3. CENOZOIC PLANKTONIC-FORAMINIFER BIOSTRATIGRAPHY OF DEEP SEA DRILLING PROJECT HOLE 462, NAURU BASIN (WESTERN EQUATORIAL PACIFIC), AND DISTRIBUTION OF THE PELAGIC COMPONENTS[1]

Isabella Premoli Silva and Donata Violanti, Istituto di Paleontologia, Università di Milano, Piazzale Gorini 15, Milano, Italy

ABSTRACT

The Cenozoic sedimentary sequence recovered at Deep Sea Drilling Project Hole 462, in the Nauru Basin, is characterized by rare layers of autochthonous pelagic clay and/or radiolarian ooze, which alternate with much more conspicuous, allochthonous, carbonate-rich graded layers.

The biostratigraphic signal, based on planktonic foraminifers, is strongly biased by heavy reworking. Nevertheless, most of the biozones of the late Eocene to Pleistocene have been recognized. Boundaries between zones are sometimes only tentatively drawn. A combination of data based on host and reworked planktonic-foraminifer faunas indicates that relatively few biozones are missing in the Cenozoic, namely the *Subbotina pseudobulloides*, *"Morozovella" trinidadensis*, *M. angulata*, and part of the *M. pusilla* Zones in the Paleocene; the *Morozovella formosa* through *Acarinina pentacamerata* Zones in the early Eocene; most of the *Hantkenina aragonensis* and *Globigerinatheka subconglobata* Zones in the middle Eocene; and the upper part of Zone N4 through Zone N6 in the early Miocene. The absence of Zones N14/N15 in the middle Miocene and the completeness of the Pliocene cannot be proved. The oldest reworked fauna is dated as mid-Cretaceous.

Quantitative analyses of the studied samples distinguish different types of graded layers, characterized primarily by varying distributions of the main fossiliferous components. Radiolarian-rich turbidites are common in the lower part of the sequence (late Eocene to early late Oligocene, and late Pleistocene). Foraminifer-rich turbidites occur primarily in the upper part of the Oligocene, in the middle Miocene, and in the Pliocene to early Pleistocene.

Accumulation rates per zonal interval have been estimated, the highest values occurring in the latest Eocene and late Oligocene (Zone P22). Relatively high rates are recorded also in the early late Oligocene, latest Oligocene, middle Miocene, and late Pliocene. It is suggested that these high accumulation rate values are related to erosional events dated at ~37, ~32, ~26, ~24?, ~13, and possibly 3 m.y. ago, as well as during the Pleistocene. The most important events are those dated at ~37 (latest Eocene) and at ~26 m.y. ago (late Oligocene, Zone P22).

INTRODUCTION

The present depth of the Nauru Basin (western equatorial pacific) is over 5000 meters, and Hole 462 was drilled at a water-depth of 5183 meters below sea level, on Anomaly M-26, which according to Larson and Hilde (1975) dates the ocean crust below the Nauru Basin at ~150 (m.y. old). Although the subsidence path of the Nauru Basin deviated from the Parson–Sclater curve (see Schlanger and Premoli Silva, this volume), its floor has been below the carbonate compensation depth (CCD) since the Early Cretaceous.

The whole Cenozoic sedimentary sequence was recovered continuously at Hole 462, at least down to Core 39 at a depth of 370 meters sub-bottom; it is characterized by an alternation of pelagic clay with carbonate-rich and/or radiolarian-rich layers, at first sight very similar to pelagic oozes. By analogy with modern sediments, and in agreement with the location of the Nauru Basin's bottom below the CCD during the whole Cenozoic, the interbedded pelagic clay, which mainly yielded fish debris and abyssal, non-calcareous agglutinated foraminifers, must be considered the only indigenous sediments in this location. Consequently, the occurrence of carbonates throughout the Cenozoic sequence at Site 462 is anomalous and results from mechanical redeposition rather than planktonic fallout.

Analysis by binocular microscope of the washed residues of the >63-μm fraction, confirmed by quantitative analyses, reveals that sediments other than pelagic clay are finely graded, and range from coarse foraminifer and/or radiolarian sand to nannofossil silt. Planktonic foraminifers exceeding 250 μm, almost without matrix, are the main components of the bottom of the most complete sequences. The sequences grade upward, via finer-grained planktonic foraminifer-radiolarian silty sand, to nannofossil silt, eventually topped by pelagic clay.

Redeposition processes involved a large amount of reworking. Unlike the Cretaceous sediments, in which reworking was a minor feature, both in total amount and in terms of ages of the eroded sediments, Cenozoic planktonic-foraminifer faunas are so mixed that the biostratigraphic signal may be strongly masked.

The associated calcareous benthic foraminifers show that the sources of the displaced material were mainly areas at bathyal depths. Shallow-water skeletal debris, frequently associated with abundant volcanic material, and outer-shelf to upper-bathyal faunas are contained in some very coarse graded layers interbedded episodically in the turbiditic sequence (see Premoli Silva

---

and Brusa, this volume). The sources area(s) of that shallow-water material might be different from those of the pelagic turbidites (see Site Summary, this volume).

Because of the heterogeneous character of sedimentation at Site 462 during the Cenozoic, a regular collection of data necessary for biostratigraphic, paleoecological, and paleogeographical interpretations was prevented. In an attempt to circumvent this heavy bias, the number of studied samples was considerably increased, beyond the number necessary from an undisturbed sequence of pelagic oozes. Moreover, samples were collected so that whole turbiditic sequences were fully represented from different stratigraphic intervals.

With the aim of separating the biostratigraphic-paleoecologic, and consequently paleooceanographic signal from the mechanical (size-sorting) overprint, and assessing how this signal, if detectable, evolved throughout the whole Cenozoic, quantitative analyses were performed on the collected samples.

Except for most of the core-catcher samples, and a few others, already treated aboard the ship, the following parameters were calculated for all the other samples:

1) Total weight of original samples, previously dried at constant temperature of 45°C;

2) Weight of the >63-μm fraction, calculated as percentage of the total weight;

3) Weight of the >150-μm and of the >250-μm fractions, calculated separately as percentage of the total weight of the >63-μm fractions when those latter fractions were abundant;

4) Carbonate content, expressed in percentage;

5) Percentages of the various biogenic and non-biogenic components of the >63-μm fraction, and, when present, of the >150-μm fraction. Those percentages were calculated on 300 grains and/or specimens;

6) Percentages of reworking of the planktonic-foraminifer faunas as total amount, and per time interval and/or biozone, were estimated.

The data and relative curves are plotted in Figures 1 to 3. Except for weights and carbonate contents, the parameters were estimated, including those for the samples treated aboard ship.

FORAMINIFER ASSEMBLAGES AND BIOSTRATIGRAPHY

As mentioned in the previous paragraph, redeposition, size sorting, and reworking strongly affected the planktonic foraminifer faunas, so they are unevenly distributed in a single sequence, and throughout the whole Cenozoic succession as well. Similar to the biostratigraphic record from the Cretaceous part of Site 462 (see Premoli Silva and Sliter, this volume), biostratigraphic events registered by planktonic faunas, even if displaced, were expected to occur in a relatively "normal" succession. During the Cenozoic, however, such normal order is difficult to detect, because (1) the planktonic–foraminifer record is largely discontinuous, (2) the youngest forms are largely diluted within heavily reworked assemblages, or absent in layers too finely graded for the specific foraminifer size. Nevertheless, with the aim to provide the best visual record, the distri-

bution of the most important species was plotted on routine range charts (Figs. 4–6). Based on those distributions, some biozones could be distinguished. It is worth mentioning that zonal assignment was frequently based on first occurrence of a few diagnostic species within assemblages dominated by reworked faunas. Consequently, zonal boundaries must be considered only tentative. In fact, the bulk of planktonic species characteristic of a specific biozone generally occur only as reworked faunas in younger (occasionally much younger) layers.

Discrepancies are expected among the biostratigraphic records based on the three main fossil groups—planktonic foraminifers, radiolarians, and calcareous nannofossils: all are affected by the same sedimentary processes, which however acted differently on the three groups because of their different behavior during mechanical redeposition (difference in size; see following chapters).

In specific diversity, ignoring their irregular vertical distribution, the planktonic-foraminifer faunas encountered in Hole 462 are typical of the tropical environment throughout the whole Cenozoic. Their preservation is good to excellent, despite redeposition. Only in a few cases, mainly confined to the uppermost part of the recovered succession, are the largest specimens, such as those belonging to globoquadrinids, mechanically broken. Traces of dissolution are absent or very rare, affecting mainly early and middle Miocene assemblages.

The zonal scheme followed in the present paper is shown in the Site Summary (this volume). It is based mainly on schemes by Hardenbol and Berggren (1978) and Berggren and Van Couvering (1974). The biozones identified are as follows (from bottom to top):

Eocene

Zone P6, *Morozovella edgari* Subzone, Early Eocene

Occurrence: Core 44.

Relatively abundant, moderately well-preserved planktonic-foraminifer faunas are recorded in Core 44, Section 1. The assemblage contains keeled morozovellids, and some acarininids. Besides the zonal marker, *Acarinina nitida*, "*Globorotalia*" *guatemalensis*, *Morozovella acuta*, *M. gracilis*, "*Morozovella*" *aequa*, "*M.*" *wilcoxensis*, and *Subbotina* sp. have been identified. They are in general concentrated at the bottom of sequence (Core 44, Section 1, 7–10 cm), and they decrease upward. Reworked Late Cretaceous and late Paleocene (Zone P4 = *Planorotalites pseudomenardii* Zone) assemblages occur in the same samples.

Zones P16/P17 *Turborotalia cerroazulensis* Zone, Late Eocene

Occurrence: Core 38 through Core 34.

The relatively diversified assemblages attributed to these zones contain *Turborotalia cerroazulensis cocoaensis*, rare *T. cerroazulensis cerroazulensis*, *T. pseudoampliapertura*, *Hantkeninae*, *Catapsydrax unicavus*, *C. perus*, *Globorotaloides suteri*, *Subbotina linaperta*, *Globoquadrina tripartita*, *G. galavisi*, *Pseudohastiger-*
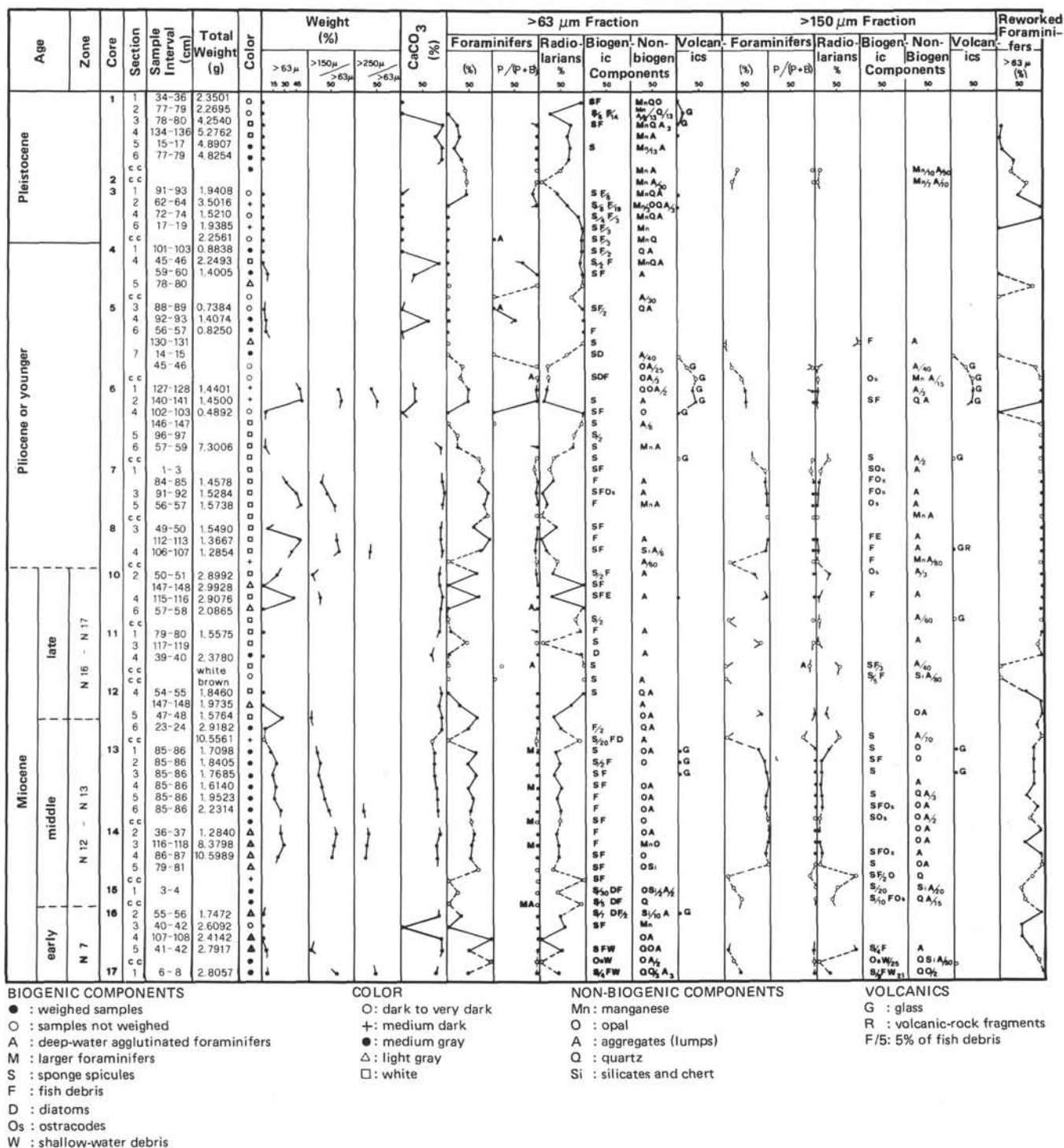
Figure 1. Quantitative sedimentological data, DSDP Hole 462, Core 1 to Core 17, Section 1, Pleistocene to early Miocene.

ina micra, and *Chiloguembelinae*. Rare are representatives of the genus *Globigerinatheka*, possibly reworked. This assemblage is relatively common in Core 37, whereas the overlying cores are almost devoid of planktonic foraminifers. *Cassigerinella chipolensis*, associated with *Chiloguembelinae, Tenuitella gemma, T. munda*, is recorded in Core 34, Section 1, 14–16 cm, at the top of which, on the basis of nannofossil and radiolarian records, the Eocene/Oligocene boundary might be placed. Rare late Oligocene forms attributable to Zone N4 (lower part), found scattered in the discussed interval, are interpreted as down-hole contaminants.

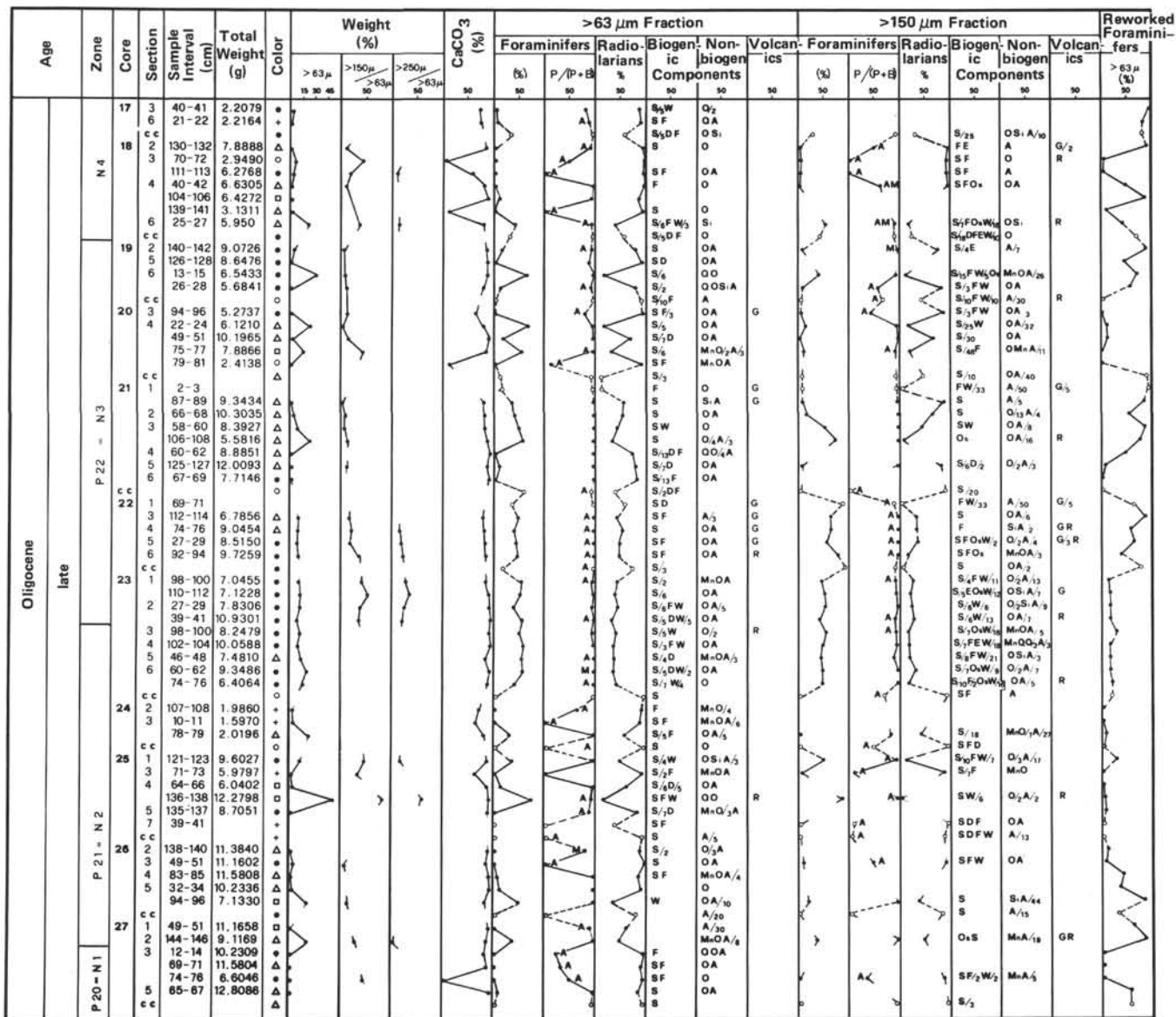Planktonic foraminifers are absent in Core 33 and in the lower part of Core 32.

Figure 2. Quantitative sedimentological data, DSDP Hole 462, Core 17, Section 2, to Core 27,CC, late Oligocene.

Oligocene

Zone P20, *Turborotalia ampliapertura* Zone, Late Oligocene

Occurrence: Core 32, Section 3, to Core 27, Section 3.

Besides the zonal marker, *Globorotalia opima opima*, *Turborotalia pseudoampliapertura*, *T. increbescens*, *Globoquadrina tripartita*, *G. galavisi*, *Catapsydrax unicavus*, *C. dissimilis*, etc. occur, associated with specimens attributable to *Globoquadrina baroemoenensis*, in Core 32, Section 3, 113–115 cm. This assemblage characterizes the lower part of Zone P20, or the boundary between Zones P19 and P20. This attribution is confirmed by the occurrence of *Globorotalia* sp. cf. *G. siakensis* in Core 29, Section 3, 62–64 cm, which, according to Blow (1969), would appear in the middle part of Zone P20.

The fine fractions (<150 µm) are dominated by *Chiloguembelinae*, *Pseudohastigerinae*, and *Tenuitellae* (*T. gemma* and *T. munda*). The latter forms are considered reworked from early Oligocene layers, along with the late Cretaceous through late Eocene assemblages. Radiolarians are strongly affected by redepositional processes in this interval.

Zone P21, *Globorotalia opima opima* Zone, Late Oligocene

Occurrence: Core 27, Section 2, to Core 23, Section 3.

Above an interval alternately yielding primarily reworked assemblages (Core 28) or devoid of planktonic foraminifers, Core 27, Section 2, 144–146 cm contains rare forms attributable to *Globoquadrina globularis*, whose appearance according to Blow (1969) would occur within Zone P21. Among the species here con-
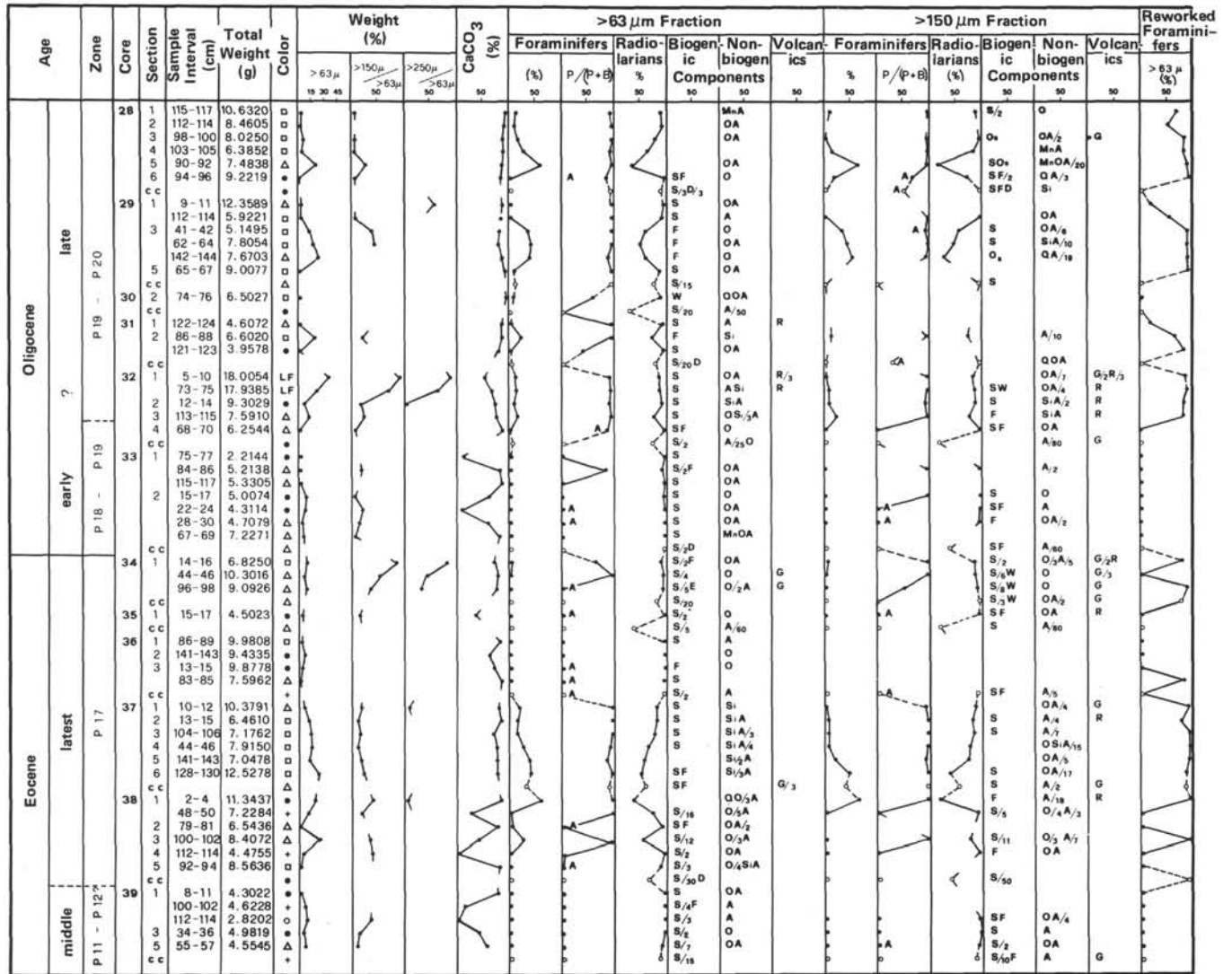
Figure 3. Quantitative sedimentological data, DSDP Hole 462, Core 28 to Core 39,CC, late Oligocene to middle Eocene.

sidered coeval with the mentioned taxon, are *Globoquadrina baroemoenensis, G. galavisi, G. winkleri, G. tripartita, Catapsydrax unicavus, C. dissimilis, Globorotaloides suteri,* and *Cassigerinella chipolensis.*

The zonal attribution is confirmed by the occurrence in the upper part of the interval (Core 25, Core 23 lower part) of primitive *Globoquadrina altispira* and *Globorotalia siakensis.* The occurrence of the zonal marker is discontinuous.

Reworking is considerable and involves also the radiolarians, which are clearly size-sorted in most of the studied samples.

Zone P22, *Globigerina angulisuturalis* Zone, Late Oligocene

Occurrence: Core 23, Section 2 through Core 19.

The beginning of Zone P22 is placed at the appearance of *Globoquadrina praedehiscens* in Core 23, Section 2, 39–41 cm. Because of the heavy reworking, the extinction level of *Globorotalia opima opima* at Hole 462 is not biostratigraphically reliable. Within this

interval, rare *Globigerinoides primordius, Globigerinita juvenilis, Globorotalia mendacis, G. semivera,* and small, thin-walled *Globorotalia,* possibly the ancestral forms of the *G. fohsi* lineage, also occur, albeit discontinuously.

In Core 23, the fine fractions (< 150 μm), previously dominated by pseudohastigerinids and tenuitellids, become composed mainly of *Cassigerinella* and *Chiloguembelina.* Also reworked material from early Oligocene layers decreases and is replaced by undifferentiated mid-Oligocene assemblages.

In Cores 21 through 19, layers rich in planktonic foraminifers are much rarer than in the underlying Cores 23 and 22, while radiolarian-rich layers increase.

Zone N4, *Globorotalia kugleri* Zone, Latest Oligocene

Occurrence: Core 18,CC to Core 17, Section 3.

The appearance of the zonal marker marks the beginning of the zone, although the planktonic-foraminifer faunas, because of the reworking, appear very similar to
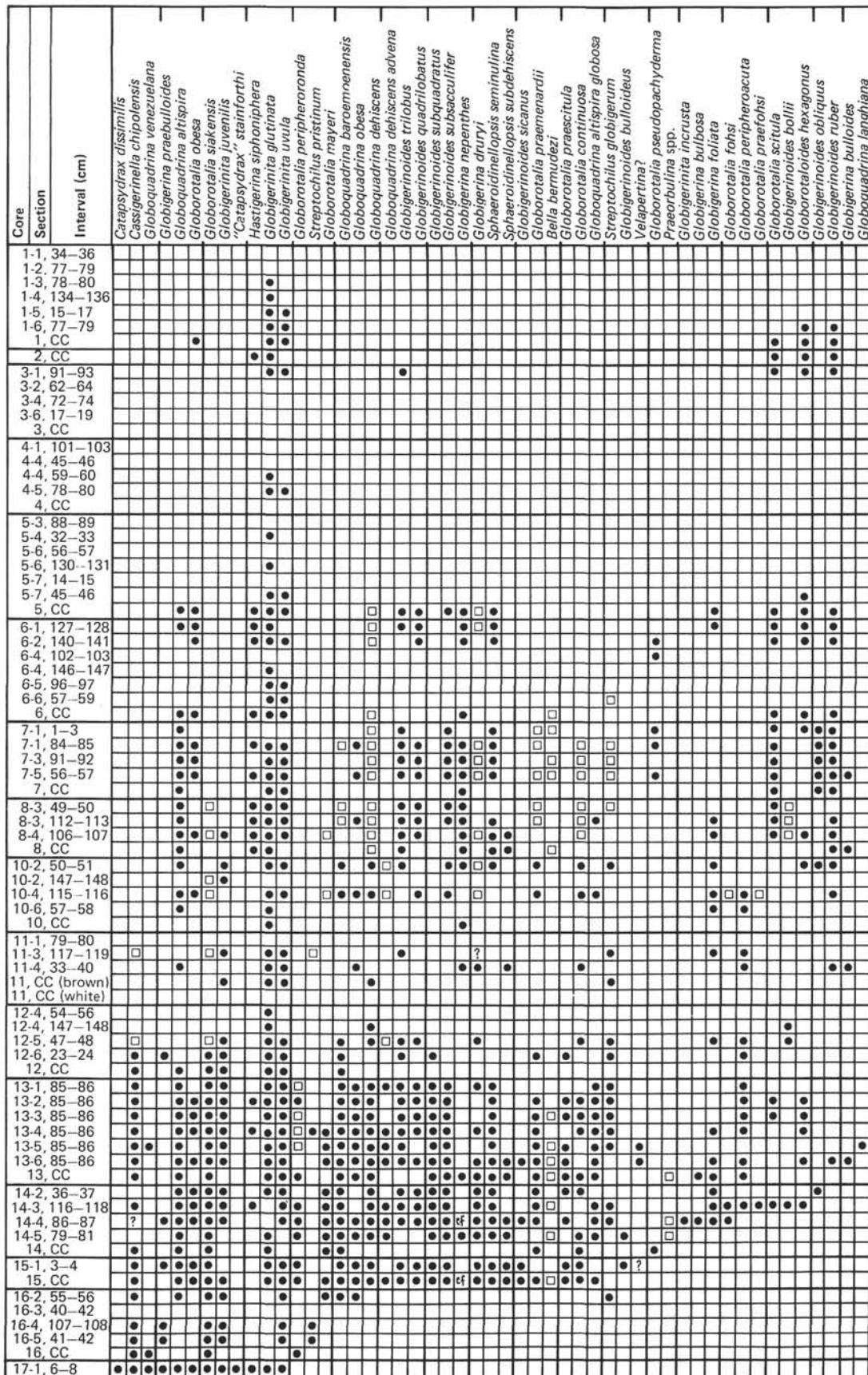
Figure 4. Distribution of selected planktonic foraminifers, DSDP Hole 462, Core 1 through Core 17, Section 1, Pleistocene to early Miocene.
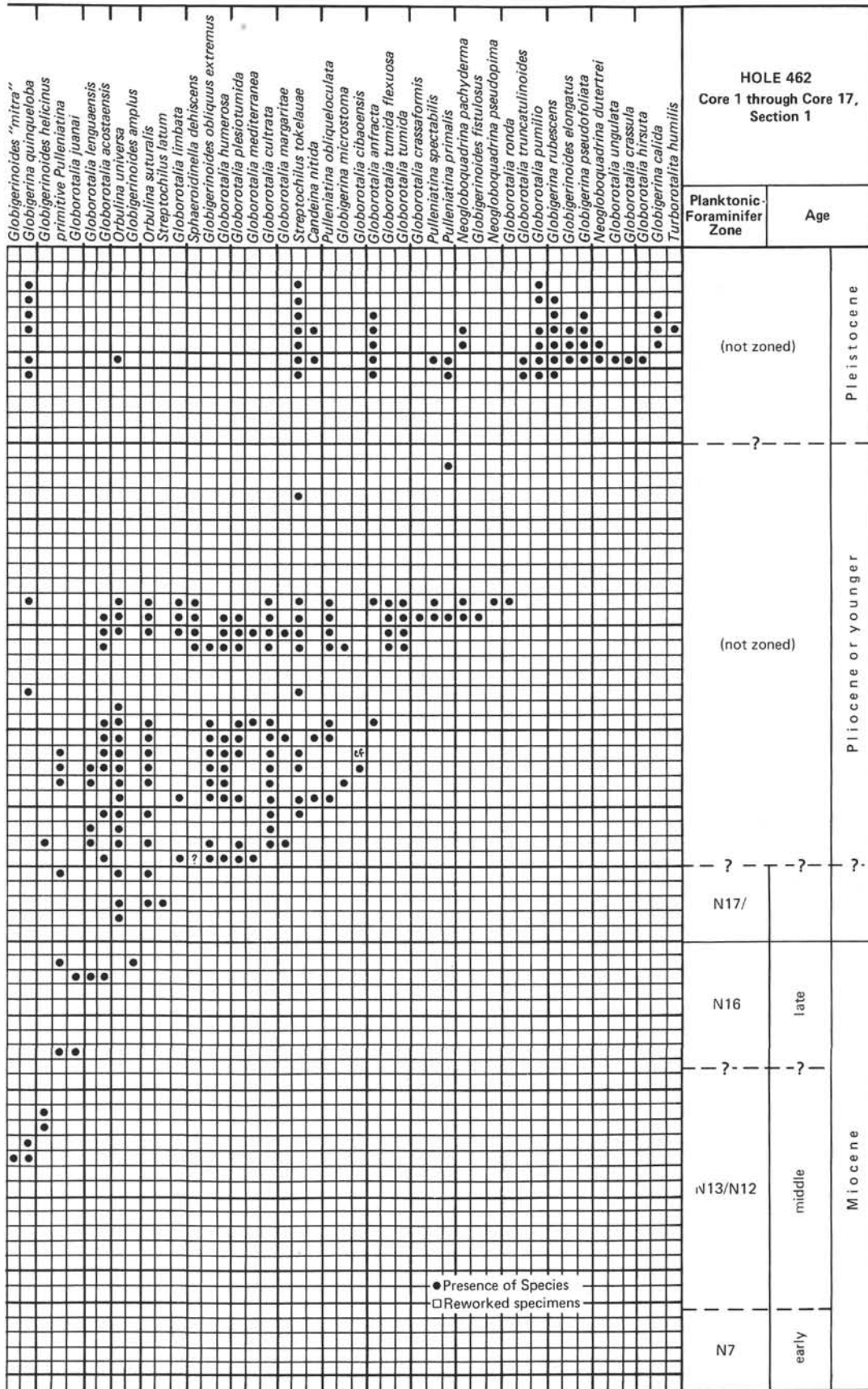
Figure 4. (Continued).

Figure 5. Distribution of selected planktonic foraminifers, DSDP Hole 462, Core 17, Section 2 through Core 27,CC, late Oligocene.

Figure 6. Distribution of selected planktonic foraminifers, DSDP Hole 462, Core 28 through Core 39,CC, late Oligocene to middle Eocene.

those below. On the basis of the absence of *Globigerinoides* and *Globoquadrina dehiscens*, this interval is still attributed to the Oligocene.

Layers rich in radiolarians are still common.

Miocene

Zone N7, Early Miocene

Occurrence: Core 17, Section 1, through Core 16.

On the occurrence of well-developed specimens of *Hastigerina siphonifera* and of *Globigerinita glutinata* in Core 17, Section 1, 6–8 cm, the top of Core 17 is attributed to Zone N7, middle to late early Miocene. Planktonic-foraminifer assemblages are dominated by forms from Zone N4.

Radiolarian-rich layers are common in this interval.

Zones N12/N13, Middle Miocene

Occurrence: Core 15,CC to Core 12, Section 6.

The attribution to Zones N12/N13 is based on the occurrence of *Globigerina druryi* and forms transitional to *Globigerina nepenthes*, and of *Sphaeroidinellopsis subdehiscens* in the core catcher of Core 15 and in the lower part of Core 14—in agreement with the range of those species proposed by Blow (1969). Rare *Velapertina* seem to occur in this interval. Again, the foraminifer-rich assemblages are dominated by reworked faunas belonging to the early and early middle Miocene. Such taxa as *Globigerinatella insueta, Beella bermudezi, Globorotalia archaeomenardii*, and *G. peripheronda* are common.

Reworked forms of early Miocene age display evidences of corrosion, perhaps due to dissolution in aggressive bottom waters.

Zone N16/N17, Late Miocene

Occurrence: Core 12, Section 5, through Core 10.

The occurrence of *Globorotalia juanai* and primitive forms attributable to *Pulleniatina*, in the absence of *Globorotalia siakensis* and *Globigerinoides subquadratus*, in Core 12, Section 5, 47–48 cm, would place this sample in the late Miocene Zone N16 or Zone N17 (see Stainforth et al., 1975; Brönnimann and Resig, 1971). In the overlying cores, *Globigerina nepenthes* and *Globigerinoides ruber* also occur, in agreement with the zonal attribution of the considered interval. Planktonic-foraminifer assemblages are, however, very rich in the more-developed *Globorotalia fohsi* lineage, considered reworked from the middle Miocene. Core 9 had no recovery.

Pliocene or Younger

Occurrence: Core 8,CC through Core 4.

The occurrence of some well-developed specimens of *Globorotalia margaritae*, and possibly *Sphaeroidinella dehiscens*, in the core-catcher sample of Core 8 and in the higher levels indicates that the host assemblage belongs to the Pliocene, although the planktonic-foraminifer assemblages are dominated by late Miocene Zone N17 faunas. The attribution of Core 8 to the Plio-

cene is confirmed by the occurrence of *Streptochilus tokelauae* in Core 8, Section 3, 49–50 cm, which ranges, according to Brönnimann and Resig (1971), from the upper part of the *G. margaritae* Zone to the lower part of the Pleistocene. The occurrence of *Globigerinoides fistulosus* in the core-catcher sample of Core 6 testifies that some of the planktonic-foraminifer faunas are attributable to the late Pliocene. However, most of the species characterizing the late Pliocene assemblages, such as the large-keeled globorotaliids, are not recorded from Hole 462. On the basis of the available data, the completeness of the Pliocene record cannot be either proved or disproved. A few forms of Pleistocene affinities occur from the bottom of Core 8. Taking into account that the highest cores recovered from Hole 462 are very disturbed by drilling and soupy, those Pleistocene forms are interpreted as down-hole contaminants. However, that the Pliocene assemblages could also be reworked into the Pleistocene, cannot be ruled out.

Pleistocene

Occurrence: Core 3 through Core 1.

The uppermost three cores yielded a discontinuous record of planktonic foraminifers attributable to the Pleistocene. Although reworking masks the biostratigraphic signal, it seems that the whole Pleistocene is represented in those cores. In particular, the occurrence of *Streptochilus tokelauae*, associated with *Pulleniatina obliquiloculata, Truncorotalia truncatulinoides, Sphaeroidinella dehiscens dehiscens* in Core 3, would suggest the presence of taxa attributable to Zone N22, whereas Core 1 is attributable to Zone N23, based on the appearance of *Globorotalia hirsuta, Globigerina calida*, and *Pulleniatina finalis*.

Pliocene and early Pleistocene assemblages, still associated with rich late Miocene faunas, are reworked in the uppermost foraminifer-rich layers (up to Core 1, Section 3).

The uppermost few meters of sediments recovered from Hole 462 are pelagic clay and do not contain any foraminifers.

Reworked Assemblages

At Hole 462, several planktonic-foraminifer faunas not recorded in their correct stratigraphic position only occur reworked in much younger layers. Analysis of these reworked assemblages enlarges the biostratigraphic record not only for the Cenozoic, but also for the Mesozoic (see Premoli Silva and Sliter, this volume).

These reworked assemblages are attributable as follows (from older to younger) (Fig. 7):

Aptian: Based on the occurrence of a specimen attributable to *Hedbergella trocoidea* in Core 6, Section 2, 140–141 cm.

Albian: Based on the occurrence of *Ticinella* sp. aff. *T. breggiensis* (Core 25, Section 4, 136–138 cm), of *Ticinella*? (Core 22, Section 5, 92–94 cm).

Albian to Cenomanian: Based on the occurrence in several samples from Core 27 of rare specimens of *Globigerinelloides bentonensis*, well-preserved *Schac-*
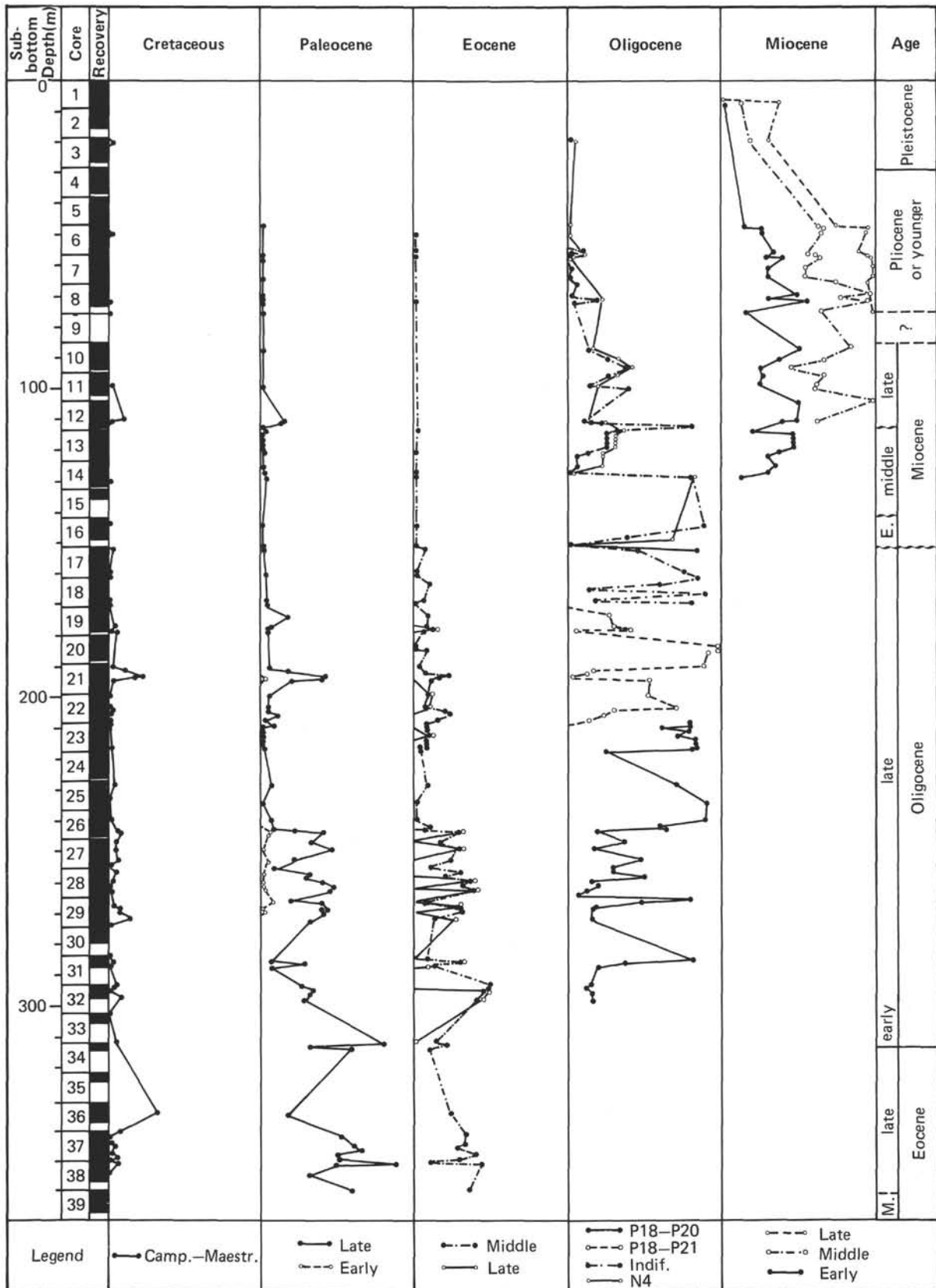
Figure 7. Distribution of reworked planktonic-foraminifer assemblages, plotted against age and/or zones for Hole 462, Core 1 to Core 39. Note that the late Paleocene assemblage includes the late Paleocene *Morozovella velascoensis* Zone and the earliest Eocene *Morozovella edgari* Zone.

koina cenomana, and *Hedbergella planispira*; they are generally contained in radiolarian-rich sandy to silty layers.

Maestrichtian: Maestrichtian and possibly Campanian planktonic foraminifers are common throughout the whole Cenozoic sequence, except for Cores 1 and 2. In the coarser layers, the most common species are *Globotruncana arca, G. rosetta, G. bulloides, G. linneiana,* and *G. ventricosa.* The finest fractions are dominated by *Heterohelicidae* (Core 29, Section 3, 142-144 cm), *Pseudoguembelina costulata* and *P. excolata* being the most common species; they are associated with *Globigerinelloides volutus, G. asper,* and *Rugoglobigerina rugosa;* moreover, *Rugoglobigerina hantkeninoides,* of early Maestrichtian age, occurs in Core 19, Section 6, 13-15 cm; *Globotruncana gagnebini,* of early to mid-Maestrichtian age, occurs in Core 13, Section 5, 85-86 cm. Finally, *Racemiguembelina fructicosa,* sometimes associated with *Trinitella* and *Globotruncana contusa,* occurs in Core 38, Section 1, 2-4 cm; Core 21, Section 3, 106-108 cm; Core 14, Section 5, 79-81 cm; and Core 11, Section 3, 117-119 cm. The latter forms are characteristic of the late Maestrichtian *Abathomphalus mayaroensis* Zone, which was not recorded in the underlying Mesozoic sequence.

Early Paleocene: *"Globigerina" eugubina* Zone or base of *Subbotina pseudobulloides* Zone—Some *Woodringina* attributable to the mentioned zones are recorded in Core 29, Section 5, 65-67 cm and, in Core 29, Section 3, 142-144 cm. *"Morozovella" uncinata* Zone—Based on the occurrence of the zonal marker in Core 29, Section 3, 62-64 cm and, Core 21, Section 3, 106-108 cm.

Late Paleocene: *Planorotalites pseudomenardii* Zone (= P4)—Based on the occurrence of the zonal marker, *Morozovella pusilla pusilla, M. laevigata, M. angulata,* etc. in Core 38, Section 1, 2-4 cm and, Core 37, Section 4, 44-46 cm.

Late Paleocene/Early Eocene: *Morozovella velascoensis* Zone (= P5) and *"Morozovella" edgari* Zone (= part of P6a) are considered together because of the many forms in common, particularly the morozovellids. The latter forms are distributed throughout the whole Cenozoic sequence. The most common species attributable to those zones are *Morozovella gracilis, M. subbotinae, M. acuta, "M." aequa, "M." wilcoxensis, "Globorotalia" guatemalensis,* and the zonal markers.

Middle Eocene: *Hantkenina aragonensis/Globigerinatheka subconglobata* Zones—Sinistrally coiled specimens of *Morozovella aragonensis* are very rarely recorded in Core 32, Section 3, 113-115 cm. *"Globigerinatheka" senni,* one of the most common reworked forms from the middle Eocene, could also be partially reworked from those zones. *Morozovella lehneri* Zone through *Truncorotaloides rohri* Zone (P12-P14)—Planktonic-foraminifer assemblages representative of these zones are very common throughout the Cenozoic sequence; they mainly occur reworked all together, and cannot be separated. The

Turborotalia cerroazulensis lineage and several species of the *Globigerinatheka* group are well represented, associated with common *"Globigerinatheka" senni.*

Late Eocene: *Globigerinatheka semiinvoluta* Zone (P15)—Based on the occurrence of the zonal marker in Core 32, Section 3, 113-115 cm. *Turborotalia cerroazulensis* Zone, topmost part (= P17)—Based on the occurrence of *Turborotalia cerroazulensis cunialensis* in Core 32, Section 1, 5-10 cm.

Early Oligocene: Zones P18/P19 (= *Pseudohastigerina micra/Cassigerinella chipolensis* Zone)—The record of these zones is attested by the occurrence of abundant *Pseudohastigerina micra, P. naguewichiensis, P. barbadoensis, Tenuitella gemma,* and *T. munda* in the finest fractions of a large number of cores (Core 32 through Core 22, and sporadically higher).

Early to Middle Miocene: Zone N8, and possibly Zone N9—Rare *Globigerinoides sicanus* and *Praeorbulina* would testify that at least a few levels attributable to those biozones have been deposited in the source area (Cores 14 and 15). Zone N10 to Zone N11—These zones are recognized on the occurrence of all evolutionary terms of the *Globorotalia fohsi* lineage, such as *G. peripheroacuta, G. praefohsi,* and *G. fohsi,* associated with *G. archaeomenardii* and forms transitional to *G. praemenardii.* They occur mainly in Core 14 through Core 6.

Combining the evidences from all the analyzed planktonic-foraminifer faunas, both surely reworked and host assemblages, only a few zones are not recorded in Hole 462. They are as follows (from older to younger):

Subbotina pseudobulloides Zone and *"Morozovella" trinidadensis* Zone, early Paleocene.

Morozovella angulata Zone, and at least the lower part of the *"Morozovella" pusilla* Zone, early late Paleocene.

Morozovella formosa Zone through *Acarinina pentacamerata* Zone, middle to late early Eocene.

Most of the *Hantkenina aragonensis* and *Globigerinatheka subconglobata* Zones, early middle Eocene.

Zone N4 (upper part) through Zone N6, early to middle early Miocene.

Because of the relatively poor characteristics of the planktonic faunas, the absence of the late middle Miocene Zones N14 and N15 cannot be proved. Moreover, few species found in Hole 462 are attributable to the Pliocene. However, faunal characteristics are such that possible gaps are very difficult to demonstrate.

On the contrary, the late Maestrichtian turns out to be more complete than is apparent from the record of the uppermost Mesozoic cores (Cores 47 and 46), which could be attributed only to the *Globotruncana gansseri* Zone (see Premoli Silva and Sliter, this volume).

Finally, it is worth mentioning that in Hole 462 some genera are poorly represented, although the pertinent size fractions and/or zonal assemblages are recorded. Among those genera are *Globigerinoides, Orbulina, Sphaeroidinella,* the *Globorotalia crassaformis* group, and, generally speaking, the large-keeled globorotaliids, such as *G. tumida* group, *G. cultrata,* etc. of Plio-

cene–Pleistocene age. Their scarcity or absence is not well understood.

ABYSSAL AGGLUTINATED BENTHIC FORAMINIFERS

As mentioned in the introduction, pelagic clay, devoid of carbonate, represents the only autochthonous sediment throughout the Cenozoic sequence of Hole 462. This is confirmed by the occurrence throughout the sedimentary succession of agglutinated, totally non-calcareous, benthic foraminifers, which today inhabit abyssal depths, below the CCD.

At Hole 462, they represent one of the few biogenic components recorded in the pelagic clay, where they are associated with fish debris, and locally with radiolarians (Core 18, Section 3, 113–115 cm). In constructing the test, they agglutinate very fine particles, such as opal laminae, volcanic material, or sponge spicules (Plate 5, Fig. 4). At the binocular-microscope scale, it seems that they mainly use clay for cementing the particles (no analysis has been done), which makes their tests very fragile. Thin films of manganese coat some of them, particularly representatives of the genus *Cyclammina*, in Cores 18, 20, and 22.

The most common species belong to the genera *Reophax, Recurvoides, Cyclammina, Paratrochamminoides?, Haplophragmoides* (Plate 5), all of which are recorded in Core 18, Section 3, 113–115 cm, constituting the largest assemblage recovered at Hole 462. Although they are recorded in the whole sequence, in the upper part down to Core 17 their occurrence is random and poor. In Cores 18 and 19, and in the interval from Core 22 to Core 27, they are however present in most studied samples. Below Core 27, they become again more randomly distributed and less abundant than in the intermediate portion of the sequence, except in Core 36, where they are relatively common (Figs. 1–3). In many samples, the deep-water agglutinated forms, even strongly diluted, occur along with large amounts of calcareous material displaced from shallower areas, rarely including shallow-water banks.

DISCUSSION OF DATA

From the quantitative analyses, the parameters which turned out to be of some importance are as follows (Figs. 1–3):

1) Weight of the sand fraction (>63 μm), plotted as percentage of the total weight of the sample dried at 45°C. The values vary largely, from less than 1% to more than 50%.

The highest values ($>30\%$) occur sporadically throughout the sequence and are related to the presence of volcanic glass (Core 6, Sections 1 and 2), shallow-water skeletal debris and volcanic-rock fragments (Core 32, Section 1; Core 34, Section 1), abundant planktonic foraminifers larger than 150 μm, sometimes associated with few fragments of shallow-water debris.

In the samples displaying such highest values, the weight of the fractions greater than 150 μm and 250 μm makes up more than 50% of the weight of the total

residue (>63 μm), and in some cases (Core 32, Section 1) almost 90%.

Manganese micronodules, even where recorded in relatively high percentages, are minor components and do not specifically increase the weight of the >63-μm fraction.

The lowest values ($<1\%$) are generally associated with abundant radiolarians (up to 100% of the residue), whereas planktonic foraminifers are totally absent (Fig. 8).

Residues with weight values greater than 1%, but less than 10%, are again constituted by abundant radiolarians, which may be associated (1) with rare benthic foraminifers, (2) with few specimens of planktonic foraminifers larger than 150 μm, or (3) small planktonic foraminifers. In Core 33, the >63-μm residues are devoid of foraminifers and consist of almost 100% radiolarians; however, the average weights range from 1 to 6%. These relatively anomalous high values are related to the occurrence of large amounts of cenosphaeres or similar forms in the fraction larger than 150-μm, which are filled with carbonate nannofossil silt.

Between those extreme values (>10–30%), the general trend is that the weight per cent increases along with increasing percentages of the total amount of planktonic foraminifers, as well as their average size. Recalling the patterns of samples displaying high weight values, as mentioned above, the increase of the weight per cent is associated with an increase of the percentages of the >150-μm and >250-μm fractions over the >63-μm residue. Radiolarian distribution is inversely related to that of planktonic foraminifers: they increase when the foraminifers decrease and vice versa.

The few exceptions to the trend are mainly the consequence of poor disaggregation (Core 37), or related to the occurrence of sparse, but much heavier, shallow-water debris (Core 32).
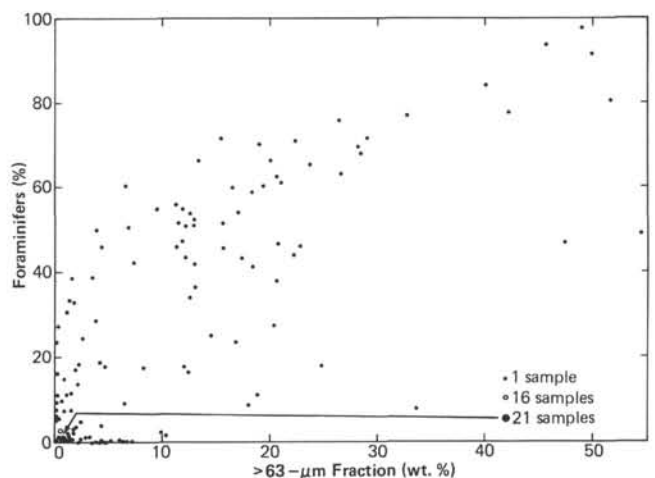

Figure 8. Variation of foraminifer content with weight of the >63-μm fraction (= sand fraction). Weight values higher than 40% are relative to coarse foraminifer sand (foraminifers $>80\%$) and very coarse layers with shallow-water debris (foraminifers $<50\%$).

2) The distribution of CaCO$_3$, as shown in Figure 9, distinguishes two very distinct groups of samples: a large group displaying >70% carbonates, and a second group in which carbonates are totally absent or carbonate content is less than 1%. Plotting the CaCO$_3$ percentage against weight per cent of the >63-μm fraction shows that among the samples yielding high carbonate percentages two subgroups may be distinguished: one characterized by less than 10% by weight of the >63-μm fraction, among which are a great number of samples displaying weight values less than 3%; and a second subgroup, characterized by a weight per cent of the >63-μm fractions higher than 10% (and up to 50%). As previously demonstrated, high weight per cents of the >63-μm fraction are strictly related to high percentages of planktonic foraminifers; in the later subgroup, the carbonate content is related to the planktonic foraminifers. In the first subgroup the high carbonate values, because of the low weight per cent must depend upon calcareous nannofossil content (Fig. 10).

3) P/(P + B) (plankton/[plankton + benthos]) ratio of foraminifers. The plankton/benthos ratio of the foraminifer faunas is strictly related to the distribution of planktonic foraminifers throughout the Cenozoic sequence. Except where foraminifers are minor components (<5%) of the >63-μm residues, the ratio is 100% or close to 100% planktonic faunas. Intermediate values are very rare, particularly in the >63-μm fractions, whereas in the fractions larger than 150 μm, in which large, deep-water agglutinated forms sometimes are common, medium values are more common. In the cases of very rare foraminifers, only benthics are found.

4) Among the other biogenic components, the fossil groups which are of some importance are as follows:

Sponge spicules are present throughout the sequence, only in rare samples are they missing. They are of some importance in Cores 39 and 38 (1–30%), in Core 35,CC to Core 33,CC (from 2–20%), in Core 25 (1–7%), in Core 23, Section 6, 74–76 cm, to Core 22,CC (2–7%), in
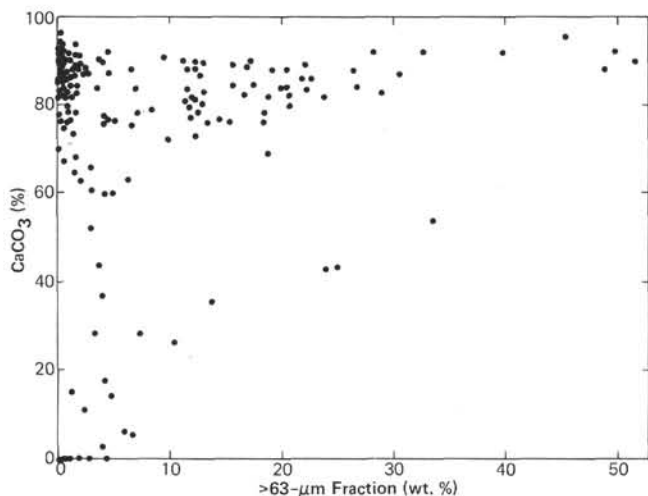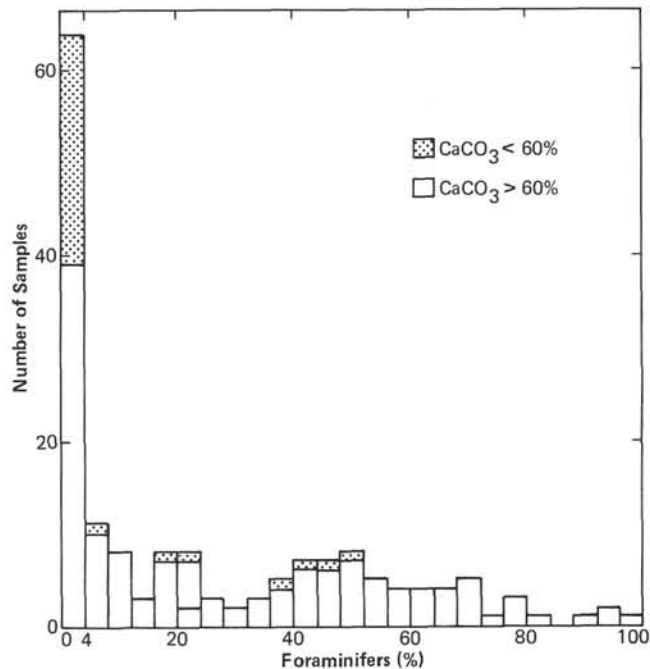
Figure 10. Distribution of foraminifer content and number of samples per class of foraminifer percentages. Note the large number of samples very poor in foraminifers: those belong to the first subgroup described in the text and show that the high carbonate content (>60%) must be dependent on the presence of calcareous nannoplankton.

Core 21,CC to Section 4, 60–62 cm (2–13%), in Core 20,CC to Core 18, Section 6, 25–27 cm (1–10%), in Core 15 (5–30%), in Core 4, Section 4, 45–46 cm to Core 3, Section 2, 62–64 cm (1%–8%). High percentages of sponge spicules occur sporadically, as in Core 31,CC, Core 30,CC, and Core 12,CC (20%), in Core 29,CC (15%), and finally in Core 1, Section 2, 77–79 cm (8%). In the above-mentioned samples, foraminifers are generally scarce, whereas radiolarians are common to abundant. Moreover, sponge spicules may be abundant in the fractions larger than 150 μm as for instance in Core 23 or in Cores 20 through 19, where up to 48% of the >150-μm residue may be spicules (Core 20, Section 4, 75–77 cm).

Shallow-water larger foraminifers and skeletal debris, as described by Premoli Silva and Brusa (this volume), occurs abundantly in few layers, where it can, however, be a very important constituent. This material occurs in Core 34, Section 1 to CC; Core 32, Section 1, 1–79 cm; Core 22, Section 1, 1–75 cm; Core 21, Section 1, 1–10 cm; Core 15, Section 1 to CC; and Core 14, Section 5, 79–81 cm, in which shallow-water skeletal debris and larger foraminifers are mainly associated with volcanic-rock fragments and glass. It also occurs in minor amounts at the bottom of coarser turbidites in Core 29, Section 1, 9–11 cm; Core 27, Section 3, 74–76 cm; Core 26, Section 3, 49–51 cm; Core 25, Section 4, 136–138 cm and Section 1, 121–123 cm; Core 23; Core 22, Section 5, 27–29 cm; Core 20, Section 4, 22–24 cm and Section 3, 94–96 cm; Core 19, Section 6 and CC; Core 18,CC and Section 6, 25–27 cm; Core 17, Section 1, 6–8 cm; Core


Figure 9. Variation of carbonate content with weight of the >63-μm fraction (= sand fraction). See text.

16,CC, Core 11, Section 3, 117–119 cm; and finally in the topmost part of Core 6. All the samples listed above display a very high weight of the sand fraction (>63 μm). Shallow-water material is always more important in the fractions larger than 150 μm.

Fish debris is a minor component of the residues from Hole 462. It is relatively abundant only in three samples (Core 3, Section 2, 62–64 cm and Section 1, 91–93 cm; and Core 1, Section 2, 77–79 cm), in which it represents 19, 6, and 14% of the total residues larger than 63 μm, respectively. Although it is present throughout the Cenozoic sequence, in all other samples, it is never more abundant than 3% (Core 3 and upper part of Core 4). As a general rule, fish debris occurs with at least 30% radiolarians.

Ostracodes are a very minor component of the sand fractions from Hole 462. They are never more abundant than 1% of the residues and occur with relatively shallow-water benthic forms.

Diatoms at Hole 462 are very rare (<1%) and randomly distributed, except in Core 25, Section 4, 64–66 cm and in the core catcher of Core 28, in which they represent 5 and 3% of the sandy fraction (>63 μm), respectively.

5) Among the non-biogenic components of some importance are volcanic ash, volcanic fragments, aggregates, and manganese micronodules.

Volcanic ash is common in Core 6, Sections 1 and 2, and in Core 5,CC to Section 7, 45–46 cm. It makes up 50% of the sand fraction (>63 μm) as isolated glass fragments and lumps which comprise aggregate planktonic foraminifers and radiolarians.

Volcanic-rock fragments occur mainly in the same samples as the shallow-water debris. Their occurrence increases the weight of the sand fractions considerably.

Some lumps are recorded throughout the sequence at Hole 462. Their cement is mainly clayey in the upper part of the sequence, and primarily calcitic in the lower part, in relationship with the beginning of diagenesis (Core 22 down).

Manganese micronodules are of some importance only in the uppermost cores recovered from Hole 462 (Cores 1–4); up to 13% of the >63-μm fraction in Core 1, Section 2, 77–79 cm and Section 5, 15–17 cm. In the underlying cores, manganese micronodules are very rarely recorded, even in the clayey layers. On the other hand, manganese can coat some of the deep-dwelling benthic foraminifers (Cores 18, 22). Where present, manganese micronodules do not significantly increase the weight of the >63-μm residues.

6) Distributional patterns of the reworked planktonic foraminiferal faunas. The rapid evolution displayed by planktonic foraminifers on which precise biostratigraphic scales are constructed enables one to distinguish, among largely mixed assemblages, as in the case of Hole 462, host faunas from reworked forms. Preliminary qualitative analysis was carried further, in an attempt to quantify not only the amount of reworked species versus the total amount of planktonic foraminifers per single sample, but also the amount of reworked species per time interval and, where possible, per zone.

The estimated percentages can be considered relatively reliable where planktonic foraminifers are morphologically well differentiated and/or their range is short, as in the Cretaceous through Eocene assemblages. Where planktonic-foraminifer assemblages are instead mainly composed of long-ranging species, such as most of the Oligocene and Miocene faunas, estimating reworked versus host forms is a difficult task; in this case, the calculated percentages must be considered only tentative. In a few cases, the different states of preservation could be used to distinguish similar faunas (early Miocene from middle Miocene assemblages).

The youngest assemblages for which percentages are estimated are attributable to the late Miocene. Estimates were not attempted for the Pliocene and Pleistocene faunas, because, in our view, reliable criteria for distinguishing them are lacking. In Figure 7, the estimated distribution of the reworked assemblages per time interval and, wherever possible, per zone is plotted against the Cenozoic sequence recovered at Hole 462. The percentages of the oldest reworked assemblages attributable to the Aptian through Cenomanian and to the earliest Paleocene *"Globigerina" eugubina* Zone are not included in Figure 7, because their values are always less than 1%. The total reworking curve of Figures 1 to 3 can be obtained by summing all the values per time interval and per zone, as plotted in Figure 7.

As a general rule, when planktonic foraminifers are the main component of the >63-μm fraction, the amount of reworking is very high: reworked forms can represent almost 100% of the planktonic-foraminifer faunas. Only in a few samples do the values deviate from the general trend; these lower values are related to the difficulties in estimating the reworking, because assemblages are dominated by long-ranging species, which in addition display a very uniform state of preservation (Core 23 samples).

The differences in age between reworked and host faunas increase in a regular fashion from the early Tertiary (from Core 39) to the Pleistocene (Core 1). Late Cretaceous through late Eocene faunas, even in very low percentages, occur as high as Core 3, dated as Pleistocene. Exceptions to this trend are related to the occurrence of reworked forms of mid-Cretaceous age. The maximum difference in age is registered in Core 6, Section 2, 140–141 cm, dated as late Pliocene, in which Aptian species are recorded (~110 m.y.).

Albian to Cenomanian species, always very rare, as mentioned above, occur also in most of the samples from Core 27: in Core 26, Section 5, 94–96 cm; Core 25, Section 4, 136–138 cm; and Core 22, Section 6, 92–94 cm.

Late Cretaceous, mainly Maestrichtian, faunas occur through most of the sequence. They are a constant, relatively important component of the reworked assemblages in the lowermost cores, with values up to 32% in Core 36. Above Core 36, they become a minor component, except for three peaks, well visible in Figure 7, corresponding to Cores 29, 21, and 12, where they represent 10 to 24% of the total faunas. Amounts higher than 8% are also present in Cores 32 and 26.

411

Species attributable to the *"Globigerina" eugubina* Zone, early Paleocene, occur in several samples from Core 29, Section 5 to Core 25, Section 1, 121–123 cm.

Late Paleocene to early Eocene assemblages (simplified in Fig. 7 as late Paleocene) are important components of the reworked assemblages up to Core 26; they can represent more than 70% of the total assemblage (Cores 37 and 34). Above Core 26, their abundance decreases abruptly to less than 10%, except for three peaks corresponding to Cores 21 and 12, as registered by the late Cretaceous faunas—plus the third one in Core 19.

Representatives of the early Paleocene *"Morozovella" uncinata* Zone occur as a minor component (<8%) in Core 29 through Core 26, Section 5, and in Core 21, Section 3, 106–108 cm.

Middle Eocene faunas display a distribution trend opposite to that of the late Paleocene assemblages, up to Core 33, then both trends become similar. They constitute almost 50% of the total assemblage up to Core 26, above which they have still some importance in Cores 23 through 17. One of the larger middle Eocene assemblages in this interval coincides with the peaks shown by Late Cretaceous and late Paleocene assemblages in Core 21.

Late Eocene faunas are less common and more irregularly distributed than the middle Eocene ones. Only in Cores 32 and 28 do they constitute more than 50% of the total assemblages. Moreover, they are mainly confined to to the interval between Cores 33 and 26.

Above Core 31, up to Core 13, the main component of the reworked assemblages are the faunas attributable to the various zones of Oligocene age. As clearly shown in Figure 7, Oligocene faunas can be so abundant in the residues as to represent almost 100% of the planktonic assemblages. Their occurrence, however, is rather irregular. Above Core 13, Oligocene faunas gradually decrease in importance, except for a peak in Core 12, which coincides with those shown by the Late Cretaceous and late Paleocene faunas. The bulk of the Miocene faunas replace the Oligocene forms from Core 13. They remain the major components of the reworked assemblages up to Core 6, above which they decrease. As shown in Figure 1, in the interval between Core 5 and the top of Core 1, only rare samples yield abundant planktonic foraminifers. Those assemblages comprise, besides the Miocene faunas, which still represent about the 30% of the total assemblages, Pliocene and possibly early Pleistocene faunas, reworked into late Pleistocene host assemblages. The amount of the youngest faunas has not been estimated, for the reasons mentioned above.

7) Reworking among radiolarian faunas. Riedel et al. (this volume) in their paper on radiolarians describe the mixed character of the radiolarian assemblages recovered from Hole 462. They also include some information on the amount of reworked specimens plotted per age time interval versus the host faunas, as contained in single samples.

Because we are not specialists in the radiolarian field, our study cannot be extended to quantify the amount of siliceous microfossils, as we did for the planktonic foraminifers. However, from simple visual observation it clearly appears that radiolarian faunas have been affected by the same sedimentary processes as the planktonic foraminifers throughout the Cenozoic sedimentary sequence.

In most samples examined from Cores 39 through 33, and in Core 4, the >63-μm residues, and particularly the >150-μm fractions, consist almost exclusively of cenosphaeres and other forms of similar shape, infilled by calcareous nannoplankton; also, the state of preservation of the radiolarians is not uniform, the host fauna being better preserved than the supposed allochthonous one. This qualitative information is confirmed by the quantitative analysis of the weight per cent of the >63-μm residues and their carbonate content. As already mentioned above, some radiolarian-rich layers are characterized by (1) relatively high weight per cent values (>1–6%), (2) a carbonate content >70%, and (3) high percentages of radiolarians in the fractions larger than 150 μm (up to 90% of the total residue; Figs. 1–3). These are the layers which yield size-sorted, possibly reworked radiolarian faunas. The samples, which are inferred to contain only autochthonous radiolarian assemblages, display weight per cent values less than 1, and they are devoid of carbonates. Examples typical of these two kinds of layers are shown in Figures 11 and 12.

CONCLUSIONS

On the basis of the data obtained from both qualitative and quantitative analyses for Hole 462, the following conclusions can be drawn.

1) From the qualitative composition and the weight per cent values of the various >63-μm fractions, the weight of the single fossil components can be ranked tentatively in the following increasing order:

Calcareous nannoplankton (>63 μm);

Empty radiolarian tests smaller than 150 μm;

Medium-sized radiolarians and thin-walled planktonic foraminifers smaller than 150 μm;

Radiolarians with nannofossil fills and planktonic foraminifers not larger than 200 μm, generally with a medium-thick wall;

Thick-walled planktonic foraminifers larger than 150 μm, up to more than 250 μm;

Small calcareous benthic foraminifers;

Larger benthic foraminifers and shallow-water skeletal debris.

Deep water agglutinated benthic foraminifers, even those of very large size (>500 μm) are much lighter than the calcareous benthic forms, and their collective weight is comparable to that of medium-sized radiolarians.

2) On the basis of the distribution of the various components in a single sequence, throughout the Cenozoic succession of Hole 462, different types of graded layers can be distinguished. The most-complete se-
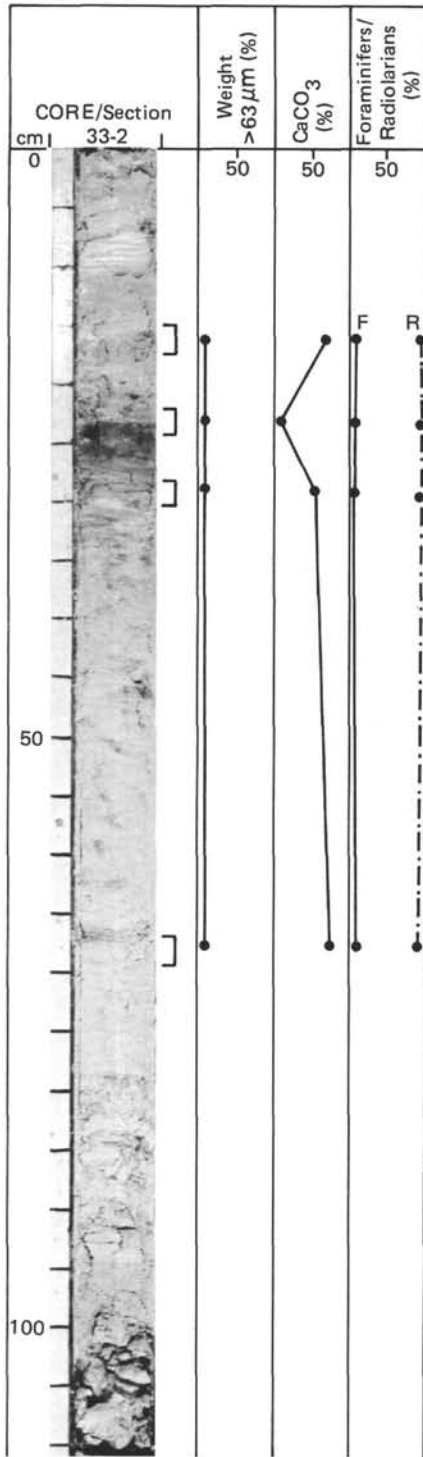
Figure 11. Hole 462, Core 33, Section 2, early Oligocene, Zones P18/P19? The darker layer at 23 cm with poor carbonate content represents autochthonous radiolarian ooze, separating two radiolarian turbidites. Weight of the >63-µm fraction is very low. Foraminifers are absent.
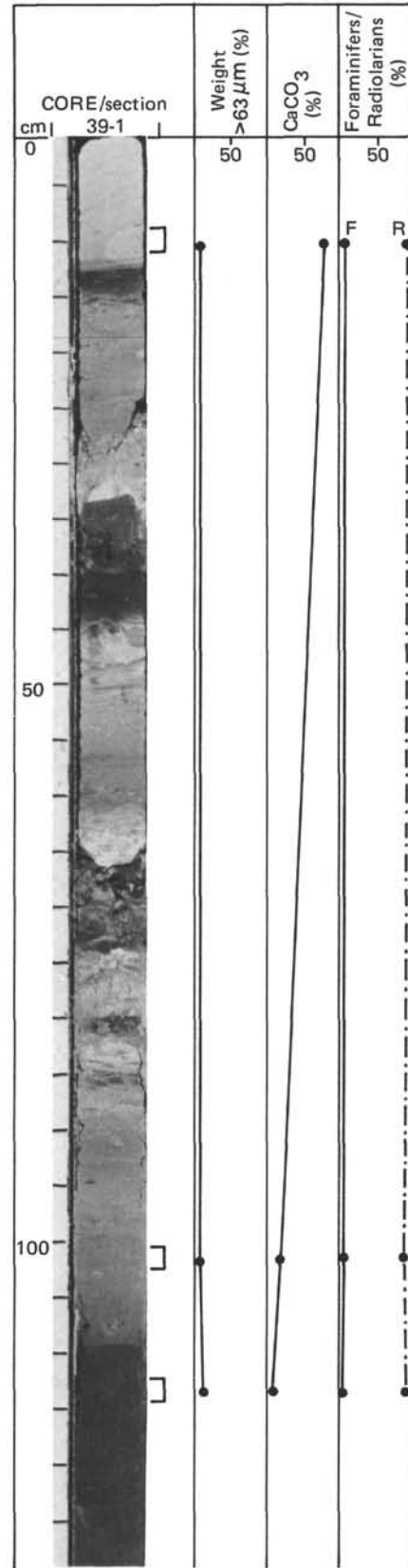
Figure 12. Hole 462, Core 39, Section 1, middle Eocene? Darker layers, as at 112 cm, are radiolarian oozes devoid of carbonate and foraminifers. Gray layer at 100 cm and whitish one at the top of the section represent respectively the finest tail and layer d) of a dominantly siliceous turbidites.

quences are characterized as follows (from top to bottom):

Top (autochthonous): pelagic clay or radiolarian ooze.

Layer d), transported: calcareous nannoplankton with few small radiolarians; carbonate content > 70%; weight ~ 1%.

Layer c), transported: calcareous nannoplankton with 80 to 30% of radiolarians and 10 to 60% of thin-walled planktonic foraminifers smaller than 150 μm; planktonic foraminifers increase downward; carbonate content 90%; weight 5 to 18% (basal); all planktonic foraminifers may be reworked.

Layer b), transported: 100% planktonic foraminifers, whose average sizes increase downward; carbonate content > 90%; weight 15 to 45% (basal); almost all planktonic foraminifers are reworked.

Layer a), transported: almost 100% planktonic foraminifers exceeding 250 μm, little shallow-water debris of small size (Core 11, Section 3, 117–119 cm); fine fraction almost absent; carbonate content about 100%; weight 50%; almost all planktonic foraminifers are reworked.

The color of layers a) to d) is whitish, grading upward to light-gray, whereas pelagic clay and/or radiolarian ooze is much darker (Fig. 13). The average thickness of the graded portion in this type of turbidite is about 50 cm. Frequently, the graded portions are thinner than 50 cm; in this case layers b) and a) are missing, and the basal layer of the sequence corresponds to layer c) (Fig. 14). The extreme case is represented by the occurrence of layer d) alone; this occurs very rarely within the Cenozoic sequence, whereas it is relatively common in the Mesozoic (Fig. 15).

Some cores, such as Core 22 through Core 29, display a very homogeneous, whitish color for long thickness (Fig. 16); more than one turbidite is clearly represented, but they are characterized by the occurrence of only the medium layers. Detailed sampling is necessary to separate one sequence from another.

Finally, in very rare cases, radiolarians are absent, and turbidites are entirely composed of carbonate.

The types of graded sequences described above are very common; the most complete ones occur primarily in Cores 7, 8, 13, 14, 22, and 23.

A second type of graded layer is characterized by the absence of planktonic foraminifers, whose place in a sequence is completely taken by radiolarians. Below the top layer, which can be either pelagic clay or radiolarian ooze, as in the former types, two layers can be distinguished:

Layer b), transported: calcareous nannoplankton and radiolarians of predominantly small size (< 150 μm); carbonate content > 70%; weight < 3%.

Layer a), transported: 100% radiolarians larger than 150 μm filled with calcareous nannoplankton; carbonate content > 70%; weight > 3–6%, and up to 10%.

Both layers are whitish, whereas the radiolarian ooze at their top is much darker (Fig. 11). Where radiolarian ooze is not present, only detailed sampling allows separation of the discrete sequences. The thickness of a complete sequence seems comparable to that of the first
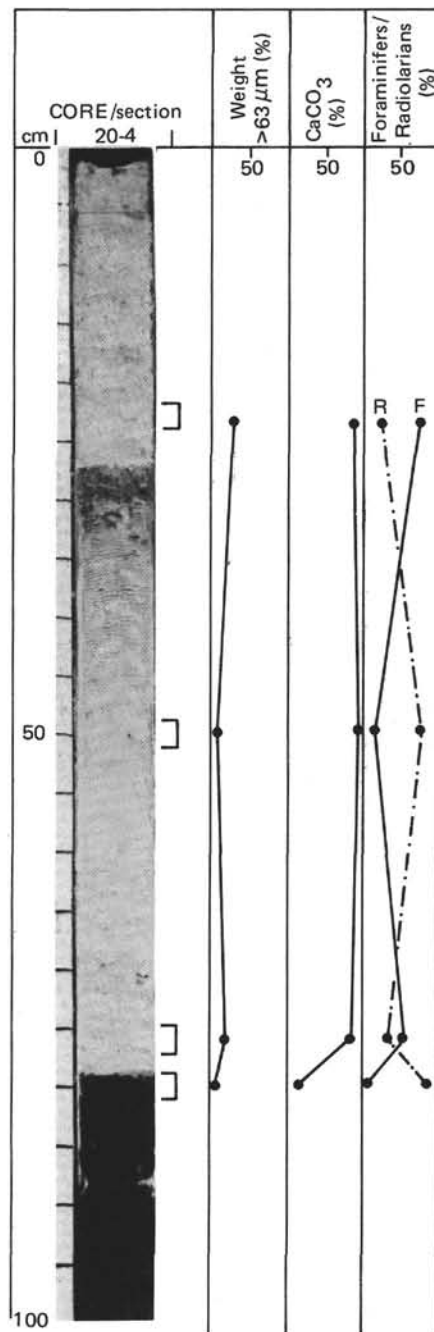

Figure 13. Hole 462, Core 20, Section 4, late Oligocene, Zone P22. At 30 to 79 cm, an example of foraminifer-radiolarian turbidite with layer a) and part of layer b) missing. Darker layer is possibly a radiolarian ooze. Note the changes in weight percent through the graded layer, whereas carbonate content remains constant.

type (see above). Sometimes sponge spicules occur with radiolarians, also in the > 150-μm fraction.

This second type of graded sequence occurs mainly in the lower part of the Cenozoic sequence at Hole 462, and in the uppermost cores. This is almost the only type occurring from Core 39 to Core 24, and possibly in Core 4 to 1.

The very coarse layers, containing large amounts of shallow-water skeletal debris and volcanic-rock frag-
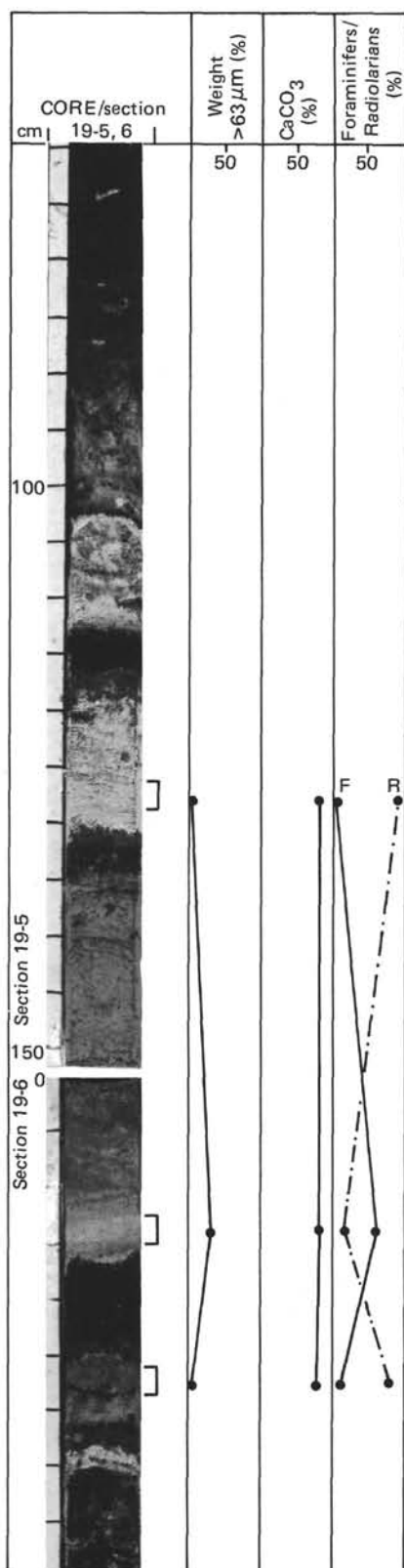
Figure 14. Hole 462, Core 19, Sections 5 and 6, late Oliocene, Zone P22. Set of incomplete turbidites of the first type: in Section 5, 135–150 cm, and Section 6, 1–15 cm, topped by radiolarian ooze, occurs a turbidite missing layer a) and most of layer b); in the overlying turbidite at Section 5, 120–131 cm only layer d) is present.
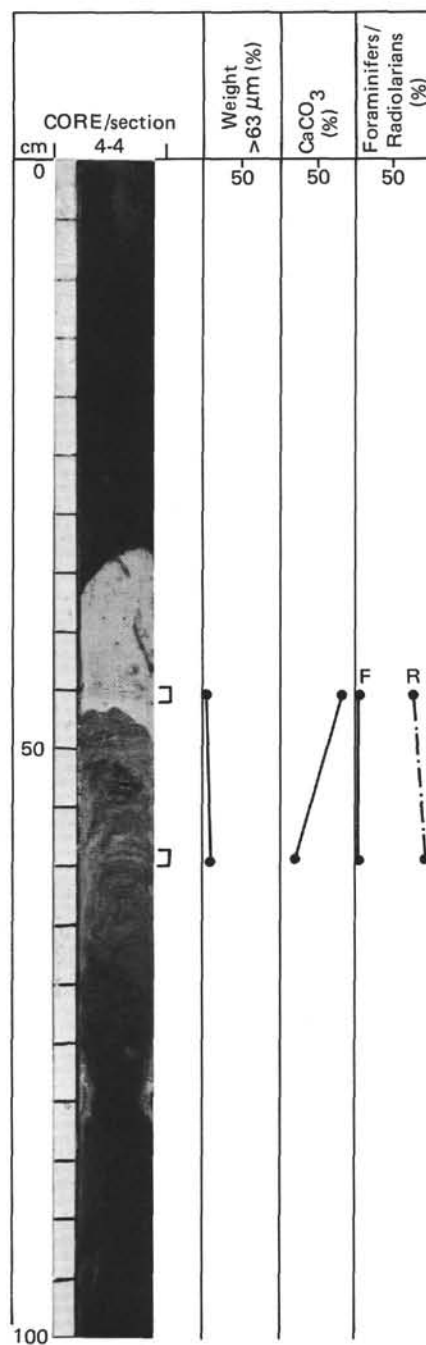

Figure 15. Hole 462, Core 4, Section 4, Pliocene or younger. A finest tail of siliceous turbidite (48–65 cm) is followed upward by thin, carbonatic turbidite, in which only layer d) is present.

ments, locally graded, are an exceptional sedimentary feature. In fact, they occur within intervals dominated by either the first or the second type of graded sequences, that is, in Core 22, 21, and 15, or in Cores 34 and 32, respectively.

3) Accumulation rate. In recent years, Berggren and Van Couvering (1974) and Hardenbol and Berggren (1978) have provided an up-to-date numerical time scale against which the main biostratigraphic events of the Cenozoic have been calibrated. On the basis of this

415
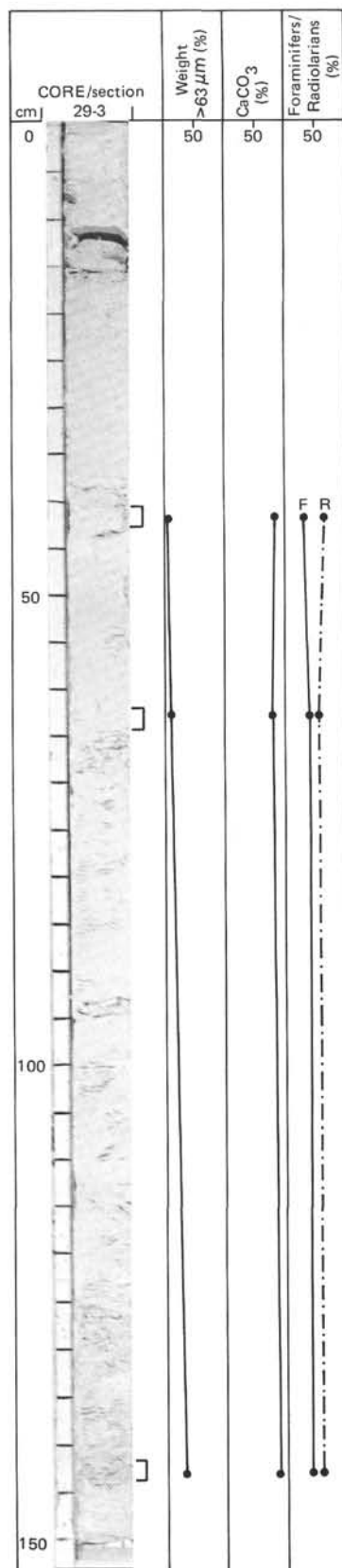
Figure 16. Hole 462, Core 29, Section 3, late Oligocene, Zone P20. The slight decrease in foraminifer content from the sample at 63 cm to that at 42 cm, and the oppsite trend shown by radiolarians, testifies that the sediments were not homogeneously deposited; the succession rather represents a set of successive turbidites.

calibration, the absolute duration of single biozones, based on those dated events, can be calculated.

The absolute ages obtained by these authors have been applied to the biostratigraphic events recognized at Hole 462 within the Cenozoic sequence, and the absolute durations of the recognized biozones, and/or portions of them when they are not fully represented, are tentatively estimated. Then, the thickness of sediments attributable to a single biozone divided by its duration allows calculation of the accumulation rate during each interval. The obtained data are plotted in Table 1.

These results show that during the Cenozoic at Site 462 the accumulation rate fluctuated consistently. The highest values are recorded at the end of the Eocene (Zone P17) and in the late Oligocene (Zone P22), with values up to 47.5 m/m.y. and 41.0 m/m.y., respectively. High values also occur in the early late Oligocene (Zone P20), in the latest Oligocene (Zone N4), in the middle Miocene (Zones N12/N13), and in the Pliocene and Pleistocene. If Cores 1 to 8 are in the future totally attributed to the Pleistocene, then for the last 1.8 m.y. the accumulation rate will be 36 m/m.y.

In some intervals, pelagic clay and/or radiolarian oozes represent important parts of sedimentary sequences, as for instance in Cores 19 to 23-2, attributed to the late Oligocene Zone P22 (one-fourth of the total thickness), or in Cores 1 to 8, of Pliocene–Pleistocene age, where they are even more important (Table 1). In those intervals, the accumulation rate plotted in Table 1 corresponds to the mean between the low rate (~10 m/m.y.) relative to the radiolarian ooze and/or pelagic clay, and the much higher rate related to the transported sediments, whose rate of accumulation increased, in the late Eocene and late Oligocene almost doubling (last column in Table 1).

High accumulation rates are associated with the occurrence in the same intervals of (1) common coarser turbidites, (2) coarser graded layers containing shallow-water skeletal debris, (3) a high degree of reworking, and (4) reworked faunas as old as the mid-Cretaceous.

Concerning the low rates of accumulation recorded form Hole 462, the available data—taking into account that transported material is still present in the intervals displaying low accumulation rates—leave open the question whether (1) the low rates are real, (2) they are the result of hiatuses, or (3) the absolute duration of the intervals has been overestimated.

4) The high rates of accumulations of siliceous and calcareous materials at the bottom of the Nauru Basin are suggested to be related to important erosional events which affected topographically more elevated areas, or even islands, surrounding the deeper basin.

Two main events are recorded at Hole 462: they are dated at:

~37 m.y. = end of the Eocene/base of the Oligocene;

~26 m.y. = late Oligocene.

Other, less important erosional events can be dated at:

~32 m.y. = early late Oligocene (Zone P20);

~24? m.y. = latest Oligocene/earliest Miocene

Table 1. Sedimentological data on Hole 462.

Cores	Age	Duration (m.y.)	Thickness (m)	Clay Thickness (m)	Accumulation Rate (total) (m/m.y.)	Accumulation Rate (transported material) (m/m.y.)
1–3	Pleistocene	1.8	28.5	10.65	15.8	22.43
4–8	Pliocene?	2.2	38.0	14.15	17.3	29.35
10–12/5	N16/N17	3.0	26.5	2.36	8.85	8.74
12/6–15	N12/N13	1.0	21.0	0.18	21.00	21.24
16–17/1	N7	2.0	11.0	1.78	5.50	5.06
17/2–18	N4	1.0	17.0	3.25	17.00	20.52
19–23/2	P22	1.0	41.0	5.60	41.00	80.38
23/3–27/2	P21	4.0	38.0	0.25	9.50	9.50
27/3–32/3	P20	2.0	48.5	0.02	24.25	24.36
32/4–33	?P18/P19	2.0	14.5	—	7.25	7.25
34–38	P17	1.0	47.5	4.80	47.50	82.05

(Zone N4);

~13 m.y. = middle Miocene (Zones N12/N13);

~3 m.y. = late Pliocene;

and during the Pleistocene.

It is worth mentioning that those ages may be considered minimum ages, because they are based on the absolute ages inferred for the planktonic foraminifers which have been submitted to some transport; there could therefore be some disparity with respect to the age of the true biostratigraphic events.

Major changes in sea level or in the bottom-current system may have been responsible for these erosional events.

REFERENCES

Berggren, W. A., and Van Couvering, J. A., 1974. Biostratigraphy, geochronology and paleoclimatology of the last 15 million years in marine and continental sequences. *Palaeogeogr., Palaeoclimatol., Paleoecol.*, 16:1–216.

Blow, W. H., 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. *Proceedings of the First International Conference on Planktonic Microfossils:* Geneva, 1967 (Vol. 1), 199–422.

Brönnimann, P., and Resig, J., 1971. A Neogene globigerinacean biochronologic time-scale of the Southwestern Pacific. *In* Winterer, E. L., Riedel, W. R., et al., *Init. Repts. DSDP*, 7, Pt. 2: Washington (U.S. Govt. Printing Office), 1235–1469.

Hardenbol, J., and Berggren, W. A., 1978. A new Paleogene numerical time scale. *Am. Assoc. Petrol. Geol., Stud. Geol.*, 6: 213–234.

Larson, R. L., and Hilde, T. W., 1975. A revised time scale of magnetic reversal for the Early Cretaceous and Late Jurassic. *J. Geophys. Res.*, 80:2586–2594.

Stainforth, R. M., 1975. Cenozoic planktonic foraminiferal zonation and characteristics of index forms. *Univ. Kansas Paleont. Contr.*, 62(1, 2).
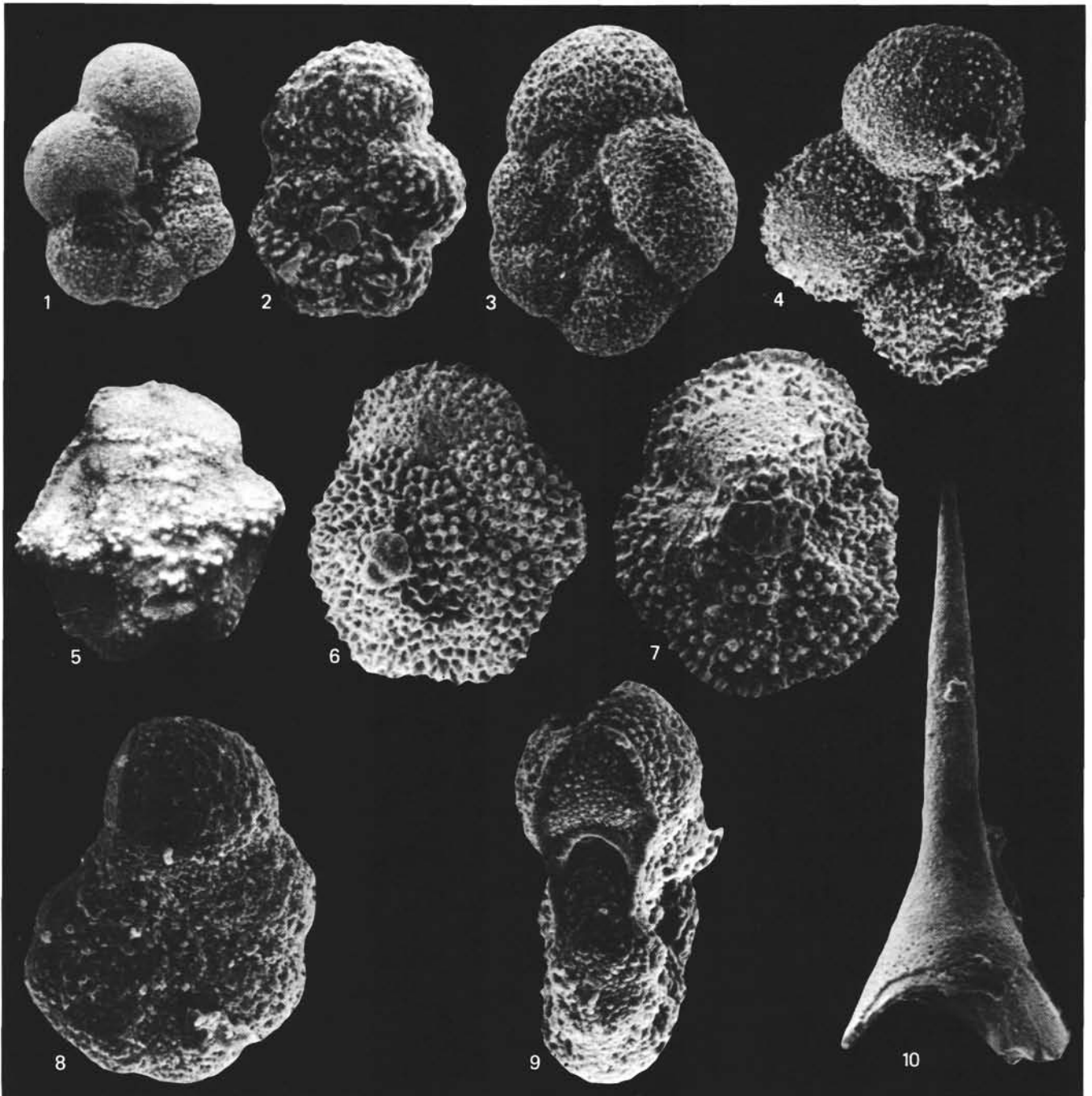
Plate 1. Foraminifers. All specimens from Hole 462, Core 27,CC, Zone P20, early late Oligocene, except specimen in Figure 5, which is from Core 14, Section 5, 79–81 cm, Zone N13, middle Miocene.

Figure 1. *Globigerinelloides* sp., spiral view, ×400.
Figure 2. *Rugoglobigerina rugosa* (Plummer), spiral view, ×240.
Figure 3. *Hedbergella* sp., spiral view, ×250.

Figure 4. *Globigerinelloides asper* (Ehrenberg), spiral view, ×250.
Figure 5. *Globotruncana contusa* (Cushman), spiral view, ×50.
Figure 6. *Morozovella pusilla* (Bolli), spiral view, ×225.
Figure 7. *Morozovella edgari* (Premoli Silva and Bolli), umbilical view, ×200.
Figure 8. *Globigerinelloides bentonensis* (Morrow), spiral view, ×400.
Figure 9. *Globigerinelloides bentonensis* (Morrow), side view, ×400.
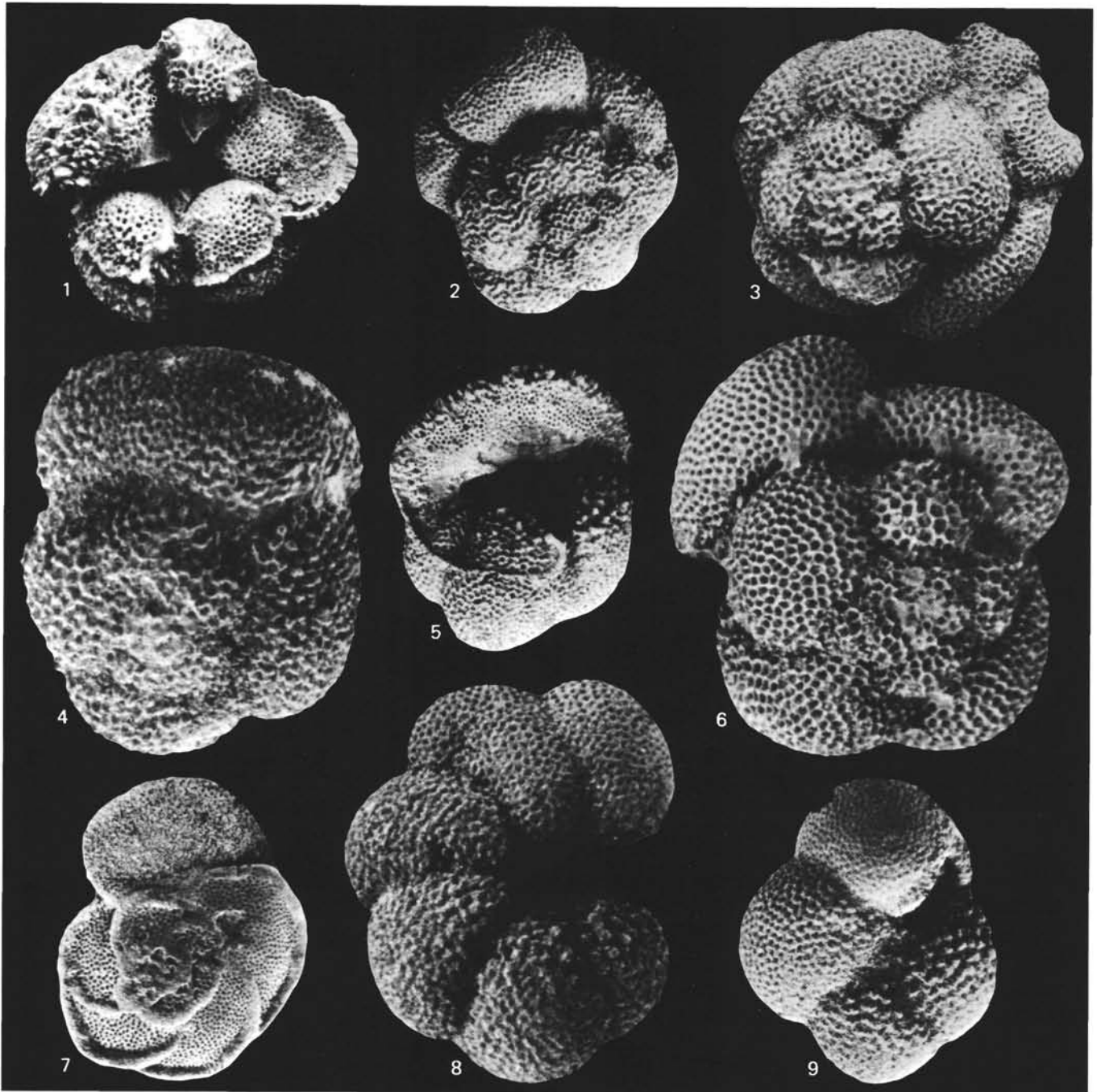Figure 10. Spine of *Hantkenina*, ×220.

Plate 2. Foraminifers. All specimens from Hole 462, Core 14, Section 5, 79–81 cm, Zone N13, middle Miocene, except specimens in Figures 6 and 9, which are from Core 11, Section 3, 117–119 cm, Zone N17, late Miocene.

Figure 1–3. *Globoquadrina altispira* Cushman and Jarvis. Fig. 1. Umbilical view, ×65. Fig. 2. Spiral view, ×75. Fig. 3. Spiral view, ×77.

Figure 4. *Globoquadrina dehiscens* Cushman, Parr, and Collins, spiral view, ×140.

Figure 5, 6. *Globoquadrina baroemoenensis* LeRoy. Fig. 5. Umbilical view, ×75. Fig. 6. Spiral view, ×100.

Figure 7. *Globorotalia cultrata* (d'Orbigny), spiral view, ×140.

Figure 8. *Globorotalia siakensis* LeRoy, umbilical view, ×145.

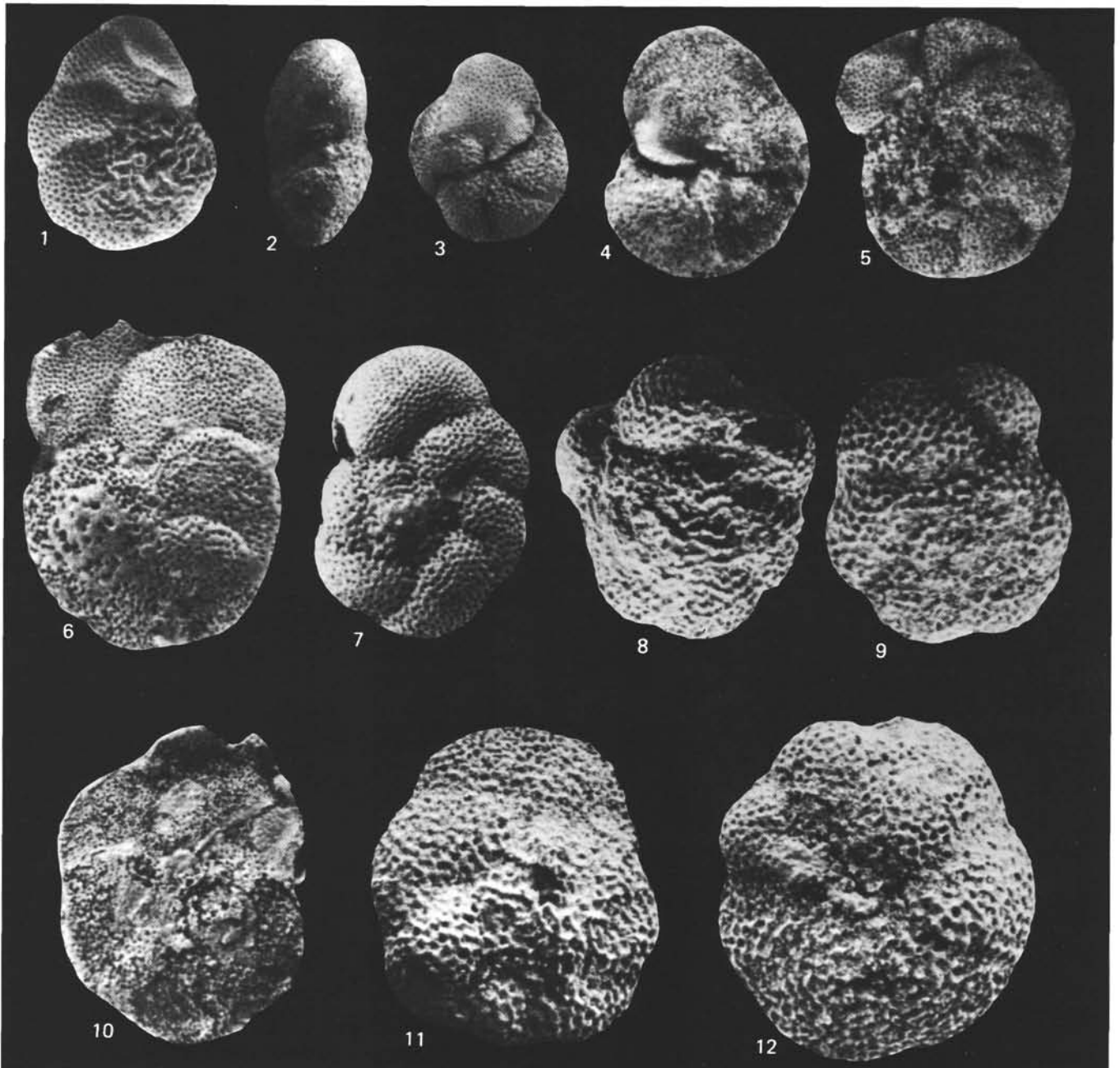Figure 9. *Globorotalia acrostoma* Wezel, umbilical view, ×145.

Plate 3. Foraminifers. All specimens from Leg 61, Hole 462, Core 11, Section 3, 117–119 cm, Zone N17, late Miocene, except specimen in Figure 1, which is from Core 14, Section 5, 79–81 cm, Zone N13, middle Miocene.

Figures 1, 2. *Globorotalia peripheroronda* Blow and Banner. Fig. 1. Spiral view, ×100. Fig. 2. Side view, ×100.

Figure 3. *Globorotalia praescitula* Blow, umbilical view, ×100.

Figures 4, 5. *Globorotalia peripheroacuta* Blow and Banner. Fig. 4. Umbilical view, ×100. Fig. 5. Spiral view, ×100.

Figure 6. *Globorotalia fohsi fohsi* Cushman and Ellisor, spiral view, ×100.

Figure 7. *Globorotalia mayeri* Cushman and Ellisor, spiral view, ×100.

Figure 8. *Globorotalia mendacis* Blow, spiral view, ×230.

Figure 9. *Globorotalia pseudokugleri* Blow, spiral view, ×230.

Figure 10. *Globorotalia fohsi robusta* Bolli, spiral view, ×100.

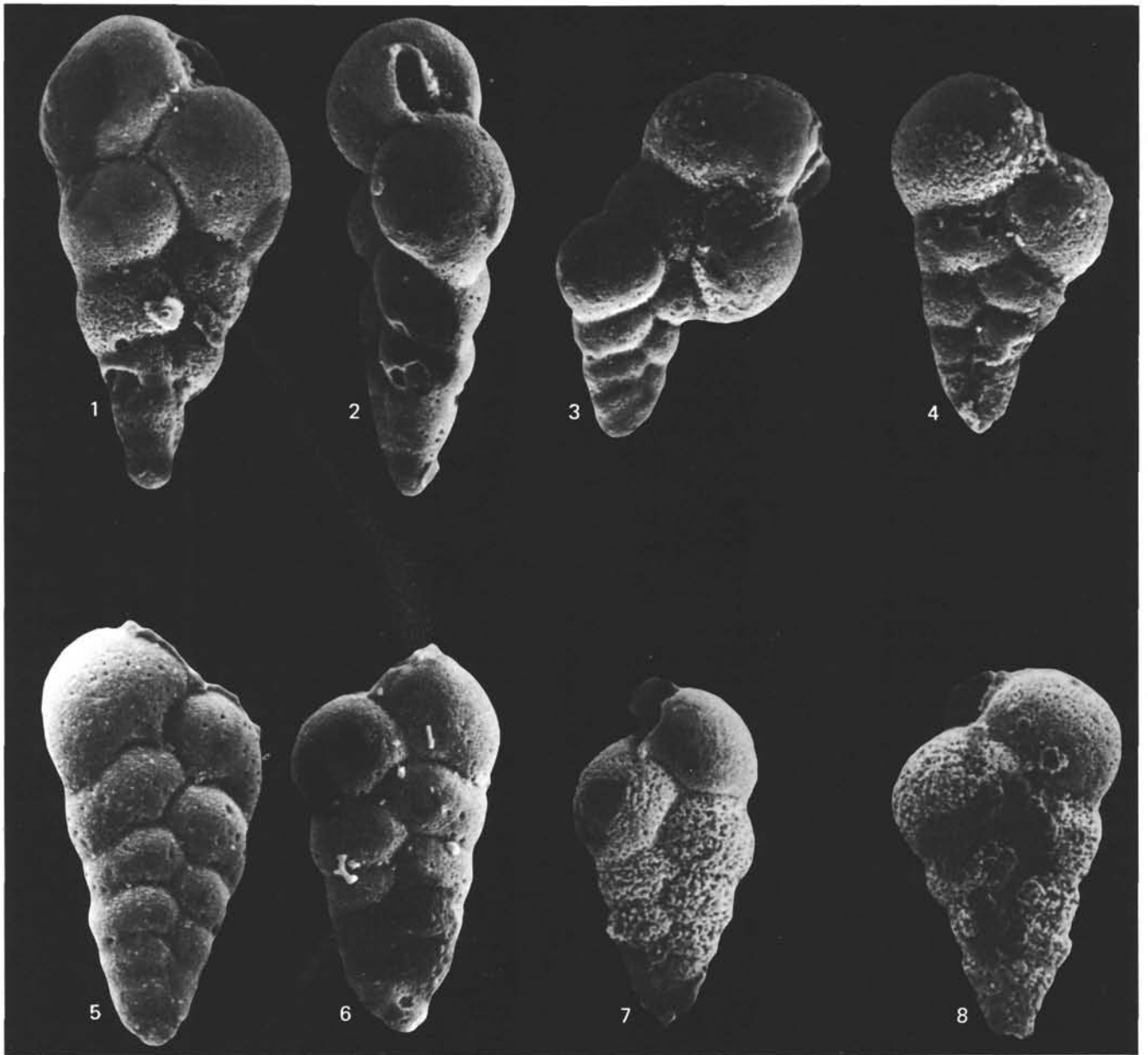Figures 11, 12. *Globorotalia kugleri* Bolli. Fig. 11. Spiral view, ×200. Fig. 12. Umbilical view, ×200.

Plate 4. Foraminifers. Specimens in Figures 1 to 6 from Hole 462, Core 1,CC, Pleistocene. Specimens in Figures 7 and 8 from Hole 462, Core 27,CC, Zone P20, early late Oligocene.

Figures 1–3. *Streptochilus tokelauae* (Boersma). Fig. 1. Frontal view, ×420. Fig. 2. Side view, ×420. Fig. 3. Aberrant specimen, ×420.

Figure 4. *Streptochilus globigerum* (Schwager), frontal view, ×420.

Figure 5. *Streptochilus latum* Brönnimann and Resig, frontal view, ×420.

Figure 6. *Streptochilus pristinum* Brönnimann and Resig, frontal view, ×420.

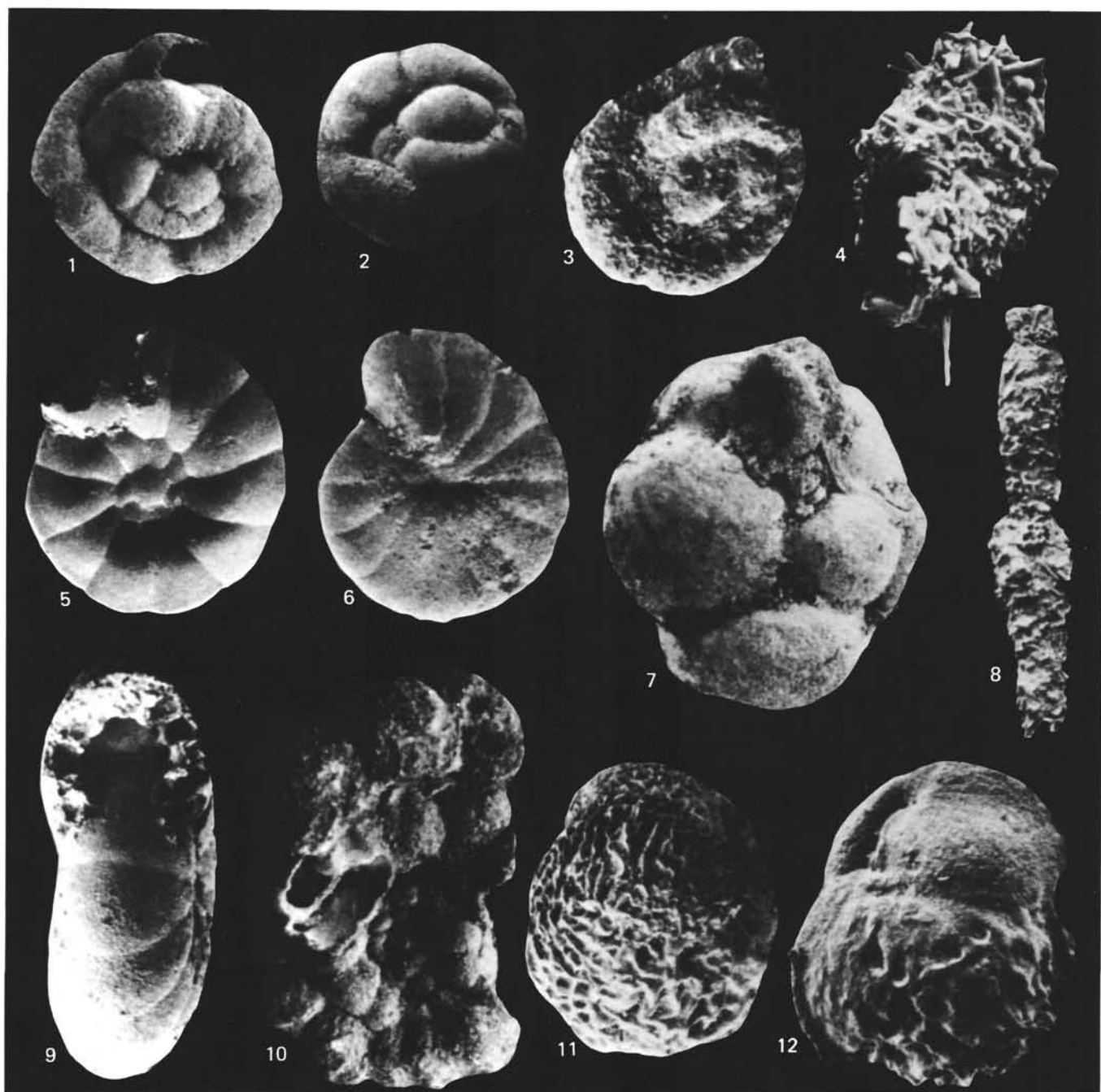Figures 7, 8. *Chiloguembelina* sp., frontal views, both ×250.

Plate 5. Foraminifers. Specimens in Figures 1 to 10, from Hole 462, Core 18, Section 3, 111–113 cm, Zone N4, latest Oligocene. Specimen in Figure 11, from Hole 462, Core 14, Section 5, 79–81 cm, Zone N13, middle Miocene. Specimen in Figure 12, from Hole 462, Core 11, Section 3, 117–119 cm, Zone N17, late Miocene.

Figure 1. *Paratrochamminoides*?; 1 ×270; 3 ×100.
Figure 2. *Recurvoides* sp., ×70.
Figure 4. *Reophax* sp., ×270.
Figure 5. *Cyclammina* sp. cf. *C. pusilla* Brady, spiral view, ×55.
Figure 6. *Cyclammina* sp. cf. *C. cancellata* Brady, spiral view, ×100.
Figure 7. *Recurvoides* sp., ×125.
Figure 8. *Rephax* sp., 135.
Figure 9. *Cyclammina* sp., spiral view, ×100.
Figure 10. *Paratrochamminoides*?, ×20.
Figure 11. *Ehrenbergina* sp., ×100.
Figure 12. *Ehrenbergina* sp., ×225.