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4. Neogene Calcareous Nannofossil Biostratigraphy and the *Coccolithus pelagicus* Abundance of ODP Leg 186 Cores from the Japan Trench[1]

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ABSTRACT

Calcareous nannofossil assemblages were studied from Ocean Drilling Program Holes 1150A, 1150B, 1151A, 1151C, and 1151D in order to estimate the age of sediments drilled in the Japan Trench of the western Pacific Ocean. The abundance and species diversity of nannofossil flora are generally low but are sufficient to show that the sedimentary sequences range from Quaternary to Miocene in age (nannofossil Zones CN15–CN3).

The abundance of *Coccolithus pelagicus,* a cold-water indicator, was studied from sediments younger than 3.83 Ma from both Holes 1150A and 1151A in order to elucidate past climate conditions. Between 3.83 and 2.82 Ma, the abundance of *C. pelagicus* was generally low, but abundance increased significantly after 2.82 Ma. In agreement with previous studies, this increase appears to be related to a change in the current system around the western Pacific Ocean and eastern Atlantic Ocean that occurred in response to the final elevation of the Isthmus of Panama.

INTRODUCTION

Calcareous nannofossils are the skeletal elements produced by unicellular photosynthetic algae that lived in the upper 200 m of the water column. They have been widely distributed in the world's oceans since

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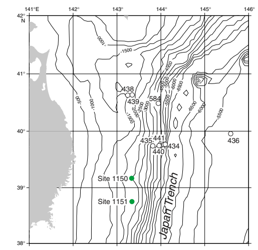
the Mesozoic and are well known as a useful tool for paleoenvironmental analysis as well as for age determination. Characteristics such as their generally high abundance, worldwide distribution, and high species diversity have been utilized for paleoenvironmental analysis and for deciphering the history of oceanic conditions, as demonstrated by many authors (Haq, 1980; Gartner et al., 1987).

During Ocean Drilling Program (ODP) Leg 186 (14 June 1999 to 14 August 1999), two sites (1150 and 1151) were drilled off the northeast coast of Japan (Fig. F1) to monitor seismic and aseismic crustal deformation associated with subduction of the Pacific plate beneath Japan (Sacks, Suyehiro, Acton, et al., 2000). These two sites yielded highly expanded Miocene–Quaternary sections (up to 1250 m thick). Nannofossil occurrence ranged from barren to very abundant at both sites, and preservation varied from poor to good (Shipboard Scientific Party, 2000a, 2000b).

F1. Map of the Japan Trench area, p. 13.



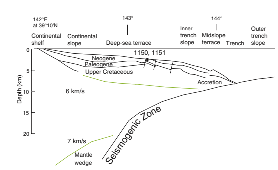
This study presents the nannofossil biostratigraphy of both sites based on the shipboard and subsequent shore-based study. Basically, the shore-based data provide more detailed information and supersede shipboard observations (Shipboard Scientific Party, 2000a, 2000b). Major events are summarized and discussed in detail below. In addition, a quantitative study of *Coccolithus pelagicus* has been carried out to help understand the geographic distribution of this taxon. Its distribution has previously been related to a change of the current system around the western Pacific and eastern Atlantic Oceans that occurred at 2.82 Ma, perhaps in conjunction with the final elevation of the Isthmus of Panama (Sato et al., 1998).

Calcareous nannofossil species considered in this report are listed in the **"Appendix,"** p. 12, where they are arranged alphabetically by genus. Bibliographical references for these taxa can be found in Perch-Nielsen (1985) and Young (1998).

OCEANOGRAPHIC AND GEOLOGIC SETTING

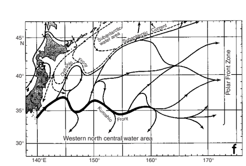
The convergent margin off northern Honshu Island has developed where Lower Cretaceous Pacific Ocean crust underthrusts the Eurasian plate in a westerly direction (Figs. F1, F2). The topographic features of the Japan Trench system consist of a deep-sea terrace, inner trench slope, midslope terrace, trench lower slope, Japan Trench, and an outer trench slope (Fig. F2) (Sacks, Suyehiro, Acton, et al., 2000). A forearc basin developed in the deep-sea terrace and trench upper slope, which extends from the northwest coast of Hokkaido more than 600 km to the south and is filled with Neogene sediments as thick as 5 km. Sites 1150 and 1151 are located on the deep-sea terrace ~100 km west of the Japan Trench (Fig. F1). They lie on the eastern edge of the forearc basin, where the Neogene section is ~1.5 km thick. These two sites are located in areas of contrasting seismicity. The northern site (Site 1150) is within a seismically active zone where microearthquakes are frequent and magnitude M7 earthquakes recur. The southern site (Site 1151) is within an aseismic zone where no such activities are observed (Sacks, Suyohiro, Acton, et al., 2000).

F2. Japan trench-arc system, p. 14.



In the Japan Trench area, the Kuroshio Current, also known as the Japan Current, is a warm, fast-moving current of the western Pacific Ocean that merges with a cold, southeastern current, the Oyashio Current, which is rich in plankton. The two currents become the North Pacific Current, which runs east through the Pacific Ocean (Fig. F3).

F3. Currents around the Japan Trench, p. 15.



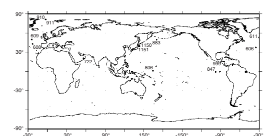
PREVIOUS STUDIES

Previous drilling in the study area took place during the DSDP (Deep Sea Drilling Project) era at eight sites during Legs 56, 57, and 87, which transected the Japan Trench at ~39.8°–40.7°N (Fig. F1). These eight sites yielded Quaternary sediments; nannofossil diversity was extremely low and preservation typically poor (Lang, 1986; Haq and Goreau, 1980; Shaffer, 1980).

ODP Legs 127 and 128 were drilled at similar latitudes west of Japan in the Japan Sea. Nannofossils were investigated from six sites by various specialists during these legs. Site 798 from Leg 127 provided a useful Pleistocene paleoceanographic reference section because of its good carbonate preservation and reliable age control based on diatoms, nannofossils, and paleomagnetics (Muza, 1996). At all of the Japan Sea ODP and DSDP sites, however, the sediment deposited between approximately 13.2 and 1.5 Ma is essentially barren of calcareous nannofossils (Rahman, 1992; Muza, 1992).

In their study of the distribution pattern of *C. pelagicus,* Sato et al. (1998) investigated eight sites from the Caribbean Sea and Atlantic, Pacific, and Indian Oceans (Fig. F4). Of these eight sites, two are located in the western Pacific Ocean, one in the high latitudes (Site 883), and the other one near the equator (Site 806). Data from the mid-latitudes of the western Pacific Ocean are needed to better establish the distribution pattern of *C. pelagicus* in the western Pacific Ocean and to test the model proposed by Sato et al. (1998) to account for its distribution.

F4. DSDP and ODP holes used, p. 16.



METHODS

Revised zonal schemes of Martini (1971; with modifications by Martini and Müller, 1986) and Bukry (1973, 1975; zonal code numbers added and modified by Okada and Bukry, 1980) were used to age-date the Cenozoic calcareous nannofossil sequences (Table T1).

T1. Nannofossil zonation and ages, p. 21.

Standard smear slides were prepared for samples from both sites at an interval of one sample every other section (or every 3 m). Calcareous nannofossils were examined using standard light-microscope techniques under crossed polarizers, transmitted light, and phase contrast at 1250× magnification. The scanning electron microscope was deployed to distinguish *Emiliania huxleyi* from small-sized *Gephyrocapsa* species and to define the Zone CN15/CN14b boundary.

Following the methodology of Sato et al. (1998), the abundance of *C. pelagicus* was investigated for sediments younger than 3.83 Ma (last occurrence [LO] of *Reticulofenestra pseudoumbilicus*) in both Holes 1150A and 1151A. For Hole 1150A, the first 200 specimens from each slide were counted to obtain the relative abundance of selected calcareous nannofossils. This procedure followed the example of Sato et al. (1998) for ODP Hole 883C. Next, 300 additional specimens were counted for each slide to determine the ratio of *C. pelagicus* in the total count of 500 specimens. For Hole 1151A, only the number of *C. pelagicus* specimens in a total of 500 nannofossils was counted for selected samples.

Preservation and abundance of calcareous nannofossil species may vary significantly because of etching, dissolution, or calcite overgrowth. A simple code system to characterize preservation is listed below:

VG = very good (no evidence of dissolution and/or overgrowth; no alteration of primary morphological characteristics and specimens appear diaphanous; specimens are identifiable to the species level).
G = good (little or no evidence of dissolution and/or overgrowth; primary morphological characteristics only slightly altered; specimens are identifiable to the species level).
M = moderate (specimens exhibit some etching and/or overgrowth; primary morphological characteristics somewhat altered; however, most specimens are identifiable to the species level).
P = poor (specimens are severely etched or exhibit overgrowth; primary morphological characteristics largely destroyed; fragmentation has occurred; specimens cannot be identified at the species and/or generic level).

Six calcareous nannofossil abundance levels are recorded as follows:

V = very abundant (>10–100 specimens per field of view).
A = abundant (1–10 specimens per field of view).
C = common (1 specimens per 2–10 fields of view).
F = few (1 specimens per 11–100 fields of view).
R = rare (1 specimens per >101–1000 fields of view).
B = barren.

ODP core identifiers indicate core type. The following abbreviations are used:

H = hydraulic piston core (HPC; also referred to as APC, or advanced hydraulic piston core).
X = extended core barrel (XCB).
R = rotary core barrel (RCB).

NANNOFOSSIL ZONATION AND BIOSTRATIGRAPHY

Site 1150

Site 1150 (39°11′N, 143°20′E) is located on the deep-sea terrace on the landward side of the Japan Trench. A sedimentary section from the two holes drilled at Site 1150 recovered a total thickness of 1181.6 m of middle Miocene to Holocene sediment (Table T2). The major lithology of the recovered sediments predominantly consists of homogenous diatomaceous silty clay and diatomaceous clay and its lithified equivalents, which are variable admixtures of biogenic siliceous microfossils, siliciclastic grains, and volcaniclastic grains (Shipboard Scientific Party, 2000a).

T2. Nannofossil datums and ages, Site 1150, p. 22.

Hole 1150A

Hole 1150A was drilled through Core 76X to a total depth of 722.6 meters below seafloor (mbsf) using the APC/XCB coring system in a water depth of 2692.2 m. The abundance and preservation of the nannofossils vary greatly. In Hole 1150A, 66 of 299 samples checked are barren (Table T3).

T3. Nannofossil range chart, Hole 1150A, p. 23.

The Pleistocene assemblage is characterized by *Calcidiscus leptoporus, C. pelagicus, E. huxleyi,* and *Pseudoemiliania lacunosa* plus specimens of *Gephyrocapsa, Reticulofenestra,* and *Helicosphaera.* The youngest coccolith assemblages belong to the *E. huxleyi* Zone (CN15) and are present from Samples 186-1150A-1H-1, 75–76 cm, to 3H-5, 75–76 cm, where *E. huxleyi* is dominant. Samples 186-1150A-3H-CC to 5H-5, 75–76 cm, were assigned to Subzone CN14b because neither *E. huxleyi* nor *P. lacunosa* was found. Calcareous nannofossils are few to common and poorly preserved in this interval. Samples 186-1150A-5H-CC to 10H-CC were assigned to Subzone CN14a because they contain both *P. lacunosa* and *Gephyrocapsa parallela.* Calcareous nannofossils are generally abundant and poorly to moderately preserved in these samples.

Samples 186-1150A-11H-1, 76–77 cm, to 14X-CC were assigned to Subzone CN13b based on rare specimens of *Gephyrocapsa caribbeanica* in Sample 14X-CC. Nannofossils are poorly preserved in these samples; 16 of the 31 samples are barren. Samples 186-1150A-15X-3, 75–76 cm, to 16X-3, 76–77 cm, were assigned to Subzone CN13a because their well-preserved common calcareous nannofossils contain no *Discoaster* or *G. caribbeanica.* The Pliocene/Pleistocene boundary was placed between Samples 186-1150A-14X-3-CC and 16X-3, 75–76 cm.

Among other nannofossil events, the first occurrence (FO) of *Reticulofenestra asanoi* was found in Sample 186-1150A-11H-5, 75–76 cm, and its LO was found in Sample 9H-CC. The rare and scattered presence of *Helicosphaera inversa* made it impossible to delimit its FO and LO. The LOs of *Calcidiscus macintyrei* and *Helicosphaera selli* occur before the FO of the *Gephyrocapsa oceanica.* The FO of *G. caribbeanica* occurs in the same sample as the FO of *G. oceanica* (Sample 186-1150A-14X-CC), so only the FO of *G. oceanica* was used for the zonation.

In the Pliocene and upper Miocene sediments, the assemblage is dominated by small *Reticulofenestra, Reticulofenestra pseudoumbilicus, Reticulofenestra gelida, Calcidiscus leptoporus*, *C. pelagicus,* and *C. macintyrei*. The genus *Discoaster,* which prefers warm water, is consistently rare to few in the non-barren samples. This limited the resolution of the zonation that could be applied here. Quality of preservation also diminishes downhole.

Samples 186-1150A-16X-CC through 22X-5, 75–76 cm, were assigned to Subzone CN12c–CN12d, the base of which is marked by the LO of *Discoaster pentaradiatus* and *Discoaster surculus*. Samples 186-1150A-22X-CC to 27X-7, 10–11 cm, were assigned to Subzone CN12b, whose base is marked by the LO of *Discoaster tamalis*. Samples 186-1150A-27X-CC to 38X-3, 10–11 cm, were assigned to Subzone CN12a because no *R. pseudoumbilicus* was found. The LO of *Amaurolithus* spp. was not detected, and the rare occurrence of *Ceratolithus rugosus* makes assignment of the base of Subzone CN10c questionable.

Hole 1150B

Hole 1150B was drilled ~44 m east of Hole 1150A with the RCB coring system in a water depth of 2692.2 m (Table T4). The hole was washed down to 703.3 mbsf before coring began, at which point 50 RCB cores were taken. The first datum encountered in Hole 1150B was the LO of *Discoaster quinqueramus,* which defines the Zone CN10/CN9 boundary; this was found in Sample 186-1150B-10R-1, 10–11 cm. A single well-preserved *Amaurolithus amplificus* in Sample 186-1150B-19R-CC puts the age of this sample between 5.99 and 6.84 Ma. From Samples 186-1150B-1R-CC through 19R-CC, about one-half of the core catcher

T4. Nannofossil range chart, Hole 1150B, p. 24.

samples (9 out of 19) are barren or contain rare nannofossils. Samples 186-1150B-10R-1, 10–11 cm, through 38R-CC were assigned to Zone CN9 by the FO of *Discoaster berggrenii.* Below this, no nannofossil datum was found. In Cores 48R, 49R, and 50R, *Catinaster coalitus* is rare to common, which indicates it is still above the base of Zone CN6. The LO of *D. surculus,* the LO and FO of *Amaurolithus* spp., *Ceratolithus acutus, Triquetrorhabdulus rugosus,* and the FO of *Discoaster loeblichii,* however, were not found.

Site 1151

Site 1151 (38°45′N, 143°20′E) is 48 km south of Site 1150 (Fig. F1). The sedimentary section from 0 to 1113 mbsf was cored with the RCB and/or APC coring systems in three holes (1151A, 1151C, and 1151D). The dominant lithology is that of diatom-, glass-, and spicule-bearing silty clay (Shipboard Scientific Party, 2000b). Occurrence of minor lithologies is rare. Nannofossil biostratigraphy suggests that the sequence represents a record from the middle Miocene to Pleistocene (Table T5).

T5. Nannofossil datums and ages, Site 1151, p. 27

Hole 1151A

From Hole 1151A, 108 cores were recovered (Cores 2R through 109R; no recovery for Core 1W) from 78.0 to 1113.46 mbsf at a water depth of 2182.2 m. The abundance and preservation of nannofossils vary greatly (Table T6).

T6. Nannofossil range chart, Hole 1151A, p. 28.

The Pleistocene assemblage was moderate to well preserved; 4 of 12 samples are barren. Core 2R was assigned to Zone CN14 because of *G. parallela* found in Sample 186-1151A-2R-CC. All three samples checked in this core yielded well-preserved abundant nannofossils. Samples 186-1151A-3R-1, 10–11 cm, through 3R-6, 10–11 cm, were assigned to Subzone 13b because of the presence of *G. oceanica* and *G. caribbeanica.* Samples 186-1151A-3R-6, 75–76 cm, to 6R-4, 75–76 cm, were assigned to Subzone CN13a because no *Discoaster* was found. The three samples between them are barren.

The Pliocene and Miocene assemblages are dominated by *Reticulofenestra, C. pelagicus,* and *C. leptoporus*. Discoasters are also common. The LO of *Discoaster brouweri* was observed in Sample 186-1151A-6R-CC, which indicates the base of Subzone CN13a. The LO of *D. pentaradiatus* was observed in Sample 186-1151A-10R-1, 75–76 cm, which indicates the base of Subzone CN12d. The nannofossils are generally abundant and moderately to well preserved in Subzone CN12d. Samples 186-1151A-10R-1, 75–76 cm, to 13R-3, 10–11 cm, were assigned to Subzones CN12b to CN12c, whereas the LO of *D. tamalis* was observed in Sample 186-1151A-13R-3, 75–76 cm, which indicates the base of Subzone CN12b. Ten of 20 samples within this interval are barren. The LO of *D. surculus* was not detected. The LO of *R. pseudoumbilicus* was observed from Sample 186-1151A-15R-CC, which indicates the base of Subzone CN12a. Nannofossils are generally abundant and moderately preserved in Subzone CN12a except for Samples 186-1151A-15R-5, 76–77 cm, and 16R-6, 10–11 cm, which are barren. The CN11/CN10c, CN10c/CN10b, and CN10b/CN10a zonal boundaries were not observed owing to the absent or sparse occurrence of the marker species.

The LO of *D. quinqueramus,* which marks the base of Subzone CN10a, was detected in Sample 186-1151A-59R-5, 75–76 cm. In Zones CN10–CN11, 42 of 169 samples are barren. The FO of *D. berggrenii,* observed in Sample 186-1151A-90R-CC, defined the base of Zone CN9. In Zone

CN9, 42 of 111 samples are barren. The CN8/CN7 and CN7/CN6 zonal boundaries were not observed in this hole. The base of Zone CN6 was recognized in Sample 186-1151A-99R-2, 15–16 cm, as indicated by the FO of *Catinaster coalitus*. Farther downhole, poorly preserved nannofossils were found in only 8 samples; the other 27 samples examined are barren. It is difficult to determine the age of the sediments from nannofossils because of their low abundance and poor preservation. Diatom data suggest that the hole terminated in the upper part of Zone CN3.

Holes 1151C and 1151D

A Pleistocene nannofossil assemblage was observed in 11 APC cores recovered from Hole 1151C (Table T7) and 10 APC cores from Hole 1151D (Table T8). The assemblage is characterized by *E. huxleyi, P. lacunosa, C. pelagicus, C. leptoporus,* and *Gephyrocapsa*.

The Subzone CN15/CN14b boundary, which is marked by the FO of *E. huxleyi,* lies between Samples 186-1151C-2H-1, 25–26 cm, and 2H-7, 25–26 cm. The nannofossils in Zone CN15 are common to abundant and well preserved at both sites. The LO of *P. lacunosa,* which marks the base of the Subzone CN14b, was observed between Samples 186-1151C-4H-4, 100–101 cm, and 4H-5, 25–26 cm. Sample 186-1151C-4H-CC is barren. The FO of *G. parallela,* which marked the Zone CN14/CN13 boundary, was observed in Samples 186-1151C-8H-CC and 186-1151D-7H-CC. The nannofossils in Zone CN14 are rare to common. Sample 186-1151D-9H-CC is barren. *G. caribbeanica* was observed in both Samples 186-1151C-11H-CC and 186-1151D-10H-CC, which indicates that the bottom of these two holes is still within Subzone CN13b.

T7. Nannofossil range chart, Hole 1151C, p. 29.

T8. Nannofossil range chart, Hole 1151D, p. 31.

ABUNDANCE OF PLIOCENE–PLEISTOCENE *COCCOLITHUS PELAGICUS*

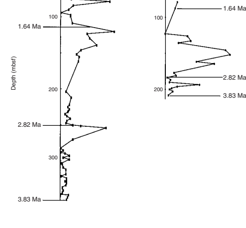
C. pelagicus is interpreted as being a cold-water species throughout the Pliocene and Quaternary (Roth, 1994). The geographical distribution of this species indicates that a change in the current system around the western Pacific and eastern Atlantic Oceans occurred at 2.82 Ma that was related to the final elevation of the Isthmus of Panama (Sato et al., 1998). ODP core coverage in the western Pacific Ocean consisted only of two sites, one equatorial and one high latitude (Sites 806 and 883; 0° and 51°N, respectively). Therefore, data for the North Pacific Ocean are badly needed around the latitude of Japan in order to determine the trend of *C. pelagicus* in this part of the globe.

Results

Following the methodology of Sato et al. (1998) (see also "Methods," p. 3), 500 nannofossil specimens per slide were counted from sediment younger than 3.83 Ma (the base of Zone CN12) from Holes 1150A and 1151A to determine the ratio of *C. pelagicus* against the total count. The results are shown in Figure F5.

For Hole 1150A, between 3.83 and 2.82 Ma, except for the two samples near the 2.82-Ma boundary that contain abundant *C. pelagicus,* 27 samples contain no more than 10 specimens of *C. pelagicus,* an average 4.6 *C. pelagicus* per 500 specimens. The abundance of *C. pelagicus* shows a peak near the 2.82-Ma boundary (52 *C. pelagicus* in 500 specimens from Sample 186-1151A-28X-3, 10–11 cm). From 2.82 to 1.65 Ma, the

F5. Number of *C. pelagicus,* Holes 1150A and 1151A, p. 17.

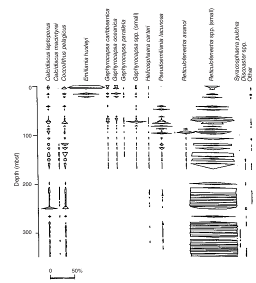


abundance of *C. pelagicus* increases significantly and varies greatly, an average of 15 per 500 specimens. In the sediment younger than 1.65 Ma, the average is 21 *C. pelagicus* per 500 specimens.

From Hole 1151A, the same pattern was observed (Fig. F5). Between 3.83 and 2.82 Ma, *C. pelagicus* averaged 9 per 500 specimens. From 2.82 to 1.65 Ma, the abundance of *C. pelagicus* increases significantly, to an average of 24.4 per 500 specimens.

The relative abundance of selected nannofossils was also determined for Hole 1150A (Fig. F6) in order to provide a comparison with a similar study by Sato et al. (1998) for Hole 883C. In Hole 1150A, *E. huxleyi* dominates the first three samples counted. Below that, small *Reticulofenestra* dominate the assemblages. Small *Gephyrocapsa* peak at 254 mbsf (Sample 186-1150A-9H-1, 76–77 cm), whereas *P. lacunosa* increases in abundance before its extinction point. *R. asanoi* was an important component during its short life span.

F6. Relative abundances of nannofossil species, Hole 1150, p. 18.

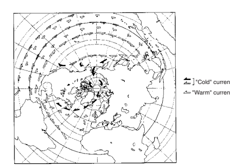


Discussion

For Hole 1150A, the abundance of *C. pelagicus* shows a peak at 2.82 Ma (Fig. F5), the same pattern seen in Holes 722A, 999, 606, and 608 located in the Indian Ocean, Caribbean Sea, and the Atlantic Ocean (Sato et al., 1998, fig. 7). Sato et al. (1998) suggested that this event was related to glaciation of the Northern Hemisphere during the late Pliocene.

The *C. pelagicus* abundance patterns shown here support the conclusions of Sato et al. (1998). Between 3.83 and 2.82 Ma, *C. pelagicus* was less abundant than it was later. This was prior to the final elevation of the Isthmus of Panama when warm currents flowed from the Atlantic Ocean to the Caribbean Sea and on into the Pacific Ocean (Fig. F7). The elevation of the isthmus closed the Central American Seaway and cut off the warm-current communication between the equatorial Atlantic and the Pacific Oceans, which caused the abundance of the *C. pelagicus* in the study area to increase (Fig. F8).

F7. Paleocurrent system before the Isthmus of Panama, p. 19.



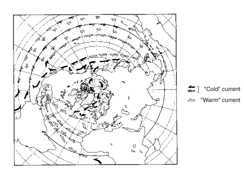
SUMMARY

The calcareous nannofossil biostratigraphy from the Sites 1150 and 1151 in the Japan Trench of the western Pacific Ocean was studied in detail. Although the abundance and species diversity of the calcareous nannofossil flora was poor, it is still possible to show that the sedimentary sequences range from Quaternary to Miocene in age (nannofossil Zones CN15 to CN3).

A sedimentary section from Holes 1150A and 1150B recovered a total thickness of 1181.6 m of middle Miocene to Holocene sediment. From Site 1151, the sediment section from 0 to 1113 mbsf was cored in three holes (1151A, 1151C, and 1151D). Nannofossil biostratigraphy suggests that the sequence represents a record from the middle Miocene to Pleistocene.

The abundance of *C. pelagicus* was studied in sediments younger than 3.83 Ma from both Holes 1150A and 1151A in order to elucidate past climate conditions. Between 3.83 and 2.82 Ma, *C. pelagicus* was less abundant than it was subsequently. This pattern supports the observations and conclusions by Sato et al. (1998), based on their study of eight DSDP/ODP sites around the globe, two of which are located in the high and equatorial latitudes of the western Pacific Ocean. My study area lies

F8. Paleocurrent system after the Isthmus of Panama, p. 20.



conveniently between the latter two sites, thereby filling a gap in the existing coverage. In agreement with their study, the change in the *C. pelagicus* abundance pattern observed here appears to be related to a change in the current system around the western Pacific Ocean and eastern Atlantic Ocean that occurred in response to the final elevation of the Isthmus of Panama.

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APPENDIX

Calcareous Nannofossils Considered in This Paper (Genera in Alphabetical Order)

Amaurolithus amplificus (Bukry and Percival, 1971) Gartner and Bukry, 1975
Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947
Calcidiscus leptoporus (Murray and Blackman, 1895) Loeblich and Tappan, 1978
Calcidiscus macintyrei (Bukry and Bramlette, 1969b) Loeblich and Tappan, 1978
Catinaster coalitus Martini and Bramlette, 1963
Ceratolithus acutus Gartner and Bukry, 1974
Ceratolithus cristatus Kamptner, 1950
Ceratolithus rugosus Bukry and Bramlette, 1968
Ceratolithus simplex Bukry, 1979
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Coronosphaera nitscens (Kamptner, 1963) Bramlette and Wilcoxon, 1967
Discoaster asymmetricus Gartner, 1969
Discoaster bellus Bukry, 1971
Discoaster berggreni Bukry, 1971
Discoaster brouweri Tan Sin Hok, 1927
Discoaster challengeri Bramlette and Riedel, 1954
Discoaster exilis Martini and Bramlette, 1963
Discoaster pentaradiatus Tan Sin Hok, 1927
Discoaster quinqueramus Gartner, 1969
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner 1967
Discoaster variabilis Martini and Bramlette, 1963
Discoaster sp. cf. *D. adamanteus* Bramlette and Wilcoxon, 1969
Emiliania huxleyi (Lohmann, 1902) Hay and Mohler, 1967
Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Gephyrocapsa spp. (small) (see Takayama and Sato, 1987)
Gephyrocapsa oceanica Kampter, 1943
Gephyrocapsa parallela Hay and Beaudry, 1973
Helicosphaera carteri (Wallich, 1877) Kampter, 1954
Helicosphaera inversa Gartner, 1980
Helicosphaera sellii Bukry and Bramlette, 1969
Helicosphaera wallichii (Lohmann, 1902) Boudreaux and Hay, 1969
Minylitha convallis Bukry, 1973
Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969
Pontosphaera Lohmann, 1902
Reticulofenestra asanoi Sato and Takayama, 1992
Reticulofenestra gelid (Geitzenauer, 1972) Backman, 1978
Reticulofenestra pseudoumbilicus (Gartner, 1967) Gartner, 1969
Reticulofenestra spp. (small) (see Takayama and Sato, 1987)
Rhabdosphaera clavigera Murray and Backman, 1898
Sphenolithus Deflandre in Grasse 1952
Syracosphaera pulchra Lohmann, 1902
Umbilicosphaera sibogae (Weber-van Bosse, 1901) Gaarder 1970

Figure F1. Map of the Japan Trench area off northeast Japan showing Leg 186 Sites 1150 and 1151 plus previous drilling sites from DSDP Legs 56, 57, and 87 and seismic lines.

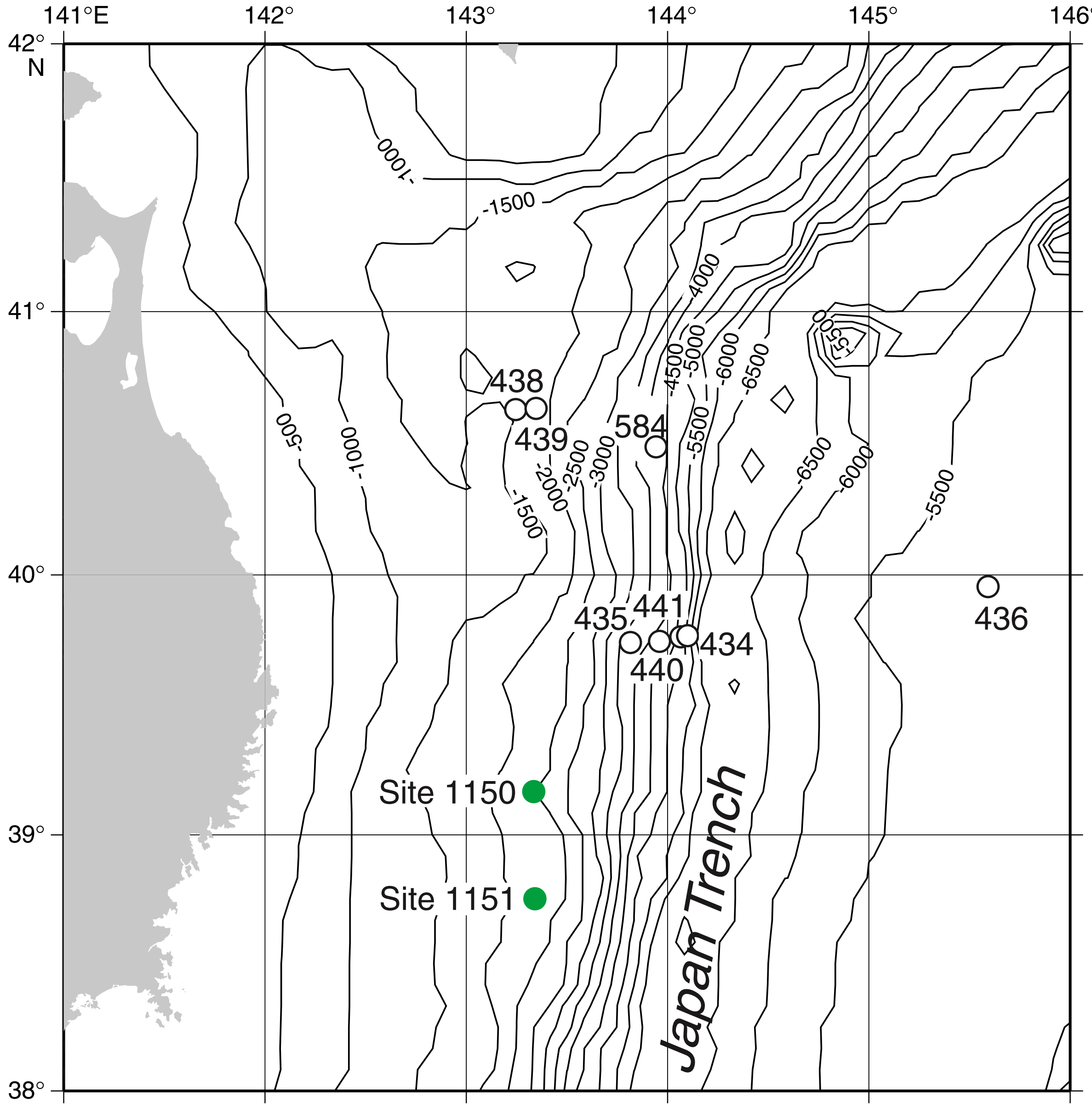

Figure F2. Schematic cross section of the Japan trench-arc system (from Suyehiro and Nishizawa, 1994).

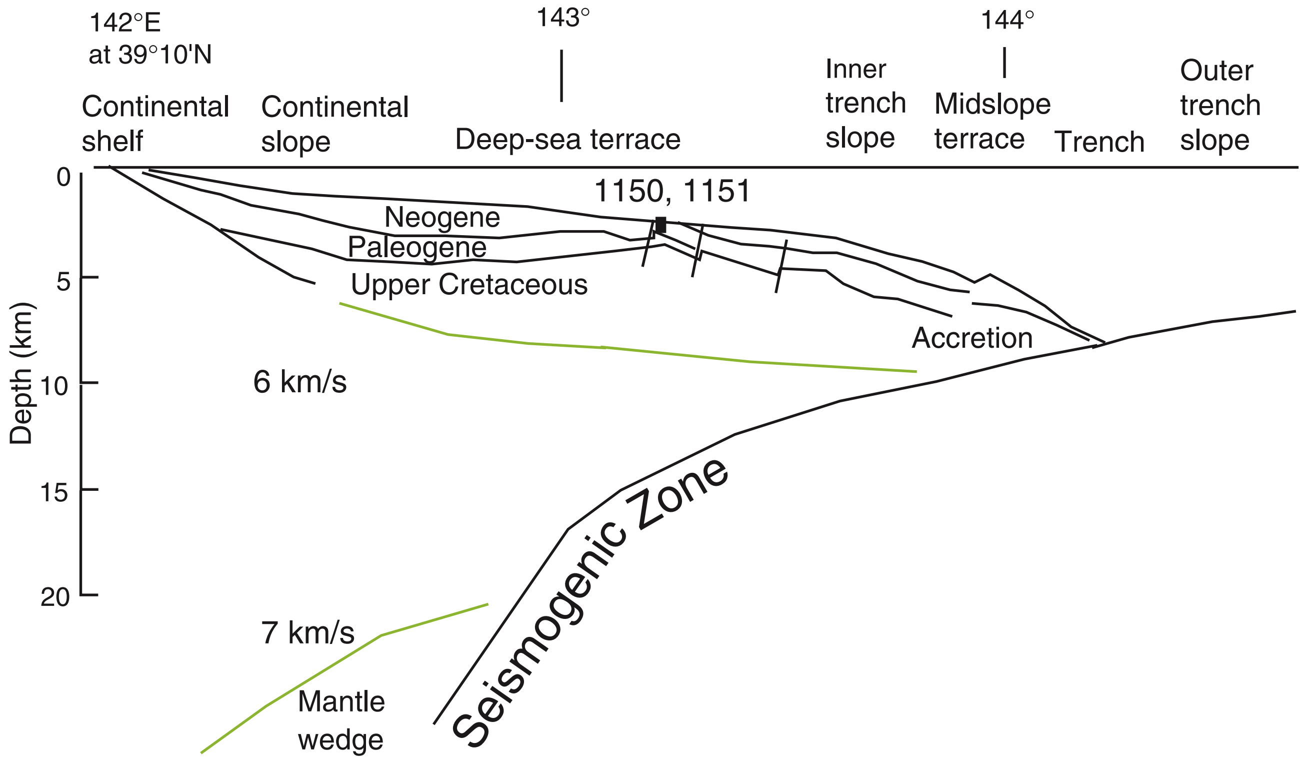

Figure F3. Current system around the Japan Trench (Kawai, 1972).

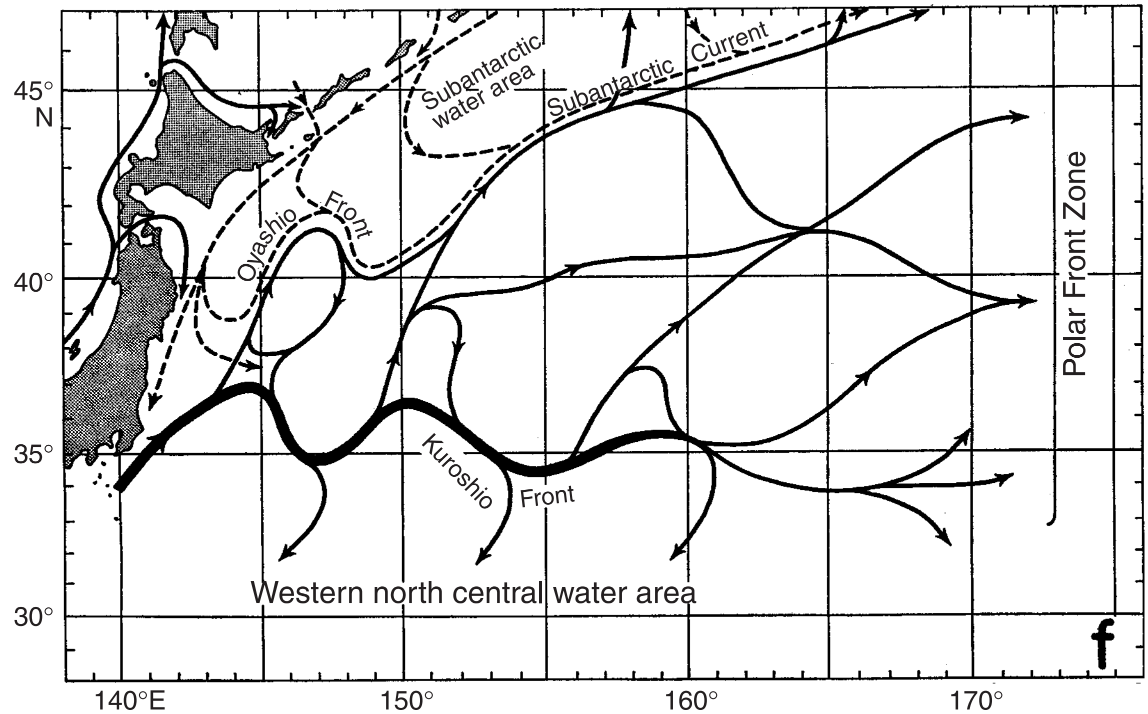

Figure F4. Location map of DSDP and ODP holes used for investigating the abundance of *Coccolithus pelagicus* by Sato et al. (1998) and in this study.

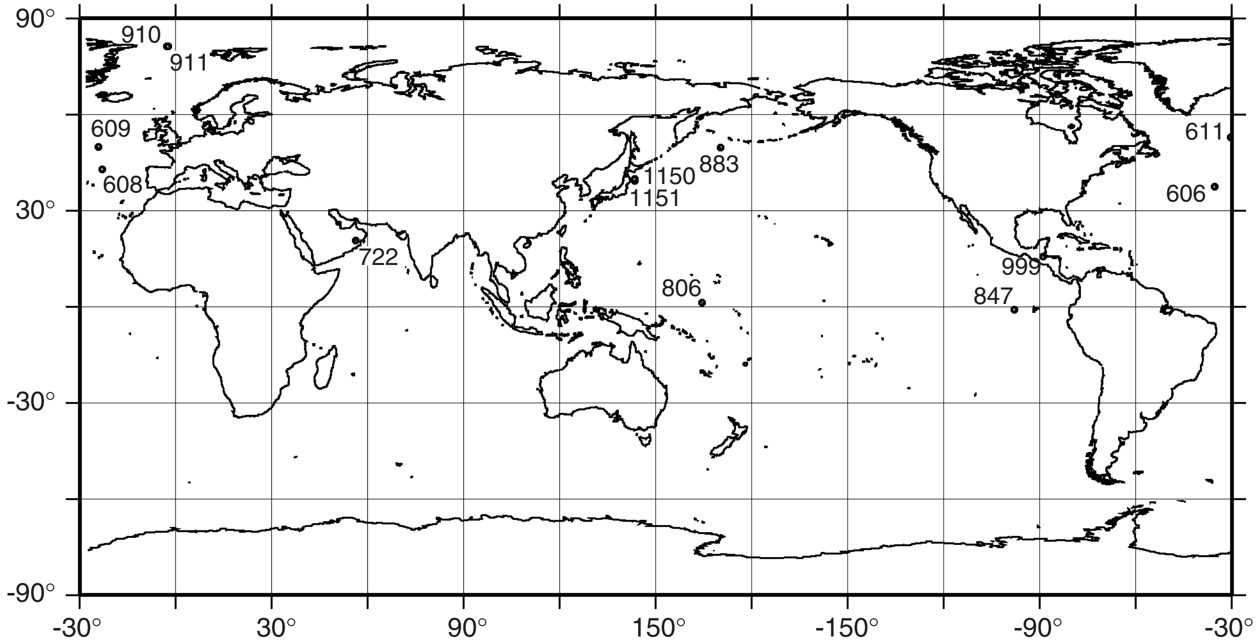

Figure F5. Number of *Coccolithus pelagicus* in 500 specimens from Holes 1150A and 1151A.

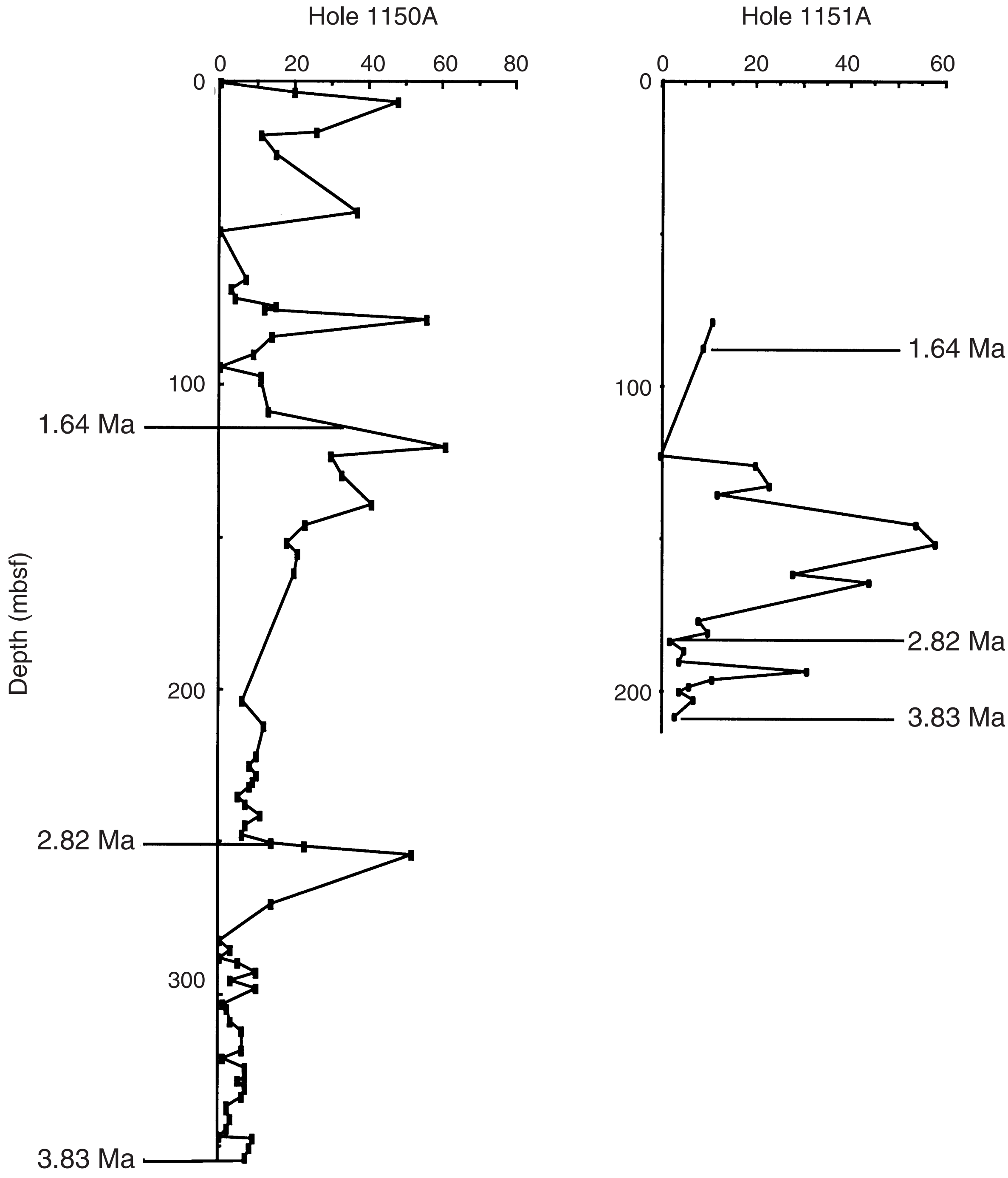

Figure F6. Relative abundance of selected nannofossil species from Hole 1150.

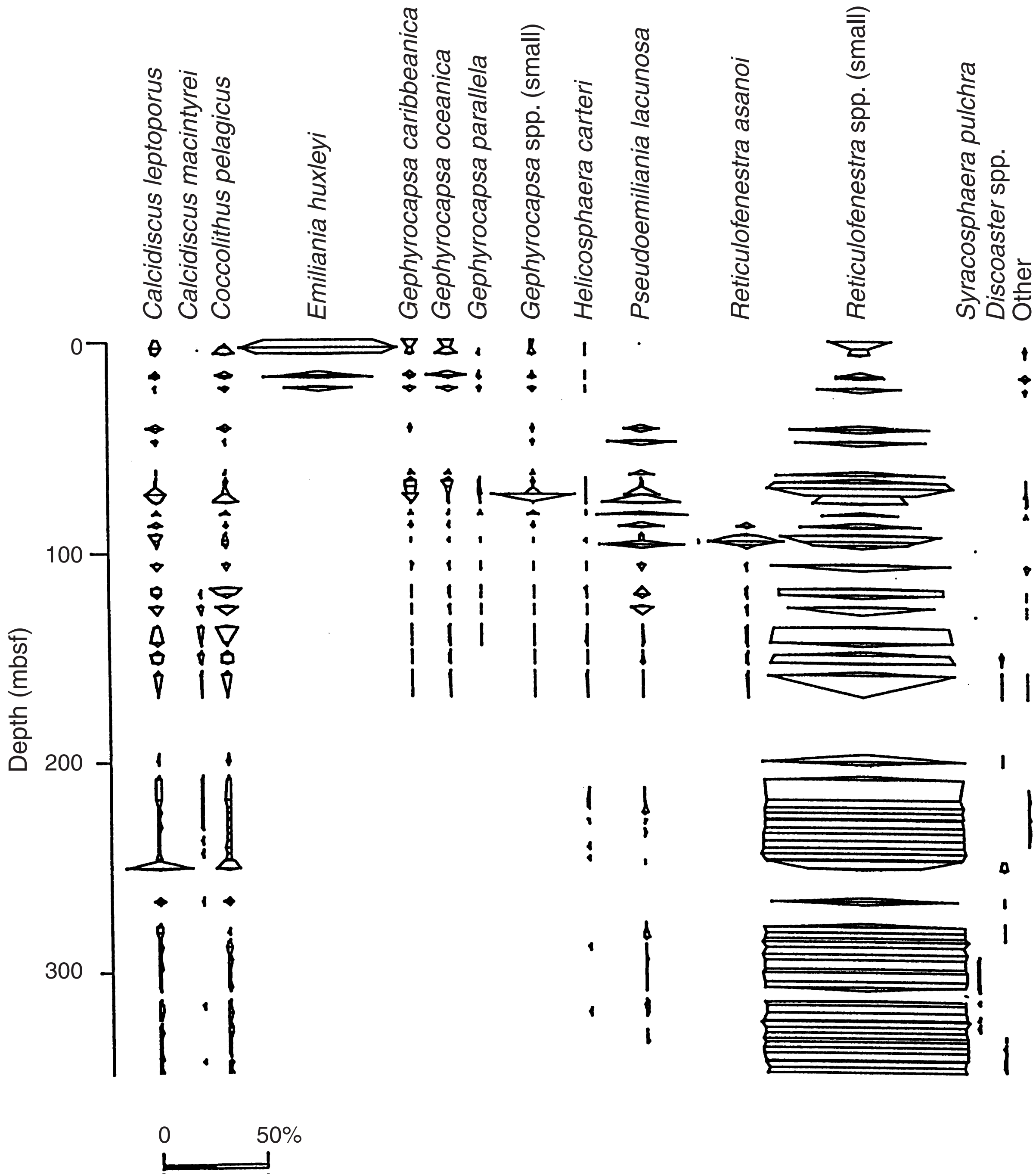

Figure F7. Reconstruction of the paleocurrent system in the Northern Hemisphere before appearance of the Isthmus of Panama (3.83–2.82 Ma) (from Sato et al., 1998, fig. 10).

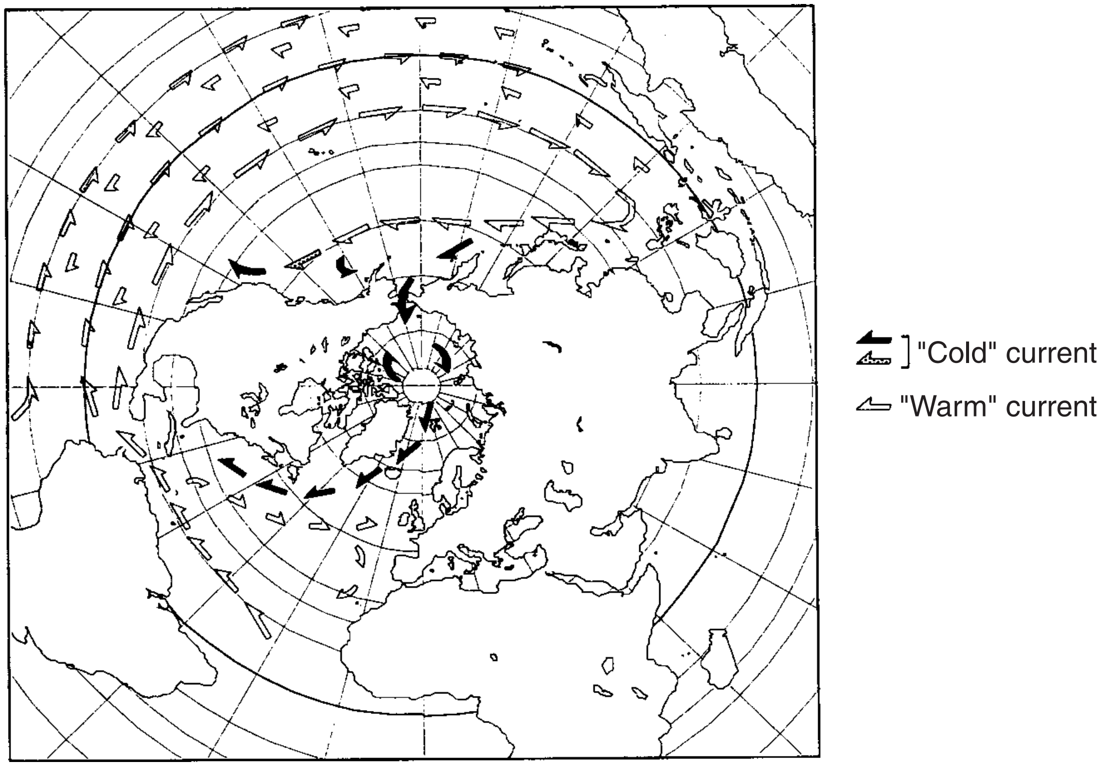

Figure F8. Reconstruction of the paleocurrent system in the Northern Hemisphere after appearance of the Isthmus of Panama (2.82–1.65 Ma) (from Sato et al., 1998, fig. 11).

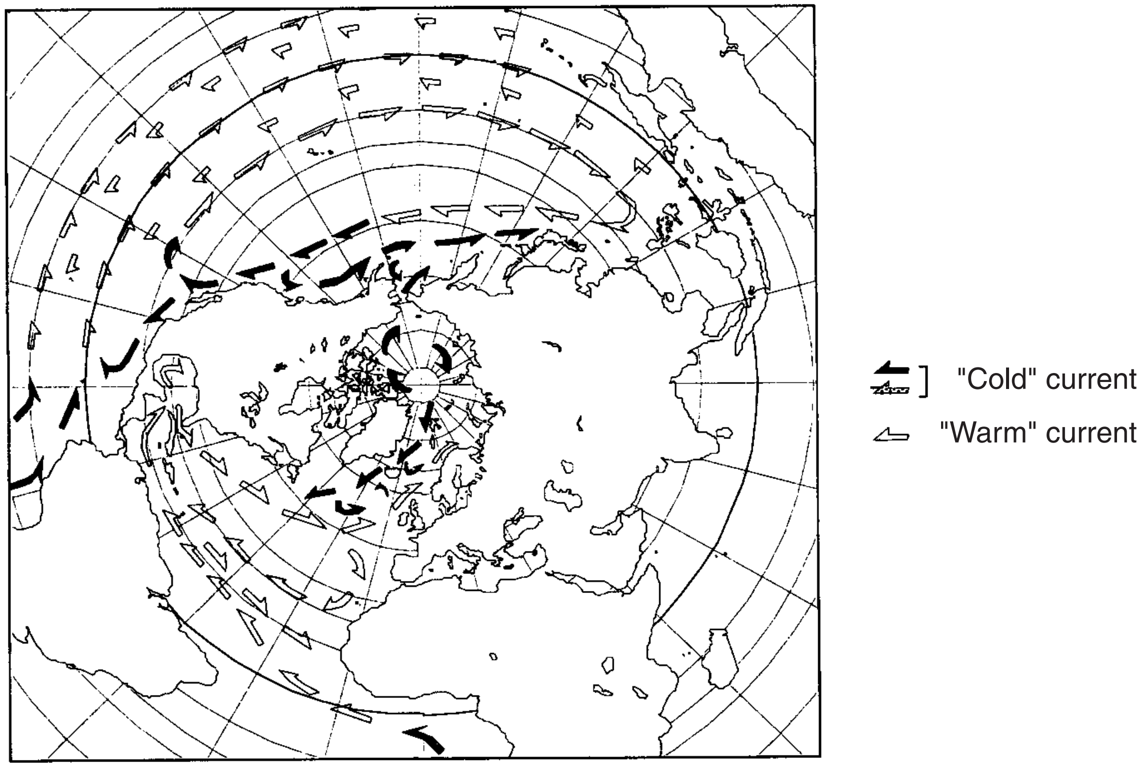

Table T1. Nannofossil zonation and ages.

Event	Zone/ subzone (base)	Age (Ma)	Reference
FO acme *Emiliania huxleyi*		0.085	1
LO *Helicosphaera inversa*		0.155	2
FO *Emiliania huxleyi*	CN15	0.248	2
LO *Pseudoemiliania lacunosa*	CN14b	0.408	2
FO *Helicosphaera inversa*		0.505	2
LO *Reticulofenestra asanoi*		0.88	3
FO *Gephyrocapsa parallela*	CN14a	0.94	3
FO *Reticulofenestra asanoi*		1.17	3
LO *Helicosphaera sellii*		1.26	3
LO *Calcidiscus macintyrei*		1.64	3
FO *Gephyrocapsa oceanica*		1.64	3
FO *Gephyrocapsa caribbeanica*	CN13b	1.71	4
Pliocene/Pleistocene boundary		1.745	2
LO *Discoaster brouweri*	CN13a	1.95	3
LO *Discoaster pentaradiatus*	CN12d	2.36	3
LO *Discoaster surculus*	CN12c	2.51	3
LO *Discoaster tamalis*	CN12b	2.82	2
LO *Sphenolithus* spp.		3.62	5
LO *Reticulofenestra pseudoumbilicus*	CN12a	3.83	3
LO *Amaurolithus* spp.	CN11	4.50	6
FO *Ceratolithus rugosus*	CN10c	5.046	7
FO *Ceratolithus acutus*	CN10b	5.089	7
LO *Triquetrorhabdulus rugosus*		5.231	7
Miocene/Pliocene boundary		5.3	
LO *Discoaster quinqueramus*	CN10a	5.537	7
LO *Amaurolithus amplificus*		5.993	7
FO *Amaurolithus amplificus*		6.840	7
LO paracme *Reticulofenestra pseudoumbilicus*		7.100	7
FO *Amaurolithus* spp.	CN9b	7.392	7
FO *Discoaster berggrenii*	CN9a	8.281	7
FO *Discoaster loeblichii*	CN8b	8.7	8
FO paracme *Reticulofenestra pseudoumbilicus*		8.788	7
LO *Discoaster hamatus*	CN8a	9.635	7
LO *Catinaster calyculus*		9.641	7
FO *Discoaster neohamatus*		10.450	7
FO *Discoaster hamatus*	CN7	10.476	7
FO *Catinaster calyculus*		10.705	7
FO *Catinaster coalitus*	CN6	10.794	7
LO *Coccolithus miopelagicus*		10.941	7
LO *Discoaster kugleri*		11.520	7
FO *Discoaster kugleri*	CN5b	11.831	7
LO *Cyclicargolithus floridanus*		13.2	9
LO *Sphenolithus heteromorphus*	CN5a	13.523	7
LO *Helicosphaera ampliaperta*	CN4	15.6	8
LO abundant *Discoaster deflandrei*		16.2	9
FO *Sphenolithus heteromorphus*	CN3	18.2	8
LO *Sphenolithus belemnos*		18.3	8
FO *Sphenolithus belemnos*	CN2	19.2	8

Notes: FO = first occurrence, LO = last occurrence. References: 1 = Thierstein et al. (1977), 2 = modified from Takayama and Sato (1987), Sato et al. (1991), Takayama (1993), and Kameo et al. (1995), 3 = Wei (1993), 4 = Berger et al. (1994), 5 = Backman and Shackleton (1983), 6 = Backman et al. (1990), 7 = Backman and Raffi (1997), 8 = Berggren et al. (1995), 9 = Raffi and Flores (1995), 10 = Berggren et al. (1985).

Table T2. Nannofossil datums, absolute ages, and depths, Site 1150.

Event	Zone/ subzone (base)	Age (Ma)	Core, section, interval (cm)	Depth (mbsf)
			186-1150A-	
FO *Emiliania huxleyi*	CN15	0.248	3H-5, 75–76 to 3H-7, 75–76	23.95–26.95
LO *Pseudoemiliania lacunosa*	CN14b	0.408	5H-5, 75–76 to 5H-CC	45.95–46.33
FO *Gephyrocapsa parallela*	CN14a	0.94	10H-7, 75–76 to 11H-1, 76–77	92.46–93.96
FO *Gephyrocapsa caribbeanica*	CN13b	1.71	14X-CC to 15H-1, 75–76	124.7–126.8
LO *Discoaster brouweri*	CN13a	1.95	16X-3, 76–77 to 16X-CC	139.3–139.6
LO *Discoaster pentaradiatus*	CN12d	2.36	22X-5, 75–76 to 22X-CC	200–202.9
LO *Discoaster tamalis*	CN12b	2.82	27X-7, 10–11 to 27X-CC	250.6–251.2
LO *Reticulofenestra pseudoumbilicus*	CN12a	3.83	38X-3, 10–11 to 38X-5, 10–11	350.7–353.7
FO *Ceratolithus rugosus*	CN10c	5.046	66X-3, 10–11 to 66X-5, 10–11	620.4–623.4
			186-1150B-	
LO *Discoaster quinqueramus*	CN10a	5.537	9R-CC to 10R-1, 10–11	781.5–787
FO *Discoaster berggrenii*	CN9a	8.28	38R-CC to 39R-1, 10–11	1058.6–1066

Note: FO = first occurrence, LO = last occurrence.

Table T3. Nannofossil range chart, Hole 1150A. (This table is available in an **oversized format.**)

Table T4. Nannofossil range chart, Hole 1150B. (See table notes. Continued on next two pages.)

Nannofossil zone/subzone	Age	Core, section, interval (cm)	Depth (mbsf)	Preservation	Group abundance	*Amaurolithus amplificus*	*Amaurolithus delicatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Catinaster coalitus*	*Ceratolithus telesmus*	*Coccolithus pelagicus*	*Discoaster bellus*	*Discoaster berggrenii*	*Discoaster brouweri*	*Discoaster challengeri*	*Discoaster exilis*	*Discoaster pentaradiatus*	*Discoaster quinqueramus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discoaster* spp.	*Helicosphaera carteri*	*Reticulofenestra gelida*	*Reticulofenestra pseudoumbilicus*	*Reticulofenestra* spp. (small)	*Sphenolithus*
		186-1150B-																									
		1R-1, 10–11	703.40	P	R																						
		1R-3, 10–11	706.23		B																						
		2R-1, 9–10	709.79		B																						
		2R-CC	711.93		B																						
		3R-1, 10–11	719.40	P	F			F																	R	F	
		3R-CC	720.11	P	F			R	R			F												F	F	R	
		4R-1, 10–11	729.10		B																						
		4R-3, 10–11	731.80	P	C			F				F												F	C	C	
		4R-CC	732.49		B																						
		5R-1, 10–11	738.70	P	C			F				F						F			F			C	C	C	F
		5R-CC	740.07	P	R																				R		
		6R-1, 10–11	748.40	P	F			F													F				F	F	
CN10a		6R-3, 10–11	751.40	P	C			F													F			C	F	C	
		6R-5, 7–9	753.60	M	A			C	C			C			F			F			F	F	C	F	C	A	C
		6R-CC	756.54	M	C			F	C			C			F			F			F			F	C	F	F
		7R-1, 10–11	758.00	M	V		R	C	C			C				F					F	F		C	F	V	F
		7R-1, 143–145	759.33	M	F			R	F			F									F			F	F		R
		8R-1, 10–11	767.70	M	C			F	F			R			R						F						F
		8R-CC	770.05	M	C			F	F			C									R		F	C	F		C
		9R-1, 10–11	777.30		B																						
		9R-2, 8–9	778.80		B																						
		9R-2, 80–81	779.50		B																						
		9R-3, 8–9	780.28	P	C			F				F					R				F			F	F	C	
		9R-3, 98–99	781.18	P	F			R																		F	
		9R-CC	781.47	P	R																			F	R		
		10R-1, 10–11	787.00	M	V							A							R		F		C	V	C		F
		10R-1, 75–76	787.65		B																						
		10R-2, 10–11	788.50		B																						
		10R-2, 75–76	789.20	M	A							C									R			C	C	C	C
	Miocene	10R-3, 10–11	789.96		B																						
		10R-CC	791.04	P	R			R	R												R			R	R		
		11R-1, 10–11	796.60	M	V			C	F			A									C		C	A	C	A	C
		11R-3, 10–11	799.48	P	C			F	R			F								R	F			R	C	C	
		11R-5, 10–11	802.13	P	F			F										R			R			F	F	F	F
		11R-CC	802.82	P	B																						
		12R-1, 10–11	806.20	G	C			F													F			F	C	C	R
		12R-3, 10–11	808.98	P	A							F						R	F		F					A	
		12R-CC	811.91	P	B																						
		13R-1, 10–11	815.80	M	C			F							R				R		F			F	C	C	
		13R-3, 10–11	817.90		B																						
		13R-CC	819.78	P	R																R					R	
		14R-1, 10–11	825.50		B																						
CN9		14R-3, 10–11	828.42		B																						
		14R-CC	830.48	M	C			F	F			R		R				F	R		F			F	C	F	R
		15R-1, 8–9	835.08		B																						
		15R-CC	837.15	M	C			R	F			F		R					F		R		R	C	R	F	F
		16R-1, 9–10	844.69	M	C			F				F										R	F	F	F	C	
		16R-3, 8–9	847.68	M	A			F	F			F							F		C			C	F	A	F
		16R-5, 8–9	850.68		B																						
		16R-CC	852.22	P	F			R				F		R							R		R	R	R		R
		17R-1, 10–11	854.30	P	F			R				R												F	F	F	
		17R-3, 10–11	857.30		B																						
		17R-CC	859.53	P	C				F			F		F							F			C		F	
		18R-1, 10–11	863.90	M	C			F						F	F				F		F			C	F	C	
		18R-3, 14–15	866.94	M	A			F	F			F															
		18R-CC	868.08	M	A			C	F			C		C							C		F	F	C	D	C
		19R-1, 8–9	873.58	M	A									F							C			F	F	A	
		19R-3, 14–15	876.64	M	C			F							F				F		F					C	
		19R-CC	877.53	M	C			F	F			R		F					F		C		F	F	F	R	F

Table T4 (continued).

Nannofossil zone/subzone	Age	Core, section, interval (cm)	Depth (mbsf)	Preservation	Group abundance	*Amaurolithus amplificus*	*Amaurolithus delicatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Catinaster coalitus*	*Ceratolithus telesmus*	*Coccolithus pelagicus*	*Discoaster bellus*	*Discoaster berggrenii*	*Discoaster brouweri*	*Discoaster challengeri*	*Discoaster exilis*	*Discoaster pentaradiatus*	*Discoaster quinqueramus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discoaster* spp.	*Helicosphaera carteri*	*Reticulofenestra gelida*	*Reticulofenestra pseudoumbilicus*	*Reticulofenestra* spp. (small)	*Sphenolithus*
		20R-1, 10–11	883.30	M	V			F	F			C		C					F		F		F	F	R	V	C
		20R-3, 10–11	886.18	M	C									F	F				C		C			F	R	F	
		20R-5, 10–11	889.18	M	V				F			F		C	R				F		C					V	F
		20R-7, 10–11	892.18	M	V			C				C		C	F				C		C			A	C	V	
		20R-CC	893.02	M	C			F	F			F		C	R				F		F		F	A	C	A	F
		21R-1, 10–11	893.00	M	V			C	F			C		F	F				F		C					V	F
		21R-3, 10–11	895.84	M	V			C				F		F										A	C	V	F
		21R-CC	898.32	P	F			F	F			R		R							F		R	R	F		
		22R-1, 22–23	902.32	M	A			C						C	F				C		C			C	C	A	
		22R-3, 10–11	904.54		B																						
		22R-5, 10–11	907.04	P	F									F										F	R	F	
		22R-7, 10–11	910.02	P	C			F	F			C		R	R									C	C	C	R
		22R-CC	910.67	M	C			F	F			C		F					R		F		R	A	C	C	F
		23R-1, 12–13	911.92	M	A			F	F					C	F				F		C		F	C	C	A	F
		23R-3, 8–9	914.88		B																						
		23R-5, 1–2	917.81	M	A			F				F		F									F	C	F	A	
		23R-CC	919.73	M	C			F	F			C		R					R		F			A	C	A	F
		24R-1, 15–16	921.65	M	V			F				F			F						F			C	C	V	F
		24R-CC	923.46	M				C	F			F		R							F		F	A	F	A	F
		25R-1, 9–10	931.19	M	C			R				F						R								C	
		25R-3, 11–12	934.13	M	V			F				C		F									F	A	C	V	
		25R-5, 12–13	937.01	M	C				F			F		F							F					C	
		25R-CC	939.07		B																						
		26R-1, 10–11	940.80		B																						
		26R-3, 10–11	943.68		B																						
		26R-5, 10–11	946.64		B																						
		26R-5, 146–147	948.00	P	R				R															R	R		R
		27R-1, 10–11	950.40	P	A			F	F												F			C	C	R	
		27R-3, 10–11	953.41	P	F			R	R			R									R			R	R	F	
CN9	Miocene	27R-5, 10–11	956.12	P	R																	R				R	
		27R-CC	957.41	P	F				F			R									F			R	F		
		28R-1, 8–9	959.98	P	F			F				F		F												F	
		28R-3, 10–11	962.95		B																						
		28R-5, 9–10	965.77	P	F									R												F	
		28R-CC	968.83	P	R									R												R	
		29R-1, 10–11	969.60	P	R			R						R							R						
		29R-3, 12–13	972.25	P	R			R																		R	
		29R-5, 29–30	975.42	P	C			R				R														C	
		29R-CC	978.02	P	R									R												R	
		30R-1, 7–8	979.17	P	F									R												F	
		30R-3, 3–4	982.13		B																						
		30R-5, 10–11	984.82		B																						
		30R-CC	987.85	P	B																						
		31R-1, 15–16	988.85		B																						
		31R-3, 4–5	991.56		B																						
		32R-1, 13–14	998.43	P	F																					F	
		32R-3, 12–13	1001.21		B																						
		32R-5, 10–11	1004.15		B																						
		32R-7, 5–6	1007.10		B																						
		32R-CC	1007.82		B																						
		33R-1, 10–11	1008.00		B																						
		33R-CC	1009.47	P	R									R							R			F	R	R	R
		34R-1, 10–11	1017.60		B																						
		34R-CC	1019.99	P	F			R		R		F												F	R	F	R
		35R-1, 10–11	1027.20		B																						
		35R-3, 10–11	1030.20		B																						
		35R-CC	1031.50	B	B																			F	F	F	
		36R-1, 10–11	1036.80	M	F																						
		36R-3, 10–11	1039.80	M	A			F				F												C	F	A	
		36R-5, 10–11	1042.80	P	R																			R	R	R	

Table T4 (continued).

Nannofossil zone/subzone	Age	Core, section, interval (cm)	Depth (mbsf)	Preservation	Group abundance	*Amaurolithus amplificus*	*Amaurolithus delicatus*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Catinaster coalitus*	*Ceratolithus telesmus*	*Coccolithus pelagicus*	*Discoaster bellus*	*Discoaster berggrenii*	*Discoaster brouweri*	*Discoaster challengeri*	*Discoaster exilis*	*Discoaster pentaradiatus*	*Discoaster quinqueramus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discoaster* spp.	*Helicosphaera carteri*	*Reticulofenestra gelida*	*Reticulofenestra pseudoumbilicus*	*Reticulofenestra* spp. (small)	*Sphenolithus*
CN9	Miocene	36R-CC	1044.73	M	C							C		F							F		F	C	F	C	F
		37R-1, 10–11	1046.60	P	R									R							R			R	R	R	
		37R-3, 10–11	1049.54	M	C			F				F												C	F	C	
		37R-CC	1050.51	M	C				F			C		C							C		F	C	F	C	F
		38R-1, 10–11	1056.40	M	A			C	F			C			F						F			C	F	A	C
		38R-1, 76–77	1057.10		B																						
		38R-2, 10–11	1057.90	M	R																				R		
		38R-CC	1058.56	P	R									R							R						
CN6–CN8		39R-1, 10–11	1066.10	P	C							F			R									F	R	C	
		39R-1, 72–73	1066.70		B																						
		39R-2, 9–10	1067.60		B																						
		39R-2, 73–74	1068.30		B																						
		39R-3, 7–8	1068.51	P	R																					R	
		39R-CC	1070.80	P	R			F	R			R									R			R		R	R
		40R-1, 10–11	1075.80	P	C							F			R									F	R	C	
		40R-3, 8–9	1078.54	P	F							R									R			R		F	
		40R-CC	1079.21	P	B																						
		41R-1, 10–11	1085.40	M	A			F				F			F						F			F	R	A	
		41R-3, 14–15	1088.33	M	A			C				F			F						F			F	C	A	F
		41R-5, 8–9	1091.27	M	A			F													F			C	C	A	
		41R-CC	1094.47	P	R							R									R		F			R	
		42R-1, 9–10	1094.99		B																						
		42R-3, 13–15	1098.04	M	A			F				F			F						F		F	C	F	A	
		42R-5, 11–12	1101.02	P	R			R																			
		42R-CC	1103.87	P	C				F			F					R				C		F	C	F	F	R
		43R-1, 14–15	1104.74	P	C			F				F									F			F	R	C	
		43R-3, 4–5	1107.59	P	C			F																F	R	C	
		43R-5, 12–13	1110.67	P	R																			R		R	
		43R-CC	1111.28	P	R																R						
		44R-1, 5–6	1114.25	P	A			F		F					F		R				F			C	F	A	
		44R-CC	1115.76	P	R					R		R									R			F	F		R
		45R-1, 76–77	1124.66	P	R																			R		R	
		45R-1, 76–77	1124.66	P	R																						
		45R-1, 76–77	1124.66	P	R							R									R			R			
		45R-1, 76–77	1124.66	P	R							F									R			C	F	C	
		45R-1, 76–77	1124.66	P	R							C			F			F			F			F	F	A	
		45R-1, 76–77	1124.66	P	R																						
		45R-1, 76–77	1124.66	P	R																						
		45R-1, 76–77	1124.66	P	R							F			R			R			R			R	R		
		45R-1, 76–77	1124.66	P	R							R			R			R			R			R	R	F	
		45R-1, 76–77	1124.66	P	R							R					F				R					C	
		45R-1, 76–77	1124.66	P	R							C	R				F	R						F	C	C	R
		45R-1, 76–77	1124.66	P	R							C					R							A	C	A	
		45R-1, 76–77	1124.66	P	R							F			F						C			F	C	A	
		45R-1, 76–77	1124.66	P	R							F			F		F							C	F	A	
		45R-1, 76–77	1124.66	P	R							F									F			F	F	C	F
		45R-1, 76–77	1124.66	P	R							C			F						F			C	F	C	
		45R-1, 76–77	1124.66	P	R																					F	
		45R-1, 76–77	1124.66	P	R																R					F	
		45R-1, 76–77	1124.66	P	R							F					F				F			F	C	F	R

Notes: Preservation: G = good, M = moderate, P = poor. Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare, B = barren.

Table T5. Nannofossil datums, absolute ages, and depth, Site 1151.

Event	Zone/ subzone (base)	Age (Ma)	Core, section, interval (cm)	Depth (mbsf)	Core, section, interval (cm)	Depth (mbsf)	Core, section, interval (cm)	Depth (mbsf)
			186-1151A-		186-1151C-		186-1151D-	
FO *Emiliania huxleyi*	CN15	0.25			2H-1, 25–26 to 2H-3, 25–26	2.45–3.95	2H-CC to 3H-CC	17.44–26.88
LO *Pseudoemiliania lacunosa*	CN14b	0.41			4H-4, 100–101 to 4H-5, 25–26	26.75–27.45	3H-CC to 4H-CC	26.88–36.42
FO *Gephyrocapsa parallela*	CN14a	0.94	2R-CC to 3R-3, 10–11	82.08–86.8	8H-CC to 9H-1, 25–26	68.95–69.30	7H-CC to 8H-CC	64.56–74.63
FO *Gephyrocapsa oceanica*					Below 11H-CC	Below 97.55		
FO *Gephyrocapsa caribbeanica*	CN13b	1.71	3R-6, 10–11 to 3R-6, 75–76	91.30–91.95				
LO *Discoaster brouweri*	CN13a	1.95	6R-4, 75–76 to 6R-CC	117.85–118.07				
LO *Discoaster pentaradiatus*	CN12d	2.36	10R-1, 10–11 to 10R-1, 75–76	151.10–151.75				
LO *Discoaster tamalis*	CN12b	2.82	13R-3, 10–11 to 13R-3, 75–76	182.90–183.55				
LO *Reticulofenestra pseudoumbilicus*	CN12a	3.83	15R-7, 10–11 to 15R-CC	208.3–208.87				
LO *Discoaster quinqueramus*	CN10a	5.54	59R-5, 10–11 to 59R-5, 75–76	629.0–629.7				
FO *Discoaster berggrenii*	CN9a	8.28	90R-CC to 91R-1, 10–11	926.1– 930.50				
FO *Catinaster coalitus*	CN6	10.79	99R-2, 15–16 to 99R-CC	1009.10–1009.53				

Note: FO = first occurrence, LO = last occurrence.

Table T6. Nannofossil range chart, Hole 1151A. (This table is available in **oversized format.**)

Table T7. Nannofossil range chart, Hole 1151C. (See table notes. Continued on next page.)

Nannofossil zone/subzone	Age	Core, section interval (cm)	Depth (mbsf)	Preservation	Group abundance	*Calcidiscus leptoporus*	*Ceratolithus acutus*	*Coccolithus pelagicus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. (small)	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera wallich*	*Pontosphaera*	*Pseudoumbilicus lacunosa*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. (small)	*Rhabdosphaera clavigera*	*Umbilicosphaera sibogae*
		186-1151C-																				
CN15	Pleistocene	1H-1, 25–26	0.25	G	A	F		A	A	F	F									C		
		1H-CC	2.10	G	C	F	R	F	C	F	F	F	C	F	C					C		
		2H-1, 25–26	2.45	G	A	C		C	C	F										C		
CN14b		2H-3, 25–26	3.95		B																	
		2H-5, 25–26	6.95		B																	
		2H-6, 25–26	8.45		B																	
		2H-6, 100–101	9.20		B																	
		2H-7, 25–26	9.95	P	R															R		
		2H-CC	12.10	M	C	F		F		C	C		C							C		
		3H-1, 25–26	11.95		B																	
		3H-1, 100–101	12.70		B																	
		3H-2, 25–26	13.45		B																	
		3H-2, 100–101	14.25		B																	
		3H-3, 25–26	14.95	P	C			F												C		
		3H-3, 100–101	15.75		B																	
		3H-5, 25–26	17.95	G	V	C		C		A	C	R	C	C			F			V		
		3H-7, 25–26	20.95	G	V	C		C		A	C		C							V		
		3H-CC	21.44	G	A	C		C		A	A		C	F						C	R	
		4H-1, 25–26	21.45	M	A	C		F		C	C		C							A		
		4H-1, 100–101	22.20		B																	
		4H-2, 25–26	22.95	M	F								F									
		4H-2, 100–101	23.75	M	C			F					C									
		4H-3, 25–26	24.45	M	A	F		F		C	C		C							A		
		4H-3, 100–101	25.25	M	C	F		C					C									
		4H-4, 25–26	25.95	M	V	F		C					V									
		4H-4, 100–101	26.75	M	V			C					V									
		4H-5, 25–26	27.45	G	V			F		F	F							F		V		
CN14a		4H-6, 25–26	28.95	G	V	F		C					V					A		V		
		4H-7, 25–26	30.45	M	A	C		F		C	C			F				C		A		R
		5H-1, 25–26	30.95		B																	
		5H-3, 25–26	33.95		B																	
		5H-5, 25–26	36.95	P	C	F		F		F								C		C		
		5H-7, 25–26	39.95	P	R															R		
		5H-CC	40.31	P	C	C		C		C	C	F	F									
		6H-1, 25–26	40.45	P	F	R														F		
		6H-3, 25–26	43.45	M	C			R										C		C		
		6H-5, 25–26	46.45	M	C	F		F					F					C		C		
		6H-7, 25–26	49.45	M	A	C		C				R	F	C		F		A		A		
		6H-CC	50.10	P	F	R		R		F	F									F		
		7H-1, 25–26	49.95		B																	
		7H-3, 25–26	52.95	P	R								R									
		7H-5, 25–26	55.95		B																	
		7H-7, 25–26	58.95		B																	
		7H-CC	59.46	P	F	F												F	F			
		8H-1, 25–26	59.45		B																	
		8H-3, 25–26	62.45	P	F	R		R										F		F		
		8H-5, 25–26	65.45	M	A	C												C	A	A		
		8H-7, 25–26	68.45		B																	
		8H-CC	69.30	M	C	C		C		F	F	R	R					F	F	C		
CN13b		9H-1, 25–26	68.95	M	A	C		C						C				A	F	A		
		9H-3, 25–26	71.95	M	A	C		F										C	C	A		
		9H-5, 25–26	74.95	M	A	F		R										C		A		
		9H-7, 25–26	77.95	B																		
		9H-CC	78.38	P	R			R		R										R		
		10H-1, 25–26	78.45	P	F	R		R			R							R		F		
		10H-3, 25–26	81.45	B																		
		10H-5, 25–26	84.45	P	R													R		R		
		10H-7, 25–26	87.45	G	A	C		A		C	C		F	F			R	C		A		
		10H-CC	88.38	M	R			R		R												
		11H-1, 25–26	87.95	G	A	C		C		C	F		F	R		R	F	C		A		

Table T7 (continued).

Nannofossil zone/subzone	Age	Core, section interval (cm)	Depth (mbsf)	Preservation	Group abundance	*Calcidiscus leptoporus*	*Ceratolithus acutus*	*Coccolithus pelagicus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. (small)	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera wallich*	*Pontosphaera*	*Pseudoumbilicus lacunosa*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. (small)	*Rhabdosphaera clavigera*	*Umbilicosphaera sibogae*
CN13b	Pleistocene	11H-3, 25–26	90.95	G	A	F		R		C	C		F	F		F	C	C		A		
		11H-5, 25–26	93.95	M	A	C		C		C	C		F					A		A		
		11H-7, 25–26	96.95	P	F								F					F		F		
		11H-CC	97.55	M	C					F								F				

Notes: Preservation: G = good, M = moderate, P = poor. Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare, B = barren.

Table T8. Nannofossil range chart, Hole 1151D.

Nannofossil zone/subzone	Age	Core	Depth (mbsf)	Group abundance	Group preservation	*Calcidiscus leptoporus*	*Ceratolithus telesmus*	*Ceratolithus simplex*	*Coccolithus pelagicus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. (small)	*Helicosphaera carteri*	*Pseudoemiliania lacunosa*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. (small)	*Rhabdosphaera clavigera*
		186-1151D-																	
CN15		1H-CC	7.51	R	M	F		R	F	F	F	F		F					
		2H-CC	17.44	C	G	C			C	C	A	A		C	C	C			F
CN14b		3H-CC	26.88	C	G	F	R		C		A	C		C				A	
CN14a		4H-CC	36.42	C	G	F			C		C	C	A	C	C	A			F
	Pleistocene	5H-CC	45.71	T	P									R		F			
		6H-CC	55.37	R	P	R			R		R					R			
		7H-CC	64.56	C	M	C			C		C	C	F	F		A			F
CN13b		8H-CC	74.63	R	M	F			F					F	F	C	F		
		10H-CC	93.27	R	P	F			R		F	F				F			

Notes: Preservation: G = good, M = moderate, P = poor. Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare, B = barren.