

# 15. CALCAREOUS NANNOFOSSILS FROM CORES RECOVERED DURING LEG 18, DEEP SEA DRILLING PROJECT: BIOSTRATIGRAPHY AND OBSERVATIONS OF DIAGENESIS

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## ABSTRACT

Calcareous nannofossils were recovered at all sites drilled during DSDP Leg 18 on a traverse from Hawaii to California to Alaska. Middle- and high-latitude coccolith assemblages are characterized by sharp reductions in species diversity due to ecological restrictions imposed by cool surface water temperatures. At Site 173 (northern California), combination range zones based on silicoflagellate and calcareous nannofossil datum levels are used to subdivide portions of the section where key latitude coccolith index species are absent. New species described from middle high latitude assemblages are *Discoaster mendomobensis*, *Coccolithus pliopelagicus*, and *Cyclicargolithus bukryi*. Early diagenesis resulting in in situ dissolution and reprecipitation of skeletal calcite is responsible for heavy secondary calcite overgrowths on discoasters and some placoliths at Site 172. A similar phenomenon promoted early cementation of a lower Miocene coccolith ooze at Site 178. This resulted in formation of a chalk unit sufficiently well lithified to withstand compactive deformation during the subsequent loading of many hundreds of meters of Neogene clastic sediments.

## INTRODUCTION AND SITE SUMMARIES

Leg 18 (northeast Pacific) of the Deep Sea Drilling Project, recovered 273 cores containing 1215 meters of sediment taken at 11 sites along a traverse from Hawaii to Alaska (Figure 1). Calcareous nannoplankton were recovered at all sites as indicated by a light microscope examination of approximately 920 core samples. Selected samples were also examined by scanning electron microscopy.

At Site 172, drilled between Hawaii and California, coring penetrated lower Oligocene calcareous nannofossil ooze near the base of a 22-meter unfossiliferous brown clay sequence. Closer to the North American continent, calcareous nannofossils are sparse to common in a 320-meter continuously cored Neogene section recovered near the coast of California (Site 173) and in Plio-Pleistocene sections drilled on the continental margin off Oregon and British Columbia (Sites 174 to 177). The calcareous nannofossil zonation adopted for Site 173 serves as the biostratigraphic framework for the more northerly sites. In a 778-meter Neogene deep-water section cored on the Alaskan Abyssal Plain at Site 178, coccoliths are rare or absent except in a 10-meter lower(?) Miocene chalk unit composed of a low-diversity cold-water nannofossil assemblage recovered near the bottom of the section. In the Gulf of Alaska, a small number of calcareous nannofossil species occur sporadically in Pleistocene sections cored north of, south of, and within the Aleutian Trench as well as along the Alaskan continental margin (Sites 179-182). Detailed discussions of the biostratigraphy, systematic paleontology, paleoecology, and diagenesis of the material

recovered are presented in the following sections of this report. Calcareous nannofossil taxa considered are listed in Table 1.

## METHODS AND PROCEDURES

Procedures used in the electron microscope studies are given by Wise and Kelts (1972). The abundance of coccolith species examined by light microscopy was tabulated using the method proposed by Hay (1970) and is presented as part of the accompanying range charts. Tabulations were made using standard smear slide preparations examined at a magnification of 1,000 X. Numbers used on the range charts to denote coccolith abundances represent the log (base ten) of the number of specimens of a particular taxon likely to be observed in any one field of view of the microscope. These numbers are determined as follows:

+1 very abundant (more than ten specimens per field of view at 1,000 X);

0 abundant (one to ten specimens per field of view at 1,000 X);

-1 common (one specimen per 2 to 10 fields of view at 1,000 X);

-2 few (one specimen per 11 to 100 fields of view at 1,000 X);

-3 rare (one specimen per 101 to 1000 fields of view at 1,000 X).

Core barrels used aboard *Glomar Challenger* are 9.1 meters long and are equipped with a detachable retaining device, the core catcher. Material from this portion of the core is labeled "CC". At some sites, an additional section, extended barrel, was joined to the core assembly below the

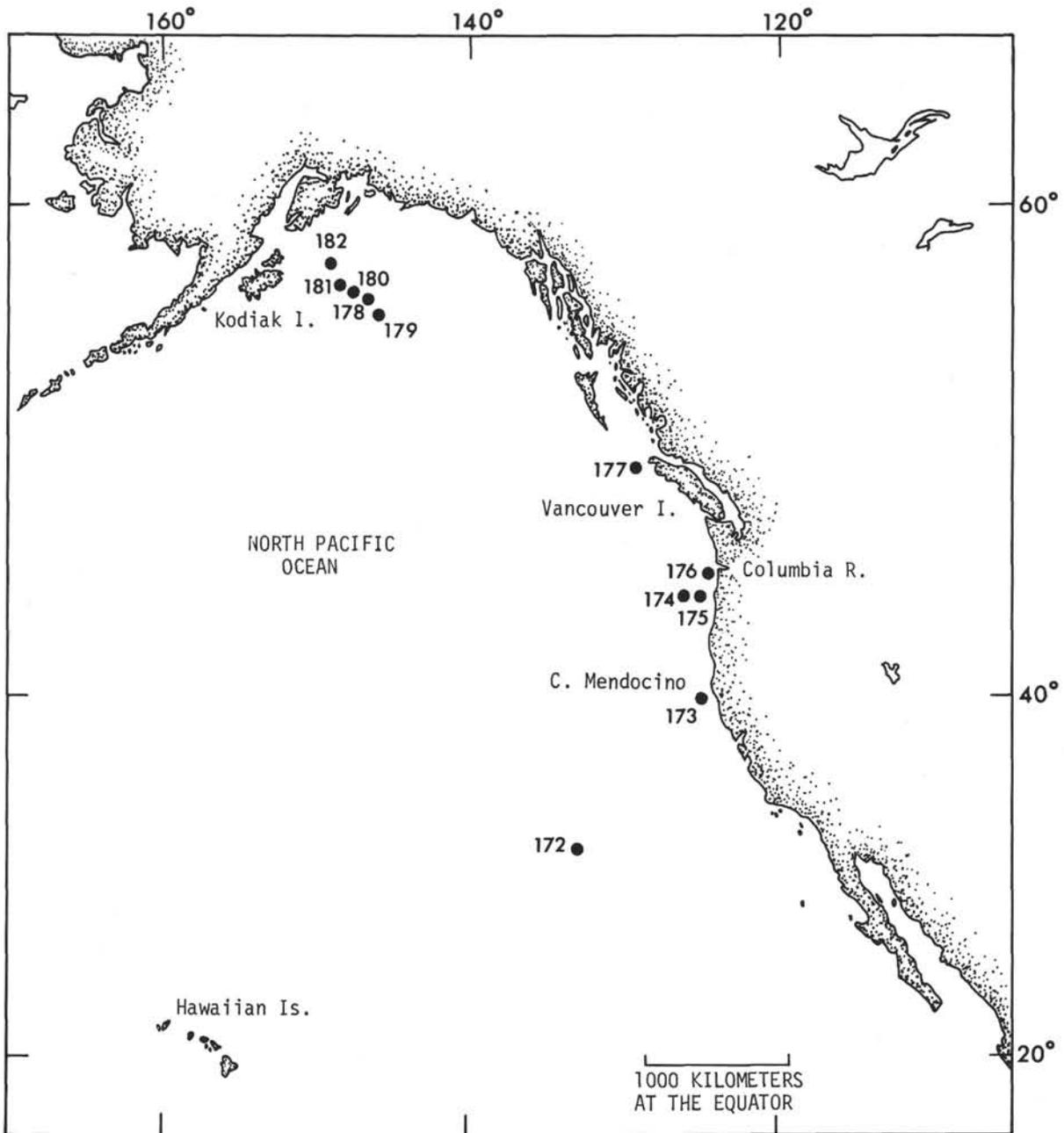


Figure 1. Site locations for DSDP Leg 18, Honolulu to Kodiak.

core catcher. Samples from this section are labeled "EB". Following a core run, the approximately 9 meters of core liner above the core catcher are cut aboard ship into six 1.5-meter sections which are numbered from the top of the core. Material sampled within one of these sections is measured in centimeters from the top of the section.

Complete sample designations are given in the following sequence: (Cruise-leg number) – (drill hole designation, consisting of site number plus letter suffix if more than one hole is drilled at the site) – (core number) – (core section number), centimeter interval below top of section sampled. For example, 18-174A-5-3(128 cm), indicates that the sample came from Leg 18, Hole 174A (the second hole drilled at Site 174), the fifth core taken, the third section from the top of that core, and 128 centimeters from the

top of section three. In most cases, core barrels recovered were not completely full of sediment. Core recoveries were then arbitrarily placed at the top of the interval drilled as determined from the driller's log. Core catcher and extended barrel samples are arbitrarily placed at the bottom of such intervals. Approximate depths in meters below the sea floor for any sample can be determined by consulting the lithologic logs given with the site reports of this volume.

#### SITE 172

(31°32.23'N, 133°22.36'W; water depth 4768 m)

Site 172, between Hawaii and California, was drilled in a region of hilly topography within crustal blocks bounded by the Murray fracture zone to the north and the Molokai fracture zone to the south. Biostratigraphic information

TABLE 1  
Calcareous Nannofossil Species Considered in This Report  
(listed in alphabetical order of the species epithets)

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*Cyclicargolithus abisectus* (Müller) Wise, n. comb.  
*Discoaster adamantus* Bramlette and Wilcoxon, 1967  
*Helicopontosphaera ampliaptera* (Bramlette and Wilcoxon) Hay, 1970  
*Emiliania annula* (Cohen) Bukry, 1972  
*Discoaster asymmetricus* Gartner, 1969  
*Watznauria barnesae* (Black) Perch-Nielsen, 1968  
*Sphenolithus belemnus* Bramlette and Wilcoxon, 1967  
*Braarudosphaera bigelowii* (Gran and Braarud) Deflandre, 1947  
*Reticulofenestra bisecta* (Hay, Mohler, and Wade) Roth, 1970  
*Discoaster braarudii* Bukry, 1971  
*Discoaster brouweri* Tan Sin Hok, 1927  
*Cyclicargolithus bukryi* Wise, n. sp.  
*Helicopontosphaera burkei* (Black) Wise, n. comb.  
*Catinaster calyculus* Martini and Bramlette, 1963  
*Triquetrorhabdulus carinatus* Martini, 1965  
*Discoaster challengerii* Bramlette and Riedel, 1954  
*Sphenolithus ciperoensis* Bramlette and Wilcoxon, 1967  
*Catinaster coalitus* Martini and Bramlette, 1963  
*Ceratolithus cristatus* Kamptner, 1950  
*Discoaster deflandrei* Bramlette and Riedel, 1954  
*Cyclicargolithus doronicoides* (Black and Barnes) Wise, n. comb.  
*Coccolithus eopelagicus* (Bramlette and Riedel) Bramlette and Sullivan, 1961  
*Discoaster exilis* Martini and Bramlette, 1963  
*Cyclicargolithus floridanus* (Roth and Hay) Bukry, 1971  
*Coccolithus formosus* (Kamptner) Wise, n. comb.  
*Discoaster hamatus* Martini and Bramlette, 1963  
*Thoracosphaera hemi* (Lohmann) Kamptner, 1954  
*Sphenolithus heteromorphus* Deflandre, 1953  
*Emiliania huxleyi* (Lohmann) Hay and Mohler in Hay et al, 1967  
*Discoaster intercalcaris* Bukry, 1971  
*Helicopontosphaera kamptneri* Hay and Mohler in Hay et al, 1967  
*Discoaster kugleri* Martini and Bramlette, 1963  
*Cyclcoccolithina leptopora* (Murray and Blackmann) Wilcoxon, 1970  
*Cyclcoccolithina macintyreii* (Bukry and Bramlette) Wilcoxon, 1970  
*Discoaster mendomobensis* Wise, n. sp.  
*Coccolithus miopelagicus* Bukry, 1971, emend.  
*Sphenolithus moriformis* (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967  
*Pontosphaera multipora* (Kamptner) Roth, 1970  
*Sphenolithus neoabies* Bukry and Bramlette, 1969  
*Discoaster neohamatus* Bukry and Bramlette, 1969  
*Coccolithus pelagicus* (Wallich) Schiller, 1930  
*Lithostromation perdurum* Deflandre, 1942  
*Discoaster perplexus* Bramlette and Riedel, 1954  
*Braarudosphaera perversus* Sullivan, 1965  
*Coccolithus pliopelagicus* Wise, n. sp.  
*Sphenolithus predistentus* Bramlette and Wilcoxon, 1967  
*Sphenolithus pseudoradians* Bramlette and Wilcoxon, 1967  
*Reticulofenestra pseudoumbilica* (Gartner) Gartner, 1969  
*Discoaster quinqueramus* Gartner, 1969  
*Ceratolithus rugosus* Bukry and Bramlette, 1968  
*Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, 1967  
*Thoracosphaera saxea* Stradner, 1961  
*Helicopontosphaera sellii* Bukry and Bramlette, 1969  
*Bramletteius serraculoides* Gartner, 1969  
*Gephyrocapsa* spp. (closed center)  
*Gephyrocapsa* spp. (open center)  
*Rhabdosphaera stylifera* Lohmann, 1902  
*Discoaster surculus* Martini and Bramlette, 1963  
*Discoaster tani* Bramlette and Riedel, 1954  
*Ceratolithus tricorniculatus* Gartner, 1967  
*Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, 1968  
*Discoaster verabilis* Martini and Bramlette, 1963

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obtained from this site was intended to be used in conjunction with information obtained from DSDP sites previously drilled along 140°W longitude. Site 172, however, is located 7° east of this line in order to investigate a secondary spreading center proposed by Malahoff and Handschumacher (1971) in a magnetic "disturbed zone" (Atwater and Menard, 1970). The hypothesis to be tested suggests that the site is underlain by magnetic anomaly 8 with a predicted basement age of about 29 m.y.

Hole 172 penetrated a small sediment pond or basin. The first two cores recovered contain brown zeolitic pelagic clays devoid of calcareous nannofossils. At 23 meters, Core 3 bottomed in basalt which was not penetrated although the drill bit was rotated against this hard layer for twenty minutes before the third core was pulled. Core 3 contains 9 meters of sediment although only 5 meters of penetration was recorded by the drillers' log. The 9-meter core apparently resulted from repeated sampling of the sediment overlying the basalt during the 20 minutes of drilling after the hard layer was encountered (see Drilling Program and Operations, Chapter 3). This action resulted in a highly disturbed core of brown clay streaked and mixed with a pale orange calcareous nannofossil ooze which can be traced to a 15-cm thick layer contained in Section 4. This thin calcareous layer is underlain by a 40-cm thick nonfossiliferous brown clay unit thought to have been deposited directly on the basalt (see Lithologic Summary, Chapter 3).

#### Biostratigraphy, Site 172

The calcareous ooze 48 cm below the top of Section 4 is nearly pure biogenous carbonate (Plate 1) except for minor amounts of zeolitic and pelagic clay. Preservation of nannofossils is generally poor although some well-preserved specimens are present. Most placoliths are heavily etched in the central area and discoasters exhibit heavy secondary calcite overgrowths. The assemblage is dominated by *Reticulofenestra bisecta* with abundant *Discoaster tani*, *D. deflandrei*, and large (20-micron) specimens of *Reticulofenestra umbilica*. *Bramletteius serraculoides*, *Coccolithus eopelagicus*, *C. formosus* (= *C. lusitanicus* Black), *Sphenolithus predistentus*, *S. moriformis*, and *S. pseudoradians* are common and *Isthmolithus recurvus* is rare. This assemblage is characteristic of the *Helicopontosphaera reticulata* Zone of Bramlette and Wilcoxon (1967) which Bukry (1081b) assigns to the lower Oligocene. This interval has been further studied in thorough detail by Roth (1970) who, in his latest revision (Roth, Baumann, and Bertolino, 1971), divides the interval into two zones, the lowermost of which is the *Ericsonia subdistica* Zone. The nannoflora from sample 172-3-4(48cm) can readily be referred to this zone which is defined as the interval from the last occurrence of *Discoaster saipanensis*, Bramlette and Riedel, to the last occurrence of *Coccolithus formosus* (Kamptner). According to Roth, Baumann, and Bertolino (1971, Figures 1, 2) this zone is roughly equivalent to nannofossil zone NN21 of Martini (1970) and Blow's foraminiferal zones P17 to P18 (Blow, 1969) to which Laughton et al. (1972, p. 17, Figure 5) assign radiometric age dates of 35 to 38

m.y. This is considerably older than the 29 m.y. age predicted for this site.

The contacts between the carbonate layer and the underlying and overlying red clay units are sharp although core distortion has distributed pods and streaks of the carbonate layer throughout Sections 1, 2, and 3 of the core. Thus it appears that the environmental conditions which favored the accumulation of calcareous nannofossils ended nearly as suddenly as they began. Sections 5 and 6 of Core 3 are also highly disturbed with streaks of carbonate running vertically down the core. Much mixing occurs where hard fragments of ash (probably derived from downhole slumping) were incorporated in the core. Thus it is possible to find nannofloras in virtually the entire length of Core 3; however, they are identical in species composition and preservation to those recovered from the carbonate layer, and all paleontologic evidence indicates that they are contaminants from that layer. It is possible that additional contributions of lower Oligocene coccoliths winnowed from promontories adjacent to the basin could have been incorporated in sediment of Core 3. Such reworked material, if present, would nevertheless be of no biostratigraphic significance.

A fourth core taken at the conclusion of drilling at Hole 172 recovered only a core catcher sample containing unfossiliferous red clay (probably derived from downhole slumping) and fragments of basalt. Water from this core yielded nannofossils similar to those recovered by Core 3.

In an attempt to recover older sediments in the basin, a second hole, 500 meters from the first, was attempted. Again drilling terminated in basalt approximately 25 meters below the sediment surface. The one core taken here yielded basalt fragments and water which contained nannofossils similar to those recovered in Hole 172. Thus it appears that the fossiliferous unit encountered in the first hole was again penetrated in Hole 172A.

#### Early Diagenesis of Carbonate, Site 172; Observations

Because the calcareous ooze at this site was deposited in deep water well below the lysocline, the more soluble elements of the fossil assemblage have been removed by chemical solution. Planktonic foraminifers, less resistant to solution than many calcareous nannofossils, are practically absent. The centers of many placoliths have been destroyed by dissolution leaving only the outer rims of the shields (Plate 2, Figure 1). The relatively resistant discoasters show few solution features and, as explained below, have accreted considerable amounts of secondary calcite made available by the in situ dissolution of other nannofossils.

Chemical dissolution does not attack all parts of coccoliths uniformly, and heavily etched placoliths can often be assigned to species by distinctive characteristics of their more resistant elements. In the light microscope, isolated rims of distal shields of *Coccolithus formosus* can be recognized by their uniformly large size (about 10 to 12 microns), circular outlines, and complete extinction under crossed nicols. Rims of *C. eopelagicus* also extinguish in cross-polarized light, but are strongly elliptical in outline. Rims of *Reticulofenestra bisecta* are distinguished from those of *R. umbilica* by their smaller size and thicker

elements which can be distinguished as striae in cross-polarized light.

Coccoliths deposited at Site 172 presumably underwent minor dissolution during their descent in the water column from the surface waters in which they were formed by phytoplankton and more extensive dissolution during their residence time in bottom sediment close to the sediment-water interface. Dissolution would have been promoted as long as the material was close enough to the sediment surface to allow diffusion of dissolved carbonate across the sediment-water interface. Once the material was buried sufficiently to prevent such exchange, dissolution presumably ceased or became practically negligible. Had it continued at a rapid rate, no recognizable skeletal material would have been preserved in this red clay sequence. Therefore, most dissolution effects observed at this site are thought to have occurred early during diagenesis.

The calcareous material at Site 172 has not been subject to many of the geologic factors which tend to obscure effects of early diagenesis in carbonate sediment such as late diagenetic alterations that result from heavy overburden pressure, pore fluid migration, introduction of dissolved carbonate from adjacent calcareous units, long-term time-dependent chemical reactions, or subaerial exposure. Because effects of early diagenesis on calcareous ooze are less well known than some effects of late diagenesis, it is interesting to study the early diagenesis of this material in some detail with the aid of the scanning electron microscope. Where possible, micrographs of coccolith taxa in Plates 2 to 6 are arranged to illustrate sequences of diagenetic events, particularly those which involve in situ dissolution and reprecipitation of skeletal calcite.

Figures 2 to 5 of Plate 2 illustrate a typical dissolution sequence exhibited by placoliths of *Reticulofenestra bisecta*. The coccolith in Figure 2 is relatively intact whereas in Figure 3, chemical solution has widened the central opening of the specimen and narrowed the width of the proximal (upper) shield. The more resistant distal shield is practically unaffected. Further dissolution has served the proximal shield of the specimen in Figure 4 along the long axis of the central ellipse. The specimen in Figure 5 is merely a remnant of one shield (distal?) heavily etched along the inner and outer circumferences.

Prominent bar-like structures in the central areas of specimens in Figures 2, 3, and 4 are of interest because such structures are considered by some to be of taxonomic importance. However, one of the bars in Figure 4 (arrow) extends into the area formerly occupied by the proximal shield of that specimen. This indicates that the bars figured here are secondary in origin and are calcite overgrowths rather than primary products of biological calcification. Further evidence to this effect is provided by the distal views of *Reticulofenestra bisecta* shown in Plate 2, Figures 6 and 7. Here the laths which characterize the central area of this species appear blocky as if overgrown with secondary calcite. Indeed a long euhedral calcite crystal in Figure 7 (arrow) projects far over the distal rim of the coccolith. Because this crystal cannot be a primary product of calcification, it is evident that the central area elements of specimens of *R. bisecta* shown in Plate 2 are overgrown

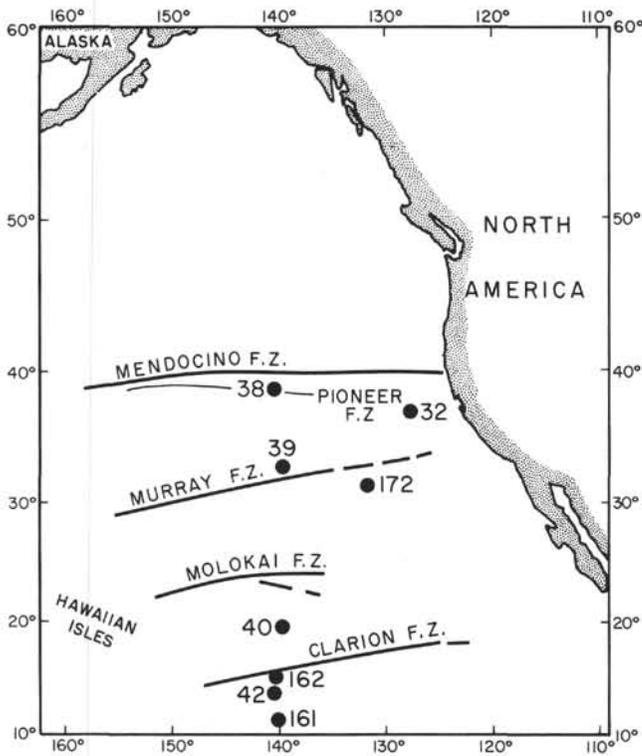


Figure 2. Location of DSDP Site 172 and neighboring sites used to establish regional correlations.

by secondary calcite. This calcite must have been derived from the in situ dissolution of other calcareous nannofossils (and possibly planktonic foraminiferal tests) present in the sediment because there is no other source of calcite in the section drilled at this Site. Thus, some of the skeletal calcite placed into solution by dissolution was not lost to the sediment by diffusion across the sediment-water interface, but was accreted as overgrowths on certain kinds of calcareous nannofossil elements which had the ability to serve as nucleation sites within the physicochemical regime that prevailed in the sediment.

The principal effect of dissolution on shields of *Reticulofenestra umbilica* (Plate 3, Figures 1-3) has been to remove the delicate lace-like grill which covers the central openings of well-preserved specimens (examples of these central area grills are illustrated by Gartner and Smith (1967, Pl. 2, Fig. 4; Pl. 3, Fig. 1).

*Coccolithus eopelagicus* (Plate 3, Figures 4-9) is the most resistant placolith in the assemblage. Chemical etching first attacks the thin laths which form the central area (Plate 3, Figures 6-7); however, the imbricate elements of the distal shield, which are more resistant, may be unaffected (Plate 3, Figure 7). The proximal shield of *C. eopelagicus* is composed of two cycles of elements inclined at different angles so as to form a herringbone pattern (Plate 3, Figure 8). The fine elements of the proximal shield are less resistant to etching than those of the distal shield and are often poorly preserved in specimens which possess an intact distal shield (Plate 3, Figure 9). Not only are distal shields better preserved, but elements exposed on their inner (proximal) sides frequently exhibit secondary calcite

overgrowths (arrow, Plate 3, Figure 9; see also Wise, 1971, and Wise and Kelts, 1972) which form along the sharp imbricate edges of the elements and then develop into blunt nodes that may overlap adjacent elements. The overgrowths probably form initially along the imbricate edges of the shield elements because calcite nucleation can be effected more easily along a crystal edge or dislocation than on a flat crystal surface.

Dissolution effects on *Coccolithus formosus* (Plate 4, Figures 1-6) are similar to those exhibited by *C. eopelagicus*. Figures 1 and 2 of Plate 4 show relatively well-preserved specimens in which the central openings have been expanded slightly by dissolution. The proximal shields, which should exhibit a two-cycle construction, are poorly preserved in specimens from Site 172. Remnants of only one cycle of elements are observed (Plate 4, Figure 3). Elements of the central area display various degrees of chemical etching (Plate 4, Figures 4, 5) and are entirely absent in many specimens in which only the more resistant distal shield is preserved (Plate 4, Figure 6).

The rudder- or paddle-like distal structures of *Bramletius serraculoides* (Plate 4, Figures 7, 8) are well-preserved in the ooze from Site 172. However, the elliptical placolith-like base which should be attached at the narrow end of the object (Gartner, 1969b) is absent from all specimens observed. Presumably these have been detached or destroyed by chemical solution.

The few complete specimens of *Sphenolithus pseudoradians* observed in the material (Plate 4, Figures 9, 10) exhibit the thin apical blades and stubby basal and lateral elements described by Roth, Franz, and Wise (1971, Pl. 1, Fig. 3). However, in most examples observed by light and electron microscopy, the basal structures have been detached by dissolution. The characteristic arrangement of the five or so blades of the apical structure, however, allows identification of this species in light and electron micrographs (Plate 4, Figures 11, 12). Most specimens of *Sphenolithus predistentus*, a form which should possess a two-piece bifurcated apical structure and single cycle basal structure (Roth, Franz, and Wise, Pl. 1, Figs. 7-9) also lack the basal elements (Plate 5, Figures 1-3). The basal structures of sphenoliths with large apical structures, therefore, appear to be quite vulnerable to detachment or disaggregation in environments of high chemical solution. In the case of the beehive-shaped *Sphenolithus moriformis*, however, where elements are more uniform in size (Plate 5, Figures 4, 5), dissolution may first cause disaggregation of the apical elements before the basal cycle is affected (Plate 5, Figure 6).

Discoasters exhibit the most prominent calcite overgrowths, and all specimens observed have accreted large amounts of secondary calcite over their entire ray surface. The quantity of calcite accreted is sufficient to double or triple the total mass of most specimens. Overgrowths on discoasters are readily recognized by the euhedral crystal faces exhibited by the inorganically precipitated calcite (Plate 5, Figures 7, 8). Crystal faces form symmetrically along individual rays of the astroliths because discoaster rays behave optically and crystallographically as single calcite crystals. Thus each ray can serve as a large nucleation site for the inorganic precipitation of calcite. The accretion of

large amounts of secondary calcite can cause considerable modification of the peripheral outlines of discoasters, and this necessarily causes problems with taxonomy (Wise, 1972). For instance, the specimens of *Discoaster tani* illustrated in Plate 5, Figures 7 and 8, appear quite different from well-preserved specimens from land sections. As explained by Bukry (1971a, p. 971), the latter are characterized by slender parallel arms and sometimes a pair of ornamental nodes toward the ray tips. However, secondary overgrowth has not only thickened the rays of specimens figured here, but has also produced tapered outlines and obscured ornamental nodes which may have been present. This phenomenon is widespread in deep-sea oozes which have undergone diagenesis (see discussion by Bukry, 1971a). *Discoaster tani*, however, is distinguished from other middle Eocene to lower Oligocene discoasters by its predominantly five-rayed form.

Secondary overgrowths on *Discoaster deflandrei* (Plate 6, Figures 1-3) cause wholesale thickening of rays and the obfuscation of the wrench-shaped bifurcations which characterize unaltered representatives of this species. The rough outline of a wrench-type bifurcation is discernible on the least heavily overgrown ray of the specimen in Plate 6, Figure 1 (arrow). Bifurcations are indicated on the other rays only by shallow notches at the ray tips. In addition to the euhedral calcite crystal faces, further evidence of calcite overgrowths on these specimens is provided by particles of skeletal debris which have been trapped between rays during the accretion of secondary calcite (arrows, Plate 6, Figures 2, 3). The particle in Figure 3 has been partially enveloped.

Discoasters which have undergone extensive calcite overgrowth may exhibit a tripartite bridge across the central area which joins every second ray (Wise and Kelts, 1972). A tendency toward such a development is illustrated by the specimen in Plate 6, Figure 3; however, the small, highly altered discoaster in Plate 6, Figure 4, shows the structure in an advanced state of development. Note also the well-developed crystal faces.

#### Early Diagenesis of Carbonate, Site 172: Discussion

Diagenetic modifications of the types illustrated in the preceding figures of astroliths have produced numerous taxonomic problems because many new discoaster species have been erected on the basis of features which can now be recognized as secondary in origin (Wise, 1972). Study of the material from Site 172 shows that forms such as *Discoaster aster* Bramlette and Riedel and *Discoaster woodringi* Bramlette and Riedel, plus many varieties and subspecies attributed to these taxa (examples, see reports by E. D. Milow in Hays et al., 1972), have been distinguished on the basis of features produced by secondary calcite overgrowth rather than on primary features of calcification.

As stated above, most of the chemical dissolution suffered by the calcareous nannofossils illustrated in Plates 1 through 6 is thought to have occurred while the skeletal particles were in residence in bottom sediment close to the sediment-water interface. Dissolution was promoted by the deposition of the material in deep water well below the lysocline. It is possible that some dissolution may have

continued at an exceedingly slow rate over the intervening 35 to 38 million years since deposition although there is no direct way to measure or estimate this. The fact that the thin but well-defined calcareous ooze layer is preserved at all, however, suggests that it must have been diagenetically stable throughout most of its existence. Indeed, the material is not as severely overgrown with calcite as younger but somewhat more deeply buried material from the equatorial Pacific (example, lower Miocene Nannofossil ooze recovered from DSDP Hole 71; Wise, unpublished). However, in view of the limited state of knowledge on early deep-sea diagenesis, all possibilities should be borne in mind. One such possibility is that skeletal calcite secreted at surface water temperatures may be less stable at the somewhat lower sea bottom temperatures, and this might cause some long-term dissolution and reprecipitation of skeletal calcite in order to achieve a more stable configuration. A second possibility is that the slow breakdown and oxidation of organic matter entrapped in skeletal calcite could produce organic acids which would cause chemical etching and reprecipitation of calcite. Such reactions might also remove inhibitors to dissolution and reprecipitation such as organic coatings on calcite grains. A third possibility is that bottom water conditions during middle Tertiary times may have been more favorable for early dissolution and reprecipitation of skeletal calcite than are bottom waters today. This is suggested by the fact that lower Oligocene to lower Miocene discoasters from many areas frequently show pronounced secondary calcite overgrowths. Emiliani's (1954) suggestion that bottom waters in equatorial areas were several degrees warmer during middle Tertiary times may be of some relevance here since warmer bottom water temperatures would increase rates of chemical reactions, including various reactions (possibly in relation to reactions with organic acids) involved in the dissolution and reprecipitation of skeletal calcite. This would presumably promote diagenetic changes in carbonate oozes deposited during these times. At present, however, the several possibilities listed above are scarcely above the level of speculation and are perhaps not applicable to the situation at Site 172 except during the initial phases of diagenesis when the material was exposed to cold oxygenated bottom waters.

It does seem probable that the calcite overgrowths did form early in diagenesis while the less stable skeletal calcites were still subject to active chemical solution. In the deep-sea environment, calcite overgrowths can form in relatively short periods of geologic time as evidenced by the heavily overgrown upper Pliocene discoasters illustrated by Boudreaux and Hay (1969, Pl. IX, Figs. 4-12). It is also noteworthy that, in general, the more solution-resistant nannofossils and nannofossil components are often the more susceptible to secondary calcite overgrowth. For example, discoasters and the distal shields of *Coccolithus eopelagicus* are perhaps the most solution-resistant objects in the sediment at Site 172. They also exhibit calcite overgrowths. Recent studies show that a definite order can be established among calcareous nannofossil species based on susceptibility toward dissolution in the deep sea (i.e., selective solution; see Hay, 1970; McIntyre and McIntyre, 1971; Schneidermann, 1971; Bukry, 1971b; Cita, 1971). It

is probable that an analogous scale, headed by discoasters, could also be established based on susceptibility for secondary calcite overgrowth.

The presence in *Reticulofenestra bisecta* of central area structures that are highly etched in some specimens but are overgrown with secondary calcite in others, is somewhat enigmatic. Such a phenomenon could be the product of many variables related to selective solution, selective calcite nucleation, and changes in the physicochemical microenvironment of diagenesis as the skeletal material is subjected sequentially during burial to (1) exposure to circulating undersaturated bottom waters, (2) pore water near the sediment-water interface which can exchange by diffusion with bottom water, and (3) pore water in equilibrium with the skeletal calcite following deeper burial.

#### Regional Correlations, Site 172

Site 172 lies on the west flank of the East Pacific Rise. This flank has experienced sea floor spreading in a generally westerly direction since Mesozoic times. Extensive calcareous nannofossil ooze correlative with that deposited at Site 172 has been penetrated at DSDP Sites 42, 161, and 162 which lie 2500 miles SSW of Site 172 (Figure 2) in the equatorial belt of high organic calcium carbonate production. Skeletal production by calcareous organisms in the equatorial belt of the East Pacific Ocean is of such magnitude that the calcium carbonate compensation level is depressed sufficiently to allow extensive carbonate oozes to accumulate in exceedingly deep water. Arrhenius (1963) and Heath (1969) suggested that the calcium carbonate compensation level in this region had been depressed below about 5,000 meters during portions of the Oligocene, and drilling results of DSDP Leg 8 (Tracy, Sutton, et al., 1971) confirmed the presence of exceptionally widespread lower Oligocene to lower Miocene carbonate ooze throughout this portion of the Pacific. This suggests the existence of high productivity by calcareous organisms during Early Oligocene to Early Miocene time. It has further been suggested (Heath, 1969) that during middle Tertiary time, bottom waters in this area may have been warmer and therefore less corrosive (in terms of solubility) with respect to carbonate sediment than they are today. This also would have promoted the accumulation of carbonate ooze in this region during Oligocene time.

Judging from modern day analogies, carbonate production during the early Oligocene would have been less intense north (and south) of the equatorial belt than within that tropical zone. However, it is likely that during productivity maxima, the carbonate compensation level would have been depressed in the more northerly regions, and this would have allowed nannofossil ooze to accumulate on promontories such as seamounts and the upper flanks of the East Pacific Rise. It was apparently during one such productivity maxima (and/or time of favorable bottom water conditions) that carbonate ooze accumulated at Site 172 which, during the early Oligocene, would have been located further up on the ridge flank than it is today. It is noteworthy that northerly DSDP sites west of Site 172 (i.e., Sites 38, 39, and 40; Figure 2) did not receive calcareous sediments during the Oligocene or Miocene, presumably because westward spreading had

carried these sites to abyssal depths well below the carbonate compensation levels reached during the middle and late Tertiary. Lower Eocene calcareous nannofossils were recovered at Sites 38, 29, and 40, however, which suggests that these sites formerly lay at positions sufficiently high on the ridge flank to have received calcareous sediment at times of low carbonate compensation level during the Paleogene. A close correlation can be established between sediments recovered at Site 172 and the pelagic sequence cored by DSDP Leg 5 at Site 32 (McManus, Burns, et al., 1970) which lies some 1000 miles to the northeast. At Site 32, very thin calcareous lenses or streaks bearing lower Oligocene nannofossils are present near the bottom of the hole at the base of a 36-meter-thick brown clay sequence. Except for this basal occurrence, the brown clay is devoid of calcareous fossils and contains radiolarians only in the upper part (McManus, Burns, et al., 1970). As at Site 172, coccoliths show evidence of etching, and disassociated parts and fragments form a significant part of the matrix. The assemblage is similar in species composition to the flora at Site 172 except for the absence of *Coccolithus formosus*, a zonal marker proposed by Roth, Baumann, and Bartolino (1971, p. 1085). According to the zonation proposed by these authors, the ooze at Site 32 can be referred to the lower part of their *Helicopontosphaera reticulata* Zone (32-35 m.y.) which would make it slightly younger than the calcareous ooze at Site 172 (35-38 m.y.). This suggests that the environmental-tectonic conditions or events which promoted the accumulation of nannofossil ooze during Early-Middle Oligocene time extended north in the East Pacific to at least 38°N latitude. However, it was restricted over large areas west of Site 172 which are north of the equatorial zone of high productivity (i.e., north of Sites 42, 161, 162, and 163). Some of the sites that did not receive calcareous sediment lie at present-day water depths equal to those at Sites 32 and 172.

According to the environmental-tectonic framework outlined here (see also Tracy et al., 1971), the ooze at Site 172 probably represents a productivity maxima which would have been felt most strongly in the equatorial regions, but which extended well beyond the margins of the tropics. Lithologically, the ooze would represent the northern feather edge of carbonate sediments that blanketed high areas along the East Pacific Rise north of the equatorial belt. The high production of skeletal calcite added sufficient calcium carbonate to the water column to depress the carbonate compensation level in the region well below preceding levels. This allowed the accumulation of carbonate ooze at sites previously below the CCL which had been accumulating brown clay. This explains the sharp contact between the nannofossil ooze and the underlying brown clay at Site 172. The carbonate ooze belt, however, apparently did not reach 38°N, where no carbonate is recorded at Site 32. As productivity of calcareous organisms waned, however, the carbonate compensation level in the region of Site 172 quickly rose again causing a cessation of carbonate deposition and the formation of a sharp contact between the carbonate ooze and the younger brown clay deposited at the site. Later, during the Early Middle Oligocene, a second productivity maxima emanating from the tropics caused nannofossil ooze to accumulate as

far north as Site 32. At this moment in geologic time, Site 32 lay sufficiently high on the ridge flank to receive calcareous sediment. No ooze accumulated 1000 miles to the southwest at Site 172, however, presumably because westward spreading had by now carried Site 172 below the depth reached by the CCL during this second productivity maxima. With subsequent westward spreading, however, both sites were moved further down the ridge flank and never again received carbonate sediment during the Oligocene.

#### SITE 173

(39° 57.71' N, 125° W; water depth 2927 m)

Site 173, on the lower continental margin off Cape Mendocino, California, was drilled to study tectonics related to the San Andreas Fault, to provide data on submarine fan deposition, and to establish an integrated Neogene biostratigraphy for the middle latitudes of the Northeast Pacific. A reasonably continuous stratigraphic reference section has not been available for cooler waters such as those found in the California Current.

Continuous coring using an extended barrel (EB) and bit assembly of new design resulted in good recovery of fossil-rich sediment until drilling was terminated in basalt at 333 meters. The sediments, late Oligocene to Pleistocene in age, consist of greyish green diatom-rich silty clay from 0 to 138 meters, diatomite from 138 to 185 meters, and glauconitic mudstone or grey calcareous nannofossil ooze from 285 to 320 meters. Despite the near total predominance of siliceous microfossils throughout most of the section, adequate calcareous nannofossil and planktonic foraminiferal assemblages were recovered to allow correlation with the richer and more diverse calcareous assemblages of the low-latitude tropical Pacific and Caribbean. Site 173, therefore, is an excellent reference section for establishing integrated biostratigraphic zonations for middle-latitude diatoms, radiolarians, silicoflagellates, calcareous nannofossils, foraminifers, and other microfossils.

It is well known that species diversity among calcareous nannofossils in all oceans decreases dramatically from low to high latitude (McIntyre and Bé, 1967; McIntyre, Ruddiman, and Roche, 1970). This decrease in diversity can be correlated with decrease in surface water temperature. Results of Leg 18 show that diversity of Neogene nannofloras decreases more sharply in the North Pacific than in the North Atlantic, probably because the Gulf Stream has been more effective in ameliorating cold seasonal temperatures in the North Atlantic than have been equivalent currents in the North Pacific. Direct comparisons between oceans, however, are somewhat difficult to evaluate, particularly since most of the nannofossil assemblages recovered on Leg 18 are etched. Some nonresistant species at middle and high latitudes in the North Pacific may have been removed from assemblages by dissolution.

Placoliths recovered at Site 173 are moderately to poorly preserved as a result of dissolution although discoasters in the grey ooze near the bottom of the section are overgrown by secondary calcite. Coccoliths are abundant in this unit, but occur only in small to moderate

numbers throughout most of the overlying units. The abundance, preservation, and distribution of species in 171 samples are indicated on the range chart in Table 2.

The reduced species diversity among the cool-water assemblages recovered at Site 173 is strikingly evidenced by the absence of key species used as zonal markers at lower latitudes such as *Helicopontosphaera ampliaperata*, *Gephyrocapsa oceanica* (*sensu stricti* of Boudreaux and Hay, 1969), *Sphenolithus belemnos*, *S. ciperoensis*, *Catinaster coalitus*, *C. calyculus*, *Discoaster hamatus*, *D. neohamatus*, *D. surculus*, *D. perplexus*, *D. kugleri*, *D. asymmetricus*, and *D. quinqueramus*. Other important guide fossils or warm-water indicators are poorly represented (for example, *Ceratolithus cristatus*, *Sphenolithus heteromorphus*, *Helicopontosphaera kamptneri*, and *Rhabdosphaera clavigera*). Instead, assemblages are characterized by forms known to have a tolerance or preference for cool water such as *Gephyrocapsa caribbeanica* (*sensu stricti* of Boudreaux and Hay) (Pleistocene), *Reticulofenestra pseudoumbilica* (Miocene-Pliocene), *Cyclicargolithus floridanus*, *Discoaster exilis* and *D. intercalcaris* (Miocene), and *Discoaster deflandrei* (Oligocene-Miocene). *Coccolithus pelagicus*, a form indicative of cool waters (6-14°C) in modern oceans (McIntyre, Ruddiman, and Roche, 1970), occurs throughout most of the section. Despite the low diversity exhibited by discoaster populations at this temperature locality, one new form, *Discoaster mendocobensis* Wise n. sp., flourished briefly in this area during a warm interval near the end of the Miocene. This large, robust astrolith (Plate 7, Figures 1-8) evolved a variety of stocky forms which contrast sharply with the many delicate, slender-rayed discoaster species that flourished in warm tropical waters during this time.

#### Biostratigraphic Zonation, Site 173

The low species diversity which characterizes the cool-water assemblages at Site 173 presents an acute problem to the biostratigrapher because many key marker species are absent, especially among the discoasters, sphenoliths, and helicopontosphaerids. Few of the twenty-six calcareous nannofossil zones and subzones defined for the Neogene of the equatorial Pacific (Bukry, 1971b) can be recognized at Site 173. A broader zonal concept has been used, therefore, to subdivide the section (see Table 3). In some instances, two or more zones recognized in equatorial regions are combined into a single zone (for example, the *Sphenolithus heteromorphus* Zone and the upper portion of the *Helicopontosphaera ampliaperata* Zone are combined into an interval designated the *Cyclicargolithus floridanus* Zone). Because many zonal marker species are totally absent in the section, secondary marker species have been designated to define some zonal boundaries. Where possible, secondary markers are chosen which define datum levels that are closely coincident with the datums that would have been provided by the primary marker species. For instance, the first stratigraphic occurrence of *Emiliania annula* coincides closely with the last occurrence of *Reticulofenestra pseudoumbilica*, the index species most often used to mark the boundary between the *Reticulofenestra pseudoumbilica* Zone and the *Discoaster brouweri* Zone.

In Table 3, zonal markers which are generally recognized as being stratigraphically significant for world-wide correlation are designated by a 1, those that are useful only for regional correlations are indicated by a 2, and those which are suspected to be of only local importance are denoted by a 3.

Despite the establishment of new zones based on secondary and tertiary datum levels defined by calcareous nannofossils, it was still not possible to subdivide portions of the middle and upper Miocene at Site 173. Because the section cored at this site will be of prime importance to land geologists working in the Tertiary basins of California, it does seem worthwhile to provide a more detailed zonation, even if such a zonation is of only local importance. This can be done if datum levels provided by siliceous nannofossils such as silicoflagellates are used in combination with those defined by calcareous nannofossils. It is convenient to study silicoflagellates concurrently with calcareous nannofossils because both groups can be observed in the same specimen preparation if standard smear slides are used.

A workable zonation for Neogene silicoflagellates of the equatorial Pacific has been proposed by Martini (1971b). His scheme utilizes easily recognized fossils which can be learned quickly by specialists who work primarily with calcareous nannofossils. One datum level defined by Martini is the extinction of the easily recognized species *Corbisema triacantha* (Ehrenberg, Pl. VII, Figs. 9-11) which, at Site 173, falls within the middle Miocene interval where control by calcareous nannofossils is poor. For this reason, the *Corbisema* datum level is used here in combination with datum levels provided by calcareous nannofossils in order to define two new zones. Double names are used to designate these silicoflagellate-calcareous nannofossil zones. The first part of the name indicates the silicoflagellate index species, the second part denotes the calcareous nannofossil index species. This type of zone is here called a *combination range zone*.

In the following discussions of zones, new or emended zones are indicated by the designation of a reference locality.

### Pleistocene

The three Pleistocene zones indicated in Table 3 are essentially those defined by Gartner (1969a) as modified by Geitzenauer (1972).

#### *Emiliana huxleyi* Zone

**Definition:** Interval which contains *Emiliana huxleyi*.

**Remarks:** The small (3- to 5-micron) name species of this zone can only be identified with certainty by means of electron microscopy. Such study, however, is impractical in samples rich in clay and poor in *Emiliana huxleyi* because it is most difficult to separate these two constituents by gravitational settling or centrifuge techniques. The base of this zone is estimated to be 250,000 years B.P. in the Atlantic Basin (McIntyre, 1970) and between 110,000 to 220,000 B.P. in the subantarctic Pacific (Geitzenauer, 1972).

#### *Gephyrocapsa* Zone

**Definition:** Interval from the last occurrence of *Emiliana annula* to the first occurrence of *Emiliana huxleyi*.

**Remarks:** At Site 173, this gap zone is characterized by the presence of *Gephyrocapsa* spp. and the absence of *Emiliana huxleyi*, *Cyclococcolithina macintyreii*, and *Emiliana annula*.

#### *Emiliana annula* Zone

**Definition:** Interval from the first occurrence of *Gephyrocapsa* to the last occurrence of *Emiliana annula*.

**Remarks:** Gartner (1969a) names this zone the *Pseudoemiliana lacunosa* Zone. The name *Emiliana annula* is here substituted for the invalid name *Pseudoemiliana lacunosa* in accordance with the taxonomic change suggested by Bukry (in press). In the subantarctic Pacific, the extrapolated age of the *Emiliana annula*-*Gephyrocapsa* zonal boundary is estimated to be 520,000 to 580,000 years B.P. (Geitzenauer, 1972). The base of the *Emiliana annula* Zone was defined by Gartner (1969a) as the last occurrence of *Discoaster brouweri*. A new definition has been applied in the Pacific (see discussion below).

### Plio-Pleistocene

#### *Cyclicargolithus dornicoides* Zone

**Definition:** Interval from the last occurrence of *Discoaster brouweri* to the first occurrence of *Gephyrocapsa* spp.

**Remarks:** According to data provided by Gartner (1969a, Fig. 7), the last stratigraphic appearance of *Discoaster brouweri* is closely coincident with the first appearance of *Gephyrocapsa* spp. (identified here as forms having a discernible bar across the central area). Bandy and Wilcoxon (1970) found that the ranges of *D. brouweri* and the earliest *gephyrocapsid* species (*G. caribbeanica* Boudreaux and Hay) *overlap* near the Pliocene-Pleistocene boundary in the Calabrian reference sections at le Castella and Maria di Catazaro, Italy. In a section at Balcom Canyon, Southern California, however, they found a gap of about 50 meters between the extinction of *Discoaster brouweri* and the first appearance of *Gephyrocapsa caribbeanica* (Bandy and Wilcoxon, 1970, Fig. 6). At Site 173, there is also a significant gap on the order of about 75 meters between these two nannofossil datums. Geitzenauer (1972), working with piston cores from the subantarctic Pacific Ocean, also observed a stratigraphic gap between the last *Discoaster brouweri* and the first *Gephyrocapsa caribbeanica* and gave this interval the name *Coccolithus dornicoides* Zone (= *Cyclicargolithus dornicoides* Zone). This is not the *Coccolithus dornicoides* Zone of Bukry (Bukry and Bramlette, 1970; Bukry, 1971b, 1971c).

At Balcom Canyon, Bandy and Wilcoxon place the Plio-Pleistocene boundary midway between the datums defined by *Discoaster brouweri* and *Gephyrocapsa* spp. at a point marked by the first appearance of the planktonic foraminiferal index species, *Globorotalia (Truncorotalia) truncatulinoides* (d'Orbigny). As a result of studies of the Calabrian reference sections, this datum is used by foraminiferal specialists to mark the Plio-Pleistocene boundary in many parts of the world. *G. truncatulinoides*,







TABLE 3  
Calcareous Nannofossil Zones and Silico flagellate-Calcareous Nannofossil Combination Range Zones, DSDP Site 173

QUATERNARY	<i>Emiliana huxleyi</i> Zone	First <i>Emiliana huxleyi</i> <sup>a</sup>
	<i>Gephyrocapsa</i> Zone	Last <i>Emiliana annula</i> <sup>a</sup>
	<i>Emiliana annula</i> Zone	First <i>Gephyrocapsa</i> spp. <sup>b</sup>
PLIO- PLEISTOCENE	<i>Coccolithus doronicoides</i> Zone	Last <i>Discoaster brouweri</i> <sup>a</sup>
UPPER PLIOCENE	<i>Discoaster brouweri</i> Zone	First <i>Emiliana annula</i> <sup>b</sup>
LOWER PLIOCENE	<i>Reticulofenestra pseudumbilica</i> Zone	Last <i>Ceratolithus tricorniculatus</i> <sup>a</sup>
	<i>Ceratolithus rugosus</i> Zone	First <i>Ceratolithus rugosus</i> <sup>a</sup>
UPPER MIOCENE	<i>Ceratolithus tricorniculatus</i> Zone	First <i>Ceratolithus tricorniculatus</i> <sup>b</sup>
	<i>Discoaster mendomobensis</i> Zone	First <i>Discoaster mendomobensis</i> <sup>c</sup>
	<i>Dictyocha aspera</i> - <i>Reticulofenestra pseudumbilica</i> Zone <sup>e</sup>	Last <i>Corbisema triacantha</i> <sup>cd</sup>
MIDDLE MIOCENE	<i>Corbisema triacantha</i> - <i>Reticulofenestra pseudumbilica</i> Zone <sup>e</sup>	Last <i>Cyclocargolithus floridanus</i> <sup>b</sup>
LOWER MIOCENE	<i>Cyclocargolithus floridanus</i> Zone	First <i>Discoaster exilis</i> <sup>b</sup>
	<i>Discoaster deflandrei</i> Zone	Last <i>Triquetrorhabdulus carinatus</i> <sup>a</sup>
	<i>Triquetrorhabdulus carinatus</i> Zone	Last <i>Reticulofenestra bisecta</i> <sup>a</sup>
OLIGOCENE	<i>Reticulofenestra bisecta</i> Zone	

<sup>a</sup>Primary datum level.

<sup>b</sup>Secondary datum level.

<sup>c</sup>Tertiary datum level.

<sup>d</sup>Silicoflagellate index species.

<sup>e</sup>Calcareous nannofossil-silicoflagellate combination range zone.

base of this zone in order to avoid problems with reworked fossils. Such may be present in this part of the section at Site 173.

#### *Reticulofenestra pseudumbilica* Zone

**Definition:** Interval from the last occurrence of *Ceratolithus tricorniculatus* to the first occurrence of *Emiliana annula*.

**Reference locality:** DSDP Site 173, 123 to 129 meters.

**Remarks:** This zone is only slightly modified from and is essentially equivalent to the zone of the same name proposed by Gartner (1969a). The first appearance of *Emiliana annula* coincides closely with the last appearance

of *Reticulofenestra pseudumbilica* which is the marker proposed by Gartner. At Site 173, the extinction of *Discoaster verabilis* occurs at or near the top of this zone.

#### *Ceratolithus rugosus* Zone

**Definition:** Interval from the first occurrence of *Ceratolithus rugosus* to the last occurrence of *Ceratolithus tricorniculatus*.

**Remarks:** This zone is defined by Bukry (1971b). It is equivalent to the interval spanned by the *Ceratolithus rugosus* and *Discoaster asymmetricus* Zones of Gartner (1969a). The zonal marker for the latter zone is absent at Site 173.

### Miocene

Except for the *Ceratolithus tricorniculatus* Zone, all zones defined for this interval are either new or have been emended in name or definition.

#### *Ceratolithus tricorniculatus* Zone

**Definition:** Interval from the first occurrence of *Ceratolithus tricorniculatus* to the first occurrence of *Ceratolithus rugosus*.

**Remarks:** The definition of this zone is included in the broader range of definitions given by Bukry (1971b). It is equivalent to the interval spanned by the *Discoaster quinqueramus* and *Ceratolithus tricorniculatus* Zones of Gartner (1969a).

#### *Discoaster mendomobensis* Zone

**Definition:** Interval from the first occurrence of *Discoaster mendomobensis* n. sp. to the first occurrence of *Ceratolithus tricorniculatus*.

**Reference locality:** DSDP Site 173, 140 to 148 meters.

**Remarks:** The name of this upper Miocene zone is suggested by Bukry (Chapter 19, this volume). This zone is known only from assemblages at Hole 173. The name species is described under "Systematic Paleontology" in this chapter. The last occurrence of *Discoaster intercalaris* is near the top of this zone. The long-ranging *Reticulofenestra pseudumbilica* and *Discoaster verabilis* dominate the sparse nannoflora through most of this zone except near the base where the name species is abundant.

#### *Dictyocha asper* – *Reticulofenestra pseudumbilica* Zone

**Definition:** Interval from the last occurrence of *Corbisema triacantha* to the first occurrence of *Discoaster mendomobensis*.

**Reference locality:** DSDP Site 173, 149 to 186 meters.

**Remarks:** This is a combination silicoflagellate-calcareous nannofossil range zone which spans a long interval from the upper middle Miocene to the lower upper Miocene. *Reticulofenestra pseudumbilica*, the dominant calcareous nannofossil in this zone, is accompanied by the long-ranging *Discoaster verabilis*, *Discoaster intercalaris*, and *Discoaster exilis* (lower part). The silicoflagellate *Dictyocha asper* (Lemmermann) (= *Dictyocha rhombica* [Schulz]) is dominant over *Dictyocha fibbula* throughout this zone. The reversal in dominance between these two species (described by Martini, 1971b) occurs in the *Discoaster mendomobensis* Zone.

#### *Corbisema triacantha* – *Reticulofenestra pseudumbilica* Zone

**Definition:** Interval from the last occurrence of *Cyclicargolithus floridanus* to the last occurrence of *Corbisema triacantha* (Ehrenberg).

**Reference locality:** DSDP Site 173, 187 to 199 meters.

**Remarks:** The top of this silicoflagellate-calcareous nannofossil combination range zone is marked by the somewhat rare but easily recognized *Corbisema triacantha* which is illustrated in Plate 7, Figures 9 through 11. In Trinidad, the extinction of *Cyclicargolithus floridanus*

occurs in the middle middle Miocene near the top of the planktonic foraminiferal *Globorotalia fohsi fohsi* Zone (Bramlette and Wilcoxon, 1967). Thus, the zone proposed here lies within the upper middle Miocene or within the *Discoaster exilis* Zone of various authors. The calcareous nannoflora is dominated by *Reticulofenestra pseudumbilica* with common *Discoaster exilis*, *D. intercalaris*, and *C. verabilis*.

#### *Cyclicargolithus floridanus* Zone

**Definition:** Interval from the first occurrence of *Discoaster exilis* to the last occurrence of *Cyclicargolithus floridanus*.

**Reference locality:** DSDP Site 173, 207 to 264 meters.

**Remarks:** Based on correlations with Trinidad (Bramlette and Wilcoxon, 1967), this long interval encompasses strata from the upper lower Miocene to the middle middle Miocene. It is roughly equivalent to the interval from the uppermost portion of the planktonic foraminiferal *Globigerinatella insueta* Zone to the top of the *Globorotalia fohsi fohsi* Zone. The first *Reticulofenestra pseudumbilica* occurs in the lower part of this zone and the first *Discoaster verabilis* and *Discoaster intercalaris* occur near the base. A rare specimen of *Sphenolithus heteromorphus* was also noted near the base. The base of the zone probably lies near or slightly below the boundary between the calcareous nannoplankton *Helicopontosphaera ampliaperta* and *Sphenolithus heteromorphus* Zones of Bramlette and Wilcoxon (1967).

#### *Discoaster deflandrei* Zone

**Definition:** Interval from the last occurrence of *Triquetrorhabdulus carinatus* to the first occurrence of *Discoaster exilis*.

**Reference locality:** DSDP Site 173, 271 to 306 meters.

**Remarks:** This zone is poorly represented at Site 173 but is characterized by the presence of *Discoaster deflandrei* in the absence of slender-rayed forms such as *Discoaster exilis*. At Site 173, rare specimens of *Sphenolithus heteromorphus* occur near the top of the zone as well as the silicoflagellate *Corbisema triacantha*. Correlations with Trinidad place this zone in the middle to upper lower Miocene. This zone is not equivalent to zones of the same name published by Edwards (1971) and Bukry (1971c). As noted by Edwards (1971), usage rather than priority should take precedence in assigning zonal names.

#### *Triquetrorhabdulus carinatus* Zone

**Definition:** Interval from the last occurrence of *Reticulofenestra bisecta* to the last occurrence of *Triquetrorhabdulus carinatus*.

**Reference locality:** DSDP Site 173, 306 to 310 meters.

**Remarks:** This zone was named by Bramlette and Wilcoxon (1967) and the definition is only slightly modified here (see discussion below).

### Oligocene

#### *Reticulofenestra bisecta* Zone

**Definition:** Interval from the first occurrence of *Triquetrorhabdulus carinatus* to the last common occurrence of *Reticulofenestra bisecta*.

**Reference locality:** DSDP Site 173, 312 to 322 meters.

**Remarks:** The base of this zone was not penetrated at Site 173; however, correlations with Trinidad (Bramlette and Wilcoxon, 1967) indicate that this zone is essentially equivalent to the uppermost Oligocene *Sphenolithus ciproensis* Zone. Datum levels used here to define the zone are among those indicated by Bramlette and Wilcoxon (1967). This writer concurs with Edwards (1971, p. 383) who states that "recognition of a zone, other than a gap zone, is strictly dependent on the presence of the defining taxa and its use cannot be extended into strata lacking those taxa even though they may be considered as correlatives." As *Sphenolithus ciproensis* is absent at Site 173, the last common occurrence of the more cosmopolitan *Reticulofenestra bisecta* (which is present) is used to mark the top of the zone. This zone is not equivalent to zones of the same name indicated by Milow (in McManus et al., 1970) or Edwards (1971).

### Distribution of Calcareous Nannofossils, Site 173

The following comments pertain to the distribution chart given in Table 2.

The submicroscopic *Emiliania huxleyi* has been identified by scanning electron microscopy in Sample 173-5-1-4(90 cm); therefore, the first core from Site 173 is assigned to the *Emiliania huxleyi* Zone, the base of which is dated at less than 250,000 years B.P. The number of species present in Core 1 is about 20 percent of the number usually encountered in Pleistocene samples from equatorial regions. The *Gephyrocapsa* Zone, which is a gap zone (Edwards, 1971), is represented by a barren interval at 6 to 8 meters, if it is present at all. The barren interval is assigned to this zone, not on the basis of contained fossils, but as a result of the arbitrary definition of this gap zone.

Specimens of *Emiliania annula* (= *Pseudoemiliania lacunosa* Gartner) are large and well preserved in Cores 2 to 5 from 9 to 38 meters. The nannoflora here is dominated by *gephyrocapsids* and related small coccoliths. All *gephyrocapsids* have bars that form acute angles to the long axis of the coccoliths, but forms with relatively large open centers do occur down to the bottom of Core 3. *Gephyrocapsids* having small or occluded centers but with a discernible bar are present down to 38 meters (Sample 173-5-3, 90 cm). A decidedly warm interval is indicated by the presence of abundant *Cyclococcolithina macintyreii* in Sample 173-4-5(90 cm). This climatic event is also indicated by foraminifers (see Ingle, this volume). This warm interval, therefore, may be of value for local correlation.

Sparse to common *Emiliania annula* occur in the long monotonous interval from the middle of Core 5 (39 meters) to the second section of Core 12 (103 meters); however, these and the other sparse coccoliths present are poorly preserved due to severe etching. The Plio-Pleistocene boundary as defined by siliceous microfossils falls within the middle of this interval at about 70 meters; however, as discussed in the previous section, the interval from 39 to 103 meters at Site 173 falls within a gap between the last appearance of *Discoaster brouweri* and the first appearance of *Gephyrocapsa* spp. Such a gap does not exist at the Calabrian reference section in Italy; therefore, the

placement of the Plio-Pleistocene boundary on the basis of calcareous nannoplankton at Site 173 is in doubt. The datum traditionally used for this placement is the extinction of *Discoaster brouweri*, which occurs in the upper portion of Core 12. Diatoms at this level, however, are dated at 2.5 m.y. (Schrader, this volume) which indicates that the extinction of *D. brouweri* occurs at least a half million years earlier in this section than it does in the type Calabrian. Thus, in terms of absolute time, the top of the biostratigraphic zone defined by the extinction of *Discoaster brouweri* seems to wedge downward (become older) going from low to middle latitudes of the northeast Pacific.

Sparse *Discoaster brouweri* do occur consistently among the generally impoverished floras from 104 to 122 meters. An increase in helicopontospherids within this interval reflects either somewhat warmer surface water conditions or better preservation of the calcareous nannofloras than is present in the preceding interval.

A marked change in the calcareous nannoflora occurs in Sample 173-14 (EB), which contains the first common *Reticulofenestra pseudoumbilica*, *Sphenolithus neoabies*, and *Discoaster verabilis* encountered in the hole. The few specimens of these taxa present in the overlying Sample 173-14-3 (90 cm) may be reworked. Both samples are assigned to the *Reticulofenestra pseudoumbilica* Zone. No specimens of *Emiliania annula* occur in these samples; therefore, the change in abundance, preservation, and composition of the nannoflora between this zone and the overlying *Discoaster brouweri* Zone is sharp and distinct. The brevity of the *Reticulofenestra pseudoumbilica* Zone (1 to 6 meters, depending on where the extended-barrel sample is placed within the unfilled core liner) may well indicate a depositional hiatus at this point in the section although no hiatus has been indicated by the diatom biostratigraphy.

The only significant numbers of ceratoliths in the hole occur between 130 and 134 meters where sparse but well-preserved *Ceratolithus rugosus* and *Ceratolithus tricorniculatus* permit recognition of two zones within a short interval which spans the Pliocene-Miocene boundary.

A warm interval, indicated by the absence of the cool-water *Coccolithus pelagicus* and the presence of warm-water planktonic foraminifers, diatoms, and silicoflagellates (see reports by Ingle, Schrader, and Bukry, this volume) is the environmental setting in which the rather bizarre upper Miocene *Discoaster mendomobensis*, Wise n. sp., flourished at this site. Below the *Discoaster mendomobensis* Zone is a long monotonous interval (149 to 199 meters) representing at least 7 million years in which little variation is noted in the sparse calcareous nannoflora. The several index species of *Discoaster intercalcaris* and *Coccolithus pelagicus*, indicates cool-water deposition. Well-preserved *Triquetrorhabdulus rugosus* in Sample 173-20(CC) (186 meters) indicates a correlation no lower than the foraminiferal *Globorotalia fohsi lobata* Zone of Trinidad (see Bramlette and Wilcoxon, 1967). The last stratigraphic occurrence of *Discoaster exilis* is noted somewhat higher in the section (167 meters); however, to avoid problems of species recognition, this writer prefers to use the easily recognized silicoflagellate, *Corbisema*

*triacantha* (Plate 4, Figures 9-11), to subdivide this part of the section.

The nannoflora between 149 and 199 meters is dominated by *Reticulofenestra pseudoumbilica*. Here, the greatly restricted discoaster population consists primarily of three forms: *Discoaster exilis*, *D. verabilis*, and *D. intercalcaris*. The latter species was named by Bukry (1971c) who found it common in upper Miocene to upper Pliocene cool-water assemblages cored by DSDP Leg 5 at sites off northern California. Bukry (1971c, p. 315) suggested that *D. intercalcaris* might be a cool-water relative of *D. verabilis* that failed to develop bifurcations. At Site 173, the range of *D. intercalcaris* closely parallels the range of *D. exilis* through the *Corbisema triacantha-Reticulofenestra pseudoumbilica* Zone and into the underlying middle Miocene. Both forms have strongly tapered rays, and in many assemblages, differ only by their ray endings which are bifurcate in *D. exilis* and bluntly truncate or knobbed in *D. intercalcaris*. It seems that many of the middle Miocene forms tabulated as *D. intercalcaris* in Table 2, therefore, may be cool-water relatives of *D. exilis*. Other forms, particularly those in the upper Miocene, may have been derived from *D. verabilis*. *D. verabilis* and *D. exilis* seem to be closely related; therefore, it would not be surprising to find in both groups a tendency toward a reduction in size of terminal bifurcations with increase in latitude as Bukry (1971c) suggested in the case of *D. verabilis*.

The *Cyclicargolithus floridanus* Zone (207-267 meters) encompasses most of the middle Miocene sediment deposited at this site. The extinction of the name species at the top of this zone is an important biostratigraphic event which can be recognized in middle latitudes where most warm-water index species are absent. The first stratigraphic appearance of *Reticulofenestra pseudoumbilica* at 252 meters and the presence of rare *Sphenolithus heteromorphus* at 262 meters indicates that the lower portion of this zone can be correlated with the *Sphenolithus heteromorphus* Zone of Trinidad.

The *Discoaster deflandrei* Zone is poorly represented at this site because of a hiatus represented in part by a nonfossiliferous interval from 285 to 306 meters. This glauconitic zone in the middle lower to upper lower Miocene is probably correlative with a similar nonfossiliferous interval encountered to the west of Site 173 during DSDP Leg 5.

The presence of rare *Sphenolithus heteromorphus* and the absence of *Reticulofenestra pseudoumbilica* in Core 30 suggests a possible correlation with the *Helicopontosphaera ampliapertura* Zone of Trinidad. Many discoasters below 273 meters in this hole are heavily overgrown with secondary calcite. However, an assortment of preservations in Core 31, Section 1, suggests possible downhole mixing at this level. Core recovery in this portion of the hole was poor.

Fragments and occasional whole specimens of *Triquetrorhabdulus carinatus* are common from 306 meters to the bottom of the hole; however, rare poorly preserved specimens of *Reticulofenestra bisecta* in the *Triquetrorhabdulus carinatus* Zone (306 to 310 meters) may be reworked. The presence of *Cyclicargolithus abisectus*

throughout this zone indicates that only the lower portion of the zone is represented in Hole 173. The upper portion, in which *C. abisectus* should be absent, is probably truncated by the hiatus associated with the barren interval between 285 and 306 meters.

Etched specimens of *Reticulofenestra bisecta* are common between 312 and 320 meters which indicates an Oligocene age for the bottom of the section at Site 173.

#### SITE 174

(44° 53.38'N, 126° 21.40'W; water depth 2799 m)

Site 174 is located on the distal portion of the Astoria submarine fan which lies off the Columbia River of Oregon at the base of the continental slope. The site was drilled in order to date the acoustic discontinuity upon which the sediments of the Astoria Fan were deposited and to study fan deposition in relation to plate tectonics of the region. Drilling and coring were conducted down to 879 meters. Fine turbidite sands of Astoria Fan were penetrated down to a lithologic contact at 284 meters, below which lay abyssal plain silt turbidites.

The first core taken at Hole 174 contains a late Pleistocene or Holocene assemblage consisting of *Braarudosphaera bigelowii*, *Ceratolithus cristatus*, *Coccolithus pelagicus*, *Gephyrocapsa* spp., *Cyclococcolithina leptopora*, and *Emiliana huxleyi*. Following an offset due to drilling problems, coring was continued at Hole 174A where a total of forty cores were taken. The distribution, abundance, and preservation of coccoliths within these cores is indicated in Table 4. Assemblages are highly diluted by clastic sediments throughout the hole. Species diversity is low, particularly in the lower portion of the hole where seldom more than two or three forms are encountered in any given sample. This low species diversity plus the presence of *Coccolithus pelagicus* in thirteen of the cores is characteristic of cool-water conditions. Warm trends are indicated in Core 11 by the presence of *Helicopontosphaera kamptneri* and *H. sellii* and in Cores 35 to 40 by the presence of *Cyclococcolithina macintyreii* and *C. leptopora*. *Braarudosphaera bigelowii* in Cores 7, 11, 16, and 31 indicates a close proximity to land.

Three Pleistocene zones distinguished at Site 173 can be recognized at this locality. Assemblages are too sparse to permit electron microscope analysis; therefore, the base of the *Emiliana huxleyi* Zone is only approximated from light microscope study. *Gephyrocapsids* occur sporadically in the first sixteen cores, but the interval from 199 to 315 meters is essentially barren of calcareous nanoplankton. It is not possible to date the sediment at the base of the fan at 285 meters; however, well-preserved *Emiliana annula* are present at 376 meters which indicates that the overlying sediment may be as young as 600,000 years according to recent dates provided by Geitzenauer (1972). *E. annula* occurs sporadically down to 446 meters, but nannofossil control below this point is poor. A few rare specimens of *Gephyrocapsa* spp. in Cores 36 and 39 indicate that the strata down to 760 meters is Pleistocene provided that these specimens (mostly in core catcher samples) are not contaminants. No age assignment can be given the last core in the hole.

TABLE 4  
Distribution of Calcareous Nannofossils, Hole 174A

Zone	Depth (m)	Sample			Abundance (R, F, C, G)	Preservation (P, M, G)	<i>Braarudosphaera bigelowii</i>	<i>Braarudosphaera perversus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclicargolithus doricoides</i>	<i>Cyclococcolithina leptopora</i>	<i>Cyclococcolithina macintyreii</i>	<i>Discoaster</i> sp. cf. <i>D. verabilis</i>	<i>Emiliana annula</i>	<i>?Emiliana huxleyi</i>	<i>Gephyrocapsa</i> spp.	<i>Helicopontosphaera kamptneri</i>	<i>Helicopontosphaera sellii</i>	<i>Thoracosphaera saxea</i>
		Core	Section	Interval (cm)															
<i>Emiliana huxleyi</i>	30	1	1	83	F	M				0				-1					
	38	1	CC		F	M	-2	-2					FR	-3					
	43	2	4	90	R	M		-2											
	44	2	5	80	R	M			-2										
	47	2	CC		F	M			-2						0	-2			
	48	3	1	118	R	M			-2		-2				-1	-2			
	50	3	3	35	R	M			-2		-2				-1	-2			
	56	3	CC		R	M			-2		-2				-1	-2			
	59	4	2	95	R	M			-2						-1	-1			
	62	4	4	138	R	M			-1						-1	-1			
	66	4	CC		R	P			-2		-3				-1	-1			
	66	5	1	33	B														
	70	5	3	128	R	P	-2	-1							-2	-2			-2
	76	5	CC		R	P	-2	-2							-2	-2			-2
	78	6	2	125	R	P		-1							-2	-2			
82	6	5	102	R	M		-1							-2	-1				
85	6	CC		F	M		-2							-1	0				
?????																			
<i>Gephyrocapsa</i>	86	7	1	60	R	P	-2	-1								-2			
	94	7	CC		R	M	-2	-3								-3			
	95	8	1	26	R	M													
	98	8	3	65	B														
	104	8	CC		R	M		-2											
	109	9	4	45	R	M			-2										
	114	9	CC						-3								-2		
	126	11	2	138	R	M					-2					-1			
	128	11	4	78	R	M									?	-2			
	131	11	6	70	R	M					-1				?	-1			
	132	11	CC		F	M	-2	-1			-1					-1	-2		
	134	12	1	136	R	M			-1						?				
	142	12	CC		R	G										0			
	144	13	2	18	R	M			-1										
	152	13	CC		R	M			-2						?	-1			
	161	14	CC		R	M										-3			
	166	15	4	84	B														
	169	15	6	92	B														
	171	15	CC		F	M			0										
	172	16	2	40	B														
	180	16	CC		R	M	-3								?	-1			
	181	17	1	50	B														
	190	17	CC		B														
193	18	3	90	B															
199	18	CC		R	M			-2											
Cores 19-23: Barren (16 samples examined)																			
Cores 24-29: Occasional <i>Coccolithus pelagicus</i>																			
315	31	2	76	F	G	-2	0	+1							-1				
322	31	CC		C	G	-1	0	+1							0				
332	32	CC		F	M			0							-1				
342	33	1	91	R	M					-1									
344	33	2	111	B															

TABLE 4 - Continued

Zone	Depth (m)	Sample			Abundance (R, F, C, G)	Preservation (P, M, G)	<i>Braarudosphaera bigelowii</i>	<i>Braarudosphaera perversus</i>	<i>Coccolithus pelagicus</i>	<i>Cyclicargolithus daronicooides</i>	<i>Cyclococcolithina leptopora</i>	<i>Cyclococcolithina macintyreii</i>	<i>Discoaster</i> sp. cf. <i>D. verabilis</i>	<i>Emiliana annula</i>	? <i>Emiliana huxleyi</i>	<i>Gephyrocapsa</i> spp.	<i>Helicopontosphaera kamptneri</i>	<i>Helicopontosphaera sellii</i>	<i>Thoracosphaera saxea</i>
		Core	Section	Interval (cm)															
<i>Gephyrocapsa</i>	351	33	CC		C	G				0						0			
	371	34	1	77	R	M				-1	-2								
	372	34	2	28	R	P					-3								
	375	34	4	40	R	B													
<i>Emiliana annula</i>	376	34	4	140	F	G	-2			-2			-1						
	380	34	CC		F	M	-2	-1		-1			-2			0			
	409	35	1	98						-2									
	418	35	CC		F	M					-1-2		-2		-1				
	446	36	1	28	B														-2
	446	36	1	50	R	M				-1-1			-2						
	447	36	1	98	R	M	-3												
	456	36	CC		R	M										-1			
	504	37	1	34	B														
	507	37	3	91	R	M					-3								
	508	37	3	110	F	M			-3		-1-2								
	508	37	4	52	B														
	512	37	CC		B														
	637	38	1	141	B														
	646	38	CC		R	M		-2		?							?		
	751	39	1	83	R	M	-2				-2								
	752	39	2	26	R	M			-1		-2-2						-1		
	753	39	3	09	B														
	753	39	3	29	B														
	754	39	3	111	B														
760	39	CC		R	M	-3	-3			?						-3			
761	40	2	13	R	M			-2		-2									
764	40	3	85	R	M			-2											
765	40	4	123	R	M			-2											
766	40	5	55	B															
777	40	5	138	B															

## SITE 175

(44° 50.2'N, 125° 14.5'W; water depth 1999 m)

Hole 175 was drilled in ponded sediment lying in ridge-and-trough topography on the lower continental slope east of Site 174. A relatively uniform series of muds and fine sands were penetrated down to 195 meters by twenty-one continuous cores and by a spot core at 233 meters. Abundance, distribution, and preservation of calcareous nannofossils in eighty core samples are given in Table 5. Coccoliths are sparse or absent in most of the cores; however, small placoliths identified here as *Cyclicargolithus daronicooides* are abundant in Cores 12 and 13. Species diversity, however, is low. The cold-water indicators *Coccolithus pelagicus* and *C. pliipelagicus* n. sp. occur in most fossiliferous samples. The latter species is not listed on the range chart, but is common in Sample 175-8-2(130 cm). A warm interval is indicated in Core 11 by the presence of rare to common *Helicopontosphaera*

*kamptneri* as well as by warm-water planktonic foraminifera (see report by Ingle, this volume). *Braarudosphaera bigelowii*, a highly soluble coccolith only preserved in shallow waters and along continental margins, is conspicuous throughout the section where it occurs in over thirty-five samples.

The twenty-two cores cut at this site are Pleistocene and represent the three zones distinguished at Sites 173 and 174. The distribution of nannofossils is quite similar to that at Site 174. The first three and a half cores are assigned to the *Emiliana huxleyi* zone on the basis of light microscope study. A lithologic change occurs at 122 meters within the *Gephyrocapsa* Zone, and well-preserved *Emiliana annula* are moderately common in Sample 175-15(CC), 16 meters below this change in lithology. These coccoliths occur sporadically through the *Emiliana annula* Zone down to 148 meters. Common to abundant *Gephyrocapsa* spp., here considered to be indicative of Pleistocene strata, occur sporadically down to the first section of Core 20. The bottom two cores are barren.

TABLE 5  
Distribution of Calcareous Nannofossils, Hole 175

KEY	Sample				Abundance (R, F, C, G)	Preservation (P, M, G)	<i>Braardosphaera bigelowii</i>	<i>Coccolithus pelagicus</i>	<i>Cyclicargolithus daronicoides</i>	<i>Cyclococcolithina leptopora</i>	<i>Emiliana annula</i>	<i>?Emiliana huxleyi</i>	<i>Gephyrocapsa</i> spp.	<i>Helicopontosphaera kamptneri</i>	<i>Reticulofenestra pseudoumbilica</i>	<i>Rhabdosphaera stylifera</i>	<i>Thoracosphaera hemi</i>	<i>Thoracosphaera saxea</i>
	Depth (m)	Core	Section	Interval (cm)														
+1 very abundant																		
0 abundant																		
-1 common																		
-2 few																		
-3 rare																		
B barren																		
RW reworked																		
FR fragment																		
Zone																		
<i>?Emiliana huxleyi</i>	3	1	2	130	F M	-1	0				0		-1					
	4	1	3	130	F M	-1					0							
	5	1	4	30	R M	-1					0							
	5	1	4	70	F M	-1	0				0		-1					
	5	1	CC		F M	-1	0				0		-1					
	6	2	1	130	F M		0				0		-1					
	9	2	3	130	R M	-1	-1					-1					-2	
	11	2	4	130	R M	-1						-2						
	14	2	CC		F M	-1	0					0			RW		-2	
	16	3	1	130	F M		0					0						
	20	3	4	133	F M	-1	0					0						-2
	22	3	5	137	R M						-2							
	24	3	CC		F M			0				+1		-1				
	28	4	3	130	F M			-1				-1						
<i>Gephyrocapsa Oceanica</i>	30	4	4	130	R M		-2											
	31	4	5	130	B													
	34	4	CC		B													
	36	5	2	130	B													
	39	5	4	130	R M	-3	-3											
	41	5	5	127	R M	-1	-1											
	42	5	6	130	B													
	43	5	CC		F M	-1	0										-3	
	44	6	1	132	R M	-1	-1											
	46	6	2	120	F M	-1	-1	?					?				-2	-2
	50	6	5	130	R M			-1									-1	
	52	6	CC		B													
	55	7	2	130				-1						-1				
	57	7	3	130	B													
	62	7	CC		R M			-3						?				
	65	8	2	130	F M	-1	-1											
	72	8	CC		F M	-1	-1	?					-1					
	74	9	2	129	R M								-1					
	81	9	CC		B													
	82	10	1	128	B													
	85	10	3	129	B													
	88	10	5	128	B													
	90	10	CC		F M	-1		?			-2			-1				
	92	11	1	118	F M			?						0	-2			
	95	11	3	130	R M	-1	-1											
	98	11	5	130	R M	-1	-1							-1	-2			
	100	11	CC		F M	-1	0	0			0				-1			
	101	12	1	118	F M			-1	+1					-1				
	110	12	CC		C G	-3	0	+1										
	111	13	1	135	C G			-1	+1									?
113	13	2	120	C G	-1	-1	+1						-1					
114	13	3	130	F M	-1	-1	0											
119	13	CC		R M			-2											
119	14	1	3	F M			-1	0										
122	14	2	130	B														
125	14	4	130	B														
128	14	CC		R M			-3											
131	15	2	135	F M			-1	0					-1					
134	15	4	120	R M			-3											

TABLE 5 - Continued

	Depth (m)	Core	Section	Interval (cm)	Abundance (R, F, C, G) Preservation (P, M, G)	<i>Braarudosphaera bigelowii</i>	<i>Coccolithus pelagicus</i>	<i>Cyclicargolithus doronicoides</i>	<i>Cyclococcolithina leptopora</i>	<i>Emiliana annula</i>	? <i>Emiliana huxleyi</i>	<i>Gephyrocapsa</i> spp.	<i>Helicopontosphaera kamptneri</i>	<i>Reticulofenestra pseudoumbilica</i>	<i>Rhabdosphaera stylifera</i>	<i>Thoracosphaera hemi</i>	<i>Thoracosphaera saxea</i>
<i>Emiliana annula</i>	138	15	CC		C G	-1	0		-3	-1		-2					
	141	16		130	F G	-1	0			-3							
	142	16	3	130	F G		-1	0				-1					
	144	16	4	130	C G		-1	0				-1					
	147	16	6	130	F G	-1	-1	0									
	148	16	CC		F G		0	-1	-3	-3							-2
	150	17	2	130	F G		-1	0				0					
	152	17	3	130	B												
	153	17	4	130	F G		-1	+1				-1					
	155	17	5	130	F M		-1	0									
	157	17	CC		C M		-1	+1				0				-3	
	158	18	1	130	F M		0	0	-2								-2
	160	18	2	130	B												
	161	18	3	130	C M		-1	+1				+1					
	162	18	4	30	B												
	166	18	CC		B												
	168	19	1	130	B												
	169	19	2	135	B												
	176	19	CC		R			-3									
	177	20	1	130	C G			-1	+1	-1		-1					-2
	179	20	2	130	F P		-1			-1							
	186	20	CC		R M			-3									-3
	187	21	1	130	B												
188	21	2	130	B													
195	21	CC		B													
225	22	1	133	B													
233	22	CC		B													

## SITE 176

(45° 56.0'N, 124° 37.0'W; water depth 187 m)

Site 176 is located in extremely shallow water on the continental shelf east of Sites 174 and 175. Coring was intended to test engineering aspects of shallow-water drilling and to date an unconformity thought to be coeval with uplift of the lower continental slope off Oregon. Five continuous cores were cut in greenish grey mud down to 42 meters where drilling was terminated following a twist-off of the bottom-hole assembly.

The distribution of calcareous nannofossils in the five cores is given in Table 6. Coccoliths occur sporadically and in small numbers in this section. The first three cores are assigned to the *Emiliana huxleyi* Zone on the basis of light microscope study. The fourth core is essentially barren. Core 5, which lies beneath the unconformity, contains a nondiagnostic assemblage (including reworked Mesozoic forms) which lacks definitive Pleistocene species. The cool-water *Coccolithus pelagicus* occurs throughout the section and *C. pliopelagicus* is common in the first section of Core 5.

## SITE 177

(50° 28.18'N, 130° 12.30'W; water depth 2006 m)

Site 177, on Paul Revere Ridge off the northwest tip of Vancouver Island, was drilled to determine if this unusual feature at the triple juncture of the Pacific, Juan de Fuca, and American plates is continental or oceanic crust. In Hole 177A, 26 cores were cut through Pleistocene muds and Pliocene fan or continental rise sediments which alternate with hemipelagic sediments deposited near the continental margin at water depths estimated to have been between 1500 and 2000 meters (Ingle, this volume). No continental shelf sediments were cored in the 507 meter hole.

Calcareous nannofossils are generally sparse or absent in Holes 177 and 177A. Species diversity is extremely low and is indicative of cool surface water conditions. Except for isolated nannofossil oozes, assemblages are highly diluted by terrigenous turbidites and muds. Ceratoliths, discoasters, and the lower Pleistocene guide fossil, *Emiliana annula*, were not observed; therefore, the "standard" succession of calcareous index nannofossils, which permitted a reasonable subdivision of the Plio-Pleistocene interval at Site 173,

TABLE 6  
 Distribution of Calcareous Nannofossils, Hole 176

Zone	Depth (m)	Sample			Abundance (R, F, C, G)	Preservation (P, M, G)	<i>Braarudosphaera bigelowii</i>	? <i>Ceratolithus</i> spp.	<i>Coccolithus pelagicus</i>	<i>Coccolithus pliopelagicus</i>	<i>Cyclococcolithina leptopora</i>	? <i>Emiliana huxleyi</i>	<i>Gephyrocapsa</i> spp.	<i>Thoracosphaera hemi</i>	<i>Thoracosphaera saxea</i>	<i>Watznaueria barnesae</i>
		Core	Section	Interval (cm)												
? <i>Emiliana huxleyi</i>	1	1	1	130	B											
	3	1	2	130	B											
	3	1	3	05	R M											
	4	1	3	120	B											
	5	1	4	60	R M											
	6	1	CC		R M											
	7	2	1	88	R M											
	8	2	2	105	R M											
	10	2	3	60	R M											
	13	2	5	130	B											
	15	2	CC		R M											
	16	3	1	130	R M											
	18	3	2	122	F M											
	21	3	4	130	F M											
22	3	5	130	B												
23	3	6	11	F M												
Indeterminant	25	3	CC		B											
	28	4	2	137	B											
	29	4	3	90	B											
	30	4	4	110	B											
	32	4	5	131	R M											
	33	4	CC		B											
	33	5	0		C M											
	34	5	1	120												
	36	5	2	30	R P											
	39	5	4	132	F M											
	39	5	5	40	B											
41	5	6	45	B												
42	5	CC		C G												

could not be recognized at this northerly site. By the same token, the "Standard Neogene Calcareous Nannoplankton Zonation" as summarized by Martini and Worsley (1970) and Martini (1971a) proved to be essentially unworkable at this locality and those drilled further north (dissolution effects notwithstanding).

The single core recovered in Hole 177 and Cores 1, 2, and 4 taken from Hole 177A contain small numbers of *Gephyrocapsa* spp. and are Pleistocene in age. Sample 177A 2-3(130 cm) contains abundant *Coccolithus pliopelagicus*, *Emiliana huxleyi*, common *Coccolithus pelagicus* and *Braarudosphaera bigelowii*, and rare *Gephyrocapsa* spp. (closed center) and *Thoracosphaera saxea*. This sample marks the base of the *Emiliana huxleyi* Zone as determined by light microscopy. In the absence of other index species, no attempt was made to subdivide the remaining Pleistocene cores. Core 3 is barren of calcareous nannofossils. Cores 5 to 13 are essentially barren except for sporadic

occurrences of *Coccolithus pelagicus*. Most sections of Core 14 contain an unusually high abundance of *Cyclicargolithus daronicooides* in a mud matrix undiluted by turbidite sands. Nineteen samples from Cores 15 to 18 are barren. Sparse *Coccolithus pelagicus*, *Cyclicargolithus daronicooides*, and rare fragments of shields of *Cyclococcolithina leptopora* occur sporadically in Cores 19 to 22. Core 25, cut beneath a basalt sill, recovered micrite derived from small (5-micron) coccoliths which can be attributed to *Coccolithus daronicooides* or perhaps to a small species of *Reticulofenestra*. No stratigraphically diagnostic calcareous nannofossils occur in this ooze, but the absence of *Gephyrocapsa* indicates a Pliocene age for this part of the section.

Whole specimens of *Braarudosphaera bigelowii*, which is indicative of near shore or shallow-water deposition, were encountered only in Cores 1 and 2. A fragment was found in Core 23.

The age of Cores 51 and 52, as determined by diatoms (Schrader, Chapter 17, this volume), is late Miocene. Core 53 is barren of coccoliths.

Core 54 is highly varied in color, ranging from chalky white, light to dark green, gray, pink to rouge, yellow, and light to dark brown. Whitish, light green, and light pink chalk is found in all five sections of the core. The remaining sediment cores from the hole (Cores 55 to 58) are barren of calcareous nannofossils.

#### Miocene Chalk: Paleontology and Paleoecology

The chalk in Core 54 is composed of a highly restricted cold-water assemblage of calcareous nannofossils which includes forms not found at warm latitudes. The nannoflora is dominated by *Cyclicargolithus bukryi*, n. sp. *Discoaster deflandrei* is common in some samples (for example, 178-54-3, 145 cm), but specimens are heavily overgrown with secondary calcite. This is the first report of Neogene discoasters from high latitudes of the North Pacific. *Coccolithus miopelagicus* and *Coccolithus* spp. cf. *pliope-lagicus* are also common in the chalk; however, sphenoliths are absent. The low diversity of this assemblage and the near absence of discoasters is a function of a cold (middle- to high-latitude) environment of deposition. *Discoaster deflandrei* is a cosmopolitan species which, in the North Atlantic, occurs in sediment as high as 59°56'N where waters are warmed by the Gulf Stream (Leg 12, Site 114; see Laughton et al., 1972). Most other species of discoaster, however, are found at low or middle latitudes and, as a rule, *Discoaster* is considered to be a warm-water genus. The two species of *Coccolithus* in Core 54 have small central areas and wide distal shields, traits shared by many Plio-Pleistocene representatives of this genus sampled at the more northerly sites drilled by Leg 18. *Cyclicargolithus bukryi* appears to be a cool-water relative of *Cyclicargolithus floridanus*. This latter species ranges no higher than the middle middle Miocene in tropical regions. This, together with presence of *Discoaster deflandrei* and the absence of *Reticulofenestra bisecta*, indicates a lower Miocene to middle middle Miocene age for the assemblage. This determination is in harmony with the lower Miocene age indicated by planktonic foraminifers in this core (see Ingle, Chapter 14, this volume).

Diatoms extend down to Section 3 of Core 54 and are considered to be Upper Miocene in age (Schrader, this volume). These may possibly have been reworked downward by burrowing organisms. If so, a depositional hiatus is present with much of the middle portion of the Miocene record missing.

Above the chalk, siliceous organisms are the dominant constituent of the planktonic fauna and flora. The combined drilling results of Sites 177 and 178 indicate that the cold-water restricted calcareous nannoplankton floras made only minor contributions to the post lower Miocene fossil record in northeast Pacific during most of the Neogene. This has resulted in the breakdown of the "standard" Neogene calcareous nannofossil zonation based on their occurrence (summarized by Martini and Worsley, 1970; Martini, 1971a). The paucity of nannofloras here cannot be attributed merely to selective species dissolution

in deep waters, but also to ecological restrictions imposed by the middle- to high-latitude environment of deposition.

#### SITE 178

(56°57.38'N, 147°07.86'W; water depth 4218 m)

Site 178, on the Alaskan Abyssal Plain 330 km southwest of Kodiak Island and south of the Aleutian Trench, was drilled and cored 777.5 meters to basement (basalt) in order to obtain biostratigraphic information for this high-latitude region and to study glacial sedimentation and ocean floor migration. With the major exception of a chalk at 742 meters (Core 54), most of the sediment was deposited at depths below the carbonate compensation level and is devoid of calcareous nannofossils. One hundred twenty-nine samples from the fifty-nine cores were examined.

The upper 270 meters of sediment consist of grey muds with glacial erratics which overlie a 472-meter sequence of interbedded muds, diatomaceous sediments, thin poorly sorted silts, and sand turbidites. The only calcareous nannofossils observed are rare specimens of well-preserved *Coccolithus pelagicus* which were probably deposited in association with turbidites (for example, 178-10-3, 130 cm at 82 meters and 178-29, CC at 558 meters). Cores 51 and 52 (658 to 690 meters) contain rare Oligocene-Miocene coccoliths deposited with olive grey muds and turbidite silts. Species include *Coccolithus pelagicus*, *Cyclicargolithus bukryi*, *Discoaster deflandrei*, *Braarudosphaera bigelowii* (extremely rare), and *Reticulofenestra umbilica* (12 to 17 microns). Several fragments and isolated rims of *R. umbilica* were also noted. Most of the above coccoliths are probably reworked from the chalk unit cored at 742 meters. The specimens of *Reticulofenestra umbilica*, however, are reworked from a lower Oligocene or Eocene source.

The occurrence of nannofossil chalk at this high latitude (56°N) and at such great depth (4960 meters below sea level) is somewhat remarkable. Although tectonics could be invoked to explain this phenomenon, it is noteworthy that the chalk is underlain by unfossiliferous pelagic clays (Cores 55 to 58) rather than turbidites. Thus, it is most probable that the chalk represents a sharp downward excursion of the carbonate compensation level produced by an exceptionally high production of calcareous phytoplankton. These supplied large amounts of skeletal carbonate to the sea floor and increased the sedimentation rate sufficiently to depress the carbonate compensation level several hundreds of meters. It has previously been noted (Tracy et al., 1971) that in the equatorial Pacific, the Early Miocene was a time of widespread carbonate deposition. Perhaps favorable current conditions allowed the incursion of carbonates into the Gulf of Alaska during this time. Our data, however, does not necessarily suggest that the chalk was deposited at precisely 56°N latitude. It could have been deposited several hundreds of kilometers further south and subsequently moved to its present position by plate motion.

#### Miocene Chalk: Diagenesis and Lithification

The chalk in Core 54 consists mostly of broken or isolated shields of *Cyclicargolithus bukryi*. The central areas

of these fossils are more susceptible to solution than the rims and, with few exceptions, have been dissolved. This suggests that the original unconsolidated nannofossil ooze was deposited well below the lysocline near the base of the carbonate compensation zone. It would not be surprising to observe in this material dissolution-reprecipitation phenomena similar to those observed at Site 172. Indeed, many discoasters in the chalk exhibit characteristic features of secondary calcite overgrowth such as crystal faces along rays (Plate 9, Figures 6, 7) and obfuscation of ray tip bifurcations. The uniform development of these overgrowths indicates that they probably formed early during diagenesis before the sediment underwent significant compaction. Later diagenesis apparently caused some solution of chalk particles as indicated by the etch channel in one ray of the astrolith in Plate 9, Figure 7. Late stage dissolution may also explain the ragged appearance of the discoaster in Plate 10, Figure 1. Some reprecipitation of calcite during a late phase of cementation is indicated by the calcite bridge which joins corresponding elements of the shields of a placolith in Plate 10, Figure 2 (arrow). Much of the groundmass of the chalk, however, consists of anhedral grains of skeletal debris, many of which served as nuclei for the precipitation of secondary calcite (Plate 10, Figure 3). Most particles which have developed calcite overgrowths have been cemented together by the secondary calcite. A few particles within the groundmass are recognizable skeletal fragments such as the little "U"-shaped particle in the upper right of Plate 10, Figure 3 (arrow) which is a remnant of the central collar and shield elements of a placolith.

A most striking feature of the chalk is the preservation of delicate skeletal structures within pore spaces of the rock. Placoliths are undeformed by compaction, and the fragile remains of heavily etched coccospheres (Plate 10, Figure 5) are intact despite the lack of calcite infillings or other forms of internal support. No pressure solution features such as interclast penetration are observed. Grosser features of the chalk, such as *Zoophygy* burrows, also show little or no effects of compactive deformation. These observations suggest that the chalk must have been lithified early during diagenesis before it was deeply buried under the present accumulation of 742 meters of clastic sediment. Early lithification allowed the chalk to withstand heavy overburden pressures during the subsequent loading of hundreds of meters of sediment.

As shown by the micrographs on Plate 10, cementation began with the precipitation of calcite overgrowths on calcareous nannofossils and on minute particles of skeletal debris. Calcite was made available by the in situ dissolution of calcareous nannofossils. As no other significant amounts of carbonate were encountered in the hole, the only possible source of carbonate cement is the chalk layer itself. The similarity in the style of overgrowths observed on discoasters in the chalk and those in the coccolith ooze at Site 172 suggests that the overgrowths at Site 178 began to form quite early during diagenesis. Some additional dissolution and reprecipitation of calcite may have occurred during later stages of diagenesis as overburden pressures increased. However, by the time a significant overburden had accumulated, the chalk was sufficiently well lithified

by early cementation that it could withstand compactive deformation. Thus, pressure solution effects such as interclast penetration and stylolization are absent in the chalk. Similarly, pore spaces have not been closed by the large scale precipitation of calcite, a phenomenon which usually accompanies these diagenetic processes.

Chalks which are thought to have been protected by early cementation from deformation during later stages of diagenesis are not unknown in the geologic record. Wolf (1968) presents an excellent discussion of a Cretaceous analogue of this phenomenon in his study of Irish chalks.

Cementation of chalk at Site 178 was apparently followed by the growth of an authigenic clay mineral within pore spaces of the rock. The clay platelets are usually flexed and grow in crude honeycomb patterns (Plate 10, Figures 2, 6) not unlike those exhibited by smectites (Wise, unpublished). X-ray analyses of insoluble residue from the chalk (Hays, this volume) does indicate the presence of the smectite, montmorillonite, in the chalk, and this identifies the authigenic clay mineral in the above micrographs. The montmorillonite probably formed as an alteration product of volcanic glass.

#### SITE 179

(56°24.54'N, 145°59.32'W; water depth 3781 m)

A 109-meter continuously cored section was cut on the eastern side of Giacomini Guyot (Gulf of Alaska, south of Site 178) in hopes of obtaining a regional biostratigraphic reference section in pelagic sediment free of deep-ocean turbidites. Of the thirteen cores recovered, calcareous nannofossils are present only in the first five. According to radiolarian and diatom determinations, these five cores are no older than 1.0 m.y. The calcareous nannofloras are composed almost exclusively of *Coccolithus pliopelagicus* and *C. pelagicus*, solution-resistant forms which are abundant in some samples. They form most of the matrix of a diatom calcareous nannofossil ooze in Sample 179-2-4(64 cm). Heavy dissolution, however, has destroyed the centers of most specimens in this sample leaving a melange of whole or fragmented distal shields. This state of preservation suggests deposition near the base of the carbonate compensation zone. The presence of the *Coccolithus pelagicus* throughout the first five cores indicates surface water paleotemperatures of between 6°C and 14°C if a direct analogy is made to the distribution of present day populations of this species (see MacIntyre, Ruddiman, and Roche, 1970).

Although coccoliths are common to abundant in pelagic sequences in the first two cores, they decrease in number in Cores 3 to 5. Poorly preserved, reworked Neogene and possibly Paleogene species occur in Cores 2 to 5. Forms such as *Cyclicargolithus bukryi* (179-2,CC), *Reticulofenestra pseudumbilica* (179-5-1, 130), and *R. umbilica* (core catchers, Cores 2 and 4) were probably introduced with turbidites which are common in this portion of the hole. Section 4 of Core 4 and most of Core 5 contain small (2.5- to 4.5-micron) coccoliths, some of which may be etched specimens of *Gephyrocapsa* or of *Cyclicargolithus doronicoides*. Below 179-5(CC), all samples examined are barren of calcareous fossils.

**Carbonate Compensation Level Migration, Site 179**

The presence of calcareous fossils in only the top five cores of the hole indicates that Site 179 was below the carbonate compensation level during the deposition of the lower portion of the section. During the lower to middle Pleistocene (about 900,000 years B.P. according to diatom determinations), the site was above the carbonate compensation level, a condition that prevailed to the present time. A flurry of phytoplankton productivity produced the diatom-calcareous nannofossil ooze in Core 2.

Assuming that the seamount drilled at Site 179 did not undergo tectonic uplift during the Pleistocene, it appears that the carbonate compensation level in the Gulf of Alaska descended during Plio-Pleistocene times, reaching a level of about 3800 meters<sup>1</sup>) some 900,000 years ago. The carbonate compensation level then continued its descent until it reached its present position in this area of about 4,000 meters. It is interesting to note that sediments in the North Atlantic record a similar drop in the carbonate compensation level during the Plio-Pleistocene interval (Gartner, 1970).

**SITE 180**

(57°21.76'N, 147°51.37'W; water depth 4923 m)

Hole 180 was drilled and cored 470 meters into the eastern Aleutian Trench in order to study deep-sea trench sedimentation and to learn more about the glacial history of Alaska. The twenty-five cores recovered contain upper Pleistocene silt turbidites, interbedded muds with silt laminae and glacial erratics. Calcareous nannoplankton are few to rare but nevertheless present in most samples from the first nineteen cores. *Coccolithus pelagicus* and *C. pliipelagicus* are generally dominant in assemblages which also contain *Gephyrocapsa* spp., an imperforate species of *Thoracosphaera*, and small 3- to 4-micron coccoliths of uncertain specific identity. Some of the latter (in cores down to at least Core 17) are probably *Emiliania huxleyi* although these small forms are too rare to permit positive identification via electron microscopy. The preservation of all Pleistocene nannofossils is quite good. Considering the great depth of water at this locality (4923 meters) and the fact that the site of deposition is well below the carbonate compensation level, it is assumed that all calcareous nannofossils observed here were eroded from shallow-lying shelf areas, transported to the trench floor by turbidity currents, and quickly buried by inflowing sediment. The high rate of sedimentation at this site (estimated at 0.3 to 2.4 km/m.y.) would account for the quick burial and excellent preservation of the nannoflora. One possible

source for these sediments may be shelf areas along the northeastern end of the trench (Tarr Bank, Wessels Reef, Cape St. Elias, and Kayak Island) where upper Pleistocene strata have been tilted and truncated by erosion.

**SITE 181**

(57°26.30'N, 148°27.88'W; water depth 3086 m)

Site 181, on a steep ridge of the lower continental slope about 2000 meters above the Aleutian Trench, was cored and drilled 369 meters below the sea floor in order to determine the age, provenance, and physical properties of rocks deformed in the lower continental slope. Sparse calcareous nannofossils are present only in a few of the thirty cores cut in the thin sands and the silt and diatom-bearing muds at this site. All coccoliths encountered below Core 10 are reworked. Cores 1 and 9 contain *Emiliania huxleyi* and are late Pleistocene in age. The first core also contains *Thoracosphaera* spp. and the cold-water forms, *Coccolithus pelagicus* and *C. pliipelagicus*. These also occur sporadically in Cores 2, 8, 9, and 10.

Cores 11 to 30 (94 to 369 meters) are barren except for occasional reworked specimens. These latter often occur in sand-size pods of calcareous material which were apparently transported to the site of deposition as discrete particles. Sample 181-19-1(112 cm) yielded a small sand-size pod of micrite which contains several small placoliths. These may have been derived from a lower Pleistocene calcareous ooze. Other grains of micritic material in Samples 181-25-1(105 cm) and 181-28(CC) contain two specimens of *Watznaueria barnesae*. A third specimen of this Mesozoic species was observed in Sample 181-26-1(125 cm).

The absence of calcareous nannoplankton in most of the material from Site 181 indicates that the original site of deposition was below the carbonate compensation level. This hypothesis assumes that the material has since been uplifted tectonically sometime during the past million years to its present water depth which is above the carbonate compensation level.

The last common downhole occurrence of *Gephyrocapsa* is in Sample 181-19(CC) although a single small specimen was observed in Sample 180-22-4(70 cm). Nannoplankton are generally less abundant in Cores 20 to 25 than in the upper portion of the hole although many of the same Pleistocene species are represented in the bottom six cores. Reworked fossils in the upper portion of the hole include Neogene forms such as *Reticulofenestra pseudoumbilica* (181-5,CC) and the Eocene-lower Oligocene coccolith *Reticulofenestra umbilica* (181-15,CC). The latter is also present in Sample 180-25-1(127 cm) and in 18-20(CC) which, in addition, contains a reworked Mesozoic specimen, *Watznaueria barnesae*.

**SITE 182**

(Hole 182: 57°52.96'N, 148°42.99'W;  
water depth 1914 m)

Hole 182A: 57°52.88'N, 148°43.39'W;  
water depth 1434 m)

Two holes on the upper continental slope off Kodiak Island were interval cored to a maximum depth of 166 meters in hopes of obtaining for this region a

<sup>1</sup> In calculating the original depositional depth represented by the carbonate boundary at the base of Core 5, the isostatic effect of loading is accommodated by halving the sample depth below the sea floor in accordance with the procedure suggested by Berger (1972). If the seamount itself has been undergoing isostatic subsidence, then the depth of original carbonate deposition would have been shallower than 3800 meters, and the Plio-Pleistocene drop in the carbonate compensation level would be even sharper than that indicated here.

biostratigraphic reference section deposited above the carbonate compensation level. The total of seven cores cut in sandy and gravel-rich muds contain sparse calcareous nannofossils except for Sample 182-3-1(130 cm) which yields abundant small forms referred here to the upper Pleistocene species, *Emiliana huxleyi*. Etching makes identification of these specimens difficult, even under the scanning electron microscope, because etched specimens of *Gephyrocapsa* can present a similar appearance. If the specimens here are *Emiliana huxleyi*, they may be contaminants introduced by downhole slumping or tectonic disturbance because diatoms indicate that Core 3 is older than 0.92 million years (Schrader, this volume). The Pleistocene marker *Gephyrocapsa* spp. is present in Cores 1 to 3, but was not observed in subjacent cores. Sparse to common *Coccolithus pelagicus* or *C. pliipelagicus* occur in all cores along with occasional *Thoracosphaera* spp. Because nannofossils are present in all cores, the material penetrated at this site was probably deposited above the carbonate compensation level.

#### SYSTEMATIC PALEONTOLOGY

Species considered in this study are listed in Table 1. Bibliographic references for these taxa are provided by Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b). Comments on selected species are given below in addition to recombinations and descriptions of three new species encountered in Leg 18 core material. The two new placolith species are most abundant in the higher latitudes of the northeast Pacific and therefore appear to be of ecologic importance. Type specimens are deposited in the U.S. National Museum, Washington, D.C., Tertiary Catalog No. 36.

#### Genus COCCOLITHUS Schwarz, 1894

##### *Coccolithus formosus* (Kamptner) Wise, n. comb. (Plate 4, Figures 1-6)

- Cyathosphaera diaphragma* Hay and Towe, 1962, Pl. 6, ?Figs. 2, 5, Non p. 510, 511, Pl. 6, Figs. 3, 4, 6.  
*Cyclococcolithus formosus* Kamptner, 1963, p. 163, Pl. 2, Fig. 8.  
*Coccolithus lusitanicus* Black, 1964, p. 312, Pl. 52, Fig. 4.  
*Ericsonia alternans* Black, 1964, p. 312, Pl. 52, Fig. 4.  
*Cyclococcolithus lusitanicus* (Black), Hay, Mohler and Wade, 1966, p. 390, Pl. 7, Figs. 3-6.  
*Cyclococcolithus orbis* Gartner and Smith, 1967, p. 4, Pl. 4, Figs. 1-3.  
*Umbilicosphaera formosa* (Kamptner) Reinhardt in Cohen and Reinhardt, 1968, p. 295.  
*Cyclococcolithina formosa* (Kamptner) Wilcoxon, 1971, p. 82.

Remarks: Perch-Nielsen (1971) has shown that the proximal shield of this taxon is composed of two cycles of elements, a feature characteristic of most if not all members of the *Coccolithus pelagicus* lineage. This feature is not shared, however, by *Cyclococcolithina leptopora*, which is the type species of the genus *Cyclococcolithina* Wilcoxon, 1971. An assignment of *Coccolithus formosus* to the genus *Cyclococcolithina*, therefore, is not considered appropriate. Crystallographic properties of *Coccolithus formosus* are essentially the same as those of *Coccolithus pelagicus*. Under cross-polarized light, the strongly imbricate elements of the distal shield are extinct whereas the proximal shield and central area are bright and transected by a sharp interference cross. The only major difference between *C. formosus* and other members of the *Coccolithus pelagicus* lineage is the nearly circular outline of the periphery and central area. In most other members of the lineage, these features are strongly elliptical; however, this difference is not necessarily cause for generic separation. Because the status of the genus *Ericsonia* Black, 1964, is in doubt (see discussion by Bukry, in press), *C. formosus* is assigned to the genus *Coccolithus*, a transfer considered to be in keeping with the close phylogenetic affinity of this form to other members of the *Coccolithus* lineage as evidenced by similar crystallography and ultrastructure.

##### *Coccolithus miopelagicus* Bukry, emend. (Plate 8, Figures 9-11)

*Coccolithus miopelagicus* Bukry, 1971, p. 310, Pl. 2, Figs. 6-9.

Description: Large placolith with medium- to small-sized central area and broad, distinctly striate rim. In cross-polarized light the central area and proximal shield are bright; however, the distal shield is dark as is characteristic of members of the genus (see Black, 1971; Bukry, in press).

Remarks: This species was first described from Miocene deposits of the East Caroline Basin, western equatorial Pacific Ocean, where forms exhibit medium-sized central areas which occupy  $42 \pm 3\%$  of the short axis of the coccolith. Specimens recovered on DSDP Leg 18 from lower(?) Miocene deposits cored in the Alaskan Abyssal Plain (Core 178-54), however, exhibit exceptionally small central areas, some of which occupy only 30% of the short axis of the coccolith. Complete gradations between these specimens and those originally assigned to the species are also present in the Alaskan material; therefore, the definition of the species is here emended to include specimens having small as well as medium-sized central areas. The proximal rim of *C. miopelagicus* is composed of two cycles of elements nearly equal in width (Plate 8, Figure 11). In the Alaskan specimen (Figure 11), the proximal shield is extremely narrow in sharp contrast to the broad distal shield. The common occurrence of this species in northern latitudes indicates a tolerance or even affinity for temperate or cold waters. The species, however, is also found at low latitudes.

Occurrence: Common in lower and middle Miocene sediment from the equatorial Atlantic and Pacific oceans, Caribbean Sea, and northeast Pacific Ocean.

Size: 13-20 microns.

Hypotype: USNM 186177, 178-54-2(27 cm) (Plate 8, Figures 9-10).

##### *Coccolithus pliipelagicus* Wise, new species (Plate 8, Figures 1-6)

Description: This medium-sized elliptical species of *Coccolithus* has a narrow, usually elongate central area and broad distal shield. Both the rim and central area are prominent in transmitted light. In cross-polarized light, the central area is bright with sharp extinction bands; the proximal (smaller) shield is also bright; however, the distal shield is dark, as is characteristic of the genus (see Bukry, in press).

Remarks: The exceptionally narrow central area, broad distal shield, and medium size of this coccolith distinguish it from similarly constructed species. The central area occupies less than 40% of the short axis of the coccolith. For most specimens, the central area occupies only about 30% of the short axis. The eccentricity of the central area ranges from 1.2 to 2.1. *C. pliipelagicus* ranges from 6 to 13 microns in length along the major axis with an average length of 9 to 10 microns. Thus, it is distinguished by its smaller size from *C. miopelagicus* which ranges from 13 to 20 microns in length. It is distinguished from *C. pelagicus* by its narrow central area and broad brim. A central area occupancy of 40% of the short axis is here considered a convenient division point between these two taxa. *C. pliipelagicus* is distinguished from *C. eopelagicus* by its smaller size and narrower central area. According to Bukry (1971c) the central area of *C. eopelagicus* occupies  $49 \pm 2\%$  of the short axis of that species.

Occurrence: *Coccolithus pliipelagicus* is common in Pliocene and Pleistocene sediments cored by DSDP Leg 18 along the west coast of the United States and Canada from Oregon to Alaska. This distribution indicates that *C. pliipelagicus* is a cool-water species common to the high latitudes of the North Pacific region. It has not been reported from the equatorial Pacific. *C. pliipelagicus* may have originated early during the Miocene as indicated by small specimens of *Coccolithus* sp. cf. *pliipelagicus* (Plate 8, Figures 7, 8) recovered in lower(?) Miocene sediment from Site 178 (Alaskan Abyssal Plain). These forms closely resemble *C. pliipelagicus* except that their central areas are less elongate and more oval than those of Plio-Pleistocene members of the species. Nevertheless, the flora from Site 178 shows that the evolution of small forms having narrow central areas was underway during Miocene times. Unfortunately, calcareous nannoplankton have not been recovered from upper

Miocene sediment of the northeast Pacific. Therefore, a complete evolutionary record of this lineage is not yet available.

**Size:** 6 to 13 microns; average 10 microns.

**Holotype:** USNM 186174 (Plate 8, Figures 1-3).

**Paratypes:** USNM 186175-186176 (Plate 8, Figures 1-6).

**Type locality:** DSDP 176-5(120 cm), Oregon continental shelf off the northwestern coast of the United States.

Genus CYCLICARGOLITHUS Bukry, 1971

*Cyclicargolithus abisectus* (Müller) Wise, n. comb.

*Coccolithus* aff. *C. bisectus* (Hay, Mohler and Wade). Bramlette and Wilcoxon, 1967, p. 102, Pl. 4, Figs. 9-10.

*Coccolithus?* *abisectus* Müller, 1970, p. 92, Pl. 9, Figs. 9-10; Pl. 12, Fig. 1.

*Dietyococites abisectus* (Müller) Bukry and Percival, 1971, p. 127, Pl. 2, Figs. 9-11.

**Remarks:** Although *C. abisectus* shows some affinity to *Reticulofenestra bisecta*, its appearance in cross-polarized light is closer to that exhibited by *Cyclicargolithus floridanus*. Because no grill structure has been shown to cover the central opening of this taxon, it is transferred to the genus *Cyclicargolithus* which lacks such structure.

*Cyclicargolithus bukryi* Wise, new species

(Plate 9, Figures 1-3)

**Description:** Distinctly subcircular placolith constructed of two shields bright in cross-polarized light which exhibit a moderate to wide central area covered or partially covered by lath-shaped plates on the distal side.

**Remarks:** Middle Tertiary coccoliths of the *Cyclicargolithus floridanus* plexus were first described from the Blake Plateau east of Florida (Roth and Hay, 1967) and secondly from Trinidad, B.W.I. (Bramlette and Wilcoxon, 1967). Although some variation in peripheral outline is exhibited by these early described specimens, all are nearly circular in outline and all have since been assigned to the genus *Cyclococcolithus* by Müller (1970) and Roth (1970). Specimens that closely resemble *C. floridanus* form the bulk of a lower(?) Miocene chalk recovered on Leg 18 at Site 173 (Alaskan Abyssal Plain). These specimens differ from *C. floridanus*, however, in having a distinctly subcircular outline with an eccentricity greater than 1.1. In addition, the Alaskan species characteristically have medium to large elliptical central areas which occupy 50% or more of the short axis of the coccolith. *C. floridanus* has a smaller, more rounded central area (compare Figures 4 and 5 of Plate 9). The central area of *C. bukryi* is also covered or partially covered by a series of imbricate lath-shaped elements (Plate 9, Figure 4). Element counts based on SEM micrographs of shields range from 48 to 54 units.

The recovery of abundant *C. bukryi* at 56°N latitude indicates a tolerance of this species for cool surface water temperatures. The conspicuous absence of the circular *C. floridanus* from the northern flora suggests that a taxonomic separation of the two species is warranted on ecologic as well as morphologic grounds.

**Occurrence:** *Cyclicargolithus bukryi* is abundant in lower? Miocene chalk recovered at Site 178 on the Alaskan Abyssal Plain, northeast Pacific Ocean.

**Size:** 6-8 microns.

**Holotype:** USNM 186178 (Plate 9, Figures 1-3).

**Paratype:** USNM 186179 (Plate 9, Figure 4).

**Type locality:** DSDP 178-54-2(27 cm).

*Cyclicargolithus dornicoides* (Black and Barnes) Wise, n. comb.

*Coccolithus dornicoides* Black and Barnes, 1961, p. 142, Pl. 25, Fig. 3.

**Remarks:** The status of this small, nondescript, open-centered taxon is in considerable doubt because the holotype shows a proximal view of the specimen and no paratypes are given. Thus it is not possible to determine if the distal shield has the tight dual cycle construction or remnants of the central bar characteristic of gephyrocapsids. Lacking evidence to this effect, the taxon is assigned to the only available Neogene genus which accommodates non-fenestrate forms having a brightly lit distal shield in

cross-polarized light. According to information given by Black (1971), the gephyrocapsids probably evolved from forms which are assigned in the present study to the genus *Cyclicargolithus*. *C. dornicoides* has features common to both genera and hence the confusion over its placement. For routine light microscope work, however, it serves as a convenient category for tabulating small (less than 6-micron) subround or semi-elliptical forms with open centers and brightly lit proximal and distal shields in crossed-polarized light. *C. dornicoides* is not plotted on the range charts below the middle Pliocene, however, because below this level, it is impossible to distinguish it from small specimens of *Reticulofenestra*.

Genus DISCOASTER Tan Sin Hok, 1927

*Discoaster mendomobensis* Wise, new species  
(Plate 7, Figures 1-8)

**Description:** This large, six-rayed species has a large central area which comprises about half the total diameter of the astrolith. It is usually surmounted by a central stem of variable size. The radially symmetric rays terminate in discernible wrench- or spade-shaped bifurcations with notched tips.

**Remarks:** Although variable in peripheral outline, this astrolith is distinguished from most other upper Miocene discoasters by its large central area and tapering, notched bifurcations. Most other upper Miocene astroliths are characterized by slender rays and small central areas. *Discoaster mendomobensis* is distinguished from *Discoaster intercalcaris* Bukry by the presence of readily discernible bifurcations and by the lack of strongly tapered rays. It is distinguished from *Discoaster kugleri* Martini and Bramlette by its high degree of ray symmetry, the presence of discernible bifurcations, and the presence of central stems in the majority of specimens.

**Occurrence:** *Discoaster mendomobensis* is presently known only from upper Miocene sediments cored 50 miles west of Cape Mendocino, California, at DSDP Site 173.

**Size:** 17 to 25 microns.

**Holotype:** USNM 186168 (Plate 7, Figures 1, 2).

**Paratypes:** USNM 186169 to 186173 (Plate 7, Figures 3-8).

**Type locality:** DSDP 173-16(CC); lower continental margin off Cape Mendocino, northern California.

Genus HELICOPONTOSPHAERA Hay and Mohler, 1967

*Helicopontosphaera burkei* (Black) Wise, n. comb.

*Helicosphaera carteri* (Wallich) Bramlette and Wilcoxon, 1967, p. 105, Pl. 6, Figs. 9-10.

*Helicosphaera burkei* Black, 1971, pp. 618-619, Pl. 45.3, Fig. 23.

**Remarks:** This Miocene species is characterized by two round perforations which lie adjacent to but are not bisected by the longitudinal suture which transects the central area. Although these perforations were not discussed by Black (1971), they are present on the carbon replica of the holotype and are well illustrated by a light micrograph provided by Bramlette and Wilcoxon (1967, Fig. 10 [crossed nicols]).

**Distribution:** Common in the Miocene of the Ciperio Section, Trinidad, and other near shore Miocene deposits of the low latitudes of the Atlantic, Pacific, and Caribbean.

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PLATE 1



Scanning electron micrograph of a lower Oligocene calcareous nannofossil ooze recovered from Site 172 (water depth, 4778 m). The ooze occurs as a 15 cm-thick band cored 22 meters below the sediment surface within an otherwise unfossiliferous red clay sequence underlain by basalt. The effects of early diagenesis on the nannofossils of this ooze are shown in the five succeeding plates. X1800.

PLATE 2

All figures are scanning electron micrographs of calcareous nannofossils from Sample 172-3-4 (60 cm)

Figure 1 Calcareous nannofossil ooze consisting mostly of the outer rims of coccolith shields, the centers of which have been removed by dissolution. Dissolution resulted from deposition in deep water at depths close to the carbonate compensation level. X3300.

Figures 2-5 *Reticulofenestra bisecta* (Hay, Mohler and Wade). Effects of calcite dissolution (and reprecipitation) on this taxon are illustrated by this series of micrographs which show progressive steps in the dissolution process.

2. A relatively well-preserved specimen with small central opening and both shields intact. Note bars which partially fill central opening. Proximal view, X5700.
3. The central opening of this specimen has been enlarged by dissolution, whereas the outer circumference of the proximal (upper) shield has been reduced; the more resistant distal shield, however, is intact. Proximal view, X4100.
4. Portions of the proximal shield aligned with the long axis of the central area of this specimen have been completely removed by dissolution. The more resistant distal shield, however, is relatively intact. Arrow points to calcite bar which extends from the central area into the space formerly occupied by a portion of the proximal shield. Apparently the bar has been lengthened by the accretion of calcite as an overgrowth which formed after a portion of the proximal shield had been destroyed. The heavy bars of the central area of specimens in Figures 2 and 3 are likewise products of secondary calcite overgrowth on the lath-shaped elements which cover the central area. Proximal view, X3800.
5. Remnant of a shield detached by dissolution. Both inner and outer circumferences of the shield have been modified by dissolution. X7700.

Figures 6, 7 Distal views of *Reticulofenestra bisecta* (Hay, Mohler, and Wade) showing anhedral blocks of calcite which cover central areas. These blocks, originally lath-shaped, have accreted calcite by means of secondary overgrowth as evidenced by the long calcite spur which extends out over the distal shield of the specimen in Figure 7 (arrow). Calcite to form these overgrowths must have been derived from the dissolution of other nannofossils in the thin ooze layer because no other source of calcite is present in the section drilled. Ample evidence of such dissolution is provided by the preceding figures and those of succeeding pages. (6) X7000; (7) X5700.

PLATE 2

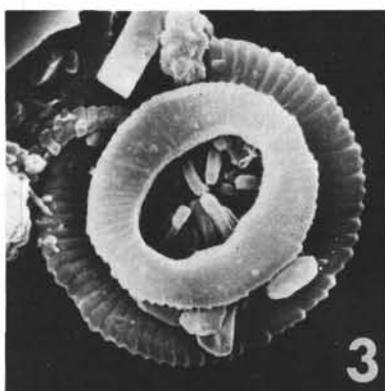
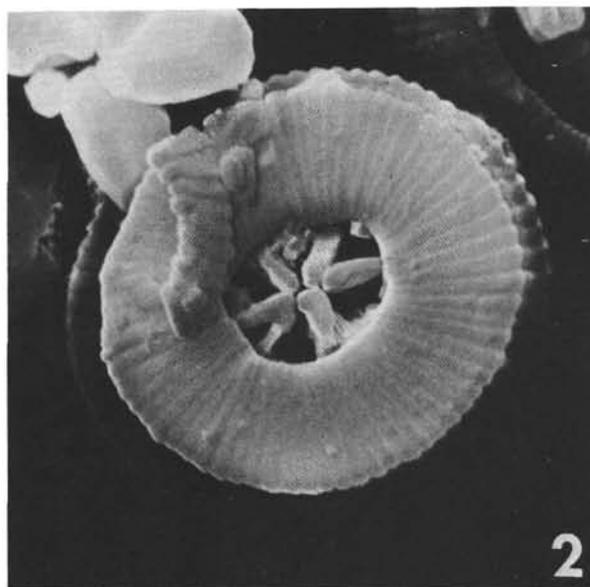
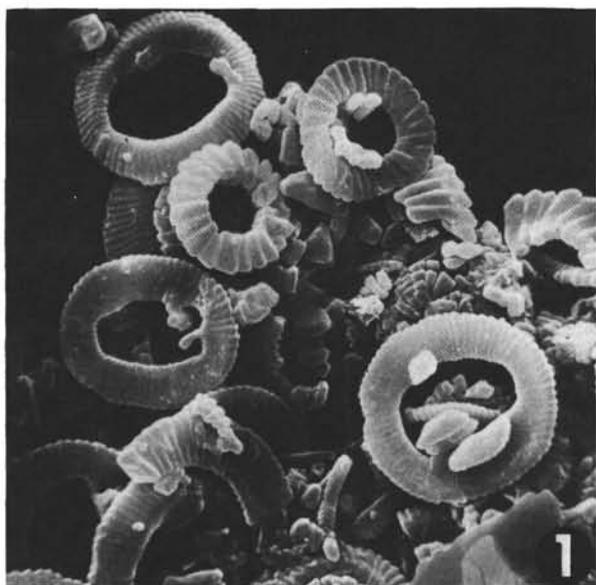


PLATE 3

All figures are scanning electron micrographs of calcareous nannofossils from Sample 172-3-4 (60 cm)

- Figures 1-3     *Reticulofenestra umbilica* (Levin). This large coccolith is relatively resistant to solution. Nevertheless, the delicate grill-like structure which normally covers the central area has been destroyed in all specimens from this sample.
1. proximal view, X2500.
  2. proximal view, X3200.
  3. distal view, X3200.
- Figures 4-9     *Coccolithus eopelagicus* (Bramlette and Riedel). The distal shield of this taxon is more resistant to dissolution than either the central area structure or the proximal shield as is shown by this series of micrographs. Figures 4-7 are distal views; Figures 8, 9 are proximal views.
- 4, 5. Intact specimens showing distal shield constructed of large, imbricate elements and central area formed by thin, imbricate laths, X2300, and X2800 respectively.
  - 6, 7. Partially damaged specimens showing corrosion of central area laths and widening of central opening. Outer distal shield of specimen in Figure 6 also shows some damage. X2700 and X3400 respectively.
  8. Corrosion of central area laths and widening of central opening are evident in this specimen; however, the proximal and distal shields are relatively intact. Secondary calcite overgrowths are present on elements of distal shield (see also following figure). Note two cycle construction of proximal shield. X2100.
  9. The fine elements of the outer cycle of the proximal shield of this specimen are largely destroyed; however, the distal shield is intact and exhibits secondary calcite overgrowths on the outer margins on some elements (arrows). These overgrowths are nucleated along the exposed edges of the imbricate elements of the distal shield. X5600.

PLATE 3

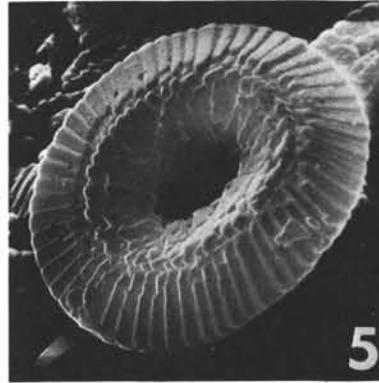
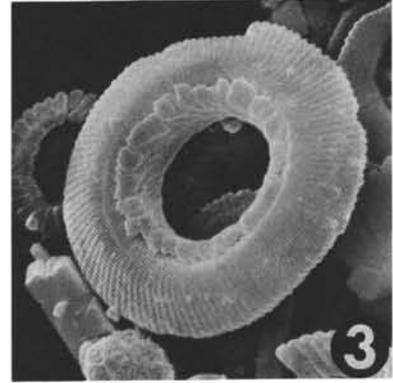


PLATE 4

All figures are scanning electron micrographs of calcareous nannofossils from Sample 172-3-4 (60 cm)

- Figures 1-6 *Coccolithus formosus* (Kamptner). This series of micrographs shows effects of dissolution on this species. meas. 252-p.i. = 39,
- 1, 2. Relatively intact specimens show some noticeable enlargement of the central opening. Distal views, X4100 and X3800 respectively.
  3. Proximal view. Central opening has been widened slightly and most of the proximal shield has been removed. The more resistant distal shield remains relatively intact. No fully intact proximal shields were observed in the specimens studied. X3800.
  - 4-6. Distal views showing progressive steps in dissolution. Laths forming the central area are corroded from both ends and along suture lines until all are eventually removed (Fig. 6). The more resistant distal shield, however, remains intact. X5000, X4100, and X4700.
- Figures 7, 8. *Bramletteius serraculoides* Gartner. Basal shields were originally attached to the narrow ends of these nannofossils but have been removed by dissolution from the specimens examined here. Only the broad rudder- or paddle-shaped distal structures remain. X4700; X6700.
- Figures 9-12. *Sphenolithus pseudoradians* Bramlette and Wilcoxon.
- 9, 10. A rare intact specimen viewed here from two angles exhibits stubby basal and lateral elements surmounted by an apical structure composed of five or more blades which intersect along the median axis. X4600; X5100.
  - 11, 12. In most specimens examined, apical structures such as these have been dissociated from their basal structures as a result of dissolution. X6300; X5100.

PLATE 4

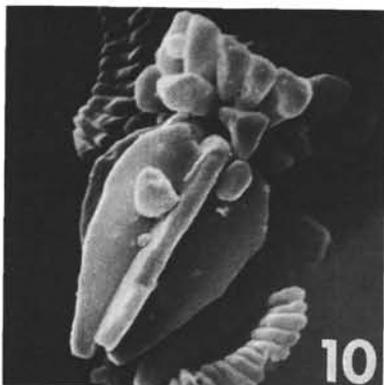
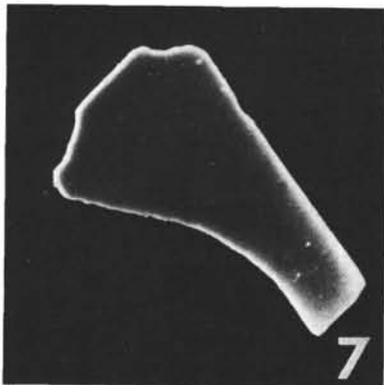
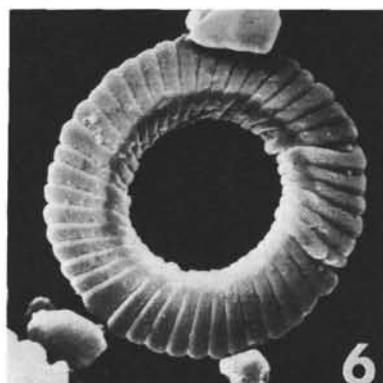


PLATE 5

All figures are scanning electron micrographs of calcareous nannosoffils from Sample 172-3-4 (60 cm)

- Figures 1-3 *Sphenolithus predistentus* Bramlette and Wilcoxon. These forms normally exhibit a single basal cycle of elements similar to those of *S. pseudoradians* shown in Plate 4, Figures 9-10. The basal cycle of specimens shown here, however, have been removed by dissolution. The apical structure consists of two sharply bifurcate segments joined along a medium suture. The bifurcations have been shortened by dissolution. X5900; X5200; and X6300.
- Figures 4-6 *Sphenolithus moriformis* (Brönniman and Stradner). The elements of these beehive-shaped sphenoliths may have accreted some secondary calcite as suggested by dimples on some elements (arrow, Figure 4). Several elements in other specimens have been removed by dissolution (Figure 6). X6800; X7400; and X9000.
- Figures 7-8 *Discoaster tani* Bramlette and Riedel. In near shore sediments, these discoasters are characterized by slender arms and sometimes by ornamental nodes. The deep sea specimens shown here, however, have accreted considerable amounts of secondary calcite in the form of overgrowths along the rays. The overgrowths exhibit discrete crystal faces and obscure any ornamental nodes which may have been present. X6000; X5700.

PLATE 5

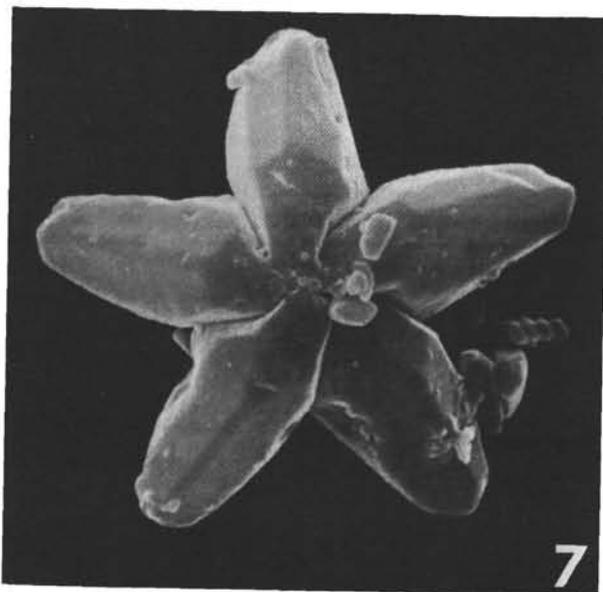
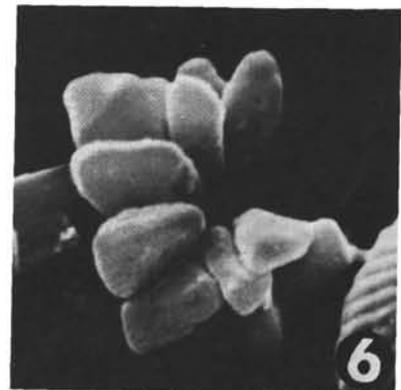
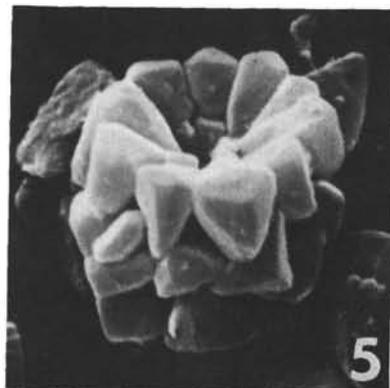
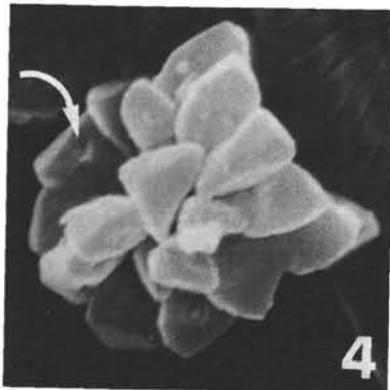


PLATE 6

All figures are scanning electron micrographs of calcareous nannofossils from Sample 172-3-4 (60 cm)

Figures 1-3 *Discoaster deflandrei* Bramlette and Riedel. These astroliths have accreted considerable amounts of secondary calcite which forms thick overgrowths on the rays. The wrench-shaped bifurcations normally exhibited by this taxon have been partially or totally obscured by the overgrowths, and the rays have been thickened two or three times normal size. The rough outline of a wrench-type bifurcation is discernible on the least heavily overgrown ray of the specimen in Figure 1 (arrow). The calcite overgrowths characteristically show euhedral calcite crystal faces along the rays as well as dimples where particles of skeletal debris have been entrapped within the secondary calcite. Larger particles of skeletal debris were entrapped between rays (arrow, Figure 2) or partially enveloped (arrow, Figure 3) when the rays were enlarged by overgrowth. In advanced stages of development, secondary calcite joins alternate rays of the discoasters to form a tripartite bridge across the central area (Figure 3). The secondary calcite which forms the overgrowths was derived early during diagenesis by the in situ dissolution of other calcareous nannofossils in the ooze. X7300; X7900; and X6200.

Figure 4 *Discoaster* spp. (left); *Reticulofenestra bisecta* (Hay, Mohler, and Wade) (right). The small discoaster has accreted an enormous amount of secondary calcite to the extent that a high tripartite bridge has been formed across the central area. Sharp euhedral crystal faces are present on all ray surfaces. X5500. (This micrograph courtesy of Dr. Sheldon Moll, Advanced Metals Research Corp., Burlington, Massachusetts).

PLATE 6

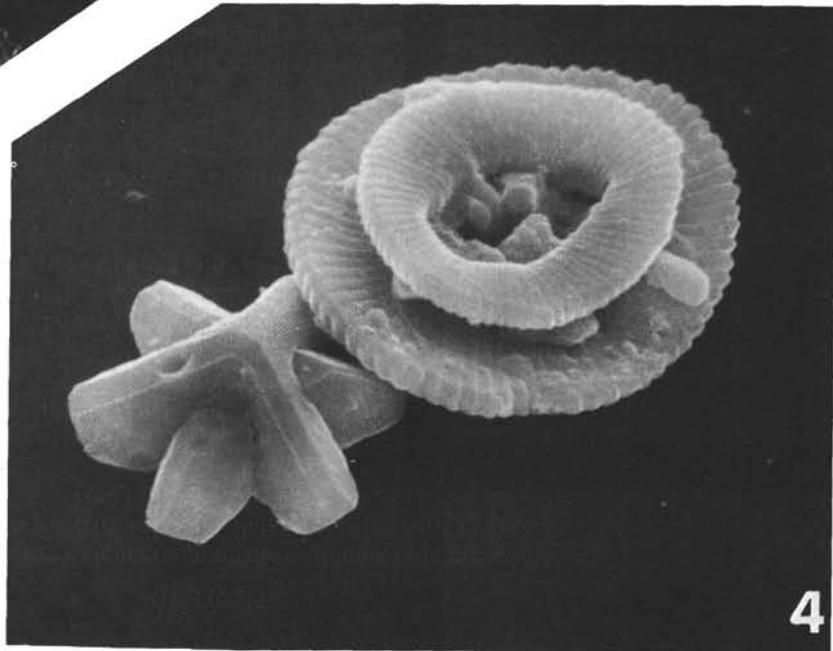
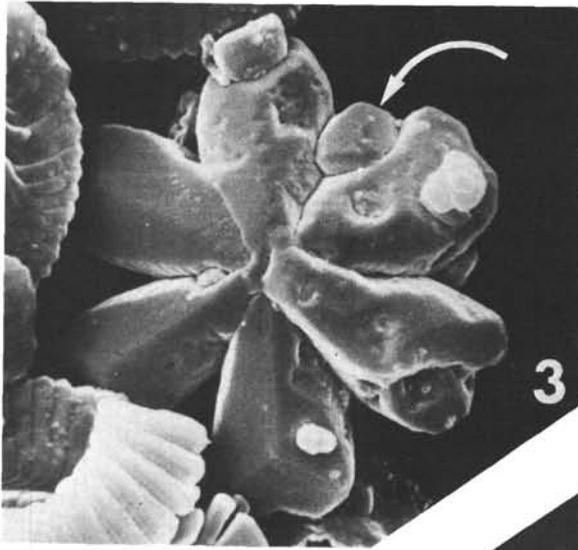
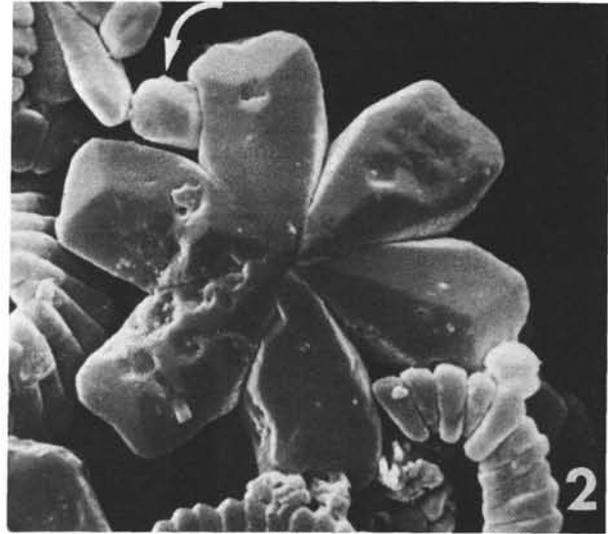
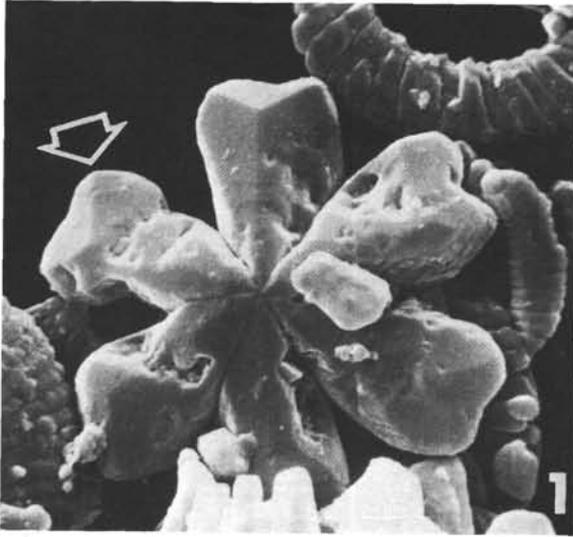


PLATE 7

All figures are light photomicrographs at a magnification of  $\times 2000$

- Figures 1-8      *Discoaster mendomobensis* Wise, n. sp., Sample 173-16(CC).  
1. Holotype USNM 186168, phase contrast.  
2. Bright field.  
3. Paratype USNM 186168, phase contrast.  
4. Paratype USNM 186170, phase contrast.  
5. Bright field.  
6. Paratype USNM 186170, bright field.  
7. Paratype USNM 186171, phase contrast.  
8. Paratypes USNM 186172 (left), 186173 (right), phase contrast.
- Figures 9-11      *Corbisema triacantha* (Ehrenberg), Sample 173-30-1 (30 cm). The extinction of this silicoflagellate marks the top of the *Corbisema triacantha-Reticulofenestra pseudoumbilica* Zone. This combination range zone is recognized in the middle Miocene portion of the section at Site 173. (9-10 bright field; (11) phase contrast.

PLATE 7

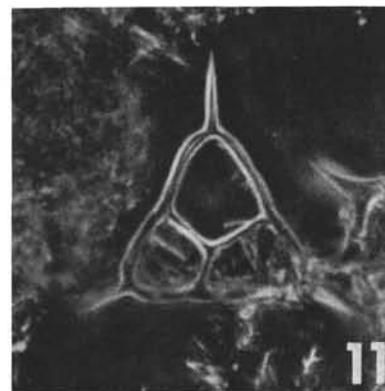
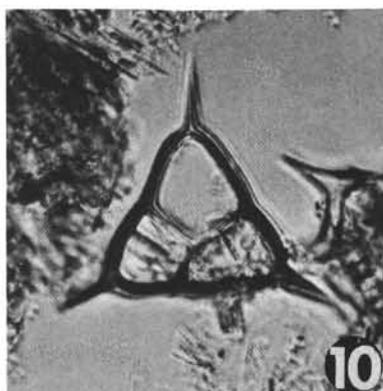
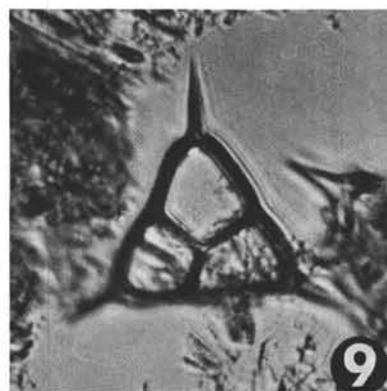
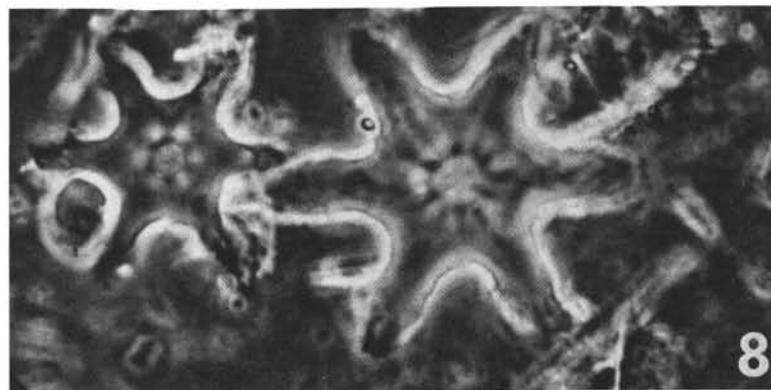
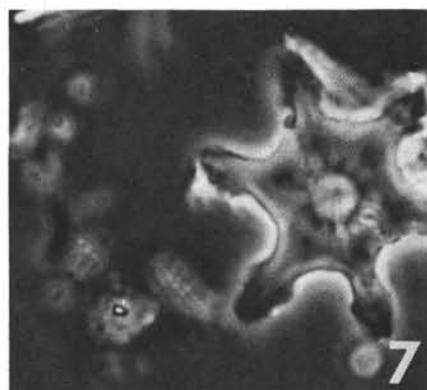
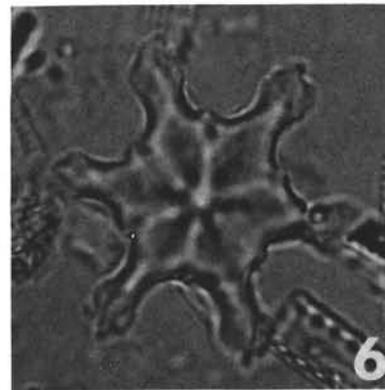
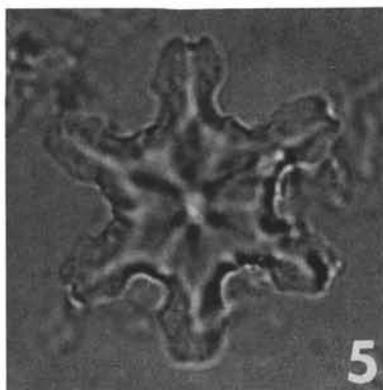
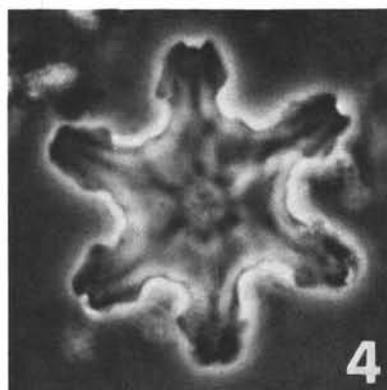
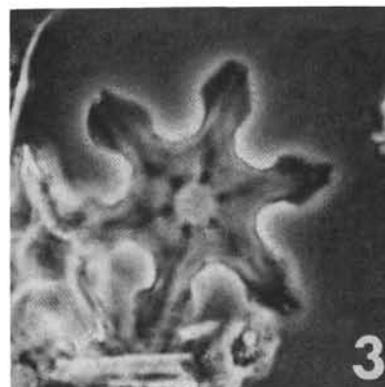
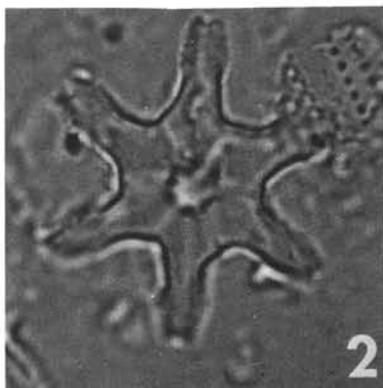
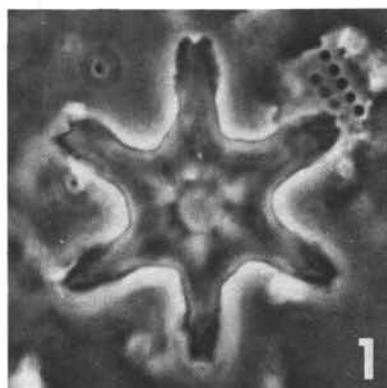


PLATE 8

Figures 1-10 are light photomicrographs at a magnification of X3200; Figure 11 is a scanning electron micrograph

- Figures 1-6      *Coccolithus pliipelagicus* Wise, n. sp.  
1. Holotype USNM 186174, phase contrast Sample 176-5-1 (120 cm).  
2. Bright field.  
3. Cross-polarized.  
4. Paratype USNM 186175, phase contrast, Sample 176-5-4 (44 cm).  
5. Bright field.  
6. Paratype USNM 186176, phase contrast, Sample 176-5-4 (44 cm).
- Figures 7 8      *Coccolithus* sp. cf. *C. pliipelagicus*.  
7. Bright field, DSDP 178-54-2 (27 cm).  
8. Phase contrast.
- Figures 9-10      *Coccolithus miopelagicus* Bukry, emend.  
9. Hypotype USNM 186177, bright field, Sample 178-54-2 (27 cm).  
10. Cross-polarized.
- Figure 11.      *Coccolithus miopelagicus* Bukry, emend. Scanning electron micrograph, proximal view, Sample 178-54-2, 27 cm, X6400. Note double cycle construction of the proximal shield.

PLATE 8

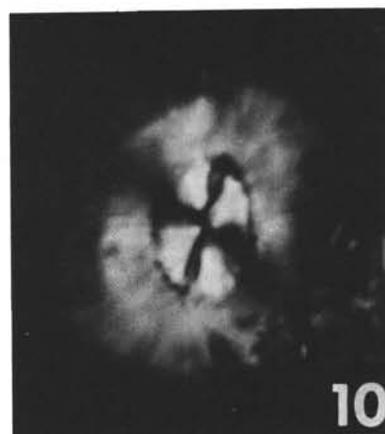
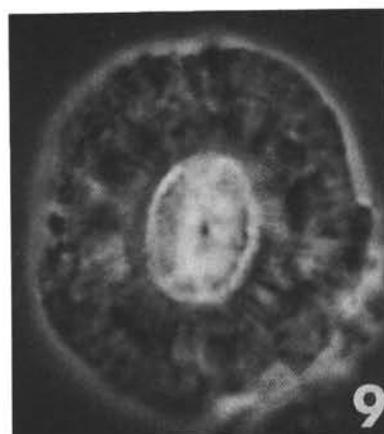
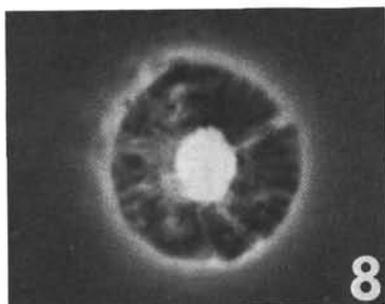
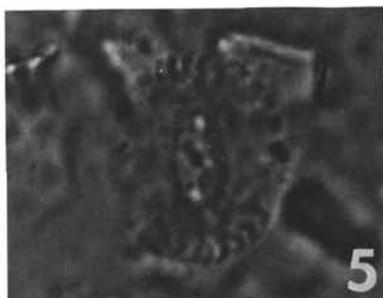
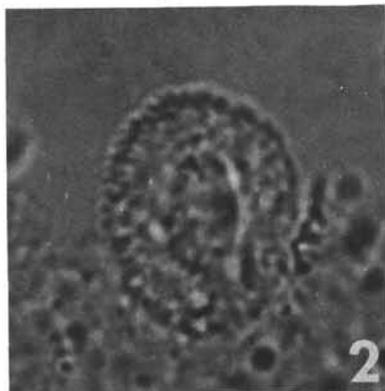
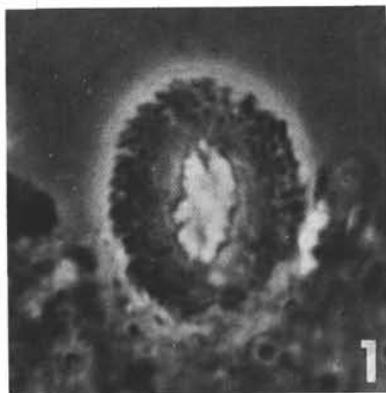


PLATE 9

Figures 1-3 are light photomicrographs; Figures 4-5 are scanning electron micrographs

- Figures 1-3     *Cyclicargolithus bukryi* Wise, n. sp.  
1. Holotype USNM 186178, phase contrast, Sample 178-54-2 (27 cm) X3200.  
2. Bright field.  
3. Cross-polarized light.
- Figure 4        *Cyclicargolithus bukryi* Wise, n. sp. Distal view; paratype USNM 186179, distal view, Sample 178-54-3, top; X8800.
- Figure 5        *Cyclicargolithus floridanus* (Roth and Hay). Distal view, sample Bo 187 (type locality of the lower Miocene planktonic foraminiferal *Globigerinatella insueta* Zone of Bolli, 1966), Trinidad, B.W.I., X9500.
- Figure 6        *Discoaster deflandrei* Bramlette and Riedel. Secondary calcite overgrowth is responsible for the development of crystal faces along the rays and for the obfuscation of the ray tip bifurcations. These overgrowths are similar to those observed in material from Site 172. They probably formed during early diagenesis. Sample 178-54-2 (27 cm); X6600.
- Figure 7        *Discoaster* sp. cf. *D. adamanteus* Bramlette and Wilcoxon. This astrolith also shows effects of secondary calcite overgrowth and subsequent dissolution which produced a groove in one ray (arrow). Sample 178-54-2 (27 cm); X7900.

PLATE 9

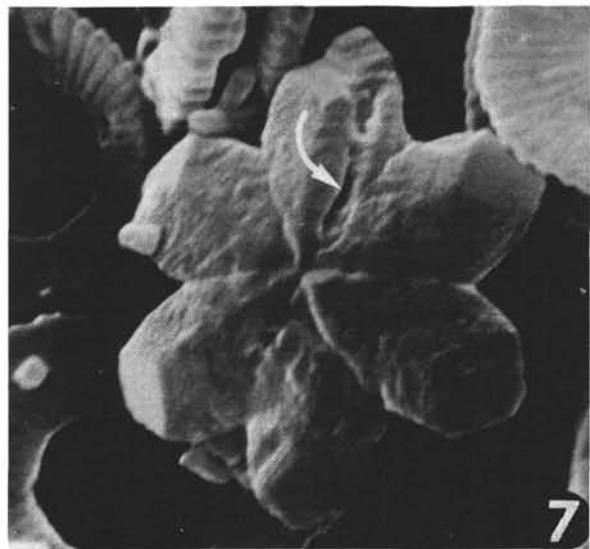
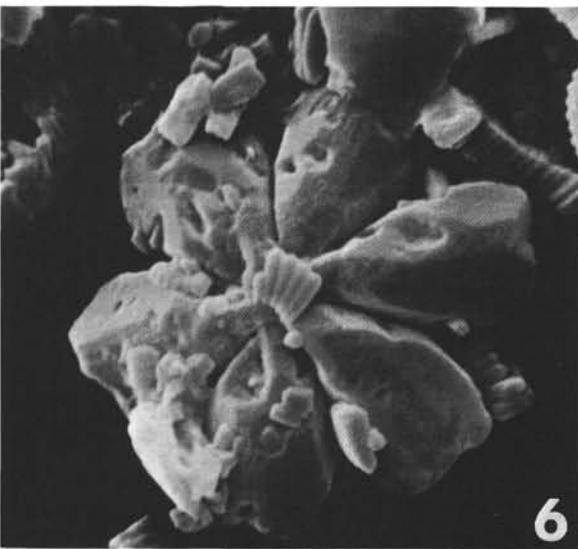
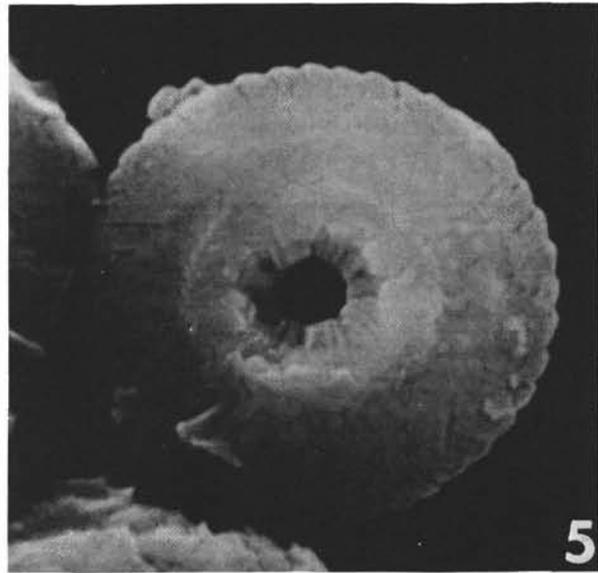
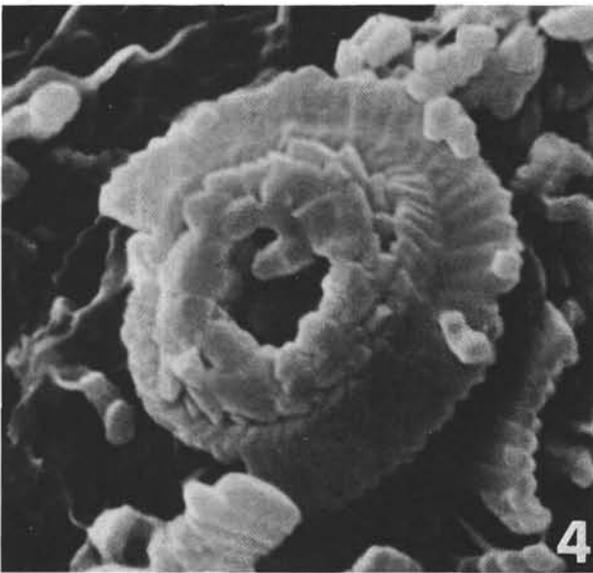
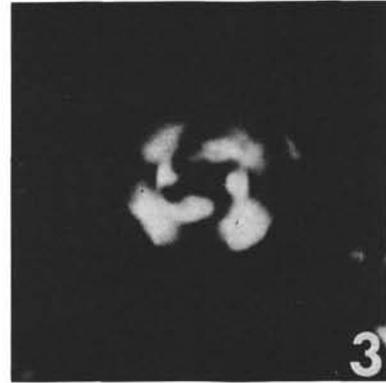
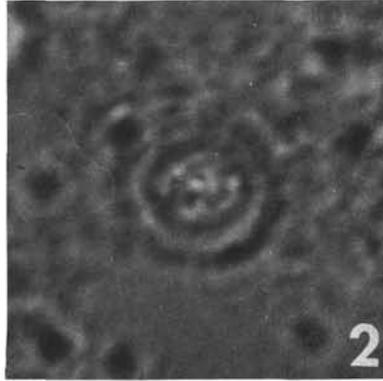
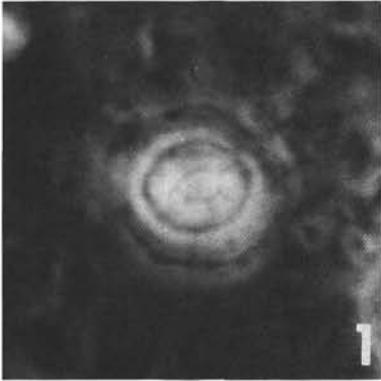


PLATE 10

All figures are scanning electron micrographs of fracture surfaces through a lower Miocene chalk from the Alaskan Abyssal Plain, Sample 178-54-2 (27 cm)

- Figure 1      *Discoaster deflandrei* Bramlette and Riedel. Accretions of secondary calcite on this specimen are quite uneven, X5200.
- Figure 2      Calcite cement joins corresponding elements of the proximal and distal shields of the placolith in the lower center of this figure (arrow) X8500.
- Figure 3      Much of the matrix of the chalk consists of small anhedral particles of skeletal debris, many of which have been overgrown by secondary calcite. Some small particles of debris are recognizable skeletal elements. For example, the little U-shaped object (arrow) consists of portions of the inner collar and shields of a placolith. X6200.
- Figure 4      No evidence of pressure solution or pressure welding is observed in the microfabric of the chalk. Placoliths such as those shown here within a small pore opening are undeformed. X12000.
- Figure 5      The delicate framework of this coccosphere of *Cyclicargolithus bukryi* Wise, n. sp. is preserved within a pore space in the chalk. Although the centers of the placoliths which form the coccosphere have been destroyed by dissolution, the fragile skeletal structure is undeformed, an indication that the chalk has suffered little compaction. Calcite cementation during early diagenesis is thought to have protected the chalk from deformation during subsequent phases of burial and sediment loading. X5950.
- Figure 6      Authigenic clay particles (montmorillonite) are common in the chalk and form honeycomb-like growths within pore spaces (upper left quarter of figure; see also Figure 2 above). X11000.

PLATE 10

