Bulletin of the Geological Survey of Japan, vol. 50 (3), p. 225-243, 1999

Reviews

Integrated stratigraphy of the Middle Miocene marine sequence in the Boso Peninsula, central Japan : a review

Masaki TAKAHASHI*, Isao MITA**, Mahito WATANABE*
and Isao MOTOYAMA***

Masaki TAKAHASHI, Isao MITA, Mahito WATANABE and Isao MOTOYAMA (1999) Integrated stratigraphy of the Middle Miocene marine sequence in the Boso Peninsula, central Japan : a review. *Bull. Geol. Surv. Japan,* vol. 50 (3), p. 225-243, 13 figs.

Abstract : Biostratigraphic investigations of siliceous and calcareous microfossils and the geochronologic results of interbedded tuff layers of the Middle Miocene marine sequence in the Boso Peninsula, central Japan, were reviewed. Diatom and radiolarian biostratigraphies were established along the Meigawa section in the Kamogawa area, central part of the Boso Peninsula, using calcareous nodules. Calcareous nannofossil biostratigraphy along the same section was recently revised. The direct stratigraphic relations among the planktonic foraminiferal, calcareous nannofossils, diatom and radiolarian biostratigraphies were clarified. The fission track age of the Kn-3 pumice tuff (15.0 ± 0.5 Ma (1σ error)) indicates the N.9/N.10 planktonic foraminiferal zone boundary, and the K-Ar age of 11.7 ± 0.2 Ma gives an age of the CN5a/CN5b calcareous nannofossil zone boundary. The most serious problems concerning the time scale is the discrepancy between the time scales of Berggren *et al.* (1995) and Wei (1995), which were constructed based on the different geomagnetic polarity time scales of Cande and Kent's (1995) and Baksi's (1993) models. Combining the established biostratigraphy with reported radiometric ages of tuff layers in the Meigawa section, we can conclude that the Berggren *et al.*'s (1995) integrated stratigraphic time scale is preferable to that of Wei (1995), when assuming the synchronism of the biohorizons across latitude.

1. Introduction

A succession of planktonic microfossil bio-events has permited the construction of a biostratigraphic time scale which is commonly employed for long-distance correlations. We can understand the geologic history in greater detail, combining the high resolution biostratigraphies with magneto- and chronostratigraphies. It is obvious that it is necessary to always revise the integrated time scale by the latest stratigraphic constraints.

Recent advances of the integrated time scale are dependent on the analysis of deep sea cores. However, chronostratigraphic constraints are quite limited, because datable volcaniclastic layers are rare in deep sea sediments. The discrepancy between the time scales of Berggren *et al.* (1995) and Wei (1995) is attributed to the lack of reliable radiometric ages for the sedimentary sequences. It is thus desirable to investigate the integrated stratigraphic study along the on-land volcano-sedimentary sequences in Japan. Fortunately, both calcareous and siliceous microfossils are obtained from some Miocene sequences in Japan, which enables us to elucidate stratigraphic relations between these microfossils directly. The Middle Miocene is a highly interesting terget because the age discrepancy between Berggren *et al.*'s and Wei's time scales amounts to more than 1.3 million years around Early/Middle Miocene boundary.

In this paper we integrate the recently reported biostratigraphic results of both the calcareous and siliceous microfossils and the radiometric ages of interbedded tuff layers in the Boso Peninsula. The stratigraphic relations of the biohorizons and dated tuff layers are clarified in order to discuss the validity of previous time scales.

* Mineral and Fuel Resources Department, GSJ
** Nihon Tennen Gas Co., Ltd. 2508 Minami-Hinata, Shirako-Machi, Chosei-Gun, Chiba 299-4205, Japan
***Department of Physics and Earth Sciences, University of the Ryukyus. Nishihara, Okinawa 903-0213, Japan

Keywords: integrated stratigraphy, Miocene, biostratigraphy, diatom, radiolaria, calcareous nannofossil, planktonic foraminifera, time scale, fission track age, Boso Peninsula, Japan

2. Geology

The Boso Peninsula is one of the best areas in Japan for late Cenozoic stratigraphic studies, because thick continuous marine sediments, yielding calcareous microfossils from most horizons, intercalates a large number of volcaniclastic layers. This sequence of fossiliferous Neogene and Pleistocene strata has only one stratigraphic break, named the Kurotaki Unconformity. Below the Kurotaki Unconformity, the thick marine sediments are subdivided into the following five formations in ascending order; the Kanigawa,

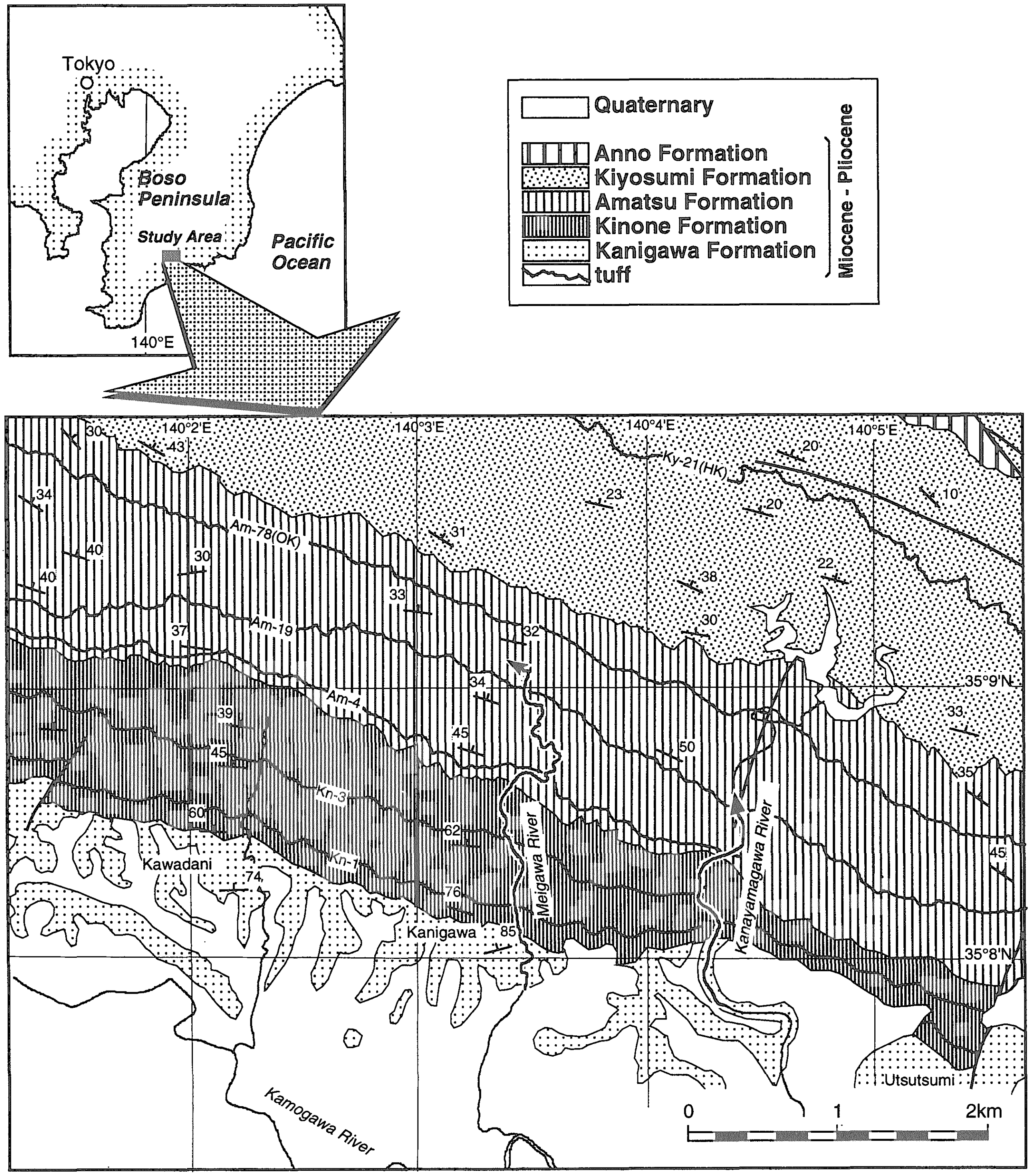


Fig. 1 Geological map of the Kamogawa area in the Boso Peninsula, central Japan, partly modified from Nakajima *et al.* (1981). The location of the Meigawa section is indicated.

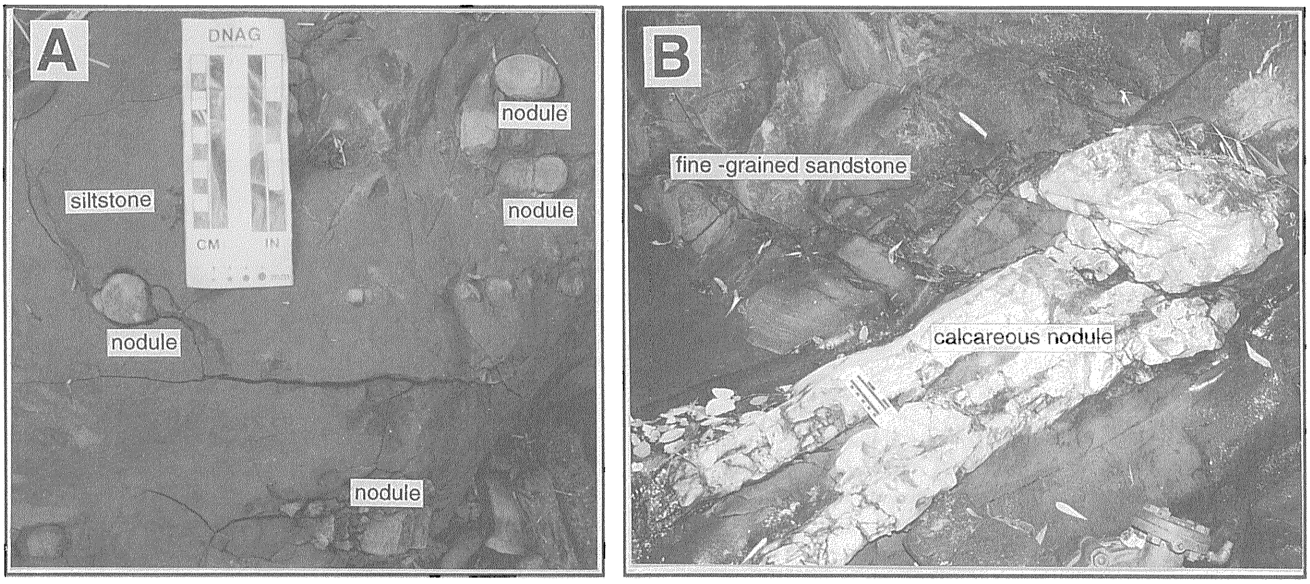


Fig. 2 Photographs of the calcareous nodules within the hemipelagic sediments of the Kanigawa Formation (A) and in the Amatsu Formation (B).

Kinone, Amatsu, Kiyosumi and Anno Formations. The lower half of this sequence, comprising the Kanigawa, Kinone and Anno Formations, is composed mainly of siltstones, while the upper half, constituted by the Kiyosumi and Anno Formations, is characterized by rhythmic alternations of sandstone and siltstone (Fig. 1).

Magnetostratigraphic analysis was applied to this sequence by many workers (Kawai, 1951; Nakagawa *et al.*, 1969; Kimura, 1974; Niitsuma, 1976), but only the last 6 m.y. history was established owing to magnetic instability (Nakagawa *et al.*, 1977). Detailed biostratigraphic studies (Oda, 1977; Honda, 1981) in conjunction with lithostratigraphic investigations clarified the relation between the many biostratigraphic events and key tuff layers. Oda (1977) established the planktonic foraminiferal biostratigraphy along the Kanayamagawa section (Fig. 1), while Honda (1981) investigated the calcareous nannofossil biostratigraphy along the Meigawa section, about 1 km west of the Kanayamagawa River. As so many key tuff layers are well correlated between these two sections, that stratigraphic relations of biohorizons between two sections are easily established. Recently the biostratigraphic investigations of siliceous microfossils (diatom and radiolaria), and an additional study of the calcareous nannofossil biostratigraphy, were performed along the Meigawa section.

As for the chronostratigraphic study, only a few fission track ages (Kasuya, 1990; Takahashi and Danhara, 1997) and K-Ar age (Takahashi *et al*, 1999) were reported.

3. Biostratigraphy

In this section, we give a brief description of biostratigraphic results of studies using diatoms (Watanabe and Takahashi, 1997), radiolaria (Motoyama and Takahashi, 1997), calcareous nannofossils (Mita and Takahashi, 1998) and planktonic foraminifera (Oda, 1977).

3.1 Diatom

Watanabe and Takahashi (1997) tried to find siliceous microfossils from the calcareous nodules in the Meigawa section. They recognized four diatom zones from the *Denticulopsis lauta* Zone (NPD4A) to the *D. praedimorpha* Zone (NPD5B) of Yanagisawa and Akiba's (1998) zonation (Fig. 3).

Samples KNG-27 and KNG-30 in the lower part of the Kinone Formation were assigned to the *D. lauta* Zone (NPD4A). The last occurrence (LO) of *Cavitatus lanceolatus* (D43.2) from KNG-27 indicates that this horizon is in the middle part of the *D. lauta* Zone (NPD4A). Samples KNG-35 to KNG-47 in the middle to uppermost part of the Kinone Formation were assigned to the *D. hyalina* Zone (NPD4B). The first occurrence (FO) of *D. hyalina* (D45) was recognized in sample KNG-35. The FO of *D. simonsenii* (D47) was tentatively placed in sample KNG-45. The last common occurrence (LCO) of *D. hyalina* (D50) was found in sample KNG-47 and the first common occurrence (FCO) of *D. simonsenii* (D50) is at near horizon (KNG-48). As sample KNG-48 from the uppermost part of the Kinone Formation did not yield *Denticulopsis praedimorpha*, this sample was assigned to the *C. nicobarica* Zone (NPD 5A). The FO of *D. praedimorpha* var. *minor* (D51) was recognized in sample KNG-49. Samples KNG-49 to KNG-79 in the lower part of the Amatsu Formation were assigned to the *D. praedimorpha* Zone (NPD5B). The LO of *C. nicobarica* (D52) was recognized in sample KNG-51.

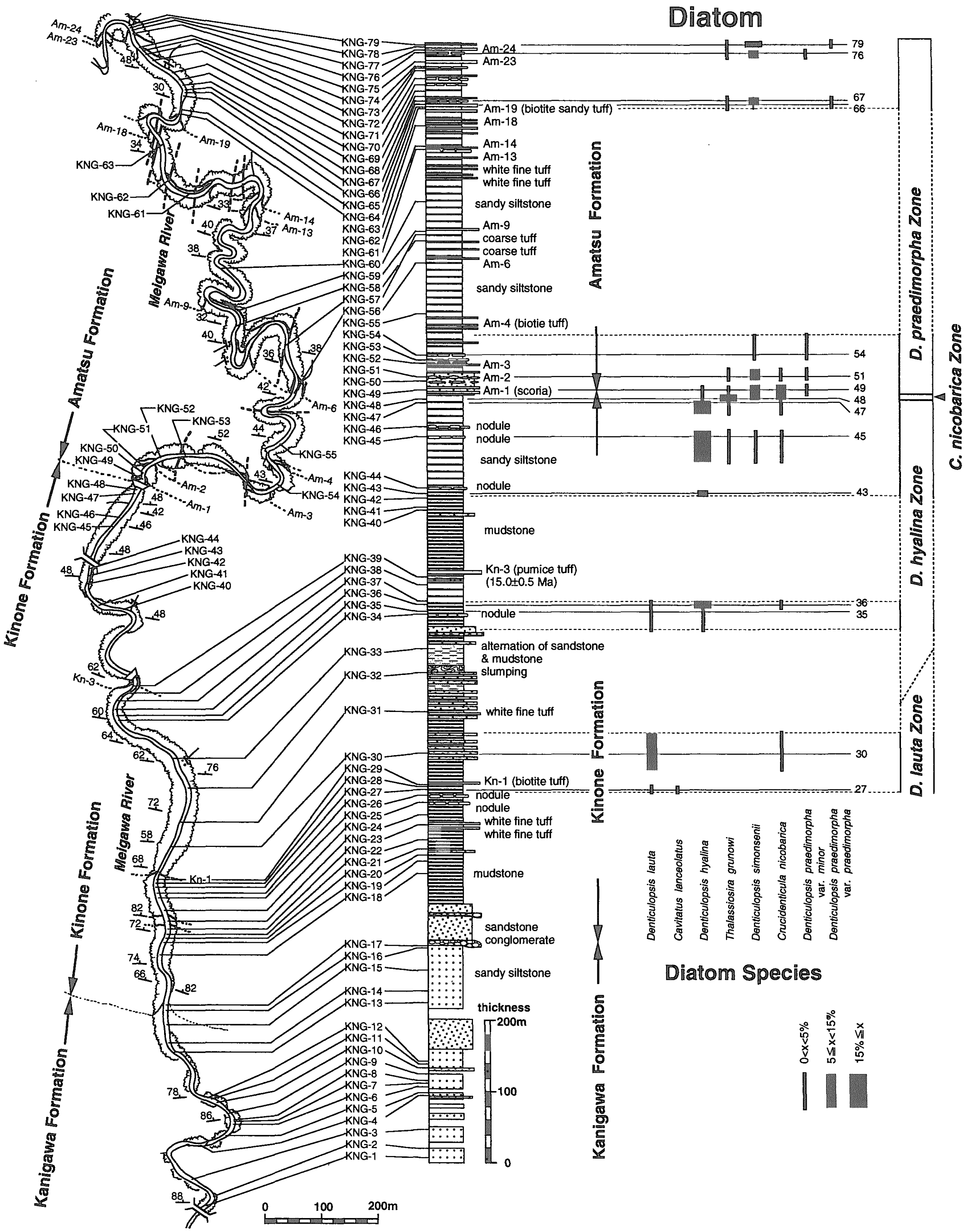


Fig. 3 Geological route map, columnar section with sample localities (horizons), stratigraphic distribution of selected diatoms and diatom zones along the Meigawa section (Watanabe and Takahashi, 1997).

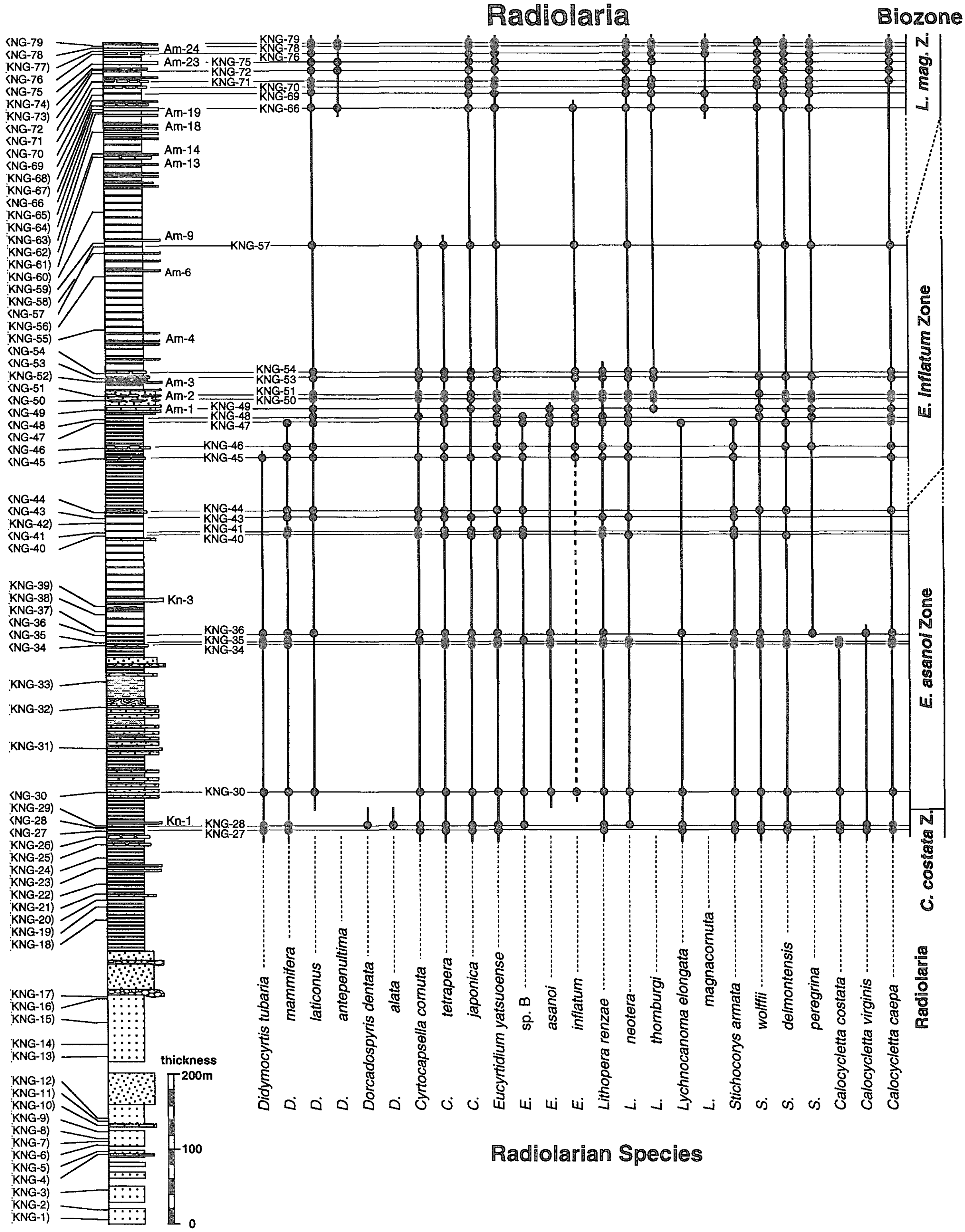


Fig. 4 Columnar section with sample horizons and stratigraphic distribution of selected radiolarians of the Meigawa section (Motoyama and Takahashi, 1997).

The FO of *D. praedimorpha* var. *praedimorpha* (D53) was recognized in sample KNG-66.

3. 2 Radiolaria

Motoyama and Takahashi (1997) studied 62 samples collected from the Meigawa section and recognized the following four radiolarian zones of Motoyama and Maruyama (1998), including two subzones (Fig. 4).

The *Calocycletta costata* Zone is defined by the interval from the FO of *C. costata* to the FO of *Eucyrtidium asanoi*. In the Meigawa section, samples KNG-27 and KNG-28 in the lower part of the Kinone Formation (around key tuff bed Kn-1) were assigned to this zone, based on the presence of *C. costata* and the absence of *E. asanoi*.

The *Eucyrtidium asanoi* Zone is the interval from the FO of *E. asanoi* to the FO of *E. inflatum*. However, FOs of these two species were recognized in the same sample (KNG-30) and the *E. asanoi* Zone was not defined in the Meigawa section in the sence of the original zonal definition. Motoyama and Takahashi (1997) adopted the first consistent occurrence (FC) of *E. inflatum* as an upper limit of this interval zone. The LOs of *C. costata* and *C. verginis* and the FO of *S. peregrina* fall in this zone.

The *Eucyrtidium inflatum* Zone is defined as the interval from the FC of *E. inflatum* to the FO of *L. magnacornuta* in this sequence. This zone can be subdivided into lower and upper Subzones, a and b respectively, by the rapid decrease (RD) of *C. tetrapera*. As Motoyama and Takahashi (1997) have not assessed abundance of *C. tetrapera* in the samples examined, they used the last consistent occurrence (LC) in sample KNG-57 as the boundary event between the two subzones tentatively. Therefore, the upper part of the Kinone Formation and lowest part of the Amatsu Formation correspond to the *E. inflatum* Zone a Subzone. The radiolarian biohorizons of the LOs of *D. tubaria*, *D. mammifera*, *Eucyrtidium* sp. B, *E. asanoi*, *S. armata*, *L. renzae* and the FO of *L. thornburgi* were recognized in this subzone. In contrast, *E. inflatum* Zone b Subzone was not recognized, due to the absence of radiolaria from a thick interval between the LO of *C. tetrapera* (KNG-57) and the FO of *L. magnacornuta* (KNG-66).

The *Lychnocanoma magnacornuta* Zone is a partial-range zone defined between the FO and LC of *L. magnacornuta* (Motoyama, 1996). Motoyama and Takahashi (1997) found the FO of this species near the Am-19 Tuff, so that the uppermost part of this section corresponds to the *L. magnacornuta* Zone. The LO of *E. inflatum* is located in this zone.

3. 3 Calcareous Nannofossil

A calcareous nannofossil biostratigraphy was first reported along the Meigawa section by Honda (1981), and recently revised by Mita and Takahashi (1998). Mita and Takahashi (1998) recognized three calcareous nannofossil zones of Okada and Bukry's (1980) zonation namely, CN3～CN4, CN5a and CN5b (Fig. 5).

Samples MEI-2 to MEI-31 are assigned to zones CN3～CN4, because *Sphenolithus heteromorphus* occurred in each sample. The CN3/CN4 boundary is originally defined by the LO of *Helicosphaera ampliaperta* (Bukry, 1973, 1975), however, unfortunately this biohorizon was not recognized in the Meigawa section. The RD of the *D. deflandrei* group (i.e. the sum of the short-arm *Discoaster* and *D. deflandrei*) is one of the most useful biohorizons to determine the CN3/CN4 boundary (Sato *et al.*, 1991; Rio *et al.*, 1990). Therefore Mita and Takahashi (1998) examined the RD of *D. deflandrei* group in the Meigawa section and concluded that the lower part of the Kinone Formation, except for its lowest two samples (MEI-1 and MEI-2), belongs to the CN4. The top of the CN4, defined by the LO of *S. heteromorphus*, was well determined between the sample MEI-31 and MEI-31.5 in the upper part of the Kinone Formation.

Zone CN5a was recognized between the uppermost part of the Kinone Formation and the lowest part of the Amatsu Formation (samples MEI-31.5 to MEI-42), in which *Cyclicargolithus floridanus* and *Reticulofenestra pseudoumbilicus* occurred dominantly. The CN5a/CN5b boundary is originally defined by the FO of *Discoaster kugleri*, however the typical form of *D. kugleri* was not encountered in the Meigawa section. The LO of *C. floridanus*, however, was used for determining the CN5a/CN5b boundary in the Meigawa section, because its biohorizon coincides with the FO of *D. kugleri* (Bukry, 1973). In this section, the LO of *C. floridanus* was recognized in MEI-42, close to the Am-4 Tuff horizon in the lowest Amatsu Formation. Therefore, Mita and Takahashi (1998) concluded that the CN5a/5b boundary was situated in the lowest part of the Amatsu Formation.

The top of the CN5b is defined by the FO of *Catinaster coalitus*, which was not found from the Meigawa section. Therefore, the lower part of the Amatsu Formation, between the Am-4 and Am-24 Tuff horizons, is placed in the CN5b.

3. 4 Planktonic Foraminifera

Oda (1977) established planktonic foraminiferal biostratigraphy along the Kanayamagawa River, 1 km east of the Meigawa section. Figure 6 shows the biostratigraphic result of Oda (1977), for the Kinone and the lower part of the Amatsu Formations.

The FO of the genus *Orbulina* defines the base of the N.9 planktonic foraminiferal zone (Blow, 1969), that is regarded as one of the most reliable datum levels for long-distance stratigraphic correlation. The biohorizon was recognized in sample K52, about 50 m

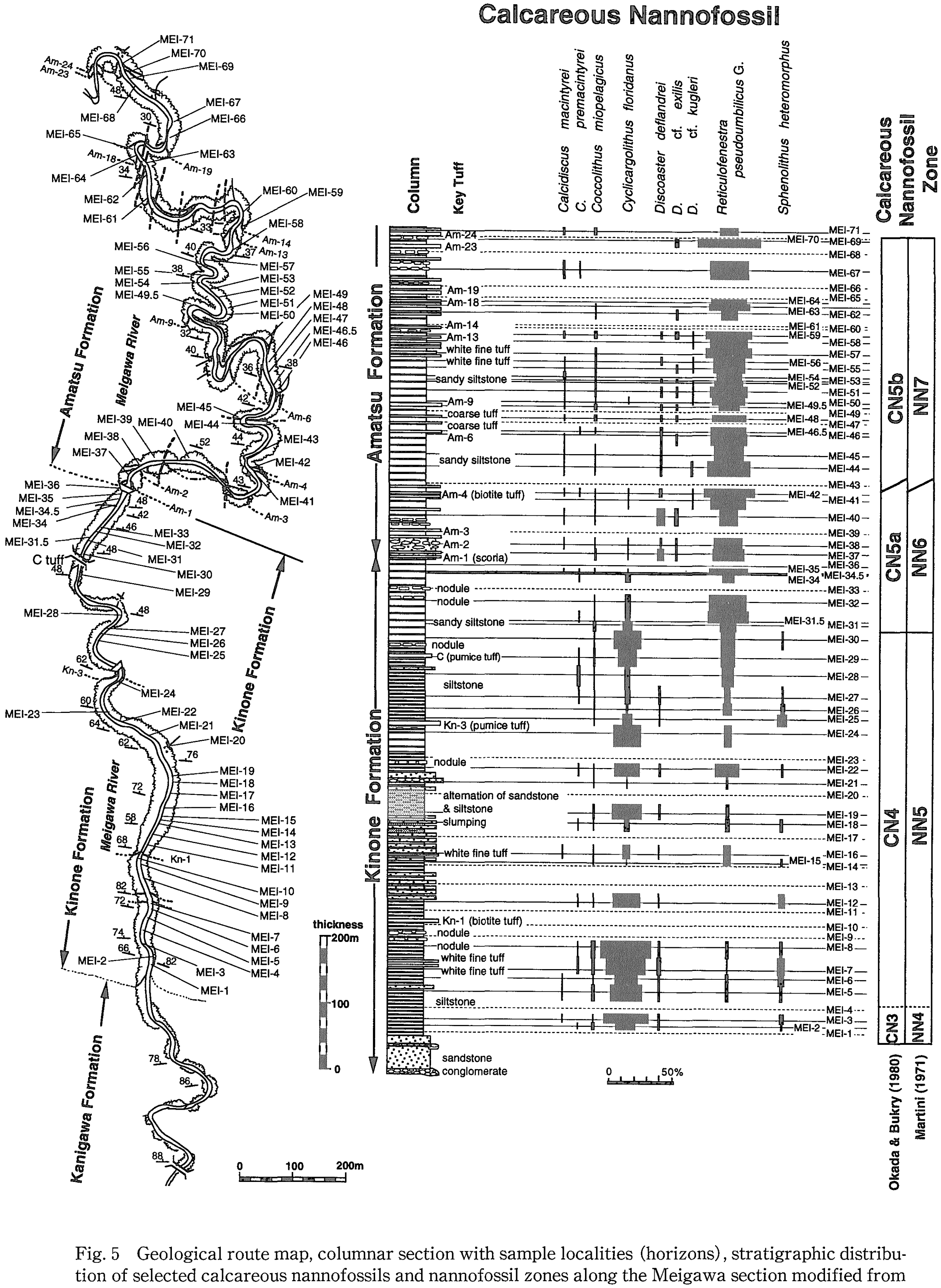


Fig. 5 Geological route map, columnar section with sample localities (horizons), stratigraphic distribution of selected calcareous nannofossils and nannofossil zones along the Meigawa section modified from Mita and Takahashi (1998).

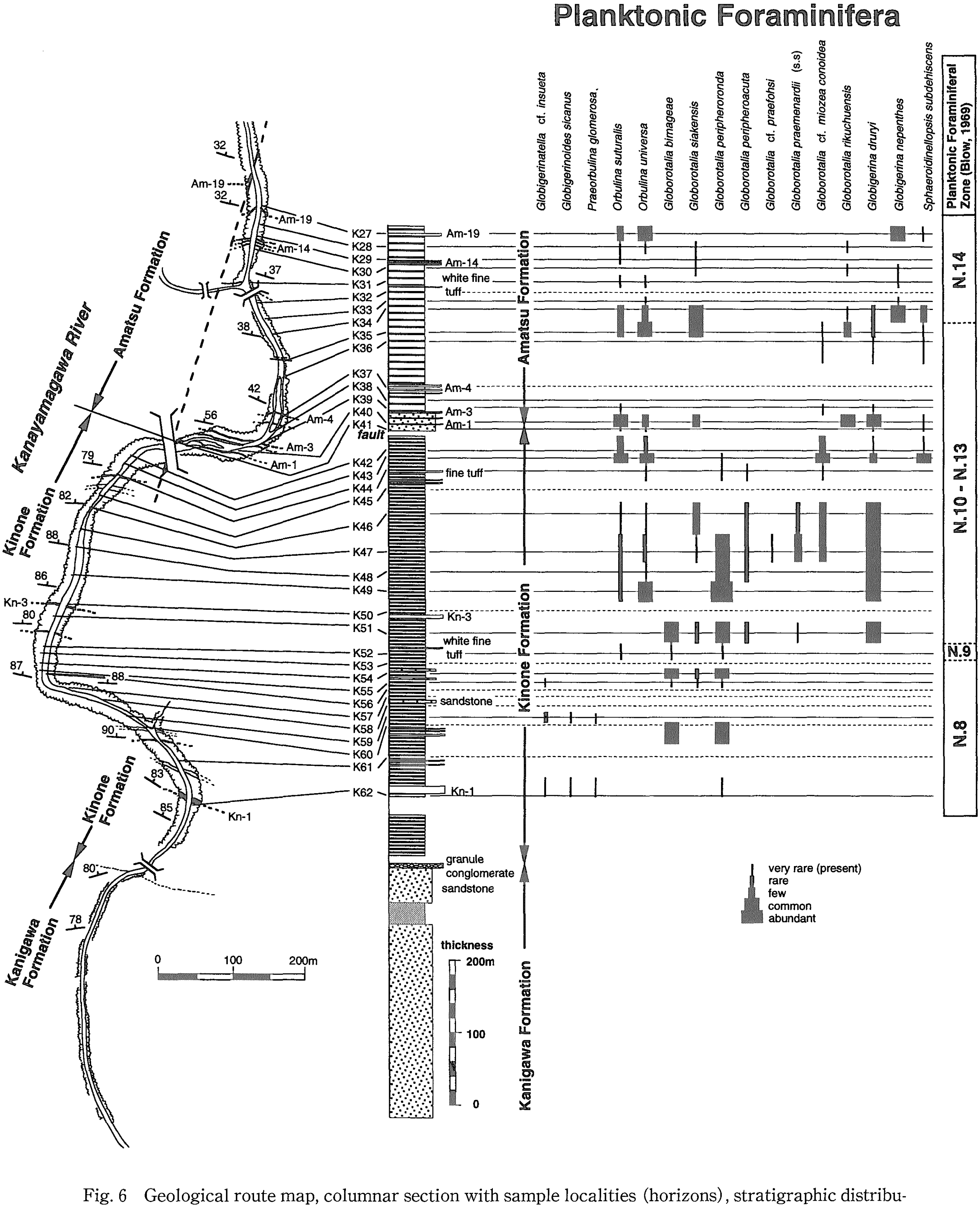


Fig. 6 Geological route map, columnar section with sample localities (horizons), stratigraphic distribution of selected planktonic foraminifera and foraminiferal zones of the Kanayamagawa section, adjacent to the Meigawa route, modified from Oda (1977). Some key tuff layers are correlated between the Kanayamagawa and Meigawa sections, enabling to recognize the stratigraphic relations of biohorizons between the two sections.

below the Kn-3 Tuff in the upper part of the Kinone Formation. The lowest two samples (K59 and 62) both yielded *Globigerinoides sicanus*, which appears from the bottom of zone N.8, so that the lower and middle part of the Kinone Formation is correlative to zone N.8, and the N.8/N.9 boundary is located about 50m below the Kn-3 Tuff.

The FO of *Globorotalia peripheroacuta*, which defines the base of the N.10 zone (Blow, 1969), was recognized in sample K51, 10-15m below the Kn-3 Tuff.

The FO of *Globigerina nepenthes* defines the base of zone N.14 (Blow, 1969). The FO of *G. nepenthes* is recognized in the sample K34, in between the Am-1 and Am-19 Tuff horizons. Therefore, the uppermost part of the Kinone Formation up to the lower part of the Amatsu Formation are correlated with zone N.10 -N.13, and the uppermost part of this section is correlative to zone N.14.

4. Geochronology

Two fission track ages and one K-Ar age were reported from the Meigawa section. The pumice tuff Kn-3 (Figs. 7 and 8) in the Kinone Formation is located about 10-15 m above the FO of *Globorotalia peripheroacuta* (Oda, 1977). Takahashi and Danhara (1997) reported a zircon fission track age of 15.0 ± 0.5 Ma (1σ error) for the Kn-3 Tuff, which directly represents the geochronological age of the N.9/N.10 boundary of the planktonic foraminiferal zones.

Kasuya (1990) obtained a zircon fission track age of 11.5 ± 0.8 Ma for the Am-4 Tuff that is intercalated in the lowest part of the Amatsu Formation (Figs. 7 and 8). Takahashi *et al.* (1999) recently reported a 11.7 ± 0.2 Ma K-Ar hornblende age for the same tuff. As the LO of *C. floridanus*, defining the CN5a/CN5b boundary of calcareous nannofossil zones, was recognized 2m below the Am-4 Tuff horizon (Fig. 5), the geochronological data indicate the absolute age of CN5a/CN5b boundary.

5. Discussions

5.1 Stratigraphic relations of biohorizons and radiometric ages

Oda (1986) established a magneto-biostratigraphic time scale for both calcareous and siliceous microfossils. This time scale has been widely used for age determination and correlation of Neogene strata in Japan. Figure 10 shows the stratigraphic relations of some selected biohorizons on the Oda's (1986) time scale and of the Kanigawa section (Fig. 9). The stratigraphic order of each biohorizon is almost fully consistent, except for some horizons.

As for the relation between the FO of *E. inflatum* and the FO of genus *Orbulina*, the inconsistency may be attributed to the sporadic occurrence of planktonic foraminifera in the studied sections. The evolutionary lineage of the genus *Orbulina* was not recognized in the study area, so the first appearance datum (FAD) of *Orbulina* might be located below the FO horizon of *Orbulina*.

The LO of *E inflatum* is located higher than the FO of *G. nepenthes*, which indicates that these two species have coexisted during the Miocene. The stratigraphic ranges of *C. floridanus* and *D. praedimorpha* also overlap. Some radiolarian biohorizons including *E. inflatum*, *C. costata* and *L. neotera* show remarkable inconsistency between Oda (1986) and the present study. This inconsistency is a serious problem because these radiolarian biohorizons are used by Oda (1986) as reference points for the age estimation of other microfossil biohorizons. The isolated occurrence of *E. inflatum* in the sample KNG-30 places the FO of this species at much lower stratigraphic horizon than the FC event of the species in the Meigawa section. Inconsistency of the FOs of *E. inflatum* with diatom events exist between Noto Peninsula (Funayama, 1988) and DSDP Leg 57 from Site 438 (Reynolds, 1980). Thus, the biostratigraphic utility of the FO of *E. inflatum* seems to be uncertain. Similarly, the biostratigraphic usefulness of the LO of *C. costata* and the FO of *L. neotera* has not been well established, although both were correlated directly to magnetostratigraphy in the equatorial Pacific cores (Therer *et al.*, 1978). Definition of the FO and LO of a radiolarian species sometimes is a troublesome work, because the sporadic occurrences usually precede and follow the consistent and common occurrence. Very rare and sporadic occurrences of *L. neotera* from Site 438 samples (Reynolds, 1980) may have shortened the stratigraphic range of the species in the sedimentary sequence. The more than 8000 radiolarians obtained by Motoyama and Takahashi (1997) in the every sample gives a high reliability for the radiolarian events recognized in the Meigawa section. Therefore, the radiolarian stratigraphy from the section is the most reliable of the Miocene radiolarian stratigraphies in and around Japan.

The refined integrated stratigraphic time scale of the interval between 15.5 and 11.5 Ma was presented by Motoyama and Takahashi (1997), as shown in Fig. 11. The time scale is based on the geomagnetic polarity time scale of Cande and Kent (1995). The radiometric ages of the Am-4 and Kn-3 are also plotted. The biostratigraphic zonations of microfossils were integrated, while magnetostratigraphy was not established along this section.

5.2 Recent controversy in the time scale

The most important controversy concerning the integrated stratigraphic time scale is the discrepancy of age estimates between the time scales of Berggren

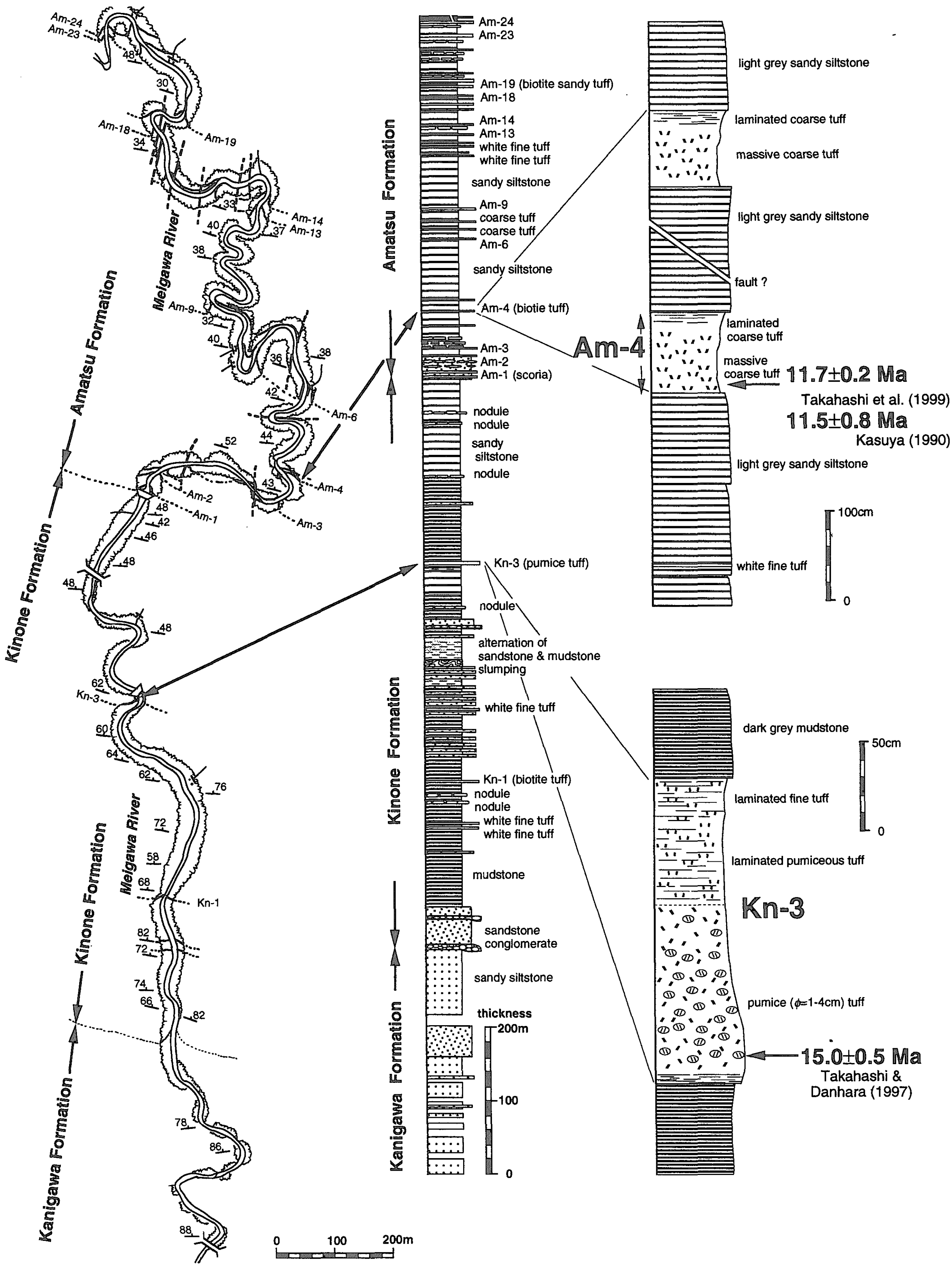


Fig. 7 The locations (horizons) of the Kn-3 and Am-4 Tuffs on the geological route map and stratigraphic column of the Meigawa section. Detailed stratigraphic columns of each tuff layer are also shown.

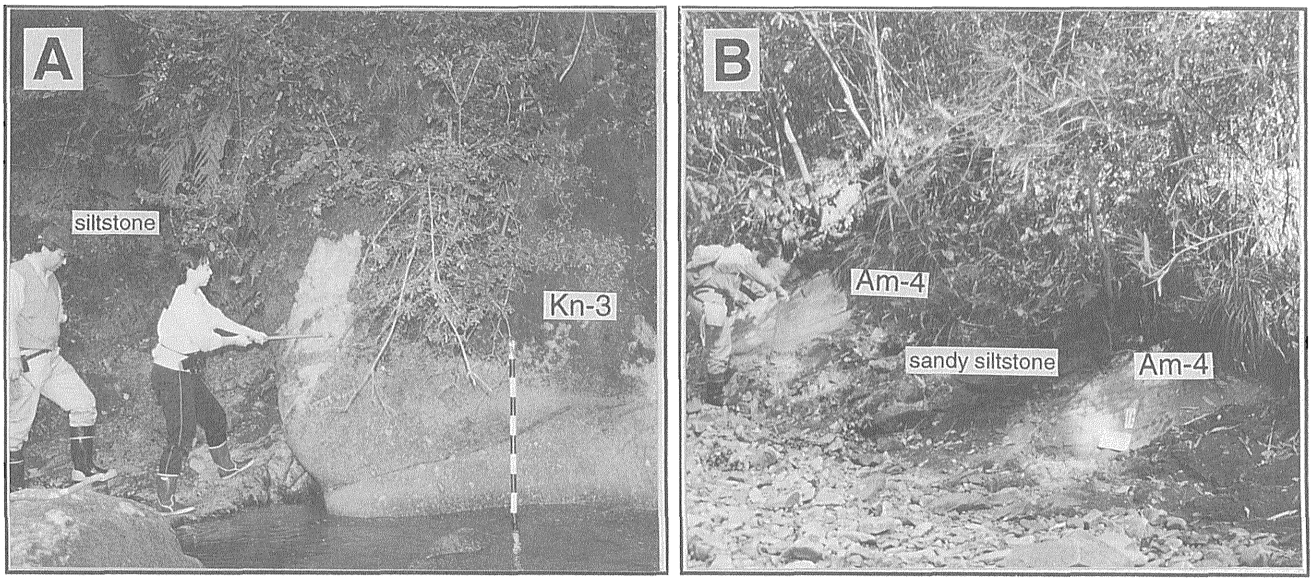


Fig. 8 Photographs of the Kn-3 (A) in the upper part of the Kinone Formation and the Am-4 (B) in the lowermost Amatsu Formation.

et al. (1995) and Wei (1995). This discrepancy is attributed to the use of different geomagnetic polarity time scales. The Berggren *et al.*'s (1995) time scale is constructed on the Cande and Kent's (1995) geomagnetic polarity time scale, while Wei (1995) constructed a time scale based on the Baksi's (1993) polarity time scale.

Cande and Kent (1992) have constructed a magnetic polarity time scale for the Late Cretaceous and Cenozoic based on a systematic analysis of marine magnetic profiles from the world's oceans and an improved set of age calibration points, and recently revised it (Cande and Kent, 1995). The latest version of the Cenozoic time scale constructed by Berggren *et al.* (1995) was based on the Cande and Kent's (1995) geomagnetic polarity time scale (Fig. 12).

On the other hand, Baksi (1990) carried out the $^{40}Ar/^{39}Ar$ incremental heating studies on whole-rock basalt samples from the Columbia River Basalt and the Steens Basalt. He combined high precision, accurate ages (standard error $<1\%$) with the known magnetostratigraphy of the Columbia River Basalt and concluded that the currently used time scales have underestimated the ages of various chrons around 16 Ma by a maximum of 0.9 m.y. Baksi (1993) constructed a Late Cenozoic geomagnetic polarity time scale, following the technique of the Cande and Kent (1992), using $^{40}Ar/^{39}Ar$ plateau ages for selected field reversals younger than 1, 2, 10, 16 and 34 Ma. His time scale was markedly different from the previous time scales, especially during the Middle-Late Miocene. As the differences between Cande and Kent's (1992, 1995) and Baksi's (1993) time scale are most marked at 4-8 Ma and 11-18 Ma, the estimations of each biozone boundary, synchronized with the geomagnetic polarities, became older (Fig. 12). Wei (1995) recalculated the ages of the magnetic reversals using the revised calibration points based on recently available radioisotopic dates and magnetostratigraphic data of Baksi (1993), while the newest version of the Cenozoic time scale of Berggren *et al.* (1995) adopted the geomagnetic polarity time scale of Cande and Kent (1995). Thus, the recent controversy concerning the estimation of the numerical ages of biostratigraphic zonation originates from the different interpretation of the marine magnetic anomaly patterns.

Figure 12 shows the relationships between the radiometric ages of the Kn-3 Tuff and Am-4 Tuff and estimated geochronometric ages for the N.9/N.10, N.13/N.14 and CN5a/CN5b boundaries. The N.9/N.10 foraminiferal boundary in the sedimentary sequence in the Boso area is correlated with a radiometric age by Takahashi and Danhara (1997). If we assume the synchronism of the FO or LO horizons of each planktonic microfossil across latitude, the estimated ages of biohorizons should be consistent with the radiometric ages of tuff layers intercalated close to them. Therefore, the absolute ages of the N.9/N.10 boundary of each time scale should be equal to the fission track age of sample Kn-3 (15.0 ± 0.5 Ma). It is clear that the Berggren *et al.*'s (1995) estimation of 14.8 Ma for the age of the N.9/N.10 boundary is well consistent with the fission track age of the Kn-3 Tuff, while Wei (1995), assuming 15.9 Ma, has overestimated it. Therefore, the fission track age of the Kn-3 Tuff may suggest that the time scales of Wei (1995) and Baksi (1993) have been overestimated the age of the Early/Middle Miocene boundary (Fig. 12).

In addition, the radiometric age of the Am-4 Tuff also offers the geochronological constraints for the latest Middle Miocene time scale. The Am-4 Tuff is located below the N.13/N.14 foraminiferal zone

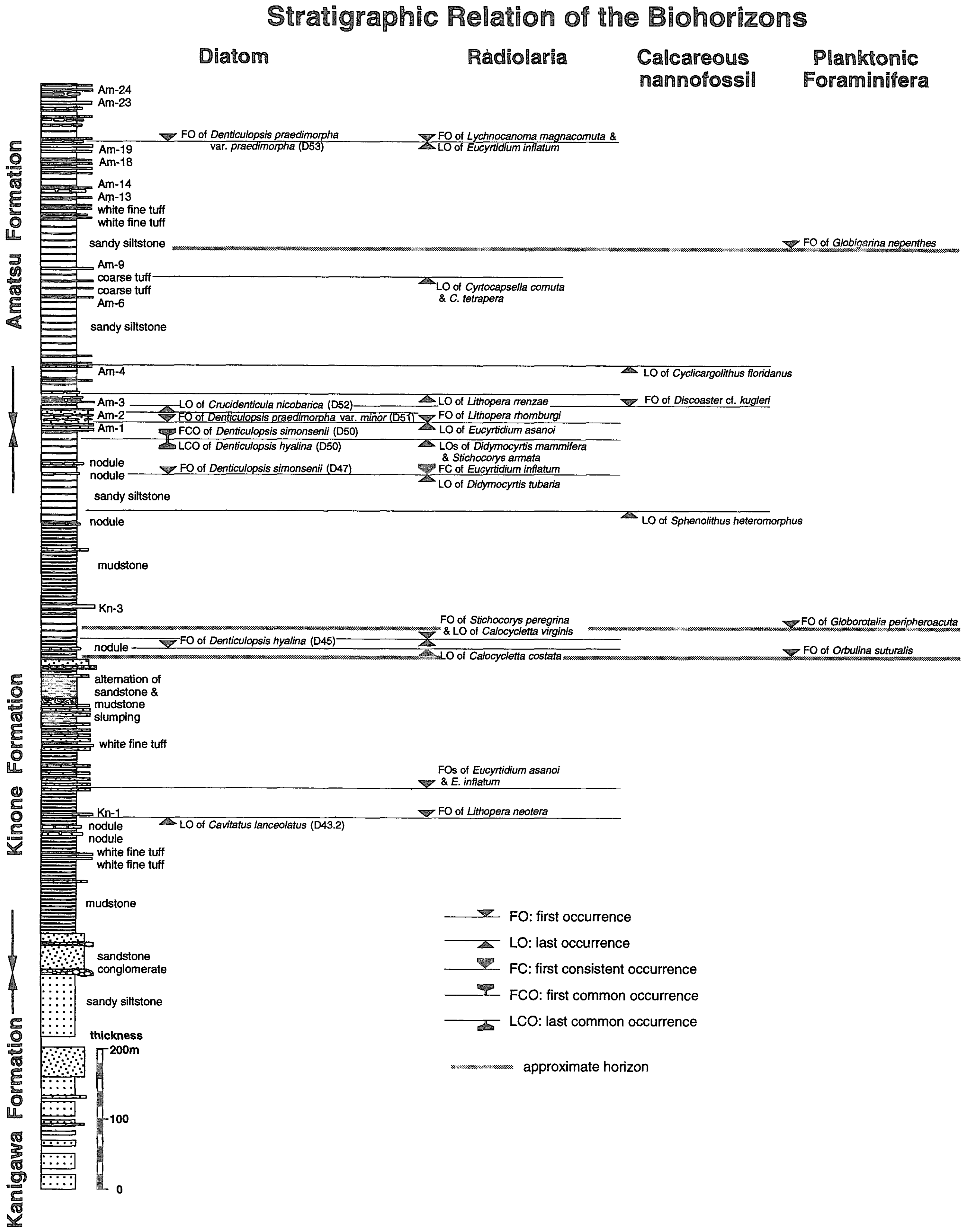


Fig. 9 Stratigraphic relationship between each microfossil biohorizon along the Meigawa section. The approximate positions of planktonic foraminiferal biohorizons, which were recognized along the Kanayamagawa section (Oda, 1977), are also plotted based on the tuff correlations between two sections.

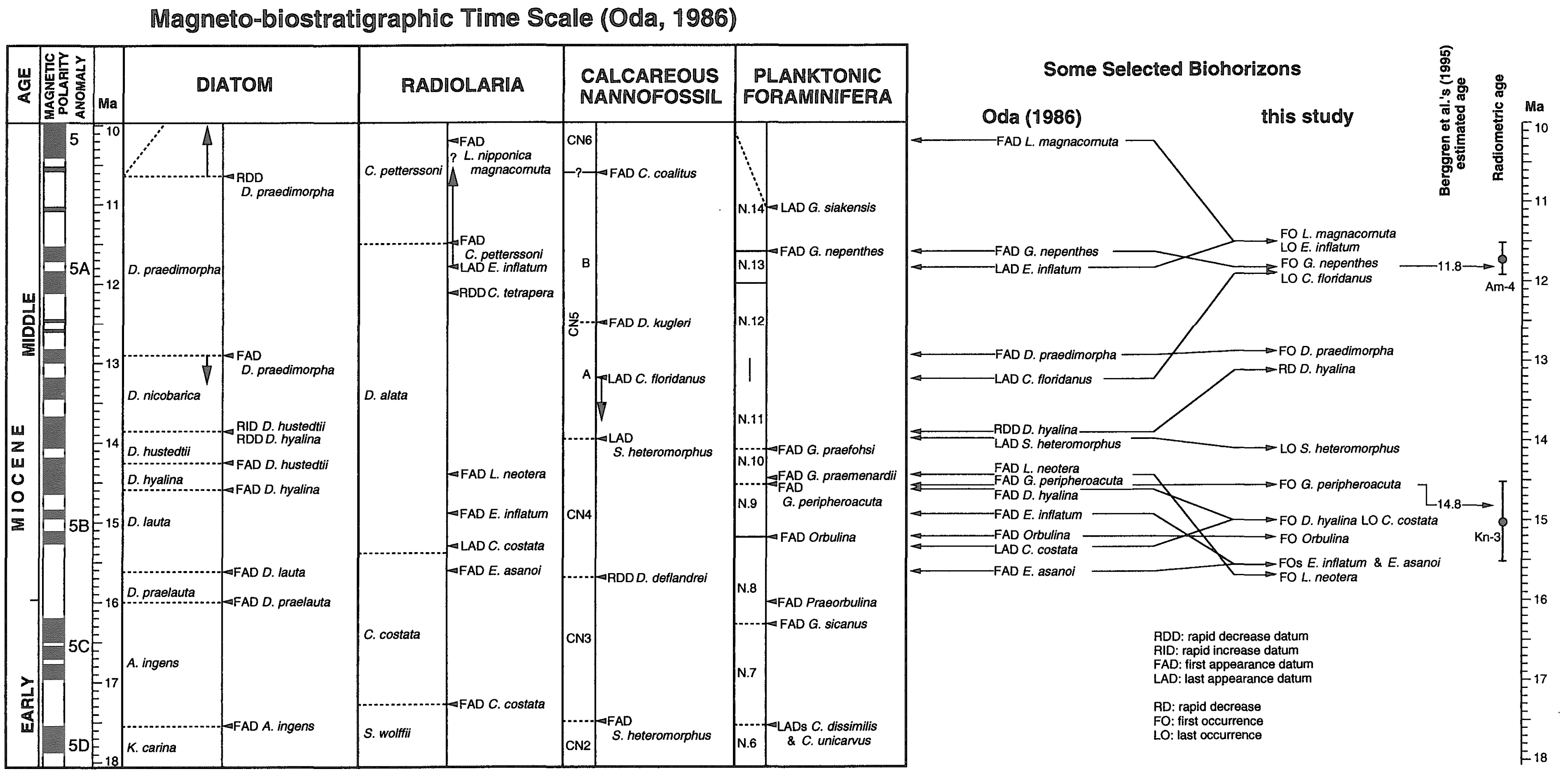
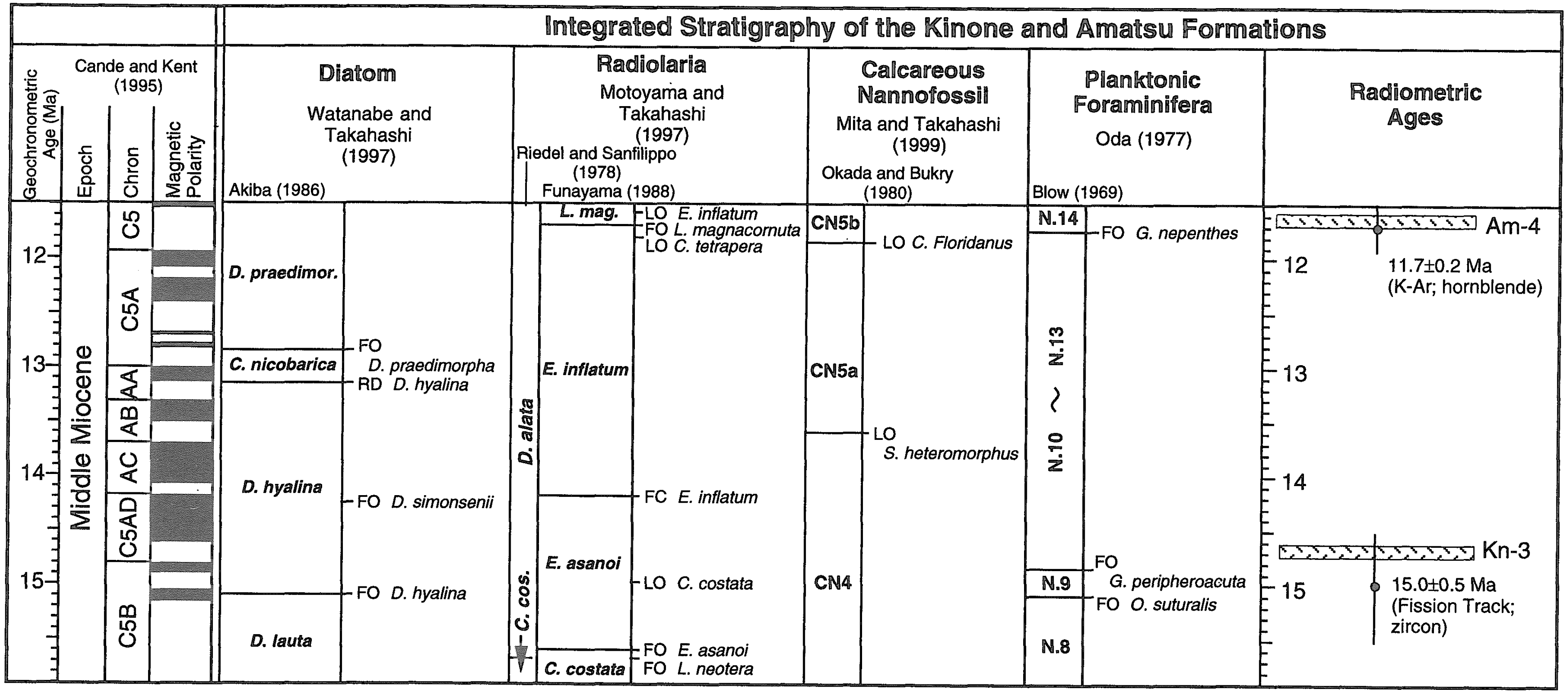


Fig. 10 Stratigraphic order of some selected biohorizons in the Oda's (1986) magneto-biostratigraphic time scale and of the Meigawa section. Crossing lines represent the changed stratigraphic relations.



FO: first occurrence
LO: last occurrence
FC: first consistent occurrence
RD: rapid decrease

Fig. 11 Composite biostratigraphy of Diatom, radiolarians, calcareous nannofossil and planktonic foraminifera of the Kinone and the lower Amatsu Formations, partly modified from Motoyama and Takahashi (1997).

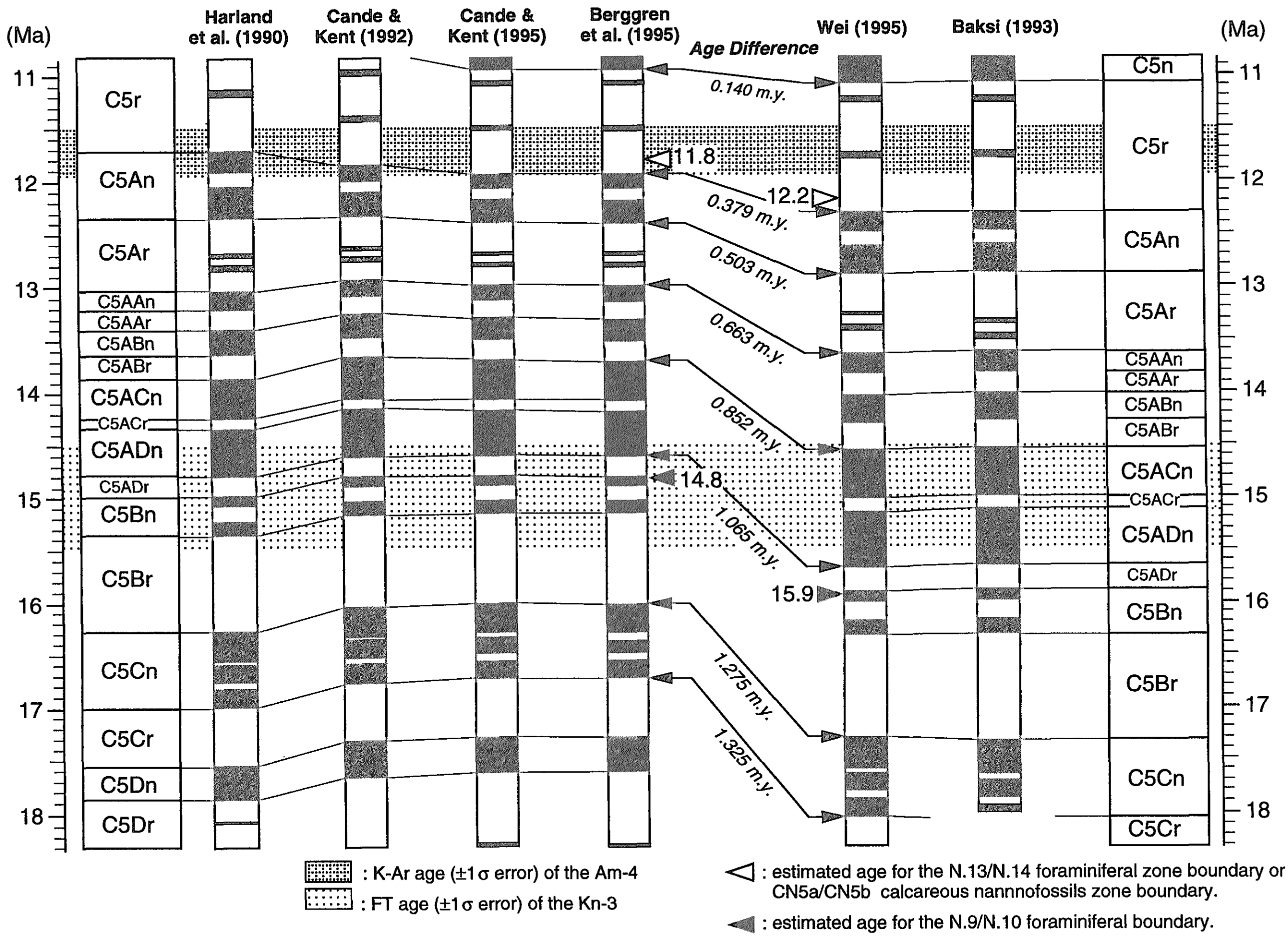


Fig. 12 Recent controversy concerning the geomagnetic polarity time scale. The difference between of the numerical ages of each reversal for both groups was mainly due to the adopted ages for the calibration points. This disparity in the time directly affects the numerical ages of each biozone boundary, because most of the boundaries have not been linked with the geochronology, but combined with the magnetostratigraphy.

boundary, defined by the FO of *G. nepenthes*, and near the CN5a/CN5b boundary of calcareous nannofossil zones, defined by the FO of *D. kugleri* or the LO of *C. floridanus*. The FO of *G. nepenthes* has been calibrated to early Chron C5r in DSDP Holes 563 (Miller *et al.*, 1985) and 608 (Miller *et al.*, 1991) and occurred at approximately the same level in the Buff Bay section of Jamaica (Berggren, 1993) with an age estimate of 11.8 Ma. As for the CN5a/CN5b boundary, the FO of *D. kugleri* is located in the lower Polarity Subchronozone C5r.3r with an estimated age of 11.8 Ma (Berggren *et al.*, 1995), same as the N.13/N.14 boundary. The LO of *C. floridanus* was well determined in the Meigawa section in lowest Amatsu Formation (Fig. 5). On the contrary, the FO of *G. nepenthes* was recognized at about 200m above the CN5a/CN5b boundary in the Meigawa section (Fig. 13).

The sediment accumulation history of the Meigawa section based on the Cande and Kent's (1995) and Baksi's (1993) geomagnetic polarity time scales are shown in Fig. 13. The age estimations of each biohorizons, based on the Cande and Kent's (1995) time scale, are after Berggren *et al.* (1995), and Yanagisawa and Akiba (1998). The ages of each biohorizon based on the Baksi's (1993) time scale were recalculated assuming the proportional positioning on the polarity pattern of Berggren *et al.* (1995), and Yanagisawa and Akiba (1998) relative to the Cande and Kent's (1995) polarity time scale.

The lower part of the Amatsu Formation is characterized by the high sediment accumulation rate of more than 100 cm/year. The Am-4 Tuff is located at the CN5a/CN5b boundary and below the N.13/N.14 biozone boundary, whose estimated age is 11.8 Ma on the Cande and Kent's (1995) time scale or 12.2 Ma on the Baksi's (1993) scale. The radiometric age of the Am-4 Tuff (11.7±0.2 Ma (K-Ar), 11.5±0.8 Ma (FT)) is consistent with the Berggren *et al.*'s (1995) estimate of the age. This suggests that the Cande and Kent's (1995) geomagnetic polarity time scale is correct, while the Baksi's (1993) time scale has overestimated its age. Therefore, we conclude that the

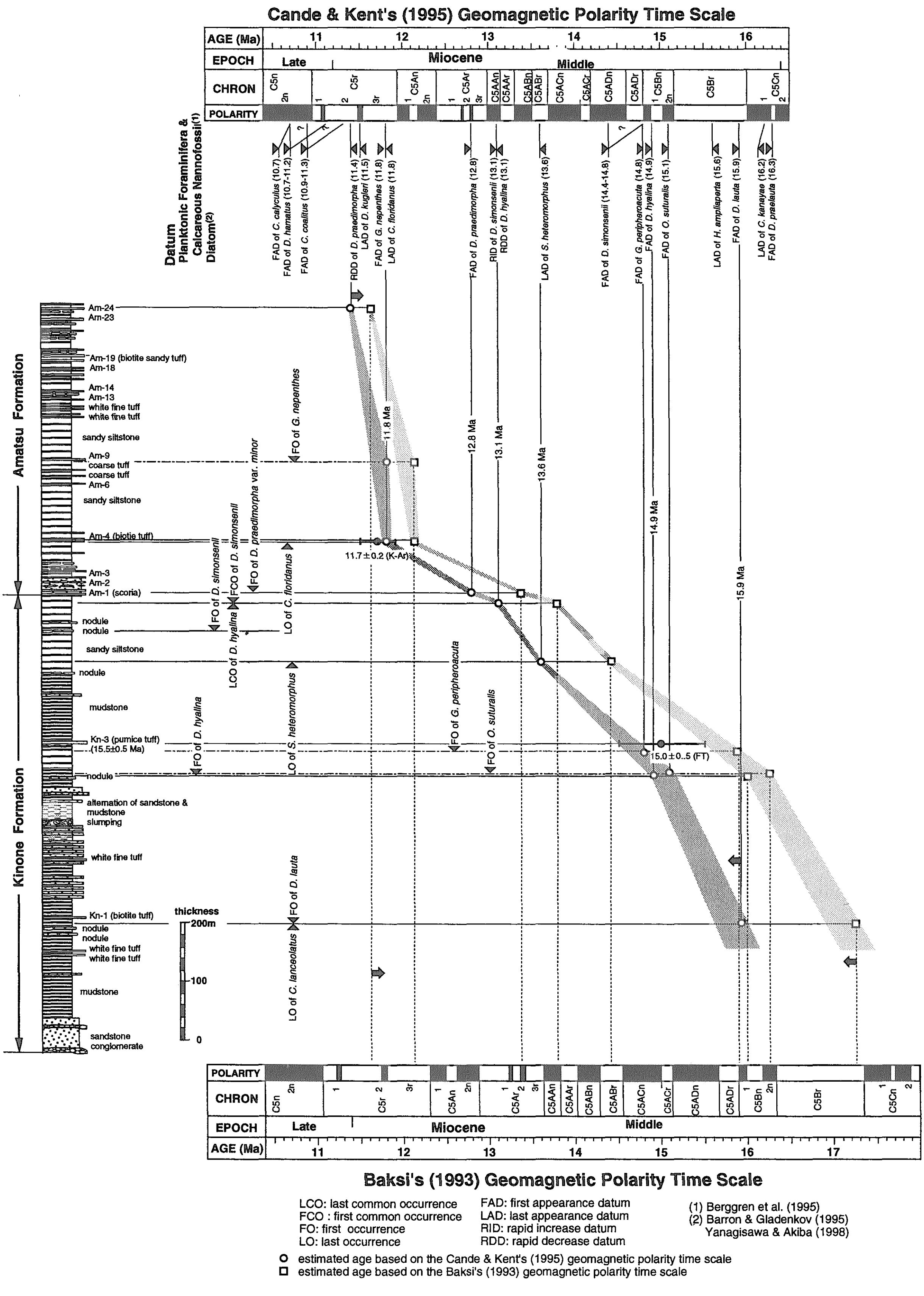


Fig. 13 Age-thickness plots based on the Cande and Kent's (1995) and Baksi's (1993) geomagnetic polarity time scales for the Kinone and lower Amatsu Formations in the Meigawa section. Radiometric ages of the Am-4 and Kn-3 Tuff beds, that are also plotted, are concordant with the Cande and Kent's (1995) time scale. However the use of the Baksi's (1993) time scale leads to an overestimation of the age of the boundary

Berggren *et al.*'s (1995) integrated stratigraphic time scale, constructed based on the Cande and Kent's (1995) geomagnetic polarity time scale, is preferable to Wei (1995) and Baksi (1993), assuming the synchronism of the biohorizons across latitude. As the discrepancy of the estimated ages of each magnetic polarity zones between two models exceeds 1.3 million years around the Early/Middle Miocene boundary (Fig. 12), the geochronologic age determination of the Kn-1 Tuff in the Kinone Formation, containing fresh biotite, is potentially important.

Biostratigraphy is one of the most useful tools for determining geologic ages. In contrast, radiometric dating yields the absolute age of intercalated volcaniclastic layers directly. Magnetostratigraphy provides worldwide time-horizons, but it only shows the digital signals of normal and reversed polarities. If we want to know the geological age of given strata, it is indispensable to obtain reliable biostratigraphic, magnetostratigraphic and geochronologic data that permit to establish a high-resolution integrated stratigraphic time scale. This requires that future research, such as biostratigraphy of other microfossils, high precision, $^{40}Ar/^{39}Ar$ dating of tuffs, magnetostratigraphy and chemostratigraphy, should be applied to the same section.

Acknowledgements : We thank Drs. Shuichi Tokuhashi and Yukio Yanagisawa of the Geological Survey of Japan for their critical reviews and suggestions for improving the manuscript.

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Received July 25, 1998
Accepted December 11, 1998

房総半島における中部中新統複合層序学：総説

高橋雅紀・三田　勲・渡辺真人・本山　功

要　旨

房総半島に分布する海成中新統下部について行われた各種の浮遊性微化石層序学的研究および放射年代学的検討を総括した。房総半島神川地域の銘川ルートにおいて確立された珪藻化石層序，放散虫化石層序，石灰質ナンノ化石層序，さらに近隣（金山川ルート）において報告されている浮遊性有孔虫化石層序の層位関係を比較し，従来の年代尺度（尾田，1986）について修正点を明示した。さらに，地磁気年代尺度に基づく複合年代尺度に関する現状の問題を整理し，さらに微化石層序学的に制約が与えられている2層（Kn-3, Am-4）の凝灰岩について測定された放射年代の層序学的意義について考察した。年代尺度に関する最も重大な論争は，Cande and Kent（1995）の地磁気年代尺度に基づいて各種の微化石層序区分を年代軸に配分したBerggren *et al.*（1995）の複合年代尺度と，Baksi（1993）の地磁気年代尺度に基づいているWei（1995）の年代尺度の間の不一致であるが，上記両凝灰岩の年代値はともにBerggren *et al.*（1995）のモデルによく符合するが，Weiの年代尺度による見積もり年代は放射年代値より有為に古い。浮遊性微化石基準面が汎地球規模で等時間面に大きく斜交しないと仮定すると，Cande and Kent（1995）の地磁気年代尺度（したがってそれに基づくBerggren *et al.*, 1995の複合年代尺度）の方が，Baksi（1993）の地磁気年代尺度（Wei，1995の複合年代尺度）より妥当であると判断された。