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11. CALCAREOUS NANNOFOSSILS FROM CONTINENTAL RISE SITE 1165, ODP LEG 188, PRYDZ BAY, ANTARCTICA[1]

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ABSTRACT

During Ocean Drilling Program (ODP) Leg 188, piston and rotary cores were recovered at three southern Indian Ocean sites on the continental margin in Prydz Bay, Antarctica, in order to obtain a detailed sedimentary record reflecting Cenozoic Antarctic glacial history and paleoenvironments. Coring at continental rise Site 1165 revealed a relatively continuous, ~1000-m, lower Miocene to upper Pliocene section overlain by a thin Quaternary cover. No nannofossils were noted at shelf Site 1166, where a discontinuous, ~343-m section of Quaternary- to Late Cretaceous-age predominantly glacial marine diamictons was recovered. At slope Site 1167, ~447 m of clayey silty sands was recovered, where nannofossils are rare and sporadic but indicate Pleistocene age for at least the upper ~227 m there.

This report focuses on data collected from Site 1165, where Neogene–Quaternary calcareous nannofossils are moderately to well preserved and sporadically present, but abundant in several intervals. Assemblages are characterized by low diversity with one or two dominant taxa. Mid- and low-latitude age-diagnostic marker species are absent. Nannofossil Zone CN15 and Subzones CN14b and CN13b–CN14a were identified in Pleistocene sediments based on the presence of *Emiliania huxleyi, Pseudoemiliania lacunosa,* and large *Gephyrocapsa caribbeanica.* Pliocene sediments are barren of nannofossils. Only general age and zonal assignments are possible for the relatively complete Miocene section (as dated by siliceous microfossils). The presence of *Minylitha convallis* in one sample permits the identification of upper Miocene Zones CN7–CN9. *Cyclicargolithus floridanus* is used to delineate presence of

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middle Miocene Zone CN5 and older. Assemblages in samples from the base of the section at Site 1165 are indicative of an early Miocene age (CN1–CN3). Overall, nannofossil assemblages are characterized by dominant *Reticulofenestra* spp., which are typical of high latitudes. *Reticulofenestra perplexa* and *Reticulofenestra producta* form nearly monospecific assemblages in a few intervals. *M. convallis* has not previously been reported in upper Miocene sediments from the Antarctic margin and likely indicate a brief warming event.

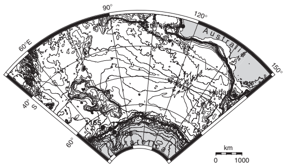
Sporadic nannofossil abundance increases at deepwater (~3500 m) Site 1165 may be due to the following processes or combination of processes: (1) high nannofloral productivity in surface waters around Prydz Bay, possibly associated with warmer intervals; (2) periodic downward fluctuations in the calcium carbonate compensation depth, permitting less dissolution (possibly the result of the first condition); or (3) rapid transport and burial downslope.

INTRODUCTION

Few calcareous nannofossil–bearing sections of Neogene age have been recovered in the extreme high latitudes of the Southern Ocean, particularly along the Antarctic margin. Haq (1976, 1980) noted the presence of coccoliths from high austral latitudes near the Antarctic margin, and Neogene nannofossils were recovered during Legs 113, 119, 120, 178, and 183 (Wise, 1983; Wei and Wise, 1990, 1992a, 1992b; Wei and Thierstein, 1991; Beaufort and Aubry, 1992; Barker, Camerlenghi, Acton, et al., 1999; Persico et al., 2003). The paucity of nannofossils in deposits of this age generally reflects cooling associated with the increased thermal isolation of the Southern Ocean around the Antarctic continent consequent to the establishment of the Antarctic Circumpolar Current (e.g., Kennett, 1977).

During Ocean Drilling Program (ODP) Leg 188, three sites were drilled along a shelf-slope-rise transect in Prydz Bay, Antarctica (Fig. **F1**). The objectives were to (1) date the earliest evidence of glacial activity in Prydz Bay and investigate the Antarctic Paleogene environment; (2) compare paleoceanographic changes reflected in continental rise sediments (Site 1165) to the sediment record of the shelf (1166) and slope (1167), which indicate changes in the East Antarctic Ice Sheet; and (3) study Lambert Glacier–Amery Ice Shelf advance and retreat recorded in upper Miocene and younger trough mouth fan sediments of the Antarctic continental slope.

F1. Locations of Sites 1165, 1166, and 1167, p. 13.



Calcareous nannofossils were most common, although sporadic, at continental rise Site 1165 (water depth = 3537 m; 64°22′S). Here, a thick Neogene section composed predominantly of fine-grained terrigenous and diatom-bearing hemipelagic sediments (sediment drift deposits) was collected (O'Brien, Cooper, Richter, et al., 2001). In addition to nannofossils, diatoms, radiolarians, and planktonic foraminifers indicate a relatively continuous, nearly 1000-m lower Miocene to upper Pliocene section that underlies a thin Quaternary cover. Data from Site 1165 indicate that at various times during the Neogene and Quaternary conditions near the Antarctic margin were favorable for surface water nannoplankton productivity and subsequent preservation of nannofossils in bottom sediments.

METHODS

Smear slides were prepared for calcareous nannofossil study using standard techniques. Slides were examined using a light microscope under crossed polarizers and transmitted light. Relative abundances were recorded at 1000×. Abundance counts in Table T1 reflect the average number of specimens per 200 fields of view. Preservation is characterized as follows:

G = good preservation (little or no evidence of dissolution and/or overgrowth; primary morphological characteristics only slightly altered; specimens are identifiable to the species level).
M = moderate preservation (specimens exhibit some etching and/or overgrowth; primary morphological characteristics sometimes altered; however, most specimens are identifiable to the species level).
P = poor preservation (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).

T1. Quaternary and Miocene calcareous nannofossils, p. 14.

Calcareous nannofossil species considered in this report are listed in the **"Appendix,"** p. 10, and are arranged alphabetically by generic epithets. Bibliographic references are found in Perch-Nielsen (1985) and Bown (1998).

BIOSTRATIGRAPHIC ZONATIONS

The nannofossil biostratigraphic framework was provided by the zonations of Martini (1971) and Okada and Bukry (1980). The numbered codes of the latter are referred to in the text and Table T1. It has been noted that Cenozoic biostratigraphic resolution significantly decreases from the low to high latitudes of the Southern Hemisphere (e.g., Pospichal et al., 1992), and as expected at Site 1165, a detailed nannofossil biostratigraphy could not be achieved for the Neogene. Nannofossil zones were necessarily combined due to lack of markers.

RESULTS

Calcareous nannofossils are sporadic in Site 1165 cores with moderate preservation and high abundance in only a few samples (Table T1). Dissolution is notable at this site, which is consistent with a corrosive deeper water environment. Where nannofossils are present, assemblages are generally characterized by low diversity and lack the usual age-diagnostic marker species. A few centimeter-scale chalky intervals are present where nannofossils are very abundant and show signs of extreme overgrowth. A limited but useful nannofossil biostratigraphy was applied to the Pleistocene section, and nannofossils were important in determining the early Miocene age for the bottom 400 m of the section down to ~1000 meters below seafloor (mbsf), where siliceous microfossils were not well preserved (O'Brien, Cooper, Richter, et al., 2001). Nannofossil age assignments are in general agreement with diatoms and radiolarians, and assemblages are comparable to those previously described from Prydz Bay and other Southern Ocean drill sites (Wise, 1983; Wei and Wise, 1990, 1992a, 1992b; Wei and Thierstein; 1991).

Hole 1165A

One core was taken from Hole 1165A, which consists of diatom ooze assigned to the upper Pleistocene–Holocene nannofossil Zone CN15 based on the presence of few *Emiliania huxleyi* in Sample 188-1165A-1H-1, 20–21 cm. The first occurrence (FO) of *E. huxleyi* was not determined below this sample in this study. Additional species present include *Gephyrocapsa oceanica, Gephyrocapsa caribbeanica, Coccolithus pelagicus,* and *Calcidiscus leptoporus* (Table T1).

Hole 1165B

Lower Miocene to Quaternary fine-grained terrigenous and diatom-bearing hemipelagic sediments (sediment drift deposits) were cored in Hole 1165B (for detailed lithologic descriptions, see O'Brien, Cooper, Richter, et al., 2001). Sample 188-1165B-1H-1, 21–22 cm, contains very rare *E. huxleyi* and is assigned to Zone CN15. The interval from Sample 188-1165B-1H-1, 97–98 cm (0.98 mbsf), to 1H-4, 21–22 cm (4.72 mbsf), is placed in Subzone CN14b. The first downhole occurrence of *Pseudoemiliania ovata* in Sample 188-1165B-1H-CC, 15–20 cm (6.81 mbsf), denotes the top of the interval assigned to Subzones CN14a–CN13b. The zonal assignment is supported by the presence of very rare specimens of *Reticulofenestra asanoi* and larger *G. caribbeanica* (~6.0 µm), whose known ranges are restricted to this interval. The base of this zone is placed at the top of an interval barren of nannofossils (Sections 188-1165B-2H-7 through 14H-6) that is dated by diatoms as Pliocene (**Whitehead and Bohaty,** this volume) (Table T1).

Sample 188-1165B-14H-CC, 34–44 cm (124.51 mbsf), contains abundant moderately preserved specimens (Table T1). The assemblage is dominated by *Reticulofenestra perplexa* (syn. *Dictyococcites antarcticus*) and *Reticulofenestra productus* with *C. pelagicus,* and very rare *Reticulofenestra pseudoumbilicus*. Several varieties of small- and medium-sized *Reticulofenestra* spp. are few to common. These have been variably assigned by previous authors to a number of species including *R. haqii, R. minuta, R. gelida,* and *R. minutula* (see the **"Appendix,"** p. 10, for comments on taxonomy). A surprise in this sample was the presence of few specimens of *Minylitha convallis,* which is noted from Zones CN8–CN9 of the upper Miocene. *Sphenolithus abies* and *Discoaster* sp. cf. *D. variabilis* were also noted in this sample.

Cores 188-1165B-15H through 24X are mostly barren of calcareous nannofossils, but very abundant specimens were noted in Sample 20X-5, 117–118 cm (163.38 mbsf), and from a thin chalky layer within the core catcher of Core 24X. The samples are dominated by *R. perplexa* with fewer *R. producta, Reticulofenestra* spp., and rare *C. pelagicus*. The assemblage is characteristic of the middle to late Miocene of the higher latitudes and can be roughly assigned to Zones CN5b–CN9. Cores 188-1165B-27X through 57X are generally barren of nannofossils (Table T1).

Cores 188-1165B-58X and 59X contain several samples where nannofossils are common to abundant. The highest occurrence of *Cyclicargolithus floridanus* in Sample 188-1165B-58X-1, 100–101 cm (512.01 mbsf) roughly indicates the top of Subzone CN5a and suggests a middle Miocene or older age (e.g., Wei and Wise, 1992a). In light of the diatom data (**Whitehead and Bohaty,** this volume), an age of late early Miocene is probable (Zones CN2–CN3). Very abundant nannofossils are present in Sample 188-1165B-58X-2, 34–35 cm, which is dominated by *Reticulofenestra* spp. but with notably abundant *C. pelagicus*. Rare reworked Oligocene specimens of *Chiasmolithus* sp., *Reticulofenestra bisecta, Reticulofenestra daviesii,* and *Reticulofenestra samodurovii* were also noted in the sample.

Below Core 188-1165B-59X down to Core 76X (674.96 mbsf), nannofossils are sporadic with assemblages dominated by species of *Reticulofenestra* with very rare occurrences of *C. floridanus, C. pelagicus,* and *Helicosphaera carteri* (Table **T1**).

Hole 1165C

Hole 1165C was rotary cored from a depth of 675.0 mbsf to 998.2 mbsf. Predominantly dark brown to gray-green mudstones were recovered, which contained sporadic moderately preserved nannofossils. A good biostratigraphy could not be achieved, but assemblages recovered are indicative of an early Miocene age for the hole, most likely encompassing nannofossil Zones CN1–CN3 (Table **T1**).

Nannofossils in Hole 1165C are dominated by small and medium-sized species of *Reticulofenestra* (*R. perplexa, R. haqii, R. minuta,* and *R. producta*) and *C. pelagicus*. Few *Reticulofenestra hesslandii* occur down through Core 188-1165C-18R and questionably below that. Rare and sporadic *C. floridanus* are present throughout, and rare *Cyclicargolithus abisectus* (small morphotype; 9.5 µm) are present in Core 188-1165C-27R and below. A single specimen of *Discoaster deflandrei* was also noted in Sample 188-1165C-12R-4, 24–26 cm, and rare specimens of *Coccolithus miopelagicus* were noted in Core 18R and below.

Samples from Sections 188-1165C-18R-3 and 18R-4 (~830.0 mbsf) contain abundant nannofossils with a notable increase in *C. pelagicus* and *S. abies,* particularly in Sample 18R-4, 51–52 cm (831.12 mbsf). The assemblage contains a higher nannofossil diversity, although it is still dominated by *Reticulofenestra* species.

In the bottom core, Sample 188-1165C-35R-1, 19–20 cm (989.69 mbsf), contains few to common specimens of a relatively rich nannoflora (>13 species) that includes common *Reticulofenestra* spp., few *C. pelagicus,* rare *C. abisectus,* and single specimens of *Helicosphaera* sp. cf. *H. paleocarteri, Helicosphaera* sp., and *Umbilicosphaera jafari*. The assemblage is assignable to the lower Miocene nannofossil Zones CN1–CN3. In Southern Ocean sections, the uppermost Oligocene is characterized by the presence of *R. bisecta* and common to abundant *R. daviesii,* which actually ranges just into the lower Miocene. No *R. bisecta* were observed in bottom-hole assemblages, and only rare and sporadic or questionable specimens of *R. daviesii* were noted. These species were reported in Antarctic margin sections such as nearby Prydz Bay, Site 739 (Wei and Thierstein, 1991), and thus it would be reasonable to predict their presence at this site if Oligocene sediments were reached.

DISCUSSION AND SUMMARY

Biostratigraphy

The presence of *E. huxleyi, P. lacunosa,* and *G. caribbeanica* (~6.0 µm) at Site 1165 facilitates the delineation of a moderately detailed Pleistocene stratigraphy (Zones CN13b–CN15). However, as expected, limited nannofossil biostratigraphic resolution was achieved for the Neogene. Because the Pliocene sediments are barren of nannofossils, *R. perplexa,* one of the few useful high-latitude markers, could not be used as a datum (top occurs in the middle Pliocene). *M. convallis* (in a single sample) and the highest occurrence of *C. floridanus* provided helpful nannofossil zonal guides for identifying the upper Miocene (Zones CN7–CN9) and middle–lower Miocene sections (CN5 and older). The absence of *R. bisecta* in nannofossil-bearing samples near the bottom of the hole indicates that the Oligocene was not reached.

Nannofossils and Paleoenvironments

Although modern calcareous nannoplankton do not thrive in surface waters south of the Antarctic Divergence (below ~62°S) (Findlay, 1998), the presence of nannofossils in varying abundances in Quaternary and older sediments at Site 1165 (64°22′S) indicates past conditions favorable for productivity and preservation. Sea bottom at Site 1165 (water depth = 3537 m) is presently below the carbonate compensation depth (CCD), and under normal conditions dissolution would be prevalent (Quilty, 1985). In regard to other calcareous microfossils at Site 1165, planktonic foraminifers are generally absent below the Pliocene and those present show signs of dissolution. Benthic foraminifer assemblages are interpreted to have been affected by dissolution as well (O'Brien, Cooper, Richter, et al., 2001). At nearby shallower sites of the Kerguelen Plateau, nannofossils are much more abundant in age- and latitude-equivalent sediments (Wei and Wise, 1990; Wei and Thierstein, 1991). The presence and fluctuations in nannofossil abundance at Site 1165 may be attributed to several processes. Likely, the periodic high nannofloral productivity in surface waters around Prydz Bay was related to the warming of surface waters. The resultant increase in carbonate supply to the bottom waters perhaps depressed the CCD and permitted the preservation of nannofossils (see discussion in Wei and Wise, 1992b).

The presence of *M. convallis* in Sample 188-1165B-14H-CC, 34–44 cm (124.51 mbsf), along with extremely rare *Discoaster* sp. cf. *D. variabilis* and *S. abies,* likely indicates that for at least a very brief period during the late Miocene sea-surface temperatures along the Antarctic margin warmed. In addition, the presence of *M. convallis* at Site 1165 extends its known geographic range to the extreme high southern latitudes and indicates its tolerance for lower sea-surface temperatures.

Some nannofossils at Site 1165 are the result of rapid downslope transport, burial, and preservation. Two examples of this latter process are evident at Site 1165. In Sample 188-1165B-14H-CC, nannofossils are abundant and fairly well preserved, along with a well-developed fauna of neritic benthic foraminifers, which were obviously brought downslope. Similarly, in Sample 188-1165C-12R-4, 24–26 cm, nannofossils are abundant in a carbonate-rich interval shipboard sedimentologists interpreted as a distal mud flow deposit (O'Brien, Cooper, Richter, et al., 2001). Retransport is further corroborated by the presence of rare reworked Oligocene–Eocene nannofossils in this sample.

As previously mentioned, assemblages recovered at Site 1165 are comparable to those of equivalent age found elsewhere in the high austral latitudes, particularly in Prydz Bay and on the Kerguelen Plateau (Wei and Thierstein, 1991; Wei and Wise, 1992a; Beaufort and Aubry, 1992). These assemblages are composed of a typical cold-water nannofossil flora. An example is *R. perplexa,* which achieves very high abundances and composes almost 100% of the assemblage at various intervals in upper Miocene to lower Pliocene austral sections (Wei and Wise, 1992b). At Site 1165 a nearly monospecific assemblage of very abundant *R. perplexa* is present in Sample 188-1165B-24X-CC, 40–50 cm (199.15 mbsf), and may represent a period of extremely high nannofloral productivity (depressing the paleo-CCD and allowing carbonate deposition?) (see Wei and Wise, 1992b). Abundance increases of *C. pelagicus* relative to *R. perplexa* have also been used as an indicator of sea-surface temperature increase in the extreme southern high latitudes (Wei and Wise, 1992b; Beaufort and Aubry, 1992). At Site 1165, a few intervals of relative abundance increases in *C. pelagicus* are noted: Sample 188-1165B-58X-2, 34–35 cm, and, in particular, Sample 188-1165C-18R-4, 51–52 cm (831.12 mbsf). These intervals are generally characterized by overall nannofossil abundance increase as well, so it presently remains speculation as to whether any *C. pelagicus* increase in itself is a significant warm-water proxy at Site 1165.

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REFERENCES

Barker, P.F., Camerlenghi, A., Acton, G.D., et al., 1999. *Proc. ODP, Init. Repts.,* 178 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.

Beaufort, L., and Aubry, M.-P., 1992. Paleoceanographic implications of a 17-m.y.-long record of high-latitude Miocene calcareous nannoplankton fluctuations. *In* Wise, S.W., Jr., Schlich, R., et al., *Proc. ODP, Sci. Results,* 130: College Station, TX (Ocean Drilling Program), 539–549.

Bown, P.R. (Ed.), 1998. *Calcareous Nannofossil Biostratigraphy:* London (Chapman-Hall).

Findlay, C.S., 1998. Living and fossil calcareous nannoplankton from the Australian sector of the Southern Ocean: implications for paleoceanography [Dissert.]. Univ. of Tasmania, Hobart.

Haq, B.U., 1976. Coccoliths in cores from the Bellingshausen abyssal plain and Antarctic continental rise (DSDP Leg 35). *In* Hollister, C.D., Craddock, C., et al., *Init. Repts. DSDP,* 35: Washington (U.S. Govt. Printing Office), 557–567.

————, 1980. Biogeographic history of Miocene calcareous nannoplankton and paleoceanography of the Atlantic Ocean. *Micropaleontology,* 26:414–443.

Kennett, J.P., 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic Ocean, and their impact on global paleoceanography. *J. Geophys. Res.,* 82:3843–3860.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proc. 2nd Int. Conf. Planktonic Microfossils Roma:* Rome (Ed. Tecnosci.), 2:739–785.

O'Brien, P.E., Cooper, A.K., Richter, C., et al., 2001. *Proc. ODP, Init. Repts.*, 188 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.

Okada, H., and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Mar. Micropaleontol.,* 5:321–325.

Perch-Nielsen, K., 1985. Mesozoic calcareous nannofossils. *In* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 329–426.

Persico, D., Wise, S.W., Jr., and Jiang, S., 2003. Oligocene–Holocene calcareous nannofossil biostratigraphy and diagenetic etch patterns on Quaternary placoliths at ODP Site 1139 on Skiff Bank, Northern Kerguelen Plateau. *In* Frey, F.A., Coffin, M.F., Wallace, P.J., and Quilty, P.G. (Eds.), *Proc. ODP, Sci. Results,* 183, 1–19 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 7845-9547, USA.

Pospichal, J., Wei, W., and Wise, S.W., Jr., 1992. Probing the limits of nannofossil stratigraphic resolution in the Southern High Latitudes. *Mem. Sci. Geol.,* 43:115–131.

Quilty, P.G., 1985. Distribution of foraminiferids in sediments of Prydz Bay, Antarctica. *Spec. Publ. S. Aust. Dep. Mines Energy,* 5:329–340.

Wei, W., and Thierstein, H.R., 1991. Upper Cretaceous and Cenozoic calcareous nannofossils of the Kerguelen Plateau (southern Indian Ocean) and Prydz Bay (East Antarctica). *In* Barron, J., Larsen, B., et al., *Proc. ODP, Sci. Results,* 119: College Station, TX (Ocean Drilling Program), 467–494.

Wei, W., and Wise, S.W., Jr., 1990. Middle Eocene to Pleistocene calcareous nannofossils recovered by Ocean Drilling Program Leg 113 in the Weddell Sea. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results,* 113: College Station, TX (Ocean Drilling Program), 639–666.

————, 1992a. Oligocene–Pleistocene calcareous nannofossils from Southern Ocean Sites 747, 748, and 751. *In* Wise, S.W., Jr., Schlich, R., et al., *Proc. ODP, Sci. Results,* 120: College Station, TX (Ocean Drilling Program), 509–521.

———, 1992b. Selected Neogene calcareous nannofossil index taxa of the Southern Ocean: biochronology, biometrics, and paleoceanography. *In* Wise, S.W., Jr., Schlich, R., et al., *Proc. ODP, Sci. Results,* 120: College Station, TX (Ocean Drilling Program), 523–537.

Wise, S.W., Jr., 1983. Mesozoic and Cenozoic calcareous nannofossils recovered by Deep Sea Drilling Project Leg 71 in the Falkland Plateau region, Southwest Atlantic Ocean. *In* Ludwig, W.J., Krasheninnikov, V.A., et al., *Init. Repts. DSDP,* 71 (Pt. 2): Washington (U.S. Govt. Printing Office), 481–550.

APPENDIX

Taxonomic Notes

Calcareous nannofossils considered in this paper in alphabetical order of generic epithets.

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

Chiasmolithus Hay, Mohler, and Wade, 1966

Coccolithus Schwarz, 1894

Coccolithus miopelagicus Bukry, 1971

Coccolithus pelagicus (Wallich) Schiller, 1930

Coccolithus pelagicus floralis Wei and Wise (1992)

Coronocyclus nitescens (Kamptner) Bramlette and Wilcoxon, 1967

Cyclicargolithus abisectus (Müller) Wise, 1973
Remarks: Specimens noted here are of the smaller variety (9.5 µm), possibly considered large *Cyclicargolithus floridanus* by some workers. Although not used as a specific marker here, its presence generally is indicative of lower Miocene Zones CN1–CN3.

Cyclicargolithus floridanus (Roth and Hay in Hay et al.) Bukry, 1971

Cyclicargolithus sp. cf. *C. floridanus*

Discoaster Tan, 1927

Discoaster calculosus Bukry, 1971

Discoaster sp. cf. *D. calculosus*

Discoaster deflandrei Bramlette and Riedel, 1954

Discoaster sp. cf. *D. deflandrei*

Discoaster variabilis Martini and Bramlette, 1963

Discoaster sp. cf. *D. variabilis*

Emiliania huxleyi (Lohmann) Hay and Mohler in Hay et al., 1967

Gephyrocapsa aperta Kamptner, 1963

Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Remarks: This taxon is separated from *Gephyrocapsa oceanica* by having a more closed central area.

Gephyrocapsa ericsonii McIntyre and Bé, 1967

Gephyrocapsa oceanica Kamptner, 1943

Gephyrocapsa parallela Hay and Beaudry, 1973

Helicosphaera Kamptner, 1954

Helicosphaera carteri (Wallich) Kamptner, 1954

Helicosphaera sp. aff. *H. carteri*

Helicosphaera euphratis Haq, 1966

Helicosphaera sp. aff. *H. euphratis*

Helicosphaera paleocarteri Theodoridis, 1984

Helicosphaera sp. cf. *H. paleocarteri*

Minylitha convallis Bukry, 1973

Pontosphaera Lohmann, 1902

Pontosphaera multipora (Kamptner) Roth, 1970

Pontosphaera pectinata (Bramlette and Sullivan) Sherwood, 1974

Pontosphaera sp. cf. *P. pectinata*

Pseudoemiliania lacunosa (Kamptner) Gartner, 1969

Pseudoemiliania ovata (Bukry) Young, 1998
Remarks: Most specimens observed here are of the small (4.0–5.0 µm) variety.

Reticulofenestra Hay, Mohler, and Wade, 1966

Reticulofenestra ampliumbilicus Theodoridis, 1984

Reticulofenestra sp. cf. *R. ampliumbilicus*

Reticulofenestra asanoi Sato and Takayama, 1992

Reticulofenestra bisecta (Hay, Mohler, and Wade) Roth, 1970

Reticulofenestra daviesii (Haq) Haq, 1971

Reticulofenestra dictyoda (Deflandre and Fert) Stradner and Edwards, 1968

Reticulofenestra gelida (Geitzenauer) Backman, 1978
Remarks: Specimens with a more closed central area and >8.0 µm are assigned to this taxon.

Reticulofenestra hesslandii (Haq) Roth, 1970
Remarks: Specimens assigned to this taxon are subcircular to subelliptical and display a similar birefringence pattern to *C. floridanus*.

Reticulofenestra haqii Backman, 1978
Remarks: Specimens assigned to this taxon have a more closed central area than the *Reticulofenestra pseudoumbilicus* morphotypes and are <8.0 µm.

Reticulofenestra minuta Roth, 1970
Remarks: Specimens <3.0 µm with an open central area and narrow distal shield are assigned to this taxon.

Reticulofenestra minutula (Gartner) Haq and Berggren, 1978
Remarks: Specimens assigned to this taxon are <8.0 µm and have an open central area (small *Reticulofenestra pseudoumbilicus*)

Reticulofenestra perplexa (Burns) Wise, 1983 (*Dictyococcites antarcticus*)
Remarks: Specimens assigned to this taxon are >4.5 µm. The first occurrence of this species is problematic. Wei and Wise (1990) give it an age of 14 Ma; however, various morphotypes are found in older sediments at this site. Likely there is a gradation between the Oligocene taxon, *R. bisecta* morphology and *R. perplexa,* with the larger *Reticulofenestra scrippsae* (6–12 µm) perhaps being an intermediate form. Few specimens of *R. perplexa* in the 6- to 8-µm size range were noted.

Reticulofenestra producta (Kamptner) n. comb. NannoWare
Remarks: Specimens assigned to this taxon are <4.5 µm.

Reticulofenestra sp. cf. *R. perplexa*
Remarks: Specimens assigned here are have smaller central area than *R. perplexa* and could be *R. haqii* with central hole overgrown.

Reticulofenestra pseudoumbilicus (Gartner) Gartner, 1969
Remarks: Specimens included here are >8.0 µm and have an open central area.

Reticulofenestra sp. cf. *R. pseudoumbilicus*

Reticulofenestra rotaria Theodoridis, 1984

Reticulofenestra samodurovii (Hay, Mohler, and Wade) Roth, 1970

Reticulofenestra scrippsae (Bukry and Percival) Roth, 1973

Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968

Sphenolithus Deflandre in Grassé, 1952

Sphenolithus abies Deflandre in Deflandre and Fert, 1954

Sphenolithus dissimilis Bukry and Percival, 1971

Sphenolithus sp. cf. *S. dissimilis*

Sphenolithus grandis Haq and Berggren, 1978

Sphenolithus sp. cf. *S. grandis*

Syracosphaera Lohmann, 1902

Triquetrorhabdulus carinatus Martini, 1965

Umbilicosphaera Lohmann, 1902

Umbilicosphaera cricota (Gartner) Cohen and Reinhardt, 1968

Umbilicosphaera jafari Müller, 1974

Umbilicosphaera sibogae foliosa (Kamptner) Okada and McIntyre, 1977

Figure F1. Locations of ODP Leg 188 Sites 1165, 1166, and 1167.

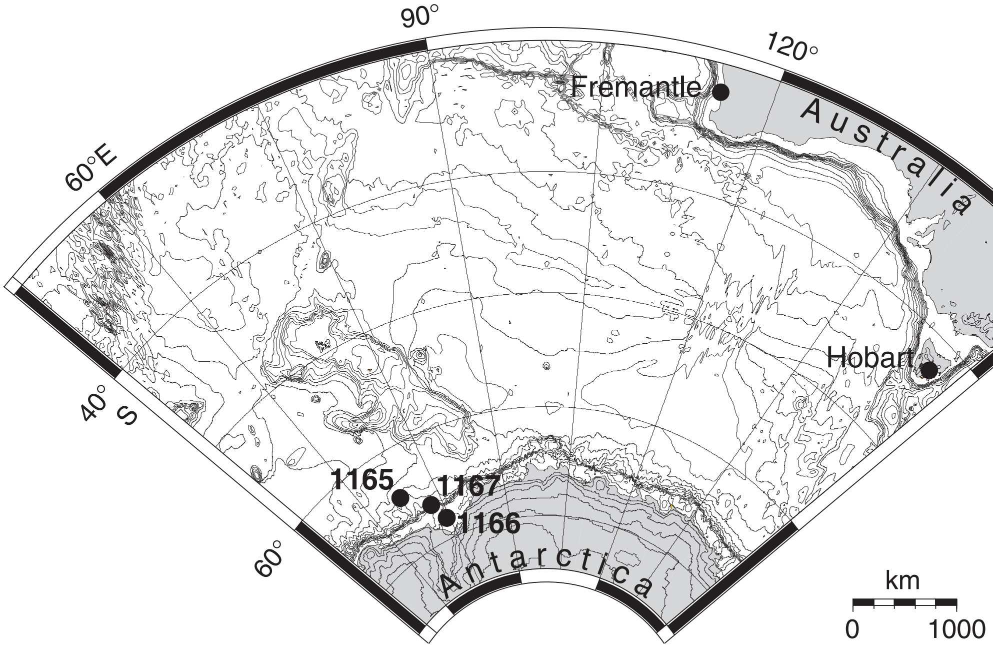

Table T1. Biostratigraphy and distribution of Quaternary and Miocene calcareous nannofossils at Site 1165. (This table is available in an **oversized format.**)