Heuer, V.B., Inagaki, F., Morono, Y., Kubo, Y., Maeda, L., and the Expedition 370 Scientists
Proceedings of the International Ocean Discovery Program Volume 370
publications.iodp.org

https://doi.org/10.14379/iodp.proc.370.201.2018

Data report: calcareous nannofossils from the middle Miocene to Pleistocene, IODP Expedition 370 Site C0023[1]

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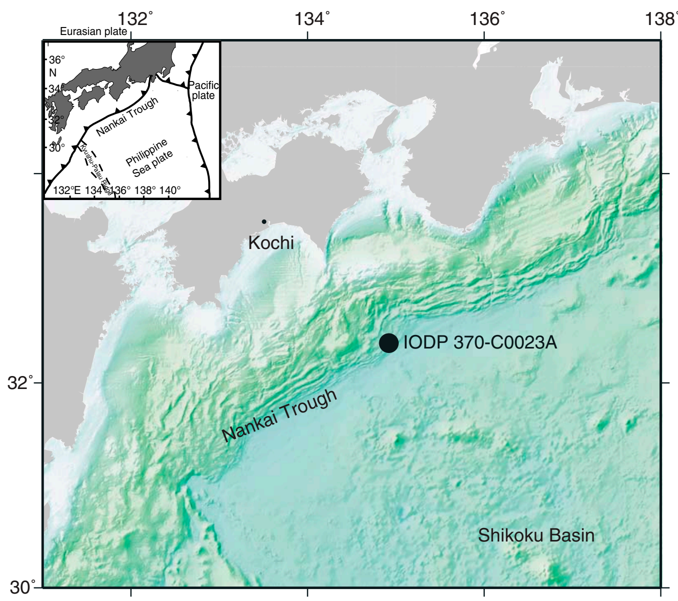
Keywords: International Ocean Discovery Program, IODP, *Chikyu*, Expedition 370, Site C0023, calcareous nannofossil, biostratigraphy, Neogene

Contents

Abstract

International Ocean Discovery Program Expedition 370 recovered marine subsurface sediments from 189 to 1126 meters below seafloor (mbsf) at Site C0023, which was established on the Nankai Trough, off Muroto Peninsula, Japan. Biostratigraphic studies based on calcareous nannofossil assemblages revealed the ages of sediments are from the middle Miocene to Pleistocene. Samples from 1126.885 to 796.530 mbsf yielded Miocene taxa such as *Coccolithus miopelagicus*, *Cyclicargolithus floridanus*, *Catinaster calyculus*, and *Discoaster quinqueramus*. The interval 790.285–774.984 mbsf spans the late Miocene to the early Pliocene, as it corresponds to bioevents spanning from the last occurrence (LO) of *D. quinqueramus* to the first occurrence of *Ceratolithus cristatus*. Samples from 769.440 to 639.982 mbsf are referred to the Pliocene based on occurrences of *C. cristatus*, *Reticulofenestra pseudoumbilicus* (≥7 µm), and/or *Discoaster surculus*. Sediments from 630.440 to 190.483 mbsf are dated to the Pleistocene, as an interval above the LO of *Discoaster pentaradiatus*. Preservation of calcareous nannofossils is poor or moderate in the middle Miocene samples and moderate to good in the samples from the upper Miocene to Pleistocene.

Figure F1. Location of Hole C0023A, drilled during Expedition 370.



Introduction

During International Ocean Discovery Program (IODP) Expedition 370, Site C0023 was drilled at 32°22.00′N, 134°57.98′E in 4776 m water depth in the northwest Pacific Ocean off Kochi, Japan (Figure **F1**). Site C0023 is located on the protothrust zone of the Nankai accretionary complex, in the vicinity of Ocean Drilling Program (ODP) Sites 808 and 1174. The Nankai accretionary complex comprises a thick sediment pile consisting of turbidite layers overlaying hemipelagic sediment accumulated on the young (~16 Ma) basaltic basement (e.g., Shipboard Scientific Party, 1991, 2001). The sedimentation rate based on biostratigraphy for the late Quaternary Nankai Trough deposit was significantly high: 800–1350 m/My in the last 0.46 My at Site 808 and 630–770 m/My in the last 0.08 My at the Site 1174 (Olafsson, 1993; Shipboard Scientific Party, 2001). On the other hand, the sedimentation rate for the hemipelagic Shikoku Basin deposits was relatively low: 24–200 m/My for sediments older than 0.46 Ma at Site 808 and 11–125 m/My for sediments older than 0.08 Ma at Site 1174 (Olafsson, 1993; Shipboard Scientific Party, 2001). The lowermost sediments above the basaltic basement were

[1] Hagino, K., and the Expedition 370 Scientists, 2018. Data report: calcareous nannofossils from the middle Miocene to Pleistocene, IODP Expedition 370 Site C0023. *In* Heuer, V.B., Inagaki, F., Morono, Y., Kubo, Y., Maeda, L., and the Expedition 370 Scientists, *Temperature Limit of the Deep Biosphere off Muroto*. Proceedings of the International Ocean Discovery Program, 370: College Station, TX (International Ocean Discovery Program). https://doi.org/10.14379/iodp.proc.370.201.2018
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MS 370-201: Received 26 August 2017 · Accepted 13 December 2017 · Published 18 April 2018

referred to middle Miocene calcareous nannofossil Zone NN5 at Site 808 (Shipboard Scientific Party, 2001).

The main objectives of this expedition were to (1) explore the limit of distribution of microbial communities in marine subsurface sediments, (2) reveal geochemical, geophysical, and hydrogeological characteristics of the subsurface sediments, and (3) examine underlying basaltic basement of the Nankai accretionary complex (see the **Expedition 370 summary** chapter [Heuer et al., 2017]). Calcareous nannofossil assemblages in the recovered sediments were studied in order to determine the ages of sediments. This data report documents the middle Miocene to Pleistocene calcareous nannofossil assemblages and assigned biostratigraphic zones recorded for this site.

Methods and materials

Hole C0023A was washed down to 181 meters below seafloor (mbsf) and then cored from 189 to 1180 mbsf using the hydraulic piston coring, extended shoe coring, and rotary core barrel systems (Figure **F1**) (see the **Expedition 370 summary** chapter [Heuer et al., 2017]). Smear slides were prepared for the study of calcareous nannofossils from sediment samples obtained from core catcher samples or from the bottoms of cores using standard techniques (e.g., Bown and Young, 1998). Calcareous nannofossils were examined at 1500× magnification under a Nikon E600 polarizing light microscope.

Nannofossil preservation was recorded as follows:

- G = good (little or no evidence of dissolution and/or overgrowth, little or no alteration of primary morphological features, and specimens are identifiable to the species level).
- M = moderate (minor dissolution or crystal overgrowth observed, some alteration of primary morphological features, but most specimens are identifiable to the species level).
- P = poor (strong dissolution or crystal overgrowth, significant alteration of primary morphological features, and many specimens are unidentifiable at the species and/or generic level).

The abundance of total calcareous nannofossils and individual species for each sample was estimated as follows:

- A = abundant (11 or more specimens per field of view).
- C = common (1–10 specimens per field of view).
- F = few (1 specimen per 2–10 fields of view).
- R = rare (1 specimen per 11–30 fields of view).
- VR = very rare (1 specimen per 31 or more fields of view).
- B = barren.

Results were correlated to the calcareous nannofossil biostratigraphic NN zones of Martini (1971) and CN zones of Okada and Bukry (1980). Furthermore, absolute ages for datums and additional biostratigraphic events were assigned on the basis of Backman et al. (2012) whenever possible. *Gephyrocapsa* spp. and *Reticulofenestra* spp. were classified to groups on the basis of coccolith size following Backman et al. (2012) and Young (1998). Calcareous nannofossil species considered in this study are listed in the **Appendix**. Bibliographic references for these taxa can be found in Perch-Nielsen (1985) and Bown (1998). In order to determine the onset of the acme of *Emiliania huxleyi*, 300 specimens of calcareous nannofossils other than *Florisphaera profunda* were identified in the samples that contained *E. huxleyi*. Age of onset of the acme of *E. huxleyi* followed Raffi et al. (2006).

Results

Biostratigraphy

A total of 88 out of 112 studied samples yielded sufficient numbers of calcareous nannofossils for biostratigraphic studies. Ages of sediments range from middle Miocene to early Pleistocene. Preservation of calcareous nannofossils is poor or moderate in middle Miocene samples and moderate to good in samples from the upper Miocene to Pleistocene (Table **T1**). The bottom two samples (370-C0023A-112R-1, 48.0–50.0 cm, and 111R-CC, 46.0–48.0 cm [1177.000–1173.980 mbsf]) are basaltic basement (see the **Expedition 370 summary** chapter [Heuer et al., 2017]) and did not yield any calcareous nannofossils.

Interval 110R-CC, 32.0–34.0 cm, through 88R-CC, 47.5–49.5 cm (1126.885–914.565 mbsf), yielded a middle Miocene calcareous nannofossil assemblage characterized by *Coccolithus miopelagicus* and *Cyclicargolithus floridanus* (Plate **P1**, figures 1, 2). In this interval, samples from interval 110R-CC, 32.0–34.0 cm, through 105R-CC, 33.0–35.0 cm (1126.885–1084.100 mbsf), were assigned to Zone NN5 (CN4) on the basis of the occurrence of *Sphenolithus heteromorphus* (17.75–13.53 Ma; Plate **P1**, figures 3a, 3b). Zone NN6 (CN5a) is a partial range zone that extends from the last occurrence (LO) of *S. heteromorphus* (13.53 Ma) to the first occurrence (FO) of *Discoaster kugleri* (11.88 Ma) (Young, 1998; Backman et al., 2012). Because *D. kugleri* was not recognized at this site, the top of Zone NN6 (CN5a) was approximated based on the LO of *C. floridanus* (~12.0 Ma) between Samples 94R-CC, 33.5–35.5 cm, and 91R-CC, 43.0–45.0 cm (977.981–947.000 mbsf). Zone NN7 (CN5b) is a successive first appearance zone defined by the FO of *D. kugleri* (base of Zone NN7) and the FO of *Catinaster coalitus* (10.79 Ma) (Young, 1998; Backman et al., 2012). This site yielded neither *D. kugleri* nor *C. coalitus*; therefore, Zone NN7 (CN5b) was assigned to between Samples 91R-CC, 43.0–45.0 cm, and 88R-CC, 47.5–49.5 cm (947.00–914.565 mbsf), based on the LO of *C. floridanus* (~12.0 Ma) and the LO of *C. miopelagicus* (~10.61 Ma).

Sample 82R-CC, 28.5–30.5 cm (856.175–856.195 mbsf), is assigned to late Miocene Zones NN9–NN10a (CN7b–CN8a) based on the occurrence of *Catinaster calyculus* (10.71–9.65 Ma; Plate **P1**, figure 5). The interval between Samples 79R-CC, 13.0–15.0 cm, and 71R-CC, 13.5–15.5 cm (832.525–796.530 mbsf), was defined as late Miocene Zone NN11 (CN9) on the basis of the FO of *Discoaster berggrenii* (8.2 Ma; Plate **P1**, figure 6) and the LO of *Discoaster quinqueramus* (5.53 Ma).

Zone NN12 (CN10a–CN10b) spans the late Miocene to early Pliocene and was recognized between Samples 70R-CC, 4.0–6.0 cm, and 66R-CC, 14.0–16.0 cm (790.285–774.982 mbsf), as an interval above the LO of *D. quinqueramus* (5.53 Ma) and below the FO of *Ceratolithus cristatus*, although the Zone NN12/NN13 (CN10b/CN10c) boundary is unreliable due to very rare discontinuous occurrences of *C. cristatus*.

Interval 65R-CC, 10.5–12.5 cm, through 47R-CC, 36.5–38.5 cm (769.440–682.983 mbsf), is dated to the early Pliocene as an interval from the FO of *C. cristatus* to the LO of *Reticulofenestra pseudoumbilicus* (≥7 μm) (3.82 Ma; Plate **P1**, figure 11). In this interval, samples from interval 65R-CC, 10.5–12.5 cm, through 61R-CC, 0.0–2.0 cm (769.440–752.165 mbsf), yielded both *C. cristatus* (Plate **P1**, figure 16) and *Amaurolithus primus* (Plate **P1**, figure 7). Zone NN15 (CN11a–NN11b) is a successive last appearance zone from the LO of *A. primus* (4.58 Ma) to the LO of *R. pseudoumbilicus* (≥7 μm) (3.82 Ma) (e.g., Young, 1998). At this site, the interval between Samples 60R-CC, 23.0–25.0 cm, and 47R-CC, 36.5–38.5 cm

Table T1. Calcareous nannofossil occurrences, Hole C0023A. **Download table in CSV format.**

Plate P1. Light microscopic images of calcareous nannofossils, Hole C0023A. 1. *Coccolithus miopelagicus* (96R-CC, 23.5–25.5 cm; cross-polarized light [XL]). 2. *Cyclicargolithus floridanus* (105R-CC, 33.0–35.0 cm; XL). 3a, 3b. *Sphenolithus heteromorphus*, (109R-CC, 56.0–58.0 cm; XL). 4. *Orthorhabdus rugosus* (74R-CC, 17.5–19.5 cm; plane-transmitted light [PL]). 5. *Catinaster calyculus* (82R-CC, 28.5–30.5 cm; PL) 6. *Discoaster berggrenii* (76R-CC, 0.0–2.0 cm; PL). 7. *Amaurolithus primus* (71R-CC, 13.5–15.5 cm; PL) 8. *Sphenolithus abies* (53R-CC, 25.5–27.5 cm; XL). 9. *Discoaster tamalis* (43R-CC, 37.5–39.5 cm; PL). 10. *Discoaster asymmetricus* (43R-CC, 37.5–39.5 cm; PL). 11. *Reticulofenestra pseudoumbilicus* (49R-CC, 18.0–20.0 cm; XL). 12. *Gephyrocapsa oceanica* (35R-CC, 33.5–35.5 cm; XL). 13. *Pseudo-emiliania lacunosa* (29R-CC, 0.0–2.0 cm; XL). 14. *Emiliania huxleyi* (8F-CC, 0.0–2.0 cm; XL). 15. *Discoaster brouweri* (50R-CC, 28.5–30.0 cm; PL). 16. *Ceratolithus cristatus* (8F-CC, 0.0–2.0 cm; XL). 17. *Braarudosphaera bigelowii* (8F-CC, 0.0–2.0 cm; XL). 18. Small *Gephyrocapsa* (8F-CC, 0.0–2.0 cm; XL).

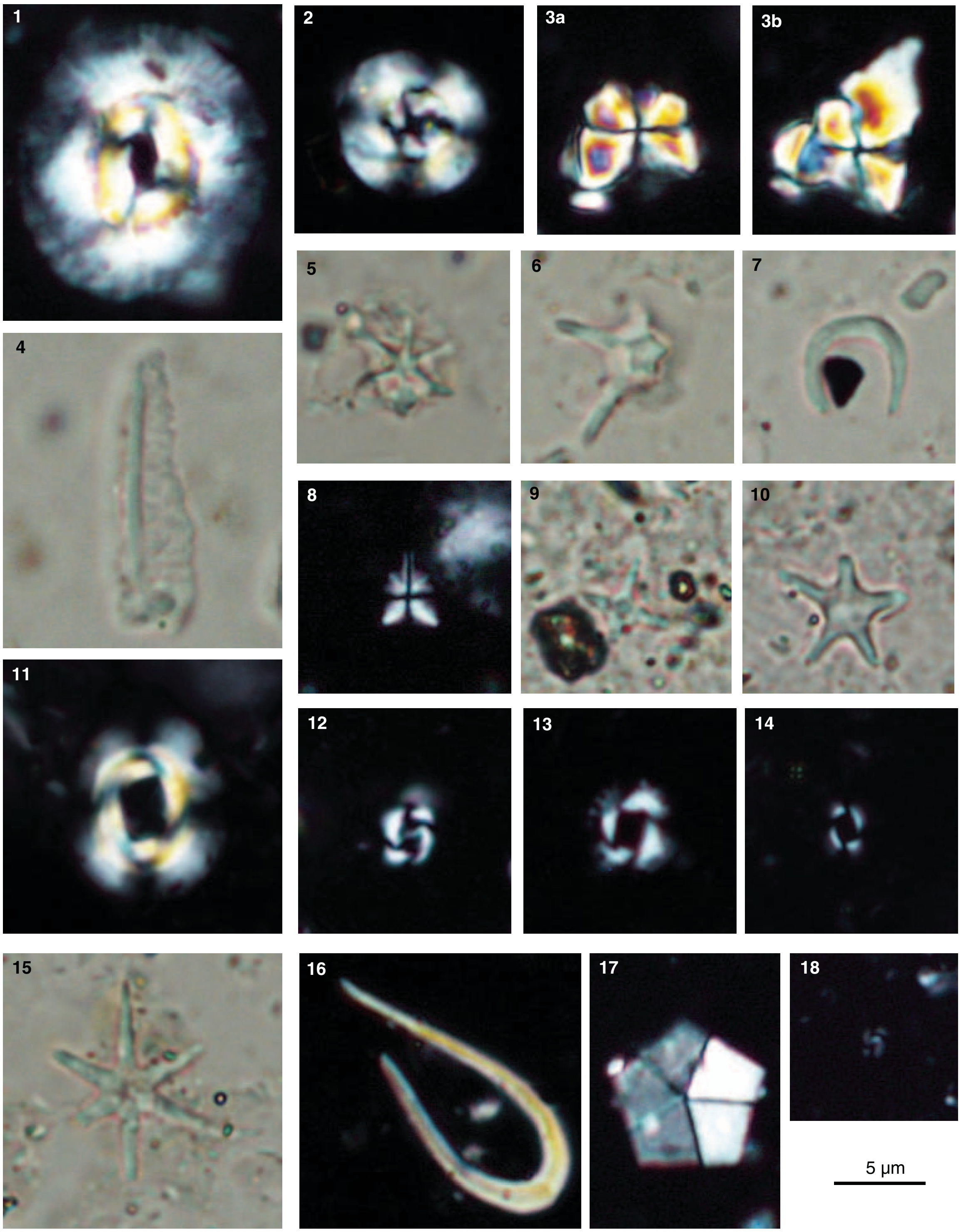


Table T2. Sedimentation rates based on selected calcareous nannofossil events, Hole C0023A. Age of each event follows Backman et al. (2012). FO = first occurrence, LO = last occurrence, RE = reentrance. **Download table in CSV format.**

Number	Event	Age (Ma)	Top core, section, interval (cm)	Bottom core, section, interval (cm)	Top depth (mbsf)	Bottom depth (mbsf)	Average depth (mbsf)	Sedimentation rate (m/My)	Sedimentation rate interval (mbsf)
			370-C0023A-	370-C0023A-					
1	FO *Emiliania huxleyi*	0.29	12F-CC, 3.0–5.0	14X-CC, 38.0–40.0	358.475	406.390	382.433	1319	0–382.433
2	LO *Pseudoemiliania lacunosa*	0.43	21R-CC, 0.0–2.0	22R-CC, 0.0–2.0	462.100	473.515	467.808	610	382.433–467.808
3	RE medium-sized *Gephyrocapsa*	1.04	27R-CC, 17.0–19.0	29R-CC, 0.0–2.0	515.380	533.810	524.595	93	467.808–524.595
4	FO medium-sized *Gephyrocapsa*	1.71	35R-CC, 33.5–35.5	36R-8, 126.5–128.5	580.360	592.245	586.303	92	524.595–586.303
5	LO *Discoaster surculus*	2.53	40R-CC, 28.5–30.5	41R-CC, 19.0–21.0	630.440	639.982	635.211	60	586.303–635.211
6	LO *Discoaster quinqueramus*	5.53	70R-CC, 4.0–6.0	71R-CC, 13.5–15.5	790.285	793.408	796.530	53	635.211–796.530
7	LO *Sphenolithus heteromorphus*	13.53	103R-CC, 31.5–33.5	105R-CC, 33.0–35.0	1070.481	1084.100	1077.291	35	796.530–1077.291

(746.030–682.983 mbsf), is referred to Zone NN15, although the base and top of Zone NN15 is unreliable due to discontinuous and very rare occurrences of *A. primus* and the possibility of reworking of *R. pseudoumbilicus*.

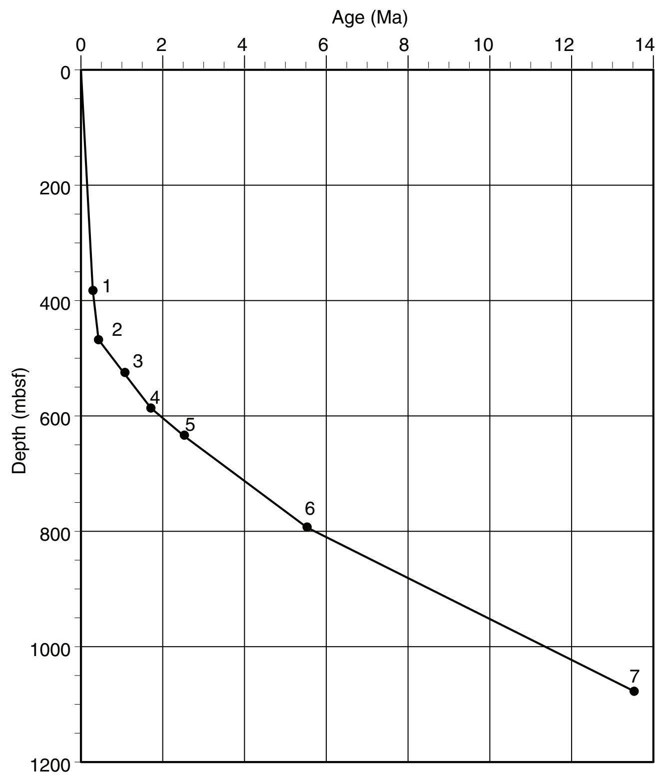
Late Pliocene Zone NN16 (CN12a–CN12c) extends from the LO of *R. pseudoumbilicus* (≥7 µm) (3.82 Ma) to the LO of *Discoaster surculus* (2.53 Ma) and was recognized between Samples 46R-CC, 28.5–30.5 cm, and 41R-CC, 19.0–21.0 cm (678.000–639.982 mbsf). In this zone, the lowermost four samples examined (Samples 46R-CC, 28.5–30.5 cm, through 43R-CC, 37.5–39.5 cm [678.000–658.982 mbsf]) were distinguished from the upper two samples (42R-CC, 49.5–51.5 cm, and 41R-CC, 19.0–21.0 cm [646.44–639.982 mbsf]) as Subzone CN12a on the basis of the LO of *Discoaster tamalis* (2.76 Ma) (Plate **P1**, figure 9). Zone NN17 (CN12c), which extends from the LO of *D. surculus* (2.53 Ma) to the LO of *Discoaster pentaradiatus* (~2.39 Ma), was not recognized in this study.

The interval between Samples 40R-CC, 28.5–30.5 cm, and 1F-CC, 19.0–21.0 cm (630.440–190.483 mbsf), is assigned to Pleistocene Zones NN18–NN21 (CN12d–CN15) as an interval above the LO of *D. pentaradiatus* (~2.39 Ma) to the present. Zone NN18 (CN12d) extends from the LO of *D. pentaradiatus* (~2.39 Ma) to the LO of *Discoaster brouweri* (1.93 Ma) (Plate **P1**, figure 15) and was recognized between Samples 40R-CC, 28.5–30.5 cm, and 38R-CC, 8.5–10.5 cm (630.440–610.035 mbsf), although the top of Zone NN18 (CN12d) is unreliable due to the rare and discontinuous occurrence of *D. brouweri*.

Zone NN19, which extends from the LO of *D. brouweri* (1.93 Ma) to the LO of *Pseudoemiliania lacunosa* (0.43 Ma), was recognized between Samples 37R-CC, 18.5–20.5 cm, and 22R-CC, 0.0–2.0 cm (596.780–473.515 mbsf). Zone NN19 can be divided into three subzones (CN13a, CN13b, and CN14d) following Okada and Bukry (1980). The Subzone CN13b/CN13a boundary was recognized on the basis of the FO of medium *Gephyrocapsa* spp. (≥3.5 µm) (1.71 Ma; Plate **P1**, figure 12) between Samples 36R-8, 126.5–128.5 cm, and 35R-CC, 33.5–35.5 cm (592.265–580.340 mbsf). The Subzone CN13b/CN14a boundary was defined based on the reentrance of medium-sized *Gephyrocapsa oceanica* (≥4.0 µm) (1.06 Ma) between Samples 29R-CC, 0.0–2.0 cm, and 27R-CC, 17.0–19.0 cm (533.810–515.380 mbsf).

The interval from Samples 21R-CC, 0.0–2.0 cm, through 14X-CC, 38.0–40.0 cm (462.100–406.390 mbsf), is assigned to Zone NN20 (CN14b) as the interval above the LO of *P. lacunosa* (0.43 Ma; Plate **P1**, figure 13) to the FO of *E. huxleyi* (0.29 Ma; Plate **P1**, figure 14). The youngest nannofossil zone (NN21 [CN15]) was recognized on the basis of the occurrence of *E. huxleyi* (0.29 Ma–present) in Samples 12F-CC, 3.0–5.0 cm, through 1F-CC, 19.0–21.0 cm (358.475–190.483 mbsf). The relative abundance of *E. huxleyi* within the total calcareous nannofossil assemblage (excluding nannoliths of *F. profunda*) is consistently lower than 5% in the samples from interval 12F-CC, 3.0–5.0 cm, through 2F-CC, 6.0–8.0 cm (358.475–204.175 mbsf), and ~17% in the uppermost Sample 1F-CC, 19.0–21.0 cm (190.500–190.483 mbsf) (not illustrated). Low relative abundances of *E. huxleyi* indicate that all samples from interval 12F-CC, 3.0–5.0 cm, through 1F-CC, 19.0–21.0 cm (358.475–190.483 mbsf), were deposited before the onset of the *E. huxleyi* acme (0.082–0.063 Ma; Raffi et al., 2006).

Figure F2. Age-depth plot based on selected calcareous nannofossil events, Hole C0023A. Numbers 1–7 refer to events in Table T2.



Sedimentation rate

A total of 7 reliable calcareous nannofossil events out of 12 recognized events were selected to construct the age/depth plot (Table **T2**; Figure **F2**). The sedimentation rate was very high in samples younger than 0.43 Ma (1319–610 m/My) and low in samples older than 0.43 Ma (93–35 m/My).

Acknowledgments

This research used samples and data provided by the International Ocean Discovery Program (IODP), which is supported in part by the National Science Foundation. This study was supported by Grant in Aid for Scientific Research Number 17K05694 financed by the Ministry of Education, Culture, Sports, Science and Technology, Japan. We are grateful to Denise K. Kulhanek of the International Ocean Discovery Program for her critical and constructive review. We wish to express gratitude to Hisatake Okada for his suggestions on this manuscript.

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Appendix

Systematic paleontology

Bibliographic references for these taxa can be found in Perch-Nielsen (1985) and Bown (1998).

Amaurolithus delicatus Gartner and Bukry, 1975
Amaurolithus primus (Bukry and Percival, 1971) Gartner and Bukry, 1975
Amaurolithus tricorniculatus (Gartner, 1967) Gartner and Bukry, 1975
Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947
Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978
Calcidiscus tropicus Kamptner, 1956 sensu Gartner, 1992
Calcidiscus macintyrei (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978
Calciosolenia spp.
Catinaster calyculus Martini and Bramlette, 1963
Catinaster coalitus Martini and Bramlette 1963
Ceratolithus armatus Müller, 1974
Ceratolithus cristatus Kamptner, 1950
Ceratolithus spp.
Coccolithus pelagicus (Wallich, 1871) Schiller, 1930
Coccolithus miopelagicus Bukry, 1971
Cyclicargolithus floridanus (Roth and Hay in Hay et al., 1967) Bukry, 1971
Discoaster asymmetricus Gartner, 1969
Discoaster berggrenii Bukry, 1971
Discoaster brouweri Tan, 1927
Discoaster bollii Martini and Bramlette, 1963
Discoaster calcaris Gartner 1967
Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster exilis Martini and Bramlette, 1963
Discoaster kugleri Martini and Bramlette, 1963
Discoaster pentaradiatus Tan, 1927
Discoaster quadramus Bukry, 1973
Discoaster quinqueramus Gartner 1969
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Discoaster triradiatus Tan, 1927
Discoaster variabilis Martini and Bramlette, 1963
Discoaster spp.
Emiliania huxleyi (Lohmann, 1902) Hay and Mohler in Hay et al., 1967
Florisphaera profunda Okada and Honjo, 1973
Gephyrocapsa ericsonii McIntyre and Bé, 1967
Gephyrocapsa oceanica Kamptner, 1943
Gephyrocapsa spp.
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954
Helicosphaera granulata (Bukry and Percival, 1971) Jafar and Martini, 1975
Helicosphaera princei da Gama and Varol, 2013
Helicosphaera sellii (Bukry and Bramlette, 1969) Jafar and Martini, 1975
Helicosphaera wallichii (Lohmann, 1902) Okada and McIntyre, 1977
Helicosphaera spp.
Orthorhabdus rugosus (Bramlette and Wilcoxon, 1967) Young and Bown, 2014

Orthorhabdus sp.
Pontosphaera spp.
Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969
Pseudoemiliania ovata (Bukry, 1973) Young, 1998
Reticulofenestra asanoi Sato and Takayama, 1992
Reticulofenestra bisecta (Hay, Mohler, and Wade, 1966) Roth, 1970
Reticulofenestra haqii Backman, 1978
Reticulofenestra minuta Roth, 1970
Reticulofenestra minutula (Gartner, 1967) Haq and Berggren, 1978
Reticulofenestra pseudoumbilicus (Gartner, 1967) Gartner, 1969?
Reticulofenestra productella (Bukry, 1975) Gallagher, 1989
Reticulofenestra spp.
Sphenolithus abies Deflandre in Deflandre and Fert, 1954
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
Sphenolithus spp.
Syracosphaera spp.
Tetralithoides spp.
Umbellosphaera irregularis Paasche in Markali and Paasche, 1955
Umbilicosphaera rotula (Kamptner, 1956) Varol, 1982
Umbilicosphaera sibogae (Weber van Bosse, 1901) Gaarder, 1970