1. Introduction

The geologic timescale is one of the most important frameworks for discovering Earth history. When we construct a geologic timescale, we tie many chronostatigraphic data such as that from biostratigraphy, magnetostratigraphy, stable isotope stratigraphy, and so on, to chronometric data, including radioisotope dating, seafloor spreading interpolation and astronomical tuning methods. For refining a geologic timescale, each component of those should be critically tested and updated by new data.

A new geologic timescale (GTS2004; Lourens et al., 2004) has been recently published. The new timescale is constructed by astronomically-tuned biostratigraphy throughout the Neogene period. However, only a few sites, namely, Atlantic ODP Sites (925 and 926), Sicily (Italy, Mediterranean) and Morocco, were used in the late Miocene interval of the timescale. Therefore, we should test the diachroneity of each biohorizon in the Pacific region by correlating biostratigraphic and chronometric data.

The planktonic foraminiferal species Neogloboquadrina acostaensis is one of the most famous marker species for Late Miocene. The first occurrence (FO) of N. acostaensis defines the zonal boundary between zones N.15 and N.16 of Blow (1969). This biohorizon has been used for identifying the Tortonian/Serravarian boundary for a long time. In the new timescale GTS2004, the first regular occurrence (FRO) of N. acostaensis is proposed as an index datum of the Tortonian/Serravarian boundary (Hilgen et al., 2000; Lourens et al., 2004). However, the FO of N. acostaensis has been reported as being diachronous between low and middle latitudes (e.g. Hilgen et al., 2000). Therefore, we need to confirm the availability of this biohorizon for Pacific Neogene stratigraphy.

We examined the planktonic foraminiferal biostratigraphy of the lower part of the Kubota Formation for a precise determination of the FO of N. acostaensis defining the N.15/N.16 boundary. Furthermore, we demonstrate the reliability of the biohorizon for dating Neogene marine strata.

2. Geologic setting of the Tanagura area

Neogene sequences are distributed as a half-basin structure in the Tanagura area (Fig. 1). The tectonic deformation is very slight except for the western margin of the basin, which was deformed by Miocene tectonic activity along the Tanagura Tectonic Line.

Neogene sequences in the Tanagura area are divided into three formations: the Akasaka, Kubota and Nikogi Formations, in ascending order. Neogene sequences are distributed as a half-basin structure in the Tanagura area (Fig. 1). The tectonic deformation is very slight except for the western margin of the basin, which was deformed by Miocene tectonic activity along the Tanagura Tectonic Line.

Numerical age of the planktonic foraminiferal zonal boundary between N.15 and N.16 in the mid-latitude northwest Pacific region

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Abstract: The first occurrence of the planktonic foraminiferal species Neogloboquadrina acostaensis, which defines the zonal boundary between zones N.15 and N.16, was precisely determined just above the KT-1 Tuff in the lower part of the Kubota Formation in the Tanagura area, Northeast Japan. According to radiometric ages of the KT-1 Tuff, this biohorizon is estimated at 10.6 Ma. Compiling deep-sea drilling data demonstrates that the biohorizon is synchronous at least in the mid-latitudes.

Keywords: biostratigraphy, planktonic foraminifera, upper Miocene, Kubota Formation, Northeast Japan

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covers the Akasaka Formation and consists of silty fine-grained sandstone. This formation yields abundant marine fossils including mollusks, foraminifers, diatoms, and so on. The Nikogi Formation unconformably overlies the Kubota Formation and mainly consists of tuffaceous sandstone with a thick basal conglomerate.

The Akasaka and Kubota formations yield Shiobara-type fauna (Iwasaki, 1970; Chinzei, 1986), which is one of typical Japanese Miocene molluscan faunas. In addition, the Kubota Formation yields abundant microfossils. Aita (1988) is the first to report planktonic foraminifers from the Kubota Formation. Subsequently, Taketani and Aita (1991) studied the radiolarian biostratigraphy of the Kubota Formation. Shimamoto et al. (1998) examined planktonic foraminifera, calcareous nannofossils and radiolarians of the Kubota Formation. More recently, Hayashi et al. (2002) re-examined its planktonic foraminiferal biostratigraphy and Yanagisawa et al. (2003) conducted detailed diatom biostratigraphy of the Kubota Formation. According to those previous studies, the Kubota Formation corresponds to planktonic foraminiferal zone N.16 of Blow (1969), calcareous nan-
nofossil zones CN5b to CN7b of Okada and Bukry (1980), diatom zone NPD6 of Yanagisawa and Akiba (1998) and the radiolarian Lychnocanoma magnacornuta Zone of Motoyama and Maruyama (1996). In addition, radiometric ages have been obtained from two tuff layers, namely, KT-1 and KT-7 Tuffs (Takahashi et al., 2001a, b) (Fig. 2).

3. Material and method

Based on previous studies (Shimamoto et al., 1998; Hayashi et al., 2002), we presumed that the FO of *N. acostaensis* would be located around the KT-1 Tuff in the lower part of the Kubota Formation. In order to determine the precise position of the biohorizon, we collected eleven sandstone samples around the KT-1 Tuff at an interval of 0.2-1 m (Fig. 3). Rock samples (80 grams of dry weight) were disaggregated using the sodium sulfate solution and naphtha methods, and wet-sieved over a 250-mesh (63 micrometers opening). The residue was oven-dried and divided with a sample splitter. Planktonic foraminifers were picked from fractions coarser than 125 micrometers. SEM microphotographs of important species were taken by a scanning electron microscope (JSM-T220A; JEOL Co. Ltd., Tokyo, Japan).

4. Result

Thirty-four planktonic foraminiferal taxa from nine samples were detected (Table 1; Fig. 3). Two samples above key bed Kt-1, namely, NK7.81 and NK7.83, contain no foraminiferal fossils. The fossil preservation was generally poor, owing to the dissolution of shell surface structures and the accretion of sand grains. The maximum value for the planktonic foraminiferal number was observed at the sample NK7.8 (369 individuals / g).

*Neogloboquadrina acostaensis* successively occurs from sample NK7.85 and upward. *Globorotaloides falconarae* is found in sample NK7.88. Three biohorizons are detected in this interval; the FO and FRO of *N. acostaensis* is recognized between samples NK7.8 and NK7.85. The FO of *G. falconarae* is placed below sample NK7.88.

5. Discussion

The previous study has detected the FOs of *N. acostaensis* and *G. falconarae* in the lower part of the Kubota Formation (Hayashi et al., 2002). In the present study, we determined detailed positions for these biohorizons.

The FO and FRO of *N. acostaensis* are placed between samples NK7.85 and NK7.8. The sample NK7.8 is only 8 cm below the KT-1 Tuff, in turn the sample NK7.85 is 90 cm above the tuff. We consider that the FO and FRO of *N. acostaensis* in the Kubota Formation should be located just above the KT-1 Tuff.

The K-Ar and fission track (FT) ages of the KT-1 Tuff were determined as 10.56 ± 0.18 Ma and 10.7 ± 0.2 Ma (error in 1 sigma), respectively (Takahashi et al., 2001a). In addition, key tuff KT-7, about 170 m upward of the Kt-1 Tuff, was dated as 10.6 ± 0.3 Ma (error in 1 sigma) by the FT method (Takahashi et al., 2001b). These radiometric ages indicate a high sedimentation rate for the Kubota Formation. Accordingly, we consider that the numerical ages of the FO and FRO of *N. acostaensis* in the Tanagura area are given by the radiometric age of the KT-1 Tuff (about 10.6 Ma). This age corresponds to the middle part of geomagnetic subchron C5n.2n of both the CK95 and GTS2004 timescales (Fig. 4). The difference between the numerical ages of C5n.2n in CK95 and GTS2004 is less than 0.1 Ma. Therefore, it is hard to determine which timescale is more concordant with the
present data.

In previous studies of deep sea cores, the FO of *N. acostaensis* has been calibrated to the lower part of subchron C5n.2n in the middle-latitude regions of the North Atlantic and the South Pacific (DSDP Sites 563, 588 and 608; compiled by Berggren *et al.*, 1995) (Fig. 5). Considering the analytical error for radiometric ages of the KT-1 Tuff, the geomagnetic correlation of Berggren *et al.* (1995) is concordant with the present study. Astronomical calibration of biohorizons has been conducted for Miocene sedimentary sequences in Sicily, in the Mediterranean (Hilgen *et al.*, 2000; Sprovieri *et al.*, 2002). According to these results, the FO and FRO of *N. acostaensis* are numerically dated to 11.80 Ma and 10.554 Ma, respectively (Sprovieri *et al.*, 2002). The former age is significantly older than Pacific and Atlantic ages proposed by Berggren *et al.* (1995) and in the present study. On the other hand, the latter age shows good agreement with the present study. The inconsistency could result from dispersal of this species from the high-latitude North Atlantic to other areas (Zachariasse and Aubry, 1994). We point out that the FO of *N. acostaensis* in DSDP Sites 588 (Jenkins and Srinivasan, 1986) and 608 (Weaver, 1987) may correspond to the FRO, like the Tanagura area. Consequently, the FO of *N. acostaensis* might be globally synchronous in mid-latitude regions such as the North Atlantic, South Pacific and Northwest Pacific.

Astronomical calibration was also been conducted at equatorial Atlantic ODP Sites 925 and 926 (compiled by Lourens *et al.*, 2004). At those sites, the FO of *N. acostaensis* was calculated as 9.83 Ma and located in subchron C5n.1n of both CK95 and GTS2004. This age is about 1 Ma younger than in mid-latitude regions. As previously reported, the FO of *N. acostaensis* is diachronous between low-latitudes and mid-latitudes (Hilgen *et al.*, 2000; Turco *et al.*, 2002). However, the Neogene magneto-biostratigraphic timescale of GTS2004 (Lourens *et al.*, 2004, Fig. 21.1) is based only on low-latitude ages (Fig. 4). For mid-latitude Miocene sequences,
we propose that the magneto-biostratigraphic relationship of Berggren et al. (1995) is more suitable than that of GTS2004.

6. Conclusion

Detailed planktonic foraminifer sampling was conducted on the lower part of the Kubota Formation in the Tanagura area, Northeast Japan, to precisely determine the FO of *N. acostaensis* and thus define the zonal boundary between zones N.15 and N.16 (Hayashi). The FO and FRO of *N. acostaensis* are just above the KT-1 Tuff that has been dated at 10.56 ± 0.2 Ma by the FT method. These ages suggest that the FO and FRO of *N. acostaensis* in the Tanagura area are essentially equal to 10.6 Ma. This numerical age corresponds to geomagnetic subchron C5n.2n on the basis of both standard timescales for CK95 and GTS2004. This magneto-biostratigraphic correlation is generally concordant with previous studies based on mid-latitude deep-sea sites. We conclude that the FO of *N. acostaensis* has good potential for dating marine strata in mid-latitude regions.

7. Taxonomic notes

Genus *Neogloboquadrina* Bandy, Frerichs and Vincent, 1967

*Neogloboquadrina acostaensis* (Blow), 1959, *Globorotalia acostaensis* Blow, 1959 pl. 17, figs. 106a-c.

**Remarks:** Twenty-seven specimens were detected in the present samples. This species is characterized by having a strongly lobulate equatorial periphery and low slit-like aperture with a distinct lip. Most individuals in the Tanagura area are dextral-coiled. In the Mediterranean, dextral coiling individuals are dominant in the interval from 11.178 to 10.011 Ma (Hilgen et al., 2002, fig 3, 3a-c).

*Neogloboquadrina atlantica praetlanatica* Foresi, Iaccarino and Salvadorini, 2002


*Neogloboquadrina praetlanatica* (Ehrenberg). Aita et al., 1999, p. 105, pl. 6, figs. 2a-c.

*Neogloboquadrina cf. pachyderma* (Ehrenberg). Hayashi et al., 2002, fig. 5, 5a-c; 6a-c; Hayashi and Takahashi, 2004, fig 3, 3a-c.

*Neogloboquadrina atlantica* (Berggren) (small-sized).
Hilgen et al., 2000, pl.2, figs. 1-4.

Remarks: More than 200 specimens were obtained. This subspecies differs from *N. continuosa* in having a widely varying position of the aperture, which is often umbilical to extraumbilical position (Hayashi et al., 2002). Foresi et al. (2002) regarded this subspecies as an ancestor of *N. acostaensis*. We consider that *Neogloboquadrina cf. mayeri* (Cushman and Ellisor) sensu Hayashi et al. (2002; fig. 3, 8a-c) and the present study might be an intermediate form between *N. atlantica praeatlantica* and *N. acostaensis*.

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