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6. Quaternary Nannofossil Biostratigraphy from Ocean Drilling Program Leg 189, Tasmanian Gateway[1]

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ABSTRACT

Quaternary sediments were recovered at all five sites drilled during Ocean Drilling Program (ODP) Leg 189 in the Tasmanian Gateway. Two of these sites lie north of the present-day Subtropical Front (STF), and three sites lie south of the STF. Quaternary sediments recovered at Sites 1168, 1170, 1171, and 1172 were studied in detail to determine the calcareous nannofossil biostratigraphy and construct an age model for these sediments. The Pliocene/Pleistocene boundary was identified by the last occurrence (LO) of *Discoaster brouweri* at Site 1172 and approximated by the LO of *Calcidiscus macintyrei* at the other sites because of a lack of discoasterids. A hiatus encompassing the entire *Helicosphaera sellii* Zone was tentatively identified at Sites 1168 and 1172 by the coincident LOs of *C. macintyrei* and *H. sellii*. Similar hiatuses have been noted at ODP Site 1127 on the Great Australian Bight, Deep Sea Drilling Project Site 282 off the Tasman subcontinent, and ODP Site 1165 in Prydz Bay, Antarctica.

INTRODUCTION

The primary objective of Ocean Drilling Program (ODP) Leg 189 was to refine the hypothesis proposed by Kennett, Houtz, et al. (1975) that climatic cooling and an Antarctic cryosphere developed as the Antarctic

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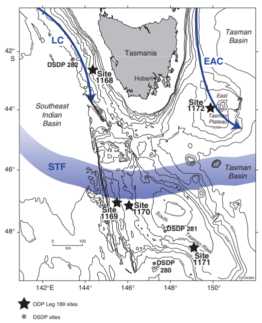
continent was thermally isolated by the developing Antarctic Circumpolar Current (Exon, Kennett, Malone, et al., 2001). Documentation of the development of the Southern Ocean in the Tasman region through the Neogene was a key secondary objective. Comparison of these records to results from recent ODP Legs 177 (Atlantic Ocean) and 188 (Indian Ocean) will facilitate better characterization of the Southern Ocean.

Quaternary sediments were recovered at all five sites drilled during ODP Leg 189 in the Tasmanian Gateway region (Fig. **F1**). Site 1168 is located on the continental rise west of Tasmania, 80 km southeast of Deep Sea Drilling Project (DSDP) Site 282. Quaternary sediments consist primarily of light greenish to greenish gray nannofossil ooze with additions of foraminifers and clay and pyrite staining (Shipboard Scientific Party, 2001b). Site 1169, located on the South Tasman Rise (STR), was not included in this study. Heavy seas during coring resulted in highly disturbed cores that are unsuitable for further analysis (Shipboard Scientific Party, 2001c). Sites 1170 and 1171 are also located on the STR (Fig. **F1**), 270 km apart and south of the modern Subtropical Front (STF). Quaternary sediments at Sites 1170 and 1171 consist of white to greenish gray nannofossil ooze with additions of clay, diatoms, and foraminifers. Pyrite staining and laminations are common throughout (Shipboard Scientific Party, 2001d, 2001e). Quaternary sediments from Site 1172, located on the East Tasman Plateau (ETP) (Fig. **F1**), consist of light greenish gray to greenish gray nannofossil foraminifer ooze and foraminifer nannofossil ooze with additions of clay. Pyrite staining and lamination are common (Shipboard Scientific Party, 2001f).

F1. Location map, p. 16.



The Tasman margin has previously been drilled; during DSDP Leg 29, 10 sites were drilled around Australia and New Zealand using the rotary core barrel system. Of the 10 sites drilled, three were located near Leg 189 drill sites. DSDP Site 282 was drilled at the foot of the continental slope west of Tasmania, and DSDP Sites 280 and 281 were drilled on the STR, south of the modern STF (Kennett, Houtz, et al., 1975). Edwards and Perch-Nielsen (1975) reported the calcareous nannofossil biostratigraphy and applied a Pleistocene zonation with only three zones. Nannofossils were common to rare, and the number of species reported was <10. A hiatus that eliminates the entire lower Pleistocene section was reported at DSDP Site 280, and at DSDP Site 282, a hiatus that extends from the upper Miocene to the lower Pleistocene was recorded. No hiatus was recorded at DSDP Site 281 (Edwards and Perch-Nielsen, 1975).

The objective of this study is to record the abundance of Quaternary calcareous nannofossils and improve on the biostratigraphic resolution as initially reported in the shipboard results (Shipboard Scientific Party, 2001b, 2001d, 2001e, 2001f). This study reports the qualitative abundance distribution of calcareous nannofossils of Holes 1168A, 1170A, 1171A, and 1172A. An age model was constructed using nannofossil datums and was compared to additional biomagnetostratigraphic and isotopic datums (**Stickley et al.,** this volume). This data can be used to guide any future quantitative work in the Quaternary sediments recovered during Leg 189.

MATERIALS AND METHODS

The nannofossil biostratigraphy presented here is based on examination of smear slides prepared from unprocessed sediment. Slides were examined using phase-contrast and cross-polarized light at 1560× on a Zeiss Photo III light microscope. The relative abundance of each species, general preservation of the assemblage, overall abundance of nannofossils, and presence of reworked nannofossils were recorded. Abundance of individual taxa, as well as overall abundance, are represented by letter codes and are recorded in Tables T1, T2, T3, and T4 according to the following definitions:

T1. Calcareous nannofossil range chart, Hole 1168A, p. 19.

T2. Calcareous nannofossil range chart, Hole 1170A, p. 20.

T3. Calcareous nannofossil range chart, Hole 1171A, p. 21.

T4. Calcareous nannofossil range chart, Hole 1172A, p. 22.

R = rare, 1 specimen per 51–200 fields of view (FOV).
F = few, 1 specimen per 11–50 FOV.
C = common, 1 specimen per 2–10 FOV.
A = abundant, 1–10 specimens per FOV.
V = very abundant, >10 specimens per FOV.

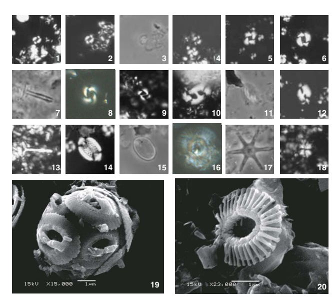
Preservation of nannofossils can vary significantly because of etching, dissolution, or calcite overgrowth. As the finding of well-preserved specimens in the same sample as overgrown or etched specimens is not uncommon, only the overall preservation of the assemblage is recorded in Tables T1, T2, T3, and T4. The overall preservation of the nannofossil assemblages in this paper was determined as follows:

G = good; individual specimens exhibit little or no dissolution, etching, or overgrowth; diagnostic characteristics of most specimens are preserved and specimens are identifiable at the species level.
M = moderate; individual specimens exhibit some evidence of dissolution, etching, or overgrowth; primary diagnostic features are somewhat altered but most specimens are identifiable at the species level.
P = poor; individual specimens exhibit considerable dissolution, etching, or overgrowth; primary diagnostic features largely destroyed; fragmentation has occurred; many specimens cannot be identified at the species level.

Upper Quaternary marker species were verified using a scanning electron microscope (SEM). Samples for the SEM were prepared according to the settling technique of de Kaenel and Bergen (1996), dried directly onto a specimen stub, and viewed with a JEOL SEM.

Calcareous nannofossil species considered in this paper are listed in the "Appendix," p. 15, where they are arranged alphabetically by generic epithet with some additional taxonomic notes. Bibliographic references for these taxa can be found in Perch-Nielsen (1985) and Bown (1999). Key marker species were photographed under the light microscope and digital SEM for taxonomic clarity (Pl. P1).

P1. Key marker species, p. 25.



At each Leg 189 site, Quaternary sediments were recovered in three holes using the advanced piston coring system. Composite sections between the three holes were created by stratigraphic correlation of multisensor track data (Shipboard Scientific Party, 2001b, 2001d, 2001e, 2001f). The composite sections extended through the Quaternary sediments; therefore, sediments from only one hole at each site were analyzed for this study.

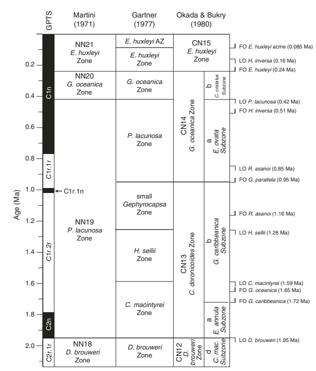
Core disturbance was determined by examining core photos (Exon, Kennett, Malone, et al., 2001) and applying the relative disturbance scale (0–5) developed by shipboard sedimentologists (Shipboard Scientific Party, 2001a). Aboard ship, the disturbance scale was used to create a graphic representation of the intensity of the core disturbance primarily at the core (9 m) scale. The disturbance representation for this study was constructed on a 10-cm scale to reflect in detail the condition of the cores studied. The disturbance scale does not differentiate between natural processes (i.e., bioturbation, slumps, etc.) and coring processes (i.e., flow-in, shattered core-liners, etc.) that are responsible for the conditions of the core.

Reworking of nannofossils was noted at all study sites. Reworking of obviously time-transgressive nannofossils was easily spotted; however, identification of reworked Pleistocene nannofossils required careful observation of their preservational state. The preservation of suspect nannofossils was compared to other assemblage nannofossils as well as the same species in adjacent samples. As the preservation was good or moderate, this method was generally useful in identifying reworked Pleistocene nannofossils within the studied sections without requiring quantitative techniques.

ZONATION

The biostratigraphic zonation scheme used for the Pleistocene (Fig. F2) is that of Gartner (1977). The marker species Gartner uses are generally present and easily recognizable and did not require a detailed morphometric analysis of gephyrocapsids, which was beyond the scope of this study. Some markers were not consistently present, and additional events were used to approximate the Gartner (1977) zonal boundaries. The bottom of the *Pseudoemiliania lacunosa* Zone is marked by the end of the dominance of small *Gephyrocapsa* species by Gartner (1977). As this could not be accurately determined with qualitative methods and the alternate marker *Gephyrocapsa parallela* is not consistently present, the last occurrence (LO) of *Reticulofenestra asanoi* was used to approximate this boundary (Fig. F2). The LO of *Helicosphaera sellii* is used here to mark the top of the *Helicosphaera sellii* Zone, taking into account that this datum has been reported as diachronous (Backman and Shackleton, 1983), ecologically sensitive, and rare at the end of its distribution (Perch-Nielsen, 1985).

F2. Combined Pleistocene zonal schemes, p. 17.



The Pliocene/Pleistocene boundary is defined by the LO of *Discoaster brouweri* (1.95 Ma) by Gartner (1977). This nannofossil definition of the Pliocene/Pleistocene boundary is 0.18 m.y. older than the magnetostratigraphically defined Pliocene/Pleistocene boundary at Termination C2n (1.77 Ma) (Berggren et al., 1995). *Discoaster brouweri* was recorded only at Site 1172; therefore, alternative nannofossil markers were used to approximate the Pliocene/Pleistocene boundary in the nannofossil biostratigraphy. At Site 1168, the first occurrence (FO) of *Gephyrocapsa caribbeanica* (1.72 Ma) was used to approximate the Pliocene/Pleistocene boundary. At Sites 1170 and 1171, the LO of *Calcidiscus macintyrei* (1.59 Ma) was used to roughly approximate the Pliocene/Pleistocene boundary, as *G. caribbeanica* and *Gephyrocapsa oceanica* (FO = 1.65 Ma) were discontinuously present.

BIOSTRATIGRAPHIC RESULTS

Hole 1168A

Site 1168 (water depth = 2463 m) is located 70 km west of the Tasmanian coast on the continental slope of the Tasmanian western margin and is north of the STF (Fig. F1). A total of 837 m of sediment (average recovery = 94.7%), ranging in age from Pleistocene to late Eocene, was penetrated in Hole 1168A; a total of 20 m of Pleistocene sediment was recovered. Well to moderately preserved calcareous nannofossils are abundant throughout the Pleistocene section. Reworked early Miocene nannofossils were noted throughout the Pleistocene interval. Stratigraphic distribution of calcareous nannofossils from Hole 1168A is presented in Table T1. Key marker events are listed in Table T5 along with their corresponding zones and ages.

Sample 189-1168A-1H-1, 15–16 cm (0.15 meters below seafloor [mbsf]), to the top of the core represents the *Emiliania huxleyi* acme Zone, with abundant *E. huxleyi* and small *Gephyrocapsa* spp. This zone is based on the dominance of *E. huxleyi* relative to small *Gephyrocapsa* spp. and was easily recognizable at this sampling resolution without quantitative analysis. Other common species include *Helicosphaera carteri, Pontosphaera japonica,* and *Calcidiscus leptoporus.*

The *Emiliania huxleyi* Zone is based on the FO of *E. huxleyi* (0.24 Ma) and extends from Samples 189-1168A-1H-1, 90–91 cm (0.90 mbsf), to 1H-2, 15–16 cm (1.65 mbsf). Very abundant small *Gephyrocapsa* spp., abundant *E. huxleyi,* and common *C. leptoporus* and *Coccolithus pelagicus* characterize the nannofossil assemblage.

Samples 189-1168A-1H-2, 90–91 cm (2.40 mbsf), to 1H-3, 15–16 cm (3.15 mbsf), are assigned to the *Gephyrocapsa oceanica* Zone. This interval zone is characterized by the absence of both *E. huxleyi* and *Pseudoemiliania lacunosa*. Common nannofossils include *C. leptoporus, C. pelagicus, H. carteri, P. japonica,* and abundant small *Gephyrocapsa* spp.

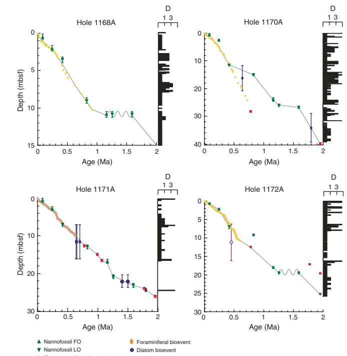
The base of the *Pseudoemiliania lacunosa* Zone was defined by Gartner (1977) on the dominance reversal from small to larger gephyrocapsids. As larger gephyrocapsids are not consistent in their distribution throughout the study area, the LO of *R. asanoi* (0.83 Ma) is used to approximate this boundary. The LO of *R. asanoi* occurs between Samples 179-1168A-2H-2, 15 cm, and 2H-2, 90 cm (9.32 mbsf). Reworked specimens of *R. asanoi* above this interval were identified by their degraded preservational state. Dominant species include *C. leptoporus, C. pelagicus,* small *Gephyrocapsa* spp., *H. carteri, P. lacunosa, P. lacunosa ovata,* and small *Reticulofenestra* spp.

The small *Gephyrocapsa* Zone extends from Samples 189-1168A-2H-2, 90–91 cm (9.70 mbsf), to 2H-3, 15–16 cm (10.45 mbsf), based on the LO of *H. sellii*. Species diversity increases in this zone with common *C. leptoporus, C. pelagicus, G. caribbeanica,* small *Gephyrocapsa* spp., *H. carteri, P. lacunosa, P. lacunosa ovata,* and *R. asanoi*. Reworking of several species was noted throughout this zone (Table T1).

Sample 189-1168A-2H-3, 90–91 cm (11.20 mbsf) contains both *H. sellii* and *C. macintyrei,* placing this sample in the *Calcidiscus macintyrei* Zone. The FO of *R. asanoi* also occurs at this level, indicating a hiatus of ~0.4 m.y. encompassing the base of the small *Gephyrocapsa* Zone and the entire *Helicosphaera sellii* Zone (Fig. F3). The FO of *G. caribbeanica* was noted at ~14.5 mbsf, within the *Calcidiscus macintyrei* Zone, and is used here to approximate the base of the Pleistocene.

Discoaster brouweri, the traditional nannofossil marker of the Pliocene/Pleistocene boundary, was not common in the Pliocene sediments of Hole 1168A (Shipboard Scientific Party, 2001b) and was not encountered in the samples studied. The first downhole discoasterid encountered was *Discoaster surculus* (2.51 Ma) at ~20 mbsf. This event (LO of *D. surculus*) along with the FO of *G. caribbeanica* indicates a possible condensed section across the Pliocene/Pleistocene boundary (Fig. F3).

F3. Sedimentation rate summary curves, p. 18.



The Pliocene/Pleistocene boundary could not be further constrained by other biomagnetostratigraphic events (**Stickley et al.,** this volume).

Hole 1170A

Site 1170 (water depth = 2704 m) is located 400 km south of Tasmania on the western section of the STR and lies in subantarctic waters between the STF and the Subantarctic Front (SAF) (Fig. **F1**). Approximately 380 m of core (average recovery = 81.8%), ranging in age from Pleistocene to middle Eocene, was recovered from Hole 1170A. Calcareous nannofossils are abundant and well to moderately preserved throughout the studied section. Stratigraphic distribution of calcareous nannofossils from Hole 1170A is presented in Table **T2.** Table **T5** lists key marker events with their corresponding depths and ages.

T5. Biomagnetostratigraphic datums, p. 23.

The *Emiliania huxleyi* acme Zone extends from Sample 189-1170A-1H-1, 60–61 cm (0.60 mbsf), to the top of the core. Within this interval, *E. huxleyi* is more abundant than small *Gephyrocapsa* spp. Other abundant species include *C. pelagicus* and small *Reticulofenestra* spp.

The base of the *Emiliania huxleyi* Zone is defined by the FO of *E. huxleyi* and extends to Sample 189-1170A-2H-1, 60–61 cm (2.30 mbsf). The nannofossil assemblage is characterized by abundant small *Gephyrocapsa* spp. and *C. pelagicus* as well as common to abundant *E. huxleyi.*

The *Gephyrocapsa oceanica* Zone, based on the absence of both *E. huxleyi* and *P. lacunosa,* continues down to Sample 189-1170A-2H-7, 60–61 cm. The base of this zone is defined by the LO of *P. lacunosa* (11.55 mbsf). Common nannofossils include *C. leptoporus, H. carteri,* small *Gephyrocapsa* spp., and abundant *C. pelagicus*. Reworking of *C. macintyrei, H. inversa, H. sellii,* and *R. asanoi* was rarely noted in this interval.

The base of the *Pseudoemiliania lacunosa* Zone is approximated by the LO of *R. asanoi* at 15.05 mbsf (between Samples 189-1170A-3H-3, 60–61cm, and 3H-3, 110–111 cm). Dominant species within this zone include *C. pelagicus,* small *Gephyrocapsa* spp., *H. carteri,* and small *Reticulofenestra* spp.

The small *Gephyrocapsa* Zone extends down to Sample 189-1170A-4H-5, 60–61 cm (26.55 mbsf), based on the LO of *H. sellii*. Common species in this zone are *C. leptoporus, C. pelagicus,* small *Gephyrocapsa* spp., *H. carteri, R. asanoi,* and small *Reticulofenestra* spp.

The *Helicosphaera sellii* Zone is represented by one sample: Sample 189-1170A-4H-5, 60–61 cm. The base of this zone is defined by the LO of *C. macintyrei* (26.8 mbsf), which is also used to approximate the Pliocene/Pleistocene boundary in Hole 1170A. Abundant small *Reticulofenestra* spp. and common *C. macintyrei, C. leptoporus, C. pelagicus,* and small *Gephyrocapsa* spp. characterize the *Calcidiscus macintyrei* Zone.

The Pliocene/Pleistocene boundary could not be more tightly constrained by nannofossils, as discoasterid species were not present in the upper Pliocene sediments (Shipboard Scientific Party, 2001d) and were not located by detailed shorebased examination (Table **T2**). The FOs of *G. caribbeanica* and *G. oceanica* were also not used to constrain the boundary, as their distribution was discontinuous. However, the Pliocene/Pleistocene boundary can be further constrained in Hole 1170A by the diatom LO of *Simonseniella barboi* (1.8 Ma) and the onset of Chron C2n (1.95 Ma) (**Stickley et al.,** this volume).

Hole 1171A

Site 1171 is located in 2148 m of water over the central STR and east of the Balleny Fracture Zone; it lies in subantarctic waters between the STF and the SAF (Fig. F1). Approximately 120 m of core (average recovery = 94%) was recovered in Hole 1171A (Shipboard Scientific Party, 2001e). Pleistocene nannofossils are well to moderately preserved and abundant. Stratigraphic distribution of calcareous nannofossils is listed in Table T3, with key marker events listed in Table T5.

Sample 189-1171A-1H-1, 15–16 cm (0.15 mbsf), to the top of the core, represents the *Emiliania huxleyi* acme Zone. *Emiliania huxleyi* is more abundant than small *Gephyrocapsa* spp., although both dominate the assemblage. *Calcidiscus leptoporus, H. carteri, Pontosphaera* spp., and small *Reticulofenestra* spp. are also present.

The lower boundary of the *Emiliania huxleyi* Zone is based on the FO of *E. huxleyi*. The zone extends to Sample 189-1171A-1H-2, 90–91 cm (2.40 mbsf). The assemblage is characterized by very abundant small *Gephyrocapsa* spp., abundant *E. huxleyi* and *C. pelagicus,* and common *C. leptoporus*. Reworked *P. lacunosa* were noted at the base of this zone.

Samples 189-1171A-1H-3, 15–16 cm (3.15 mbsf), to 1H-5, 90–91 cm (6.90 mbsf), are assigned to the *Gephyrocapsa oceanica* Zone. The base of this zone is identified by the LO of *P. lacunosa*. Common to abundant *C. leptoporus* and *C. pelagicus* and abundant small *Gephyrocapsa* spp. and small *Reticulofenestra* spp. characterize this interval.

The base of the *Pseudoemiliania lacunosa* Zone is approximated by the LO of *R. asanoi* between Samples 189-1171A-2H-4, 90–91 cm, and 2H-5, 15–16 cm (12.88 mbsf). The FO of *Gephyrocapsa parallela* was used by Gartner (1977) to define the base of this zone but was only observed in two samples in Hole 1171A. Assemblage species include *C. pelagicus,* small *Gephyrocapsa* spp., *H. carteri, P. lacunosa ovata,* and small *Reticulofenestra* spp.

The small *Gephyrocapsa* Zone extends down to ~21 mbsf (Sample 189-1171A-3H-3, 90–91 cm), where the LO of *H. sellii* was noted. Species diversity increases within this zone with abundant *C. leptoporus, C. pelagicus,* small *Gephyrocapsa* spp., *H. carteri, P. lacunosa, P. lacunosa ovata,* and small *Reticulofenestra* spp. The FO of *R. asanoi* occurs within this zone.

The base of the *Helicosphaera sellii* Zone is defined by the LO of *C. macintyrei* at ~23 mbsf (between Samples 189-1171A-3H-5, 15–16 cm, and 3H-5, 90–91 cm). The *Helicosphaera sellii* Zone is represented by three samples in Hole 1171A, with *H. sellii* rare and discontinuous at the top of this zone.

As at Site 1170, the Pliocene/Pleistocene boundary could not be determined by nannofossils, as *D. brouweri* was not reported in the upper Pliocene sediments (Shipboard Scientific Party, 2001e), nor was it recorded by this study (Table T3). The Pliocene/Pleistocene boundary can be constrained by the LO of *C. macintyrei* (1.59 Ma); the LOs of diatoms *Fragilariopsis barronii* (1.4 Ma), *Thalassiosira tetraoestrupii* var. *reimeri* (1.5 Ma), *Proboscia barboi* (1.8 Ma); and the termination of Chron C2n (1.77 Ma) and onset of Chron C2n (1.95Ma). The Pliocene/Pleistocene boundary, defined by the termination of Chron C2n (1.77 Ma), is placed at ~24 mbsf (Stickley et al., this volume).

Hole 1172A

Site 1172 lies on the flat western side of the ETP, just north of the STF and under the influence of the East Australian Current (EAC) in cool, temperate waters (Fig. **F1**). Approximately 480 m of sediment (recovery = 93%) was recovered in Hole 1172A. Calcareous nannofossils are abundant and well to moderately preserved throughout the study section. Preservational indicators range from intact coccospheres in well-preserved assemblages to little u's (individual placolith elements) in moderately preserved assemblages (Hay and Beaudry, 1973). Stratigraphic distribution of calcareous nannofossils is listed in Table **T4.** Key marker events are listed in Table **T5** with corresponding ages and depths.

Sample 189-1172A-1H-1, 15–16 cm (0.15 mbsf), to the top of the core represents the *Emiliania huxleyi* acme Zone, with *E. huxleyi* dominant to small *Gephyrocapsa* spp. Common nannofossil species include *C. leptoporus, C. pelagicus,* and small *Reticulofenestra* spp., with few *H. carteri.*

The *Emiliania huxleyi* Zone extends down to Sample 189-1172A-1H-2, 15–16 cm, defined by the FO of *E. huxleyi.* Very abundant small *Gephyrocapsa* spp. and common *E. huxleyi, C. leptoporus,* and *C. pelagicus* characterize the nannofossil assemblage.

Samples 189-1172A-1H-2, 117–118 cm (2.67 mbsf), through 2H-1, 15–16 cm (6.45 mbsf), represent the *Gephyrocapsa oceanica* Zone. The base of this interval zone is defined by the LO of *P. lacunosa*. The assemblage includes common *C. leptoporus,* common to abundant *C. pelagicus,* few to common *G. caribbeanica* and *G. oceanica,* and abundant small *Gephyrocapsa* spp. and small *Reticulofenestra* spp. Reworked specimens of *D. brouweri* and *H. inversa* were noted in this interval.

The base of the *Pseudoemiliania lacunosa* Zone is approximated at Site 1172 by the LO of *R. asanoi* at ~9 mbsf (Sample 189-1172A-2H-2, 117–118 cm). Abundant species include small *Gephyrocapsa* spp. and small *Reticulofenestra* spp., with common *H. carteri, C. pelagicus,* and *C. leptoporus*.

The small *Gephyrocapsa* Zone extends down to Sample 189-1172A-3H-3, 15–16 cm, based on the LO of *H. sellii*. Species are diverse with common to abundant *C. leptoporus, C. pelagicus,* small *Gephyrocapsa* spp., and small *Reticulofenestra* spp., *H. carteri,* and *P. lacunosa.*

Sample 189-1172A-3H-3, 117–118 cm (19.97 mbsf), contains both *H. sellii* and *C. macintyrei,* placing this sample in the *Calcidiscus macintyrei* Zone. The concurrent appearance of both species indicates a hiatus of ~0.3 m.y. encompassing the *Helicosphaera sellii* Zone. The Pliocene/Pleistocene boundary is defined by the LO of *D. brouweri* (1.95 Ma) and is placed between Samples 189-1172A-3H-7, 15–16 cm, and 3H-CC (~25.25 mbsf). The *Calcidiscus macintyrei* Zone is characterized by *C. leptoporus, C. pelagicus,* small *Gephyrocapsa* spp., small *Reticulofenestra* spp., and few *C. macintyrei, H. carteri, P. japonica,* and *P. lacunosa.*

AGE MODEL AND SEDIMENTATION RATES

An age-depth model for the Quaternary section of Holes 1168A, 1170A, 1171A, and 1172A (Fig. **F3**) was constructed from biomagnetostratigraphic, benthic oxygen isotope (BOI), and reflectance stratigraphy datums as reported by **Stickley et al.** (this volume). The line represents the visual best-fit age model. Vertical error bars represent uncertainty in the datum depth intervals because of sample spacing. The biomagnetostratigraphic datums used are listed in Table **T5,** along with their age, depth, and interval. The reader is referred to **Stickley et al.** (this volume) for the BOI and reflectance stratigraphy datums as well as a description of materials and methods for these stratigraphies.

The age depth model for Hole 1168A is based on 10 nannofossil datums, one foraminifer datum, the FO of *Globorotalia truncatulinoides* (Table **T5**), and benthic oxygen isotope stratigraphy (see **Stickley et al.,** this volume). There is good agreement between the nannofossil datums and the BOI datums down to 0.9 Ma (bottom of the BOI datums), with linear sedimentation rates (LSRs) averaging 0.9 cm/k.y. A hiatus defined by the LOs of *R. asanoi, H. sellii,* and *C. macintyrei* occurs at 10.8 mbsf and lasts ~0.4 m.y. Sedimentation rates in the lower Pleistocene are high at 2.8 cm/k.y. before decreasing across the Pliocene/Pleistocene boundary to ~0.7 cm/k.y. The Pliocene/Pleistocene boundary (1.77 Ma) is placed at ~15 mbsf (Fig. **F3**) based on linear extrapolation.

Site 1168 is the only Leg 189 site in which the FO of *G. truncatulinoides* falls within the best-fit age depth model. In Holes 1170A, 1171A, and 1172A, the FO of *G. truncatulinoides* falls well off the best-fit line. This disparity could be a result of the large sampling resolution (~9 m) of the currently available datums, or it may be the result of a poorly calibrated age for this event in the southwest Pacific Ocean, as a similar disparity was noted at ODP Leg 181 (Carter, McCave, Richter, Carter, et al., 1999) and Leg 182 sites (Brunner et al., 2002).

Hole 1170A displays a pattern of sedimentation (Fig. **F3**) similar to Site 1168. The age-depth model is based on seven nannofossil datums and is constrained by one radiolarian datum, two diatom datums, one magnetostratigraphic datum (Table **T5**), and BOI datums (**Stickley et al.,** this volume). However, the nannofossil and the BOI datums only agree to ~12 mbsf. Beyond that, the nannofossil datums diverge significantly from the BOI datums, which indicates fairly linear sedimentation to ~26 mbsf. The core recovered in this interval does show significant disturbance (Fig. **F3**) (Shipboard Scientific Party, 2001d), which may explain the disparity between the stratigraphies. The authors prefer the sedimentation pattern defined by nannofossils, as it shows the most similarity to Site 1171, where the stratigraphy is much less in doubt.

Sedimentation rates average ~2 cm/k.y. down to ~26 mbsf in Hole 1170A. They decrease to 0.2 cm/k.y. for ~0.3 m.y. and then increase to ~2 cm/k.y. in the lower Pleistocene sediments. The sedimentation pattern across the Pliocene/Pleistocene boundary is constrained by nannofossil, diatom, and magnetostratigraphic datums. The Pliocene/Pleistocene boundary (1.77 Ma) is located at ~33 mbsf (Fig. **F3**) based on linear extrapolation.

The Hole 1171A age model is based on seven nannofossil, six diatom, and five magnetostratigraphic datums (Table **T5**) as well as light reflectance stratigraphy (see **Stickley et al.,** this volume). There is excellent agreement between the nannofossil datums and the light reflectance stratigraphy down to ~10 mbsf, where the light reflectance datums end. The sedimentation pattern is similar to that seen in Hole 1170A, with an average LSR in the upper Pleistocene of ~1.9 cm/k.y. The LSR decreases to ~0.7 cm/k.y. from 1.26 Ma until the end of the Pleistocene. The Pliocene/Pleistocene boundary is located at 24.0 mbsf based on the termination of Chron C2n (Table **T5**).

Hole 1172A shows a similar sedimentation pattern to Hole 1168A. There is good agreement between the nannofossil stratigraphy and the

BOI datums down to ~11 mbsf, where the BOI stratigraphy ends, with the exception of the LO of *R. asanoi*. The LO of *R. asanoi* falls well off the age-depth plot and is not included in the calculations of LSRs. Under the light microscope the specimens show no obvious evidence of being reworked, and the cores through this interval are not highly disturbed. Linear sedimentation rates average ~1.5 cm/k.y. down to ~20 mbsf. This interval is further confined by the radiolarian LO of *Stylatractus universus* and the onset of Chron C1n (Table **T5**). A hiatus from 1.26 to 1.59 Ma is identified at 21.71 mbsf and is similar to the hiatus noted in Hole 1168A. The nannofossil datums indicate an increased LSR (~2.5 cm/k.y.) in the lower Pleistocene sediments and across the Pliocene/Pleistocene boundary (Fig. **F3**), similar to the patterns seen in Holes 1168A and 1170A. There is disagreement with the magnetostratigraphic datums in the lower Pleistocene–upper Pliocene sediments, with the magnetostratigraphy placing the Pliocene/Pleistocene boundary at 17.1 mbsf, well above the nannofossil datums. The disagreement may be caused by core disturbance (Fig. **F3**) (Shipboard Scientific Party, 2001f). The magnetostratigraphy of Site 1172 also shows disagreement with nannofossil datums in the Miocene (**McGonigal and Wei,** this volume), and possible causes for this disagreement are discussed by **Stickley et al.** (this volume).

DISCUSSION

In comparing these four sites, it is evident that discoasters occur in the upper Pliocene sediments of the northern sites (1168 and 1172) but are noticeably absent at Sites 1170 and 1171 (Shipboard Scientific Party, 2001b, 2001d, 2001e, 2001f). Discoasters have been traditionally used as indicators of warm-water environments (Perch-Nielsen, 1985), whereas more recent analysis suggests that they are indicators of oligotrophic conditions (Aubry, 1993). As discoasters are extinct and warm waters are often oligotrophic, it is difficult to tease the two factors apart. Nevertheless, it is clear that an oceanographic boundary separated the northern sites from the southern sites in the latest Pliocene. This oceanographic boundary is inferred to be a paleo-Subtropical Front. The modern STF is a surficial expression of the 12°C thermobar (Findlay and Flores, 2000).

The presence of *D. brouweri* in Hole 1172A but not Hole 1168A suggests that there was also a temperature or nutrient difference between the western and eastern coasts of Tasmania in the latest Pliocene. The modern EAC, which bathes the ETR, is warmer than the Leeuwin Current, which runs down the west coast of Australia and across the Great Australian Bight toward Tasmania (Fig. **F1**). The apparent warmer surface water conditions at Site 1172 were also noted during the late Miocene (McGonigal, submitted [**N1**]). Surface water conditions at Site 1172 diverged from those at Sites 1168, 1170, and 1171 in the late Miocene, based on the ratio of *Reticulofenestra perplexa* to *C. pelagicus*. This difference was attributed to the beginning of EAC activity in the East Tasman Plateau region.

The hiatus observed at Sites 1168 and 1172 is similar to hiatuses found around the Southern Ocean. Edwards and Perch-Nielsen (1975) indicate a hiatus at DSDP Site 280 (Fig. **F1**) that eliminates the entire lower Pleistocene as well as a hiatus at DSDP Site 282 that extends from the upper Miocene LO of *Triquetrorhabdulus rugosus* (5.5 Ma) to the middle Pleistocene LO of *P. lacunosa*. No hiatus was recorded at DSDP Site

281, and a middle Pleistocene hiatus at DSDP Site 283 (Fig. F1) was later discounted by Hornibrook (1982). Lohmann (1986) reported the LOs of *C. macintyrei* and *H. sellii* as co-occurring at DSDP Site 593, Challenger Plateau. The reliability of the LO of *C. macintyrei* was called into question, however, based on sedimentation rate issues and disagreement with the magnetostratigraphic interpretation (Nelson et al., 1986). At shallow-water ODP Site 1120, Campbell Plateau, a hiatus below the small *Gephyrocapsa* Zone was noted with an associated hardground, separating Pleistocene and Miocene sediments (Shipboard Scientific Party, 1999). ODP Site 1127 on the Great Australian Bight records an early Pleistocene hiatus eliminating the *Helicosphaera sellii* Zone (Ladner, 2002). Brunner et al. (2002) attributed a regional hiatus at Sites 1126, 1127, 1130, 1132, and 1134 to a major fall in sea level associated with third-order sequence boundary events. Flores and Marino (2002) observed a Pleistocene hiatus at ODP Site 1088 located in the South Atlantic Ocean south of the STF. This hiatus is marked by the closely spaced FO of *R. asanoi* and the LO of *C. macintyrei,* encompassing approximately the same interval as the *Helicosphaera sellii* Zone. *Helicosphaera sellii* was not recorded at any ODP Leg 177 sites. The other carbonate-rich sites (1089 and 1090) do not reveal this hiatus, although Site 1090 does reveal a condensed *Helicosphaera sellii* Zone. Fontanesi and Villa (2002) identified a hiatus in ODP Hole 1165B (Prydz Bay, Antarctica) in SubChron C2r.2r, a magnetostratigraphic zone that correlates with the *Helicosphaera sellii* Zone in age.

Helicosphaera sellii is generally rare and sporadic at the top of its range and is not regarded as a consistent pelagic bioevent. Issues with the possible diachroneity of *C. macintyrei* have also arisen and contribute to the tentative identification of this hiatus. The work by Brunner et al. (2002) and the tightly constrained bioevents at Site 1171 demonstrate the LOs of *H. sellii* and *C. macintyrei* to be reliable events from the Great Australian Bight, south of the STF (48°S) in the Tasmanian Gateway.

The distribution of the sites recording this hiatus around the Southern Ocean may indicate a potential circum-Antarctic hiatus. Brunner et al. (2002) suggest that this is only a local manifestation of third-order sequence boundary events. The identification of a hiatus at Site 1165 in Prydz Bay and at Site 1088 in the South Atlantic, in sediments of roughly similar age, disputes the restriction of this event to the Southern Ocean sector around Australia. The suspect nature of *H. sellii* and *C. macintyrei* may have contributed to lack of identification of this event based solely on nannofossil biostratigraphy at other locations. Further research and quantitative analysis of previously drilled sites could reveal the extent of this event. The prominence of this event at shallower sites (1168 and 1172) from this study supports the idea that this event is associated with a lowering of sea level and not enhanced current activity.

CONCLUSIONS

In all samples recovered at Leg 189 Sites 1168, 1170, 1171, and 1172, calcareous nannofossils were abundant and generally well preserved. Using the Gartner (1977) Pleistocene zonation scheme, a biostratigraphic analysis of these four sites was performed. A hiatus was observed at Sites 1168 and 1172 that eliminates the *Helicosphaera sellii* Zone, a time interval of ~0.3 m.y. Similar hiatuses were noted at DSDP

Site 282 off the Tasman subcontinent (Edwards and Perch-Nielsen, 1975), ODP Site 1127 on the Great Australian Bight (Ladner, 2002), ODP Site 1088 in the South Atlantic Ocean (Flores and Marino, 2002), and ODP Site 1165 in Prydz Bay, Antarctica (Fontanesi and Villa, 2002). This hiatus has been attributed to a major lowering of sea level (Brunner et al., 2002), which is supported by its manifestation at shallower Leg 189 sites.

The presence of *Discoaster brouweri* only at Site 1172 suggests that surface waters were warmer there than at Sites 1168, 1170, and 1171 in the late Pliocene. Greater species diversity at Sites 1168 and 1172 than at Sites 1170 and 1171 also suggests the presence of a paleo-STF across the area during the Pleistocene. Similar sedimentation patterns were observed at all Leg 189 sites, with Site 1168 having the lowest average sedimentation rate throughout the Pleistocene. Sedimentation was uniform across the Pliocene/Pleistocene boundary, with a hiatus (Sites 1168 and 1172) or slower LSR (Sites 1170 and 1171) noted from ~1.26 to 1.59 Ma and then fairly uniform sedimentation to the top of the core.

The nannofossil biostratigraphy reported here agrees well with the biomagneto-benthic oxygen isotope, and light reflectance stratigraphy reported by **Stickley et al.** (this volume). The disagreement with BOI datums in Hole 1170A may have been caused by the disturbed nature of the cores through that interval (Fig. **F3**). The discrepancy with the magnetostratigraphy in Hole 1172A needs further examination, as does the puzzling apparent diachroneity of the LO of *R. asanoi*.

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APPENDIX

Calcareous Nannofossils Considered in This Paper in Alphabetical Order of Generic Epithets

Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947.

Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978.

Calcidiscus macintyrei (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978 (Pl. **P1**, fig. 16).

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930.

Cyclicargolithus abisectus (Müller, 1970) Wise, 1973.

Discoaster brouweri Tan, 1927, emend. Bramlette and Riedel, 1954.

Discoaster deflandrei Bramlette and Riedel, 1954.

Discoaster surculus Martini and Bramlette, 1963 (Pl. **P1**, fig. 17).

Emiliania huxleyi (Lohmann, 1902) Hay and Mohler, 1967 (Pl. **P1**, figs. 1–4, 20).

Gephyrocapsa caribbeanica Boudreaux and Hay, 1969.
Remarks: 4–5 µm.

Gephyrocapsa oceanica Kamptner (1943) (Pl. **P1**, fig. 9).
Remarks: 4–5 µm.

Gephyrocapsa parallela Hay and Beaudry, 1973.
Remarks: 4–7 µm; center area = 50% of diameter, bar angle = 70°–90°.

Gephyrocapsa spp. <4 µm (Pl. **P1**, fig. 19).

Helicosphaera carteri (Wallich, 1877) Kamptner, 1954.

Helicosphaera inversa Gartner, 1980.

Helicosphaera selli Bukry and Bramlette, 1969 (Pl. **P1**, figs. 10–12).

Pontosphaera indoceanica Cepek, 1973 (Pl. **P1**, figs. 14, 15).

Pontosphaera japonica (Takayama, 1967) Nishida, 1971.

Pontosphaera spp.

Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969 (Pl. **P1**, fig. 5).

Pseudoemiliania lacunosa ovata (Bukry, 1973) Young, 1990 (Pl. **P1**, fig. 6).

Reticulofenestra asanoi Sato and Takayama, 1992 (Pl. **P1**, fig. 8).

Reticulofenestra spp. <4 µm.

Rhabdosphaera clavigera Murray and Blackman, 1898 (Pl. **P1**, figs. 7, 13).

Sphenolithus neoabies Bukry and Bramlette, 1969 (Pl. **P1**, fig. 18).

Sphenolithus moriformis (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967.

Sphenolithus spp. <4 µm

Umbilicosphaera jafarii Müller, 1974.

Figure F1. Location map of Leg 189 Sites 1168–1172 in the offshore Tasmanian region. The contours of the regional bathymetric chart are 500-m intervals (modified after Exon, Kennett, Malone, et al., 2001). LC = Leeuwin Current, EAC = East Australian Current, STF = Subtropical Front.

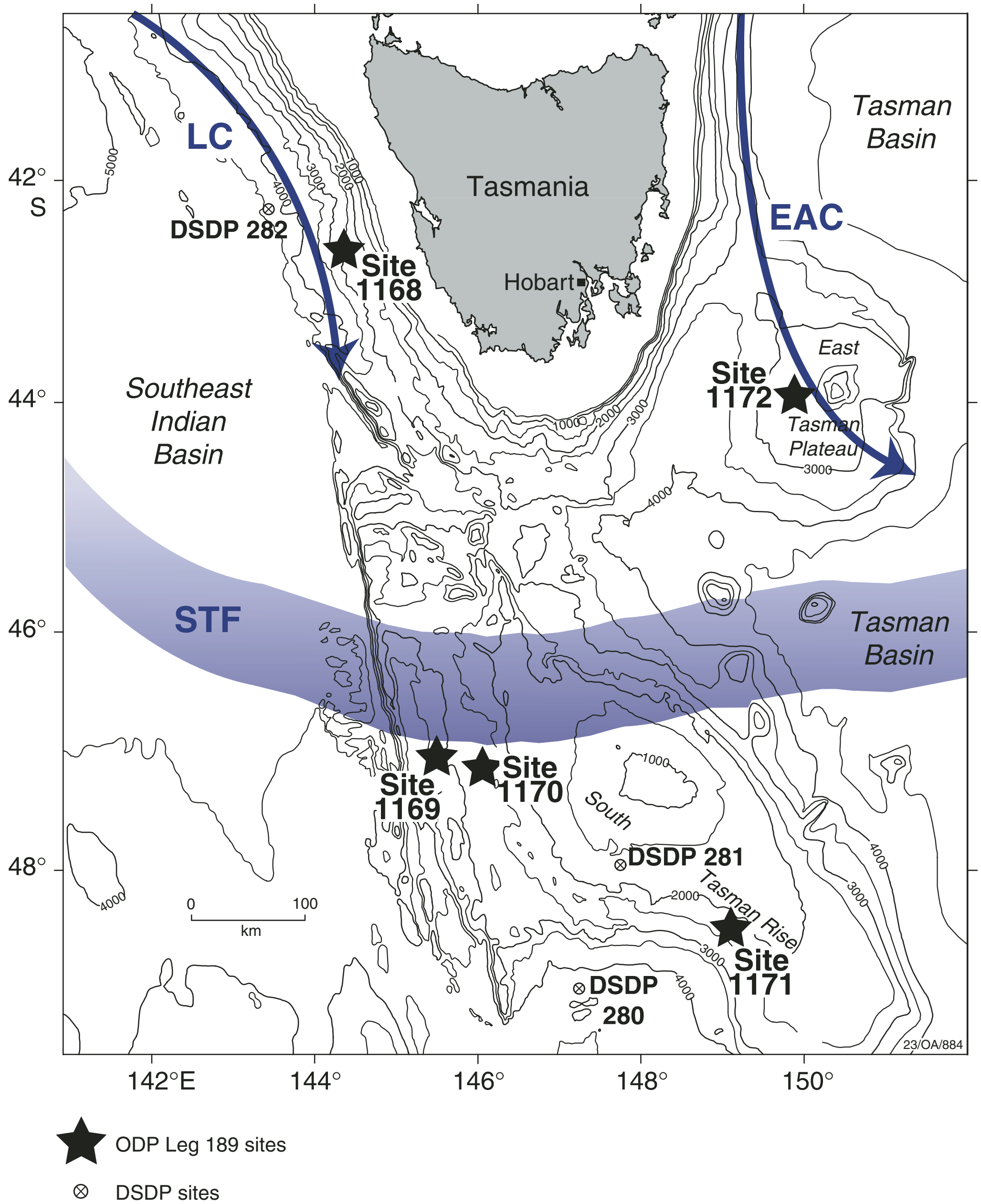


Figure F2. Combined Quaternary zonal schemes of Martini (1971), Gartner (1977), and Okada and Bukry (1980). GPTS = Geomagnetic Polarity Timescale (after Berggren et al., 1995). LO = last occurrence, FO = first occurrence. AZ = acme zone.

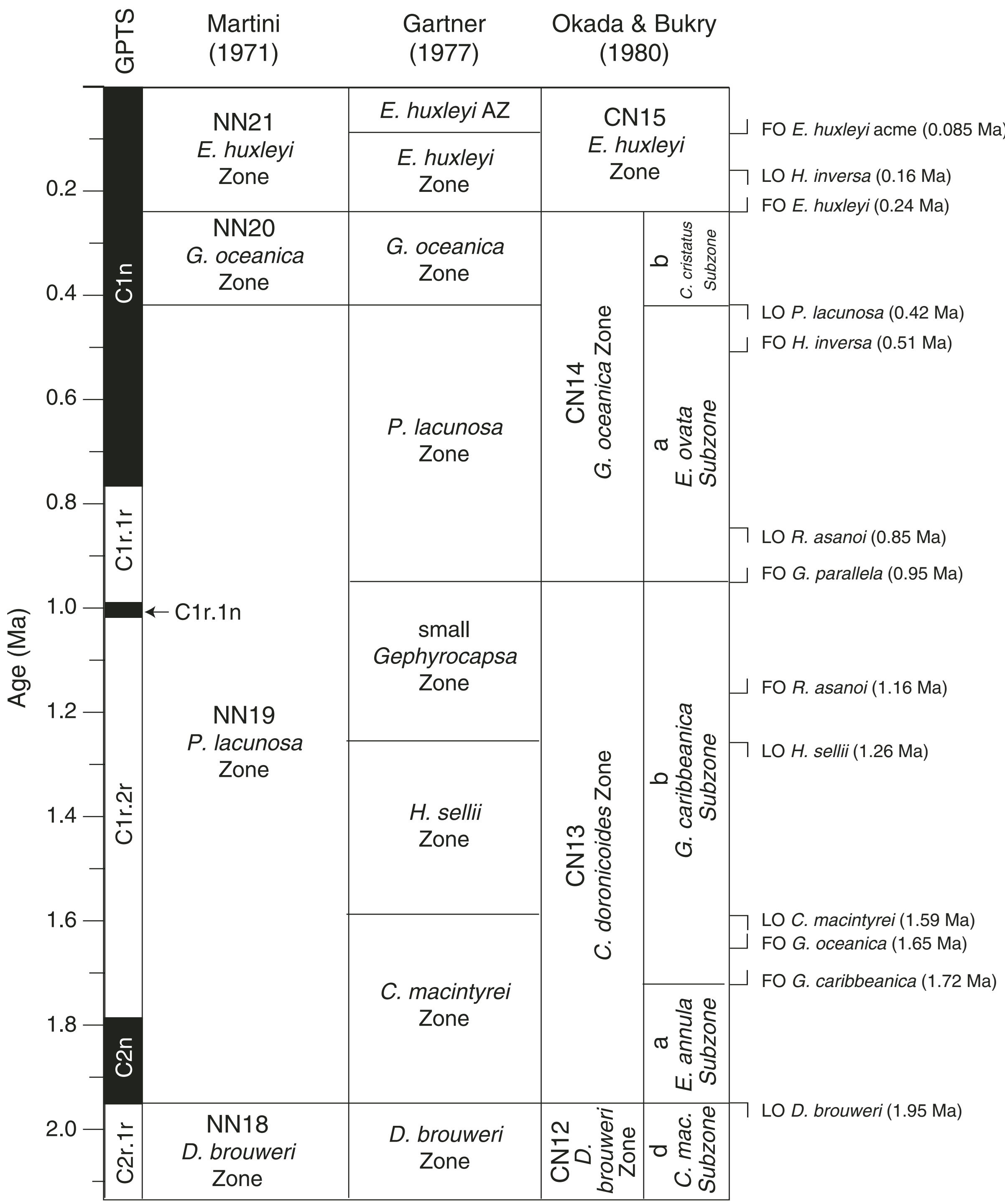


Figure F3. Sedimentation rate summary curves for Holes 1168A, 1170A, 1171A, and 1172A through the Quaternary. D = relative disturbance of core material based on visual examination of core photos. See Table T5, p. 23, for biomagnetostratigraphy datums used and Stickley et al. (this volume) for oxygen isotope and reflectance stratigraphy. LO = last occurrence, FO = first occurrence.

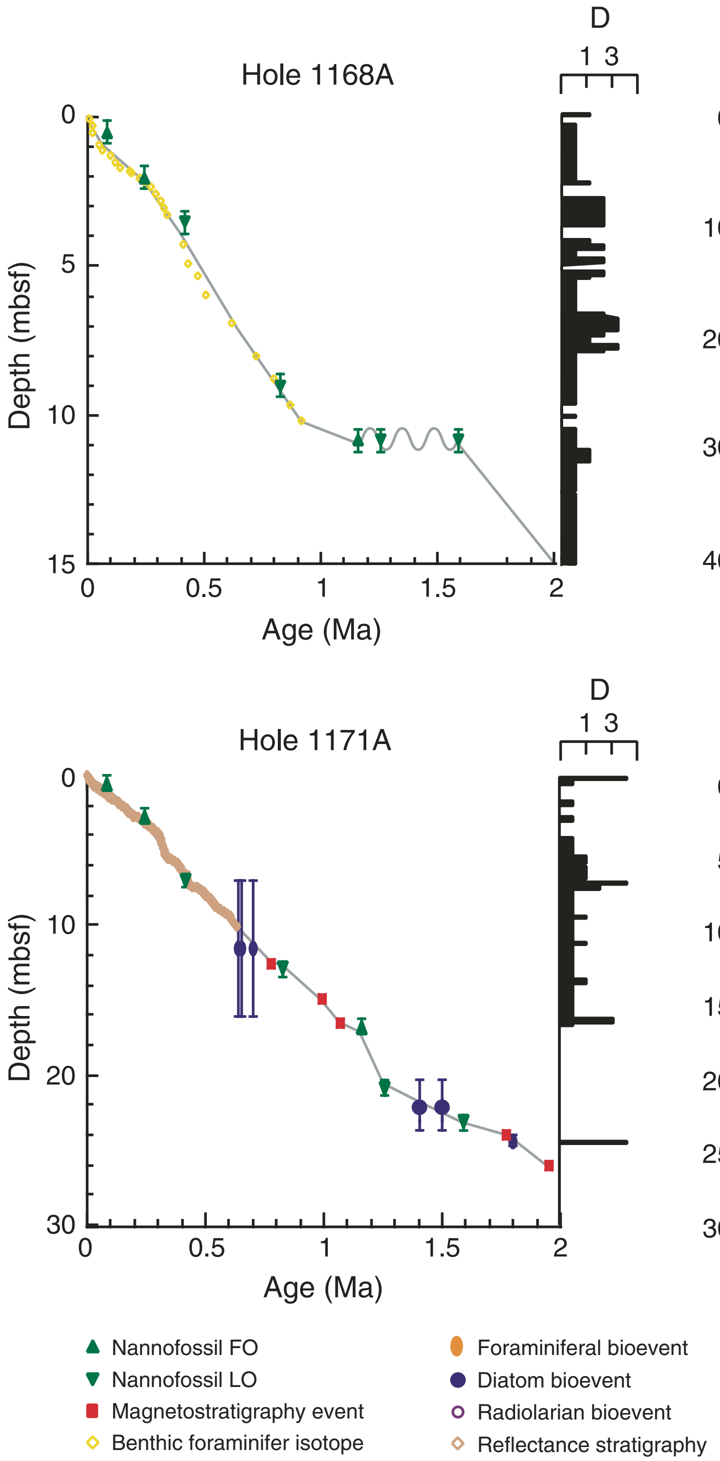


Table T1. Stratigraphic distribution of calcareous nannofossils from Site 1168.

Age	Gartner (1977)	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Discoaster deflandrei*	*Discoaster surculus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. <4 µm	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera sellii*	*Pontosphaera indooceanica*	*Pontosphaera japonica*	*Pseudoemiliania lacunosa*	*Pseudoemiliana lacunosa ovata*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. <4 µm	*Rhabdosphaera clavigera*	*Sphenolithus neoabies*	*Sphenolithus* spp.	*Umbilicosphaera jafarii*
		189-1168A-																												
Pleistocene	*Emiliania huxleyi acme* Zone	1H-1, 15–16	0.15	A	G		A		F				V			F	A	C				C				R				
	Emiliania huxleyi Zone	1H-1, 90–91	0.90	A	G		C		C				A				V	F				F								
		1H-2, 15–16	1.65	A	G		F		C				A		R		V					F								
	Gephyrocapsa oceanica Zone	1H-2, 90–91	2.40	A	G		A		A								V	A				A				V				
		1H-3, 15–16	3.15	A	G		A		F								V	R				R					R			
	Pseudoemiliania lacunosa Zone	1H-3, 90–91	3.90	A	G		A		A		r			R			V	C				F	A	A		V				
		1H-4, 15–16	4.65	A	G		V		C								V	A				F	V	C		V				
		1H-4, 90–91	5.40	A	G		A		A								V	C				F	A	C	c					
		1H-5, 15–16	6.15	A	G		A		A								V	C				F	A	C	c					
		1H-5, 90–91	6.90	A	G		V		A					C	C		V	A		r		C	A	C	c		C	r	r	R
		1H-CC	7.24	A	G		V		A					C	C		V	A	F			A	V		c	V				
		2H-1, 15–16	7.45	A	G		A		C					R			V	A	R		A	C	A		a	V	R	r		
		2H-1, 90–91	8.20	A	G		A		A				c	V	A			F					V	V						
	Small *Gephyrocapsa* Zone	2H-2, 15–16	8.95	A	G		A		A					A	A		V	A	R	r	F	C	A	C	C	V		r		
		2H-2, 90–91	9.70	A	G		A		A	r				C	C		V	A	R	f	F	F	A	C	A	V				
		2H-3, 15–16	10.45	A	M		A		A	r	f						F					A	A	C	F	V	R	a	f	
	Calcidiscus macintyrei Zone	2H-3, 90–91	11.20	A	G		A	F	V					R	R		V	C		F		F	A	C		V				A
		2H-4, 15–16	11.95	A	M		V	C	V		r						V	A		A		F	A	C		V				C
		2H-4, 90–91	12.70	A	M		V	A	V						R		V	C		F		F	C	C		V				A
		2H-5, 15–16	13.45	A	G		A	A	V					R	F		A	A		C		A	C	C		V				
		2H-5, 90–91	14.20	A	G		V	A	A					R			A	A		A		A	C			V				
		2H-6, 15–16	14.95	A	G		V	A	V								C	A		A		C	C			V				F
		2H-6, 90–91	15.70	A	P	R	A	C	V								C	A		C		F	C			V				C
		2H-7, 15–16	16.45	A	M		A	A	A								V	A		F		F	A			V				A
		2H-CC	16.80	A	M		V	A	V									A		A		C	A			V				
		3H-1, 15–16	16.95	A	G		A	C	V								A	C		C		C	A			V				
		3H-1, 90–91	17.70	A	G		V	C	V								A	A		C		C	A			V	C	c		
		3H-2, 15–16	18.45	A	G		V	C	V								C	A		C		C	C			V				
		3H-2, 90–91	19.20	A	G		V	C	V									A		C		A	A			V				
		3H-3. 15–16	19.95	A	M		V	A	V									A				C	A			V				
Pliocene	*Discoaster brouweri* Zone	3H-3, 90–91	20.70	A	M		V	A	V		C	C					C	A				C	A			V				
		3H-4, 15–16	21.45	A	M		V	A	V		C	C					C	A		C		C	C			V				

Notes: Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare. Lowercase letters indicate reworked specimens. Preservation: G = good, M = moderate, P = poor.

Table T2. Stratigraphic distribution of calcareous nannofossils, Hole 1170A.

Age	Gartner (1977)	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa* spp. <4 µm	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera sellii*	*Pontosphaera japonica*	*Pontosphaera* spp.	*Pseudoemiliania lacunosa*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. <4 µm	*Rhabdosphaera clavigera*
		189-1170A-																			
Pleistocene	*Emiliania huxleyi* acme Zone	1H-1, 60–61	0.60	A	M	C		V	V			A	C			R	F			A	
	Emiliania huxleyi Zone	1H-1, 110–111	1.10	A	G	F		A	A			A	C							A	
		2H-1, 60–61	2.30	A	M	F		A	C			A	F							V	
	Gephyrocapsa oceanica Zone	2H-1, 110–111	2.80	A	G	A		A				V	F							A	
		2H-2, 60–61	3.80	A	G	C		A				A	C	r						A	
		2H-2, 110–111	4.30	A	G	A		A				C	C				R			A	
		2H-3, 60–61	5.30	A	G	C		A				V	C				F			V	
		2H-3, 110–111	5.80	A	G	C		C				A	C							V	
		2H-4, 60–61	6.80	A	M	C		C				A	C				F			V	
		2H-4, 110–111	7.30	A	G	A		C				C								V	
		2H-5, 60–61	8.30	A	M	C		A				V	C				F			V	
		2H-6, 110–111	8.80	A	G	C	r	A				V	C						r	V	
		2H-6, 60–61	9.80	A	G	F		C				V	F							A	
		2H-6, 110–111	10.30	A	G	F		C				V	C							V	
		2H-7, 60–61	11.30	A	G	F		C				A	C		r					V	
	Pseudoemiliania lacunosa Zone	3H-1, 60–61	11.80	A	G	C		C				A	C				R	F		V	
		3H-1, 110–111	12.30	A	M	C		C				A	C					F		A	
		3H-2, 60–61	13.30	A	M	C		C				A	F					C		A	
		3H-2, 110–111	13.80	A	G	F		C				A	F					C		A	
		3H-3, 60–61	14.80	A	G	C		C				C	C					F		A	
	Small *Gephyrocapsa* Zone	3H-3, 110–111	15.30	A	G	C		C				C	C					F	R	A	
		3H-4, 60–61	16.30	A	M	C		A				A	C					C	C	V	
		3H-4, 110–111	16.80	A	M	A		V				C	C					C	F	V	
		3H-5, 60–61	17.52	A	M	C		A				C	C					A	R	V	
		3H-5, 110–111	18.02	A	G	C		A				F	C					C	F	A	
		3H-6, 60–61	19.02	A	G	C		A			R	C	C					A	F	A	
		3H-6, 110–111	19.52	A	G	F		C				C	C					A	C	A	
		3H-7, 60–61	20.52	A	M	F		C				F	C					A	V	A	
		4H-1, 64–65	21.34	A	G	C		C				F	C					A	C	A	
		4H-2, 60–61	22.20	A	G	C		C				F	F				F	A	C	A	
		4H-2, 110–111	22.70	A	G	C		C				C	C			F	C	A	C	V	
		4H-3, 60–61	23.63	A	G	C		C			F	C	C			R		C	C	A	
		4H-3, 110–111	24.13	A	G	C		C		C		C	F				F	A		A	
		4H-4, 60–61	25.09	A	G	C		C		F	F	C	F					C		A	
		4H-4, 110–111	25.59	A	G	C		F				C	C					C		V	
	Helicosphaera sellii Zone	4H-5, 60–61	26.55	A	M	F		C			C	C	F		R	F	F	A		A	
	Calcidiscus macintyrei Zone	4H-5, 110–111	27.05	A	G	C	F	F		F	F	F	C		R		R	F		A	
		4H-6, 60–61	28.05	A	G	C	F	F		C	A	C	F		F			C		A	
		4H-6, 110–111	28.55	A	G	F	F	F				C						C		A	
		5H-1, 58–59	30.78	A	M	C	A			A	A	F						C		A	
		5H-1, 110–111	31.30	A	G	C	C	F		C	F	F	F		R			C		A	
		5H-2, 60–61	32.30	A	G	C	C	F		R		F	A		C			C		A	
		5H-2, 110–111	32.80	A	G	C	R	C				C	F				F	C		A	
		5H-3, 60–61	33.80	A	G	C	C	A		F		A	F		R			C		A	
		5H-3, 110–111	34.30	A	M	C	C	A				A	F					C		A	
		5H-4, 60–61	35.30	A	M	C	C	C				C	C		F			A		A	
		5H-4, 110–111	35.80	A	M	C	C	C				A	F					C		A	
		5H-5, 60–61	36.80	A	G	C	C	C				C						C		A	
		5H-5, 110–111	37.30	A	G	F	F	F				C	R					A		A	
		5H-6, 60–61	38.30	A	G	C	C	C				C						A		A	

Notes: Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare. Lowercase letters indicate reworked specimens. Preservation: G = good, M = moderate.

Table T3. Stratigraphic distribution of calcareous nannofossils from Hole 1171A.

Age	Gartner (1977)	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. <4 µm	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera sellii*	*Pontosphaera indooceanica*	*Pontosphaera japonica*	*Pontosphaera* spp.	*Pseudoemiliania lacunosa*	*Pseudoemiliania lacunosa ovata*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. <4 µm	*Rhabdosphaera clavigera*	*Umbilicosphaera jafarii*
		189-1171A-																							
Pleistocene	*Emiliania huxleyi* acme Zone	1H-1, 15–16	0.15	A	M	A		A	A			F	c	C					A				A	F	
	Emiliania huxleyi Zone	1H-1, 90–91	0.90	A	M	C		A	A			F	V	A					F				A		
		1H-2, 15–16	1.65	A	M	C		A	A				A	C									A		
		1H-2, 90–91	2.40	A	M	C		A	F				A	C					F	f	f		A		
	Gephyrocapsa oceanica Zone	1H-3, 15–16	3.15	A	P	A		A					A	A					C				A		
		1H-3, 90–91	3.90	A	M	C		C		C			V	F					C		c		A		
		1H-4, 15–16	4.65	A	M	A		A			C		V	A					C				A		
		1H-4, 90–91	5.40	A	M	A		A					V	F					C				A		
		1H-5, 15–16	6.15	A	M	A		C					V	F					C				A		
		1H-5, 90–91	6.90	A	G	C		C					V	F	r				F				A	F	
	Pseudoemiliania lacunosa Zone	1H-CC	7.02	A	G	C		A					V	C					C	A	A		V		
		2H-1, 90–91	8.00	A	G	A		A					V	A					C	F			V		
		2H-2, 15–16	8.75	A	M	C		V					V	C					F	F			V		
		2H-2, 90–91	9.50	A	M	A		A					A	A			C			A	A	c	A		
		2H-3, 15–16	10.25	A	M	C		A			F		A	C	F				C	C	C		A		
		2H-3, 90–91	11.00	A	G	C		C				C	V	C					C	A	A		A		
		2H-4, 15–16	11.75	A	G	C		V				F	V	C						C			A		
		2H-4, 90–91	12.50	A	G	C		C					V	C			C	C		F			V		
	Small *Gephyrocapsa* Zone	2H-5, 15–16	13.25	A	P	A		C					C	C					C	C	C	C	C		
		2H-5, 90–91	14.00	A	G	A		A		F	F		A	C					C	A	A	C	A		
		2H-6, 15–16	14.75	A	G	A		A					A	A					A	A	A	C	A		
		2H-6, 90–91	15.50	A	G	V		V		F			A	V					C	A	A	F	A		
		2H-CC	16.10	A	G	V		V					A	A					A	A	A	C	A		
		3H-1, 90–91	17.50	A	G	V		C			F		A	A					A	V	V		V		
		3H-2, 15–16	18.25	A	G	A		C		C	C		A	A					C	A	A		V		
		3H-2, 90–91	19.00	A	G	V		C		V	C		V	A						A	A		V		A
		3H-3, 15–16	19.75	A	G	V		A		C	A		A	A						A	V		V		
		3H-3, 90–91	20.50	A	G	A		A		A	F		A	A					C	C			V		
	Helicosphaera sellii Zone	3H-4, 15–16	21.25	A	G	A		V		C			A	A		R				C			V		
		3H-4, 90–91	22.00	A	G	A		V						A						C	F		V		
		3H-5, 15–16	22.75	A	G	A		A						C		R				F			A		
	Calcidiscus macintyrei Zone	3H-5, 90–91	23.50	A	G	A	F	A		R				F		C				A	C		A		
		3H-6, 15–16	24.25	A	G	A	C	A					F			F				C	C		A		
		4H-1, 15–16	26.25	A	M	F		A						C	c	C				F			A		
		4H-1, 90–91	27.00	A	G	C	A	A						C		F			C		F		C		F
		4H-2, 15–16	27.75	A	G	A	F	A					F	C		C			C	C			C		
		4H-2, 90–91	28.50	A	G	A	A	A					C						C	F	C		C		
		4H-3, 15–16	29.25	A	G	C	A	A					F			F			F	F			A		
		4H-3, 90–91	30.00	A	G	C	C	A						F		C			F	F			C		

Notes: Abundance: V = very abundant, C = common, F = few. Lowercase letters indicate reworked specimens. Preservation: G = good, M = moderate, P = poor.

Table T4. Stratigraphic distribution of calcareous nannofossils, Hole 1172A.

Age	Gartner (1977)	Core, section, interval (cm)	Depth (mbsf)	Abundance	Preservation	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Discoaster brouweri*	*Discoaster deflandrei*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa parallela*	*Gephyrocapsa* spp. <4 µm	*Helicosphaera carteri*	*Helicosphaera inversa*	*Helicosphaera sellii*	*Pontosphaera indooceanica*	*Pontosphaera japonica*	*Pontosphaera* spp.	*Pseudoemiliania lacunosa*	*Reticulofenestra asanoi*	*Reticulofenestra* spp. <4 µm	*Rhabdosphaera clavigera*	*Umbilicosphaera jafarii*
		189-1172A-																								
Pleistocene	*Emiliania huxleyi* acme Zone	1H-1, 15–16	0.15	A	G	C		C			A	F	C	F	A	F				R	R			A	C	
	Emiliania huxleyi Zone	1H-1, 117–118	1.17	A	G	C		C			C	F	C		A	F				R	R			V		
		1H-2, 15–16	1.65	A	G	C		A			C	F			V	F					R			A	F	
	Gephyrocapsa oceanica Zone	1H-2, 117–118	2.67	A	G	C		C				F	F		V	F				R	R			A		
		1H-3, 15–16	3.15	A	G	C		A				F	C		V	F					R			A		
		1H-3, 117–118	4.17	A	G	C		A				C	F		V	F				R	R			V		
		1H-4, 15–16	4.65	A	G	C		C				C	R		V	F			R	R	R			C		
		1H-4, 117–118	5.67	A	M	C		F					C	C	V	F	c			R	F			V		
		1H-5, 15–16	5.85	A	G	C		C					R	F	V	F	c		R	R	F			A	F	
		1H-, CC	6.24	A	G	C		C	r			F	R	C	V	F				R	R			V		
		2H-1, 15–16	6.45	A	G	C		C				C		C	V	F	f			R	R			C	C	
	Pseudoemiliania lacunosa Zone	2H-1, 118–119	7.48	A	G	C		C				F	A	C	V	F					R	C		V		
		2H-2, 15–16	7.95	A	M	C		C				A	C		V	C				R	R	C		A		
		2H-2, 117–118	9.01	A	G	C		C				A			V	C				R	R	C		V		
	Small *Gephyrocapsa* Zone	2H-3, 15–16	9.45	A	G	C		C	r			C	C	R	V	C				R	R	F	R	C		
		2H-3, 117–118	10.47	A	G	C		C				C		R	A	F					R	F	F	A		
		2H-4, 15–16	10.95	A	M	C		A				C	R	R	C	F			R	R	R	F	F	R		R
		2H-4, 117–118	11.97	A	M	C		A				F		F	C	R				R	R	C	F	A		
		2H-5, 15–16	12.45	A	G	C		A				C	F	R	A	F				R	R	R	C	A	F	
		2H-5, 117–118	13.47	A	G	C		C				A			A	F				R	R	C	A	A		
		2H-6, 15–16	13.95	A	G	C		C				A	F		A	F				R	R	C	C	C	F	
		2H-6, 117–118	14.97	A	G	C		C				C	R		A	R			R	R	R	F	C	V		
		2H-7, 15–16	15.45	A	G	C		C				F	R		V	F				R		C	C	A	R	
		2H-, CC	15.75	A	G	A		R				F			V	C			R	R	R	F	A	A		
		3H-1, 28–29	16.08	A	G	A		C				C	C		A	F			R	R		R	C	F	F	
		3H-1, 130–131	17.10	A	M	A		C					C		A	F			R	R	F	R	F	A		
		3H-2, 15–16	17.45	A	G	A		F				F	C		A	C			F	F	R	R	F	F	C	
		3H-2, 117–118	18.47	A	G	A	f	C				F	C		A	F			F	F	R	R		A		
		3H-3, 15–16	18.95	A	G	A		A				F	C		A	F			F	F	R	C		C		
	Calcidiscus macintyrei Zone	3H-3, 117–118	19.97	A	M	A	F	R				C	R		A	F		F		F	R	F		A		
		3H-4, 15–16	20.45	A	M	C	F	C				C	C		A	F				F	R	F		F	F	
		3H-4, 117–118	21.47	A	M	A	F	C				C	C		V	F		R		R		F		A		
		3H-5, 15–16	21.95	A	G	A	F	C					R		V	F		F		R		F		C		
		3H-5, 117–118	22.97	A	G	A	R	A							A	F		R		R		F		A		
		3H-6, 15–16	23.45	A	M	C	F	V	r						A	R		R		R		R		F		
		3H-6, 117–118	24.47	A	G	C	C	A		r						C		C				A			F	
		3H-7, 15–16	24.95	A	M			V								F		F				C		A		
Pliocene	*Discoaster brouweri* Zone	3H-CC	25.54	A	G	A	A	A	C					F				A				A		A		

Notes: Abundance: V = very abundant, A = abundant, C = common, F = few, R = rare. Lowercase letters indicate reworked specimens. Preservation: G = good, M = moderate.

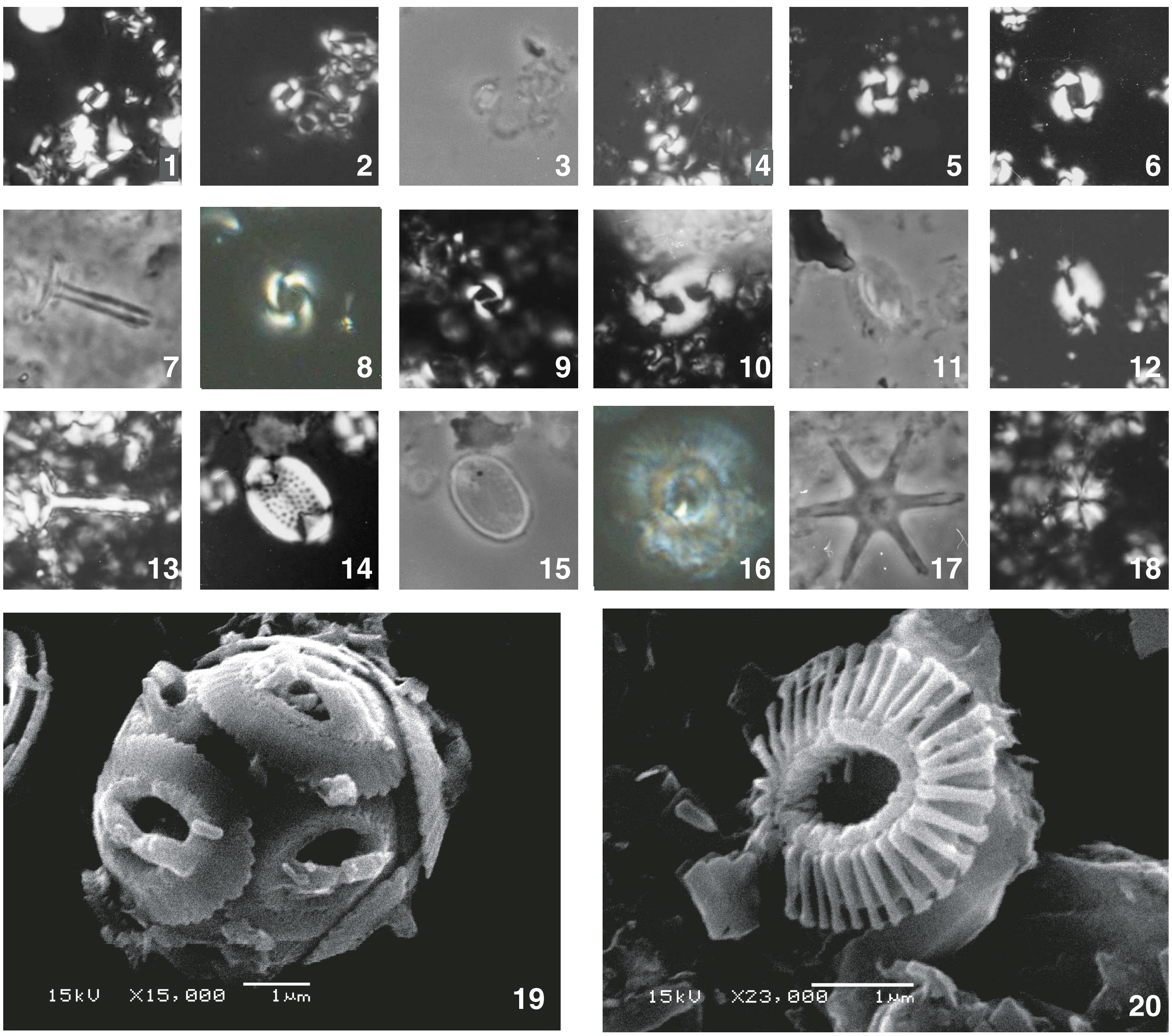
Table T5. Biomagnetostratigraphic datums used to create linear sedimentation plot. (See table notes. Continued on next page.)

Age (Ma)	Event	Top: Core, section, interval (cm)	Top: Depth (mbsf)	Bottom: Core, section, interval (cm)	Bottom: Depth (mbsf)	Mean depth (mbsf)	Stratigraphic error (±m)	Reference
	Calcareous nannofossil event	189-1168A-		189-1168A-				
0.085	FO *Emiliania huxleyi* acme	1H-1, 15–16	0.15	1H-1, 90–91	0.90	0.53	0.38	1
0.24	FO *Emiliania huxleyi*	1H-2, 15–16	1.65	1H-2, 90–91	2.40	2.03	0.38	2
0.42	LO *Pseudoemiliania lacunosa*	1H-3, 15–16	3.15	1H-3, 90–91	3.90	3.53	0.38	3
0.83	LO *Reticulofenestra asano*i	2H-1, 90–91	8.20	2H-2, 15–16	8.95	8.58	0.38	3
1.16	FO *Reticulofenestra asanoi*	2H-3, 15–16	10.45	2H-3, 90–91	11.20	10.83	0.38	3
1.26	LO *Helicosphaera sellii*	2H-3, 15–16	10.45	2H-3, 90–91	11.20	10.83	0.38	3
1.59	LO *Calcidiscus macintyrei*	2H-3, 15–16	10.45	2H-3, 90–91	11.20	10.83	0.38	1
1.65	FO *Gephyrocapsa oceanica*	2H-5, 15–16	13.45	2H-5, 90–91	14.20	13.83	0.38	3
1.72	FO *Gephyrocapsa caribbeanica*	2H-5, 90–91	14.20	2H-6, 15–16	14.95	14.58	0.38	3
2.51	LO *Discoaster surculus*	3H-3, 15–16	19.95	3H-3, 90–91	20.70	20.33	0.38	4
	Other biomagnetostratigraphic events							
2.00	FO *Globorotalia truncatulinoides* (F)	2H-3, 78–83	11.08	2H, CC	17.00	14.04	2.96	5
2.50	LO *Invertocysta* sp. (D)	3H-CC	26.58	4H-3, 60	29.86	28.22	1.64	5
2.65	LO *Amiculosphaera umbracula* (D)	2H-CC	16.965	3H-3, 60–62	20.41	18.69	1.72	5
	Calcareous nannofossil event	189-1170A-		189-1170A-				
0.085	FO *Emiliania huxleyi* acme	1H-1, 60–61	0.61	1H-1, 110–111	1.11	0.86	0.25	1
0.24	FO *Emiliania huxleyi*	2H-1, 60–61	2.31	2H-1, 110–111	2.81	2.56	0.25	2
0.42	LO *Pseudoemiliania lacunosa*	2H-7, 60–61	11.30	3H-1, 60–61	11.80	11.55	0.25	3
0.83	LO *Reticulofenestra asanoi*	3H-3, 60–61	14.80	3H-3, 110–111	15.30	15.05	0.25	3
1.16	FO *Reticulofenestra asanoi*	4H-3, 60–61	23.63	4H-3, 110–111	24.13	23.88	0.25	3
1.26	LO *Helicosphaera selli*	4H-4, 110–111	25.59	4H-5, 60–61	26.55	26.07	0.48	3
1.59	LO *Calcidiscus macintyrei*	4H-5, 60–61	26.55	4H-5, 110–111	27.05	26.80	0.25	1
	Other biomagnetostratigraphic events							
0.45	LO *Stylatractus universus* (R)	1H-CC	1.57	2H-CC	11.64	6.60	5.03	5
0.64	LO *Actinocyclus ingens* (D)	2H-CC	11.64	3H-CC	20.71	16.17	4.54	5
1.8	LO *Simonseniella barboi* (D)	4H-CC	29.01	5H-CC	39.39	34.20	5.19	5
1.95	Onset C2n (M)					39.70		5
	Calcareous nannofossil event	189-1171A-		189-1171A-				
0.085	FO *Emiliania huxleyi* acme	1H-1, 15–16	0.15	1H-1, 90–91	0.90	0.53	0.38	1
0.24	FO *Emiliania huxleyi*	1H-2, 90–91	2.40	1H-3, 15–16	3.15	2.78	0.38	2
0.42	LO *Pseudoemiliania lacunosa*	1H-5, 90–91	6.90	1H-CC	7.02	6.96	0.06	3
0.85	LO *Reticulofenestra asanoi*	2H-4, 90–91	12.50	2H-5, 15–16	13.25	12.88	0.38	3
1.16	FO *Reticulofenestra asanoi*	2H-4, 90–91	16.10	3H-1, 90–91	17.50	16.80	0.70	3
1.26	LO *Helicosphaera sellii*	3H-3, 90–91	20.50	3H-4, 15–16	21.25	20.88	0.38	3
1.59	LO *Calcidiscus macintyrei*	3H-5, 15–16	22.75	3H-5, 90–91	23.50	23.13	0.38	1
	Other biomagnetostratigraphic events							
0.640	LO *Actinocyclus ingens* (D)	1H-CC	7.01	2H-CC	16.05	11.53	4.52	5
0.650	LO *Fragilariopsis reinholdii* (D)	1H-CC	7.01	2H-CC	16.05	11.53	4.52	5
0.700	LO *Thalassiosira fasiculata* (D)	1H-CC	7.01	2H-CC	16.05	11.53	4.52	5
0.780	Onset C1n (M)*					12.60		5
0.990	Termination C1r.1n (M)*					14.90		5
1.070	Onset C1r.1n (M)*					16.50		5
1.400	LO *Fragilariopsis barronii* (D)	2H-CC	16.10	3H-CC	24.70	20.40	4.30	5
1.500	LO *Thalassiosira tetraoestrupii* var. *reimeri* (D)	2H-CC	16.10	3H-CC	24.70	20.40	4.30	5
1.770	Termination C2n (M)*					24.00		5
1.800	LO *Proboscia barboi* (D)	Termination C2n	24.00	3H-CC	24.70	24.35	0.35	5
1.950	Onset C2n (M)*					26.00		5
	Calcareous nannofossil event	189-1172A-		189-1172A-				
0.085	FO *Emiliania huxleyi* acme	1H-1, 15–16	0.15	1H-1, 117–118	1.17	0.66	0.51	1
0.24	FO *Emiliania huxleyi*	1H-2, 15–16	1.65	1H-2, 117–118	2.67	2.16	0.51	2
0.42	LO *Pseudoemiliania lacunosa*	2H-1, 15–16	6.45	2H-1, 118–119	7.48	6.97	0.52	3
0.86	LO *Reticulofenestra asanoi*	2H-2, 117–118	9.01	2H-3, 15–16	9.45	9.23	0.22	3
1.16	FO *Reticulofenestra asanoi*	3H-2, 15–16	17.45	3H-2, 117–118	18.47	17.96	0.51	3
1.26	LO *Helicosphaera sellii*	3H-3, 15–16	18.95	3H-3, 117–118	19.97	19.46	0.51	3
1.59	LO *Calcidiscus macintyrei*	3H-3, 15–16	18.95	3H-3, 117–118	19.97	19.46	0.51	1
1.65	FO *Gephyrocapsa oceanica*	3H-4, 117–118	21.47	3H-5, 15–16	21.95	21.71	0.24	3
1.72	FO *Gephyrocapsa caribbeanica*	3H-4, 117–118	21.47	3H-5, 15–16	21.95	21.71	0.24	3
1.95	LO *Discoaster brouweri*	3H-7, 15–16	24.95	3H-CC	25.54	25.25	0.30	1
	Other biomagnetostratigraphic events							
0.45	LO *Stylatractus universus* (R)[†]	1H-CC	2.79	2H-CC	12.73	7.76	4.97	5
0.78	Onset 1n (M)[†]					12.5		5
1.77	Termination 2n (M)[†]					17.1		5
1.95	Onset 2n (M)[†]					19.55		5

Table T5 (continued).

Notes: LO = last occurrence, FO = first occurrence. F = foraminiferal bioevent, D = dinocyst bioevent, Dm = diatom bioevent, R = radiolarian bioevent, M = magnetostratigraphic event, * = event from Hole 1171C, † = event from Hole 1172B. 1 = Berggren et al., 1995; 2 = Naish et al., 1998; 3 = Sato and Kameo, 1996; 4 = Wei, 1993; 5 = **Stickley et al.,** this volume.

Plate P1. Magnification = 1800× unless specified otherwise. PH = phase-contrast light, XPL = cross-polarized light, SEM = scanning electron microscope. **1–4.** *Emiliania huxleyi;* (1) Sample 189-1168A-2H-1, 90–91 cm, XPL; (2, 3) Sample 189-1171A-1H-2, 15–16 cm, (2) XPL, (3) PH; (4) Sample 189-1171A-2H-2, 90–91 cm, XPL. **5.** *Pseudoemiliania lacunosa* (Sample 189-1168A-1H-4, 90–91 cm, XPL). **6.** *Pseudoemiliania lacunosa ovata* (Sample 189-1170A-2H-5, 15–16 cm, XPL). **7, 13.** *Rhabdosphaera clavigera* (Sample 189-1168A-1H-5, 90–91 cm); (7) PH, (13) XPL. **8.** *Reticulofenestra asanoi* (Sample 189-1171A-2H-5, 90–91 cm, PH). **9.** *Gephyrocapsa oceanica* (Sample 189-1170A-4H-6, 60–61 cm, XPL). **10.** *Heliocosphaera sellii* (Sample 189-1170A-5H-4, 60–61 cm, XPL). **11, 12.** *Helicosphaera sellii* (Sample 189-1168A-CC); (11) PH, (12) XPL. **14, 15.** *Pontosphaera indoceanica* (Sample 189-1171A-2H-2, 90–91 cm); (14) XPL, (15) PH. **16.** *Calcidiscus macintyrei* (Sample 189-1171A-4H-1, 90–91 cm, XPL). **17.** *Discoaster brouweri* (Sample 189-1172A-1H-CC, PH). **18.** *Sphenolithus abies* (Sample 189-1168A-2H-2, 15–16 cm, XPL) (750×). **19.** *Gephyrocapsa* sp. <4 µm (Sample 189-1172A-1H-1, 117–118 cm) (SEM). **20.** *Emiliania huxleyi* (Sample 189-1168A-1H-1, 15–16 cm) (SEM).



CHAPTER NOTE*

N1. McGonigal, K.L., submitted. Quantitative Miocene calcareous nannofossil biostratigraphy from the Tasmanian Seaway. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Climate Evolution in the Southern Ocean and Australia's Cenozoic Flight Northward from Antarctica.* Antarct. Res. Ser.

*Dates reflect file corrections or revisions.