Data report: middle Miocene to Pliocene planktonic foraminiferal biostratigraphy of the northern part of the Shikoku Basin, IODP Expedition 322 Site C0012[1]

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Chapter contents

Abstract

Planktonic foraminifers collected from Site C0012 drilled during Integrated Ocean Drilling Program Expedition 322 in the northern part of the Shikoku Basin, northwestern Pacific Ocean, were examined to establish a reference biostratigraphy of the Nankai Trough Seismogenic Zone. With the exception of several barren intervals, planktonic foraminifers are present throughout the cores at the studied site. Nineteen biohorizons are recognized at the studied site. Among these, four biohorizons are refined and fifteen are newly detected after the onboard study. The studied sequence correlates with Zones M7 to PL4, ranging in age from middle Miocene to Pliocene. A new age-depth plot of the studied site is presented on the basis of foraminiferal data from this study combined with nannofossil biohorizons determined by the onboard study.

Introduction

The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) was designed for the comprehensive understanding of the repeated mega-earthquake zone along the subduction boundary of the Philippine Sea Plate. Integrated Ocean Drilling Program (IODP) Expedition 322 is a part of the second stage of the NanTroSEIZE project. One of the main purposes of the expedition was to characterize incoming sediment and the upper igneous basement prior to their arrival at the subduction front of the Nankai Trough (see the **"Expedition 322 summary"** chapter [Underwood et al., 2010]). During the expedition, the R/V *Chikyu* drilled at Sites C0011 and C0012 in the northern part of the Shikoku Basin in the northwest Pacific Ocean. Site C0012 (32°44.888′N, 136°55.024′E, 3510.7 m water depth) is located near the crest of a prominent basement high known as Kashinosaki Knoll (Fig. **F1**). At this site, ocean floor sediment and igneous basement rocks were recovered with a rotary core barrel (RCB) system from 60–537.81 and 537.81–576 m coring depth below seafloor (CSF-A), respectively. The uppermost 60 m of sediment was jetted and therefore was not collected. The recovered sediment is mainly composed of hemipelagic claystone to siltstone with many intercalating volcanic and sand layers.

The reconstruction of the detailed deformation process of the Nankai Seismogenic Zone requires a combined stratigraphic ap-

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proach that includes biostratigraphic methods. According to results of the first stage of NanTroSEIZE, sediment from the Pliocene to late Miocene accretionary complex of the subduction zone bears calcareous microfossils including planktonic foraminifers (Ashi et al., 2009; Hayashi et al., 2011). The sediment composing the accretionary prism was originally deposited as continuous ocean-floor sediment of the Shikoku Basin. The onboard study (see the **"Site C0012"** chapter [Expedition 322 Scientists, 2010]) revealed that the Pliocene to middle Miocene interval of Site C0012 yields planktonic foraminiferal fossils. Therefore, this site has a good potential for establishing a standard biostratigraphy for the middle to late Miocene interval of the Nankai Seismogenic Zone. Thus, the purpose of this study is to construct a planktonic foraminiferal biostratigraphy of Site C0012 as a reference biostratigraphy for the NanTroSEIZE project.

Methods and materials

Samples used for this research were collected from Hole C0012A at an interval of 1–2 samples per core. We treated 51 samples ranging in age from middle Miocene to Pliocene. The stratigraphy of the studied site is divided into seven units; Unit I (0.0–150.86 m CSF-A) is upper Shikoku Basin deposits mainly composed of hemipelagic silty clay to silty claystone with thin interbeds of volcanic ash. Unit II (150.86–219.81 m CSF-A) is middle Shikoku Basin deposits consisting of silty claystone alternating with volcanic sandstone. Unit III (219.81–331.81 m CSF-A) is lower Shikoku Basin hemipelagites characterized by bioturbated silty claystone. Unit IV (331.81–418.29 m CSF-A) is lower Shikoku Basin turbidites consisting of alternations of silty claystone, clayey siltstone, and siltstone. Unit V (415.58–528.51 m CSF-A) is volcaniclastic-rich sediment composed of silty claystone alternating with tuff. Unit VI (528.51–537.81 m CSF-A) consists of pelagic claystone. Unit VII (537.81 m CSF-A to the bottom) is the Kashinosaki Knoll basement and is mainly composed of basalt. Each microfossil sample was collected from undisturbed hemipelagic sediment from Unit I to Unit VI.

Sediment samples of 0.5–1.0 g dry weight were disaggregated through the sodium tetraphenylborate method (Hanken, 1979). After the samples became macerated, each was wet-sieved through a 63 µm screen. Dried residues were then divided into suitable volumes yielding around 200 planktonic foraminiferal specimens with the use of a sample splitter. Planktonic foraminiferal specimens larger than 125 µm were picked up under a binocular microscope. Scanning electron microphotographs of selected index species were obtained with a JCM-5000 (JEOL Co. Ltd., Japan). To calculate foraminiferal flux (number/cm^2/k.y.), we used the onboard data set of dry density and accumulation rate (see the **"Site C0012"** chapter [Expedition 322 Scientists, 2010]).

The quality of each biohorizon was determined on the basis of the criteria of Hayashi et al. (2013) as follows (Fig. **F2**):

- Quality A = biohorizons recognized by continuous occurrences above their lowest occurrence and below their highest occurrence.
- Quality B = biohorizons showing discontinuous occurrence above their lowest occurrence and below their highest occurrence.
- Quality C = biohorizons characterized by both rare and sporadic occurrences of the marker taxa.

Taxonomic names in this study generally follow Wade et al. (2011) and Hayashi et al. (2013) except for *Paragloborotalia siakensis*. This species has previously been regarded as a junior synonym of *Paragloborotalia mayeri* by many workers (e.g., Bolli and Saunders, 1982). On the basis of scanning electron microphotographs of both holotypes newly redrawn by Zachariasse and Sudijono (2012), we identified all of our specimens as *P. siakensis* rather than *P. mayeri*.

We used the planktonic foraminiferal zonation defined by Berggren et al. (1995) and revised by Wade et al. (2011). The astronomically tuned timetable of planktonic foraminiferal biohorizons in the current timescale (ATNTS2004; Lourens et al., 2004) has been revised in part by Wade et al. (2011). Independent of this, Tian et al. (2008) presented an astronomically tuned timescale over the past 23 Ma at Ocean Drilling Program (ODP) Site 1148 in the South China Sea. We considered both ages for biohorizons of this study.

Results

With the exception of several barren interval, 72 taxa belonging to 20 genera of planktonic foraminifers were detected at Site C0012 (Table **T1**). Fossil preservation is generally moderate to poor. In particular, sediment from the lower part of Unit II to the upper part of Unit III has very rare occurrences of planktonic foraminifers with poor preservation and barren intervals (Table **T1;** Fig. **F3**). These barren samples contain only thick-walled benthic foraminifers with surfaces disfigured by dissolution. Therefore, the rare occurrences and barren intervals might be the results of dissolution processes beneath the carbonate compensation depth.

A total of 19 biohorizons were recognized in this study (Table **T2**). During the onboard preliminary observation, five biohorizons were reported from CC samples (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]). Among them, the lowest biohorizon, characterized by the first occurrence of *Orbulina universa,* should be disregarded because our study detected a younger biohorizon marked by the first occurrence of *Fohsella peripheroacuta* below this horizon. Other four biohorizons (8, 10, 14, and 17 of Table T2) were redefined after examination of section samples in this study.

The last occurrences of *Dentoglobigerina altispira altispira* (the base of Zone PL5) and *Sphaeroidinellopsis seminulina* sensu lato (the base of Zone PL4) should be located above Sample 322-C0012A-2R-4, 0.0–8.0 cm (64.54 m CSF-A). *Globorotalia plesiotumida* sparsely occur and the last occurrence of this species is estimated to be above Sample 3R-1, 60.0–68.0 cm (70.14 m CSF-A). The last occurrence of *Globoturborotalita nepenthes* (the base of Zone PL2) is clearly between Samples 3R-1, 60.0–68.0 cm (70.14 m CSF-A), and 4R-1, 50.0–58.0 cm (79.54 m CSF-A). The zonal maker species *Globorotalia tumida* appears in two samples, with the first occurrence (the base of Zone PL1a) recognized between Samples 4R-1, 50.0–58.0 cm (79.54 m CSF-A), and 5R-4, 50.0–58.0 cm (93.54 m CSF-A). Only one specimens of *Hirsutella margaritae* was detected in this study from Sample 10R-5, 60.0–68.0 cm (137.14 m CSF-A). However, this species was also observed in Samples 4R-CC, 14.0–19.0 cm (80.79 m CSF-A), and 7R-CC, 10.0–15.0 cm (107.95 m CSF-A) during the onboard study (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]). Therefore, the first occurrence of this species is suggested to be below Sample 10R-5, 60.0–68.0 cm. *Globorotalia lenguaensis,* the zonal marker of the base of Zone M14, was found in Sample 9R-1, 42.0–50.0 cm. Considering the sporadic occurrence of this species reported during the onboard study (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]), the last occurrence of this species is implied to be above Sample 9R-1, 42.0–50.0 cm (121.46 m CSF-A). *Globigerinoides conglobatus* was recognized from Samples 4R-CC, 14.0–19.0 cm (80.79 m CSF-A), and 6R-CC, 10.5–15.5 cm (101.845 m CSF-A) during the onboard study (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]). In this study, however, we detected only one individual of this species in Sample 4R-1, 50.0–58.0 cm (79.54 m CSF-A). Thus the first occurrence of this species should be located below Sample 6R-CC, 10.5–15.5 cm (101.845 m CSF-A). The dominant coiling direction of *Neogloboquadrina acostaensis* switches from sinistral to dextral between Samples 11R-5, 74.0–82.0 cm (146.78 m CSF-A), and 11R-7, 46.0–54.0 cm (149.50 m CSF-A). The first occurrence of *G. plesiotumida* (the base of Subzone M13b) is placed between Samples 21R-4, 40.0–48.0 cm (239.64 m CSF-A), and 22R-3, 45.0–53.0 cm (247.69 m CSF-A). *Globoturborotalita extremus* individuals were obtained from three samples, with the first occurrence of this species implied to occur below Sample 16R-4, 70.0–78.0 cm (192.74 m CSF-A). The last occurrence of *Globoquadrina dehiscens* lies between Samples 24R-4, 52.0–60.0 cm (268.26 m CSF-A), and 25R-1, 53.0–61.0 cm (273.27 m CSF-A). The first occurrence of *N. acostaensis* (the base of Subzone M13a) may be located below Samples 26R-2, 68.0–76.0 cm (284.42 m CSF-A). However, the precise position of this biohorizon cannot be determined because of the scarce fossil occurrence within it. The last occurrence of *P. siakensis* (the base of Zone M12) is detected between Samples 25R-1, 53.0–61.0 cm (273.27 m CSF-A), and 25R-5, 68.0–76.0 cm (279.42 m CSF-A). *Globoturborotalita decoraperta* is characterized by rare and sporadic occurrences and the lowest horizon where it is found is in Sample 26R-2, 68.0–76.0 cm (284.42 m CSF-A). Therefore, the first occurrence of this species could be suggested to be below this sample. The last occurrence of *Globigerinoides subquadratus* occurs between Samples 27R-3, 38.0–46.0 cm (295.12 m CSF-A), and 28R-3, 65.0–73.0 cm (304.89 m CSF-A). The first occurrence of *G. nepenthes* (the base of Zone M11) may be found below Samples 31R-5, 74.0–82.0 cm (336.48 m CSF-A). However, the position of this biohorizon may be subject to uncertainty because the species shows only sporadic occurrence in the middle Miocene interval at this site. The last occurrence of *Fohsella peripheroronda* is detected between Samples 36R-3, 80.0–88.0 cm (379.84 m CSF-A), and 37R-1, 35.0–43.0 cm (385.89 m CSF-A). The lowermost sample at the studied site (Sample 50R-3, 70.0–78.0 cm; 512.74 m CSF-A) contains *F. peripheroacuta.* Therefore, this sample may be considered younger than the first occurrence of *F. peripheroacuta* (the base of the Zone M7).

At Site C0012, the first occurrence of *N. acostaensis* (the base of Subzone M13a) is located below the last occurrence of *P. siakensis* (the base of Zone M12). Such discrepancy in these two biohorizons has been reported widely in subtropical to temperate regions. For example, the last occurrence of *P. siakensis* also crosses over the first occurrence of *N. acostaensis* at Deep Sea Drilling Project Site 563 in the North Atlantic (Miller et al., 1994) and at IODP Site U1338 in the eastern equatorial Pacific (Hayashi et al., 2013). Wade et al. (2011) suggested that the discrepancy in the Atlantic Ocean may be due to diachrony of the extinction of *P. siakensis*. In the western Pacific, however, our study is the first report of the overlap range of *N. acostaensis* and *P. siakensis*. Further study is required to clarify the reason of the discrepancy in this region.

Figure F3 represents the age-depth plot of Site C0012 using biohorizons of calcareous nannofossils (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]) and planktonic foraminifers (this study). The results indicate that foraminiferal biohorizons of this study generally are consistent with the calcareous nannofossil data. In particular, comparison of the two different timetables reveals that biohorizons of the study by Tian et al. (2008) are more concordant with calcareous nannofossil data than those of the study by Wade et al. (2011) (Fig. F3). This result can be explained by the difference in ecological provinces: Tian et al. (2008) constructed their astronomically tuned timescale by using sites in the South China Sea, approximately 2300 km southwest of Site C0012, whereas that of Wade et al. (2011) is mainly based on Atlantic sites (ODP Sites 925 and 926) and eastern equatorial Pacific sites (ODP Legs 111 and 138). Among these biohorizons, the last occurrences of *G. dehiscens* and *F. peripheroronda* have been previously reported as diachronous around the Japanese Islands. Motoyama et al. (2004) mentioned that the age of the last occurrence of *G. dehiscens* was estimated at approximately 8.4–9.6 Ma at ODP Leg 186 in the Sanriku forearc basin in northeastern Japan. The last occurrence of *F. peripheroronda* was numerically determined as 13.0 Ma by biotite K-Ar ages in the Karasuyama area in the central part of the Honshu Island (Hayashi and Takahashi, 2002). The precise understanding of diachronous biohorizons around Japan requires further studies.

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Figure F1. Map showing Site C0012 with previous Deep Sea Drilling Project, Ocean Drilling Program, and Integrated Ocean Drilling Program sites in and around Nankai Trough in the northwestern Pacific Ocean.

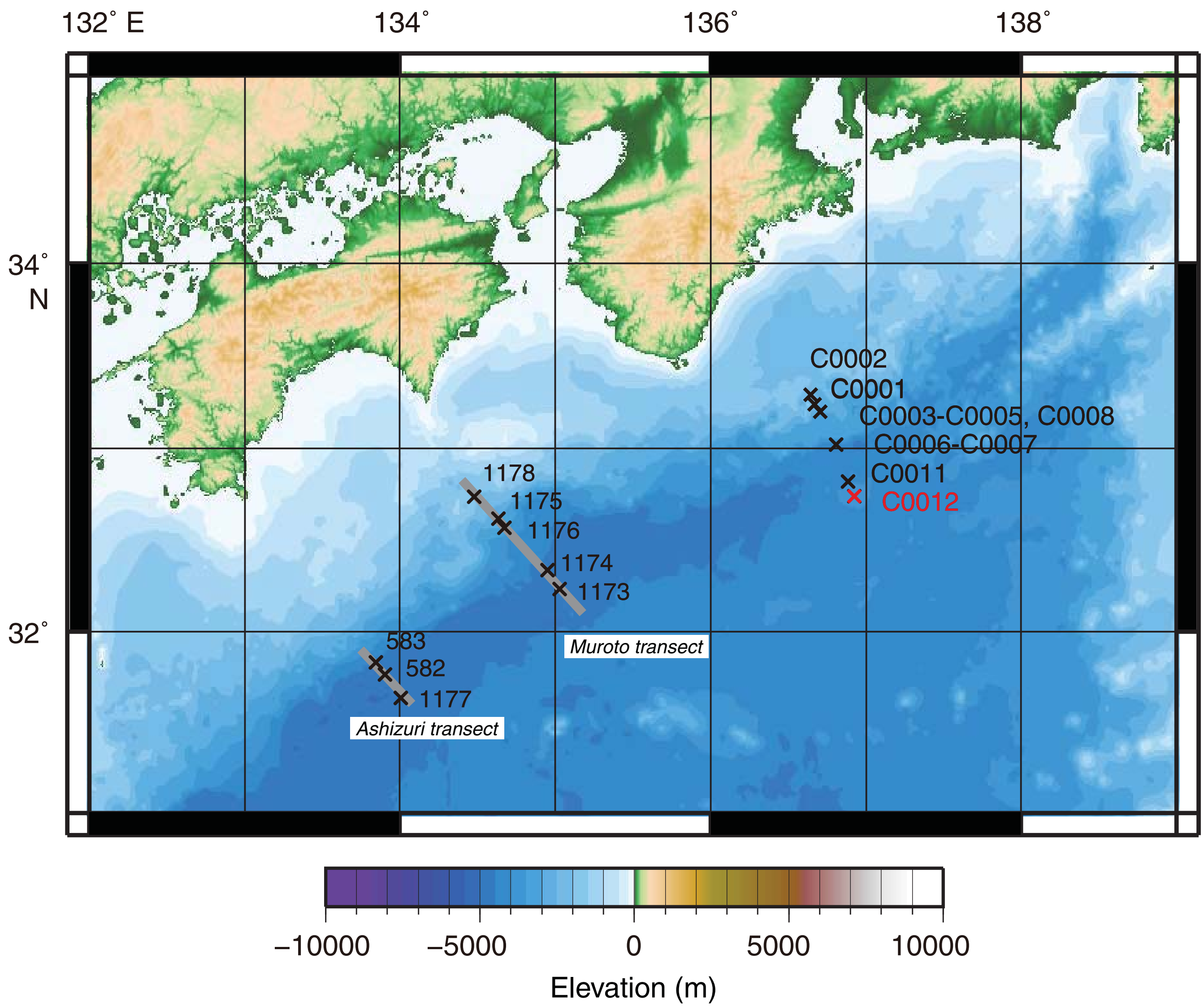

Figure F2. Schematic illustration of quality criterion (A–C) of biohorizons (partly modified after Hayashi et al., 2013). LO = last occurrence, FO = first occurrence.

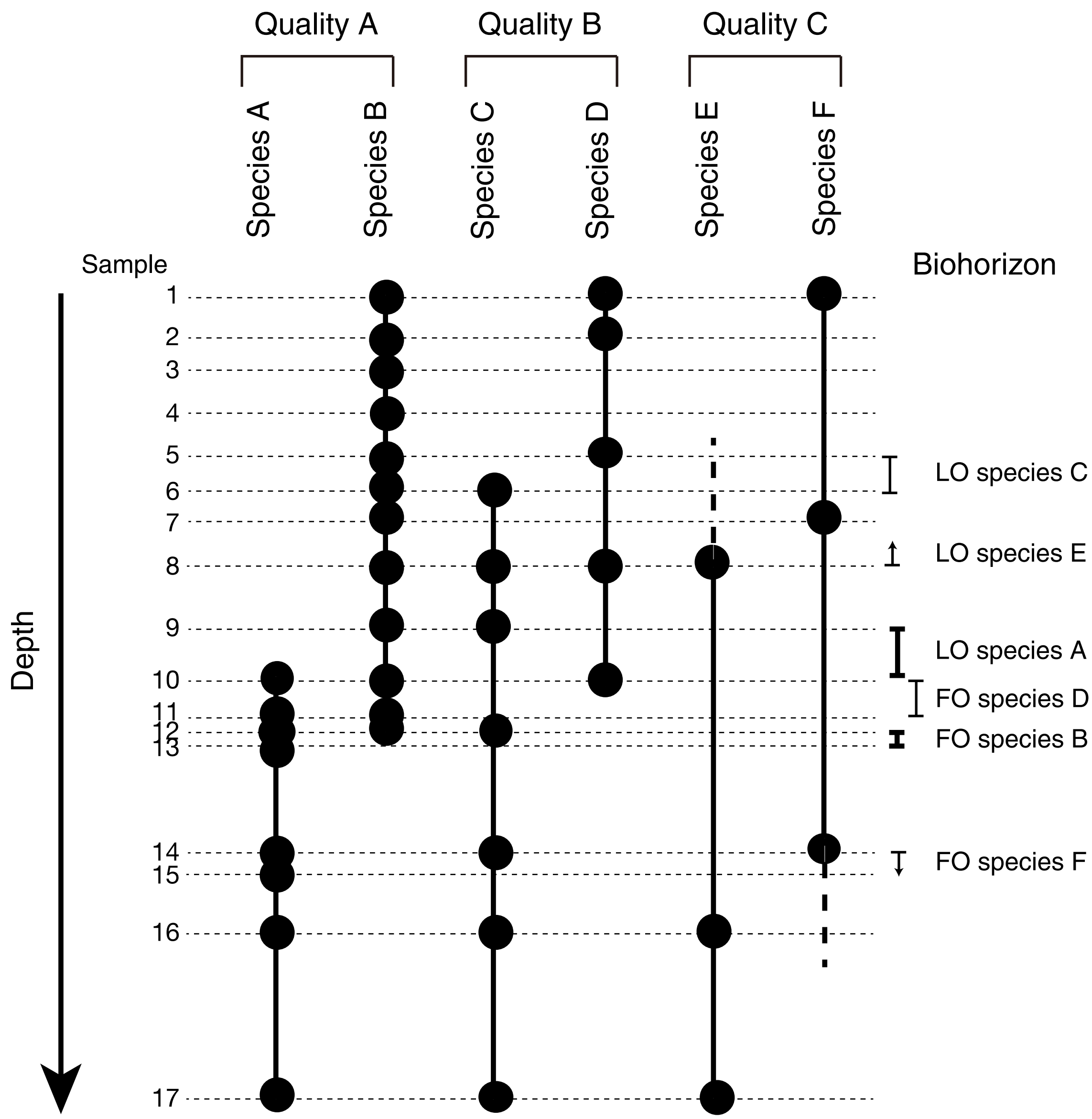

Figure F3. Age-depth plot for Site C0012 and depth plots of planktonic foraminiferal (PF) flux, benthic foraminiferal (BF) flux, and planktonic/total foraminiferal (P/T) ratio. Planktonic foraminiferal biohorizons are plotted on the basis of Wade et al. (2011) and Tian et al. (2008) timescales. Nannofossil data are quoted from the onboard data (see the "Site C0012" chapter [Expedition 322 Scientists, 2010]). Biohorizon numbers are defined in Table T2.

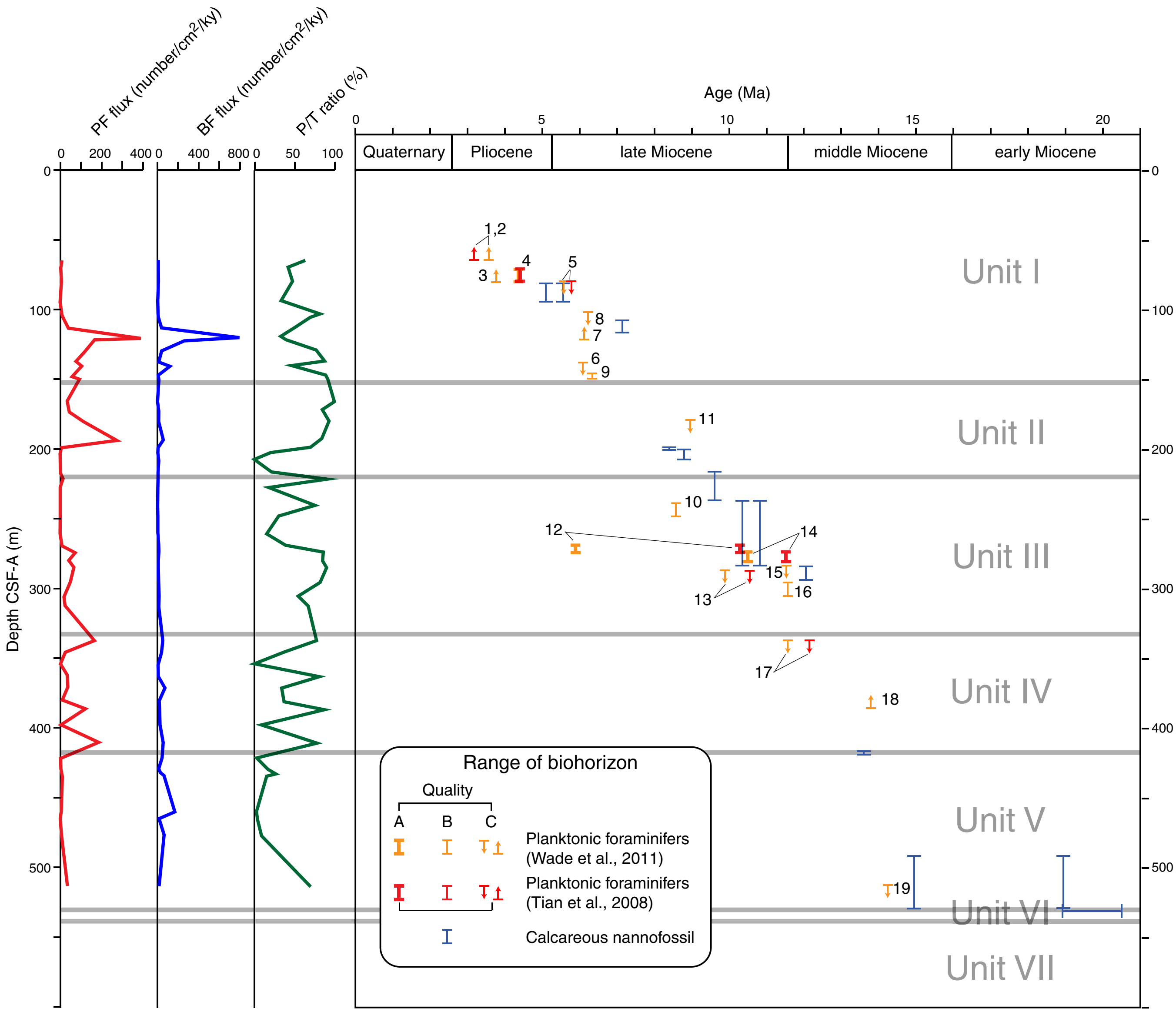

Table T1. Stratigraphic distribution of planktonic foraminiferal species, Hole C0012A. This table is available in an **oversized format.**

Table T2. Planktonic foraminiferal biohorizons including depth range, mean depth, and samples containing biohorizons, Hole C0012A.

Event (base of zone)	Age BW11 (Ma)	Age TJ08 (Ma)	Top, core, section, interval (cm)	Depth CSF-A (m)	Bottom, core, section, interval (cm)	Bottom depth CSF-A (m)	Mean depth CSF-A (m)	Range (±m)	Quality
			322-C0012A-		322-C0012A-				
LO *Dentoglobigerina altispira altispira* (PL5)	3.47	3.18	—	—	2R-4, 0.0–8.0	64.54	64.54	—	C
LO *Sphaeroidinellopsis seminulina* sensu lato (PL4)	3.59		—	—	2R-4, 0.0–8.0	64.54	64.54	—	C
LO *Globorotalia plesiotumida*	3.77		—	—	3R-1, 60.0–68.0	70.14	70.14	—	C
LO *Globoturborotalita nepenthes* (PL2)	4.37	4.43	3R-1, 60.0–68.0	70.14	4R-1, 50.0–58.0	79.54	74.84	4.70	A
FO *Globorotalia tumida* (PL1a)	5.57	5.77	4R-1, 50.0–58.0	79.54	—	—	79.54	—	C
FO *Hirsutella margaritae*	6.08		10R-5, 60.0–68.0	137.14	—	—	137.14	—	C
LO *Globorotalia lenguaensis* (M14)	6.13		—	—	9R-1, 42.0–50.0	121.46	121.46	—	C
FO *Globigerinoides conglobatus*	6.20		6R-CC, 10.5–15.5	101.85	—	—	101.85	—	C
StoD *Neogloboquadrina acostaensis*	6.34		11R-5, 74.0–82.0	146.78	11R-7, 46.0–54.0	149.50	148.14	1.36	B
FO *Globorotalia plesiotumida* (M13b)	8.58		21R-4, 40.0–48.0	239.64	22R-3, 45.0–53.0	247.60	243.62	3.98	B
FO *Globoturborotalita extremus*	8.93		—	—	16R-4, 70.0–78.0	192.74	192.74	—	C
LO *Globoquadrina dehiscens*	5.92	10.26	24R-4, 52.0–60.0	268.26	25R-1. 53.0–61.0	273.27	270.77	2.51	A
FO *Neogloboquadrina acostaensis* (M13a)	9.83	10.50	26R-2, 68.0–76.0	284.42	—	—	284.42	—	C
LO *Paragloborotalia siakensis* (M12)	10.46	11.50	25R-1, 53.0–61.0	273.27	25R-5, 68.0–76.0	279.42	276.35	3.08	A
FO *Globoturborotalita decoraperta*	11.49		26R-2, 68.0–76.0	284.42	—	—	284.42	—	C
LO *Globigerinoides subquadratus*	11.54		27R-3, 38.0–46.0	295.12	28R-3, 65.0–73.0	300.01	297.57	2.44	B
FO *Globoturborotalita nepenthes* (M11)	11.63	12.13	31R-5, 74.0–82.0	336.48	—	—	336.48	—	C
LO *Fohsella peripheroronda*	13.80		—	—	37R-1, 35.0–43.0	385.89	385.89	—	C
FO *Fohsella peripheroacuta* (M7)	14.24		50R-3, 70.0–78.0	512.74	—	—	512.74	—	C

BW11 = Wade et al. (2011), TJ08 = Tian et al. (2008). FO = first occurrence, LO = last occurrence, StoD = coiling direction change from sinistral to dextral.

Plate P1. 1. *Dentoglobigerina altispira altispira* (Cushman and Jarvis); Sample 322-C0012A-2R-4, 0.0–8.0 cm. **2a–2c.** *Fohsella peripheroacuta* (Blow and Banner); Sample 41R-6, 12.0–20.0 cm. **3.** *Globigerinoides subquadratus Brönnimann;* Sample 28R-3, 65.0–73.0 cm. **4a–4c.** *Globorotalia tumida* (Brady); Sample 2R-4, 0.0–8.0 cm. **5.** *Globoquadrina dehiscens* (Chapman, Parr and Collins); Sample 44R-3, 92.0–100.0 cm. **6.** *Globoturborotalita nepenthes* (Todd); Sample 7R-3, 60.0–68.0 cm. **7a–7b.** *Neogloboquadrina acostaensis* (Blow); Sample 10R-6, 60.0–68.0 cm. **8a–8b.** *Paragloborotalia siakensis* (LeRoy); Sample 31R-5, 74.0–82.0 cm. **9a–9b.** *Sphaeroidinellopsis seminulina* (Schwager); Sample 4R-1, 50.0–58.0 cm. Scale bars = 100 µm.