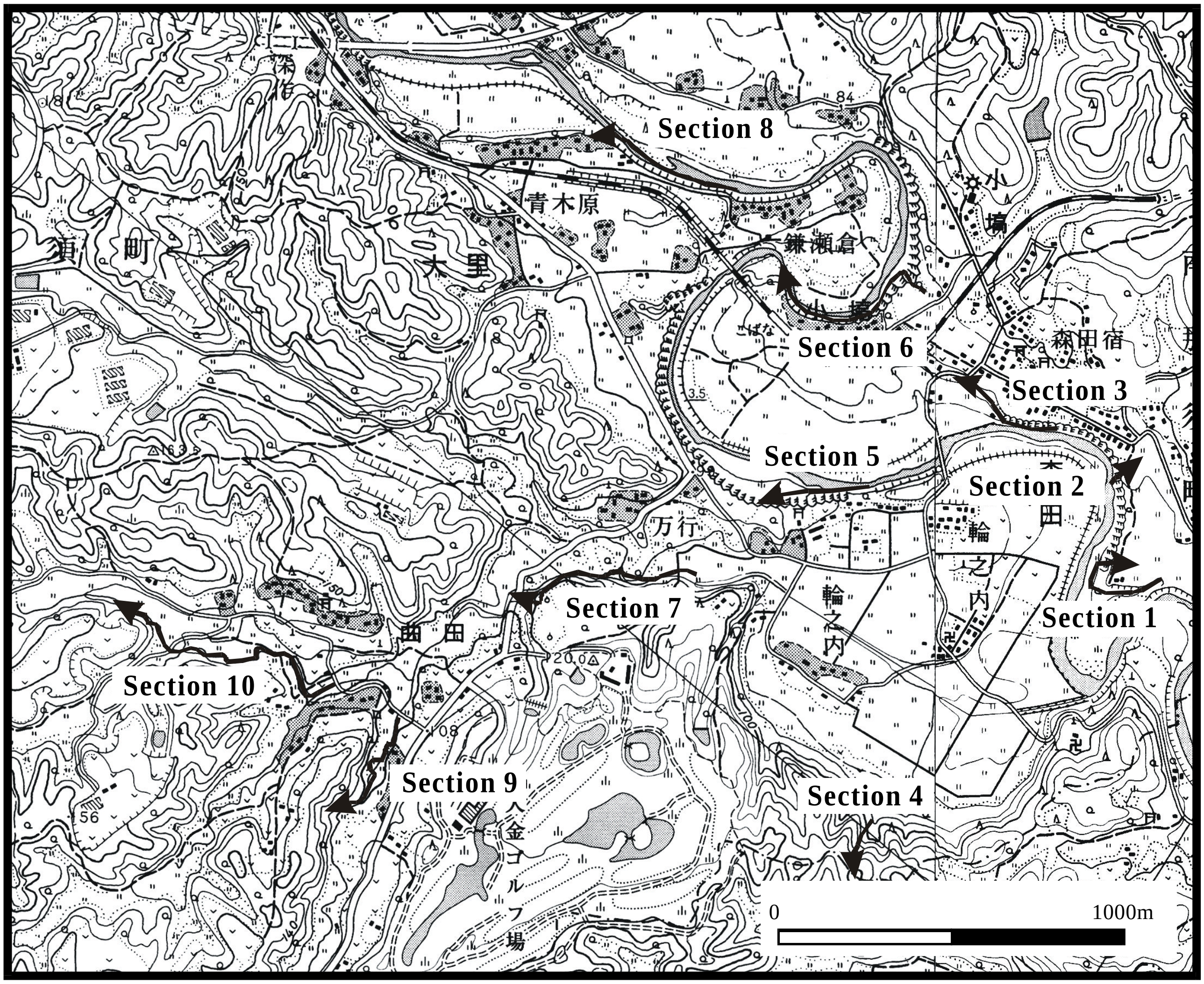

Figure 2. Map showing the routes of each columnar section of Figure 3 (topographic maps: "Niita" and "Karasuyama", scale 1:25000, Geographical Survey Institute of Japan).

in intervals of about 1 to 5 meters.

Seventy-one samples (displayed in bold characters in Figures 3a and 3b) were treated with the following procedure, others were reposited for other analyses, such as nannofossils biostratigraphy by Tanaka and Takahashi (1998). Rock samples (160 grams of dry weight) were disaggregated using saturated sodium sulfate solution, naphtha and NaTPB methods (Hanken, 1979) and wet-sieved through a 200-mesh (74 micrometers opening). The residue was divided with a sample splitter into an aliquot containing around 200 specimens of planktonic foraminifera. Planktonic foraminifera were picked from fractions coarser than 125 micrometers. Foraminiferal number of each sample was counted on the fraction, including un-identifiable specimens. Calculated foraminiferal number per gram of dry weight of each sample is displayed in Figures 4a and 4b.

Each biostratigraphic event (called "biohorizon" in this study) is mainly based on the species well-reported from Japan. A biohorizon possibly exists at any place between two nearest significant samples. In this study, we assume that each biohorizon is located at the midpoint between the two samples.

SEM photographs of important species were taken with a field-emission type scanning electron microscope (JSM-6330F; JEOL Co. Ltd.) owned by Institute of Geology and Paleontology, Graduate School of Science, Tohoku University.

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

Sixty-eight species of planktonic foraminifers were identified in 55 of the 71 disaggregated samples; in the other 16 samples the tests failed due to dissolution of the

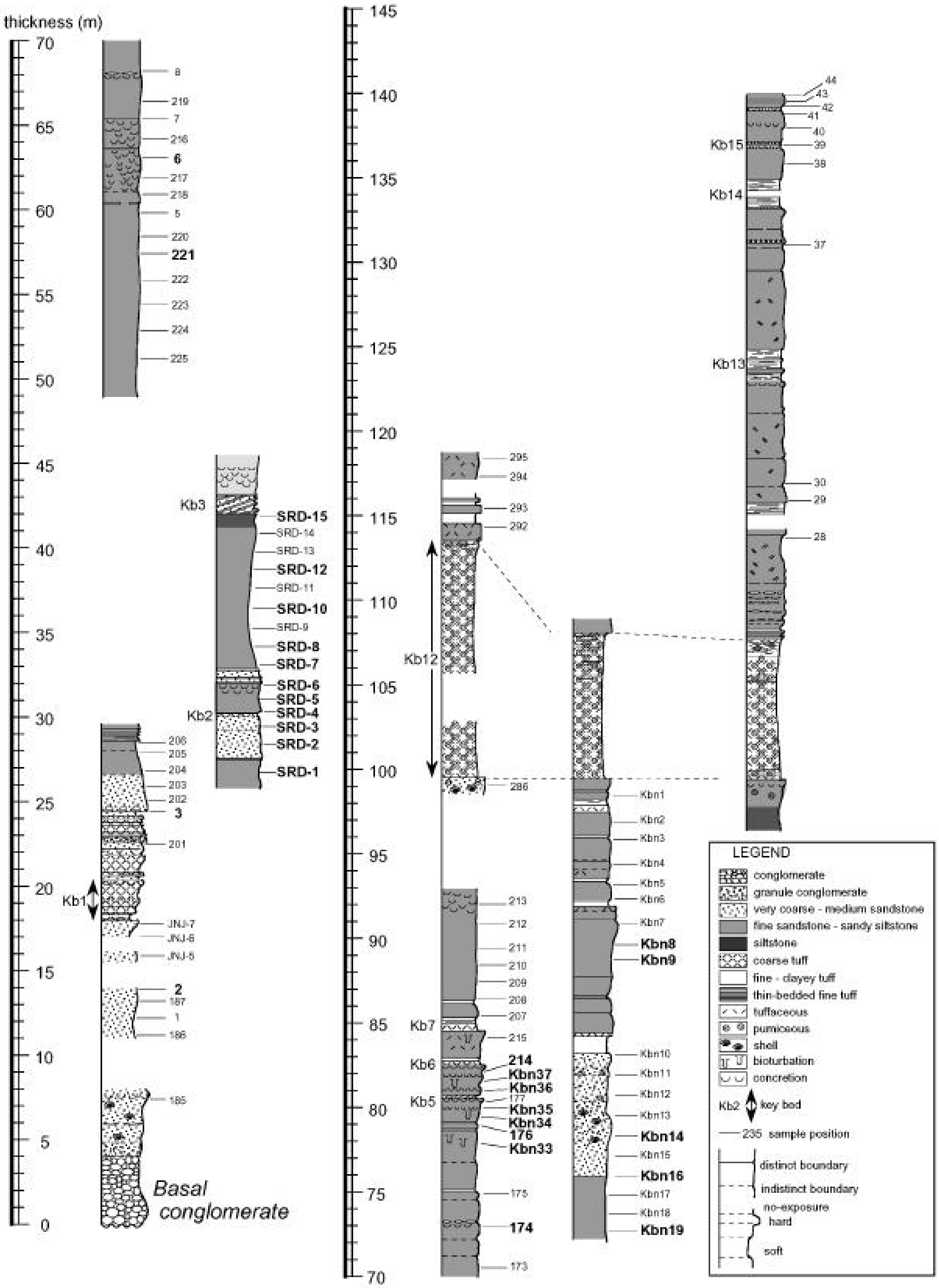

Figure 3a. Stratigraphic positions of collected samples on the detailed columnar sections of the Kobana and Ogane Formations. Samples which are displayed in bold characters are examined, others are reposited (*e.g*. for nannofossils biostratigraphy; Tanaka and Takahashi, 1998). Each number of columnar section is after Figure 2.

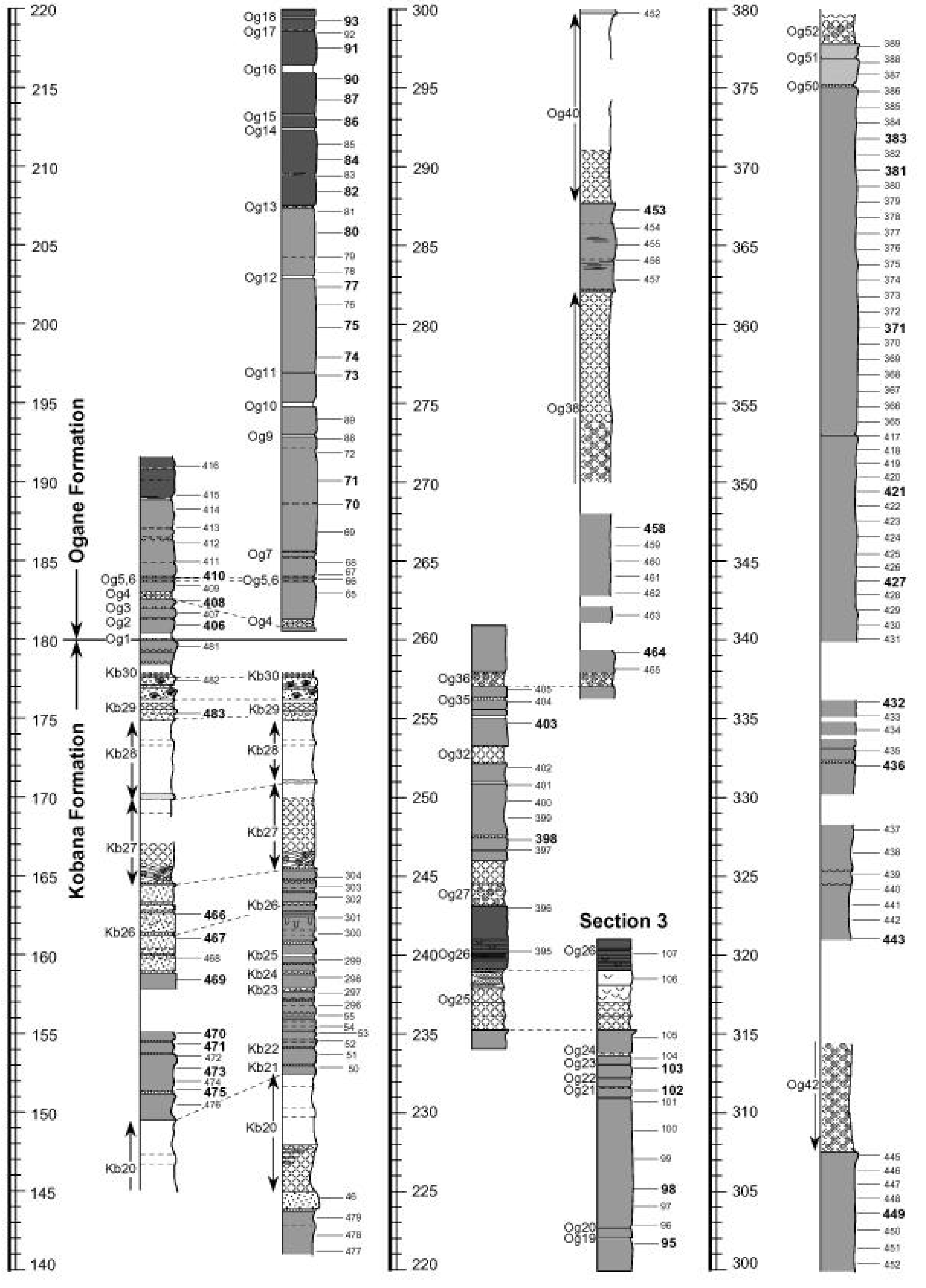

Figure 3b. Continued.

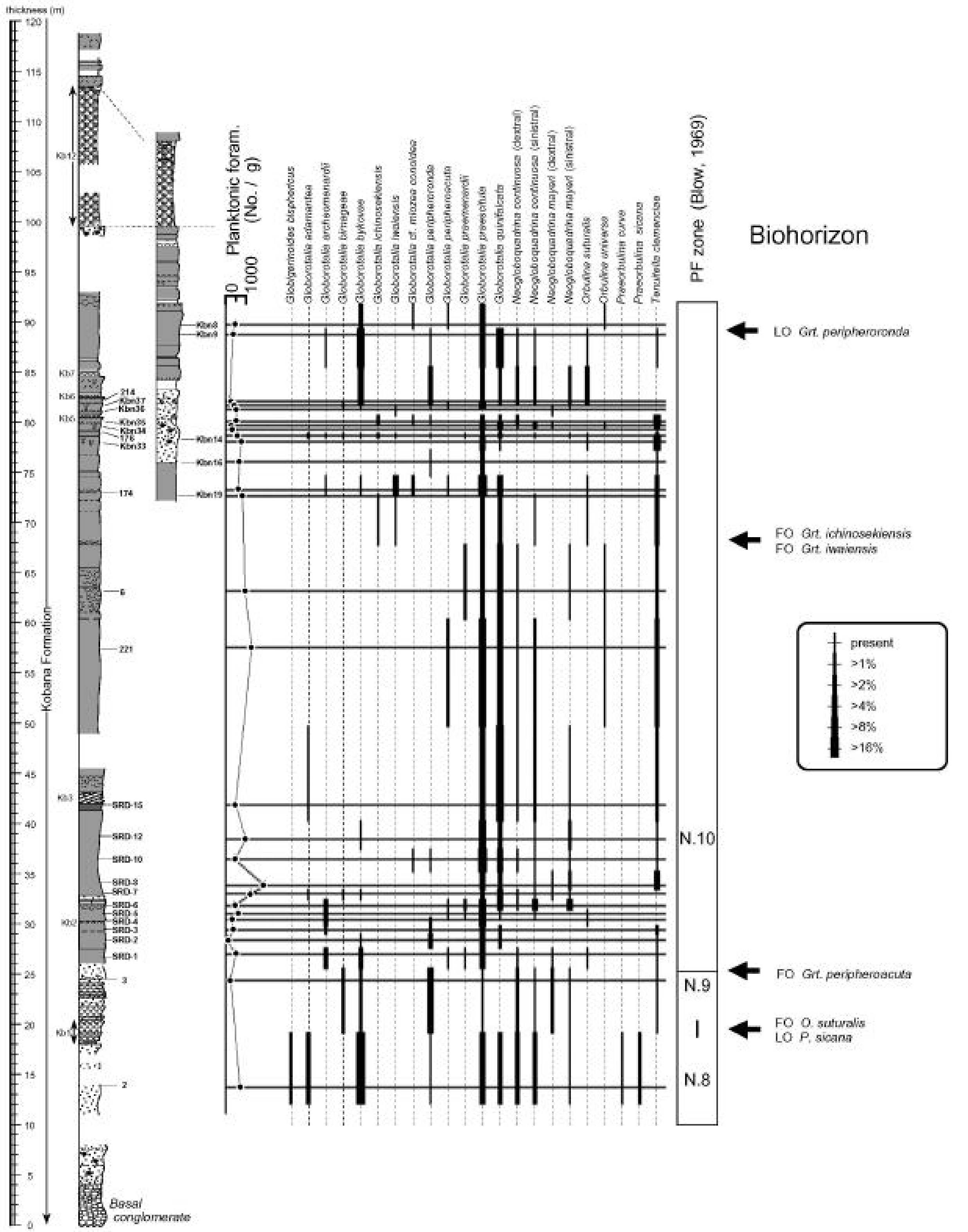

Figure 4a. Stratigraphic distribution of selected planktonic foraminiferal species from the Arakawa Group. Samples displayed in dashed lines are barren of fossils, presumably owing to secondary dissolution of calcareous tests. Then, we considered those dashed samples as unsignificant. Note that each biostratigraphic event possibly exists at any place between nearest two significant samples. In this figure, we assume that each biohorizon places at the midpoint of the two solid-lined samples. FO: First Occurrence, LO: Last Occurrence, S to D: dominant coiling direction change from sinistral to dextral.

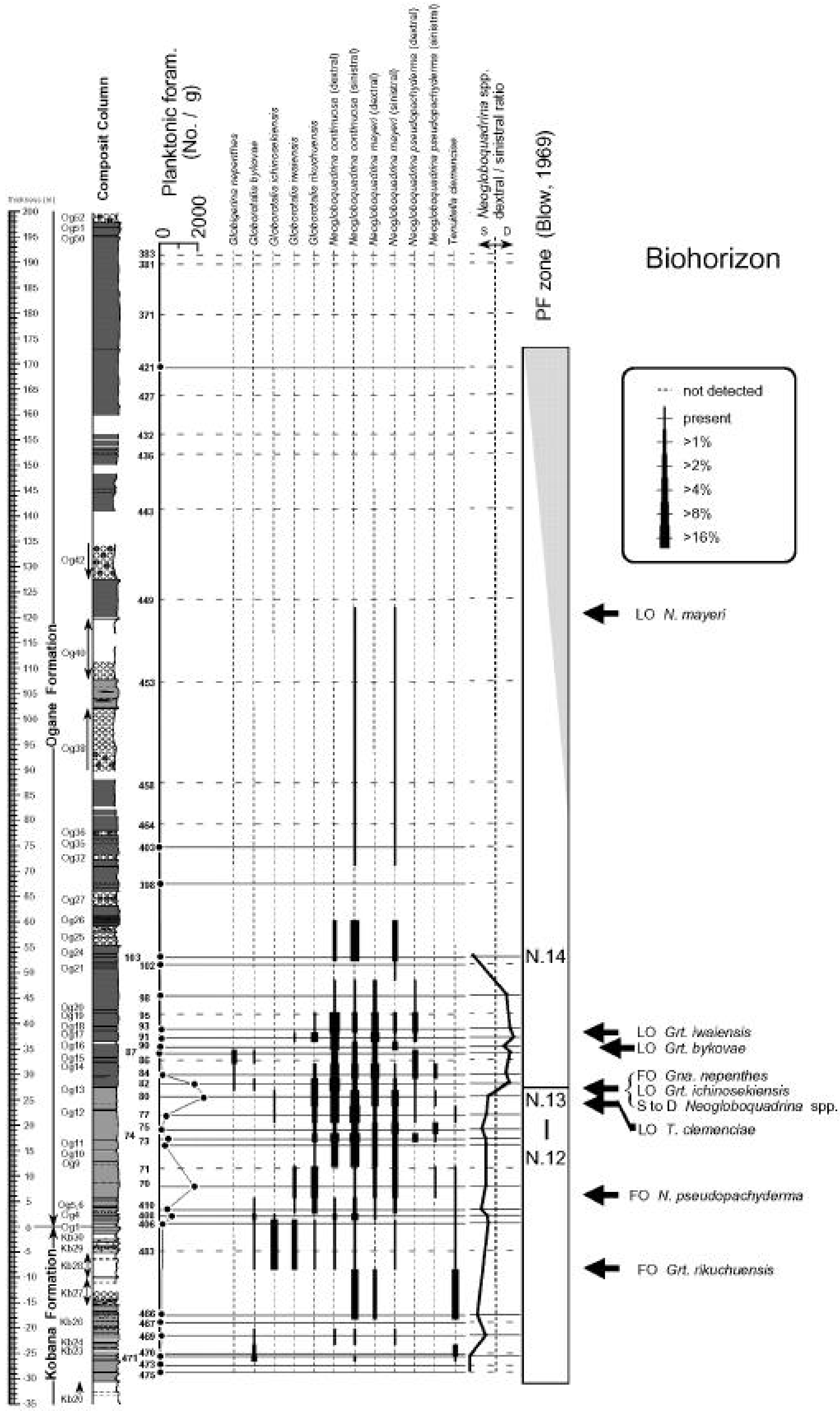

Figure 4b. Continued.

foraminifera (displayed as dashed line in Figure 4b). Preservation of these fossils ranges from "moderate" to "poor" (Plate I). Planktonic foraminiferal abundances in the Kobana and Ogane Formation ranged from 0 to 2,500 per gram of dried rock sample, averaging about 730 for the Kobana Formation, and 250 for the Ogane Formation. It is possible to say that these are high values in the Japanese Miocene strata exposed on land. The fact is strongly suggestive of an open-sea environment.

Based on the stratigraphic distribution of the identified species (Figures 4a and 4b), 15 biohorizons were recognized. The last occurrence (LO) of *Praeorbulina sicana* and the first occurrence (FO) of *Orbulina suturalis* occur between samples 2 and 3 of the lowermost part of the Kobana Formation. The FO of *Globorotalia peripheroacuta* was recognized between samples 3 and SRD-1. The FOs of *Globorotalia ichinosekiensis* and *Globorotalia iwaiensis* were detected between samples 6 and Kbn19. The LO of *Globorotalia peripheroronda* was recognized between samples Kbn9 and Kbn8 in the middle part of the Kobana Formation. The FO of *Globorotalia rikuchuensis* occurred in an interval between samples 466 and 406 near the top of the Kobana Formation. The FO of *Neogloboquadrina pseudopachyderma* was recognized between samples 410 and 406 in the lowermost part of the Ogane Formation. The LO of *Tenuitella clemenciae* was detected between samples 77 and 80 of the lower part of the Ogane Formation. The FO of *Globigerina nepenthes*, the LO of *Globorotalia ichinosekiensis* and a dominant coiling direction change from sinistral to dextral (S to D) of *Neogloboquadrina* spp. (*N. continuosa*, *N. mayeri* and *N. pseudopachyderma*) were recognized between samples 80 and 82, near the Og13 key bed. The LO of *Globorotalia bykovae* was recognized between samples 87 and 90. The LO of the *Globorotalia iwaiensis* was detected between samples 91 and 93. The LO of the *Neogloboquadrina mayeri* occurred between samples 403 and 421 in the middle part of the Ogane Formation.

The lowermost part of the Kobana Formation corresponds to zone N.8 / N.9 of Blow (1969) because of the presence of *Praeorbulina* spp. and the absence of *Orbulina* spp. The lower to middle part of the formation is limited to zone N.10 because of the co-occurrence of *Grt. peripheroronda* and *Grt. peripheroacuta*. The FO of *Gna. nepenthes* defines the lower boundary of zone N.14 and the LO of *N. mayeri* limits the upper boundary of this zone. Therefore, strata between these two biohorizons in the lower to middle part of the Ogane Formation correspond to zone N.14. Lower boundaries of zones N.11, N.12 and N.13 are uncertain due to the lack of key species.

NUMERICAL AGES OF BIOHORIZONS

Numerical ages of these biohorizons were estimated on the basis of K-Ar chronostratigraphy (Takahashi *et al*., 1999, 2000). First a sediment accumulation curve was constructed using eight K-Ar ages; the duration for the accumulation of volcaniclastic layers was set to zero (Figure 5). Ages of the biohorizons were estimated from the curve by linear interposition between two nearest control points (K-Ar ages). In the lower and upper parts of the studied section, three of those (the FO of *P. sicana* and the LOs of *O. suturalis* and *N. mayeri*) cannot be constrained by two radiometric ages. Then, we proposed either upper or lower limits of those ages.

Each numerical age (Table 1) may contain an error reflecting the precision of the radioisotope dating (*i.e.* about 0.2 Ma; Takahashi *et al*., 2000).

DISCUSSION

The biohorizon of the S to D of *Neogloboquadrina* spp. (11 in Table 1) was firstly recognized in this work. Other biohorizons have been previously detected in several sequences in Japan (Table 1). Six of them (1, 2, 3, 7, 10 and 15) are recognized in the marine sequence of the Boso Peninsula, central Japan (Oda, 1977). In this sequence, the relationship between foraminiferal biohorizons and diatom biostratigraphy is clarified (Watanabe and Takahashi, 1997). Two of the biohorizons (7 and 10) have been reported from the Tomioka area, central Japan (Takayanagi *et al*., 1976) and are constrained by ^{40}Ar-^{39}Ar ages of two pyroclastic layers (Odin *et al.*, 1995). Ten of them (4, 5, 6, 7, 8, 9, 10, 12, 13 and 14) have been detected in the Ichinoseki area, Northeast Japan, and can be combined with siliceous microbiostratigraphy (Hayashi *et al.*, 1999). We attempted to present numerical ages of planktonic foraminiferal biohorizons on the basis of the reported age constraints such as radiometric ages and diatom biohorizons. As listed in Table 1, five of them (6, 9, 10, 12 and 14) appear to be synchronous at least within Japan. We propose here five biohorizons for determining the Japanese marine strata.

Berggren *et al*. (1995) presented numerical ages of seven of the discussed biohorizons (1, 2, 3, 6, 9, 10 and 15; Table 1). Four of these ages (1, 2, 10 and 15) show no distinct difference from those in Japan. Therefore we can correlate marine strata in Japan with a global biostratigraphic time scale using these biohorizons. Odin *et al.* (1995) estimated the numerical age of the FO of *Gna. nepenthes* (10 of above) in Tomioka in central Japan and in central Apennines in Italy on the basis of ^{40}Ar-^{39}Ar geochronology. They indicated that the biohorizon shows a better reproducibility for sites located between low and mid-latitudes. The numerical age of this biohorizon in the Karasuyama area coincides with previous estimates. In contrast, numerical ages of biohorizons 3, 6 and 9 are different from those of our study (Table 1).

The FO of *Grt. peripheroacuta* of the present area is 0.8 Ma younger than that of Berggren *et al*. (1995). It

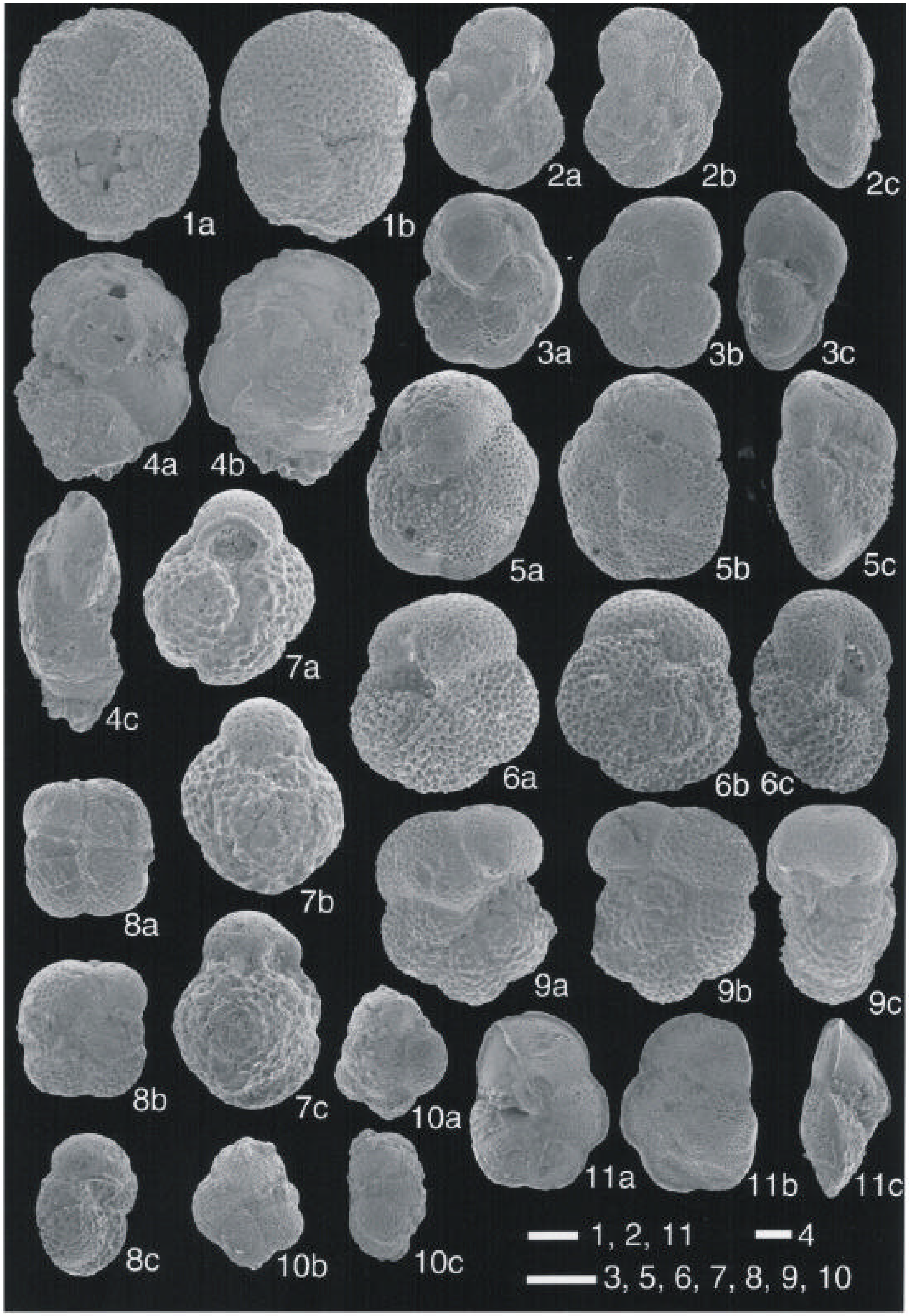

Plate I. Selected foraminiferal species from the Kobana and Ogane Formations. 1a-b: *Praeorbulina sicana* (de Stefani), sample 2; 2a-c: *Globorotalia peripheroacuta* Blow and Banner, sample 221; 3a-c: *Globorotalia peripheroronda* Blow and Banner, sample 3; 4a-c: *Globorotalia ichinosekiensis* Takayanagi and Oda, sample Kbn23; 5a-c: *Globorotalia bykovae* (Aisenstat), sample 469; 6a-c: *Globorotalia rikuchuensis* Takayanagi and Oda, sample 91; 7a-c: *Globigerina nepenthes* Todd, sample 87; 8a-c: *Neogloboquadrina pseudopachyderma* (Cita), sample 80; 9a-c: *Neogloboquadrina mayeri* (Cushman and Ellisor), sample 80; 10a-c: *Tenuitella clemenciae* (Bermudez), sample 470; 11a-c: *Globorotalia iwaiensis* Takayanagi and Oda, sample 70. Scale bars = 100 μm.

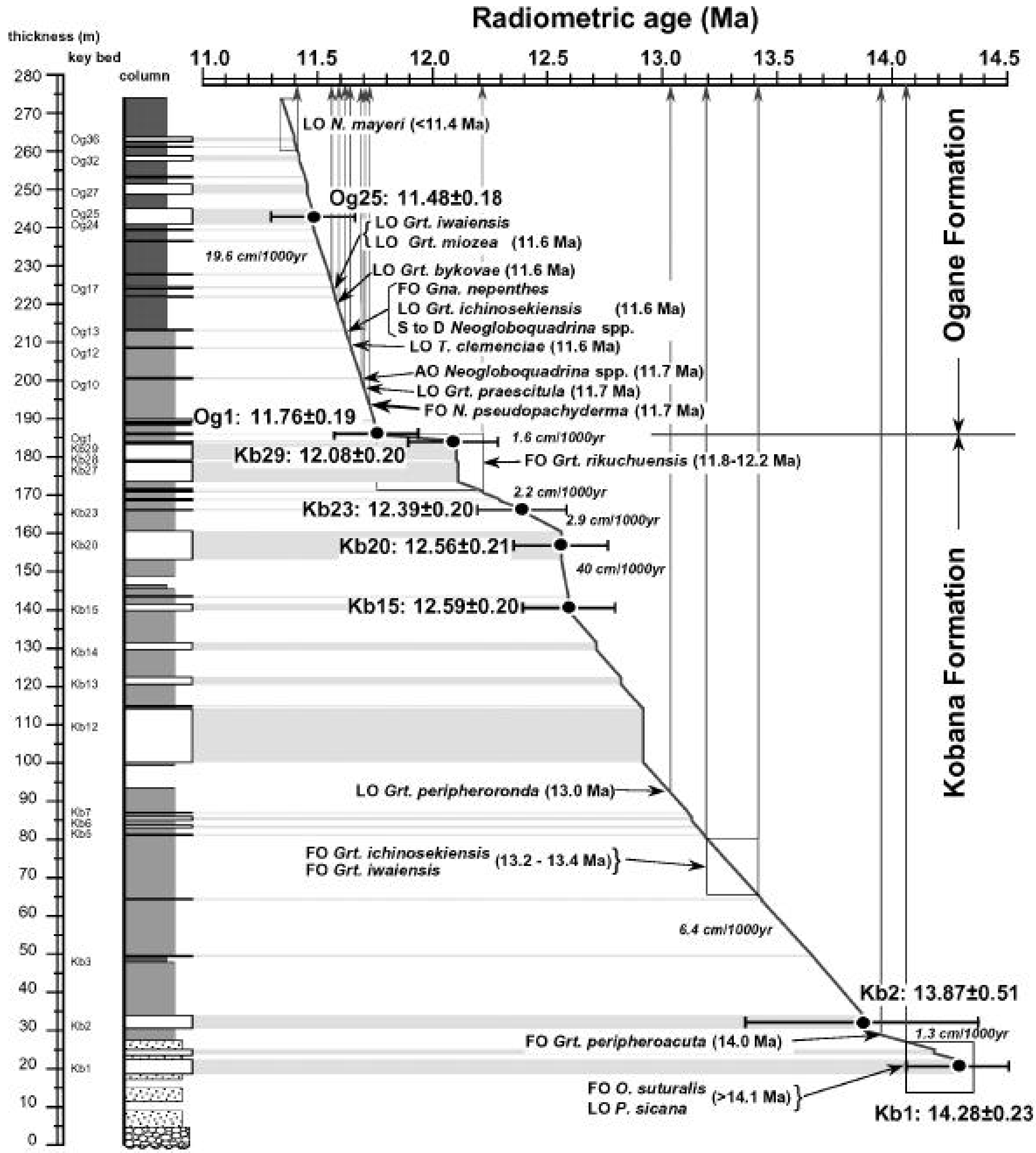

Figure 5. Sediment accumulation curve for the Kobana and Ogane Formations, based on the K-Ar chronostratigraphy. Numerical ages of each planktonic foraminiferal biohorizon are estimated. Note that tuff layers displayed by gray belts were excluded because we assume that they have formed almost instantly in comparison with the surrounding sediment. Position of each biohorizon is assumed as the midpoint of nearest two significant samples, except for six (the LOs *P. sicana* and *N. mayeri* and the FOs *O. suturalis, Grt. ichinosekiensis, Grt. iwaiensis, Grt. rikuchuensis*) with greater interval of samples. The six biohorizons are displayed with both/either lower and/or upper limits of age.

has been known that the biogeographic distribution of this species is strongly restricted in low-latitude region (Saito, 1977). Then, the occurrence of this species is strongly influenced by latitudinal thermal gradient. In Japan, the species has been reported from only few sections. It can say that the biohorizon of *Grt. peripheroacuta* is not useful for dating marine strata in the mid-latitude region such as around Japan.

Berggren *et al.* (1995) quoted the magnetobiostratigraphic correlation of the LO of *Grt. peripheroronda* (6 of above) from Berggren *et al.* (1985). These authors correlated the biohorizon with the lower part of the

Table 1. Comparison of numerical ages (Ma) of planktonic foraminiferal biohorizons from marine sequences in the Ichinoseki, Karasuyama (this study), Tomioka and Boso areas with data in Berggren *et al*. (1995).This areas are displayed in Figure 1. FO: First Occurrence; LO: Last Occurrence; S to D: Coiling direction change from sinistral to dextral. (1): Oda (1977); (2): Watanabe and Takahashi (1997); (3): Takayanagi *et al*. (1976); (4): Odin *et al*. (1995); (5): Hayashi *et al*. (1999).

	Berggren *et al*. (1995)	**Boso Peninsula** (1, 2)	**Tomioka** (3, 4)	**Karasuyama** (This study)	**Ichinoseki** (5)	**Average of Japan**
1) LO *Neogloboquadrina mayeri*	11.4	11.5		<11.4		11.4
2) LO *Globorotalia ichinosekiensis*				11.6	11.8	11.6
3) S to D *Neogloboquadrina* spp.				11.6		11.6
4) LO *Globorotalia iwaiensis*				11.6	11.8	11.7
5) FO *Globigerina nepenthes*	11.8	11.7	11.5	11.6	12.0	11.7
6) LO *Tenuitella clemenciae*	12.3			11.6	11.9	11.8
7) LO *Globorotalia bykovae*				11.6	12.0	11.8
8) FO *Neogloboquadrina pseudopachyderma*				11.7	12.6	12.3
9) FO *Globorotalia rikuchuensis*		13.3	11.5	11.8-12.2	12.6	12.4
10) LO *Globorotalia peripheroronda*	14.6	13.5		13.0	12.8	13.0
11) FO *Globorotalia iwaiensis*				13.2-13.4	12.8	13.0
12) FO *Globorotalia ichinosekiensis*				13.2-13.4	12.9-13.1	13.3
13) FO *Globorotalia peripheroacuta*	14.8	14.7		14.0		14.5
14) FO *Orbulina suturalis*	15.1	15.0		>14.1		15.1
15) LO *Praeorbulina sicana*	14.8	15.4		>14.1		15.2-15.7

normal subchron C5AD referring to results from western North Atlantic DSDP Sites 558 and 563 (Miller *et al.*, 1985). But Miller *et al.* (1985) never mentioned the LO of *Grt. peripheroronda*. Echols (1985) examined a planktonic foraminiferal biostratigraphy of these DSDP sites and reported the biohorizon from Core 6 of Hole 563. According to Miller *et al.* (1985), Core 6 of Hole 563 is approximately referable to C5A chronozone. The numerical age of this chron is between 11.9 and 13.0 Ma (Cande and Kent, 1995). Such numerical age agrees with our estimate. Spencer-Cervato *et al.* (1994) compiled DSDP and ODP data and pointed out that the LO of *Grt. peripheroronda* showed a diachroneity; mean age of five sites is 12.82 Ma with a standard deviation of 2.08 Ma based on the time scale of Cande and Kent (1992). They suggested that the observed diachroneity is caused by a latitudinal migration of this taxon, as the biohorizon tends to be older from low towards mid-latitude. In our result, however, the numerical age of the biohorizon is younger than that of low latitude. This suggests that in the NE Pacific, *Grt. peripheroronda* survived longer than elsewhere.

The LO of *T. clemenciae* (9 of above) was correlated with paleomagnetic chron C4An.2n in ODP Hole 747A from the southern Kerguelen Plateau (Li *et al*., 1992 quoted by Berggren *et al.*, 1995). However, this species received one's little attention elsewhere. Therefore, detailed distribution of this biohorizon is still obscure. We assume that the difference of numerical ages between Berggren *et al.* (1995) and our estimate may be caused by biogeographical characteristics of the species or local paleoceanographic conditions.

CONCLUSIONS

1) Planktonic foraminiferal biostratigraphy was examined in the Kobana and Ogane Formations, Arakawa Group in the Karasuyama area, central Japan, 15 biohorizons were recognized.

2) The studied section can be correlated with the planktonic foraminiferal zones N.8 to N.14.

3) Numerical ages of recognized biohorizons were estimated on the basis of eight K-Ar data.

4) Five planktonic foraminiferal biohorizons (LOs *Grt. peripheroronda, T. clemenciae, Grt. ichinosekiensis* and *Grt. iwaiensis* and the FO *Gna. nepenthes*) can be regarded as synchronous within Japan.

5) Numerical ages of four biohorizons (LOs *P. sicana* and *N. mayeri* and the FOs *O. suturalis* and *Gna. nepenthes*) in Japan coincide with those of Berggren *et al*. (1995).

ACKNOWLEDGMENTS

We wish to express our deep appreciation to Prof. emer. Tsunemasa Saito of Tohoku University, for his kind suggestions on classification of planktonic foraminifers. We also thank Prof. Kunio Kaiho of Tohoku University and Dr. Michal Kucera of Royal Holloway University of London for reviewing the manuscript.

REFERENCES

Aoshima, M., 1987, Foraminiferal fossils from the Arakawa Group (1): Memoirs of Tochigi Prefecture Museum, 5, 37-55.

Berggren, W.A.; Kent, D.V.; van Couvering, J.A., 1985, Neogene geochronology and chronostratigraphy: Snelling, N.J. (ed.), The chronology of the Geological record: London, Geological Society of London, Memoir, 10, 211-260.

Berggren, W.A., Kent, D.V., Swisher, C.C., III, Aubry, M.-P., 1995, A revised Cenozoic geochronology and chronostratigraphy: Berggren, W.A., Kent, D.V., Aubry, M.-P., Hardenbol, J., (eds.), Geochronology, time scales and global stratigraphic correlation: Society for Sedimentary Geology (SEPM), Special Publication, 54, 129- 212.

Blow, W.H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy, *in* Brönnimann, P., Renz, H.R., (eds.), Proceedings of 1st International Conference Planktonic Microfossils, Geneva, 1967, 1, 199- 422.

Cande, S.C., Kent, D.V., 1992, A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, 97, 13,917- 13,951.

Cande, S.C., Kent, D.V., 1995, Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, 100, 6,093- 6,095.

Echols, D.J., 1985, Lower Oligocene through Pleistocene planktonic foraminiferal biostratigraphy, North Atlantic Sites 588 and 563 (Mid-Atlantic Ridge), *in* Bougault, H. *et al.*, (eds.), Initial reports of the Deep Sea Drilling Project: College Station, Texas, Texas A & M University, Ocean Drilling Program, 82 (2), 547-557.

Hanken, N.-M., 1979, The use of sodium tetraphenylborate and sodium chloride in the extraction of fossils from shales: Journal of Paleontology, 53, 738-740.

Hayashi, H., Yanagisawa, Y., Suzuki, N., Tanaka, Y., Saito, T., 1999, Integrated microbiostratigraphy of the Middle Miocene sequences in the Shimokurosawa district, Ichinoseki City, Iwate Prefecture, Northeast Japan: The Journal of the Geological Society of Japan, 105, 480-494 (Japanese with English abstract).

Honda, N., 1981, Upper Cenozoic calcareous nannofossil biostratigraphy of the Pacific side of Japan: Tohoku University, Ph. D. dissertation, 110p.

Irizuki, T., Ishizaki, K., Takahashi, M., Usami, M., 1998, Ostracode faunal changes after the mid-Neogene climatic optimum elucidated in the Middle Miocene Kobana Formation, central Japan: Paleontological Research, 2, 30-46.

Kasuya, M., 1987, Comparative study of Miocene fission-track chronology and magneto-biochronology: Science Reports of the Tohoku University, 2nd Series, 58, 93-106.

Kawada, K., 1948, On the Tertiary distributed around the Washinoko Massif, Tochigi Prefecture: Journal of the Geological Society of Japan, 53, 92 (in Japanese, title translated).

Maiya, S., 1978, Late Cenozoic planktonic foraminiferal biostratigraphy of the oil-field region of Northeast Japan, *in* Prof. N. Ikebe Memorial Volume, Cenozoic Geology of Japan: Osaka, Japan, Professor Ikebe Memorial Association, 217-229 (in Japanese with English abstract).

Miller, K.G., Aubry, M-P., Khan, M.J., Melillo, A.J., Kent, D.V., Berggren, W A, 1985, Oligocene-Miocene biostratigraphy, magnetostratigraphy, and isotopic stratigraphy of the western North Atlantic: Geology, 13, 257-261.

Oda, M., 1977, Planktonic foraminiferal biostratigraphy of the Late Cenozoic sedimentary sequence, central Honshu, Japan: Science Reports of the Tohoku University, 2nd Series, 48, 1-76.

Oda, M., Hasegawa, S., Honda, N., Maruyama, T., Funayama, M., 1984, Integrated biostratigraphy of planktonic foraminifera, calcareous nannofossils, radiolarians and diatoms of middle and upper Miocene sequences of central and northeast Honshu, Japan: Palaeogeography, Palaeoclimatology, Palaeoecology, 46**,** 53-69.

Odin, G.S., Takahashi, M., Cosca, M., 1995, 40/Ar-39/Ar geochronology of biostratigraphically controlled Miocene tuffs from central Japan: Comparison with Italy and age of the Serravallian-Tortonian boundary: Chemical Geology (Isotope Geoscience Section), 125**,** 105-121.

Saito, T., 1977, Late Cenozoic planktonic foraminiferal datum levels: the present state of knowledge toward accomplishing pan-Pacific stratigraphic correlation, *in* Saito, T., Ujiie', H. (eds.), Proceedings of the 1st International Congress on Pacific Neogene Stratigraphy: Kaiyo Shuppan, Tokyo, 61-80.

Sakai, T., 1986, Lithostratigraphy of Neogene Arakawa Group at the Type Section (Tochigi Prefecture, Japan): Utsunomiya University, Bulletin of the Faculty of General Education, 19 (2), 49-70 (Japanese with English abstract).

Spencer-Cervato, C., Thierstein, H.R., Lazarus, D.B., Beckmann, J-P., 1994, How synchronous are Neogene marine plankton events?: Paleoceanography, 9, 739-763.

Sugie, H., 1993, Analysis of paleoenvironment by radiolarians in the Late Miocene Arakawa Group (Tochigi Prefecture, Japan): News of Osaka Micropaleontologists, Special volume, 9, 313-335 (Japanese with English abstract).

Takahashi, M., Tanaka, Y., Mita, I., 1999, Chronostratigraphy of the middle Miocene marine sequence in the Karasuyama area, central Japan: With special reference to the CN5a / CN5b boundary: Journal of the Japanese Association of Petroleum Technologists, 64**,** 454-461.

Takahashi, M., Hayashi, H., Tanaka, Y., Okada, T., 2000, Geochronologic constraints on some important calcareous microfossil biohorizons in the lower part of the Miocene Karasuyama sequence, Japan: *in* Odin, G.S. (ed.), Phanerozoic Time Scale: International Union of Geological Sciences (IUGS), Subcommission of Geochronology, Bulletin of Liaison and Informations, 16, 27-36.

Takayanagi, Y., Takayama, T., Sakai, T., Oda, M., Kitazato, H., 1976, Microbiostratigraphy of some Middle Miocene sequences in northern Japan, *in* Takayanagi, Y., Saito, T. (eds.), Progress in micropaleontology; Selected papers in honor of Prof. Kiyoshi Asano: New York, Micropaleontology Press, 356- 381.

Tanaka, Y., Takahashi, M., 1998, Calcareous nannofossil biostratigraphy of the lower part of the Miocene Arakawa Group in the Karasuyama area, Tochigi Prefecture, central Japan: Journal of Geological Society of Japan, 104, 779-793 (Japanese with English abstract).

Usami, M., Oda, M., Takahashi, M., 1995, Planktonic foraminiferal biostratigraphy of Arakawa Group Kobana Formation, Tochigi Prefecture: Abstracts of the 102nd Annual Meeting of the Geological Society of Japan, 137 (in Japanese).

Usami, M., Oda, M, Takahashi, M., 1996, Planktonic foraminiferal biostratigraphy of the Kobana Formation, Arakawa Group: Abstracts of the 103rd Annual Meeting of the Geological Society of Japan, 144 (in Japanese).

Watanabe, M., Takahashi, M., 1997, Diatom biostratigraphy of the

Middle Miocene Kinone and lower Amatsu Formations in the Boso Peninsula, central Japan: Journal of the Japanese Association for Petroleum Technology, 62, 215-225 (Japanese with English abstract).
Yanagisawa, Y., Sugie, H., Sakai, T., Aita, Y., 2000, Marine diatom biostratigraphy and paleoenvironmental change of the Miocene Arakawa Group in the Karasuyama area, Japan: Abstracts of the 107th Annual Meeting of the Geological Society of Japan, 74 (in Japanese).

Manuscript received: May 1, 2000
Corrected manuscript received: August 26, 2000
Manuscript accepted: December 12, 2001

POSTSCRIPT

A part of this study has been published in a Japanese journal, the Journal of the Geological Society of Japan, after the submission of this manuscript:

Hayashi, H., Takahashi, M., 2000, Planktonic foraminiferal biostratigraphy of the middle part of the Miocene Arakawa Group in the Karasuyama area, Tochigi Prefecture, central Japan: Journal of the Geological Society of Japan, 106, 689-702 (in Japanese with English abstract).

In the paper referenced above, we discussed the planktonic foraminiferal biostratigraphy from the upper part of the Kobana to the Ogane Formations (upper half of the present study). A faunal list of the interval is given in that paper. The faunal list of the lower to middle part of the Kobana Formation is presented in the following Appendix.

Appendix. Faunal list of the lower to middle part of the Kobana Formation. The list includes all species from 28 samples in the lower to middle part of the Kobana Formation.

	2	3	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	SRD8	SRD10	SRD12	SRD15	221	6	174	Kbn33	176	Kbn34	Kbn35	Kbn36	Kbn37	214	Kbn19	Kbn16	Kbn14	Kbn9	Kbn8
Biorbulina biobata(d'Orbigny)																						2						
Catapsydrax spp.																					1					1		
Globigerina angustiumbilicata Bolli	2	8	5	3	9	7	6	1	4	9	4		5	2	3	7	16	17	20	5	6	1		15	14	24	7	
Globigerina druryi Akers				4				2	1							3	3					1		3			1	1
Globigerina falconensis Blow	3	1		6		3		2	8	3	2			2	3	4	2	2		2		6	2	5	1	21	6	
Globigerina praebulloides Blow	66	89	117	108	96	80	96	38	129	53	69	68	49	33	59	33	17	31	31	30	70	78	19	62	78	145	44	41
Globigerina pseudociperoensis Blow	9	2	3	1	3	1						1								5		7				3	2	2
Globigerina umbilicata Orr and Zaitzeff					1										1						2							
Globigerina weissi Saito		42		2	1	2	1	1	17	22	10	5		7	5	5	7	1	2	5			4	4	2	31		
Globigerina woodi Jenkins	55	28	16	23	18	30	18	7	28	15	17	4	9	39	22	54	20	4	18	37	16	27	17	74	6	38	22	23
Globigerinella obesa (Bolli)	1		1	2	3	4	5	1	2			1	2	5	4	1	1	3		8		1	2			2		2
Globigerinita glutinata (Egger)	2	78	54	13	15	8	17	19	84	87	79	65	47	47	14	20	13	8	15	23	19	22	8	37	12	37	30	14
Globigerinita uvula (Ehrenberg)		6	2	2			1	3	6	1	3		3		2	3	1	1	4	1	1	2	1	2	1	1	1	
Globigerinoides bisphericus Todd	4																											
Globigerinoides bollii Blow			1	6	1	3	1		2	2	3								1							4		1
Globigerinoides immaturus LeRoy	2	14	7		4	7	7		3		2	4	2	1		2	6	2	1	2	4	5	2	3		1	4	5
Globigerinoides obliquus Bolli	1	4				1	1												3	1				4		1		
Globigerinoides quadrilobatus (d'Orbigny)	2	7	3	5	10	1	6		6	5	4		1	2			4	7	5	2	6	8	2	2		6	2	3
Globigerinoides subquadratus (Broennimann)	2		3	1						1		1	1				1	1					2	2				1
Globigerinoides trilobus (Reuss)			1	1	3		1	1				1			2	1	1			1	1	1		1				2
Globoquadrina altispira (Cushman and Jarvis)				4			1					1		1	8	1		5	12		1	4				2		2
*Globoquadrina altispira globosa*Bolli						1								1	1	2	2		1			2		1		2		
Globoquadrina baroemoenensis (LeRoy)		4		1	2		2	1	1			1			1		4	6	8		2	4						1
Globoquadrina dehiscens (Chapman, Parr and Collins)	2	1	2	2	4				2	1				2			5	1		6	2		1	1	1	7	9	1
Globoquadrina larmeui Akers		1				1	2																					
Globoquadrina venezuelana (Hedberg)		5		4			1				1				1	2	1	3	3	6	2		1	1		1		
Globoquadrina spp.																										2	1	
Globorotalia adamantea Saito	8								1				1													5		
Globorotalia archeomenardii Bolli			6		3	4	5	5								2										2	1	
Globorotalia birnageae Blow		5							1													1				1		
Globorotalia cf. *birnageae* Blow											1		1											3			1	
Globorotalia bykovae (Aisenstat)	45	5	7	1					1			1				2						1	4			2	26	4
Globorotalia cf. *denseconnexa* Subbotina		1																										
Globorotalia ichinosekiensis Takayanagi and Oda																				2				1		4		
Globorotalia iwaiensis Takayanagi and Oda																9					1			2		1		
Globorotalia cf.*iwaiensis* Takayanagi and Oda															1												1	
Globorotalia miozea Finlay			1												1									1				1
Globorotalia cf. *miozea* Finlay											1			11								15	22					
Globorotalia cf. *miozea conoidea* Walter											1					3				1								1
Globorotalia panda Jenkins																				2	1					1		
Globorotalia peripheroronda Blow and Banner	2	17		6	3	3					1									1		2	2		1	1	1	
Globorotalia peripheroacuta Blow and Banner			1				1	1						2		2						1						1
Globorotalia cf. *peripheroacuta* Blow and Banner				3			3				1							1										
Globorotalia praemenardii Cushman and Stainforth			1				1	2							2											1		
Globorotalia praescitula Blow	14	3	17	15	15	17	19	13	10	16	46	23	13	18	5	42	8	3	8	4		26	2	7	3	8	15	7

Appendix. Continued.

	2	3	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	SRD8	SRD10	SRD12	SRD15	221	6	174	Kbn33	176	Kbn34	Kbn35	Kbn36	Kbn37	214	Kbn19	Kbn16	Kbn14	Kbn9	Kbn8
Globorotalia quinifalcata Saito and Maiya	5			4	3		1	7	20	6	15	7	20	11	9	9	1	2	9	2			1	9		9	16	
Globorotalia scitula (Brady)			1	1	4	4	9	19	26	9	14	17	10					5	12									
Globorotalia spp.															1	1												1
Globorotaloides aff. *falconarae* Giannelli and Salvatorini																											1	
Globorotaloides spp.			1																								1	
Neogloboquadrina continuosa (Blow) (dextral)	7	5	1					1	1		1		1	1	1				1	2			1				1	
Neogloboquadrina continuosa (Blow) (sinistral)	9	3					1	6	2	2	1	1	3	3					4				1	1		1	1	
Neogloboquadrina mayeri (Cushman and Ellisor) (dextral)		5	1						3	1									1		1							
Neogloboquadrina mayeri (Cushman and Ellisor) (sinistral)	1	3						6	2	3	2	3	1		1							2	1			1		
Neogloboquadrina nympha Jenkins (dextral)																												
Neogloboquadrina nympha Jenkins (sinistral)						1																	1					
Orbulina suturalis Broennimann			2			1	1									2	1						2	1		3	1	
Orbulina universa d'Orbigny														1	1				1									1
Praeorbulina curva (Blow)	1																											
Praeorbulina sicana (de Stefani)	3																											
Sphaeroidinellopsis disjuncta (Finlay)			7	3		1		1	2		1	1	1		4				3	1	1					4	2	
Sphaeroidinellopsis seminulina (Schwager)				1																		4				1	1	
Tenuitella clemenciae (Bermudez)		2	1	2	3					10	2	1	3	4	2	7	11	1	9	14				10	1	8	1	
Tenuitella minutissima (Bolli)												1		3		2	1											
Species	22	21	26	27	21	22	25	20	24	17	24	20	18	20	25	25	22	20	23	23	18	24	20	25	11	36	26	21
Total number of identified specimens	246	339	263	224	201	180	207	137	362	246	281	207	173	196	154	219	126	104	172	163	137	223	98	252	120	382	199	115
Miscellaneous	19	20	102	29	65	23	37	16	124	141	62	179	198	54	32	7	20	13	23	47	52	49	35	66	17	49	52	73
Total number of specimens	265	359	365	253	266	203	244	153	486	387	343	386	371	250	186	226	146	117	195	210	189	272	133	318	137	431	251	188
Number / g	848	287.2	580.8	101.2	425.6	324.8	780.8	489.6	1555.2	2476.8	548.8	1235.2	593.6	1600	1190	723.	934.4	374.4	312	672	604.8	435.2	212.	1017.6	876.8	689.6	401.6	601.6
Preservation (poor 1 <------> 5 good)	2	3	2	3	2	4	4	3	3	2	2	2	1	3	3	3	3	2	2	2	2	2	2	3	2	5	3	1