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7. Data Report: Calcareous Nannofossil Stratigraphy at Sites 1088 and 1090 (ODP Leg 177, Southern Ocean)[1]

Maria Marino[2] and José Abel Flores[3]

INTRODUCTION

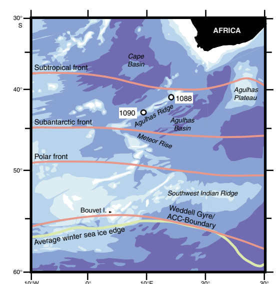
During ODP Leg 177, a Miocene to Pliocene calcareous nannofossil record was recovered at Sites 1088 and 1090 (Fig. F1). Site 1088, located at 41°8′S, shows a continuous middle–upper Miocene to Pliocene carbonate sequence that was deposited at relatively high sedimentation rates (Shipboard Scientific Party, 1999a). Moreover, Site 1088 proved suitable for calcareous nannofossil analysis as a means to improve the biostratigraphy at this southern latitude.

Site 1090 was drilled at 42°54′S; a tephra layer marks a significant disconformity at the Miocene/Pliocene boundary of this sequence (Shipboard Scientific Party, 1999b). Although nannofossil assemblages are poorly preserved at this site (Shipboard Scientific Party, 1999b), they may help in determining the age of the disconformity and its paleoceanographic significance.

MATERIAL AND METHODS

One to two samples per section were analyzed for Site 1090, Cores 177-1090B-5H through 15H. A total of 124 samples were taken from Cores 177-1088B-3H through 13H and from Cores 177-1088C-2H through 13X-CC; up to two samples per section were examined in the vicinity of biozonal events. Smear slides were prepared from unprocessed sediment and were examined with a light microscope (Zeiss Ax-

F1. Location map of Sites 1088 and 1090, p. 11.



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[2]Dipartimento di Geologia e Geofisica, via E. Orabona, 4, 70125 Bari, Italy. marino@geo.uniba.it
[3]Departamento de Geologia, Facultad de Ciencias, 37088 Salamanca, Spain.

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ioskop) at 1000× magnification; 1600× magnification was also used for the identification of very small specimens (< 3 µm). About 2.64 mm^2 of smear slides (150 fields of view at 1000× magnification) were examined to estimate semiquantitative abundance of nannofossils. Two additional traverses of slides were scanned to establish with confidence the presence/absence of very rare species ("x" in the tables). Six calcareous nannofossil abundance levels were recorded for each taxon; they are as follows:

VA = very abundant (>50 specimens per field of view).
A = abundant (11–50 specimens per field of view).
C = common (1–10 specimens per field of view).
F = few (0.1 to <1 specimens per field of view).
R = rare (0.02 to <0.1 specimens per field of view).
RR = very rare (<0.02 specimens per field of view).

Preservation of nannofossils was recorded as good (G), moderate (M), poor (P), and very poor (VP).

Quantitative abundances were established only for nannofossil assemblages from Site 1088. Poor preservation, impoverished assemblages, and the presence of hiatuses as well as rarity of marker species prevented quantitative analyses at Site 1090. Following Driever (1988) and Young (1990, 1998), the "reticulofenestrid complex," including both specimens with open and closed central area, was size defined as follows: *Reticulofenestra* >7 µm (*Reticulonfenestra pseudoumbilicus*), *Reticulofenestra* 5–7 µm (small *R. pseudoumbilicus*), *Reticulofenestra* 3–5 µm (*Reticulofenestra minutula*), and *Reticulofenestra* <3 µm (*R. minuta*). The small *Gephyrocapsa* abundance was quantitatively evaluated in a few samples taken near the lower/middle Pliocene boundary in order to detect the small *Gephyrocapsa* acme that occurs in this interval. For this purpose, the small *Gephyrocapsa* specimens were counted within a total of 50 small coccoliths (<5 µm) present in the most central part of several fields of view of different areas of the slide. The abundances of *Discoaster* spp. were determined in the Miocene and Pliocene intervals of Site 1088 by counting the number of specimens of the species within 150 fields of view. Other genera (helicoliths, sphenoliths, ceratolithids, and *Triquetrorhabdulus* spp.) were represented by rare and sporadic specimens or were even absent; this prevented us from using quantitative analyses for precise zonal attribution at both sites.

BIOSTRATIGRAPHY

The standard zonation of Martini (1971) was primarily applied in this study. Additional biostratigraphic events were used to improve biozonal assignment for intervals where standard marker species were very rare or absent. In this we have followed Theodoridis (1984), Olafsson (1989), Fornaciari et al. (1990), Rio et al. (1990a, 1990b), Bukry (1991), Gartner (1992), Fornaciari et al. (1993, 1996), Raffi and Flores (1995), Raffi et al. (1995), Di Stefano et al. (1996), Fornaciari and Rio (1996), de Kaenel and Villa (1996), and Maiorano and Monechi (1998). A summary of Neogene nannofossil events is also reported in Young (1998), to whom the reader is referred for the distribution of species and for both primary and additional bioevents considered in this chapter.

RESULTS

Semiquantitative and quantitative analyses performed on nannofossil assemblages are shown in Tables T1 and T2. A synthesis of the biostratigraphic results, focusing mainly on biozonal assignment, is discussed below. More detailed biostratigraphic comments are discussed in Marino and Flores (in press), to whom the reader may refer.

T1. Distribution of calcareous nannofossils, Site 1088, p. 12.

T2. Distribution of calcareous nannofossils, Site 1090, p. 13.

Site 1088

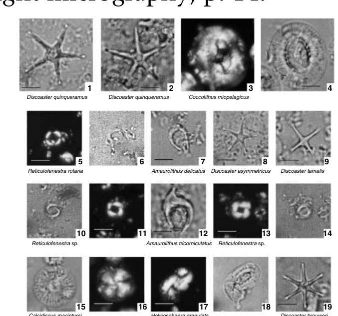
The interval between the bottom of Hole 1088C (Sample 177-1088C-13X-CC [17–22 cm]) up to the level of Sample 11X-CC (72–77 cm) yields a middle Miocene assemblage with *Coccolithus miopelagicus, Cyclicargolithus floridanus,* and *Calcidiscus premacintyrei* (Table T1). It is assigned to Zone NN6 based on the absence of *Sphenolithus heteromorphus* and *Discoaster kugleri.* The presence of *Reticulofenestra* spp. (5–7 and >7 μm) characterizes this interval.

D. kugleri was not detected at Site 1088. The base of Zone NN7 was approximated by the first occurrence of *Calcidiscus macintyrei* between Samples 177-1088C-11X-CC (72–77 cm) and 11X-4, 20–21 cm. The base of Zone NN8 was not recognized on the basis of the biozonal marker *Catinaster coalitus.* However, the NN7/NN8 zonal boundary may be approximated by the last occurrence (LO) of *C. miopelagicus* (Raffi and Flores, 1995). On this basis, we tentatively locate the NN7/NN8 zonal boundary between Samples 177-1088C-7X-CC (16–21 cm) and 7X-4, 140 cm.

The base of Zone NN9 was recognized on the basis of the first occurrence (FO) of *Discoaster hamatus* between Samples 177-1088C-4H-1, 140 cm, and 4H-1, 70 cm, at 142.49 meters composite depth (mcd). The LO of *D. hamatus* defines the base of Zone NN10 between Samples 177-1088B-13H-3, 70 cm, and 13H-1, 70 cm, at 112.2 mcd (Table T1).

The FO of *Discoaster quinqueramus* defines the NN10/NN11 boundary between Samples 177-1088B-11H-5, 70 cm, and 11H-4, 130 cm. The base of Subzone NN11b is defined based on the FO of *Amaurolithus primus.* Although this event is not reliable at Site 1088 because of the rarity and discontinuous presence of all *Amaurolithus* spp. (Table T1), it is tentatively placed at 71.285 mcd, between Samples 177-1088B-8H-CC (10–15 cm) and 177-1088B-8H-6, 130 cm. Very rare specimens of *Reticulofenestra rotaria* (Pl. P1, figs. 5, 6) are present through the inferred Subzones NN11a/NN11b boundary (Table T1). The species, which has a short stratigraphic range restricted to Subzone NN11b in the Mediterranean area (Theodoridis, 1984) and in the eastern equatorial Pacific Ocean (Raffi and Flores, 1995), is recorded for the first time in this sector of the Atlantic Ocean, where it shows an older distribution. The slight discrepancy in the distribution of *R. rotaria* at different latitudes may be due to the low reliability of the FO of *A. primus* at Site 1088 or to the possible diachronous character of the occurrence of *R. rotaria.* A temporary disappearance (paracme) of *Reticulofenestra* >7 μm in size is also recorded at the same stratigraphic level.

P1. Calcareous nannofossils under light micrography, p. 14.



The LO of *D. quinqueramus* defines the base of Zone NN12 between Samples 177-1088B-6H-7, 12 cm, and 6H-5, 70 cm, and this event was used to approximate the Miocene/Pliocene boundary at 51.41 mcd. The interval between the LO of *D. quinqueramus* and the LO of *R. pseudoumbilicus* at 33.65 mcd was referred to the combined Zones NN12–NN15 because the FO of *Ceratolithus rugosus* and the common first occurrence of *Discoaster asymmetricus* were not recognized to delineate Zone NN13 and Zones NN14–NN15, respectively. However, the continuous occurrence of rare specimens of *D. asymmetricus* (Pl. **P1,** fig. 8) could tentatively be used to place the base of Zones NN14–NN15 between Samples 177-1088B-5H-5, 68 cm, and 5H-4, 140 cm, at 40.29 mcd. It is worth noting a paracme of *Reticulofenestra* >7 µm at the base of the Pliocene interval, in agreement with data of Rio et al. (1990b) and Di Stefano et al. (1996). This paracme is present nearly contemporaneous with the presence of circular reticulofenestrids 4–5 µm in size, characterized by a narrow shield, wide collar, and open central area (Pl. **P1,** figs. 10, 11, 13, 14).

Zone NN16, comprised from the LO of *R. pseudoumbilicus* to the LO of *Discoaster surculus,* was recognized between Samples 177-1088B-4H-6, 140 cm, and 3H-6, 105–106 cm (Table **T1**). An acme of small *Gephyrocapsa* occurs across the NN14–NN15/NN16 zonal boundary, according to stratigraphic data of Driever (1988) and Marino (1994). The LO of *D. pentaradiatus* and the LO of *Discoaster brouweri* allowed the recognition of the base of Zones NN18 and NN19 between Samples 177-1088B-3H-6, 30 cm, and 3H-5, 140 cm, at 22.6 mcd and between Samples 177-1088B-3H-4, 140 cm, and 3H-4, 105–106 cm, at 20.725 mcd, respectively.

Site 1090

The lower part of the studied interval at Site 1090 is characterized by the presence of *Cyclicargolithus abisectus* (>10 µm, following Fornaciari et al., 1990), which disappears between Samples 177-1090B-15H-4, 30 cm, and 15H-3, 130 cm, at 138.75 mcd (Table **T2**). The event occurs close to or just above the Oligocene/Miocene boundary (Fornaciari et al., 1990) and defines the base of Subzone CN1b of Okada and Bukry (1980). However, we were not able to define this zonal boundary at Site 1090 because the authors did not specify any morphometric criteria about *C. abisectus,* whereas we referred to *C. abisectus* specimens only >10 µm.

The interval from the base of the hole to Sample 177-1090B-10H-1, 140 cm (82.74 mcd), is referred to as combined Zones NN1–NN3, interpreted as an interval above the last occurrence of *Reticulofenestra bisecta* at 145.35 mcd (M. Marino and J.A. Flores, unpubl. data) and below the first occurrence of *S. heteromorphus* (Table **T2**). The presence of *Triquetrorhabdulus carinatus* from the bottom of the studied hole up to Sample 177-1090B-15H-1, 30 cm, and of *Sphenolithus belemnos* from Samples 177-1090B-10H-3, 140 cm, to 10H-1, 140 cm, could indicate a possible identification of Zones NN2 and NN3, respectively (see discussion in Marino and Flores, in press).

The interval between Samples 177-1090B-9H-CC (13–18 cm) and 8H-5, 30 cm (from 84.92 to 71 mcd), is difficult to interpret because of the absence of marker species and possible reworking phenomena. The lower part of this interval, between 84.92 and 76.06 mcd, is probably referable to the upper middle Miocene because of the absence of *S. heteromorphus* and *C. macintyrei* and the consistent presence of *Reticulofenestra* >7 µm. The upper part of the interval, between 76.06 and 71 mcd, is characterized by the absence of *Reticulofenestra* >7 µm (late Miocene paracme of the species?) and by the possible presence of *Minylitha convallis* (just one poorly preserved specimen in one sample!). All this may indicate a late Miocene age (Subzones NN10b–NN11a), in agreement with data reported in Young (1998). According to this interpretation, the presence of *C. floridanus* and *Discoaster deflandrei* (Table **T2**) has to be considered as reworked because their last common occurrences are known to fall within Zones NN6 and NN4, respectively. A second possible age model could be inferred for the interval between 84.92 and 71 mcd, which may be interpreted as early Miocene in age, and so older than the FO of *S. heteromorphus*. In this case, *D. deflandrei* and *C. floridanus* represent autochthonous occurrences and the nannofossil assemblages are lacking in other lower Miocene marker species because of poor preservation (see discussion in Marino and Flores, in press).

A significant and abrupt variation in nannofossil assemblage occurs above 71 mcd. The assemblages are characterized by the absence of *C. floridanus* and *D. deflandrei* and by the abundance or dominance of small reticulofenestrids <5 µm (*R. minuta, R. minutula,* and *Dictyococcites* spp.) (Table **T2**). The interval from 71 to 52.85 mcd is tentatively referred to the combined Pliocene Zones NN12–NN17. In particular, the basal part, from 71 to 68.96 mcd, is characterized by the lower Pliocene paracme of *Reticulofenestra* >7 µm (Rio et al., 1990b; Di Stefano et al., 1996). The LO of *R. pseudoumbilicus* is recorded between Samples 177-1090B-8H-2, 140 cm, and 8H-2, 30 cm, at the same level as the FO of *Pseudoemiliania lacunosa*. The co-occurrence of the two events is not in agreement with data from Site 1088 or with biochronology proposed by Shackleton et al. (1995) and Gartner (1990), and it may indicate the presence of a disconformity around 67.26 mcd (Marino and Flores, in press). It is worth noting the presence of common specimens of small *Gephyrocapsa* between Samples 177-1090B-8H-4, 30 cm, and 8H-1, 120 cm, from 66.11 to 68.21 mcd. This abundance of small gephyrocapsids may be correlated to the acme occurring at the lower/middle Pliocene boundary, both at Site 1088 and in the Mediterranean area (Driever, 1988; Marino, 1994).

The LO of *D. pentaradiatus* is present at 52.85 mcd, between Samples 177-1090B-6H-7, 30 cm, and 6H-6, 130 cm, and defines the base of Zone NN18. The base of Zone NN19 is recognized on the basis of the LO of *D. brouweri* between Samples 177-1090B-6H-2, 130 cm, and 6H-1, 130 cm, at 45.85 mcd.

SUMMARY

Distribution of calcareous nannofossils at Sites 1088 and 1090 has been obtained based on semiquantitative and quantitative analyses. Preservation and species diversity at Site 1088 allowed the recognition, mainly based on standard events, of biozones from Miocene NN6 to Pliocene NN19. At this site, two paracmes of *Reticulofenestra* >7 µm in size were recorded in the upper Miocene and lowermost Pliocene intervals, and an acme of small *Gephyrocapsa* was detected at the lower/middle Pliocene boundary.

Miocene to Pliocene nannofossil assemblages are poorly preserved and show low diversity at Site 1090, hampering accurate biozonal subdivision. The Pliocene interval was referred to combined Zones NN12–NN17 and to Zones from NN17 to NN19. The Miocene sediments, ~10 m thick, just below the Miocene/Pliocene disconformity present at 71 mcd (Shipboard Scientific Party, 1999b) are difficult to interpret for age assignment because of the absence of marker species and possible reworking. The lower sequence down to the bottom of the hole was referred to lower Miocene Zones NN1–NN3.

ACKNOWLEDGMENTS

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APPENDIX

Taxonomic List

Calcareous nannofossils are listed by alphabetical order of generic epithet. Bibliographic references for most of taxa can be found in Perch-Nielsen (1985). Any references not cited therein are included in the bibliography. Biometric definitions of problematic species adopted in this study are also reported.

Amaurolithus amplificus (Bukry and Percival, 1971)
Amaurolithus delicatus Gartner and Bukry, 1975
Amaurolithus primus (Bukry and Percival, 1971)
Ceratolithus tricorniculatus (Gartner, 1967)
Calcidiscus leptoporus (Murray and Blackman, 1989)
Calcidiscus radiatus (Kamptner, 1954)
Calcidiscus tropicus Kamptner, 1956
Calcidiscus macintyrei (Bukry and Bramlette 1969) (≥11 µm)
Calcidiscus premacintyrei Theodoridis, 1984
Catinaster coalitus Martini and Bramlette, 1963
Ceratolithus acutus Gartner and Bukry, 1974
Coccolithus miopelagicus Bukry, 1971 (>13 µm)
Coccolithus pelagicus (Wallich, 1877) (<13 µm)
Cryptococcolithus mediaperforatus (Varol, 1991)
Cyclicargolithus abisectus (Müller, 1970) (>10 µm)
Cyclicargolithus floridanus (Roth and Hay in Hay et al., 1967) (<10 µm)
Dictyococcites productus (Kamptner, 1963)
Discoaster asymmetricus Gartner, 1969
Discoaster bellus Bukry and Percival, 1971
Discoaster brouweri (Tan, 1927)
Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster druggii Bramlette and Wilcoxon, 1967 (>15 µm)
Discoaster hamatus Martini and Bramlette, 1963
Discoaster kugleri Martini and Bramlette, 1963
Discoaster intercalaris (Bukry, 1971)
Discoaster loeblichii Bramlette and Riedel, 1954
Discoaster neohamatus Bukry and Bramlette, 1969
Discoaster neoerectus Bukry, 1971
Discoaster pansus (Bukry and Percival, 1971)
Discoaster pentaradiatus (Tan, 1927)
Discoaster prepentaradiatus Bukry and Percival, 1971
Discoaster quinqueramus Gartner, 1969
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Discoaster variabilis Martini and Bramlette, 1963
Gephyrocapsa medium (4–5.5 µm) sensu Rio, 1982
Gephyrocapsa small (<3.5 µm) sensu Gartner, 1969
Hayaster perplexus (Bramlette and Riedel, 1954)
Hayella aperta Theodoridis, 1984
Helicosphaera carteri (Wallich, 1899)
Helicosphaera granulata Bukry and Percival, 1971
Helicosphaera sellii Bukry and Bramlette, 1969
Minylitha convallis Bukry, 1973
Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969 (>4 µm)
Reticulofenestra bisecta (Hay, Mohler, and Wade, 1967)
Reticulofenestra minuta Roth, 1970 (<3 µm)
Reticulofenestra minutula (Gartner, 1967) (3–5 µm)
Reticulofenestra pseudoumbilicus (Gartner, 1967) (>7 µm)
Reticulofenestra pseudoumbilicus small (5–7 µm)
Reticulofenestra rotaria Theodoridis, 1984

Scapholithus fossilis Deflandre in Deflandre and Fert, 1954
Sphenolithus abies Deflandre in Deflandre and Fert, 1954
Sphenolithus abies/neoabies (sensu Rio et al., 1990)
Sphenolithus belemnos Bramlette and Wilcoxon, 1967
Sphenolithus cometa de Kaenel and Villa, 1996
Sphenolithus conicus Bukry, 1971
Sphenolithus disbelemnos Fornaciari and Rio, 1996
Sphenolithus dissimilis Bukry and Percival, 1971
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Brönnimann and Stradner, 1960)
Sphenolithus neoabies Bukry and Bramlette, 1969
Sphenolithus tintinnabulum Maiorano and Monechi, 1997
Tetralithoides simeonidesii Theodoridis, 1984
Triquetrorhabdulus carinatus Martini, 1965
Triquetrorhabdulus rugosus Bramlette and Wilcoxon, 1967

Figure F1. Location map of Sites 1088 and 1090 (modified from Shipboard Scientific Party, 1999).

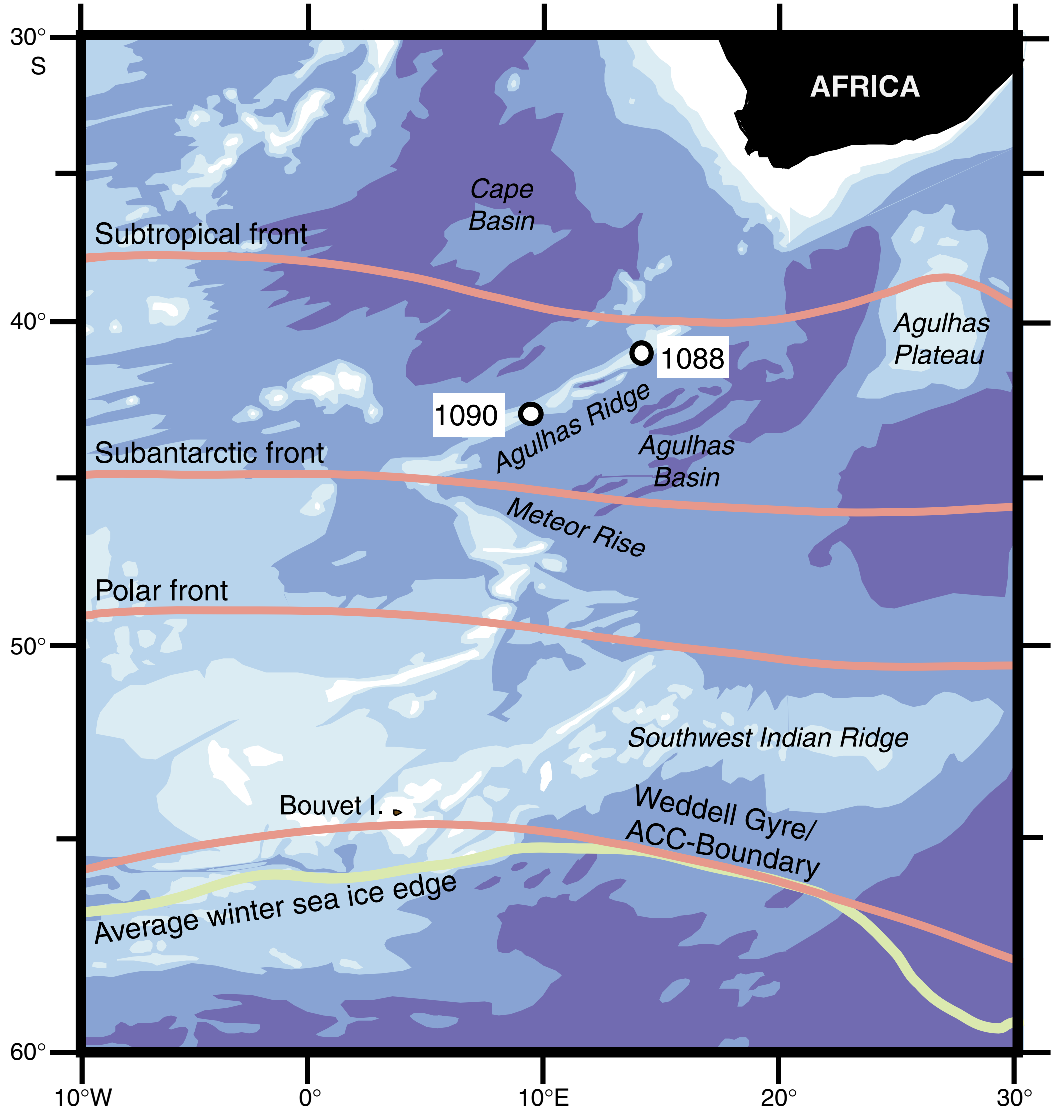

Table T1. Distribution of Miocene to Pliocene calcareous nannofossils at Site 1088. (This table is available in an **oversized format** and **ASCII format**.)

Table T2. Miocene to Pliocene distribution of calcareous nannofossils at Site 1090. See **"Material and Methods,"** p. 1, for explanation of the abundance symbols. (This table is available in an **oversized format** and **ASCII format**.)

Plate P1. Light micrography: XP = cross-polarized light, PL = plain transmitted light. Scale bar = 5 µm. **1.** *Discoaster quinqueramus* (Sample 177-1088B-8H-1, 140 cm); PL. **2.** *Discoaster quinqueramus* (Sample 177-1088B-8H-1, 70 cm); PL. **3, 4.** *Coccolithus miopelagicus* (Sample 177-1088C-9H-2, 140 cm); (3) XP and (4) PL. **5, 6.** *Reticulofenestra rotaria* (Sample 177-1088B-8H-5, 140 cm); (5) XP and (6) PL. **7.** *Amaurolithus delicatus* (Sample 177-1088B-9H-1, 140 cm); PL. **8.** *Discoaster asymmetricus* (Sample 177-1088B-5H-4, 140 cm); PL. **9.** *Discoaster tamalis* (Sample 177-1090B-8H-1, 30 cm); PL. **10, 11.** *Reticulofenestra* sp. (Sample 177-1088B-6H-7, 12 cm); (1) PL and (11) XP. **12.** *Amaurolithus tricorniculatus* (Sample 177-1088B-8H-1, 70 cm); PL. **13, 14.** *Reticulofenestra* sp. (Sample 177-1088B-6H-5, 70 cm); (13) XP and (14) PL. **15, 16.** *Calcidiscus macintyrei* (Sample 177-1088C-11X-3, 70 cm); (15) PL and (16) XP. **17, 18.** *Helicosphaera granulata* (Sample 177-1088C-13X-7, 20 cm); (17) XP and (18) PL. **19.** *Discoaster brouweri* (Sample 177-1090B-8H-1, 30 cm); PL.