

2. DIATOM BIOSTRATIGRAPHY, LEG 150¹

Lloyd H. Burckle²

ABSTRACT

Diatoms are present in middle to lower upper Miocene sections of all holes examined during Leg 150, but are generally absent or in low abundance in Pleistocene to middle upper Miocene sediments. An exception is the alternating diatom-rich, diatom-poor intervals in upper Quaternary sediments. Five new diatom zones, covering an interval from near the lower/middle Miocene boundary to the lower upper Miocene, are proposed. Some of the taxon used to define these zones are also used in zonal schemes for the East Coast of the United States, and allow for correlations to be drawn between this region and Leg 150 sites. Lower Miocene and older levels are not included in this study. Although older Tertiary diatoms are present at some of the sites, dissolution has largely compromised their usefulness as zonal markers.

INTRODUCTION

In an Ingmar Bergman film (I've forgotten which one), one of the lead characters, a medical doctor, declares that the first duty of a physician is to ask forgiveness of his patients—forgiveness for prolonging their lives. Biostratigraphers are frequently also in need of asking forgiveness of their readers—not for prolonging their lives (we are not known for that) but forgiveness for plaguing their existence with yet another biostratigraphic zonal scheme. This paper reports on diatoms recovered during Leg 150 and describes a new diatom zonal scheme for these cores and for this region of the Atlantic. A new zonal scheme, which actually draws upon elements of several already established schemes is, in my view, entirely appropriate. Leg 150 cores were recovered from the westernmost mid-North Atlantic (off the New Jersey coast) in water depths ranging from upper continental slope to bathyal (Fig. 1). It is this setting that calls for a new zonal scheme. Some, but not all, of the zonal markers for the East Coast Diatom Zones (ECDZ) of Andrews (1988) are present in many Leg 150 cores. Similarly, some low-latitude zonal markers of Burckle (1972) and higher latitude markers of Baldauf (1984) are also present. Shipboard analysis suggested that, although the Burckle (1972) and Baldauf (1984, 1986) schemes are perfectly reliable in their own geographic setting, some danger is associated with directly applying them to the region off the coast of New Jersey. There are two principle concerns: (1) the zonal markers that are useful in other regions may be diachronous into the Leg 150 area; and (2) because microfossil occurrences are frequently water-mass-related, such zonal markers may also be discontinuous in their temporal distribution, thus compromising their utility. That is, how is one to differentiate between a life occurrence and an occurrence due to reworking?

Although the East Coast of North America has been slowly subsiding under the influence of compaction and isostasy (Steckler and Watts, 1982), it has also been long recognized as an important source of information about Cenozoic sea-level history (Greenlee and Moore, 1988; Greenlee et al., 1988). This was obvious in the early part of this century but became even more apparent after oil companies were granted permission, in the 1970s, to explore seismically and by drill bit the upper slope and shelf off New Jersey. At the same

time the U.S. Geological Survey joined the quest, not for oil, but to advance our knowledge of both processes and chronology in what is seen to be a fairly stable portion of an unstable world (Scholle, 1977, 1980). The Deep Sea Drilling Program (DSDP) began its contribution to study of this region with DSDP Leg 11 (Hollister, Ewing, et al., 1972), which discontinuously cored in water depths ranging from the lower continental rise to the lower continental slope. In large part, Eocene sediments were recovered. Subsequent DSDP legs (DSDP Legs 93 and 95) moved into shallower waters that, among other concerns, were designed to address questions about sea-level change along the East Coast of North America. This objective was not fully realized because time constraints prevented drilling above the lower continental slope. These latter cruises, however, indicated that important unconformities were present in the Tertiary record and, although not directly attributed to sea-level change (since the unconformities were well below the reach of sea level), could apparently be correlated to other upslope proxies for sea-level change.

Leg 150 was designed to complete the drilled sequence from the lower continental slope to the continental shelf. Unfortunately, safety considerations forced planners to set aside one of the original objectives of Leg 150 (i.e., to drill on the continental shelf). As a result, the shallowest site occupied was on the upper continental slope. Because drilling on the adjacent New Jersey coastal plain was already underway, the decision not to drill the continental shelf leaves a significant gap in the information that ought to be available. However, it is expected that within the next few years drilling will take place on the shelf. Leg 150 made it possible to drill through upper continental slope unconformities that were identified both on seismic records and in cores recovered from deeper water. Because of uncertainties in interpreting the seismic records and in tracing reflectors from site to site, stratigraphic micropaleontology became a valuable tool in interpreting these records. All microfossil groups played their part in filling this role. Dinoflagellates and diatoms were useful for determining the middle and late Miocene. This was fortunate because planktonic foraminifers and calcareous nannoplankton occurred only sporadically through this interval. Diatoms were generally present in low abundances in Pleistocene sediments, and absent from the few Pliocene sediments encountered, as well as from the upper part of the upper Miocene. Their first consistent downcore occurrence is in the middle part of the upper Miocene, below which they generally persisted through the middle Miocene. In most cases, diatoms began to show signs of increasing dissolution in lower Miocene sediments. In a few cases, however, they persisted into the Oligocene and even into

¹Mountain, G.S., Miller, K.G., Blum, P., Poag, C.W., and Twichell, D.C. (Eds.), 1996. *Proc. ODP, Sci. Results*, 150: College Station, TX (Ocean Drilling Program).

²Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, U.S.A. burckle@ldeo.columbia.edu

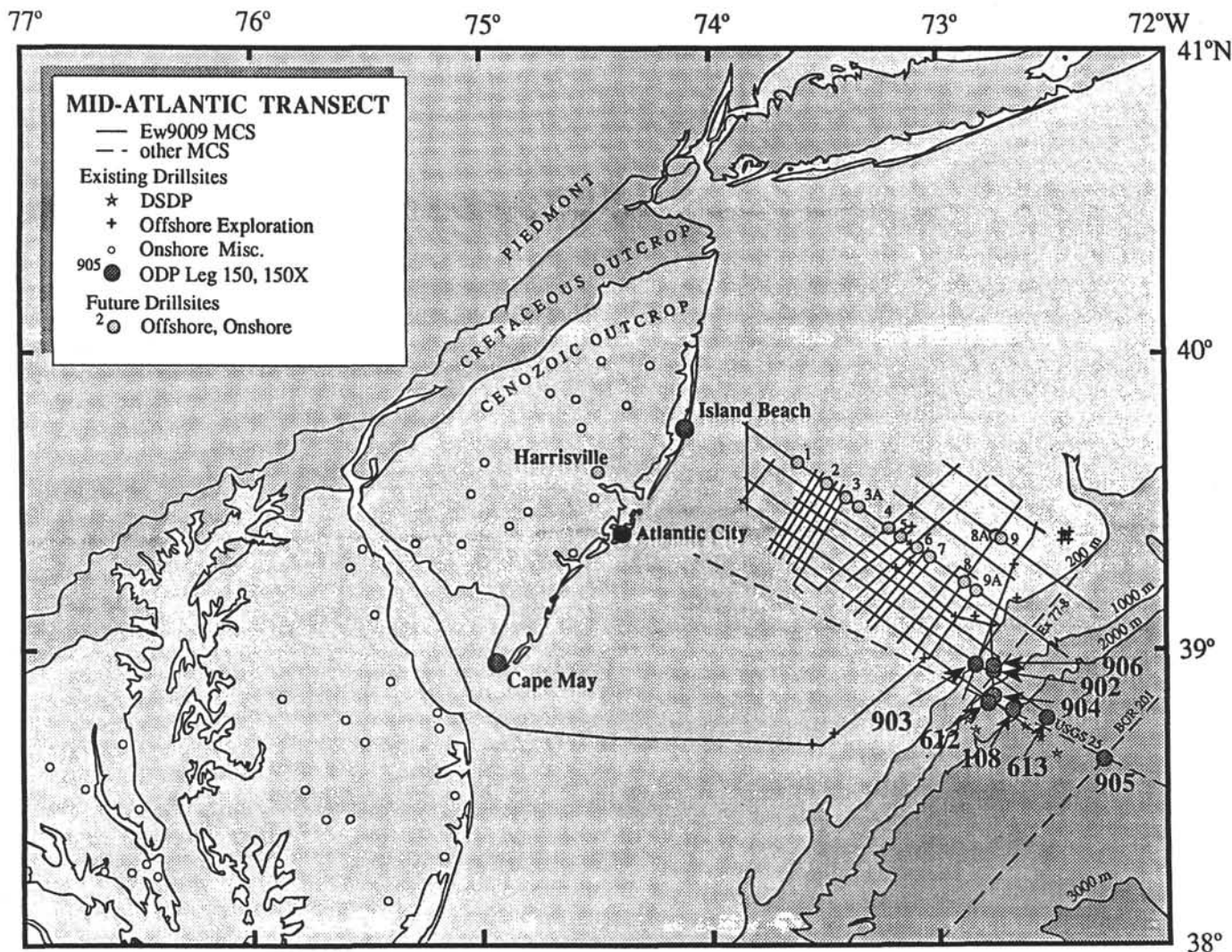


Figure 1. Map of the continental shelf and slope off the coast of New Jersey and New York showing the distribution of core sites occupied during Leg 150. Drill sites occupied by DSDP, as well as future drill sites, are also shown. The shelf break is at approximately 200 m; below that level the contour interval is 1000 m.

the upper Eocene. It was apparent, however, that dissolution had taken its toll in these middle and lower Cenozoic sediments, for diversity tended to be low and only the robust forms were present.

METHODS

Diatom slides were prepared using the method described by Schrader (1974). Each diatomist may have different preparation techniques, but they are generally similar enough for application of the biostratigraphic method. Significant differences exist in acceptable preparation methods, however, when one is doing quantitative analysis of diatoms.

PREVIOUS WORK

As previous comments indicate, little prior work has been done on diatoms recovered in the vicinity of Leg 150 drill sites. Although DSDP Leg 11 occupied several sites in the western North Atlantic and off the East Coast of the United States, no diatoms were reported, very likely because the objectives of DSDP Leg 11 were to recover

old sediment just above the crust and to determine the "paleoceanography of the developing Atlantic" (Hollister, Ewing, et al., 1972). The DSDP Leg 93 core sites, did, however, recover diatoms. Site 604 (38°42.79'N, 72°32.95'W) was occupied above the uppermost continental slope some 160 km from the U.S. coast. Abbott (1987a) identified Miocene through Pliocene diatoms at this site (which also had a mix of Eocene forms), whereas Gombos (1987) recovered Eocene diatoms at Site 605 (38°44.53'N, 72°36.55'W), which was occupied above the upper continental rise. Due to dissolution, largely robust forms were preserved through the diatom-bearing interval, and Gombos (1987) reported the presence of only one significant diatom datum. Diatoms were also recovered from holes drilled during DSDP Leg 95 (Poag, Watts, et al., 1987). Abbott (1987b) examined two sites (Site 612 at 38°49.21'N, 72°46.43'W, and Site 613 at 38°46.26'N, 72°30.43'W) occupied off the coast of New Jersey. Possibly late Miocene to Pleistocene diatoms were present but the floras were too sparse and poorly preserved for any definitive ages to be determined. These are the only diatom records from the immediate vicinity of Leg 150 sites.

However, as noted previously, diatom zonal schemes have been proposed for regions north and south of Leg 150 sites, as well as on the East Coast of North America. Some, but not all, of the elements

of these zonal schemes occur in Leg 150 sediment cores. The original work in the equatorial regions was done by Burckle (1972, 1978b), who established late Neogene diatom zones and datum levels tied directly to a paleomagnetic stratigraphy. Many of the elements of this zonal scheme were ably incorporated into the biostratigraphic scheme of Barron (1985). Burckle (1978a, 1982) also showed that some of the Pacific zonal markers extended into the Indian Ocean and even to the Mediterranean. Their presence in the latter basin strongly suggests that they were also present in the equatorial Atlantic. To the north of the Leg 150 area (i.e., in the vicinity of the Rockall Bank), Baldauf (1984) defined a diatom zonal scheme covering the interval from the middle Miocene to the Holocene. Ten zones were proposed which, in some cases, contained floral elements also found in lower latitudes. Nevertheless, most of the species used to define these zones are endemic to higher latitudes and occur only sporadically in middle to lower latitudes. Judging from the overall results of Leg 81, the zonal scheme of Baldauf (1984) was successful in developing age models for sites that covered the middle Miocene to Holocene. It is also worth noting that Baldauf (1984) found diatoms in uppermost Miocene to Pleistocene sediments, an interval that was essentially barren of diatoms in Leg 150 sites.

Andrews (1976, 1988) has ably summarized work done on marine Miocene diatoms of the southeastern United States and incorporated these data into a revised East Coast Diatom Zonation (termed ECDZ by Andrews, 1988). Because of the discontinuous nature of the marine outcrops in this region these zones are not necessarily stratigraphically conterminous. His ECDZ 1, for example, covers the middle early Miocene whereas the overlying ECDZ 2 is in the upper early Miocene and is separated from the older zone by something on the order of 1.5 m.y. Similarly, there is a gap (of about a half million years) between his ECDZ 3–4 and ECDZ 5. Andrews (1988) formally proposed these zones as East Coast Diatom Zones 1 through 7 (referred to as ECDZ 1–7). By second-order correlation, these zones were tied to the planktonic foraminiferal zones of Blow (1969) and the calcareous nannofossil zones of Martini and Worsley (1970). The biostratigraphic work done on the East Coast of the United States is important to Leg 150 in that some of the zonal markers identified by Andrews (1988) also occur in Leg 150 sediments, offering us the possibility of tying the Andrews zonal scheme to the open-ocean marine record.

ZONATION

There are two points to be made here. In devising a zonal scheme for the Leg 150 sites, I have chosen to restrict myself to Neogene sediments. This is primarily because downcore dissolution has largely compromised the older (i.e., Paleogene) assemblages. At many of the sites, partially dissolved assemblages are present in the lower Miocene, and dissolution becomes more extreme in Oligocene and Eocene sediments. At only one site (Site 904) were in-place sediments containing Eocene diatoms encountered. The reader should further be cautioned that this zonation represents a mix between open-ocean stratigraphic markers (Burckle, 1972, 1978b; Baldauf, 1984) and those established by Andrews (1988) from continental marine (shallow-water) sections studied along the East Coast of North America. An additional point that needs to be made is that this zonal scheme is very sensitive to location. It is entirely possible that some zonal elements will not be present if one tries to apply this scheme in regions some distance from Leg 150 sites. Indeed, I found that in deeper water sites (Sites 904 and 905, for example), the more open-ocean zonal markers were present at the expense of the nearshore marine forms and the zonal scheme proposed here appeared to be only marginally successful. In such cases, one can apply the North Atlantic zonation of Baldauf (1984).

Coscinodiscus lewisianus Zone

Definition. The base of this zone is defined by the first occurrence of *D. novaecaesarae*. The top is defined by the last occurrence of the nominate taxon.

Remarks. The last occurrence of *C. lewisianus* in Leg 150 sites may be nearly isochronous with other reported last occurrences in the North Atlantic. Burckle (1978b), using cores from the equatorial Pacific, tied this datum directly to the middle of Magnetic Chron 13 (C5An) whereas Baldauf (1984), using second-order correlation, tied it to the lower part of Magnetic Chron 14 (C5Ar). Similarly, Andrews (1988), again using second-order correlation, tied this last occurrence to the lower part of foraminiferal Zone N11 of Blow (1969), approximately equivalent to somewhere in Magnetic Chron 14 (Berggren et al., 1985). In the absence of more high-resolution data, therefore, one can suggest that the last occurrence of *C. lewisianus* is essentially isochronous between the equatorial regions and higher latitudes.

Other Floral Elements. *A. ellipticus*, *A. ingens*, *A. tenellus*, *A. undulatus*, *Cavitatus miocenicus*, *Coscinodiscus endoi*, *C. marginatus*, *Delphineis novaecaesarae*, *D. penelliptica*, *Denticulopsis hustedtii*, *D. punctata* var. *hustedtii*, *Mediaria splendida*, *Melosira complexa*, *M. westii*, *Paralia sulcata*, *P. sulcata* var. *coronata*, *Rhizosolenia miocenica*, *Rosellia paleacea*, *Thalassionema nitzschoides*, *Thalassiosira grunowii*, and *Stephanopyxis grunowii*.

Correlation. The top of this zone (i.e., the last occurrence of *C. lewisianus*) is approximately equivalent to the N10/N11 Zonal boundary of Blow (1969) and the middle of the NN6 Zone of Martini and Worsley (1970). Andrews (1988) places the last occurrence of *C. lewisianus* in the lowermost part of his ECDZ 6. As noted above, Burckle (1978b) places the top in the middle of Magnetic Chron 13 (C5Ar) whereas Baldauf (1984) and Andrews (1988) place it in Magnetic Chron 14 (C5An). Van Fossen and Urdat (this volume) place the top of this zone equivalent to Chron C5Ar, which is correlative with Magnetic Chron 13 of Burckle (1978b). However, it should be noted that *C. lewisianus* tends to become rare and difficult to find toward its last occurrence; therefore, the minor discrepancy in last occurrence between the three protagonists may be more apparent than real. The base of this zone is equivalent to the middle of ECDZ 3–4 of Andrews (1988) and the upper part of foraminiferal Zone N8 of Blow (1969). In terms of the East Coast (U.S.) zones of Andrews (1988), this zone is roughly correlative with an interval from the middle part of ECDZ 3–4 to the lowermost part of ECDZ 6.

Rhizosolenia barboi/*Delphineis penelliptica* Zone

Definition. The base of this zone is defined by the last occurrence of *C. lewisianus*. The top is defined by the last occurrence of *D. penelliptica*.

Remarks. Although this zone does not contain any secondary markers, there are a number of species that are common to it and that can aid in identification of the zone. These include *D. hustedtii*, *D. punctata* var. *hustedtii*, *R. miocenica*, and *Stephanopyxis grunowii*. *Denticulopsis punctata* var. *hustedtii* is an especially useful form in that it also occurs through much of the middle Miocene in the equatorial Pacific. Although this species was not observed by Andrews (1988) in East Coast (U.S.) sections, some of the other species were present (specifically *D. hustedtii*) that provide a useful tie to the Andrews (1988) zonal scheme.

Other Floral Elements. *A. ingens*, *A. tenellus*, *C. endoi*, *D. hustedtii*, *D. punctata* var. *hustedtii*, *R. barboi*, *R. miocenica*, and *S. grunowii*.

Correlation. This zone correlates with the middle part of ECDZ 6 of Andrews (1988) and the lowermost part of the *Crucidentacula nicobarica* Zone of Baldauf (1984). Further, it correlates with the

middle of foraminiferal Zone N11 of Blow (1969) and the upper middle part of Zone NN6 of Martini and Worsley (1970). Consideration of the equatorial Pacific diatom biostratigraphy of Burckle (1978b) and Burckle et al. (1982) suggests that this interval may be tentatively correlated with the lower part of Magnetic Chron 12 (C5Ar) and the upper part of Magnetic Chron 13 (C5An).

D. punctata var. *hustedtii* Zone

Definition. The base of this zone is defined by the last occurrence of *D. penelliptica*. The top is defined by the last occurrence of *D. punctata* var. *hustedtii*.

Remarks. This zone is equivalent, in part, to the *R. barboi* and *C. nicobarica* Zones of Baldauf (1984). Although these two species occur in Leg 150 sites, it was not possible to employ them in a zonal context, primarily because they were not consistent in their occurrence. This was particularly true for those sites occupied on the upper slopes. The deepest site (Site 905) recovered on Leg 150 did feature acceptable continuity of these species.

Other Floral Elements. *A. ellipticus*, *A. ingens*, *A. tenellus*, *A. undulatus*, *D. hustedtii*, *D. punctata* var. *hustedtii*, *M. splendida*, *M. westii*, *P. complexa*, *P. sulcata*, *P. sulcata* var. *coronata*, *T. nitzschioides*, and *T. grunowii*.

Correlation. The base of this zone is correlative with the lower part of the *C. nicobarica* Zone of Baldauf (1984); its base is correlative with the upper part of the *R. barboi* Zone of Baldauf (1984). I tentatively correlate the *D. punctata* var. *hustedtii* Zone with the upper part of ECDZ 6 and all of ECDZ 7. Again, if one considers the equatorial Pacific diatom biostratigraphy of Burckle (1978b) and Burckle et al. (1982), then this zone may be correlated with the middle to upper part of Magnetic Chron 12 (C5Ar). As noted previously, I follow Baldauf (1984) in using the last occurrence of the nominate taxon to identify the middle/upper Miocene boundary.

Delphineis novaecaesaraea Zone

Definition. The base of this zone is defined by the last occurrence of *Denticulopsis punctata* var. *hustedtii*. The top is defined by the last occurrence of *D. novaecaesaraea*.

Remarks. This is the lowermost zone in the upper Miocene. Please note that Baldauf (1984) has the *C. yabei* directly overlying the *D. punctata* var. *hustedtii* Zone. In the scheme proposed here, the lower part of the *C. yabei* Zone of Baldauf (1984) is correlative with the *D. novaecaesaraea* Zone.

Other Floral Elements. *A. ellipticus*, *A. ingens*, *A. tenellus*, *C. endoi*, *D. hustedtii*, *D. penelliptica*, *R. miocenica*, *R. alata*, *Hemidiscus cuneiformis*, *Stephanopyxis grunowii*, and *Thalassiosira grunowii*.

Correlation. This zone very likely correlates with the uppermost part of ECDZ 6 and all of ECDZ 7 of Andrews (1988); there are good reasons for suggesting that the upper part of the zone extends above the zonal scheme of Andrews (1988) since he shows *D. novaecaesaraea* ranging younger than the youngest of the ECDZ. This further suggests that ECDZ 7 is well below the middle/late Miocene boundary as indicated by Andrews (1988). Following Burckle et al. (1982) and Baldauf (1984), this zone is tied to the lower part of Magnetic Chron 11 (C5n); further, it is correlated with foraminiferal Zones N15 and N16 of Blow (1969) and the upper part of Zone NN8 of Martini and Worsley (1970).

Coscinodiscus yabei Zone

Definition. The base of this zone is defined by the last occurrence of *D. novaecaesaraea*. The top is not defined because, at Leg 150 sites, this zone always underlies an interval of diatom dissolution. My best estimate, however, is that the top of the *C. yabei* Zone proposed

here is very likely older than the top of the *C. yabei* Zone of Burckle (1972) and Baldauf (1984).

Remarks. Baldauf (1984) has pointed out that the last occurrence of *C. yabei* is diachronous between high and low latitudes, being younger in lower latitudes. For that reason, he used the last occurrence of *C. plicatus* (now called *Thalassiosira grunowii*; Akiba and Yanagisawa, 1986), which was found to be contemporaneous with the youngest last occurrence of *C. yabei*, to define the top of his zone. In Leg 150 sites, *T. grunowii* ranges above the last occurrence of *C. yabei*. However, the true top is still not identified since the last occurrence of *T. grunowii* is directly beneath a zone of dissolution. Another diatom last occurrence, that of *D. hustedtii*, is also diachronous (i.e., younger) into higher latitudes (Burckle et al., 1982) and, therefore, not suitable for extra-latitude correlations. Burckle et al. (1982) recorded the last occurrence of this species in Magnetic Chron 10 in the equatorial Pacific but, along with others, showed that its last occurrence in the Pacific was younger in higher latitudes. This, however, was not the experience of Baldauf (1984) in sediments from around the Rockall Bank (North Atlantic). He records the last occurrence of this species in what are essentially lower upper Miocene sediments.

Other Floral Elements. *A. ellipticus*, *A. ingens*, *A. undulatus*, *A. tenellus*, *C. endoi*, *Cymatosira immunitis*, *D. novaecaesaraea*, *D. hustedtii*, *M. splendida*, *R. barboi*, *T. nitzschioides*, and *T. grunowii*.

Correlation. Burckle (1972) did not define the base of the *C. yabei* Zone in low latitudes. Based on diatom biostratigraphy across the middle/late Miocene boundary, however, one might place the lower boundary of this zone in Magnetic Chron 11 (C5n). Please note that this would not conform with the definition of the lower boundary of the *C. yabei* Zone of Baldauf (1984) since, in the zonal scheme proposed here, the base of the underlying *D. novaecaesaraea* Zone is correlative with the base of the *C. yabei* Zone of Baldauf (1984). The *C. yabei* zone, as defined here, is approximately correlative with the whole of Magnetic Chron 11 (C5n) and may range as young as Magnetic Chron 8, although this is certainly speculative. This zone is also correlative with all of the lower and middle part of foraminiferal zone N16 of Blow (1969) and the upper part of Zone NN8 of Martini and Worsley (1970).

Pseudoeunotia doliolus Zone

Definition. The base of this zone is defined by the last occurrence of *N. reinholdii*. The nominate taxon is extant.

Remarks. Although Leg 150 sediments containing the nominate taxon are certainly Pleistocene in age there is no assurance that they are late Pleistocene. This is because sediments through much of the Pleistocene are barren of diatoms or have very few. For this reason, the absence of *N. reinholdii* (the presence of which defines the next zone below the *P. doliolus* Zone) may be due to dissolution or dilution rather than to its extinction. I prefer that, in the context of this report, the reader apply a broad definition to the *Pseudoeunotia doliolus* Zone as one covering the entire Pleistocene. Although most of the Pleistocene intervals in Leg 150 sediments have few or no diatoms, there are exceptions. Some holes contained a middle late Pleistocene interval that alternated between diatom-rich and diatom-poor sediments. The diatom-rich sediment is dominated by valves of the robust diatom, *Coscinodiscus marginatus*. Discussion of this interval is given in a separate report on the Pleistocene (Christensen et al., this volume).

Other Floral Elements. *Actinopterychus undulatus*, *Azpeitia nodulifera*, *C. asteromphalus*, *C. marginatus*, *Cyclotella stylorum*, *H. cuneiformis*, *R. tessellata*, *Stephanopyxis* spp., *T. nitzschioides*, and *T. ostrupii*.

Correlation. The *Pseudoeunotia doliolus* Zone (in the broad sense, as defined above) correlates with the zone of the same name of Burckle (1972) and Baldauf (1984). Further, it correlates with the for-

aminiferous N22 and N23 Zones of Blow (1969) and calcareous nanofossil Zones NN19 and NN20; correlation is also indicated with the Brunhes Magnetic Chron as well as that part of the Matuyama Magnetic Chron which is younger than the Olduvai Subchron.

BIOSTRATIGRAPHY

Site 902

Site 902 is located at 38°56.080'N, 72°46.349'W, in 857 m of water. The primary objective was to sample a post-lower Eocene section containing seismic reflections that were traceable to beneath the continental shelf. A secondary, but not unimportant objective, was to establish a correlation with the onshore diatom zones of Andrews (1988). Diatoms are generally rare to absent from the Quaternary to the upper part of the upper Miocene. They are more abundant and generally show good preservation in the interval from the lower upper Miocene to the lower Miocene. Below this level dissolution increases and diversity and abundance drop markedly; only the more robust forms are preserved.

Hole 902A

In Hole 902A (38°56.080'N, 72°46.349'W) a 32-m section was recovered. It is placed entirely in the *P. doliolus* Zone based upon the presence of this species and the absence of *Nitzschia reinholdii*. As noted earlier, the *P. doliolus* Zone should be considered in the broad sense; that is, it is taken to include the entire rather than the upper Pleistocene.

Hole 902B

Hole 902B (38°56.078'N, 72°46.364'W) recovered a 9.5-m-thick section that was barren of diatoms.

Hole 902C

Hole 902C (38°56.078'N, 72°46.364'W) recovered a 130-m-thick section of upper Quaternary sediments, as well as a lower barren section that may be as old as late Miocene. Sediments from the surface to a depth of 95 m below seafloor (mbsf) belong to the *P. doliolus* Zone. Diatom abundances range from nil (barren) to common and the preservation is generally moderate. No diatoms were observed between 95 mbsf and the bottom of the hole (130 mbsf).

Hole 902D

Hole 902D (38°56.079'N, 72°46.375'W) penetrated some 740 m of upper Quaternary to Eocene sediments (Table 1). The surface to a depth of approximately 105 mbsf is in the *P. doliolus* Zone. An interval of opal dissolution occurs directly below that to an approximate depth of 130 mbsf. I am also unsure of the age of sediments between 130 and 152 mbsf. Although few to common diatoms are present, no age-diagnostic species were observed. Indeed, the diatom zones that have been reported from upper Miocene-lower Pliocene sediments of the North Atlantic (*Nitzschia porteri*-*N. miocenica*, *Thalassiosira convexa*, *Nitzschia jouseae*, and *Nitzschia marina* Zones; Baldauf, 1984) are not present in Hole 902D. The presence of *Actinocyclus ingens* below a depth of 188 mbsf suggests that this interval is older than middle-late Miocene. A Miocene age for this sample is also supported by the presence of the silicoflagellates *Mesocena diodon* and *Distephanus crux*. The presence of *Denticulopsis hustedtii* in the next sample below may also be used to support an age of early late Miocene.

Although zonal markers were not always observed, the interval between 162 and 228 mbsf probably belongs to the *Coscinodiscus*

yabei Zone of Baldauf (1984). The base of this zone is picked with some caution because the indicator species, *D. novaecaesaraea*, is not present continuously below this zone. The interval between 228 and 292 mbsf is placed in the *D. novaecaesarae* Zone. In contrast to the results of Baldauf (1984) in the North Atlantic, *Denticulopsis praedimorpha* does not occur in this zone. The interval between 292 and 393 mbsf covers the *D. punctata* var. *hustedtii* Zone. The *Denticulopsis* (now *Crucidenticula*) *nicobarica* Zone of Baldauf (1984) is missing from Hole 902D as is the *R. barboi* Zone. The *R. barboi*/*D. penelliptica* Zone occurs between 393 and 478 mbsf and is approximately correlative with the lowermost part of the *D. nicobarica* Zone and the very uppermost part of the *C. lewisianus* Zone of Baldauf (1984). This latter zone, in the sense used here, occurs between 478 and 536 mbsf. Few diatoms occur below the *C. lewisianus* Zone in Hole 902D; they are not placed within a zone although some samples contain robust specimens of *Stephanopyxis* spp.

Site 903

Site 903 is located at 38°56.298'N, 72°49.032'W, in 1158 m of water. The primary objective was to sample post-lower Eocene sequence boundaries. Secondary objectives included the obtaining of an unusually thick lower Miocene section and the opportunity to evaluate the effect of glacioeustatic changes on the stratigraphic record of passive margins. Diatoms are generally rare to absent from the Quaternary to the middle to upper part of the upper Miocene. They are more abundant, and with generally good preservation, in the interval from the lower upper Miocene to the lower Miocene. Below this level, dissolution increases and diversity and abundance drops markedly as only the more robust forms are preserved.

Hole 903A

Hole 903A (38°56.298'N, 72°49.032'W) recovered 637 m of sediment (Table 2). The interval from 9.5 to 423 mbsf was either barren of diatoms or had very few; certainly no age-diagnostic forms were observed although the aspect of the flora suggested that it very likely belonged to the *P. doliolus* Zone (in the broad sense, as defined above). Similarly, zonal placement of the interval between 423 and 451 mbsf must also be vague; the aspect of the poorly preserved fauna suggests that this interval is older than Pliocene but younger than middle Miocene. As with other sites from Leg 150, this very likely is part of the diatom-dissolution interval that occurs above the lower part of the upper Miocene. Zonal markers at about 461 mbsf suggest that all or most of the *C. yabei* Zone is missing from this hole; at this level, the last occurrence of *D. novaecaesaraea* is observed. This last occurrence is used to define the base of the *C. yabei* Zone. Thus, unlike Hole 902D, a significant disconformity may exist in the upper Miocene part of this hole. The *D. novaecaesaraea* Zone occurs between depths of 461 and 548 m; its base defines the middle/upper Miocene boundary. The hole bottomed at 702 mbsf in the *D. punctata* var. *hustedtii* Zone.

Hole 903B

Hole 903B (38°56.304'N, 72°49.026'W) recovered 154 m of sediment. Most of the section had no or very few diatoms; however, the entire interval is considered to be in the *P. doliolus* Zone (in the broad sense described above) because of the sporadic occurrence of the nominate taxon.

Hole 903C

Hole 903C (38°56.303'N, 72°49.024'W) was washed down to a depth of 485 mbsf before coring began. No sediment was recovered in the first four cores (485 to 505 mbsf); however, diatoms bearing

Table 1. Diatoms recovered from Hole 902D.

[illegible]

Table 1 (continued).

Core, section, interval (cm)			Abundance	Preservation	<i>Actinocyclus ehrenbergii</i>		<i>A. ellipticus</i>	<i>A. ingens</i>	<i>A. tenellus</i>	<i>Asteromphalus undulatus</i>	<i>Azpeitia endoi</i>	<i>Cavitas jouseana</i>	<i>Coscinodiscus asteromphalus</i>	<i>C. lewisianus</i>	<i>C. marginatus</i>	<i>C. perforatus</i>	<i>C. radiatus</i>	<i>C. temperi</i> var. <i>delicata</i>	<i>C. tuberculatus</i>	<i>C. yabei</i>	<i>Craspedodiscus coscinodiscus</i>	<i>Crucidentacula nicobarica</i>	<i>Cymatosira immunitis</i>	<i>Delphineis novaecaesariensis</i>	<i>D. penelliptica</i>	<i>Denticulopsis hustedtii</i>	<i>D. lauta</i>	<i>D. punctata</i> var. <i>hustedtii</i>	<i>Hemidiscus cuneiformis</i>	<i>Mediaria splendida</i>	<i>Nitzschia marina</i>	<i>Paralia sulcata</i>	<i>P. sulcata</i> var. <i>coronata</i>	<i>Pseudoeunotia doliolus</i>	<i>Rhaphidodiscus marylandicus</i>	<i>Rhizosolenia alata</i>	<i>R. barboi</i>	<i>R. hebetata</i>	<i>R. miocenica</i>	<i>R. praebarboi</i>	<i>R. styliformis</i>	<i>Rossetella paleacea</i>	<i>Stephanopyxis</i> sp.	<i>S. grunowii</i>	<i>S. turris</i>	<i>Thalassionema nitzschioides</i>	<i>Thalassiosira gravida</i>	<i>T. grunowii</i>	<i>T. lineata</i>	<i>T. ostrupii</i>																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							

Note: R = rare, C = common, A = abundant, B = barren, P = poor, M = moderate, G = good.

Table 2. Diatoms recovered from Hole 903A.

Core, section, interval (cm)	Abundance	Preservation	<i>A. ellipticus</i>	<i>A. ingens</i>	<i>A. tenellus</i>	<i>Actinopterychus undulatus</i>	<i>Aspetitia endoi</i>	<i>Cavities jouseana</i>	<i>C. marginatus</i>	<i>C. temperi</i>	<i>C. temperi var. delicata</i>	<i>C. yabei</i>	<i>Craspedodiscus coscinodiscus</i>	<i>Cymatosira immutis</i>	<i>Delphineis novaezelandica</i>	<i>Denticulopsis hustedtii</i>	<i>D. punctata var. hustedtii</i>	<i>Hemidiscus cuneiformis</i>	<i>Mediaria splendida</i>	<i>Paralia sulcata</i>	<i>P. sulcata var. coronata</i>	<i>R. barboi</i>	<i>R. praebarboi</i>	<i>Roperia tessellata</i>	<i>Rossetella paleacea</i>	<i>S. grunowii</i>	<i>S. turris</i>	<i>Thalassionema nitzschioides</i>	<i>T. grunowii</i>	<i>T. lineata</i>
1H-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	R
2H-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
5H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
6H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
9H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12H-CC	R	M	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13H-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15H-CC	R	M	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
21X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
22X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
23X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
24X-CC	C	G	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	F
25X-CC	C	M	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.
26X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
27X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
28X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
31X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
32X-CC	F	M	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	R
33X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
34X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
35X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
36X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
37X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
38X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
39X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
40X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
41X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
42X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
43X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
44X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
45X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
46X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
47X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
48X-CC	F	M	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	F	.	.
49X-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.
50X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
51X-CC	C	M	.	.	.	R	R	.	.	.	.	.	.	.	R	.	.	.	R	.	.	.	.	.	R	.	F	R	.	.
52X-2, 20-21	C	M	.	.	.	R	.	.	.	.	.	.	.	R	R	F	.	.	.	.	.	.	.	R	.	F	F	.	.	.
52X-CC	F	M	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	F	F	.	.	.
53X-CC	C	M	R	.	.	.	.	.	.	.	.	.	.	.	R	R	.	.	R	R	.	.	.	.	.	F	F	R	.	.
54X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
55X-CC	A	G	R	F	.	.	.	.	.	.	R	.	.	.	F	R	.	.	.	.	.	.	.	.	.	.	C	R	.	.
56X-CC	F	M	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	F	.	.
57X-CC	C	M	.	F	.	.	.	R	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	F	F	R	R	.
58X-CC	C	P	.	.	R	.	.	.	.	R	.	.	.	.	F	R	.	R	F	R	.	.	.	.	.	F	F	R	.	.
59X-2, 20-21	C	M	.	.	R	R	R	.	.	.	.	.	.	.	R	F	.	F	.	R	.	.	R	.	.	.	.	.	.	.
59X-2, 20-21	C	M	.	R	.	R	.	.	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
59X-4, 20-21	C	M	.	C	R	.	R	.	.	.	.	.	.	.	F	R	.	.	.	R	.	.	.	.	.	.	.	.	.	.

Table 2 (continued).

Core, section, interval (cm)	Abundance	Preservation	<i>A. ellipticus</i>	<i>A. ingens</i>	<i>A. tenellus</i>	<i>Actinoprychus undulatus</i>	<i>Azpeitia endoi</i>	<i>Covitas jouseana</i>	<i>C. marginatus</i>	<i>C. temperi</i>	<i>C. temperi</i> var. <i>delicata</i>	<i>C. yabei</i>	<i>Craspedodiscus coscinodiscus</i>	<i>Cynatosira immutis</i>	<i>Delphineis novaecaesaraea</i>	<i>Denticulopsis hustedtii</i>	<i>D. punctata</i> var. <i>hustedtii</i>	<i>Hemidiscus cuneiformis</i>	<i>Mediaria splendida</i>	<i>Paralia sulcata</i>	<i>P. sulcata</i> var. <i>coronata</i>	<i>R. barboi</i>	<i>R. praeborboi</i>	<i>Roperia tessellata</i>	<i>Rossetia paleacea</i>	<i>S. grunowii</i>	<i>S. turris</i>	<i>Thalassionema nitzschioides</i>	<i>T. grunowii</i>	<i>T. lineata</i>
59X-5, 20-21	C	M	.	.	.	.	R	.	.	.	.	.	.	.	F	.	.	R	.	R	.	.	.	.	.	.	F	R	.	.
59X-6, 20-21	C	M	.	.	.	.	R	.	.	.	.	.	.	.	F	R	.	.	.	R	.	.	.	.	.	.	F	R	.	.
59X-7, 20-21	C	M	.	F	R	R	.	.	.	.	.	.	.	.	R	F	.	.	.	R	R	.	.	.	.	.	F	R	.	.
59X-CC	C	P	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	F	R	.	.
60X-1, 20-21	C	G	.	R	R	R	R	.	.	R	.	.	.	.	F	R	.	R	.	R	.	.	.	.	.	.	F	R	.	.
60X-2, 60-61	C	P-M	.	.	.	R	.	.	.	R	.	.	.	.	F	R	R	.	R	R	R	.	.	.	.	.	F	R	.	.
60X-3, 20-21	C	M	.	R	R	.	R	.	.	.	.	.	.	.	R	R	R	R	.	F	R	.	.	.	.	.	F	R	.	.
60X-CC	R	P	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.
61X-CC	F	P	.	R	.	.	.	.	.	.	.	.	.	.	R	R	.	.	.	R	.	.	.	.	.	.	F	R	.	.
62X-CC	C	M	.	.	R	R	.	.	.	R	.	.	.	.	R	R	R	.	.	.	R	.	.	.	.	.	F	R	.	.
63X-CC	F-C	M	.	.	R	R	R	.	.	.	.	.	.	.	F	R	.	.	.	R	R	.	.	.	.	.	F	R	.	.
64X-6, 60-61	F	M	.	.	.	R	.	.	.	.	.	.	.	.	.	R	.	.	.	R	.	.	.	.	.	.	F	.	R	.
64X-CC	C	M	.	R	.	.	.	.	.	R	.	.	R	.	R	R	.	.	.	R	R	.	.	R	.	.	.	R	.	.
65X-3, 20-21	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	R	.	.	.	.	.	.	.	F	.	.	.
65X-6, 20-21	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	F	.	.	.
65X-CC	F	P	.	R	.	R	.	.	.	R	.	.	.	.	R	R	.	.	.	.	R	.	.	.	.	.	F	.	.	.
66X-CC	F	M	.	.	.	R	.	.	.	R	R	.	.	.	R	R	R	.	.	.	.	.	.	.	.	.	F	R	R	.
67X-CC	F	M	.	R	.	R	.	.	.	R	.	.	.	.	R	R	F	R	.	.	.	.	.	.	.	.	R	R	.	.
68X-CC	F	M	R	.	.	.	.	.	.	R	.	.	.	.	R	R	R	.	.	.	.	.	R	.	.	.	F	R	.	.
69X-CC	C	M	.	R	.	.	.	.	.	R	.	.	.	.	.	C	R	.	.	R	.	.	.	.	.	.	R	R	.	.
70X-CC	F-C	M	R	.	.	R	.	.	.	R	.	.	R	F	F	T	.	.	.	.	.	.	.	.	.	.	.	.	.	.
71X-CC	C	M	.	F	.	.	.	.	.	R	R	.	.	.	F	F	.	.	.	R	.	.	.	.	.	.	F	.	.	.
72X-CC	A	M	.	.	.	R	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	.	.	.	.	.	A	.	.	.
73X-CC	C	M	.	.	.	R	.	.	.	.	.	R	R	R	F	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.
74X-CC	C-A	M	.	.	.	.	.	.	.	.	.	.	.	.	R	F	.	.	.	.	.	.	.	.	.	.	A	.	.	.
75X-CC	C-A	M	R	.	.	R	.	.	.	R	R	.	.	.	F	F	.	.	.	F	R	.	.	.	.	C-A	.	R	.	.
76X-CC	C	M	.	.	.	R	.	.	.	.	.	.	.	.	R	R	R	.	.	R	.	.	.	.	.	C	.	.	.	.

Note: R = rare, C = common, A = abundant, B = barren, P = poor, M = moderate, G = good.

sediment was present in Core 150-903C-5R. The *C. yabei* Zone was not recovered in this hole. If any upper Pliocene sediment was recovered here it comprised a very short interval. The *D. novaecaesaraea* Zone probably covers the interval from about 508 to 525 mbsf. This is directly underlain, at 525 mbsf, by the *D. punctata* var. *hustedtii* Zone. If one follows the lead of Burckle et al. (1982) and Baldauf (1984) the upper boundary of this zone should be in the uppermost part of Magnetic Chron 12 (C5Ar) and approximately at the middle/upper Miocene boundary. The interval between 525 and approximately 820 mbsf belongs to the *D. punctata* var. *hustedtii* Zone. The underlying *R. barboi*/*D. penelliptica* Zone, if it is present in this hole, must be greatly truncated since the top of the *C. lewisianus* Zone occurs at 820 mbsf. This latter zone extends down to a depth of 910 mbsf. Although diatom were present, progressive downcore dissolution made it difficult to identify the base of this zone.

Hole 903D

Hole 903D (38°56.299'N, 72°49.042'W) penetrated to 1037 mbsf and was washed to 784 mbsf before coring began. The *D. punctata* var. *hustedtii* Zone occurs between this depth and 832 mbsf. The underlying *R. barboi*/*D. penelliptica* Zone, if it is present in this hole, must be greatly truncated since the top of the *C. lewisianus* Zone occurs at 842 mbsf. This latter zone extends down to 894 mbsf. Miocene diatoms are present below this zone but, because of downhole dissolution, these are not zoned.

Site 904

Site 904 was located at 38°51.806'N, 72°46.084'W, in 1710 m of water. This site, along with Site 905, were the two deep-water holes recovered during Leg 150. The primary objective was to sample post-lower Eocene sequence boundaries; a primary target was the Miocene succession because it was felt that this site suffered less microfossil dissolution during this time interval. Diatom occurrence is sporadic in the upper part of the hole (to a subbottom depth of 104 m) but they become more common below a prominent sand unit; thereafter, they are present with varying degrees of preservation down into upper Eocene sediments.

Hole 904A

Hole 904A (38°51.806'N, 72°46.084'W) was drilled to a depth of 576.7 m and recovered Quaternary to upper Eocene sediments (Table 3). The top 104 m of this hole were largely barren of diatoms. At 56 mbsf, however, a few diatoms were encountered that placed this interval in the *P. doliolus* Zone. The presence of *N. reinholdii* suggests that we may have penetrated into the lower Pleistocene (i.e., the *N. reinholdii* Zone). This latter zone was not identified in the North Atlantic (Baldauf, 1984). Diatoms first appear in abundance at 111 mbsf in sediments that underlie a prominent sand unit. The level just below this sand unit belongs to the *D. novaecaesaraea* Zone. Because the overlying *C. yabei* Zone is absent, but is present in some other sites,

Table 3. Diatoms recovered from Hole 906A.

Core, section	Abundance	Preservation	<i>A. ellipticus</i>	<i>A. ingens</i>	<i>A. tenellus</i>	<i>Asteromphalus undulatus</i>	<i>Aspetia endoi</i>	<i>Cavitas jouseana</i>	<i>C. lewisianus</i>	<i>C. marginatus</i>	<i>C. temperi</i>	<i>Craspedodiscus coscinodiscus</i>	<i>Crucidenticula nicobarica</i>	<i>Cymatosira immunitis</i>	<i>Delphineis novaezelandica</i>	<i>Denticulopsis hyalina</i>	<i>D. hustedtii</i>	<i>D. punctata</i> var. <i>hustedtii</i>	<i>Mediaria splendida</i>	<i>Nitzschia marina</i>	<i>Paralia sulcata</i>	<i>P. sulcata</i> var. <i>coronata</i>	<i>Pseudoeunotia doliolus</i>	<i>R. barboi</i>	<i>R. miocenica</i>	<i>R. praeborboi</i>	<i>R. styliformis</i>	<i>Roperia tessellata</i>	<i>S. grunowii</i>	<i>S. turris</i>	<i>Thalassionema nitzschoides</i>	<i>T. grunowii</i>
1H-CC	F	G	.	.	.	R	.	.	R	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	R	.	R	R	.
2H-CC	R	G	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3H-CC	R	M	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	R	.	R	.	.	.	.	.	R	.	.	.	R	R
4H-CC	C	G	.	.	.	R	.	.	C	.	.	.	.	.	.	.	.	.	R	.	R	.	.	.	R	.	R	F	R	.	.	.
5H-CC	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.	.
6H-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	R	.	.	.
7H-CC	F	M	.	R	.	R	.	.	.	.	.	.	.	R	R	.	.	.	.	R	.	R	.	.	.	.	F	R	.	.	.	.
8X-CC	F	M	.	R	R	.	.	.	.	.	.	.	.	R	R	R	.	.	R	.	.	R	.	.	.	.	R	R	R	.	.	.
9X-CC	C	M	.	.	.	R	R	.	.	.	.	.	.	R	R	R	.	.	.	.	.	.	.	.	.	.	R	R	R	.	.	.
14X-CC	C	M	.	.	R	.	.	.	.	.	.	.	.	R	R	R	R	.	.	.	.	.	.	.	.	.	R	R	R	.	.	.
15X-CC	C	P	.	.	.	.	.	R	.	R	.	R	.	R	R	R	.	.	.	.	.	R	R	.	.	.	.	R	R	.	.	.
16X-CC	F	P-M	.	.	R	.	.	.	.	.	.	.	.	R	R	R	.	.	.	R	.	.	.	.	.	.	R	R	R	.	.	.
17X-CC	F-C	P-M	.	.	R	R	.	.	.	.	.	.	.	R	R	R	.	.	.	R	.	.	.	.	.	.	.	F	R	.	.	.
18X-CC	C	M	.	R	R	R	.	.	.	R	.	.	.	R	R	R	R	.	.	.	.	R	.	.	.	.	C	R	.	.	.	.
19X-CC	C	P-M	R	R	.	R	R	.	.	.	.	.	.	R	R	R	R	R	.	.	.	.	R	.	.	.	R	R	R	.	.	.
20X-CC	C	M	R	.	.	R	.	.	.	.	R	.	.	R	R	R	.	.	.	.	.	R	.	.	.	.	C	R	.	.	.	.
21X-CC	C	M	.	R	.	R	.	.	R	.	.	.	.	R	R	R	.	.	.	R	.	.	.	.	.	.	R	R	.	.	.	.
22X-CC	C	M	R	R	R	R	R	.	.	.	.	.	.	R	R	R	R	.	.	.	.	R	.	.	.	.	R	R	.	.	.	.
23X-CC	C-A	M	.	.	.	R	.	.	R	.	.	.	.	R	C	C	R	.	.	.	.	R	.	.	.	.	R	C	R	.	.	.
24X-CC	C	M	R	R	.	R	.	.	R	.	.	.	.	R	C	R	R	.	.	.	.	R	.	.	.	.	R	R	R	.	.	.
25X-CC	C	M	.	R	.	R	.	R	.	R	.	.	.	R	R	R	R	.	.	.	R	.	.	.	.	.	.	R	R	.	.	.
26X-CC	C	M	R	R	.	R	R	R	R	.	R	.	.	R	R	R	.	.	.	.	R	.	.	.	.	.	C	F	.	.	.	.
27X-CC	C	M	.	R	.	R	.	R	.	R	.	.	.	R	R	R	R	.	.	.	.	R	R	.	.	.	R	R	R	.	.	.
28X-CC	C	M	R	R	.	R	R	.	R	.	.	.	.	R	F	R	R	R	R	R	.	.	.	.	.	.	R	F	.	.	.	.
29X-CC	C	M	R	.	.	R	.	.	.	.	.	.	.	R	R	R	R	R	.	.	.	.	R	R	.	.	F	.	.	.	.	.
30X-CC	C	M	R	R	.	.	.	R	.	R	.	R	.	R	R	R	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.
31X-CC	F	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.
32X-CC	C	M	.	R	R	R	R	.	R	.	.	.	.	R	R	R	.	.	.	.	.	R	.	.	.	.	R	R	.	.	.	.
33X-CC	C	M	.	.	R	.	.	R	.	.	.	.	.	C	R	R	.	.	.	R	.	.	R	.	.	.	C	R	.	.	.	.
34X-CC	F	M	.	.	.	.	.	.	R	.	.	.	.	R	.	.	.	.	R	.	.	.	.	.	.	.	F	R	.	.	.	.
35X-CC	C	M	.	R	R	.	R	.	R	.	.	.	.	R	R	R	R	.	.	.	.	R	R	.	.	.	F	R	.	.	.	.
36X-CC	F-C	M	R	R	.	R	.	R	.	.	R	.	.	R	R	R	R	.	.	R	.	.	.	.	.	.	F	R	.	.	.	.
37X-CC	C	M	R	R	.	R	.	.	.	.	.	.	.	F	R	R	R	.	.	.	.	R	.	R	.	.	R	R	.	.	.	.
38X-CC	C	M	.	R	.	R	.	.	.	.	.	.	.	F	R	R	.	.	.	.	.	R	.	.	.	.	R	R	R	.	.	.
39X-CC	C	M	R	R	R	.	R	.	R	.	.	.	.	R	R	R	R	.	.	.	.	.	.	.	.	.	R	.	R	.	.	.
40X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
41X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
42X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
43X-CC	B		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
45X-CC	C	M	R	R	R	.	.	.	.	.	.	.	.	R	.	.	.	.	R	.	.	R	R	R	.	.	R	C	R	R	.	.
46X-CC	C	M	R	R	R	R	.	.	R	.	.	.	.	R	R	R	R	R	.	.	.	.	R	.	.	.	C	R	.	.	.	.
47X-CC	C	P-M	R	R	R	R	.	.	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	.	.	.	C	R	.	.	.	.
48X-CC	F-C	P	R	R	.	R	.	.	.	.	R	R	.	R	R	.	R	.	R	.	F	R	.	.	.	.	F	R	.	.	.	.
49X-CC	C	P	R	.	.	R	.	.	R	.	.	.	.	R	R	.	R	.	R	.	.	R	.	.	.	.	C	.	.	.	.	.
50X-CC	C	P-M	.	R	.	.	.	.	.	.	.	.	.	R	R	R	R	.	.	R	.	.	.	.	.	.	R	F	R	R	.	.

Note: R = rare, C = common, A = abundant, B = barren, P = poor, M = moderate, G = good.

I suggest that considerable erosion removed most of the upper Miocene and, possibly, Pliocene sediments at this site locality. This zone extends to 148 mbsf, below which the *D. punctata* var. *hustedtii* Zone is encountered.

There is some difficulty in identifying the base of the *D. punctata* var. *hustedtii* Zone because *D. penelliptica*, the taxon used to identify it, is a nearshore form and very likely did not range this far from coastal waters. Therefore, my inability to identify the *R. barboi/D. penelliptica* Zone in Hole 904A may illustrate how sensitive this zonal scheme is to location. As noted above, this zone is identified by the last occurrence of *C. lewisianus* at the base and the last occurrence of *D. penelliptica* at the top. However, because this hole is located so far

from the coast, more open-ocean diatoms are present at the expense of the nearshore forms. Hence, the last occurrence of *C. lewisianus* coincides with the last occurrence of *D. penelliptica* (195 mbsf). This may signal a hiatus; on the other hand, it may signal a failure of the zonal concept. The base of the *C. lewisianus* Zone occurs at approximately 250 mbsf.

Site 905

Site 905 was located at 38°36.828'N, 72°17.024'W, in 3619 m of water. The water depth was greatest here of the five sites occupied during Leg 150; it was also the most seaward of these sites. One ob-

jective was to sample the Oligocene-to-Holocene deep-sea expression of eustatic sea-level change. The object was to compare this sea-level history with the history of down- and along-slope sediment transport processes.

Hole 905A

Hole 905A (38°36.828'N, 72°17.024'W) was drilled to a depth of 910.6 m and recovered Quaternary to middle Miocene sediments. Diatom concentrations ranged from rare to abundant; the upper part of the hole was a slumped deposit with rare to few resedimented diatoms, usually from Eocene sediments. As noted, few samples in the upper part of the hole are in a normal sequence. An exception is a sample at 55 mbsf that belongs to the *Pseudeunotia doliolus* Zone. Other intervals that appear to be part of a normal hemipelagic sequence include a sample at 63 mbsf. Depths between 72 and 173 mbsf contain rare to few Eocene diatoms, most commonly from the upper Eocene. Species include *Hemiaulus danicus*, *Melosira architecturalis*, *Pterotheca aculeifera*, *Pyxilla reticulata*, *Triceratium kanayae*, and *T. kanayae* var. *quadriloba*. The interval between 182 and 500 mbsf contains rare to few diatoms that generally are not age-diagnostic. The species that occur most usually in this interval are *Paralia sulcata*, *P. sulcata* var. *coronata*, and *Thalassionema nitzschioides*. The presence of these species suggests a Neogene age but nothing more specific than that.

A study of deeper samples suggests that the interval between 500 and 567 mbsf belongs to the lower upper Miocene *C. yabei* Zone. Below this, to a depth of 617 mbsf, is the *D. novaecaesaraea* Zone, which in turn is underlain by the *D. punctata* var. *hustedtii* Zone (which bottoms at 663 mbsf). It is interesting that Hole 905A has a more complete lower upper Miocene section, in that both the *C. yabei* Zone and the underlying *D. novaecaesaraea* Zone are present. The underlying *R. barboi*/*D. penelliptica* Zone extends from 663 to 741 mbsf, whereas the *C. lewisianus* Zone extends from 741 to 887 mbsf.

Site 906

Site 906 was located at 38°57.896'N, 72°45.997'W, in 1526 m of water in the thalweg of the present-day Berkeley Canyon. The intended purpose of drilling was to bypass upper Miocene sediments and to penetrate a buried Miocene canyon. The scientific objectives were to compare data from this site with that of Site 902, to evaluate the timing and mode of sediment deposition, and to determine the time of canyon cutting with respect to sea-level change.

Hole 906A

Hole 906A was drilled to a depth of 602.4 mbsf and recovered Quaternary to Eocene sediments. Diatom concentrations ranged from rare to abundant; they were entirely absent from Eocene sediments and were sporadic in occurrence through the upper Miocene to Pleistocene. Although diatoms were not always present, the interval from the surface to 37 mbsf was in the *Pseudeunotia doliolus* Zone. An interval below this (down to 53 mbsf) had few to no diatoms. Although several genera were identifiable, the only species observed was *Thalassionema nitzschioides*. It is suggested, however, that these samples are pre-Pleistocene in age. The degree of preservation and the overall aspect of the assemblage, even though it is depauperate, is not Pleistocene. Based upon superposition it is most likely assignable to the uppermost Miocene or Pliocene.

The lower upper Miocene *Coscinodiscus yabei* Zone is not present in this hole. As with several other sites in Leg 150, the first downcore occurrence of diatoms (at a depth of approximately 62 mbsf) is in the lowermost upper Miocene *D. novaecaesaraea* Zone; a major hiatus separates this zone from the overlying *Pseudeunotia doliolus* Zone (Pleistocene). The *D. novaecaesaraea* Zone extends

down to 129 mbsf, where it is underlain by the *D. punctata* var. *hustedtii* Zone. The approximate level of the middle/upper Miocene boundary is placed at about 129 mbsf. The next two underlying zonal markers (the last occurrence of *D. penelliptica*, which defines the top of the *R. barboi*/*D. penelliptica*, and the last occurrence of *C. lewisianus*, which marks the top of the *C. lewisianus* Zone), were not observed. This suggests that the *D. punctata* var. *hustedtii* Zone extends from 178 mbsf to approximately 476 mbsf, below which upper Oligocene sediments are encountered. At approximately 476 mbsf, a major unconformity has removed lower middle Miocene and lower Miocene sediments. This unconformity is also determined by the presence of Oligocene species between 486 and 544 mbsf; such species as *Bogorovia veniamini*, *Cavitatus jouseanus*, *Coscinodiscus rhombicus*, *Melosira architecturalis*, *Pseudopyxilla russica*, *Rocella gelida*, *R. vigilans*, *Stephanogonia grunowii*, and *S. grossecellulata* are recognized. No zonal designations are given. Samples below 544 m are essentially barren of diatoms; a few fragments are present in some samples but their condition defies identification to species or even generic levels.

DISCUSSION

The diatom biostratigraphy developed and described for Leg 150 coring sites can be used to address two themes: the stratigraphic tie between Leg 150 sites and the East Coast Diatom Zones of Andrews (1988) and the core-to-core correlations of seismic reflectors. Figure 2 shows the Andrews zonation and its stratigraphic setting relative to the zonation of Blow (1969) and Martini and Worsley (1970), whereas Figure 3 illustrates the biostratigraphic and magnetostratigraphic framework with which part of the ECDZ of Andrews (1988) is tied to the open ocean marine record. The left side of Figure 3 shows the last appearance datums for selected diatom species in the equatorial Pacific. These datums are directly tied to the paleomagnetic reversal record (Burckle, 1978b; Burckle et al., 1982). Further, all four of these datums are found in Leg 150 sites and three of them (the FAD, or first appearance datum, and LAD of *D. hustedtii* and the LAD of *C. lewisianus*) are found in the continental marine sections studied by Andrews (1988). The right side of Figure 3 shows where these datums fall in Hole 902D.

In Figure 4, I show that some of the datum levels occurring in Hole 902D were also noted by Andrews (1988) in sections from the East Coast of the United States. If one examines the interval between the LAD of *D. novaecaesaraea* and the LAD of *C. lewisianus* in both Hole 902D and in the zonal scheme of Andrews (1988), it should be apparent that all of ECDZ 7 and most of ECDZ 6 falls in Magnetic Chron 12 (C5Ar) and, very likely, in the upper part of Magnetic Chron 13 (C5An). Further, if one compares the FAD of diatoms in Figures 3 and 4 (particularly the FAD of *D. hustedtii* and *D. novaecaesaraea*), ECDZ 3–4 and ECDZ 5 must be older than Magnetic Chron 14 (C5A.An). This indicates that ECDZ 1 and 2 are very likely in the upper part of the lower Miocene, as suggested by Andrews (1988; see also Fig. 2) and as determined by Sugarman et al. (1993). I am not able to further refine the chronostratigraphic position of ECDZ 1 and 2. That task may be left to others who have greater familiarity with early Miocene nearshore taxa.

The second theme is site-to-site correlations based upon the diatom zonal scheme described here. These correlations are given in Figure 5. These data suggest that there are Pleistocene age unconformities in holes drilled at Sites 902, 904, and 906. There is an apparently upper Miocene unconformity in Site 903 but my data do not indicate whether the Pleistocene is also involved. Similar comments may be made for Site 905; here a dissolution zone that spans the upper upper Miocene to the lower Pleistocene may mask additional unconformities. In a number of sites (Sites 902, 904, and possibly 903) there is an unconformity at or about the middle/upper Miocene

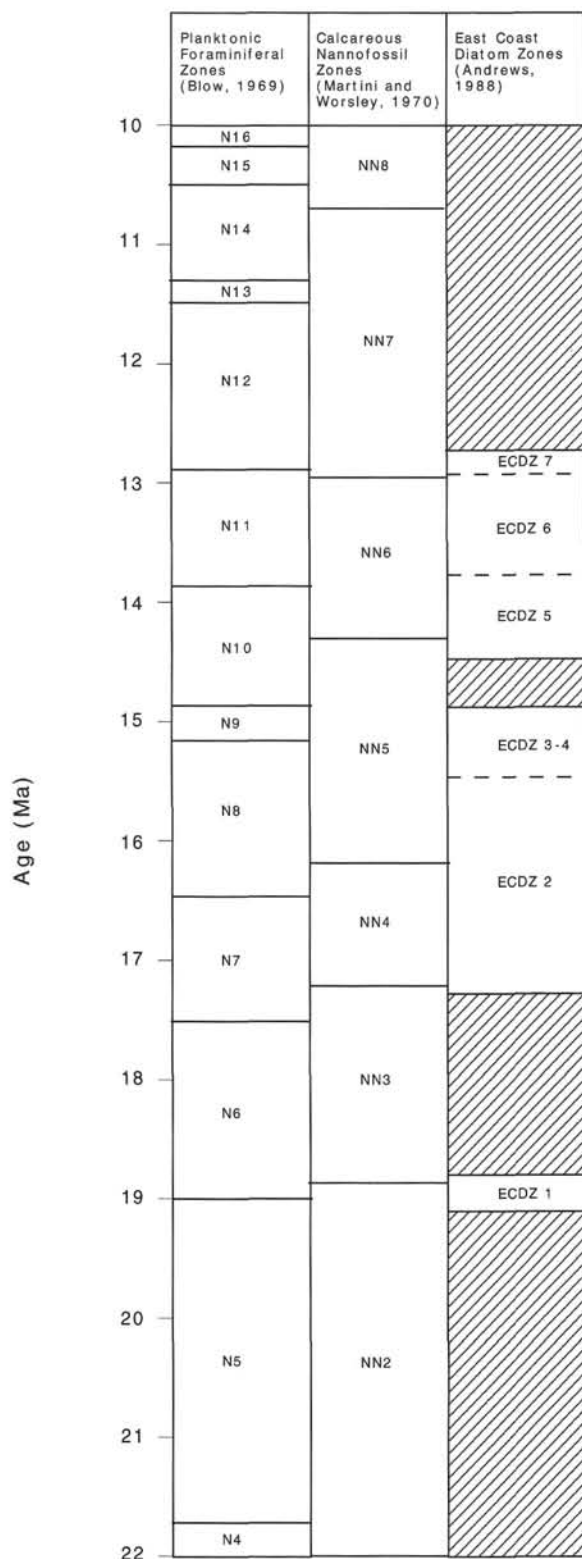


Figure 2. The East Coast Diatom Zone (ECDZ) scheme of Andrews (1988) relative to the foraminiferal zonation of Blow (1969) and the calcareous nannofossil zonation of Martini and Worsley (1970). Note that, as described in the text, the Andrews zones are not vertically conterminous.

boundary. Older middle Miocene unconformities may be present but I am unable to resolve them.

It is instructive to test the integrity of this zonal scheme by comparing it with the site-to-site correlation of major reflectors. I have chosen the Tuscan reflector because of its prominence and because it was identified in four of the five sites occupied. In Figure 5, I have indicated the level where the Tuscan reflector falls relative to the diatom zonal scheme. Note that, in the case of Sites 902, 903, and 904, sediments representing this reflector are found in the *D. punctata* var. *hustedtii* Zone; the single exception is at Site 906, where it occurs in the *D. novaecesaraea* Zone. Because of reworking of older diatoms into this part of the section, it was frequently difficult to find in-place zonal markers at this site. The presence of Tuscan reflector in the *D. novaecesaraea* Zone (although it occurs in the *D. punctata* var. *hustedtii* Zone in all other sites), therefore, should not be taken as an anomaly of nature but, rather, as a failure of the biostratigraphic method.

I refrain from discussing any paleoceanographic implications of diatom occurrences for the following reasons: (1) sample spacing was too coarse to derive any meaningful paleoceanographic message; (2) the absence of diatoms from most Oligocene and Eocene sediments was likely due to dissolution and not to any surface-water dynamics; and (3) their sporadic occurrence in Pliocene(?) and Pleistocene sediments appeared to be due to dilution resulting from increased terrigenous and shallow-water marine sediment input. Certainly, this increased sediment input is related to climatic forcing as the Earth experienced more severe climatic extremes during the late Pliocene and Pleistocene.

ACKNOWLEDGMENTS

Discussions with colleagues on board ship (S. Snyder, S. Gartner, and L. de Veruill) were much valued and appreciated. Similarly, I benefited greatly from the fact that many of those who were on board ship are also colleagues at Lamont-Doherty. Post-cruise exchanges with M. Katz, K. Miller, G. Mountain, and M. Van Fossen were of considerable help.

REFERENCES

- Abbott, W.H., 1987a. Diatom occurrences, Deep Sea Drilling Project Site 604. In van Hinte, J.E., Wise, S.W., Jr., et al., *Init. Repts. DSDP*, 93: Washington (U.S. Govt. Printing Office), 789-792.
- , 1987b. Diatom occurrences, Deep Sea Drilling Project Sites 612 and 613. In Poag, C.W., Watts, A.B., et al., *Init. Repts. DSDP*, 95: Washington (U.S. Govt. Printing Office), 417-418.
- Abbott, W.H., and Andrews, G.W., 1976. Middle Miocene diatoms from the Hawthorne formation of the Ridgeland trough, South Carolina and Georgia. *Micropaleontology*, 25:225-271.
- Akiba, F., 1986. Middle Miocene to Quaternary diatom biostratigraphy in the Nankai trough and Japan trench, and modified lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the north Pacific. In Kagami, H., Karig, D.E., Coulbourn, W.T., et al., *Init. Repts. DSDP*, 87: Washington (U.S. Govt. Printing Office), 393-481.
- Akiba, F., Hiramatsu, C., and Yanagisawa, Y., 1993. A Cenozoic diatom genus *Cavitatus* Williams; an emended description and two new biostratigraphically useful species, *C. lanceolatus* and *C. rectus* from Japan. *Bull. Nat. Sci. Mus. Ser. C: Geol. Paleontol. (Tokyo)*, 19:11-39.
- Akiba, F., and Yanagisawa, Y., 1986. Taxonomy, morphology and phylogeny of the Neogene diatom zonal marker species in the middle-to-high latitudes of the North Pacific. In Kagami, H., Karig, D.E., Coulbourn, W.T., et al., *Init. Repts. DSDP*, 87: Washington (U.S. Govt. Printing Office), 483-554.
- Andrews, G.W., 1976. Miocene marine diatoms from the Choptank formation, Calvert county, Maryland. *Geol. Surv. Prof. Pap. U.S.*, 910:1-26.
- , 1977. Morphology and stratigraphic significance of *Delphineis*, a new marine diatom genus. *Nova Hedwigia Beih.*, 54:243-260.

- , 1978. Marine diatom sequence in Miocene strata of the Chesapeake Bay region, Maryland. *Micropaleontology*, 24:371–406.
- , 1980. Neogene diatoms from Petersburg, Virginia. *Micropaleontology*, 26:17–48.
- , 1988. A revised marine diatom zonation for Miocene strata of the southeastern United States. *Geol. Surv. Prof. Pap. U.S.*, 1481:1–29.
- Baldauf, J.G., 1984. Cenozoic diatom biostratigraphy and paleoceanography of the Rockall Plateau region, North Atlantic. Deep Sea Drilling Project Leg 81. In Roberts, D.G., Schnitker, D., et al., *Init. Repts. DSDP*, 81: Washington (U.S. Govt. Printing Office), 439–478.
- , 1986. Diatom biostratigraphic and paleoceanographic interpretations for the middle and high latitude North Atlantic Ocean. In Summerhayes, C.P., and Shackleton, N.J. (Eds.), *North Atlantic Paleoceanography*. Geol. Soc. Spec. Publ. London, 21:243–252.
- Baldauf, J.G., and Barron, J.A., 1982. Diatom biostratigraphy and paleoecology of the type section of the Luisian stage, central California. *Micropaleontology*, 28:59–84.
- Barron, J.A., 1981. Late Cenozoic diatom biostratigraphy and paleoceanography of the middle-latitude eastern North Pacific. Deep Sea Drilling Project Leg 63. In Yeats, R.S., Haq, B.U., et al., *Init. Repts. DSDP*, 63: Washington (U.S. Govt. Printing Office), 507–538.
- , 1985. Miocene to Holocene planktic diatoms. In Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*: Cambridge (Cambridge Univ. Press), 763–809.
- Berggren, W.A., Kent, D.V., and Van Couvering, J.A., 1985. The Neogene, Part 2. Neogene geochronology and chronostratigraphy. In Snelling, N.J. (Ed.), *The Chronology of the Geological Record*. Geol. Soc. London Mem., 10:211–260.
- Blow, W.H., 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. In Brönnimann, P., and Renz, H.H. (Eds.), *Proc. First Int. Conf. Planktonic Microfossils*, Geneva, 1967: Leiden (E.J. Brill), 1:199–422.
- Brightwell, T., 1860. Diatomaceae, Part 1. *Q. J. Microsc. Sci.*, 7:179–181.
- Burckle, L.H., 1972. Late Cenozoic planktonic diatom zones from the eastern equatorial Pacific. In Simonsen, R. (Ed.), *First Symposium on Recent and Fossil Marine Diatoms*. Nova Hedwigia Beih., 39:217–246.
- , 1978a. Diatom biostratigraphy of Unit 2 (Tripoli) of the neotratotype Messinian. *Riv. Ital. Paleontol.*, 84:1037–1050.
- , 1978b. Early Miocene to Pliocene diatom datum level for the equatorial Pacific. *Proc. Second Working Group Mtg. Biostratigraphic Datum Planes, Pacific Neogene, IGCP Proj. 114*. Spec. Publ., Geol. Res. Dev. Ctr., 1:25–44.
- , 1982. Diatom biostratigraphy of late Miocene and Pliocene sediments of eastern Java. *Mar. Micropaleontol.*, 7:363–368.
- Burckle, L.H., Keigwin, L.D., and Opdyke, N.D., 1982. Middle and late Miocene stable isotope stratigraphy: correlation to the paleomagnetic reversal record. *Micropaleontology*, 28:329–334.
- Cleve, P.T., and Grunow, A., 1880. Beiträge zur Kenntnis der arktischen Diatomeen. *Kongl. Sven. Vetensk. Handl.*, 17:1–121.
- Ehrenberg, C.G., 1841. Über Verbreitung und Einfluss des mikroskopischen Lebens in Süd- und Nordamerika. *Abh. K. Akad. Berlin*, 139–144.
- , 1854–1856. *Mikrogeologie: Das Erden und Felsen schaffende Wirken des unsichtbar kleinen selbständigen Lebens auf der Erde*: Leipzig (Leopold Voss).
- Fenner, J., 1978. Cenozoic diatom biostratigraphy of the equatorial and southern Atlantic Ocean. In Supko, P.R., Perch-Nielsen, K., et al., *Init. Repts. DSDP*, 39 (Suppl., Pt. 2): Washington (U.S. Govt. Printing Office), 491–624.
- , 1984. Eocene-Oligocene planktic diatom stratigraphy in the low latitudes and the high southern latitudes. *Micropaleontology*, 30:319–342.
- Forti, S., 1909. Studi per una monografia del genere *Pyxilla* (Diatomee) e dei generi affini. *Nuova Notarisa*, 20:5–24.
- Fryxell, G.A., Sims, P.A., and Watkins, T.P., 1986. *Azpeitia* (Bacillariophyceae): related genera and promorphology. *Syst. Bot. Monogr.*, 13:1–74.
- Gombos, A.M., Jr., 1987. Middle Eocene diatoms from the North Atlantic, Deep Sea Drilling Project Site 605. In van Hinte, J.E., Wise, S.W., Jr., et al., *Init. Repts. DSDP*, 93: Washington (U.S. Govt. Printing Office), 793–799.
- Gombos, A.M., Jr., and Ciesielski, P.F., 1983. Late Eocene to early Miocene diatoms from the southwest Atlantic. In Ludwig, W.J., Krashenninnikov, V.A., et al., *Init. Repts. DSDP*, 71 (Pt. 2): Washington (U.S. Govt. Printing Office), 583–634.
- Greenlee, S.M., and Moore, T.C., 1988. Recognition and interpretation of depositional sequences and calculation of sea level changes from stratigraphic data-offshore New Jersey and Alabama Tertiary. In Wilgus, C.K., Posamentier, H., Ross, C.A., and Kendall, C.G.St.C. (Eds.), *Sea-level Changes: An Integrated Approach*. Spec. Publ.—Soc. Econ. Paleontol. Mineral., 42:329–353.
- Greenlee, S.M., Schroeder, F.W., and Vail, P.R., 1988. Seismic stratigraphic and geohistory analysis of Tertiary strata from the continental shelf off New Jersey: calculation of eustatic fluctuations from stratigraphic data. In Sheridan, R.E., and Grow, J.A. (Eds.), *The Atlantic Continental Margin*. Geol. Soc. Am., Geol. of North Am. Ser., 437–444.
- Greville, R.K., 1866. Descriptions of new and rare diatoms. Series 20. *Trans. Microsc. Soc. London*, New Ser., 14:121–130.
- Grove, E., and Sturt, G., 1887. On a fossil marine diatomaceous deposit from Oamaru, Otago, New Zealand (Pt. 4). *J. Quekett Microsc. Club*, Ser. 2, 3:131–148.
- Hollister, C.D., Ewing, J.I., et al., 1972. *Init. Repts. DSDP*, 11: Washington (U.S. Govt. Printing Office).
- Hustedt, F., 1927–1966. Die Kieselalgen Deutschland, Österreichs und der Schweiz unter Berücksichtigung der übrigen Länder Europas sowie der angrenzenden Meeresgebiete. In Rabenhorst, L. (Ed.), *Kryptogamen-Flora von Deutschland, Österreich und der Schweiz*: Leipzig (Akad. Verlagsges.).
- Kanaya, T., 1959. Miocene diatom assemblages from the Onnagawa Formation and their distribution in correlative formations in northeast Japan. *Sci. Rep. Tohoku Univ.*, Ser. 2, 30:1–130.
- Kanaya, T., and Koizumi, I., 1970. The progress in the younger Cenozoic diatom biostratigraphy in the northern circum-Pacific Region. *J. Mar. Geol.*, 6:47–66.
- Kützing, F.T., 1844. *Die kieselchaligen Bacillarien oder Diatomeen*: Nordhausen (W. Köhne).
- Martini, E., and Worsley, T., 1970. Standard Neogene calcareous nannoplankton zonation. *Nature*, 225:228–290.
- Poag, C.W., Watts, A.B., et al., 1987. *Init. Repts. DSDP*, 95: Washington (U.S. Govt. Printing Office).
- Pritchard, A., 1861. *A History of the Infusoria* (4th ed.): London (Whittaker and Co.).
- Rattray, J., 1890. A revision of the genus *Actinocyclus* Ehr. *J. Quekett Microsc. Club*, Ser. 2, 4:137–212.
- Schmidt, A., et al., 1874. *Atlas der Diatomaceenkunde*: Leipzig (O.R. Reissland).
- Scholle, P.A. (Ed.), 1977. Geological studies on the COST No. B-2 well, U.S. mid-Atlantic outer continental shelf area. *Geol. Surv. Circ. (U.S.)*, 750.
- , 1980. Geological studies of the COST No. B-3 well, United States mid-Atlantic continental slope area. *Geol. Surv. Circ. (U.S.)*, 833.
- Schrader, H.-J., 1973. Cenozoic diatoms from the Northeast Pacific, Leg 18. In Kulm, L.D., von Huene, R., et al., *Init. Repts. DSDP*, 18: Washington (U.S. Govt. Printing Office), 673–797.
- , 1974. Proposal for a standardized method of cleaning diatom-bearing deep-sea and land-exposed marine sediments. In Simonsen, R. (Ed.), *3rd Symp. Recent and Fossil Marine Diatoms*. Nova Hedwigia, 45:403–409.
- Sheshukova-Poretzkaya, V.S., 1962. Novie i redkie Bacillariophyta iz diatomovoi suiti Sakhalina. *Uch. Zap. Ser. Biol. Nauk (Leningrad Univ.)*, 49:203–211.
- Simonsen, R., 1979. The diatom system: ideas on phylogeny. *Bacillaria*, 2:9–71.
- Steckler, M.S., and Watts, A.B., 1982. Subsidence history and tectonic evolution of Atlantic-type continental margins. In Scrutton, R.A. (Ed.), *Dynamics of Passive Margins*. AGU Geodyn. Ser., 6:184–196.
- Sugarman, P.J., Miller, K.G., Owens, J.P., and Feigenson, M.D., 1993. Strontium isotope and sequence stratigraphy of the Miocene Kirkwood Formation, Southern New Jersey. *Geol. Soc. Am. Bull.*, 105:423–436.
- Tempere, J., and Peragallo, H., 1907–1915. *Diatomees du Monde Entier* (2nd ed.): Arcachon, Grez-sur-loing (S.-et-M.).
- Van Heurck, H., 1880–1896. *Synopsis des Diatomées de Belgique*: Anvers (Ducaju et Cie).
- Watts, A.B., and Steckler, M.S., 1979. Subsidence and eustasy at the continental margin of eastern North America. In Talwani, M., Hay, W., and Ryan, W.B.F. (Eds.), *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*. Am. Geophys. Union, Maurice Ewing Ser., 3:218–234.

Date of initial receipt: 6 March 1995

Date of acceptance: 7 February 1996

Ms 150SR-005

APPENDIX

List of Flora

- Actinocyclus ellipticus* Grunow in Van Heurck 1883, pl. 124, fig. 10; Schrader 1973, pl. 8, figs. 7–9, 12–14, 16, 17. (Pl. 2, Fig. 9)
- Actinocyclus ingens* Rattray, 1890, p. 149, pl. 11, fig. 7; Baldauf and Barron, 1982, p. 68, pl. 1, figs. 6–8. (Pl. 1, Fig. 9; Pl. 2, Fig. 7)
- Actinocyclus tenellus* (Brebisson) Andrews, 1976, p. 14, pl. 3, figs. 8–9. (Pl. 1, Fig. 11)
- Actinopterychus undulatus* (Bailey) Ralfs in Pritchard 1861, p. 839, pl. 5, fig. 88. (Pl. 1, Fig. 10)
- Azpeitia endoi* Fryxell et al., 1986, p. 16, pls. XIV, XV, XXX. (Pl. 2, Fig. 8)
- Azpeitia nodulifera* (Schmidt) G. Fryxell and P.A. Sims; Fryxell, Sims, and Watkins, 1986, pp. 19, 20, figs. XVII, XVIII.
- Bogorovia veniamini* (Jouse) Schrader; Barron, 1985, p. 780, pl. 9, fig. 5.
- Cavitatus jouseanus* (Sheshukova-Poretzkaya) Akiba, Hiramatsu, and Yanagisawa, 1993, pp. 20–21, figs. 6–20.
- Cavitatus miocenicus* (Schrader) Akiba and Yanagisawa, Akiba, Hiramatsu, and Yanagisawa, 1993, p. 28, figs. 9–11.
- Coscinodiscus asteromphalus* Ehrenberg; Abbott and Andrews, 1979, p. 235, pl. 2, fig. 7.
- Coscinodiscus lewisianus* Greville 1866, p. 78, pl. 8, figs. 8–10. (Pl. 2, Fig. 12).
- Coscinodiscus marginatus* Ehrenberg, 1841, p. 142; Ehrenberg, 1854, pl. 18, fig. 44. (Pl. 2, Fig. 14)
- Coscinodiscus rhombicus* Grunow in Van Heurck (1883), Rattray (1890), p. 568.
- Coscinodiscus temperei* var. *delicata* Barron (Pl. 1, Fig. 7; Pl. 2, Fig. 1)
- Coscinodiscus tuberculatus* Greville (1861), p. 4, pl. 4, fig. 6.
- Coscinodiscus yabei* Kanaya, 1959, pl. 5, figs. 6–9; Schrader, 1973, p. 704, pl. 6, figs. 1–6.
- Craspedodiscus coscinodiscus* Ehrenberg, Abbott and Andrews, 1976, p. 240, pl. 3, fig. 13.
- Crucidentacula nicobarica* (Grunow) Akiba and Yanagisawa; Akiba, 1986, pl. 26, figs. 1–4.
- Cyclotella stylorum* Brightwell 1860, p. 96, pl. 6, fig. 16.
- Cymatosira immunitis* (Lohman) Abbott, Abbott and Andrews, 1976, p. 242, pl. 3, fig. 18.
- Delphineis novaecaesarae* (Kain and Schultze) Andrews, 1977, pp. 250, 251, pl. 2, figs. 23, 24; Andrews, 1988, p. 18, pl. 2, 6, figs. 9–12, 5, 6. (Pl. 1, Figs. 1, 3, 5, 6, 8)
- Delphineis penelliptica* Andrews, 1977, pp. 253, 254, pl. 1, figs. 16–20; Andrews, 1988, p. 19, pl. 2, 6, figs. 17–20, figs. 9, 10. (Pl. 1, Figs. 2, 4, 8)
- Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen, 1979, p. 64; Schrader 1973, p. 704, pl. 2, figs. 28–34, 36–47. (Pl. 2, Fig. 5)
- Denticulopsis lauta* (Bailey) Simonsen, 1979; Akiba and Yanagisawa, 1986, p. 489, pl. 7, figs. 16–29. (Pl. 2, Fig. 4)
- Denticulopsis punctata* var. *hustedtii* (Schrader) Simonsen, 1979; Barron, 1981, pl. 4, fig. 1. (Pl. 2, Figs. 2, 3)
- Denticulopsis praedimorpha* (Akiba) Barron, 1981, p. 529, pl. 4, figs. 8–10.
- Hemiaulus danicus* Grunow in Cleve and Moller, 1878; Hustedt (1930), p. 877, fig. 521.
- Hemidiscus cuneiformis* Wallich, Hustedt, 1930, pp. 904–907, fig. 542.
- Mediaria splendida* Sheshukova-Poretzkaya 1962, p. 210, pl. 2, fig. 5.
- Melosira architecturalis* Brun in Schmidt et al. 1874–1959, pl. 177, figs. 45–50.
- Melosira italica* (Ehrenberg 1838) Kützing, 1844, p. 55, pl. 2, fig. 6.
- Melosira westii* Smith, Abbott and Andrews, 1976, p. 246, pl. 4, fig. 23.
- Nitzschia marina* Grunow in Cleve and Grunow, 1880, p. 70; Schrader, 1973, pl. 4, figs. 17–19.
- Nitzschia reinholdii* Kanaya and Koizumi, 1970; Schrader, 1973, p. 708, pl. 4, figs. 12–16, pl. 5, figs. 1–9.
- Paralia complexa* (Lohman) Andrews (1976), p. 156, pl. 5, figs. 1–7.
- Paralia sulcata* (Ehrenberg) Cleve, Andrews, 1980, p. 31, pl. 2, fig. 23.
- Paralia sulcata* var. *coronata* (Ehrenberg) Andrews; Andrews (1976), p. 9, pl. 1, figs. 7, 8.
- Pseudoeunotia doliolus* (Wallich) Grunow in Van Heurck, 1881, pl. 35, fig. 22.
- Pseudopyxilla russica* (Pantocsek) Forti; Forti 1909, p. 14, pl. 1, fig. 13.
- Pterotheca aculeifera* (Grunow) Van Heurck, 1896, p. 430, fig. 151; Fenner, 1978, p. 526, pl. 17, figs. 8–21.
- Pyxilla reticulata* Grove and Sturt 1887, p. 145, pl. 13, fig. 50.
- Rhaphidodiscus marylandicus* Christian, 1886, p. 218 (nomen nudum); Andrews, 1988, p. 19, pl. 2, figs. 25, 26.
- Rhizosolenia alata* Brightwell; Schrader, 1973, pl. 10, fig. 12.
- Rhizosolenia barboi* (Brun) Tempere and Peragallo, 1908, p. 26, no. 47; Schrader, 1973, p. 709, pl. 24, figs. 4, 7.
- Rhizosolenia calcaravis* Schultze; Hustedt, 1927–1930, p. 592, fig. 339.
- Rhizosolenia hebetata* Bailey, 1856, p. 5, pl. 1, figs. 18, 19.
- Rhizosolenia miocenica* Schrader, 1973, p. 707, pl. 10, figs. 2–6, 9–11.
- Rocella gelida* (Mann) Bukry; Gombos and Ciesielski, 1983, pl. 6, figs. 1–6, pl. 26, fig. 1.
- Rocella vigilans* (Kolbe) Fenner; Gombos and Ciesielski, 1983, pl. 6, figs. 7–10, pl. 26, fig. 2.
- Roperia tessellata* (Roper) Grunow in Van Heurck, Hustedt, 1930, pp. 523, 524, fig. 297.
- Rossiella paleacea* (Grunow) Desikachary and Maheshwari, Barron, 1985, p. 790, pl. 9, figs. 6–7.
- Stephanogonia actinopterychus* (Ehrenberg) Grunow, Andrews, 1976, p. 19, pl. 6, fig. 8. (Pl. 2, Fig. 6)
- Stephanopyxis grunowii* Grove and Sturt in A. Schmidt, 1888, pl. 130, figs. 1–5.
- Thalassionema nitzschioides* Grunow in Van Heurck, Hustedt, 1959, p. 244, fig. 725.
- Thalassiosira grunowii* Akiba and Yanagisawa, 1986, p. 493, pl. 27, fig. 5, pl. 29, figs. 1–86, pl. 30, figs. 1–10. (Pl. 2, Fig. 13)
- Thalassiosira lineata* (Ehrenberg) Hasle and Fryxell, 1984, p. 22, figs. 15–25.
- Thalassiosira oestrupii* (Ostenfeld) Proskina-Lavrenko; Hustedt, 1930, p. 318, fig. 155.
- Triceratium kanayae* Fenner, 1984, p. 334, pl. 1, figs. 5–6.
- Triceratium kanayae* var. *quadriloba* Fenner, 1984, p. 334, pl. 2, figs. 3–4.

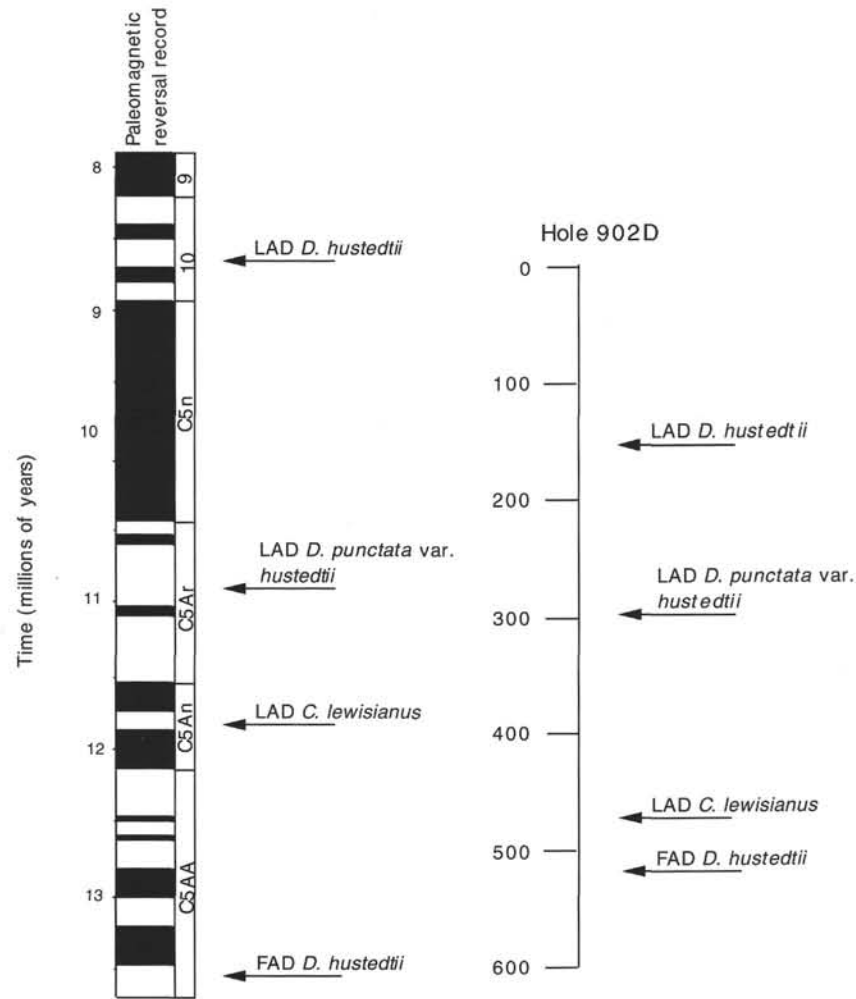


Figure 3. The last appearance datum (LAD) for selected species from the equatorial Pacific and for Hole 902D. These species were selected because their LAD in the equatorial Pacific is directly tied to the paleomagnetic reversal record and because in Leg 150 sites these same species have their LAD at approximately the same chronostratigraphy.

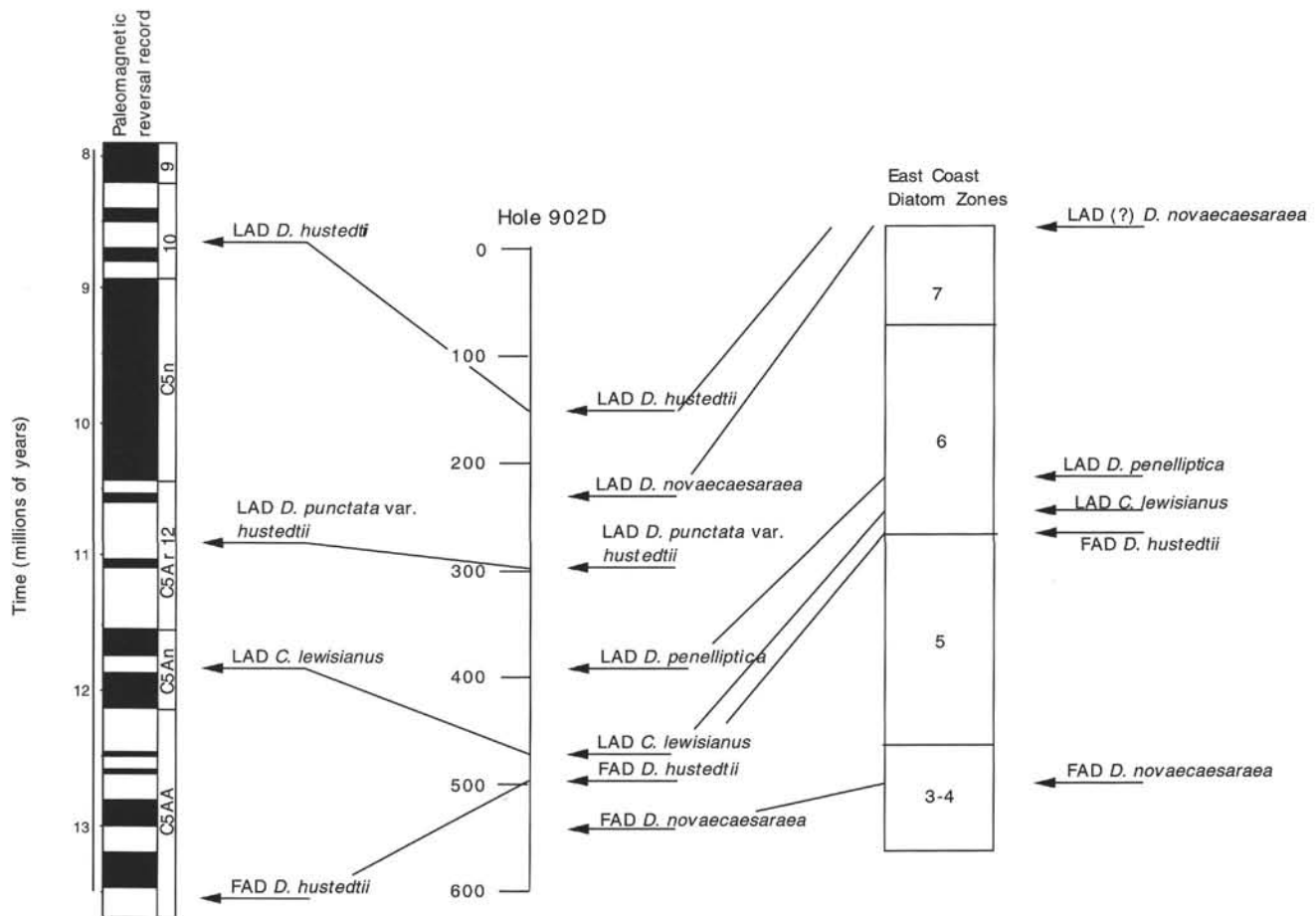


Figure 4. Correlation between the ECDZ of Andrews (1988) and the paleomagnetic stratigraphy. The latter data were recovered from piston cores from the equatorial Pacific (Burckle, 1972, 1978b; Burckle et al., 1982). In this case, Hole 902D is used to achieve the correlation; however, any other Leg 150 site that penetrated through the middle Miocene could also have been used.

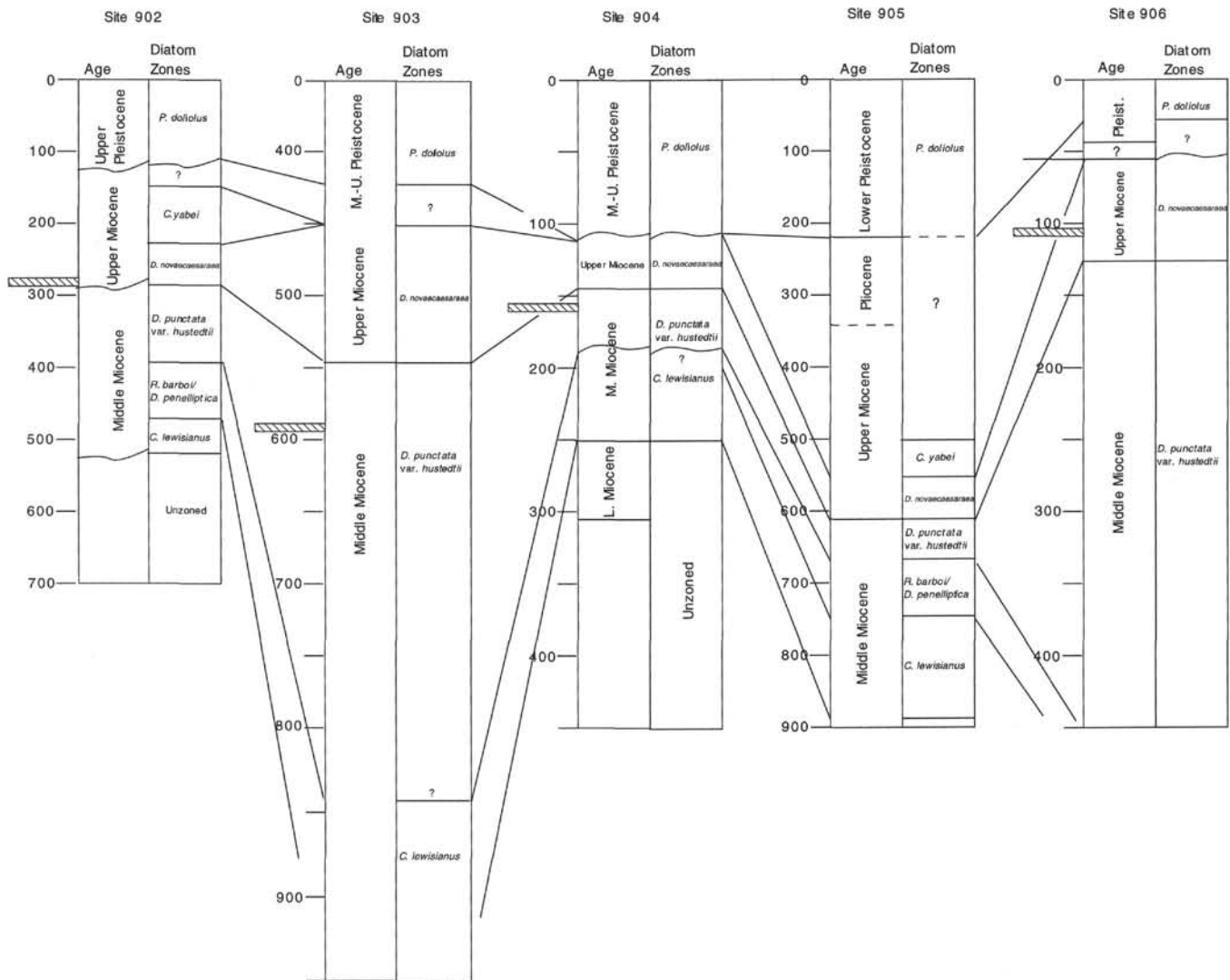


Figure 5. Correlation between Leg 150 sites based on diatom biostratigraphy. The slanted bar next to each site (except Site 905) marks the approximate position of Tuscan seismic reflector. Sediments representing this reflector were not observed at Site 905. Note that in the case of Sites 902, 903, and 904, sediments representing this reflector are found in the *D. punctata* var. *hustedtii* Zone. The single exception is Site 906, where it occurs in the *D. novaecaeasaraea* Zone. This is believed to be the result of reworking of older sediment (and older diatoms) in the upper part of this site and the consequent dilution of zonal markers.

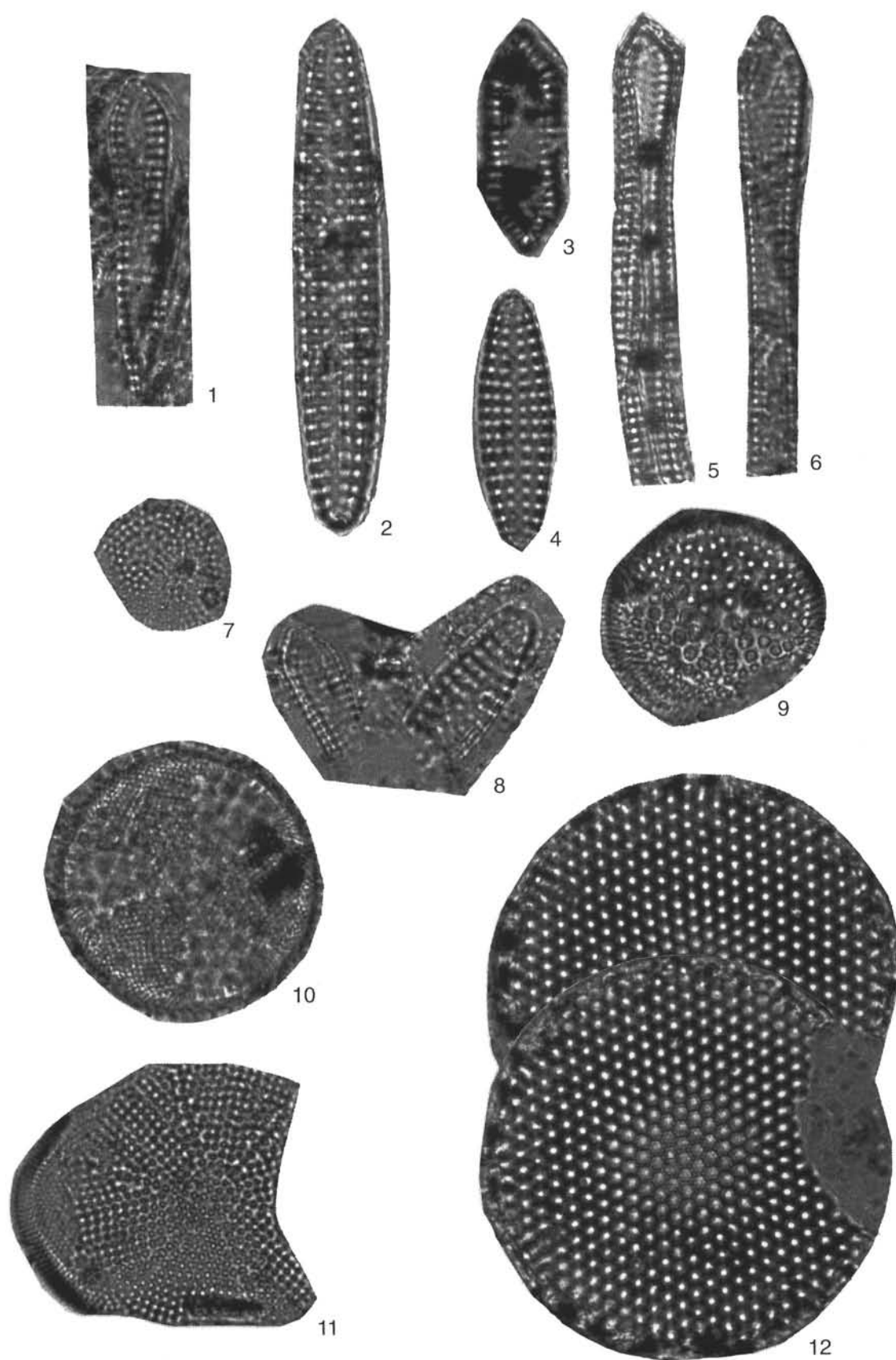


Plate 1. **1, 3, 5, 6, 8 (left).** *Delphineis novaezacaesaraea* (Kain and Schultze) Andrews. Sample 150-904A-27X-CC. **2, 4, 8 (right).** *Delphineis penelliptica* Andrews. Sample 904A-27X-CC. **7.** *Coscinodiscus temperei* var. *delicata* Barron. Sample 902D-33R-CC. **9.** *Actinocyclus ingens* Rattray. Sample 904A-27X-CC. **10.** *Actinoptychus undulatus* (Bailey) Ralfs. Sample 904A-14H-CC. **11.** *Actinocyclus tenellus* (Brebisson) Andrews. Sample 902D-42X-CC. **12.** *Thalassiosira* cf. *T. eccentrica* (Ehrenberg) Cleve. Sample 904A-27X-CC. All photographs are $\times 800$.

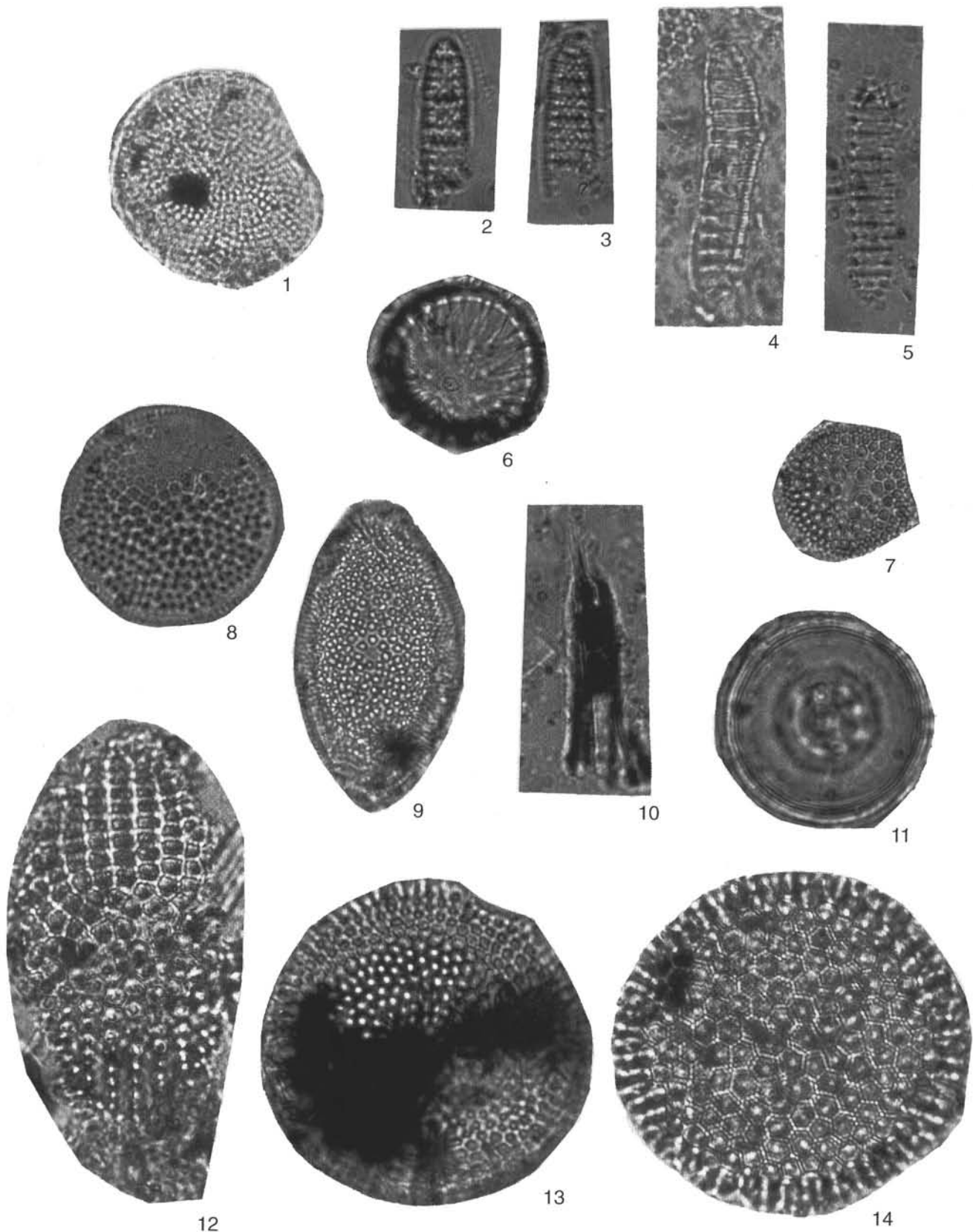


Plate 2. 1. *Coscinodiscus temperei* var. *delicata* Barron. Sample 150-902D-33R-CC. 2, 3. *Denticulopsis punctata* var. *hustedtii* (Schrader) Simonsen. Sample 902D-42X-CC. 4. *Denticulopsis lauta* (Bailey) Simonsen. Sample 903C-22R-CC. 5. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen. Sample 903C-22R-CC. 6. *Stephanogonia actinoptychus* (Ehrenberg) Grunow. 7. *Actinocyclus ingens* Rattray. Sample 903C-22R-CC. 8. *Azpeitia endoi* Fryxell et Sims. Sample 902D-42X-CC. 9. *Actinocyclus ellipticus* Grunow in Van Heurck. Sample 902D-42X-CC. 10. *Rhizosolenia miocenica* Schrader. Sample 903C-21R-CC. 11. *Melosira westii* Smith, Abbott, and Andrews. Sample 902D-42X-CC. 12. *Coscinodiscus lewisianus* Greville. Sample 903C-26R-CC. 13. *Thalassiosira grunowii* Akiba and Yanagisawa. Sample 903C-22R-CC. 14. *Coscinodiscus marginatus* Ehrenberg. Sample 903C-21R-CC. All photographs are $\times 800$.