

30. NEOGENE PLANKTONIC FORAMINIFERA OF THE INDIAN OCEAN (DSDP, LEG 26)

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INTRODUCTION

This report is the result of a study of the Neogene deposits cored in the Indian Ocean during Leg 26 of the Deep Sea Drilling Project.

The main purposes of the study were: (a) qualitative, and in some degree quantitative, study of the planktonic foraminiferal assemblages found in the holes drilled; (b) determination of the stratigraphic ranges of the main species; (c) establishment of biostratigraphical zonations in the area under study; (d) correlation of the sites drilled; and (e) where possible, the drawing of ecological paleoclimatological as well as taxonomical conclusions.

Time restrictions in the publication schedule did not permit several aspects of the conclusions drawn to be investigated in detail. For the same reason, unfortunately, no study of benthonic fauna was completed. Hopefully, it will be carried out in the near future.

In spite of these shortcomings, I hope that the main results of this study are adequately based and correct.

To save space, the following abbreviations are used for the samples cited in text and in the plates explanations. Each sample is characterized by numbers which signify core number, section number of that core, and, set off by commas, depth from the top of the section in centimeters. Thus 3-2, 40-42 cm signifies that this sample was taken from Core 3, Section 2, at a depth of 40-42 cm from the top of the section. Samples from the core catchers are designated by the number of the core and the letters "CC." Thus, a sample taken from the core catcher material of Core 5 will be marked as 5, CC.

MATERIAL AND METHODS

Leg 26 was started on 6 September 1972, in Durban, South Africa, and ended on 31 October 1972, in Fremantle, Australia. The *Glomar Challenger* crossed the Indian Ocean mainly in the temperate zone; only two sites were located in the subtropical zone.

During Leg 26, the shipboard paleontologists worked together in determining the age of the sediments cored. At that time practically the only material studied was from core catchers (average volume of each core catcher is about 25-30 cc). In special, infrequent, cases some additional samples, taken near the biostratigraphic boundaries, were examined also.

In total, nine sites were drilled (Sites 250-258). Six of them (Sites 250, 251, 253, 254, 255, 258) gave well- or relatively well-preserved faunas. Three other sites (Sites 252, 256, 257), situated in very deep water, were barren because of dissolution effects.

The list of sites cored is given in Table 1.

TABLE 1
Site Summary

Site	Latitude S	Longitude E	Water Depth (m)
250	33°27.74'	39°22.15'	5119
251	36°30.26'	49°29.08'	3489
252	37°02.44'	59°14.33'	5032
253	24°52.65'	87°21.97'	1962
254	30°58.15'	87°53.72'	1253
255	31°07.87'	93°43.72'	1144
256	23°27.35'	100°46.46'	5361
257	30°59.16'	108°20.99'	5278
258	33°47.69'	112°28.42'	2793

Figure 1 shows the location of the sites studied.

For study in the shore laboratory R. Herb took Cretaceous and Paleogene foraminifera and E. Boltovskoy took Neogene foraminifera. The Paleogene-Neogene transitional zone was sampled by both. The following samples were taken by E. Boltovskoy:

1) One sample per core section and at closer intervals near biostratigraphic boundaries (each sample was about 10 cc).

2) Samples from those places in cores which showed some lithologic changes.

3) Additional material from core catchers for more detailed study than that completed aboard ship.

The following numbers of Neogene samples were studied from each site.

Site 250	117
Site 251	194
Site 252	12
Site 253	89
Site 254	175
Site 255	17
Site 256	44
Site 257	31
Site 258	200
Total	879

All the samples were soaked and, if necessary, treated with hydrogen peroxide, or boiled in a weak solution of washing soda. In some cases, if the sediment was rather consolidated, a mixture of sodium pyrophosphate and 15% hydrogen peroxide was used.

Then the material was washed over a screen having average mesh of 0.063 mm (U.S. Sieve Series Mesh no. 230). The washed residue was then dried, and from each sample 200-250 foraminiferal tests were picked out at random. The remaining residue was thoroughly examined and all rare specimens, as well as probable indicator species, were also extracted. It was observed

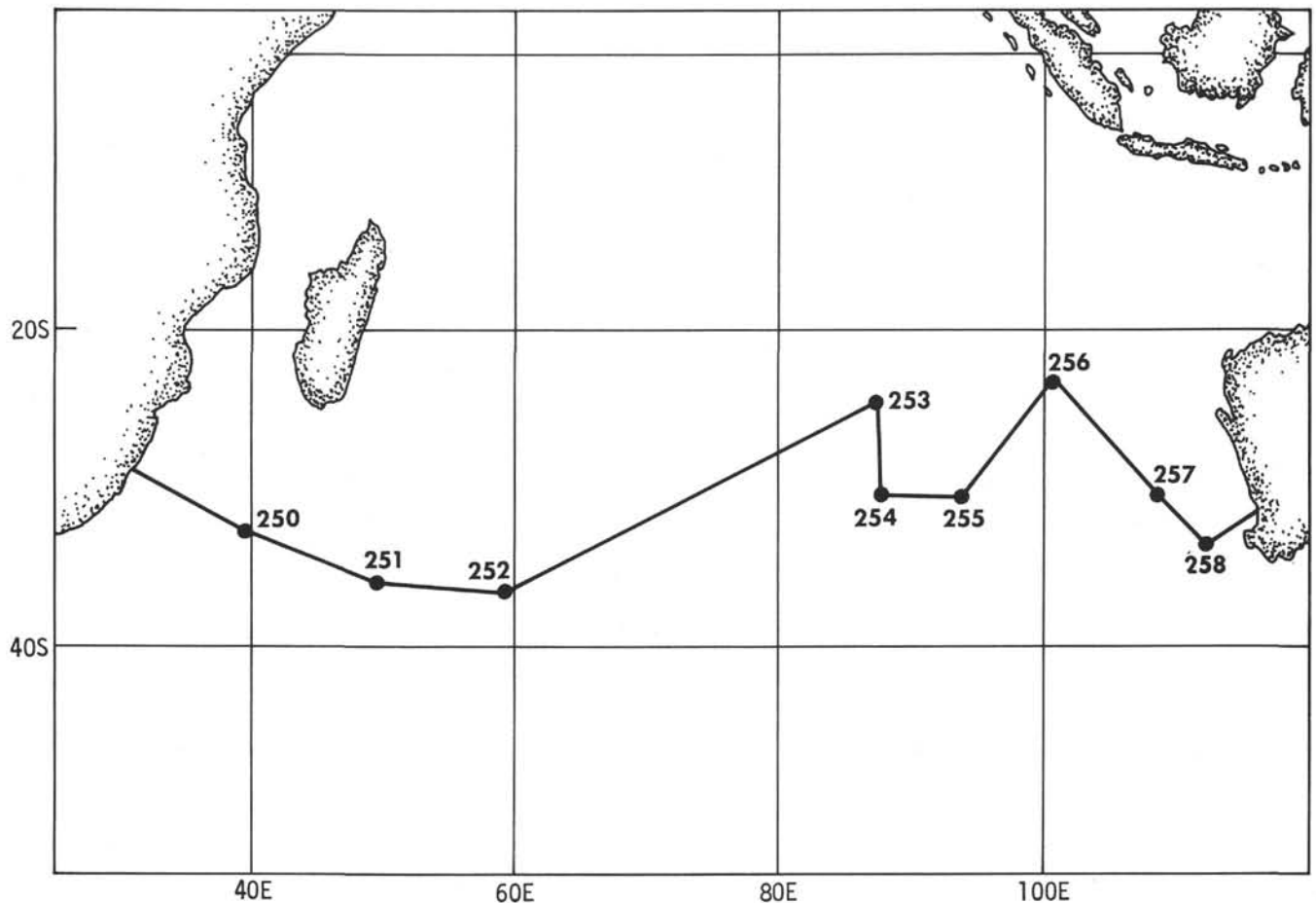


Figure 1. Location of the sites studied.

that in many cases marker species were very scarce, and, for this reason, they were not found in the first 200-250 specimens, but only by checking the remaining residues. In addition, for the location of the Quaternary/Pliocene boundary (see section on Biostratigraphical Boundaries) where the relationship between *Globorotalia truncatulinoides* and *G. tosaensis* was taken as the main criterion, at least 100 specimens of these species were collected at random from each sample. If the fauna was poor, the whole sample was checked and all the foraminiferal tests found were picked out. In cases where the material was attacked chemically, fewer than 200-250 specimens were found.

The subsequent steps were as follows: taxonomic identification, counting, and mounting of selected specimens in foraminiferal slides.

The following point should be emphasized with respect to taxonomic identification. The confusions which exist in the taxonomy of foraminifera are really enormous (Boltovskoy, 1965). These confusions have serious consequence for all kinds of paleontological conclusions. Therefore special attention should be paid to the identification of the species recorded.

Certainly I do not claim that all the identifications in this paper are correct. However, I do claim that I did everything I possibly could to achieve this goal.

For this purpose, directly after the cruise, I spent several days in Wellington where I compared my identifications with the foraminiferal collections stored in the Geological Survey of New Zealand and discussed many taxonomic problems with micropaleontologists working there. In Buenos Aires all the identifications were compared with a rather rich collection stored in the Museo Argentino de Ciencias Naturales "B. Rivadavia." During my postcruise-meeting trip to the U.S.A. I discussed several species with F. L. Parker, Scripps Institution of Oceanography, La Jolla, California, and R. Todd, U.S. National Museum, Washington. Finally, I spent several days in Washington to compare my fauna with the enormous foraminiferal collections of the Smithsonian Institution. In addition, to give to my colleagues the opportunity to better understand how I interpret the species recorded, I have tried to provide photographs of almost all of the species found (see Plates 1-14).

Counting the recorded specimens of each species permitted me to put on the range charts not only the existence of the species but also their abundance. However, it should be noted that the abundance signs are not precise. Nevertheless, they help to better display the vertical appearance and disappearance of each species.

Although all the species were determined and counted, not all of them were used for range charts or discussed and figured in the systematical part of this report. Some relatively rare species were excluded. The most important of these are probably those which belong to the *Globigerina bulloides* group (*G. bulloides*, *G. parabolloides*, *G. praebulloides*, *G. falconensis*, *G. ouchitaensis*, *G. gnaucki*, and some others). Their exclusion is justified not only by their limited importance for stratigraphical purposes in the area under study, but also by confusion and uncertainty regarding their taxonomic separation. The very short time between the cruise and the postcruise meeting and subsequent presentation of the finished report for publication is another reason why this group was not studied in detail, and, therefore, not included in the range charts.

All the samples which contained any kind of planktonic foraminiferal contamination were noted on the range charts. They compose somewhat less than 5% of the total quantity of Neogene samples which were not barren. But what does attract attention is that in two-thirds of the contaminated samples the contamination was evidently caused aboard ship, or less probably, during treatment in the laboratory, because Quaternary elements were found mixed with Pliocene or Miocene fauna.

MAJOR BIOSTRATIGRAPHIC BOUNDARIES AND FAUNAL ASSOCIATIONS

Unfortunately, there is no uniformity of opinion concerning what foraminiferal criteria should be employed to locate the boundaries between different geologic strata. This is explained mainly because different authors have studied material from different areas with distinct climatic conditions, and, thus, with distinct faunas. In addition, correlation is complicated by the disturbance of the geological sequences which can take place in the cores and by the absence (or excessive abundance) of some foraminiferal species due to the effect of selective dissolution. An alternating presence and/or absence of several species in a core may be caused by climatic fluctuations which took place in past geological epochs. Undoubtedly, the absence of uniformity of opinion with respect to boundary location is also explained to a certain degree by the confusion existing in foraminiferal taxonomy.

In locating the major biostratigraphic boundaries in this report, both foraminiferal and nannoplankton data were taken into consideration. In almost all cases a good correlation was observed between the conclusions reached by utilizing each of these two planktonic groups. In several cases, relatively small discrepancies were smoothed over after discussion aboard the *Glomar Challenger* or during the postcruise meeting and by checking additional samples. In only two cases (Sites 251 and 258) could the differences of opinion with respect to location of the Pliocene/Quaternary boundary not be resolved by mutual discussion. These cases are discussed later.

As for the zonations, different zonal schemes are used by different micropaleontologists. Those best elaborated

and based on the richest material are the zonations by Bolli (1966) (the first chart of this zonation from the middle Miocene into the Pliocene was published by Bolli and Bermúdez [1965]) and Blow (1969) (the first chart of this zonation was published by Banner and Blow [1965]).

Although Blow, in his zonation, used letters and numbers to name different zones and this method is unacceptable in the existing stratigraphic code, I find it much more convenient and practical than using specific names. Several species established as marker species by the authors of the zonations cited were not found in the present material. However, by using other species (as well as using the nannoplankton data), it was possible to relate many sequences to the zones established previously. It would seem rather illogical to call a zone by the name of foraminiferal species which was not found either in this zone or in the area. At the same time several species were found which could be considered as marker species for the present area, but they were not mentioned in the zonations of Bolli or Blow. Therefore, I prefer to use Blow's method of calling zones by letters and numbers.

I was unable to find all Blow's zones in the sites studied, and, in many cases, I was forced to distinguish larger units than single zones. This can be explained primarily by the fact that Blow's zonation (as well as Bolli's) is based principally on tropical and subtropical material, whereas sites studied in the present report are located in the temperate zone. An exception is Site 253 which is located in the subtropical zone and where the general character of the assemblages is of warm water. However, detailed zonation at this site was not carried out because, in spite of the subtropical location of the site, several species cited by Blow or Bolli were not found there, and many species recorded in this study are not included in the zonations of Bolli or Blow. In addition, there are discrepancies in the stratigraphic range of several common species; those established by Bolli and Blow are not the same as those established in the Leg 26 material, in general, and at Site 253, in particular.

It should also be mentioned that so-called "systems of datum levels" are in use by some micropaleontologists (Jenkins, 1966; Berggren, 1972). I agree with Beckmann (1971) that these systems can be very practical for initial prompt identification in samples aboard a ship. However, they are not very practical for detailed study in a shore laboratory because dissolution effects can eliminate several marker species. Furthermore, several species can be missing for other reasons or may have somewhat different ranges.

It would be possible to create a new zonation (or a "revised" zonation) on the basis of material collected during Leg 26; however, I do not think that this would be the right way to handle the problem. First of all, I do not think that material of one leg is sufficient to create a new well-founded zonal scheme. Secondly, I am of the opinion that it is much better to try to adjust your results to a well-known zonation than to create a new one based on insufficient evidence. This approach can lead to the possibility of world-wide correlation. Thus, I tried to use Blow's zones wherever possible.

Several criteria used to locate different boundaries are briefly discussed below. Only the more important and recent published works are cited. By citing specific names, the original forms used by the authors of the papers cited are conserved. The criteria used in this report to locate stratigraphic boundaries, as well as the foraminiferal assemblages typical of different ages, are discussed.

The Oligocene/Miocene Boundary and Subdivision of the Miocene

Blow (1969) stated that the first appearance of *Globigerinoides primordius* defines the base of the Miocene, and the extinction of *Globigerina angulisurensis*, *Globigerina ciperoensis*, *Turborotalia kugleri*, and some other species takes place in the basal Miocene.

According to Bandy and Ingle (1970), the base of the lower Miocene in tropical waters is characterized by the first appearance of *Globigerinoides trilobus*. Other typical species are: *Globigerina concinna*, *Catapsydrax stainforthi*, and *Globorotalia suteri*. Middle Miocene can be located by the first appearance of "*Orbulina*" *suturalis* and upper Miocene by the presence of *Globigerina siphonifera*, "*Orbulina*" *universa*, and *Globorotalia menardii*.

Krashennikov (1971) stated that the base of the lower Miocene is marked by the first appearance of *Globorotalia kugleri*. The base of the middle Miocene is marked by the first appearance of *Globorotalia fohsi* and *G. menardii*. *G. miocenica*'s first appearance marks the base of the upper Miocene.

In the present report the following assemblages and paleontological events were considered as indicative for the Oligocene and Miocene periods.

Oligocene marker species: *Globigerina ampliapertura*, *G. angulisurensis*, *G. angiporoides*, *Globorotalia pseudobulloides*, and several other species such as *Globigerina cryptomphala*, *G. tripartita*, *G. yeguaensis*, *G. euapertura*, etc., which extend into the early Miocene.

The Oligocene/Miocene boundary: *Globigerina ampliapertura*, *G. angulisurensis*, and *G. angiporoides* become extinct. *Globoquadrina venezuelana*, *G. altispira*, *Globigerinoides trilobus*, *s.l.*, *G. sicanus*, *Globorotalia miozea conoidea*, and *Globigerina "praerubra"* appear.

Early Miocene: in addition to the above-mentioned species, very typical early Miocene foraminifera are *Globigerinita dissimilis dissimilis*, *G. dissimilis ciperoensis*, *Globorotalia kugleri*, and, in the uppermost lower Miocene and lowermost middle Miocene, *Globorotalia peripheroronda*.

Lower Miocene/middle Miocene boundary: many species which composed the Oligocene fauna become extinct. From this group only *Globoquadrina dehiscens dehiscens* and *Globorotalia opima, s.l.* extend into the middle Miocene. Many species, as, for instance, *Globigerinoides amplus*, *G. bulloideus*, *G. ruber*, *Globigerinopsis aguasayensis*, *Globorotalia margaritae*, *G. petaliformis*, *Orbulina universa*, appear.

Middle Miocene: the most typical and/or common foraminifera in the middle Miocene assemblage are *Globorotalia miozea conoidea*, *G. aff. limbata*, *Globo-*

quadrina dehiscens dehiscens, *G. venezuelana*, *Globigerina nepenthes*, *G. decoraperta*, *Globigerinoides bulloideus*, *G. ruber*, *G. trilobus*, *G. mitra* and *Sphaeroidinella seminulina*.

Middle Miocene/upper Miocene boundary: appearance of *Globorotalia crassaformis*, *G. limbata*, *G. menardii, s.l.*, *G. scitula*, and *Sphaeroidinella subdehiscens*.

Upper Miocene: the most typical and/or common species are *Globorotalia miozea conoidea*, *G. limbata*, *G. margaritae*, *Globigerina nepenthes*, *G. decoraperta*, *Globigerinoides trilobus*, *G. bulloideus*, *G. obliquus, s.l.*, *G. amplus*, and *Sphaeroidinella seminulina*.

The Miocene/Pliocene Boundary and Subdivision of the Pliocene

This boundary was located by different authors using the following criteria.

Banner and Blow (1965): *Sphaeroidinella subdehiscens* was replaced by its descendant, *S. dehiscens*.

Bandy and Wade (1967): (a) disappearance of *Sphaeroidinella seminulina*, *Globoquadrina altispira*, and *Globorotalia tumida miocenica*; (b) appearance of *Globorotalia inflata* and *G. truncatulinoides*; and (c) great development of *Pulleniatina obliquiloculata*, *Globorotalia puncticulata*, and *Sphaeroidinella dehiscens*.

Jenkins (1967): appearance of *Globorotalia inflata*, *G. crassaformis*, and *G. hirsuta*.

Blow (1969): appearance of *Globorotalia tumida tumida* and the replacement of *Sphaeroidinella subdehiscens paenedehiscens* by its descendant *S. dehiscens dehiscens*.

Berggren (1969) and Cifelli (1970): appearance of *Sphaeroidinella dehiscens*.

Bandy et al. (1971): appearance of *Sphaeroidinella dehiscens* and, very close to this event, the extinction of *S. subdehiscens* and *Globoquadrina altispira*.

We can summarize by stating that the majority of researchers locate the Miocene/Pliocene boundary where: (a) *Sphaeroidinella subdehiscens* is replaced by its descendant *S. dehiscens*. (b) *Globoquadrina altispira* becomes extinct, and (c) *Globorotalia inflata* and *G. crassaformis* appear.

In the present material *Sphaeroidinella dehiscens* and *S. subdehiscens* are rare species. *Globorotalia inflata* and *G. crassaformis* are common and abundant. The latter two species were taken as the main marker species in locating the Pliocene. The frequent and abundant occurrence of these species was used to locate the beginning of the Pliocene. Their first occurrence at almost all sites was in the uppermost Miocene. *Globorotalia crassaformis* always appeared somewhat earlier than *G. inflata*, and the latter species is probably a better marker species for the beginning of the Pliocene.

In addition, the following species appeared at the beginning of the Pliocene: *Globorotalia crotonensis*, *G. hirsuta*, and *Pulleniatina primalis*. The following became extinct: *Globigerinita unicava*, *Globigerinopsis aguasayensis*, *Globorotalia petaliformis*, and *Orbulina suturalis*.

The Pliocene

In the Pliocene sequence Blow (1969) distinguished the upper part of Zone N18, Zones N19 and N20, and the lower part of Zone N21. Parker (1967) considered that entire zones N19, N20, and N21 compose the Pliocene. These three zones can be interpreted as lower, middle, and upper Pliocene, respectively. Parker (1973) gives probably the most clear criteria for the subdivision of the Pliocene in the Atlantic deep-sea section. She uses *Sphaeroidinella dehiscens* to mark the beginning of the lower Pliocene, *Globigerinoides fistulosus*, *Globorotalia exilis*, and *G. miocenica* to mark the beginning of the middle Pliocene, and *Globorotalia tosaensis* to indicate the beginning of the upper Pliocene. Parker's scheme corresponds rather well to the subdivision recognized in the present study.

The criteria to locate the beginning of the Pliocene were discussed above.

Middle Pliocene was located in the material of the present study where for the first time *Globigerinoides fistulosus*, *G. pyramidalis*, *Globoquadrina dutertrei*, and *Globorotalia crassula* appeared. *Globorotalia exilis* was not found at all and *G. miocenica* was determined tentatively. An additional criterion used in the present study to locate the lower/middle Pliocene boundary was the extinction of *Globigerina nepenthes* and *Globigerinoides amplus*.

The upper Pliocene was located when *Globigerina calida*, *Globoquadrina humerosa*, and *Globorotalia truncatulinoides* appeared for the first time. *Globorotalia tosaensis* was recorded for the first time in the middle Pliocene in the present material.

The Pliocene/Quaternary Boundary

The following criteria have been used by different authors to locate this boundary.

Bandy (1967), Jenkins (1967): change in coiling direction of *Globigerina pachyderma* from dominantly dextral to sinistral.

Ericson et al. (1964), Ericson and Wollin (1964, 1968): (a) change in coiling direction of *Globorotalia menardii* from 95% dextral to 95% sinistral, (b) disappearance of *Globigerinoides sacculifer fistulosa*, (c) extinction of *Globorotalia multicamerata*, (d) increase in size of *Globorotalia menardii*, (e) appearance in abundance of *Globorotalia truncatulinoides*. The latter criterion is the most important according to the authors cited (Ericson and Wollin, 1968).

Parker (1967): disappearance of *Globigerinoides fistulosus* and *Globoquadrina pseudofoliata*, appearance of *Globigerinoides tenellus*.

Berggren et al. (1967), Berggren (1969), Bandy and Wilcoxon (1970), Bolli (1970), Cifelli (1970), Hays and Berggren (1971), and Poag (1971): appearance of *Globorotalia truncatulinoides*.

Blow (1969): appearance of *Globorotalia tosaensis tenuithecica* from its ancestor, *G. crassaformis oceanica*.

Lamb (1969): extinction of *Globoquadrina altispira* and appearance in the lower Pleistocene of *Globorotalia truncatulinoides*.

The replacement of *Globorotalia tosaensis* by *G. truncatulinoides* is the most universally accepted of the criteria listed above. Unfortunately, no unity of opinion exists as to the exact location of the Pliocene/Quaternary boundary using this criterion. Should this boundary be placed (a) at the last appearance of *Globorotalia tosaensis*? (b) at the first appearance of *Globorotalia truncatulinoides*? (c) when *Globorotalia truncatulinoides* appears in appreciable quantity? (d) when only *Globorotalia truncatulinoides* is found and no specimens of *G. tosaensis*? The vertical distribution of the *Globorotalia tosaensis*/*G. truncatulinoides* group observed at Site 258 illustrates well that the location of the boundary depends very much on the criterion accepted. All the specimens of these two species found at the site mentioned were counted. Their vertical distribution can be described as follows.

The first geological appearance of *Globorotalia tosaensis* (isolated specimens) at this site was recorded at a depth of 55.5 meters (the uppermost middle Pliocene). At a depth of 45.5 meters the first specimens of *Globorotalia truncatulinoides* were found (upper Pliocene). In the layer between 45.5 and 30.20 meters both species were present, but *Globorotalia tosaensis* was almost always more numerous than *G. tosaensis*. Between 30.20 and 28 meters both species were found in approximately the same quantity. Starting from 28 meters upward, *Globorotalia truncatulinoides* became more numerous than *G. tosaensis*. At a depth of approximately 19 meters *Globorotalia truncatulinoides* became abundant. At a depth of 2.20 meters the last specimen of *Globorotalia tosaensis* was found. The layer between 2.20 and 0 meters contained only *Globorotalia truncatulinoides*.

Now, where should the Pliocene/Quaternary be located? At a depth of 45.5 meters? At a depth of 19 meters? Or at a depth of 2.20 meters?

Another rather good example is seen at Site 251. The appearance and disappearance of *Globorotalia truncatulinoides* and *G. tosaensis* observed at this site is as follows: First appearance of *Globorotalia tosaensis* was at a depth of 59 meters. First appearance of *Globorotalia truncatulinoides* was at a depth of 54.5 meters. *G. truncatulinoides* was more numerous than *G. tosaensis* at 37 meters, and *G. truncatulinoides* was abundant at 30 meters. The uppermost appearance of *G. tosaensis* is at 5 meters.

The distributions described are a natural consequence of the fact that the replacement of *Globorotalia* by *G. truncatulinoides* was a rather long process which took considerable time and was accompanied by the formation of a series of intermediate forms.

In the present study the following criterion was taken to separate the Quaternary from the Pliocene by means of *Globorotalia truncatulinoides*/*G. tosaensis* data. As mentioned above, in addition to 200–250 planktonic specimens picked out at random from each sample, at least 100 specimens of *Globorotalia truncatulinoides*/*G. tosaensis* group were also separated at random. The relationship between the species was calculated for every sample. If this ratio was more than 1 (meaning that

Globorotalia truncatulinoides predominated over *G. tosaensis*), the sample was considered Quaternary. If this ratio was less than 1, the core was considered to be Pliocene.

This criterion was taken as the principal one to locate the Pliocene/Quaternary boundary at all sites. At four sites (250, 253, 254, and 255) the boundary located in this way corresponded exactly with the boundary determined using nannoplankton. At two sites (250 and 258) foraminiferal method gave a location for the boundary of 10-15 meters higher than the nannoplankton method. As both sites are located quite far south, perhaps climatic conditions (lower temperatures) are the reason for this discrepancy. Opinions have been expressed (Kennett and Geitzenauer [1969]), that *Globorotalia truncatulinoides* and *G. tosaensis* are phenotypic variants or separate taxa with distinct environmental preferences. The latter species preferred colder water and in colder water it was more numerous. Thus, at Sites 250 and 258, the coldest, *Globorotalia tosaensis* was more numerous and, for this reason, the Pliocene/Quaternary boundary is higher than that located by means of nannoplankton data. However, it should be pointed out that the location of the boundary in question at Sites 251 and 258 was checked using other foraminiferal faunal criteria. In summary, it is not clear why there is a discrepancy in the placement of the Pliocene/Quaternary boundary at these sites.

The Quaternary

The Quaternary lasted about 1.8 m.y. (Berggren, 1972). It is divided into Pleistocene and Holocene. Different points of view exist regarding the number, character, and duration of glacial epochs which took place during the Pleistocene. Material collected for the usual work carried out with *Glomar Challenger* material is not suitable for study of Quaternary paleoclimatic fluctuations because this kind of study requires closely spaced samples. However, to carry out a study of the above-mentioned fluctuations at Site 253, a series of samples at 10-cm intervals was taken. The results are published in this volume as a separate paper entitled "Late Pliocene and Quaternary paleoclimatic changes."

The Holocene is postglacial time, and its duration, according to the majority of researchers, has been 11,000 years. The Pleistocene/Holocene boundary is rather difficult to locate faunally, because the faunas are practically identical. There are differences, but they are very insignificant and do not have world-wide application.

Blow (1969), for instance, interpreted his Zone N23 as the Holocene and probably the uppermost part of the Pleistocene. He emphasized that the appearance of two new species are recorded, namely *Hastigerina adamsi* and *Hastigerinella digitata*. In addition, *Pulleniatina obliquiloculata finalis* and *Sphaeroidinella dehiscens excavata* became abundant.

Parker (1973) separates the Holocene from the Pleistocene using the presences of pink-walled *Globigerina rubescens* and *Globigerinoides ruber* in the Pleistocene. Boltovskoy (1968) separated pink-walled

specimens of the latter species under the name *Globigerinoides ruber, forma rosea*, to distinguish them from white-walled specimens, *G. ruber, forma alba*. The criterion of Parker perhaps is not very good. Orr (1969) and Jenkins and Orr (1972) considered that the preservation of pigmented specimens depends on the sedimentation rate. Rapid sedimentation rates allowed for the preservation of more pigmented specimens than did low rates.

For the temperate zone a good criterion is the general change of fauna to the more warm water type. As *Globorotalia menardii* is a typical warm-water species, Ericson et al. (1964) and Ericson and Wollin (1968) used its appearance in abundance to determine the end of the Pleistocene.

Bandy (1967) used the change in coiling direction of *Globigerina pachyderma* from sinistral to dextral.

In only two sites on Leg 26 was it possible to separate Holocene from Pleistocene deposits. At Site 258 the Holocene/Pleistocene boundary was located using Parker's criterion. The results were rather unexpected; the Holocene sediments appeared to be 8.5 meters thick. At Site 253 the boundary was located by means of a detailed paleoclimatic study utilizing the relationship between *Globorotalia menardii* and *G. inflata* (Boltovskoy, Late Pliocene and Quaternary paleoclimatic changes, this volume). The results obtained were much more as expected, namely the limit between Holocene and Pleistocene was fixed approximately at a depth of 30 cm from the bottom surface.

DESCRIPTION OF THE SITES

The range charts of selected species (Figures 2-7) show the most important changes which occurred in foraminiferal fauna from early Miocene to Recent in the middle part of the Indian Ocean. Qualitative, as well as quantitative, data are noted on these charts. As was explained above, some species were not studied in detail for several reasons, and, thus, are not included in the range charts. An examination of the range charts also gives an idea of what criteria were used by the author in locating the biostratigraphic boundaries at each site. The problem of biostratigraphical boundaries was previously discussed and is also treated in the following descriptions of the sites.

Site 250 (Figure 2)

Site 250 is located in the Mozambique Basin. Two holes, 250 and 250A, were cored. Hole 250 was cored from the surface to a depth of 18.5 meters, then drilled to a depth of 55.5 meters and then cored again from 55.5 to 65 meters. Hole 250A was continuously cored from 54.5 to 83 meters and then discontinuously cored from 115.5 to 738.5 meters. The Neogene sequence encountered at this site is 672 meters thick and consists of clayey coccolith ooze, detrital silty clays, and detrital clay.

The foraminiferal fauna from this sequence has been affected by solution and, in many sections, has been completely dissolved. Assemblages found are poor

qualitatively and quantitatively and not very suitable for use either in age determination or for drawing ecological conclusions.

At least the uppermost 83 meters are Quaternary in age. No way was found to separate Holocene from Pleistocene sediments. The foraminiferal assemblage recorded from the Quaternary deposits is evidently of a temperate zone type. *Globorotalia inflata*, s.l., which is a typical cold-temperate species, strongly predominates. It is accompanied by: (a) cold-temperate species such as *Globigerina pachyderma* (dex.) and *G. quinqueloba*, *Globorotalia truncatulinoides/tosaensis*; (b) warm-temperate species, *Globorotalia hirsuta*, *G. cf. humilis*, and *Globigerinella aequilateralis*; and (c) a few warm-water species, *Globorotalia menardii*, *Globigerinoides ruber*, *G. conglobatus*, and *G. elongatus*. The whole assemblage indicates lower temperature than observed in the same area today. Benthonic species indicative of great depths were found (*Cibicides kullenbergi*, *Epistominella japonica*, and *Nonion soldanii*), and many typical deep-water *Fissurina*, *Parafissurina*, *Lagena*, etc.). The assemblage does not show any important changes through the Quaternary.

Cored material found below the Quaternary deposits is late Pliocene in age. It contains more or less the same poor fauna but without *Globorotalia truncatulinoides*. *Globorotalia tosaensis*, was found, however. The thickness of the late Pliocene sediments is at least 43.5 meters. It is very probably more because some parts of the section were not cored, and a part of the cored section appeared to be barren.

Neither middle nor lower Pliocene deposits were recorded.

At the depth of 235 meters the upper Miocene (Zones N16-N18) was found. The fauna is still poorer qualitatively and quantitatively than the Pliocene fauna. The absence of several typical Pliocene species (*Globorotalia inflata*, s.l.; *G. crotonensis*; *Sphaeroidinella dehiscens*; *Pulleniatina obliquiloculata*, s.s., etc.) indicates a Miocene age for the sediments.

A great sequence of completely barren sediments (about 300 m) was drilled below the upper Miocene section. Only one sample in this section contained debris of some arenaceous benthonic foraminifera.

Below this sequence about 40 meters of lower Miocene were encountered. The sediments were partially barren, but, in some places, contained a rather typical lower Miocene fauna (*Globorotalia kugleri*, *G. peripheroronda*, *Globigerinita dissimilis dissimilis*, etc.). They can be considered as Zones N4-N8. In addition, some evidently reworked Eocene and Oligocene foraminifera were recorded from these lower Miocene sediments. Some arenaceous benthonic foraminifera of long-ranging species were found, too.

An assemblage of calcareous benthonic foraminifera found in Sample 18, CC is of special interest and rather enigmatic. This assemblage consisted of specimens of *Rotalia cubensis*, *Reussella spinulosa*, *Bolivina tortuosa*, *Elphidium crispum*, *Nodobaculariella cassis*, *Sphaeroidina bulloides*, *Quinqueloculina bradyana*, and some other shallow-water species typical of a subtropical and even a tropical zone. All the specimens were

in a very good state of preservation and belong to the Recent fauna, although it is possible that they also lived during the Miocene. If this assemblage contained also Recent planktonic foraminifera, I would think it to be the result of contamination aboard *Glomar Challenger*. However, no typical specimens of Recent planktonic species were found in the sample. Thus, it is more logical to assume that the benthonic assemblage mentioned is the result of sediment transport from shallower areas which occurred during the early Miocene.

A very few damaged benthonic calcareous specimens were recorded in Sample 17, CC; however, no typical shallow water dwellers were found among them.

Site 251 (Figure 3)

This site is located about 180 km north of the middle part of the Southwest Branch of the Indian Ridge. Two holes were drilled. Hole 251 extended from 0 to 87.5 meters, subbottom; it was stopped for technical reasons. The whole sequence was cored. Hole 251A was drilled to a depth of 489 meters in sediments and an additional 10 meters into the underlying basalt and cored intermittently (276.5 m were cored, 158.4 m were recovered). The Neogene-Recent sequence consisted of 486.5 meters of nannoplankton ooze and chalk.

Site 251 is paleontologically very interesting and valuable because it has yielded a complete, and presumably, uninterrupted, midlatitudinal Neogene sequence for the Indian Ocean. Unfortunately, however, owing to the great depth, the fauna was affected by solution, insignificantly in Quaternary deposits, but considerably in the Miocene, especially the lower Miocene. In several Miocene samples the foraminiferal assemblages consisted of only two to four of the most resistant species. There were samples in lower Miocene which contained only very small-sized, practically unidentifiable specimens. These factors considerably decreased the value of the site as a possible standard.

In all the assemblages down to the middle and lower Pliocene *Globorotalia inflata*, s.l. predominates. It is always accompanied by *Globorotalia crassaformis* which in the Pliocene sediments is not as numerous as the former species. Only in the upper Miocene does *Globorotalia crassaformis* become more abundant than *G. inflata*. In a part of the upper and middle Miocene section the predominant species is *Globorotalia miozea conoidea*. *Globigerina pachyderma* (dex.), *G. bulloides*, *Globorotalia truncatulinoides/tosaensis*, *Globigerinella aequilateralis*, *Orbulina universa*, *Globigerinoides ruber*, and *G. trilobus*, s.l. are other species which compose the Quaternary and Pliocene assemblages. The whole fauna is typical of the temperate zone. Such a characteristic warm water species as *Globorotalia menardii*, s.l. is found sporadically and as isolated specimens.

The changes in the relationship between warm-water and cold-water faunas suggest some climatic fluctuations. However, these fluctuations were relatively insignificant and not well pronounced.

The thickness of the Quaternary deposits is 37 meters. It was not possible to divide them into Holocene and Pleistocene.

The Quaternary/Pliocene boundary was located using the criterion of the change in ratio of *Globorotalia truncatulinoides*: *G. tosaensis*. In addition, this boundary is characterized by a temperature change, indicated by some increase of cold-water elements and decrease of warm-water elements in the Quaternary section as compared with the Pliocene section. The thickness of the Pliocene deposits is 93 meters.

It was possible to distinguish upper Pliocene (Zone N21); however, no paleontological evidence was found to separate the middle Pliocene (Zone N20) from the lower Pliocene (Zone N19). The upper Pliocene was detected by the first appearance of *Globoquadrina humerosa*. Simultaneously came *Globorotalia margaritae* and, somewhat lower in the section, *G. acostaensis* became extinct.

The Pliocene/Miocene boundary was located using *Globorotalia inflata, s.l.* as a criterion. It was rare to very rare in the upper Miocene but became frequent in the Pliocene. Other species did not show any important change in their vertical distribution across the boundary. *Globorotalia crassaformis* was frequent in the Pliocene and uppermost Miocene sediments. It appeared a little lower in the section than *Globorotalia inflata, s.l.*

Morphological changes which take place in *Globorotalia inflata, s.l.* are of interest and importance for stratigraphical purposes. They can be observed at other sites too, but are especially evident at Site 251.

At this location, in the Pliocene sequence, especially in the upper Pliocene, *Globorotalia inflata, s.l.*, is represented by typical specimens, identical to those found in the Recent oceans. In the upper Miocene section, however, it is very difficult to separate *Globorotalia inflata, s.l.*, from *G. crassaformis*. Both species look very much alike and are connected by all kinds of transitional forms. *Globorotalia inflata, s.l.* at that time had four or even five chambers in the final whorl, a less vaulted umbilical side, flat or almost flat spiral side, and its outline was subquadrangular. On the other hand, during the same epoch many transitional forms between *Globorotalia inflata, s.l.*, and *G. miozea conoidea* also existed and their separation sometimes is very difficult. This problem is discussed in detail in the section on Systematics.

The whole thickness of the Miocene deposits drilled at Site 251 is more than 350 meters. Using foraminiferal criteria, the sequence was divided into three parts: upper Miocene (153.5m), middle Miocene (161 m), and lower Miocene (41 m). It was not possible to subdivide the sequence into zones.

In the upper part of the upper Miocene sequence *Globorotalia crassaformis* was the dominant species, but in the lower part of the upper Miocene, as well as in middle and lower Miocene sequences, *Globorotalia miozea conoidea* predominated.

The following criteria were used for the subdivision of the Miocene sequence. The appearance of *Globorotalia limbata* and *G. acostaensis* marked the middle/upper Miocene boundary. *Globorotalia peripheroronda* was used as an indicator of the lower/middle Miocene boundary.

The unsatisfactory state of preservation of the foraminifera at Site 251 precluded my drawing any paleoclimatological or ecological conclusions.

Site 252

Site 252 is located in the northern part of Crozet Basin. It was drilled down to 247 meters. However, only six cores were taken and these were at some distance from one other. Sediments encountered were radiolarian clay, radiolarian silty clay, clay, and diatom-bearing clay.

Evidently the sediments were deposited below the carbonate compensation depth, as almost no calcareous foraminifera were found. The few planktonic specimens found were some very rare *Globorotalia inflata, s.l.*, recorded from a depth of 9.5 meters. According to nannoplankton data, at that depth Quaternary deposits are found.

Site 253 (Figure 4)

Site 253 was located on the southern half of the Ninetyeast Ridge. It is the northernmost site drilled during Leg 26 which contained a well-preserved fauna; 526 meters were cored; the lowermost 33 meters were partially drilled and partially cored. One meter was drilled into basalt. The Neogene sequence is 85 meters of calcareous ooze.

The foraminiferal fauna was very well preserved in Quaternary and Pliocene deposits, slightly affected by solution in the upper Miocene, and damaged in middle and lower Miocene. The whole Neogene sequence appears to have no gaps; however, I was unable, with the material available, to subdivide the sequence into zones.

The thickness of the Quaternary sediments at Site 253 is 5 meters. A study of additional samples taken at small intervals established that the Holocene sequence is only 30 cm thick (Boltovskoy, Late Pliocene and Quaternary paleoclimatic changes, this volume).

The Quaternary/Pliocene boundary was located by means of the *Globorotalia truncatulinoides*: *G. tosaensis* relationship. In addition, in the lowermost part of the Quaternary sequence, isolated Pliocene markers were recorded, namely *Pulleniatina obliquiloculata praecursor*.

In the Pliocene sequence *Globorotalia crotonensis* and, somewhat lower, *G. limbata* and *Globigerinoides fistulosus* were found.

The upper Pliocene fauna of Core 1 is underlain in Core 2 by the middle and lower Pliocene assemblages. The former is characterized by the last appearance of *Sphaeroidinella seminulina*, *Globoquadrina venezuelana*, and *G. altispira*. The lower Pliocene fauna is characterized by presence of *Globorotalia margaritae*.

Below the lower Pliocene upper Miocene deposits were found. The upper part of this section contained *Sphaeroidinella subdehiscens*, *Globigerinopsis aguasayensis*, *Globigerinoides amplus*, and some other species.

The middle Miocene was recorded in Core 7 where *Globigerinoides mitra*, *G. bulloideus*, and *Globorotalia peripheroronda* were found.

In the lower Miocene sequence the first occurrence (going downward) of *Globigerina yeguaensis*,

Dissolution Effects (entire assemblage):
 0 - Not affected; 1 - Slightly affected; 2 - Damaged;
 3 - Strongly damaged; and 4 - Destroyed.

Abundance (each species):

Abundant (■); Common (◼); Rare (●); Very rare (isolated) (▲)

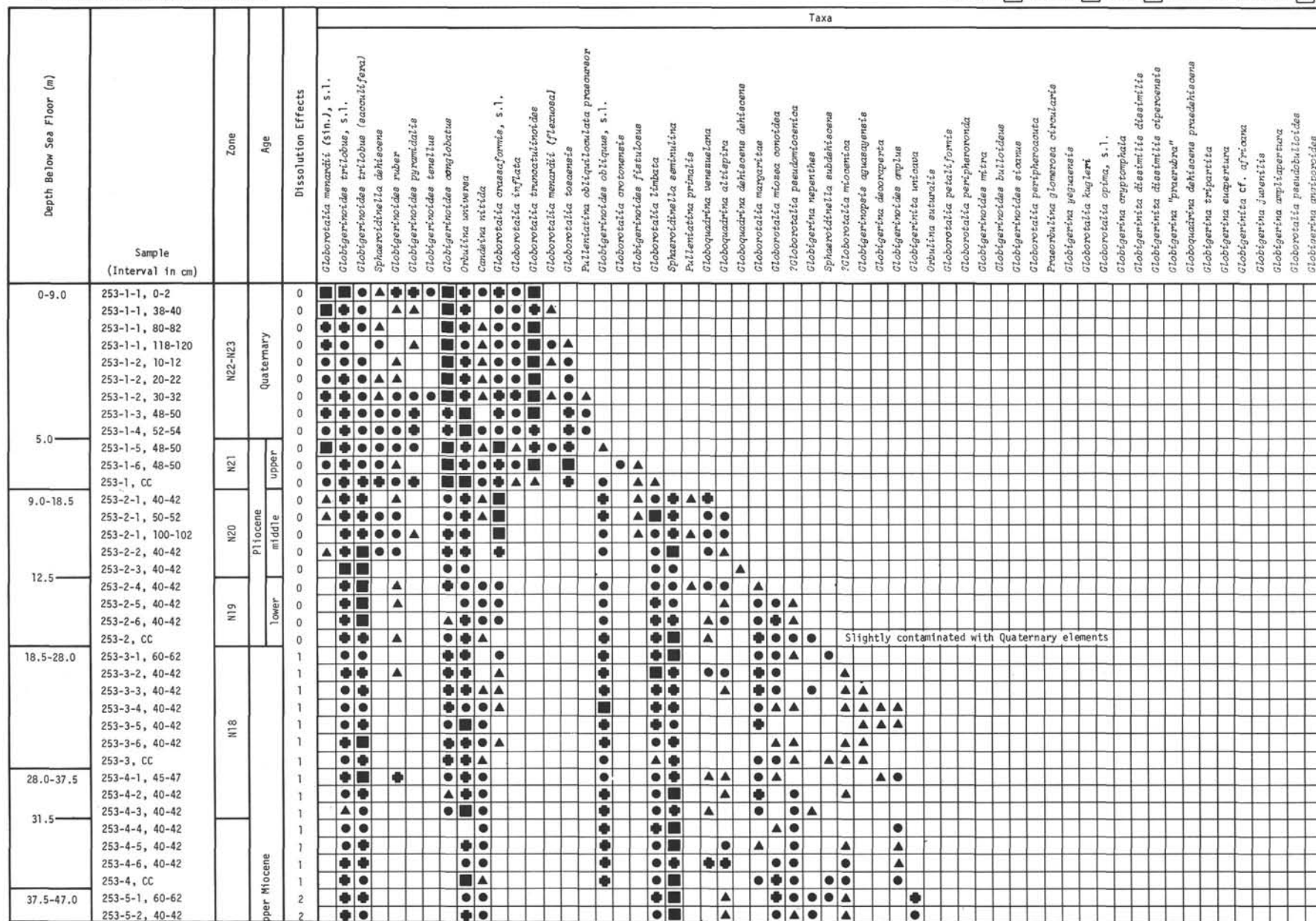


Figure 4. Range chart of selected Planktonic Foraminifera species at Site 253.

Globorotalia kugleri, and somewhat lower, of *G. opima*, s.l. *Globigerinita dissimilis dissimilis*, *G. dissimilis ciperensis*, and *Globigerina "praerubra"* were noted. In addition- the lower Miocene assemblages contained a great number of unidentifiable (usually extremely small) planktonic foraminifera.

As shown on Figure 4, at Site 253 the foraminiferal assemblages of Miocene and Oligocene are very different. The change from Oligocene to Miocene fauna is observed in about 10 meters of section, which means that it was geologically rather abrupt. To locate the boundary between Oligocene and Miocene the extinction of *Globigerina ampliapertura*, *G. juvenilis*, and *Globorotalia pseudobulloides*, and appearance of *Globoquadrina venezuelana*, *G. dehiscens dehiscens*, and *Globigerina decoraperta* was used.

Site 253 is a valuable site. Its shortcomings are the small thickness of the whole Neogene sequence (85 m) and the relatively small number of samples taken for the complete sequence, which very probably contains all the zones. Many more samples should be taken before zone boundaries can be established.

Site 254 (Figure 5)

This site is located on the Ninetyeast Ridge, approximately where the ridge joins Broken Ridge. The base of the Neogene is at a depth of 167 meters. A discontinuous Neogene sequence was recognized by means of foraminifera at this site. However, in many cases, it was not possible to separate individual zones. Fifteen samples in the Miocene section appear to be contaminated, fortunately with Quaternary specimens which were easy to separate from the in situ Miocene ones. Foraminiferal tests were well preserved throughout all the cores. Lithologically, the Neogene sequence consists mainly of coccolith-foram ooze and foram-coccolith ooze.

The Quaternary sequence is only 5.5 meters thick. The foraminiferal assemblages in it are typical of the temperate zone. *Globorotalia inflata*, s.l. is the dominant species and *G. menardii*, s.l. is found only as isolated tests. The uppermost sample, taken at a depth of 40-42 cm below the bottom sample, contained rare specimens of *Globorotalia tosaensis* and did not have any Holocene indicators. This proves that the whole sequence is Pleistocene. If Holocene is present, it is represented by a thin layer (not thicker than 40 cm).

The underlying sediments are Pliocene in age. Their age is well documented on the basis of planktonic foraminifera. The Quaternary/Pliocene boundary was located by means of the relationship between *Globorotalia truncatulinoides* and *G. tosaensis* and by the presence in the Pliocene sediments of *G. crotonensis*. The Pliocene was apparently colder; no specimens of *Globorotalia menardii*, s.l. were recorded.

The Pliocene sequence was divided into three parts. In the upper Pliocene (2 m) *Globorotalia crotonensis* is the characteristic species. In the middle Pliocene sequence (7.5 m) the extinction of *Globoquadrina venezuelana* and *Sphaeroidinella seminulina* is recorded in the uppermost part. The uppermost occurrence of *Globorotalia*

margaritae was recorded at a depth of 15.42 meters. This is the uppermost lower Pliocene sediment.

The Pliocene/Miocene boundary was located using foraminiferal criteria. In the lowermost Pliocene *Globorotalia inflata*, s.l. and *G. crassaformis* were recorded frequently. In the uppermost Miocene only isolated specimens of these species were found. As at other sites the first occurrence of *Globorotalia crassaformis* was recorded at Site 254 a little earlier than *G. inflata*, s.l.

The Miocene sequence (142.5 m) is much thicker than the Pliocene. It was also divided into three parts. The extinction of *Globigerinita unicava*, *Globigerinopsis aguasayensis*, and somewhat lower of *Globigerinoides sicanus* and *Globorotalia* aff. *limbata*, were taken tentatively as the main criteria for locating the upper part of the middle Miocene.

The faunistical differences between middle and lower Miocene are well illustrated on the range chart (Figure 5). The extinction of such typical lower Miocene species as *Globigerinita dissimilis dissimilis*, *G. dissimilis ciperensis*, *Globigerina euapertura*, and some others are characteristic features of the termination of that epoch.

The Miocene/Oligocene boundary is also easily observed on the same chart. *Globoquadrina venezuelana* and *G. dehiscens dehiscens* make their first appearance in lowermost Miocene deposits. *Globigerina angulisuturalis* and *G. angioporoides* characterize the Oligocene, although it should be noted that isolated specimens of the latter species were recorded in lower Miocene deposits too.

A great number of quite small unidentifiable planktonic foraminifera was observed in practically all the Miocene samples. Sometimes these specimens were more numerous than those which could be identified.

It is interesting to mention the relationship observed between the number of specimens of *Globorotalia inflata*, s.l., *G. crassaformis*, and *G. miozea conoidea*. From lower Pliocene downward the first two species decrease numerically whereas *Globorotalia miozea conoidea* increases. In the Miocene deposits *G. inflata*, s.l. and *G. crassaformis* are not found and *G. miozea conoidea* is widely distributed and numerous. It appears that the two species replace the single earlier species.

Site 255 (Figure 6)

This site is located atop Broken Ridge. It was drilled to a depth of 108.5 meters and cored almost throughout the hole; only 9.5 meters (between 13.5 and 23 m) were left uncored. Unfortunately, recovery at Site 255 was very low, from 99 meters cored only 7.9 meters of core material and several core catchers were obtained. The Neogene sequence consists of a nannoplankton foraminiferal ooze. The foraminiferal tests are well preserved except in the lower Miocene material where many shells are damaged. The site is located approximately at the same latitude as Site 254 and its fauna is of the same temperate zone type. *Globorotalia inflata*, s.l. strongly predominates. As at Site 254, the uppermost sample (taken at depth of 4 m below bottom surface) contains *Globorotalia tosaensis* and no typical Holocene forms. Thus, it was not possible to distinguish

Holocene sediments. The Holocene/Pleistocene boundary lies somewhere in the uppermost 4 meters of sediment.

The Quaternary/Pliocene boundary was determined by means of the *Globorotalia truncatulinoides*: *G. tosaensis* relationship. Also, several species (among them: *Globorotalia miozea conoidea*, *Globigerina nepenthes*, *Sphaeroidinella seminulina* and some others) became extinct at the end of the Pliocene. It was not possible to subdivide the Pliocene sediments.

In the Miocene sequence only upper, middle and lower Miocene were distinguished. Zones were not separated. The upper part of the lower Miocene was not detected at all.

Below the lower Miocene sediments is a sequence of unknown age. Under this sequence middle Eocene deposits were found.

Site 256

This site is situated in the southern part of Wharton Basin. It was drilled to 270 meters of which 251 meters were reddish to grayish brown clays and 19 meters basalt: 99 meters were cored. Because of the great depth the fauna was in a very bad state of preservation; many samples did not contain anything at all and several samples had either arenaceous foraminifera, which could not be used as age determinants, or rare calcareous benthonic or very small-sized unidentifiable planktonic species.

The best-preserved fauna was encountered in Sample 5-2, 35-39 cm, at a depth of 125.5 meters below the bottom surface. It contained *Globorotalia miozea conoidea*, *G. margaritae*, *G. inflata*, *s.l.*, *Globigerina decoraperta*, *G. nepenthes*, *G. quinqueloba*, *Globigerinita glutinata*, and many minute unidentifiable planktonic foraminifera. Specimens were small sized, rather rare numerically, but well preserved. They did not look reworked. This assemblage can be either uppermost late Miocene or, more probably, early Pliocene in age. Thus, at least the upper 125.5 meters should be considered as Pliocene. I could not determine with the material available exactly how much of the uppermost 125.5 meters is Quaternary in age. In Sample 1-3, 40-42 cm, taken at depth of 3.5 meters down from the sea bottom, *Globigerina nepenthes* (one specimen) and a probable *Globorotalia miozea conoidea* (also one specimen) were found. Both species cannot be younger than early Pliocene in age. Sample 1, CC (depth 9.5 m) contained *Globigerinoides trilobus*, *s.l.*, *Globorotalia inflata*, *s.l.*, and probable *Globorotalia tosaensis* which are also Pliocene in age. Thus, the Quaternary section is certainly less than 3.5 meters in thickness.

The sediments below the upper 125.5 meters (Pliocene-Quaternary section) were either completely barren or contained poorly preserved arenaceous foraminifera of a very wide stratigraphic range. The exact age determination of this sequence was impossible.

Based on radiolarian data, the lowermost sediments are Cretaceous in age.

The whole Neogene sequence at Site 256 undoubtedly was deposited at a depth below the carbonate compensation depth.

Site 257

This site is located in the southeastern part of the Wharton Basin. It was drilled down to a depth of 326.5 meters of which 155.5 meters were cored. Lithologically the sediments are detrital clay, clayey coccolith ooze, and chalk. As this site was below the lysocline for a long period, no calcareous fossils were found in the uppermost layers; only arenaceous benthonic foraminifera, in a rather bad state of preservation, were encountered. Specimens of *Globotruncana* found in Core 5 (depth 125 m) indicate a Cretaceous age of this layer.

Site 258 (Figure 7)

Site 258 is located on the north flank of Naturaliste Plateau. Two holes were drilled: Hole 258 to 525 meters, and Hole 258A to 123.5 meters. The Neogene deposits are 114 meters of a gray-white calcareous ooze. Foraminiferal tests are very well preserved.

This is the site where the Quaternary section could be divided into Holocene and Pleistocene. For this subdivision the criterion suggested by Parker (1973) was used. The oldest sample which contained *Globigerinoides ruber* (*f. rosea*) is Sample 1-6, 110-112 cm. In the same material one pink-walled *Globigerina rubescens* was also found. This sample was found from a depth of 8.5 meters below the bottom surface. Thus, if we accept the Parker's criterion, the uppermost 8.5 meters of Quaternary sediments are Holocene. The underlying 20.5 meters are Pleistocene. The whole thickness of the Quaternary sequence is 29 meters. Doubts with respect to validity of this criterion were discussed previously. Not being sure that the Holocene/Pleistocene boundary is located correctly, I prefer to leave it uncertain.

The Quaternary/Pliocene boundary was located utilizing the *Globorotalia truncatulinoides*: *G. tosaensis* ratio. As an additional criterion, the extinction of *Globorotalia crotonensis* and *Globigerinoides obliquus*, *s.l.* was taken.

The limit between the upper Pliocene and middle Pliocene is marked (among other things) by the extinction of *Globoquadrina altispira* and the appearance of *Globorotalia truncatulinoides*, *Globorotalia tosaensis*, *Pulleniatina obliquiloculata*, *s.s.*; *P. obliquiloculata praecursor*, and *Globigerinoides pyramidalis* appear in the lowermost middle Pliocene.

The most characteristic species of the lower Pliocene is *Globorotalia margaritae*.

For the location of the Pliocene/Miocene boundary the occurrence of *Globorotalia inflata*, *s.l.* and *G. crassaformis* was used. The sporadic records of rare or isolated specimens of the former species in the upper Miocene are in marked contrast to the abundant (or frequent) and ubiquitous appearance of specimens of the same species in the Pliocene. More or less the same phenomenon (but not as well pronounced) was observed with respect to *Globorotalia crassaformis*.

The following very typical upper Miocene species were encountered somewhat below the Pliocene/Miocene boundary: *Orbulina suturalis*, *Globigerinoides amplus*, *Globigerinita unicava*, and *Globorotalia petaliformis*.

Dissolution Effects (entire assemblage):
 0 - Not affected; 1 - Slightly affected; 2 - Damaged;
 3 - Strongly damaged; and 4 - Destroyed.

Abundance (each species):

Abundant (■); Common (●); Rare (○); Very rare (isolated) (▲)

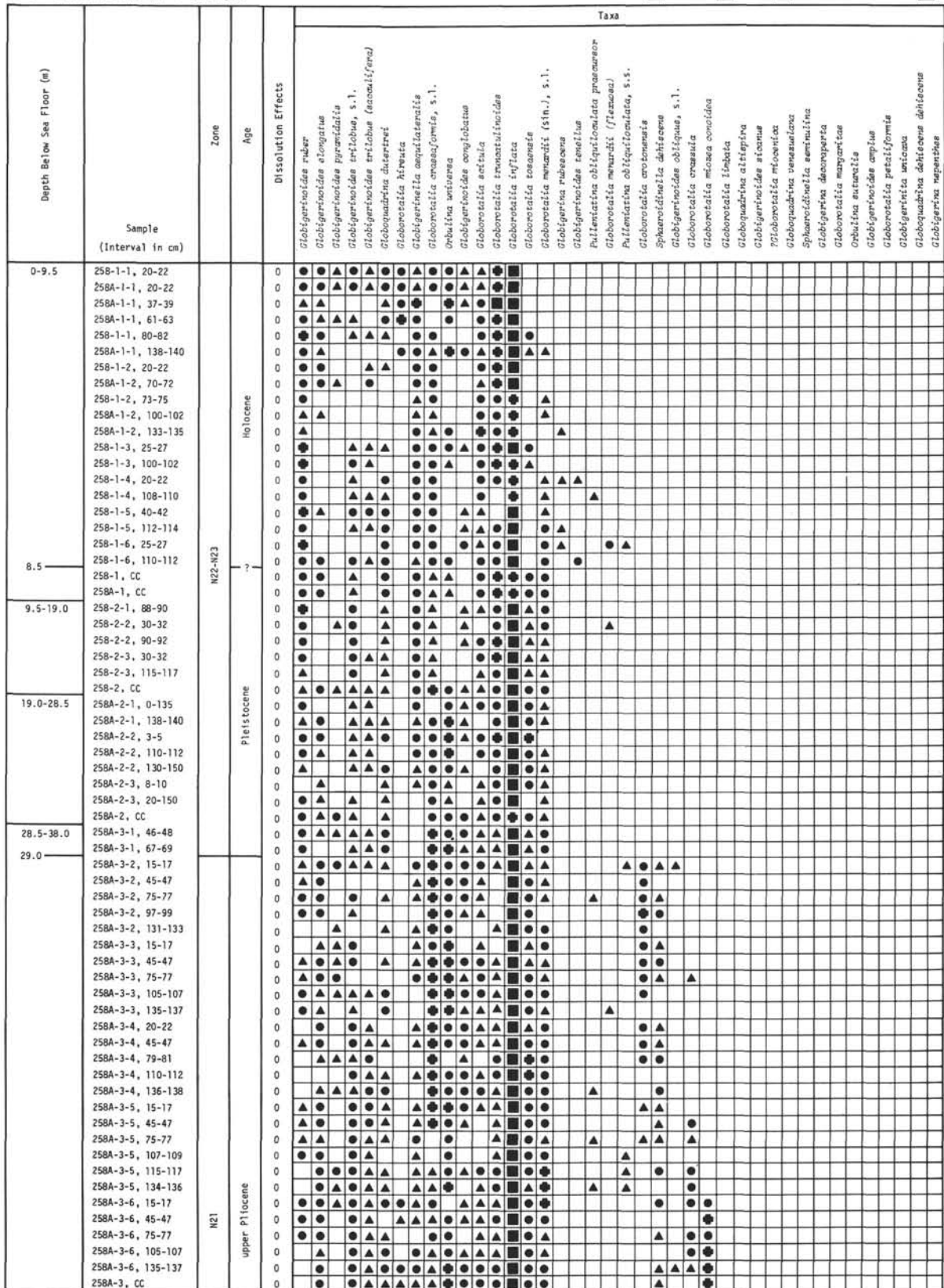


Figure 7. Range chart of selected Planktonic Foraminifera species at Site 258 (Holes 258 and 258A).

It is interesting to mention that, as at Sites 253 and 254, the Miocene assemblages at Site 258 contained a great number of very small unidentifiable planktonic foraminifera.

The upper Miocene sediments were the oldest Neogene deposits encountered at Site 258. At the depth of 114 meters, Cretaceous deposits were found.

Quaternary foraminiferal assemblages of Site 258 are typical of the temperate zone. *Globorotalia inflata*, *s.l.* strongly predominates and *G. menardii*, *s.l.* is recorded sporadically and as isolated individuals.

Site 258 showed a rather enigmatic stratigraphic range for *Globigerinoides sicanius*. For detail see the Systematics Section, below.

CORRELATION OF SITES AND SEDIMENTATION RATES

Sites 250, 251, 254, 255, and 258 were selected for correlation of their stratigraphical columns. These sites are located latitudinally between the parallels 31° and 36°30'S. The Miocene/Pliocene and Pliocene/Quaternary boundaries were correlated; the zones, however, were not correlated. In cases where these boundaries could not be located precisely, they were placed in the middle of the indefinite section and marked with a dashed line (Figure 8). Lithologic character is noted in a very summarized and abbreviated form. For lithological details see the special paper on lithology in this volume.

The resulting correlation chart (Figure 8) shows clearly that the minimum thickness of Quaternary, Pliocene, and Miocene deposits is at Sites 254 and 255. These sites are located on Ninetyeast Ridge and Broken Ridge, respectively, and for this reason they have the shallowest depths. On both sides of these ridges the thickness of the Neogene deposits increases. It is especially great on the western side near the African continent where, at Site 250, sediments are composed chiefly of terrigenous material (detrital clay).

The different thicknesses are the result of different rates of accumulation. Near the continent, accumulation is the most rapid because of terrigenous material brought from the land. Depth is a factor because in deep areas calcareous material is dissolved. Bottom relief also plays a role; it has been established that on submarine rises the sedimentation rate is much lower than in basins. The correlation chart presented is a good example of the influence of all these factors.

For the determination of sedimentation rates, age dates used were taken from Berggren's study (Berggren, 1972). According to Berggren, the Quaternary lasted 1.8 m.y., the Pliocene 3.2 m.y., and the Miocene 17.5 m.y. The consolidation of the sediments was not taken into account in calculating the sedimentation rates. The following values were obtained.

1) For the Quaternary: between 3 m/m.y. (Site 254) and approximately 54 m/m.y. (Site 250).

2) For the Pliocene: between 4 m/m.y. (Site 255) and approximately 31 m/m.y. (Site 250).

3) For the Miocene: between approximately 1.4 m/m.y. (Site 255) and approximately 27 m/m.y. (Site 250).

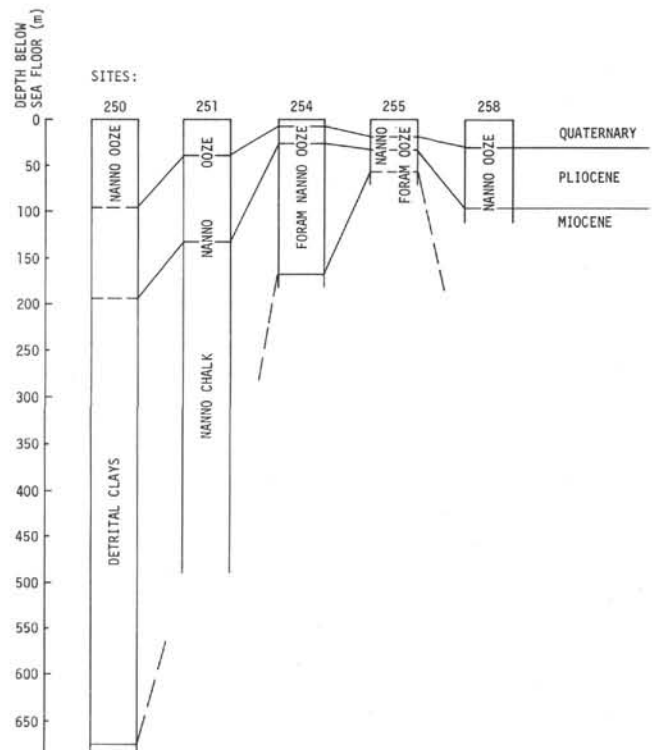


Figure 8. Correlation of the sites.

GENERAL RANGE CHART OF SELECTED SPECIES

Records of the vertical distribution of the 70 selected foraminiferal planktonic species at all the sites were taken into consideration to prepare a general biostratigraphical range chart (Figure 9).

It should be emphasized that this range chart is based only on the data obtained from this study and is not influenced by studies carried out by other investigators. *Globigerinita unicava*, for instance, is well known from Oligocene. Nevertheless, because in the present material its oldest occurrence was in the early Miocene, I put its range beginning at that age. It is quite probable that if I could have studied more Oligocene material, I could have extended its range.

The ranges of the majority of the species were found to be approximately the same as those established by authors who studied other areas. There are some small differences which are not important. The same species does not necessarily appear at the same time in all areas. However, the biostratigraphic ranges of several species appear to be considerably different from ranges known

from the literature. Some of them were found in older layers, but as the lower limit of this study is the Miocene/Oligocene boundary, as might be expected, more often they were found in deposits younger than those recorded by previous authors. Since some of these species are used by micropaleontologists as marker species, I found it of interest to prepare the following table for these species (Table 2).

The differences listed above are substantial and need explanation. The following three explanations can be suggested.

1) Determinations of the ages of the Leg 26 samples were wrong. I do not think that such is the case, because age identification was checked using other foraminiferal assemblages and nannoplankton data.

2) Reworked specimens of the species cited were found in the younger deposits. This explanation should be denied too, not only because of the state of preservation of the specimens under discussion (this reason can be sometimes misleading), but also for the following reasons. If we admit that they are reworked, how can we explain that in many cases specimens of only one presumably reworked species are found in the in situ assemblage, and no specimens of other species, which are much more resistant to dissolution? For instance, at Site 258 many specimens of *Globigerinoides sicanus* were found in the Pliocene material, but none of the other foraminifera which are also considered as typical Miocene markers.

3) The third explanation is that the species mentioned really had higher ranges (at least in the Indian Ocean)

than have yet been accepted. I think that this explanation is the best one, because some of these species have already been found in deposits much younger than those recorded in the literature. Baumann (1972), for instance, found *Globigerina cryptomphala*, *G. tripartita*, and *Globorotalia opima, s.l.* in the early Miocene of Borneo. Soediono (1970) encountered in Spain, in the Espejos formation (which is considered to be early Miocene-middle Miocene in age), *Globigerina tripartita* and *Globorotalia opima, s.l.*

It is certainly possible that taxonomical identifications in this report are wrong. But, as I stated above, maximum attention was given to the correct identification. All the species cited in Table 2 are illustrated in the plates, thus identifications can be roughly checked.

SYSTEMATIC PALEONTOLOGY

This section contains a very brief discussion of the species considered as the most significant and representative of the Neogene deposits of the central part of the Indian Ocean.

Very few species have been excluded from the range charts and still fewer from the discussion.

For the convenience of the readers, all species are arranged in alphabetical order. Neither primary citations nor synonymies are given for the species cited. However, scanning electron photographs of almost all the species discussed are presented, and at the end of this report a faunal reference list is included.

I am aware that several of the species listed probably do not have real zoological value and are junior synonyms of previously established taxa. I am also of the opinion that in some cases the wrong

TABLE 2
The Youngest Recorded Age of Extinction

Species Name	According to Literature	According to This Report
<i>Globigerina angiporoides</i>	early Oligocene (Blow, 1969)	early Miocene
<i>Globigerina cryptomphala</i>	late Eocene (Glaessner, 1937)	lower Miocene
<i>Globigerina tripartita</i>	late Oligocene (Blow, 1969)	lower Miocene
<i>Globigerina yeguaensis</i>	late Oligocene (Postuma, 1971)	early Miocene
<i>Globigerinita unicava</i>	early Miocene (Blow, 1969)	late Miocene
<i>Globigerinoides sicanus</i>	middle Miocene (Postuma, 1971)	middle Pliocene
<i>Globorotalia miozea conoidea</i>	late Miocene (Jenkins, 1967)	late Pliocene
<i>Globorotalia pseudobullodes</i>	Eocene (Plummer, 1926)	Oligocene
<i>Globorotalia opima, s.l.</i>	late Oligocene (Blow, 1969)	middle Miocene

subspecific name was used. I cited, for the same sample for instance, two subspecific names of the same species. However, two planktonic subspecies can be encountered in the same sediment sample only if during their life they occupied quite different depth ranges, and this is not very probable. Not having sufficient material and time for real taxonomic studies, I preferred, in these cases, not to enter into the taxonomical details and leave existing taxa such as they are in common stratigraphic usage.

The present report is not primarily a taxonomic work. Its main aim is the examination of age determinations and biostratigraphy, and where possible, the drawing of paleoclimatological conclusions. Nevertheless, in some cases, which were evident and did not require special detailed taxonomic studies, I have drawn some taxonomic conclusions and even established a new species. In addition, I have used some taxonomic conclusions regarding living species which were the result of previous studies of Recent faunas, but which were sometimes not in agreement with common usage by micropaleontologists.

Where the statement "found at all the sites" was used, it should be understood to mean only those sites which contained preserved fauna. Sites 252, 256, and 257, because of their great depth, were barren.

All hypotypes are deposited in the Foraminiferal Collection of Museo Argentino de Ciencias Naturales "B. Rivadavia" (FMACN) and have corresponding numbers.

Candeina nitida d'Orbigny, 1839
(Plate 1, Figure 4)

This foraminifer is a typical warm-water species. It was found only at the northernmost site (Site 253) and was represented by rather large but never common specimens. At Site 253 it appeared in the upper Miocene and was recorded throughout the section, with some short interruptions, up to the top sample.

Globigerina ampliapertura Bolli, 1957
(Plate 1, Figures 1-3, 5, 6)

According to Bolli (1966) and Blow (1969), this species ranges from the upper Eocene into the Oligocene. It was found only in the Oligocene deposits at Site 253 and was represented by good typical specimens. Rare specimens encountered in the lower Miocene of Site 251 were apparently redeposited.

Globigerina angiporoides Hornibrook, 1965
(Plate 1, Figures 7, 8)

Rare but very typical representatives of this species were found in the Oligocene section at Sites 253 and 254. In the latter site some isolated specimens were recorded from the lower Miocene sediments indicating that perhaps it would be right to extend the stratigraphic range of this species. Specimens found did not look reworked.

Globigerina angulisuturalis Bolli, 1957

Very rare specimens of this species were found in Sample 20, CC of Site 254 (Oligocene).

Globigerina bulloides d'Orbigny, 1826
(Plate 2, Figure 4)

As explained above, *G. bulloides* and several closely related species are not included in the range charts. However, it should be noted that when considering paleoclimatic conditions, the *G. bulloides* group was taken into account as typical representatives of cold-temperate waters.

G. bulloides-group representatives were found rather frequently at Sites 254 and 258. They were less frequent at Site 251 and infrequent at Sites 253 and 250. At the last site the small number of *G. bulloides* is probably explained by the effects of dissolution.

Figure 4, Plate 2 shows a typical representative of *G. bulloides*.

Globigerina calida Parker, 1962
(Plate 1, Figure 9)

G. calida is a foraminifer which connects *G. bulloides* and *Globigerina aequilateralis*. It is more characteristic and more easily distinguishable from *G. bulloides* than *G. falconensis*. In the material studied typical specimens were found very rarely in the upper Pliocene-Quaternary section of Sites 250 and 251.

Globigerina cryptomphala Glaessner, 1937
(Plate 2, Figures 1, 2, 5-10)

This species was found in the Oligocene and lower Miocene deposits at Sites 250, 253, 254, and 255. At Site 251 *G. cryptomphala* was not present, probably because of the southern location of this site. This species evidently preferred the warm waters of low latitudes. Glaessner interpreted this foraminifer as an abnormal form of *Globigerina bulloides* and gave a rather schematic species description. However, he emphasized that it is very abundant in the upper Eocene deposits of the North Caucasus and does not appear later. The most characteristic feature of this species, according to Glaessner, is a small, poorly developed last chamber which partially covers the umbilical aperture. The final whorl has four normal chambers.

Among several hundred specimens found, many looked exactly like the holotype figured by Glaessner. However, many specimens were not quite identical. The main difference was in the shape and location of the final, poorly developed chamber. As a matter of fact it is not a real chamber but rather a patch or valve whose main purpose is most probably to protect the entrance of the aperture.

Figures 1, 2, 5, 7, and 9 on Plate 2 show typical representatives of *G. cryptomphala*. Figures 6, 8, and 10 on the same plate show different kinds of aberrations in the form and location of the protecting valve. Some specimens were found without any protecting valve.

The range of *G. cryptomphala* found in the Leg 26 material is considerably younger than that given by Glaessner. For details see the range charts in Figures 2-7.

Globigerina decoraperta Takayanagi and Saito, 1962
(Plate 1, Figure 10)

G. decoraperta was represented at all the sites by rather typical specimens. It ranged from the lower Miocene into the upper Pliocene. Unfortunately, this species grades in its upper range into *G. rubescens* and in its lower range into *G. woodi*. In addition, it is very closely related to *G. druryi* and to a certain degree to *G. apertura*. This circumstance creates difficulties in identifying it correctly and thus decreases the value of *G. decoraperta* as a stratigraphic indicator.

Globigerina euapertura Jenkins, 1960
(Plate 1, Figures 11, 12)

This foraminifer occurred at three sites, principally the northern ones, indicating it is a warm-water species. It possesses a tightly coiled test and a low-arched, sometimes not very regular, shaped aperture. It ranges stratigraphically from the Oligocene through the lower Miocene.

Globigerina falconensis Blow, 1959
(Plate 2, Figure 3)

This foraminifer undoubtedly is very closely related to *G. bulloides*, representing its subtropical "branch." It was not separated from the *G. bulloides* group.

Globigerina juvenilis Bolli, 1957
(Plate 1, Figure 13)

This species was found to be sporadic and rare in the Oligocene and lower Miocene section at Site 253.

Globigerina linaperta Finlay, 1939
(Plate 1, Figure 14)

According to Finlay this is a middle Eocene species. Blow (1969) considered it as late Eocene. Isolated but rather typical specimens of this species were found in Sample 19, CC at Site 250. They were well preserved and did not look reworked; however, the whole of Core 19 at Site 250 is lower Miocene (*Globigerinoides trilobus*, *Globorotalia kugleri*) in age. It is not clear whether the stratigraphic range of *G. linaperta* should be changed, or the specimens found are not in situ but are reworked.

Globigerina nepenthes Todd, 1957
(Plate 1, Figures 15, 16)

This very typical and easily identifiable species was found at almost all the sites studied, sometimes in great numbers. It ranges upward,

according to Blow (1969), Kaneps (1973), and Parker (1973) through the lower Pliocene. Poag and Akers (1967) recorded it from the middle Pliocene, accompanied by *Globorotalia truncatulinoides*, *G. inflata*, and *Sphaeroidinella dehiscens*. At Site 255 *G. nepenthes* was found with the same species; however, I am inclined to consider the sediments (because of the occurrence of *G. truncatulinoides*) as upper Pliocene. This is the highest appearance of the species discussed. In other sites *G. nepenthes* ranges only through the lower Pliocene.

***Globigerina pachyderma* (Ehrenberg, 1873)**
(Plate 2, Figures 11, 12)

Only the dextral form of this species was found and only at the southernmost site (Site 251). This species, especially its sinistral specimens, is a typical cold-water indicator. Dextral-coiled tests characterize Subantarctic waters and can be found also in the temperate zone where mixing of Subantarctic waters takes place. *G. pachyderma* ranges from Pliocene to Recent. At Site 251 it was recorded from the section which was determined as lower and/or middle Pliocene in age.

Globigerina "praerubra"
(Plate 2, Figures 13-16)

This species may be new; I have not been able as yet to find any known species to which it could be ascribed. However, I prefer for the time being not to establish a new taxon on the basis of the available material. Therefore, temporarily, the species name is in quotation marks. It is a temporary name given only for use in this report.

At first glance *G. "praerubra"* looks rather like *Globigerinoides ruber*. It is low trochospiral and its umbilical side has the same pattern of three chambers and a rounded aperture in the final chamber which is located opposite the penultimate and antepenultimate chambers. However, it is different from *G. ruber* in several ways. First of all no supplementary apertures are present; thus the species discussed belongs not to the genus *Globigerinoides* but *Globigerina*. Also, in many specimens the aperture shows a clear tendency to be asymmetrical. In some cases almost four chambers are in the final whorl and thus the aperture is situated opposite the two-and-a-half or even three preceding chambers. These specimens are similar to those of the *Globigerina decoraperta* group.

G. "praerubra" is perhaps an ancestor of *Globigerinoides ruber*. The latter species ranges from middle Miocene to Recent. The same range of *Globigerinoides ruber* was observed in the present material. *G. "praerubra"* was recorded in the three northern sites (Sites 253-255) in the lower Miocene, with the exception of Site 254 where it was also found in the middle Miocene. Blow (1969) stated that the developmental trend of *Globigerinoides trilobus* is from a test with only one aperture to those with several. It is quite possible that the same trend took place in *Globigerinoides ruber*.

***Globigerina quinqueloba* Natland, 1958**
(Plate 3, Figures 1, 2)

Typical specimens of this species were found only in the Quaternary and upper Miocene deposits of Site 250. According to Parker (1973), *G. quinqueloba* ranges at least from the upper Miocene. It is a cold- and cool-water species; therefore, it is unlikely to be common in the material under study.

***Globigerina rubescens* Hofker, 1956**
(Plate 4, Figure 2)

I found this species only in Quaternary deposits at Site 258. It is interesting to note that even in the lowermost sample which contained this species (depth 8.5 m below bottom surface) several tests were pink. Parker (1973) gives this species a range from the middle Pliocene and states that pink specimens are marker specimens for the Holocene.

***Globigerina tripartita* Koch, 1926**
(Plate 3, Figures 5-10)

There is some confusion with respect to the interpretation of this species, as it has much similarity with *Globigerina rohri* and several other related species living more or less during the same epoch.

In this study I considered as *G. tripartita* those specimens which had three chambers in the final whorl, did not possess apertural teeth, and whose spiral side was convex. A peculiar feature, which many specimens in the present material had, was a small poorly developed bulla-like chamber, which looked similar to the protecting valve described in *G. cryptomphala*, and partially covered the umbilical aperture. This formation was previously observed by Soediono (1970) who studied foraminifera of the Espejo formation (early Miocene to middle Miocene) in Spain and found a very high number of specimens of *G. tripartita* with the same anomalous final chamber.

Sometimes it was rather difficult to separate *G. tripartita* from *Globoquadrina dehiscens praedeheiscens*. However, in their typical representatives they do differ, as *G. dehiscens praedeheiscens* has apertural teeth, its dorsal side is less convex (almost flat), and its peripheral outline is somewhat angular.

According to Blow (1969), *G. tripartita* ranges from upper Eocene to upper Oligocene. I found this species in the two northern sites (Sites 253 and 254), and in both cases it ranged from Oligocene to lower Miocene. This was discussed previously.

***Globigerina yeguaensis* Weinzierl and Applin, 1929**
(Plate 3, Figures 11, 12)

Rather typical representatives of this species were found at the three northern sites (Sites 253-255). They ranged from Oligocene to lower Miocene inclusively.

***Globigerinella aequilateralis* (Brady, 1884)**
(Plate 3, Figure 3)

Many typical specimens were found at all the sites except the two northern ones (Sites 253, 254). This indicates that the species prefers warm-temperate waters but not warm water. The oldest sediments where *G. aequilateralis* was encountered are upper Miocene in age.

***Globigerinita cf. africana* Blow and Banner, 1962**
(Plate 3, Figures 13-16)

The most characteristic features of this species, according to Blow and Banner, are its very large bulla which covers the umbilicus and three accessory apertures (at least) which are easily distinguishable. My specimens have the same type of bulla and the other morphological characteristics are also very similar to those of *G. africana* with the exception of the supplementary apertures. These are very badly developed in specimens from the Leg 26 material; sometimes it was practically impossible to find them. This circumstance forced me to use the designation "cf."

As for the range of *G. africana*, it is, according to Blow (1969), from P14 to P16 Zones (upper Eocene). *G. cf. africana* was found at Sites 253-255 in Oligocene and lower Miocene deposits.

***Globigerinita dissimilis ciproensis* Blow and Banner, 1962**
(Plate 4, Figures 1, 5)

This subspecies was separated from *G. dissimilis dissimilis* (nominat subspecies) by Blow and Banner chiefly on the basis of the difference in their bulla. Whereas the bulla in *G. dissimilis dissimilis* is attached to the final and antepenultimate chambers only, and thus produces two accessory apertures, in *G. dissimilis ciproensis* a bulla produces three or even four accessory apertures.

This subspecies was found as isolated specimens in the Oligocene and lower Miocene sections.

***Globigerinita dissimilis dissimilis* (Cushman and Bermúdez, 1937)**
(Plate 4, Figure 6)

This subspecies is somewhat more frequent than the preceding one, but its range at the sites studied is similar to that of *G. dissimilis ciproensis*.

***Globigerinita glutinata* (Egger, 1893)**
(Plate 3, Figure 4)

Rare specimens were found at Site 250 where their occurrence was sporadic from the upper Miocene to the Quaternary inclusively.

Globigerinita unicava (Bolli, Loeblich, and Tappan, 1957)
(Plate 4, Figures 7-9)

The most distinctive characteristic of this species is its bulla which is subquadrate and is attached at three sides leaving an arched infralaminar accessory opening on the fourth side. As in the other species with a formation partially covering the primary aperture, the bulla of *G. unicava* is rather changeable in shape and, to some degree, position.

Although, according to Blow (1969), this foraminifer ranges from Oligocene to lower Miocene, it was found at Site 254 in the middle Miocene and at Sites 253 and 258 even in the upper Miocene.

Globigerinoides amplus Perconig, 1968
(Plate 4, Figures 10-15)

This taxon was established by Perconig as a subspecies of *Globigerinoides obliquus* Bolli. However, specimens found in the present study (Sites 253 and 258) were so typical and easily distinguishable from *G. obliquus* that I preferred to raise this taxon to the specific rank. It should be mentioned that the specimens had much similarity with *G. emeisi*. Nevertheless, the presence of many supplementary apertures (*G. emeisi* has only one) and in many cases a very high trochospiral test (*G. emeisi* is low trochospiral) in these specimens indicates that they are much closer to *G. amplus*.

G. amplus was recorded in the present material in the upper and also in middle Miocene. This extends downward the upper Miocene—lower Pliocene range of this foraminifer given by Perconig.

Globigerinoides bulloideus Crescenti, 1966
(Plate 4, Figures 3, 4)

This species was recorded from middle Miocene. Parker (1973) found it in the upper Miocene. In the present material *G. bulloideus* was found at Sites 253 and 254 in the middle Miocene, but at Sites 251 and 255 it ranged through the upper Miocene. Numerically it was never very frequent; in many samples only isolated specimens were encountered.

G. bulloideus is rather close to *G. bollii*; the latter differs from the former principally in being more compressed.

Globigerinoides conglobatus (Brady, 1884)
(Plate 4, Figures 16)

This species occurs in abundance only in upper Pliocene and Quaternary sediments at Site 253. Its first appearance is in the upper Miocene.

Globigerinoides elongatus (d'Orbigny, 1826)
(Plate 5, Figure 3)

Typical but scattered representatives of this species were found in lower Pliocene to Recent sediments.

Globigerinoides fistulosus (Schubert, 1911)
(Plate 5, Figure 16)

For convenience, following Parker's (1973) point of view, I interpret this foraminifer for this report as a species, although probably it would be biologically more correct to consider it as a form of *Globigerinoides trilobus* or to relate it to *G. trilobus*, f. *sacculifera*. It is an excellent marker species for middle and late Pliocene.

Globigerinoides mitra Todd, 1957
(Plate 5, Figures 1, 2)

This species is evidently a warm-water one as it was found only at the northernmost site (Site 253) where its vertical range was from lower Miocene to middle Miocene inclusive. The specimens found differ from the description and figures given by Todd in that supplementary apertures are somewhat larger than those in the primary types.

Globigerinoides obliquus Bolli, 1957, s.l.
(Plate 5, Figures 4-6)

I share the point of view of Parker (1967) who lumped together *G. obliquus obliquus* and *G. obliquus extremus*. It was found in several sites from the lower and middle Miocene through the upper Pliocene.

Globigerinoides pyramidalis (van den Broeck, 1876)
(Plate 5, Figure 7)

The oldest records of this species are from the lower Pliocene (Site 258). I originally related this foraminifer to *Globigerinoides ruber* (Boltovskoy, 1969). Now I am inclined to consider it as much more closely related to *G. elongatus*. It is possible that it represents only a forma of the latter. Until a detailed study of this problem is carried out, I prefer to interpret it tentatively as a species.

Globigerinoides ruber (d'Orbigny, 1839)

This species is fairly frequent at all the sites studied. The lowest records are from the middle Miocene.

Globigerinoides sicanus de Stefani, 1952
(Plate 5, Figures 8-12)

According to Blow (1969), this species ranges from the lower Miocene to the base of the middle Miocene. According to Reiss and Gvirtzman (1966), it becomes extinct at the base of the upper Miocene.

At Sites 253-255 *G. sicanus* ranged up to the middle Miocene. However, at Site 258, typically developed specimens of this species were found through the middle Pliocene. The specimens found did not look reworked and as no other reworked species were found in these sediments, it is difficult to believe that *G. sicanus* found in the Pliocene section of Site 258 is resedimented. Thus, the upper limit of this species appears to be much higher than has been observed in other areas.

The following interesting morphological feature was observed in many specimens of *G. sicanus* recorded from the material of the present study. A very small, rounded, final chamber with its axis perpendicular to the main axis of the test was situated more or less in the middle of many specimens (Plate 5, Figures 11, 12). This final chamber partially covers the aperture. Probably it can be compared in function to the similar feature (abnormal last chamber) of *Globigerina cryptomphala*, *G. tripartita*, and several *Globigerinita* species described above.

Globigerinoides tenellus Parker, 1958
(Plate 6, Figure 4)

Parker (1967) states that this is a typical Quaternary species which does not appear until the Pleistocene. Isolated specimens were found in the Quaternary at Sites 253 and 258.

Globigerinoides trilobus (Reuss, 1850), s.l.
(Plate 5, Figures 13-15)

No separation was made between *G. trilobus* in Reuss interpretation and the foraminifer described in 1939 by Le Roy under the name of *Globigerinoides sacculifer* var. *immatura*. They were lumped together and considered as *G. trilobus*, s.l.

This is one of the most ubiquitous species in the Neogene deposits of the Indian Ocean. It was found at all the sites and in almost all the samples. Its lowest record is lower Miocene at Sites 250 and 253. However, specimens in many samples were small sized and not well developed. This is probably a result of too cool temperature during the Neogene in this part of the Indian Ocean for this warm-water dweller.

Globigerinoides trilobus (Reuss), forma sacculifera (Brady, 1884)
(Plate 6, Figures 1, 2)

The reasons why this foraminifer is interpreted as a *forma* of *G. trilobus*, and not as an independent species (as it is considered by the majority of authors) have been discussed in a previous paper

(Boltovskoy, 1971). This *forma* is less numerous than typical representatives of *G. trilobus*, and its first appearance is recorded in the present material somewhat later than the appearance of *G. trilobus*, *forma typica*, namely, in the middle rather than the lower Miocene.

Globigerinopsis aguasayensis Bolli, 1962

(Plate 6, Figures 5-14)

Blow (1969) gives a very narrow range for this species, namely Zones N10 N12 only, which is the lower part of the middle Miocene.

Specimens referable to this species were found not only in the middle Miocene but also in the upper Miocene and in the uppermost part (Zone N8) of the lower Miocene.

Globoquadrina altispira (Cushman and Jarvis, 1936)

(Plate 6, Figures 15, 16; Plate 7, Figure 1)

G. altispira has a high-spired test and usually five (less frequently four) chambers in the last coil. A relatively small number of specimens of this species was found in this study. Its stratigraphic range was throughout the Miocene and it became extinct in the middle Pliocene.

Globoquadrina dehisces dehisces (Chapman, Parr, and Collins, 1934)

(Plate 7, Figures 2-4)

Undoubtedly this species has been described several times by different authors under different names. For junior synonymy see Parker (1967). The characteristic features of *G. dehisces* by which it is distinguished from the closely related species, *G. venezuelana*, are the downward curving sides of the apertural face, a flat spiral side, and a somewhat less-rounded cross-section outline.

Globoquadrina dehisces praedeisces Blow and Banner, 1962

(Plate 7, Figures 5-9)

This species is a marker of the upper Oligocene and lower Miocene. According to Blow (1969), it developed from *Globigerina tripartita* and was ancestral to *Globoquadrina dehisces dehisces*. Thus, the three forms mentioned should have much in common. *G. dehisces dehisces* and *G. dehisces praedeisces* are especially similar as they both belong to the same species. The latter differs from the former chiefly in having: (a) only three chambers in the final whorl, (b) a more triangular aperture, (c) a lower apertural face, and (d) a more rounded shape. There are several morphological differences which distinguish *G. dehisces praedeisces* from *Globigerina tripartita*, but the most important is that the former has apertural teeth.

It is interesting to note that among specimens of *G. dehisces praedeisces* there are many tests with an abnormal, poorly developed last chamber partially covering the aperture (Plate 7, Figures 7, 8). As mentioned above, a similar formation was observed in many foraminifera from the lower Miocene of the sites studied.

Globoquadrina dutertrei (d'Orbigny, 1839)

(Plate 7, Figure 10)

According to Parker (1967), *G. dutertrei* developed from *G. humerosa* in the uppermost Pliocene. Data obtained from the present study enlarge its range downward through middle Pliocene, although isolated specimens of *G. dutertrei* were found in middle Pliocene sediments at only one site (Site 258). At Sites 250 and 255 *G. dutertrei* is recorded from the upper Pliocene and Quaternary, respectively.

Globoquadrina hexagona (Natland, 1938)

(Plate 6, Figure 3)

This is a rather typical Pliocene-Quaternary species. Isolated but characteristic specimens were recorded from the Pliocene sediments of Site 251.

Globoquadrina humerosa (Takayanagi and Saito, 1962)

(Plate 7, Figure 15)

A very few specimens of this species were encountered in the upper Pliocene at Site 251.

Globoquadrina venezuelana (Hedberg, 1937)

(Plate 7, Figures 11-14)

According to Blow (1969), *G. venezuelana* and *G. dehisces* both became extinct in the lower Pliocene. According to Parker (1967) and Postuma (1971), the latter species becomes extinct somewhat earlier than the former, namely *G. dehisces* at the Miocene/Pliocene boundary or in the upper Miocene and *G. venezuelana* in the upper or middle Pliocene.

In the present study in the majority of the cases the same phenomenon could be observed; *G. dehisces* had a shorter range than *G. venezuelana*. However, the youngest sediments in which both were found were middle Pliocene.

Globorotalia acostaensis Blow, 1959

(Plate 8, Figures 1-4)

This commonly used marker species is extremely scarce in the Indian Ocean and occurs very sporadically only at Site 251, so that no consistent range could be determined. A few specimens were more or less typical; many were tentatively considered as *G. acostaensis*.

Globorotalia crassaformis (Galloway and Wissler, 1927), s.l.

(Plate 8, Figures 5-11)

This is one of the most common upper Neogene species of the Indian Ocean. It was found at all the sites, sometimes very abundantly. Specimens referable to *G. crassaformis* are morphologically rather variable. It is very probable that a thorough and detailed study will prove that not one but several species make up the group which is called *G. crassaformis* in this report. Therefore, I prefer to use the name *G. crassaformis*, s.l.

There are some differences of opinion with respect to the range of *G. crassaformis*. Kennett (1966) preferred to correlate the first appearance of this species with the beginning of Pliocene. Parker (1967) stated that the lowest occurrence of *G. crassaformis* is found near the base of middle Pliocene. According to Blow (1969), its first occurrence is in the upper Miocene. In the material of the present study this species was first recorded at all the sites in the upper Miocene. At Sites 251 and 255 the same samples contained the lowermost appearance of both *G. crassaformis* and *G. inflata*. At Sites 250, 253, 254, and 258 the former species appears in the upper Miocene, but somewhat earlier than *G. inflata*.

Globorotalia crassula Cushman and Stewart, 1930

(Plate 8, Figures 12-16)

There is no unanimity in the interpretation of this species. In the present report I am following the viewpoint of Kaneps (1973) who wrote that *G. crassula*, in his interpretation, is very much like *G. crassaformis* but has a flattened test. He adds that "the test may be biconvex, concavo-convex or plano-convex and it may be unkeeled, partially keeled, or carinate" (Kaneps, 1973, p.737). This is also true with respect to my specimens, although the great majority of them can be described as biconvex with a spiral side less convex than the umbilical side. There are usually 4-4.5 chambers in the final whorl; however, 5 chambers can occur too. Poag (1972), and Jenkins and Orr (1972) presented figures of *G. crassula* which look like those found in the present study. According to the latter authors, the stratigraphic range of *G. crassula* in the eastern equatorial Pacific is upper Miocene-Recent.

G. crassula was found in the upper Miocene-upper Pliocene section of Site 258.

Globorotalia crotonensis Conato and Follador, 1967

(Plate 10, Figures 1-7)

This species was described from the middle Pliocene of Italy. Later it was found in the Pliocene of the Southwestern Atlantic (Boltovskoy, 1973) and in the middle Pliocene-Recent in the Tropical Atlantic (Parker, 1973).

In the present material, *G. crotonensis* has much similarity with *G. miozea conoidea*. However, *G. miozea conoidea* usually has a very high-vaulted umbilical side and a less, but somewhat convex, dorsal side, and its ultimate and penultimate chambers exhibit a peripheral keel.

G. crotonensis is not as convex, its periphery is rounded, and often it has a somewhat open umbilicus. In addition, these species occupy different stratigraphic positions. *G. crotonensis* is a good middle and upper Pliocene marker, and only isolated specimens of this species were found in the Quaternary section at Site 250. *G. miozea conoidea* is a typical Miocene species, although it ranges through Pliocene too. The species can sometimes be found together in Pliocene sediments. *G. crotonensis* may have developed from *G. miozea conoidea*.

***Globorotalia hirsuta* (d'Orbigny, 1839)**

A few relatively rare specimens were recorded from Pliocene-Quaternary sediments at Sites 255 and 258.

***Globorotalia* cf. *humilis* (Brady, 1884)**

(Plate 7, Figure 16)

This foraminifer was tentatively ascribed to *G. humilis* because in some aspects it looks like that species; however, it differs considerably in having fewer chambers, very poorly defined sutures (often invisible), a smaller size, and a more elongated shape. It is a rather enigmatic foraminifer. Even after studying several thousand Recent plankton samples, I have found this species in Recent planktonic assemblages very seldom. However, I found it abundantly in the Quaternary sediments of the southwestern Atlantic (Boltovskoy, 1973) and in the upper Miocene-Quaternary deposits at Site 250. It is interesting to note that, concerning *G. humilis*, Ruddiman et al. (1970) also emphasized that this species was found in the North Atlantic cores but was not found in plankton tows.

***Globorotalia inflata* (d'Orbigny, 1839)**

(Plate 9, Figures 1-8)

This is one of the most common species encountered in the material from Leg 26.

As stated previously, *G. inflata* is considered by many researchers as the best marker for the beginning of the Pliocene. It was used in this way in the present work. However, it should be emphasized that it is not the first appearance of *G. inflata* that signifies the lowermost Pliocene sediments, but the level at which this species becomes abundant or at least common. Naturally, this criterion can be used only in the temperate zone.

At Sites 250, 251, 254, and 258 *G. inflata* was found in the uppermost Miocene deposits (Zones N16-N18), but as very rare isolated specimens. At the same sites even the lowermost Pliocene samples possessed abundant populations of *G. inflata*.

It is also of interest to mention that although it is not difficult to separate *G. inflata* from *G. crassaformis* in Quaternary deposits, such is not the case in earlier deposits. In upper Pliocene deposits several kinds of transitional forms may be encountered and this makes the separation of these two species difficult. Among the population of *G. inflata* the number of specimens with four chambers in the final whorl, a flat dorsal side, an angular periphery, and less-vaulted ventral side increases. Simultaneously, *Globorotalia crassaformis* loses its lobulate peripheral outline and the truncate convexity of its umbilical side. As a result many specimens are found whose assignment to one or another species is extremely difficult. This situation grows worse downwards and in the lower Pliocene sediments the number of transitional forms becomes greater than the number of those whose identification is more or less straightforward.

The transformation of *G. inflata* and *G. crassaformis* described above is especially well illustrated at Site 254.

In the Miocene deposits *G. inflata* exhibits a gradational series with *G. miozea conoidea*. This phenomenon was especially well observed at Site 251. Site 253 yields an interesting picture of a gradational decrease upwards in the number of specimens of *G. miozea conoidea* and a corresponding increase in the number of *G. inflata* and *G. crassaformis* specimens.

Undoubtedly *G. inflata* and *G. crassaformis* are closely related species, and it is highly probable that McInnes (1965) was right when he stated that *G. inflata* evolved from *G. miozea* during the Miocene in the South Pacific and migrated to the Northern Hemisphere in early Pliocene time. Probably, it is still better to consider *G. miozea* as an ancestor not only of *G. inflata*, but also of *G. crassaformis*.

***Globorotalia kugleri* Bolli, 1957**

(Plate 9, Figures 9, 10)

This is a good marker of short stratigraphic range. According to Blow (1969), it characterizes Zone N3 (the uppermost Oligocene) and Zone N4 (the lowermost Miocene).

Rather typical, but rare representatives of this species were found in the lower Miocene only at Site 253.

***Globorotalia limbata* (Fornasini, 1902)**

(Plate 10, Figures 8-16; Plate 11, Figure 1)

In the interpretation of this species I accepted Parker's (1973) point of view that *G. limbata* is very closely related to *G. multicamerata* and that they can be distinguished by means of the following criterion: if a specimen has eight or more chambers in the final whorl, it should be considered as *G. multicamerata*; if less, *G. limbata*. Parker adds that "the present concept is a utilitarian one which may not be tenable from the point of view of a natural classification." However, this is the best way to handle the situation until the whole problem of the taxonomic position of both species is studied in detail.

G. limbata found in the Leg 26 material is characterized by its rather circular outline, by its chambers which increase somewhat (not very rapidly) in size as they are added, and by its deep open umbilicus. The sutures of this species on the dorsal side are usually limbate.

G. limbata is definitely dextral in the Pliocene. In the upper Miocene it abruptly changes its coiling direction to sinistral and goes back and forth from sinistral to dextral several times.

As an example of the changes coiling direction of *G. limbata*, the following observations can be described. At Site 253 the first appearance of this species was recorded in the lowermost sample of the upper Miocene; sinistral specimens were dominant at that time. The coiling direction subsequently changed abruptly four times; thus dextral coiling dominated twice, and sinistral coiling was predominant twice. It should be emphasized that in all cases the predominance was very strong, about 95% to 5% or more. Each period of dominance was observed to persist vertically over several meters (7-10 m) of sections. With the beginning of the Pliocene, practically all the specimens became dextral and this coiling direction, without any change, lasted until the extinction of the species, which took place within the upper Pliocene.

G. limbata was found at three sites, 251, 253, and 258. This indicates that it did not have any strong latitudinal preference. At all of the sites its stratigraphic range was from upper Miocene through upper Pliocene.

***Globorotalia* aff. *limbata* (Fornasini, 1902)**

(Plate 11, Figures 2-4)

This species was found in the middle Miocene sediments at Sites 254 and 255. It differs from *G. limbata* in having fewer chambers in the final whorl (only 5 or 6) and usually a more convex spiral side. Its outline is more rounded as it does not exhibit a lobing of the final part of the last coil. It can be supposed that *G. aff. limbata* is an ancestor of *G. limbata*.

***Globorotalia margaritae* Bolli and Bermúdez, 1965**

(Plate 9, Figures 13-16)

Thanks to the very typical last chamber, which looks from the umbilical side like a triangular "piece of pie," *G. margaritae* is an easily identifiable species. It has a relatively narrow keel and a rather convexly rounded spiral side.

At three sites *G. margaritae* was found in middle Miocene sediments. This record extends the stratigraphic range of this species considered by the majority of researchers (Blow, 1969; Postuma, 1971; Parker, 1973) as an indicator of deposits not older than upper Miocene.

***Globorotalia menardii* (d'Orbigny, 1839) (sin), s.l.**

(Plate 9, Figure 11)

For this report I lumped under the name *G. menardii*, s.l. specimens which can be considered as typical *G. menardii* and those which are

interpreted by different authors as *G. cultrata*, *G. tumida*, and *G. unguolata*. This does not mean that I really consider them as one species. I do not wish to discuss here the rather complicated relationships existing among these species. Undoubtedly they are closely related and I lumped them together for convenience. Since the area under study is located mainly in the temperate zone, the majority of the cores contained only very rare isolated specimens of *G. menardii*, *s.l.* Citing them separately would give poor and unreliable data, especially if we take into account that in very many cases it was really very difficult to separate the species mentioned from numerous transitional forms.

**Globorotalia menardii (d'Orbigny 1839),
forma flexuosa (Koch, 1923)**
(Plate 9, Figure 12)

This foraminifer is treated separately and was not included in *G. menardii*, *s.l.* for the following reasons: (a) it is a very easily identifiable taxon, (b) it has been used by several authors as a marker species.

It was first recorded and described by Koch (1923) as a subspecies of *G. tumida*. The tendency to create a *forma flexuosa* in *G. tumida* was mentioned also by Parker (1967). However, *forma flexuosa* is widely applied also to *G. menardii*. Ericson et al. (1964), for instance, interpreted this foraminifer as a subspecies of *G. menardii* and stated that it became extinct during the main Wisconsin epoch. Boltovskoy (1968), Bé and McIntyre (1970), and Adegoké et al. (1971) found it in the Recent plankton of the Atlantic and Indian oceans. The facts that (a) *forma flexuosa* can be found among *G. menardii* and *G. tumida*, (b) its records are known interruptedly from within the Miocene to the Recent, and (c) that the greatest percentages of *forma flexuosa* were observed in the populations of *G. menardii* characterized by many aberrant forms testify to the supposition that *forma flexuosa* is a result of some environmental influence. Lidz (1966) states that aberrant specimens of *G. menardii* can be formed at abnormally high temperatures. Bé and McIntyre (1970) do not accept this explanation as sufficient, and the data from the present study do not confirm the supposition of Lidz either.

In the material studied *G. menardii* (*sin.*), *s.l.* ranges from upper Miocene to Recent.

?Globorotalia miocenica Palmer, 1945
(Plate 12, Figures 1-3)

This is a rather common species in the Neogene sediments of the Indian Ocean. It ranges from middle Miocene through middle Pliocene. It was tentatively ascribed to *G. miocenica*: however, being not sure of this identification, a question mark has been left. Specimens are rather large and planoconvex. They have a flat dorsal side, a characteristic which indicates a close relationship with typical specimens of *G. miocenica*. However, other characteristics, such as, for example, a smaller number of chambers in final whorl, a highly vaulted last chamber on the ventral side, and some others, distinguish this species from *G. miocenica*.

Globorotalia miozea conoidea Walters, 1965
(Plate 11, Figures 5-18)

G. miozea conoidea was one of the most common species in the Miocene and lower Pliocene sediments, especially at Sites 254 and 258. It was also recorded in sediments as high as middle Pliocene at Sites 251 and 254, and in the upper Pliocene at Site 258. For remarks on its morphological appearance, see the discussion of *G. crotonensis*.

G. miozea conoidea, according to researchers from New Zealand (Walters, 1965; McInnes, 1965; Hornibrook, 1967; Jenkins, 1971), is a typical Miocene marker. Olsson (1971) gives it a range from Miocene to Pliocene. The records of the present study extend upward considerably the stratigraphic range of *G. miozea conoidea*.

Globorotalia opima Bolli, 1957, s.l.
(Plate 12, Figures 4-8)

It was difficult to separate *G. opima opima* from *G. opima nana*. Both foraminifers have all kinds of transitional forms. They were therefore combined under *G. opima*, *s.l.*

Specimens ascribed to this species were recorded at all sites (nowhere very frequently) mostly in lower Miocene sediments. At Sites 251 and 255 it was also recorded in middle Miocene sediments and at Sites 253 and 254 it was found in Oligocene deposits.

These data contradict the widely accepted interpretation of *G. opima* as a typical Oligocene species. The specimens found in Miocene deposits did not have the appearance of being reworked. They were found rather continuously in the section at all the sites with the same assemblage. This proves that they were in situ. Thus, it seems that the upper limit of *G. opima*, *s.l.* should be considerably raised up to the middle Miocene at least, for the Indian Ocean.

Finds of *G. opima*, *s.l.* in Miocene sediments are not new. Soediono (1970) recorded *G. opima nana* from the Miocene deposits in Spain and Baumann (1972) recorded specimens in Borneo.

Globorotalia peripheroacuta Blow and Banner, 1959
(Plate 12, Figures 9-11)

This species was found in the middle Miocene sediments at Sites 251, 253-255, in very limited numbers.

Globorotalia peripheroronda Blow and Banner
(Plate 12, Figures 13, 14)

G. peripheroronda was found at the same sites as the foregoing species and also at Site 250. Its range is somewhat wider, and it is somewhat more numerous than *G. peripheroacuta*. Both species are excellent lower and middle Miocene markers because they are easily identifiable and have a relatively short stratigraphic range.

Globorotalia petaliformis n. sp.
(Plate 14, Figures 1-16)

Description: Test free, medium in size compared with other species of *Globorotalia*, trochospiral, sinistrally coiled, biconvex, the umbilical side considerably more convex than the spiral side (rare specimens are equally biconvex). There are also planoconvex tests in which the spiral side is flat; equatorial periphery almost circular; peripheral outline strongly lobate. Axial periphery angled, sometimes rather round. Chambers angular, rhomboid, about 13-16 in the whole test arranged in 2.5-3 coils. Early whorl sometimes raised above the subsequent ones. Five chambers compose the final whorl; often they are offset from each other creating an imbricate appearance on the spiral side. Sutures variable from simple to strongly limbate, sometimes raised; curved on the spiral side, curved or radial, and depressed on the umbilical side. Umbilicus can be closed or narrow and deep. Aperture arched, interiomarginal, extraumbilical-umbilical, bordered by a rim. Wall calcareous, moderately thick, fairly smooth, rather coarsely perforate, sometimes pustulate on the umbilical side near the aperture. The largest diameter 0.25-0.45 mm. The height of the test 0.16-0.30 mm.

Occurrence: *Globorotalia petaliformis* n. sp. occurred abundantly in the middle Miocene deposits of Site 254 and as rare or isolated specimens in middle Miocene of Sites 253 and 255, and in upper Miocene of Sites 253-255.

Diagnosis and comparison: The most striking features of *Globorotalia petaliformis* n. sp. are the very lobate peripheral outline and the often step-like sutures on the spiral side which give an imbricate appearance. Because of these characteristics, the test of this species resembles a flower; hence the name *petaliformis* (petalled).

It is a very variable species, especially concerning its biconvexity, the character of the sutures, the kind of angularity of the peripheral margin, and its imbricate appearance. However, it is a very peculiar and easily identifiable foraminifer which is not closely related to any *Globorotalia* as yet described. Some tests of *Globorotalia petaliformis* n. sp., because of the imbricate appearance, resemble the Recent cold-water species *Globorotalia cavernula* Bé.

Type level: Middle and upper Miocene of the middle part of the Indian Ocean.

Type specimens:

Holotype: (Plate 14, Figures 1a, 1b) from core catcher 10 (10, CC) at Site 254. Depth from the sea bed, 91 meters. Dimensions of the

holotype: greatest diameter 0.40 mm; height 0.21 mm. Deposited in the Foraminiferal Collection of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" under number FMACN 7646.

Paratypes: About 400 specimens from the middle and upper Miocene of Sites 253, 254, 255, and 258 of L5g 26 of the DSDP. Deposited in the same collection under number FMACN 7647.

Type locality: Holotype: Leg 26, Hole 254, DSDP. Lat 30°58.15'S, long 87°53.72'E. Water depth 1253 meters. Depth from the sea floor 91 meters.

Observations: I prefer to establish it as a new taxon but not to put it in open nomenclature because it is a very peculiar, typical, and easily identifiable species which, in addition, has a relatively short stratigraphic range. In spite of all my efforts to find at least a related species, I was not able to find any.

Globorotalia pseudobulloides (Plummer, 1926)

(Plate 13, Figures 2, 3)

Plummer (1926) described this species from the Eocene sediments of Texas. Rather typical specimens were found in Oligocene sediments at Site 253.

?Globorotalia pseudomiocena Bolli and Bermúdez, 1965

(Plate 12, Figures 12, 15, 16)

G. pseudomiocena, according to Bolli and Bermúdez (1965), differs from *G. miocena* mainly in its slightly convex spiral side and somewhat more lobulate periphery. The form recognized here is assigned only tentatively to *G. pseudomiocena*.

Globorotalia cf. pseudopima Blow, 1969

(Plate 13, Figure 4)

According to Blow (1969, p.387), in *Globorotalia (Turborotalia) acostaensis pseudopima* the aperture "extends slightly beyond the midplane of the periphery and thus encroaches slightly onto the dorsal side." In specimens tentatively named *G. cf. pseudopima* the aperture is situated completely on the ventral side. Other morphological characteristics of both foraminifers are identical. Their stratigraphical ranges, however, are not identical. *G. pseudopima* was recorded from the base of Zone N20 (middle Pliocene) to the Recent. I found specimens ascribed to *G. cf. pseudopima* only at Site 251, from the upper Miocene to upper Pliocene.

Globorotalia scitula (Brady, 1882)

(Plate 13, Figure 1)

This species was recorded only at Site 258 where its occurrence was almost uninterrupted from the upper Miocene to Recent. The specimens are small but typical.

Globorotalia tosaensis Takayanagi and Saito, 1962

(Plate 13, Figures 5-7)

The importance of this species as an indicator for the location of the Pliocene/Quaternary boundary, as well as its stratigraphic range, was discussed previously.

Globorotalia truncatulinoides (d'Orbigny, 1839)

(Plate 13, Figures 9-11)

This species was found at all the sites; the lowest records were from upper Pliocene sediments. Details of its range were discussed previously.

Orbulina suturalis Bronnimann, 1951

(Plate 13, Figure 8)

According to Reiss and Gvirtzman (1966), *O. suturalis* ranges in Israel from the lower Miocene into the upper Miocene. The same range was found at the Leg 26 sites. This range is much more limited than that presented by Blow (1969), namely, from the lowermost middle Miocene up to Recent.

Specimens were small sized and, in the majority of the samples, quantitatively rare.

Orbulina universa d'Orbigny, 1839

This is one of the most common species in the material studied. It was recorded at all the sites but was especially abundant at Sites 253, 254, and 258. Its stratigraphic range in Leg 26 material is from middle Miocene to Recent.

Praeorbulina glomerosa circularis (Blow, 1956)

This species, according to Blow (1969), has a very short stratigraphic range, occurring only in Zones N8 (uppermost lower Miocene) and N9 (lowermost middle Miocene). It is a very characteristic species whose identification does not present any problem. It was found at two sites: 251 and 253. However, although at the latter site its range corresponds perfectly with the data of Blow, at Site 251 isolated specimens occurred much lower (down to Zone N5) and much higher (up to Zones N13-N15) in the section.

Pulleniatina obliquiloculata (Parker and Jones, 1862), and related spp.

(Plate 13, Figure 13)

Banner and Blow (1965) studied species referable to the genus *Pulleniatina*, redescribed existing taxa, established some new ones, and detailed the stratigraphic ranges of all of them. They compiled the following table.

Pulleniatina primalis Banner and Blow: Zones N17-N20

Pulleniatina obliquiloculata praecursor Banner and Blow: Zones N19-N21

Pulleniatina obliquiloculata (Parker and Jones), s.s.: Zones N22-Recent.

Pulleniatina obliquiloculata finalis Banner and Blow: Zones N22-Recent.

Of all these taxa the following three were found in the Leg 26 material:

P. primalis (Zones N19-N20; Site 253), *P. obliquiloculata praecursor* (Zones N22-N23, Site 253; Zones N20-N23, Site 258), and *P. obliquiloculata*, s.s. (Zones N21-N23, Site 250; Zones N20-N23, Site 258).

Sphaeroidinella dehiscens (Parker and Jones, 1865)

(Plate 13, Figure 15)

This species is interpreted by many authors as an excellent marker of the Miocene/Pliocene boundary. Above this boundary *S. dehiscens* can be found, and below it, its ancestor *S. subdehiscens* is found.

S. dehiscens was recorded at all sites, never very frequently, and only in the Pliocene/Quaternary sediments.

Sphaeroidinella seminulina (Schwager, 1866)

(Plate 13, Figures 14, 16, 17)

This is very variable species. Its variability was discussed by Parker (1967). According to Blow (1969), it ranges from lower Miocene to lower Pliocene. Parker (1967) raises the position of its extinction to the middle Pliocene.

S. seminulina was found at all sites with the exception of the westernmost one (Site 250). Its stratigraphic range is lower Miocene-middle Pliocene. In the upper part of its range this species is characterized by a very coarsely cancellated test surface. In several cases it was very difficult to distinguish this species from *S. subdehiscens*. Kaneps (1973, p.735) states that the only difference is "a final pointed, oblique chamber in *S. seminulina*, resulting in four chambers in the final whorl."

Sphaeroidinella subdehiscens Blow, 1959

(Plate 13, Figure 12)

This taxon was separated by Blow from *S. dehiscens* on the basis of the following differences: absence of supplementary apertures, less embracing chambers, more visible sutures, generally smaller test, and more lobate equatorial periphery. It is typically a Miocene species; however, it can range through the Pliocene (Parker, 1973). Rare specimens of it were recorded at Sites 251, 253, 254 and 255 from the upper Miocene to lower/middle Pliocene.

INDIAN OCEAN FROM MIOCENE TO RECENT

The Miocene climate is considered to have been warm; however, according to several authors, during the upper Miocene a period of low temperatures took place. Kennett (1968) stated that at that time the Antarctic Convergence occupied a much more northerly position than now (approximately 39°S). At the present its position is about 60°S.

Bandy (1969) also found that during the upper Miocene a cold period occurred in several areas. This is proved, according to Bandy et al. (1971), by the presence of *Globigerina bulloides* in tropical areas, of *Globigerina pachyderma* (sin.) in the temperate zone, and of glacial sediments in the Antarctic.

Hays (1969) found that in the Miocene, approximately 10 m.y. ago, a glacial epoch took place in Alaska.

The simplest way to estimate the surface-water temperature of the past geological epochs using planktonic foraminifera is to compare the fossil assemblages with Recent ones of different climatic zones. This method has three difficulties: (a) comparison should be made on the basis of living species because we do not know the temperature requirements of extinct species. It is well known that the older the assemblage, the fewer the number of species in common with the Recent fauna; (b) even when comparing the lists of living species we are not sure that a species, which lives in certain temperature limits now, had the same limits in the past; (c) the dissolution effect can strongly change any fossil assemblage.

There are some additional criteria which can be used to reach paleotemperature conclusions based on foraminifera. For instance, a warm-water fauna is usually much richer qualitatively than a cold-water one; the representatives of genus *Globigerinoides* are mostly warm-water species, etc. Unfortunately the applicability of these criteria is also dependent on dissolution effects.

The vertical distribution of fauna encountered at the sites studied does not show any dramatic change during the Miocene. The sedimentation rate also was close to that for the Recent.

As for benthonic foraminifera, time did not permit a detailed study. However, many specimens were picked out and examined. They did not show any changes which could be attributed to the results of major changes of depth. Nevertheless, it should be taken into account that in deep-water depth changes are very difficult to detect by means of benthonic foraminifera. Deep-water benthonic foraminifera are still insufficiently studied to be used for this kind of study and many species have a large depth range. However, other observations indicate that ocean depths or the depth of the lysocline changed during the Miocene in the area of our study, at least at Sites 251 and 253. The foraminiferal assemblages of the early Miocene are strongly affected by dissolution at both sites mentioned. These assemblages are less affected in middle and late Miocene, and the foraminiferal fauna is well preserved in the Pliocene sediments. The most logical explanations of this phenomenon are that either depths were greater

in the Miocene, or that the lysocline was shallower, whereas during the Pliocene, either the water was shallower or the lysocline was deeper, and thus, dissolution could not have affected foraminiferal tests. These changes were gradual and depths were always at least bathyal during the Pliocene.

Thus, we can conclude that the circulation system of oceanic currents, the general character of the depths, and climatic zonation during the Miocene time were approximately the same as now. The mean temperature, however, was probably somewhat higher than at the present. Only in the late Miocene did a relatively short period of low temperature take place in the Indian Ocean. This temperature decrease was mentioned for other areas previously by Kennett (1968), Bandy (1969), and Hays (1969). It is shown in the present material by a considerable decrease in abundance of such typical warm-water species as *Globigerinoides trilobus*, s.l., *G. ruber* and, to a certain degree, *Globorotalia menardii*, s.l. The latter species is relatively rare in the area under study and therefore is not so useful as the two former species. While the warm-water species decreased, the *Globigerina bulloides* group (cold and cold-temperate indicator) increased in number. But even at the southernmost site (Site 251, lat 36°30.26'S), no specimens of a typical cold-water indicator—a sinistraly coiled *Globigerina pachyderma*—were found, and warm-water *Globigerinoides conglobatus*, *G. trilobus*, *G. ruber* still lived, although as rare individuals. This means that the area was still in the Temperate Zone.

In the description of Site 251 above, a lower Miocene assemblage of benthonic foraminifera of quite shallow water is recorded. It is suggested, however, that this assemblage is the result of sediment transport, but not of dramatic changes of oceanic depth in this area. Unfortunately no data were available to determine more exactly the origin of this benthonic assemblage.

As for the Pliocene, it can be suggested that the average temperature of the surface water during this time was a little lower than in the Miocene. In addition, according to various authors, a cold period (or periods) also occurred, and several authors consider that it was still colder than that which took place in the Miocene.

Bolli et al. (1968), for example, after studying Pliocene sediments in the Caribbean Sea, recognized at least two glacial periods there.

Bandy (1969) stated that in the middle Pliocene the surface-water temperatures in the temperate zone were similar to those found during Pleistocene glacial epochs, namely between 2°C and 8°C.

Bermúdez and Bolli (1969) are of opinion that in the lower Pliocene the water temperatures of the oceans were lower than at present.

Kennett et al. (1971) found two glacial epochs in the Pliocene of New Zealand, one in the middle Pliocene and the other in the upper Pliocene.

Boltovskoy (1973) also found that in the southwestern Atlantic the Pliocene was a period with temperatures similar to those of the glacial epochs of the Pleistocene, i.e., considerably lower than the present day.

The study of the Leg 26 material revealed fluctuations of temperature during the Pliocene at some sites; however, with the exception of Site 253, these fluctuations were very insignificant and it would not be correct to interpret them as an effect of real glacial epochs.

At Site 253, at a depth of 8 meters below the bottom surface, the foraminiferal assemblage indicated a temperature decrease. The evidences of lower temperatures are an increase in the number of specimens of *Globorotalia truncatulinoides/tosaensis*, a decrease in the number of specimens of *G. menardii*, *s.l.*, *Globigerinoides ruber*, etc. This temperature decrease can be seen still better in a detailed climatic curve prepared using samples taken at 10-cm intervals (see Boltovskoy, late Pliocene and Quaternary paleoclimatic changes, this volume). No temperature decrease was observed in the middle Pliocene.

The Pleistocene is a time of glacial/interglacial oscillations. Usually one considers that glaciation began at the beginning of the Pleistocene; however, there are many authors who do not correlate these events.

Since a separate paper is devoted to Quaternary temperature changes, it would be out of place to go into details here. It can be stated that the Quaternary temperature oscillations were not sufficiently well pronounced to be correlated with known glacial and interglacial epochs.

An analysis of the Pliocene-Recent planktonic foraminiferal assemblages, as well as of the benthonic foraminiferal fauna, proved that during the Pliocene, just as during the Miocene, oceanographical conditions in the area under study hardly changed.

The following minor biological phenomenon is of interest with reference to the Indian Ocean during the Miocene. Several *Globigerina* (*G. cryptomphala*, *G. tripartita*, *G. unicava*), *Globigerinita* (*G. cf. africana*, *G. dissimilis dissimilis*, *G. dissimilis ciproensis*), and even *Globoquadrina* (*G. dehiscens praedehiscens*) developed an interesting structure, a poorly developed bulla-like last chamber which, like a valve, partially covered the aperture. In some of the species listed it is well known and is a characteristic feature. However, in others it is observed for the first time. Also, as far as the author knows, the small final chamber which covers the aperture of *Globigerinoides sicanus* described in this report has not previously been observed. The main function of this structure apparently is to protect the aperture from predators and parasites.

The great development of foraminifera with this protection in the Miocene suggests that foraminiferal predators were common at that time in the Indian Ocean.

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PLATE 1

- Figure 1 *Globigerina ampliapertura* Bolli, $\times 90$; Sample 253-10-2, 40-42 cm, hypotype: slide FMACN 7649.
- Figure 2 *Globigerina ampliapertura* Bolli, $\times 80$; Sample 253-11, CC; hypotype: slide FMACN 7649.
- Figure 3 *Globigerina ampliapertura* Bolli, $\times 100$; Sample 253-11, CC; hypotype: slide FMACN 7649.
- Figure 4 *Candeina nitida* d'Orbigny, $\times 64$; Sample 253-1, CC; hypotype: slide FMACN 7650.
- Figure 5 *Globigerina ampliapertura* Bolli, $\times 72$; Sample 253-11, CC; hypotype: slide FMACN 7649.
- Figure 6 *Globigerina ampliapertura* Bolli, $\times 80$; Sample 253-11, CC; hypotype: slide FMACN 7649.
- Figure 7 *Globigerina angioporoides* Hornibrook, $\times 100$; Sample 253-11-6, 40-42 cm; hypotype: slide FMACN 7651.
- Figure 8 *Globigerina angioporoides* Hornibrook, $\times 100$; Sample 253-11-6, 40-42 cm; hypotype: slide FMACN 7651.
- Figure 9 *Globigerina calida* Parker, $\times 56$; Sample 251-2-2, 39-41 cm; hypotype: slide FMACN 7652.
- Figure 10 *Globigerina decoraperta* Takayanagi and Saito, $\times 200$; Sample 258A-5-5, 148-150 cm; hypotype: slide FMACN 7653.
- Figure 11 *Globigerina euapertura* Jenkins, $\times 100$; Sample 254-19, CC; hypotype: slide FMACN 7654.
- Figure 12 *Globigerina euapertura* Jenkins, $\times 120$; Sample 254-19, CC; hypotype: slide FMACN 7654.
- Figure 13 *Globigerina juvenilis* Bolli, $\times 100$; Sample 253-10, CC; hypotype: slide FMACN 7655.
- Figure 14 *Globigerina linaperta* Finlay, $\times 100$; Sample 250A-19, CC; hypotype: slide FMACN 7656.
- Figure 15 *Globigerina nepenthes* Todd, $\times 80$; Sample 254-4-4, 115-117 cm; hypotype: slide FMACN 7657.
- Figure 16 *Globigerina nepenthes* Todd, $\times 80$; Sample 254-4-4, 115-117 cm; hypotype: slide FMACN 7657.

PLATE 1

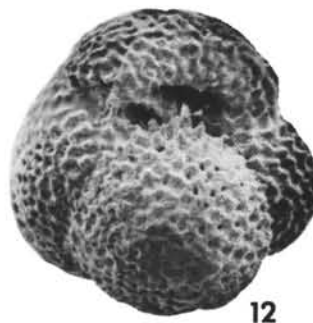
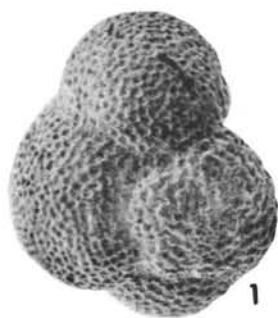


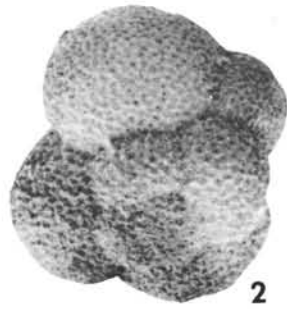
PLATE 2

- Figure 1 *Globigerina cryptomphala* (Glaessner), $\times 80$; Sample 254-18-2, 40-42 cm; hypotype: slide FMACN 7658.
- Figure 2 *Globigerina cryptomphala* (Glaessner), $\times 60$; Sample 254-17, CC; hypotype: slide FMACN 7658.
- Figure 3 *Globigerina falconensis* Blow, $\times 120$; Sample 254-1, CC; hypotype: slide FMACN 7659.
- Figure 4 *Globigerina bulloides* d'Orbigny, $\times 56$; Sample 254-2-1, 115-117 cm; hypotype: slide FMACN 7660.
- Figure 5 *Globigerina cryptomphala* (Glaessner), $\times 72$; Sample 254-19-1, 40-42 cm; hypotype: slide FMACN 7658.
- Figure 6 *Globigerina cryptomphala* (Glaessner), $\times 48$; Sample 254-17, CC; hypotype: slide FMACN 7658.
- Figure 7 *Globigerina cryptomphala* (Glaessner), $\times 48$; Sample 254-17, CC; hypotype: slide FMACN 7658.
- Figure 8 *Globigerina cryptomphala* (Glaessner), $\times 80$; Sample 253-10-2, 40-42 cm; hypotype: slide FMACN 7658.
- Figure 9 *Globigerina cryptomphala* (Glaessner), $\times 80$; Sample 254-5-3, 40-42 cm; hypotype: slide FMACN 7658.
- Figure 10 *Globigerina cryptomphala* (Glaessner), $\times 80$; Sample 254-17, CC; hypotype: slide FMACN 7658.
- Figure 11 *Globigerina pachyderma* (Ehrenberg) (dex.), $\times 120$; Sample 251-3-2, 40-42 cm; hypotype: slide FMACN 7661.
- Figure 12 *Globigerina pachyderma* (Ehrenberg) (dex.), $\times 120$; Sample 251-3-2, 40-42 cm; hypotype: slide FMACN 7661.
- Figure 13 *Globigerina "praerubra,"* $\times 88$; Sample 254-11, CC; hypotype: slide FMACN 7662.
- Figure 14 *Globigerina "praerubra,"* $\times 120$; Sample 254-12-2, 40-42 cm; hypotype: slide FMACN 7662.
- Figure 15 *Globigerina "praerubra,"* $\times 100$; Sample 254-18-5, 115-117 cm; hypotype: slide FMACN 7662.
- Figure 16 *Globigerina "praerubra,"* $\times 72$; Sample 254-15, CC; hypotype: slide FMACN 7662.

PLATE 2



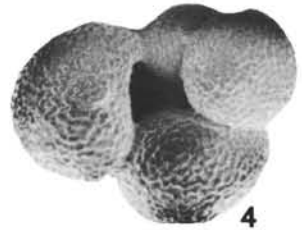
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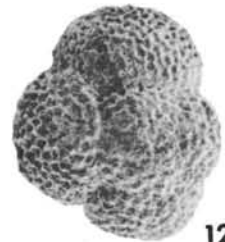
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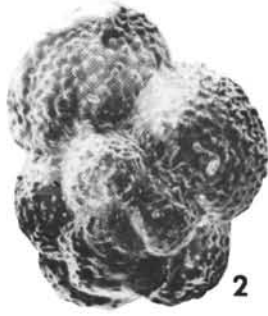
PLATE 3

- Figure 1 *Globigerina quinqueloba* Natland, $\times 200$; Sample 251A-1, CC; hypotype: slide FMACN 7663.
- Figure 2 *Globigerina quinqueloba* Natlant, $\times 200$; Sample 251A-1, CC; hypotype: slide FMACN 7663.
- Figure 3 *Globigerinella aequilateralis* (Brady), $\times 64$; Sample 2582-1, 88-90 cm; hypotype: slide FMACN 7664.
- Figure 4 *Globigerinita glutinata* (Egger), $\times 100$; Sample 250-4, CC; hypotype: slide FMACN 7665.
- Figure 5 *Globigerina tripartita* Koch, $\times 72$; Sample 253-12, CC; hypotype: slide FMACN 7666.
- Figure 6 *Globigerina tripartita* Koch, $\times 52$; Sample 253-10-5, 40-42 cm; hypotype: slide FMACN 7666.
- Figure 7 *Globigerina tripartita* Koch, $\times 60$; Sample 253-12, CC; hypotype: slide FMACN 7666.
- Figure 8 *Globigerina tripartita* Koch, $\times 64$; Sample 253-12-4, 53-55 cm; hypotype: slide FMACN 7666.
- Figure 9 *Globigerina tripartita* Koch, $\times 64$; Sample 253-12, CC; hypotype: slide FMACN 7666.
- Figure 10 *Globigerina tripartita* Koch, $\times 60$; Sample 253-10, CC; hypotype: slide FMACN 7666.
- Figure 11 *Globigerina yeguaensis* Weinzierl and Applin, $\times 80$; Sample 253-12-4, 53-55 cm; hypotype: slide FMACN 7667.
- Figure 12 *Globigerina yeguaensis* Weinzierl and Applin, $\times 56$; Sample 253-8, CC; hypotype: slide FMACN 7667.
- Figure 13 *Globigerinita* cf. *africana* Blow and Banner, $\times 56$; Sample 254-19-3, 115-117 cm; hypotype: slide FMACN 7668.
- Figure 14 *Globigerinita* cf. *africana* Blow and Banner, $\times 48$; Sample 25418-3, 125-127 cm; hypotype: slide FMACN 7668.
- Figure 15 *Globigerinita* cf. *africana* Blow and Banner, $\times 48$; Sample 254-18-3, 125-127 cm; hypotype: slide FMACN 7668.
- Figure 16 *Globigerinita* cf. *africana* Blow and Banner, $\times 80$; Sample 254-18-3, 125-127 cm; hypotype: slide FMACN 7668.

PLATE 3



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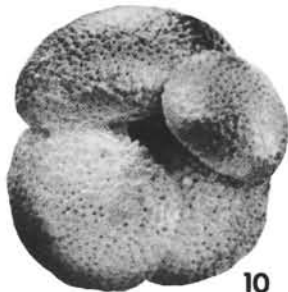
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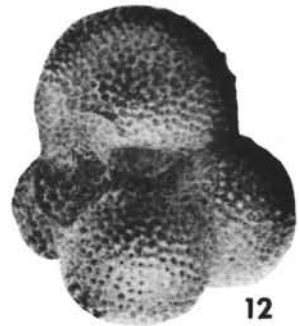
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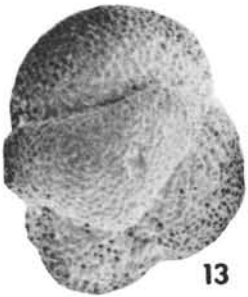
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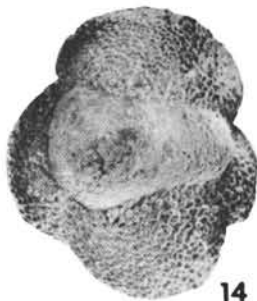
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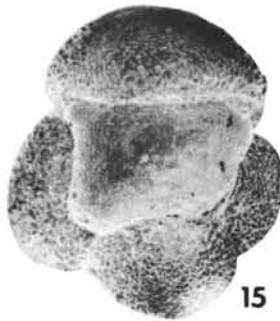
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PLATE 4

- Figure 1 *Globigerinita dissimilis ciperensis* Blow and Banner, $\times 64$; Sample 254-19-1, 40-42 cm; hypotype: slide FMACN 7669.
- Figure 2 *Globigerina rubescens* Hofker, $\times 160$; Sample 258-1-4, 20-22 cm; hypotype: slide FMACN 7670.
- Figure 3 *Globigerinoides bulloideus* Crescenti, $\times 80$; Sample 254-10-2, 115-117 cm; hypotype: slide FMACN 7671.
- Figure 4 *Globigerinoides bulloideus* Crescenti, $\times 80$; Sample 254-10-2, 115-117 cm; hypotype: slide FMACN 7671.
- Figure 5 *Globigerinita dissimilis ciperensis* Blow and Banner, $\times 52$; Sample 254-19-1, 40-42 cm; hypotype: slide FMACN 7669.
- Figure 6 *Globigerinita dissimilis dissimilis* (Cushman and Bermúdez), $\times 72$; Sample 254-19, CC; hypotype: slide FMACN 7672.
- Figure 7 *Globigerinita unicava* (Bolli, Loeblich, and Tappan), $\times 80$; Sample 254-5-3, 40-42 cm; hypotype: slide FMACN 7673.
- Figure 8 *Globigerinita unicava* (Bolli, Loeblich, and Tappan), $\times 80$; Sample 254-5-3, 40-42 cm; hypotype: slide FMACN 7673.
- Figure 9 *Globigerinita unicava* (Bolli, Loeblich, and Tappan), $\times 88$; Sample 254-5-3, 40-42 cm; hypotype: slide FMACN 7673.
- Figure 10 *Globigerinoides amplus* Perconig, $\times 64$; Sample 253-5-6, 40-42 cm; hypotype: slide FMACN 7674.
- Figure 11 *Globigerinoides amplus* Perconig, $\times 80$; Sample 253-5-6, 40-42 cm; hypotype: slide FMACN 7674.
- Figure 12 *Globigerinoides amplus* Perconig, $\times 56$; Sample 253-6-5, 40-42 cm; hypotype: slide FMACN 7674.
- Figure 13 *Globigerinoides amplus* Perconig, $\times 76$; Sample 253-5-6, 40-42 cm; hypotype: slide FMACN 7674.
- Figure 14 *Globigerinoides amplus* Perconig, $\times 68$; Sample 253-4-1, 45-47 cm; hypotype: slide FMACN 7674.
- Figure 15 *Globigerinoides amplus* Perconig, $\times 60$; Sample 253-6-5, 40-42 cm; hypotype: slide FMACN 7674.
- Figure 16 *Globigerinoides conglobatus* (Brady), $\times 48$; Sample 254-1-2, 115-117 cm; hypotype: slide FMACN 7674.

PLATE 4

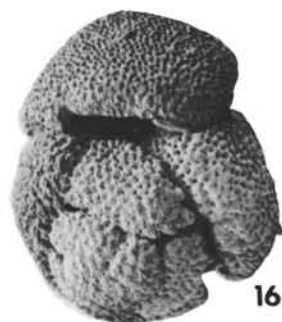
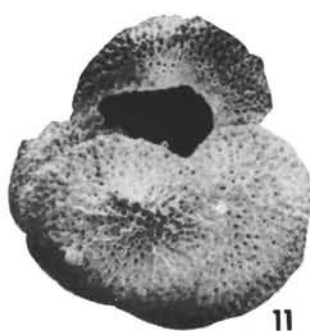
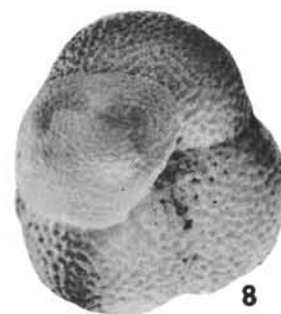


PLATE 5

- Figure 1 *Globigerinoides mitra* Todd, $\times 52$; Sample 253-7-1, 70-72 cm; hypotype: slide FMACN 7676.
- Figure 2 *Globigerinoides mitra* Todd, $\times 80$; Sample 253-7, CC; hypotype: slide FMACN 7676.
- Figure 3 *Globigerinoides elongatus* (d'Orbigny), $\times 80$; Sample 254-1, CC; hypotype: slide FMACN 7677.
- Figure 4 *Globigerinoides obliquus* Bolli, *s.l.* $\times 80$; Sample 254-2-3, 40-42 cm; hypotype: slide FMACN 7678.
- Figure 5 *Globigerinoides obliquus* Bolli, *s.l.* $\times 64$; Sample 254-2-3, 40-42 cm; hypotype: slide FMACN 7678.
- Figure 6 *Globigerinoides obliquus* Bolli, *s.l.* $\times 64$; Sample 253-3-4, 40-42 cm; hypotype: slide FMACN 7678.
- Figure 7 *Globigerinoides pyramidalis* (van den Broeck), $\times 64$; Sample 253-1-3, 48-50 cm; hypotype: slide FMACN 7679.
- Figure 8 *Globigerinoides sicanus* de Stefani, $\times 100$; Sample 253-8-2, 40-42 cm; hypotype: slide FMACN 7680.
- Figure 9 *Globigerinoides sicanus* de Stefani, $\times 100$; Sample 253-8-4, 60-62 cm; hypotype: slide FMACN 7680.
- Figure 10 *Globigerinoides sicanus* de Stefani, $\times 80$; Sample 254-10-6, 40-42 cm; hypotype: slide FMACN 7680.
- Figure 11 *Globigerinoides sicanus* de Stefani, $\times 100$; Sample 254-12-4, 140-142 cm; hypotype: slide FMACN 7680.
- Figure 12 *Globigerinoides sicanus* de Stefani, $\times 80$; Sample 254-12-4, 140-142 cm; hypotype: slide FMACN 7680.
- Figure 13 *Globigerinoides trilobus* (Reuss), *s.l.* $\times 48$; Sample 253-2-1, 100-102 cm; hypotype: slide FMACN 7681.
- Figure 14 *Globigerinoides trilobus* (Reuss), *s.l.* $\times 48$; Sample 253-2-4, 40-42 cm; hypotype: slide FMACN 7681.
- Figure 15 *Globigerinoides trilobus* (Reuss), *s.l.* $\times 60$; Sample 253-2-1, 100-102 cm; hypotype: slide FMACN 7681.
- Figure 16 *Globigerinoides fistulosus* (Schubert), $\times 32$; Sample 253-2-1, 50-52 cm; hypotype: slide FMACN 7682.

PLATE 5

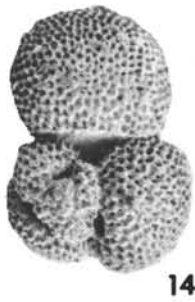
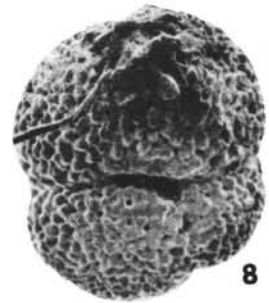
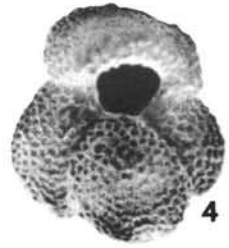


PLATE 6

- Figure 1 *Globigerinoides trilobus* (Reuss), *f. sacculifera* (Brady), $\times 32$; Sample 253-2-6, 40-42 cm; hypotype: slide FMACN 7683.
- Figure 2 *Globigerinoides trilobus* (Reuss), *f. sacculifera* (Brady) $\times 40$; Sample 253-2-6, 40-42; hypotype: slide FMACN 7683.
- Figure 3 *Globoquadrina hexagona* (Natland), $\times 100$; Sample 251-5, CC; hypotype: slide FMACN 7684.
- Figure 4 *Globigerinoides tenellus* Parker, $\times 120$; Sample 258A-1-6, 110-112 cm; hypotype: slide FMACN 7685.
- Figure 5 *Globigerinopsis aguasayensis* Bolli, $\times 48$; Sample 254-6-6, 115-117 cm; hypotype: slide FMACN 7686.
- Figure 6 *Globigerinopsis aguasayensis* Bolli, $\times 48$; Sample 254-6, CC; hypotype: slide FMACN 7686.
- Figure 7 *Globigerinopsis aguasayensis* Bolli, $\times 48$; Sample 254-6, CC; hypotype: slide FMACN 7686.
- Figure 8 *Globigerinopsis aguasayensis* Bolli, $\times 40$; Sample 254-6-5, 40-42 cm; hypotype: slide FMACN 7686.
- Figure 9 *Globigerinopsis aguasayensis* Bolli, $\times 40$; Sample 254-7-2, 115-117 cm; hypotype: slide FMACN 7686.
- Figure 10 *Globigerinopsis aguasayensis* Bolli, $\times 40$; Sample 254-7-5, 115-117 cm; hypotype: slide FMACN 7686.
- Figure 11 *Globigerinopsis aguasayensis* Bolli, $\times 52$; Sample 254-5-3, 115-117 cm; hypotype: slide FMACN 7686.
- Figure 12 *Globigerinopsis aguasayensis* Bolli, $\times 32$; Sample 254-6, CC; hypotype: slide FMACN 7686.
- Figure 13 *Globigerinopsis aguasayensis* Bolli, $\times 40$; Sample 254-6-5, 40-42 cm; hypotype: slide FMACN 7686.
- Figure 14 *Globigerinopsis aguasayensis* Bolli, $\times 40$; Sample 254-7, CC; hypotype: slide FMACN 7686.
- Figure 15 *Globoquadrina altispira* (Cushman and Jarvis), $\times 56$; Sample 251A-7-5, 40-42 cm; hypotype: slide FMACN 7687.
- Figure 16 *Globoquadrina altispira* (Cushman and Jarvis), $\times 48$; Sample 251A-13-1, 66-68 cm; hypotype: slide FMACN 7687.

PLATE 6

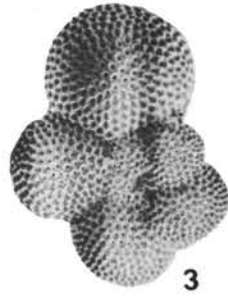


PLATE 7

- Figure 1 *Globoquadrina altispira* (Cushman and Jarvis),
×60; Sample 253-4-6, 40-42 cm; hypotype: slide
FMACN 7687.
- Figure 2 *Globoquadrina dehiscens dehiscens* (Chapman,
Parr, and Collins), ×64; Sample 253-7-1, 70-72
cm; hypotype: slide FMACN 7688.
- Figure 3 *Globoquadrina dehiscens dehiscens* (Chapman,
Parr, and Collins), ×64; Sample 253-7-1, 70-72
cm; hypotype: slide FMACN 7688.
- Figure 4 *Globoquadrina dehiscens dehiscens* (Chapman,
Parr, and Collins), ×60; Sample 254-10-5, 40-42
cm; hypotype: slide FMACN 7688.
- Figure 5 *Globoquadrina dehiscens praedehiscens* Blow and
Banner, ×48; Sample 254-19-1, 40-42 cm;
hypotype: slide FMACN 7689.
- Figure 6 *Globoquadrina dehiscens praedehiscens* Blow and
Banner, ×56; Sample 254-18-6, 115-117 cm;
hypotype: slide FMACN 7689.
- Figure 7 *Globoquadrina dehiscens praedehiscens* Blow and
Banner, ×48; Sample 254-19-5, 115-117 cm;
hypotype: slide FMACN 7689.
- Figure 8 *Globoquadrina dehiscens praedehiscens* Blow and
Banner, ×48; Sample 254-19-2, 115-117 cm;
hypotype: slide FMACN 7689.
- Figure 9 *Globoquadrina dehiscens praedehiscens* Blow and
Banner, ×60; Sample 253-9-5, 40-42 cm;
hypotype: slide FMACN 7689.
- Figure 10 *Globoquadrina dutertrei* (d'Orbigny), ×64; Sample
258A-1-1, 61-63 cm; hypotype: slide FMACN
7690.
- Figure 11 *Globoquadrina venezuelana* (Hedberg), ×80;
Sample 255-3, CC; hypotype: slide FMACN 7691.
- Figure 12 *Globoquadrina venezuelana* (Hedberg), ×56;
Sample 255-4-2, 39-41 cm; hypotype: slide
FMACN 7691.
- Figure 13 *Globoquadrina venezuelana* (Hedberg), ×60;
Sample 251A-16-3, 40-42 cm; hypotype: slide
FMACN 7691.
- Figure 14 *Globoquadrina venezuelana* (Hedberg), ×68;
Sample 254-2-3, 115-117 cm; hypotype: slide
FMACN 7691.
- Figure 15 *Globoquadrina humerosa* (Takayanagi and Saito),
×100; Sample 251-8-1, 40-42 cm; hypotype: slide
FMACN 7692.
- Figure 16 *Globorotalia cf. humilis* (Brady), ×240; Sample
250-3-1, 39-43 cm; hypotype: is lost.

PLATE 7

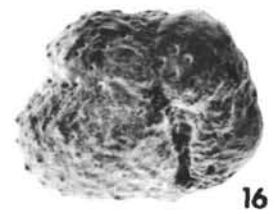
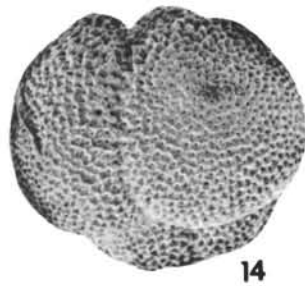
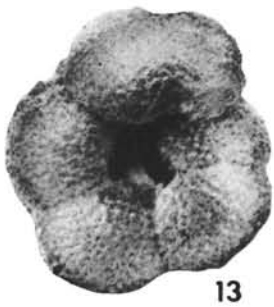
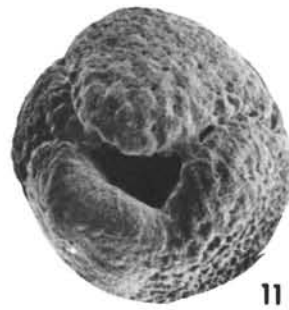
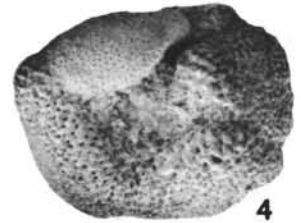
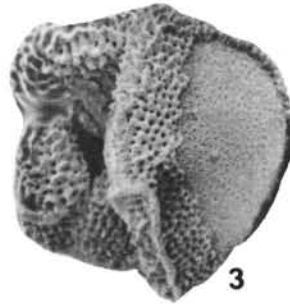


PLATE 8

- Figure 1 *Globorotalia acostaensis* Blow, $\times 120$; Sample 251A-6-4, 40-42 cm; hypotype: slide FMACN 7693.
- Figure 2 *Globorotalia acostaensis* Blow, $\times 100$; Sample 251A-6-4, 40-42 cm; hypotype: slide FMACN 7693.
- Figure 3 *Globorotalia acostaensis* Blow, $\times 100$; Sample 251A-5-3, 40-42 cm; hypotype: slide FMACN 7693.
- Figure 4 *Globorotalia acostaensis* Blow, $\times 80$; Sample 251A-6-5, 125-127 cm; hypotype: slide FMACN 7693.
- Figure 5 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 60$; Sample 254-2-6, 40-42 cm; hypotype: slide FMACN 7694.
- Figure 6 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 60$; Sample 254-2-6, 40-42 cm; hypotype: slide FMACN 7694.
- Figure 7 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 64$; Sample 254-2-6, 40-42 cm; hypotype: slide FMACN 7694.
- Figure 8 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 60$; Sample 254-2-6, 40-42 cm; hypotype: slide FMACN 7694.
- Figure 9 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 56$; Sample 253-1, CC; hypotype: slide FMACN 7694.
- Figure 10 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 56$; Sample 254-1-3, 100-102 cm; hypotype: slide FMACN 7694.
- Figure 11 *Globorotalia crassaformis* (Galloway and Wissler), *s.l.*, $\times 48$; Sample 258-3-4, 40-42 cm; hypotype: slide FMACN 7694.
- Figure 12 *Globorotalia crassula* Cushman and Stewart, $\times 60$; Sample 258A-6-4, 104-106 cm; hypotype: slide FMACN 7695.
- Figure 13 *Globorotalia crassula* Cushman and Stewart, $\times 52$; Sample 258A-4-2, 75-77 cm; hypotype: slide FMACN 7695.
- Figure 14 *Globorotalia crassula* Cushman and Stewart, $\times 72$; Sample 258A-4-1, 120-122 cm; hypotype: slide FMACN 7695.
- Figure 15 *Globorotalia crassula* Cushman and Stewart, $\times 52$; Sample 258A-5-2, 60-62 cm; hypotype: slide FMACN 7695.
- Figure 16 *Globorotalia crassula* Cushman and Stewart, $\times 60$; Sample 258-3-4, 40-42 cm; hypotype: slide FMACN 7695.
- Figure 17 *Globorotalia crassula* Cushman and Stewart, $\times 52$; Sample 258A-4-2, 105-107 cm; hypotype: slide FMACN 7695.

PLATE 8

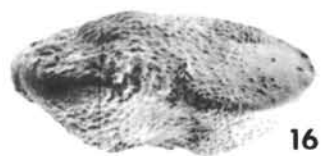
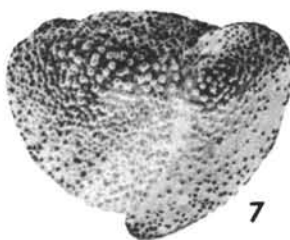
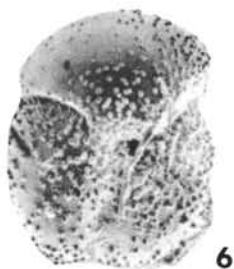
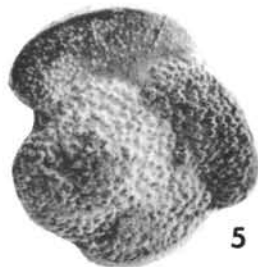
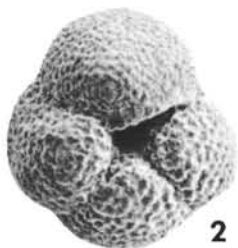
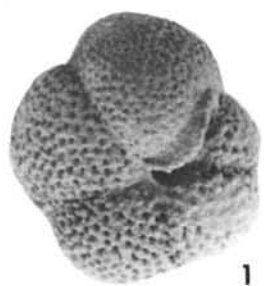


PLATE 9

- Figure 1 *Globorotalia inflata* (d'Orbigny), $\times 80$; Sample 254-3-4, 115-117 cm; hypotype: slide FMACN 7696.
- Figure 2 *Globorotalia inflata* (d'Orbigny), $\times 56$; Sample 254-3-6, 115-117 cm; hypotype: slide FMACN 7696.
- Figure 3 *Globorotalia inflata* (d'Orbigny), $\times 64$; Sample 254-2-3, 40-42 cm; hypotype: slide FMACN 7696.
- Figure 4 *Globorotalia inflata* (d'Orbigny), $\times 72$; Sample 254-3-1, 40-42 cm; hypotype: slide FMACN 7696.
- Figure 5 *Globorotalia inflata* (d'Orbigny), $\times 64$; Sample 254-3, CC; hypotype: slide FMACN 7696.
- Figure 6 *Globorotalia inflata* (d'Orbigny), $\times 56$; Sample 254-1-3, 100-102 cm; hypotype: slide FMACN 7696.
- Figure 7 *Globorotalia inflata* (d'Orbigny), $\times 64$; Sample 254-1-3, 100-102 cm; hypotype: slide FMACN 7696.
- Figure 8 *Globorotalia inflata* (d'Orbigny), $\times 64$; Sample 254-2-3, 40-42 cm; hypotype: slide FMACN 7696.
- Figure 9 *Globorotalia kugleri* Bolli, $\times 120$; Sample 253-8, CC; hypotype: slide FMACN 7697.
- Figure 10 *Globorotalia kugleri* Bolli, $\times 120$; Sample 253-8, CC; hypotype: slide FMACN 7697.
- Figure 11 *Globorotalia menardii* (d'Orbigny) (sin.), *s.l.*, $\times 28$; Sample 253-1-6, 48-50 cm; hypotype: slide FMACN 7698.
- Figure 12 *Globorotalia menardii* (d'Orbigny), *f. flexuosa* (Koch), $\times 40$; Sample 253-1-1, 118-120 cm; hypotype: slide FMACN 7700.
- Figure 13 *Globorotalia margaritae* Bolli and Bermúdez, $\times 60$; Sample 253-2-5, 40-42 cm; hypotype: slide FMACN 7701.
- Figure 14 *Globorotalia margaritae* Bolli and Bermúdez, $\times 60$; Sample 253-2, CC; hypotype: slide FMACN 7701.
- Figure 15 *Globorotalia margaritae* Bolli and Bermúdez, $\times 60$; Sample 253-2-5, 40-42 cm; hypotype: slide FMACN 7701.
- Figure 16 *Globorotalia margaritae* Bolli and Bermúdez, $\times 80$; Sample 253-2, CC; hypotype: slide FMACN 7701.

PLATE 9

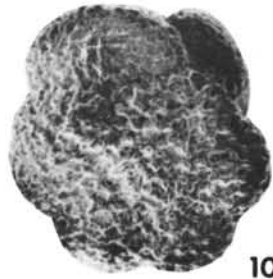
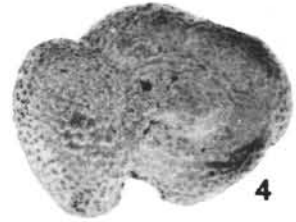
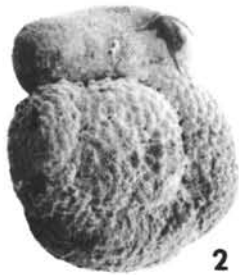
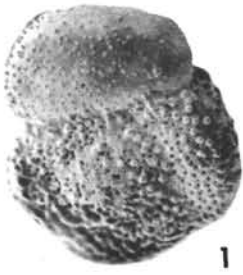


PLATE 10

- Figure 1 *Globorotalia crotonensis* Conato and Follador, ×40; Sample 251A-1-5, 40-42 cm; hypotype: slide FMACN 7702.
- Figure 2 *Globorotalia crotonensis* Conato and Follador, ×48; Sample 251A-4, CC; hypotype: slide FMACN 7702.
- Figure 3 *Globorotalia crotonensis* Conato and Follador, ×80; Sample 251A-4, CC; hypotype: slide FMACN 7702.
- Figure 4 *Globorotalia crotonensis* Conato and Follador, ×64; Sample 251-10-5, 40-42 cm; hypotype: slide FMACN 7702.
- Figure 5 *Globorotalia crotonensis* Conato and Follador, ×64; Sample 251A-1-2, 40-42 cm; hypotype: slide FMACN 7702.
- Figure 6 *Globorotalia crotonensis* Conato and Follador, ×56; Sample 251A-4, CC; hypotype: slide FMACN 7702.
- Figure 7 *Globorotalia crotonensis* Conato and Follador, ×64; Sample 251A-4, CC; hypotype: slide FMACN 7702.
- Figure 8 *Globorotalia limbata* (Fornasini), ×48; Sample 253-2-1, 50-52 cm; hypotype: slide FMACN 7703.
- Figure 9 *Globorotalia limbata* (Fornasini), ×72; Sample 253-3-2, 40-42 cm; hypotype: slide FMACN 7703.
- Figure 10 *Globorotalia limbata* (Fornasini), ×48; Sample 253-3-2, 40-42 cm; hypotype: slide FMACN 7703.
- Figure 11 *Globorotalia limbata* (Fornasini), ×48; Sample 253-5, CC; hypotype: slide FMACN 7703.
- Figure 12 *Globorotalia limbata* (Fornasini), ×48; Sample 253-2-6, 40-42 cm; hypotype: slide FMACN 7703.
- Figure 13 *Globorotalia limbata* (Fornasini), ×48; Sample 253-2-5, 40-42 cm; hypotype: slide FMACN 7703.
- Figure 14 *Globorotalia limbata* (Fornasini), ×48; Sample 253-1, CC; hypotype: slide FMACN 7703.
- Figure 15 *Globorotalia limbata* (Fornasini), ×50; Sample 253-2-4, 40-42 cm; hypotype: slide FMACN 7703.
- Figure 16 *Globorotalia limbata* (Fornasini), ×52; Sample 253-3-2, 40-42 cm; hypotype: slide FMACN 7703.

PLATE 10

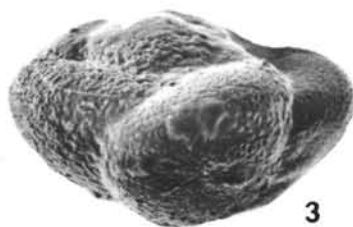
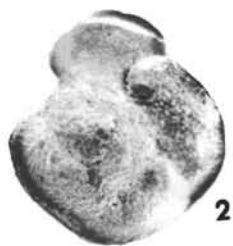


PLATE 11

- Figure 1 *Globorotalia limbata* (Fornasini), $\times 48$; Sample 253-2, CC; hypotype: slide FMACN 7703.
- Figure 2 *Globorotalia* aff. *limbata* (Fornasini), $\times 60$; Sample 254-8-2, 40-42 cm; hypotype: slide FMACN 7704.
- Figure 3 *Globorotalia* aff. *limbata* (Fornasini), $\times 68$; Sample 254-8-2, 115-117 cm; hypotype: slide FMACN 7704.
- Figure 4 *Globorotalia* aff. *limbata* (Fornasini), $\times 72$; Sample 254-7, CC; hypotype: slide FMACN 7704.
- Figure 5 *Globorotalia miozea conoidea* Walters, $\times 48$; Sample 254-3-2, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 6 *Globorotalia miozea conoidea* Walters, $\times 60$; Sample 251A-5-1, 40-42 cm; hypotype: slide FMACN 7705.
- Figure 7 *Globorotalia miozea conoidea* Walters, $\times 68$; Sample 251A-10, CC; hypotype: slide FMACN 7705.
- Figure 8 *Globorotalia miozea conoidea* Walters, $\times 56$; Sample 254-3-2, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 9 *Globorotalia miozea conoidea* Walters, $\times 40$; Sample 254-3-2, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 10 *Globorotalia miozea conoidea* Walters, $\times 40$; Sample 254-2-6, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 11 *Globorotalia miozea conoidea* Walters, $\times 40$; Sample 254-2-6, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 12 *Globorotalia miozea conoidea* Walters, $\times 64$; Sample 251A-5-1, 40-42 cm; hypotype: slide FMACN 7705.
- Figure 13 *Globorotalia miozea conoidea* Walters, $\times 64$; Sample 254-2-6, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 14 *Globorotalia miozea conoidea* Walters, $\times 64$; Sample 254-3-2, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 15 *Globorotalia miozea conoidea* Walters, $\times 60$; Sample 254-3-2, 115-117 cm; hypotype: slide FMACN 7705.
- Figure 16 *Globorotalia miozea conoidea* Walters, $\times 60$; Sample 254-3-2, 40-42 cm; hypotype: slide FMACN 7705.
- Figure 17 *Globorotalia miozea conoidea* Walters, $\times 48$; Sample 254-3-2, 40-42 cm; hypotype: slide FMACN 7705.
- Figure 18 *Globorotalia miozea conoidea* Walters, $\times 60$; Sample 254-3-2, 40-42 cm; hypotype: slide FMACN 7705.

PLATE 11

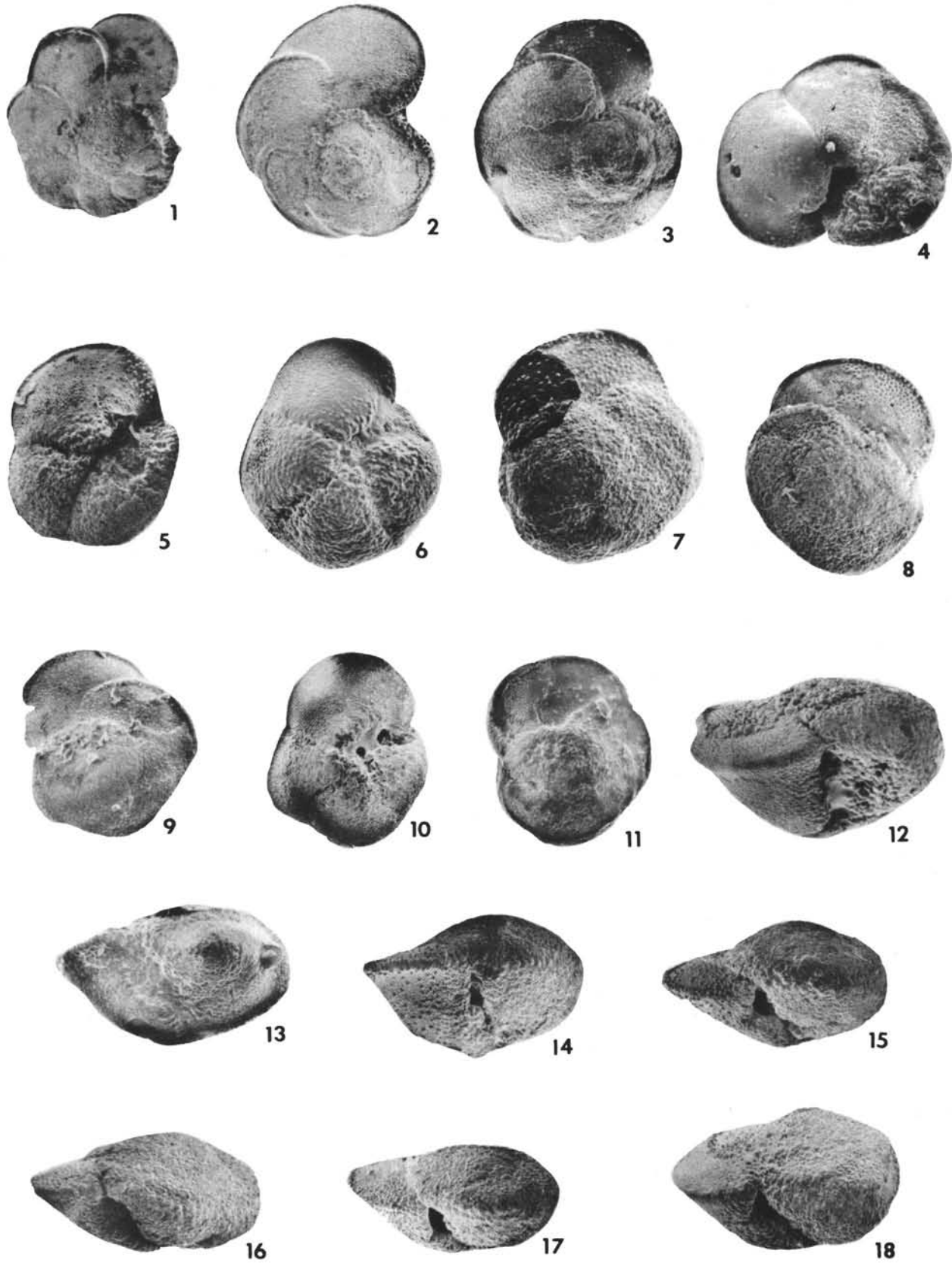


PLATE 12

- Figure 1 *?Globorotalia miocenica* Palmer, $\times 48$; Sample 254-10, CC; hypotype: slide FMACN 7706.
- Figure 2 *?Globorotalia miocenica* Palmer, $\times 80$; Sample 254-10-6, 115-117 cm; hypotype: slide FMACN 7706.
- Figure 3 *?Globorotalia miocenica* Palmer, $\times 64$; Sample 254-9-3, 115-117 cm; hypotype: slide FMACN 7706.
- Figure 4 *Globorotalia opima* Bolli, *s.l.*, $\times 80$; Sample 253-9-2, 24-26 cm; hypotype: slide FMACN 7707.
- Figure 5 *Globorotalia opima* Bolli, *s.l.*, $\times 92$; Sample 254-19, CC; hypotype: slide FMACN 7707.
- Figure 6 *Globorotalia opima* Bolli, *s.l.*, $\times 80$; Sample 254-19-2, 115-117 cm; hypotype: slide FMACN 7707.
- Figure 7 *Globorotalia opima* Bolli, *s.l.*, $\times 100$; Sample 254-20, CC; hypotype: slide FMACN 7707.
- Figure 8 *Globorotalia opima* Bolli, *s.l.*, $\times 80$; Sample 254-18-3, 125-127 cm; hypotype: slide FMACN 7707.
- Figure 9 *Globorotalia peripheroacuta* Blow and Banner, $\times 92$; Sample 253-7, CC; hypotype: slide FMACN 7708.
- Figure 10 *Globorotalia peripheroacuta* Blow and Banner, $\times 120$; Sample 253-8-2, 40-42 cm; hypotype: slide FMACN 7708.
- Figure 11 *Globorotalia peripheroacuta* Blow and Banner, $\times 92$; Sample 253-8-2, 40-42 cm; hypotype: slide FMACN 7708.
- Figure 12 *?Globorotalia pseudomiocenica* Bolli and Bermúdez, $\times 80$; Sample 254-12-1, 40-42 cm; hypotype: slide FMACN 7710.
- Figure 13 *Globorotalia peripheroronda* Blow and Banner, $\times 100$; Sample 254-11-3, 40-42 cm; hypotype: slide FMACN 7709.
- Figure 14 *Globorotalia peripheroronda* Blow and Banner, $\times 112$; Sample 254-11-4, 115-117 cm; hypotype: slide FMACN 7709.
- Figure 15 *?Globorotalia pseudomiocenica* Bolli and Bermúdez, $\times 80$; Sample 254-12-1, 40-42 cm; hypotype: slide FMACN 7710.
- Figure 16 *?Globorotalia pseudomiocenica* Bolli and Bermúdez, $\times 76$; Sample 254-12-3, 141-143 cm; hypotype: slide FMACN 7710.

PLATE 12

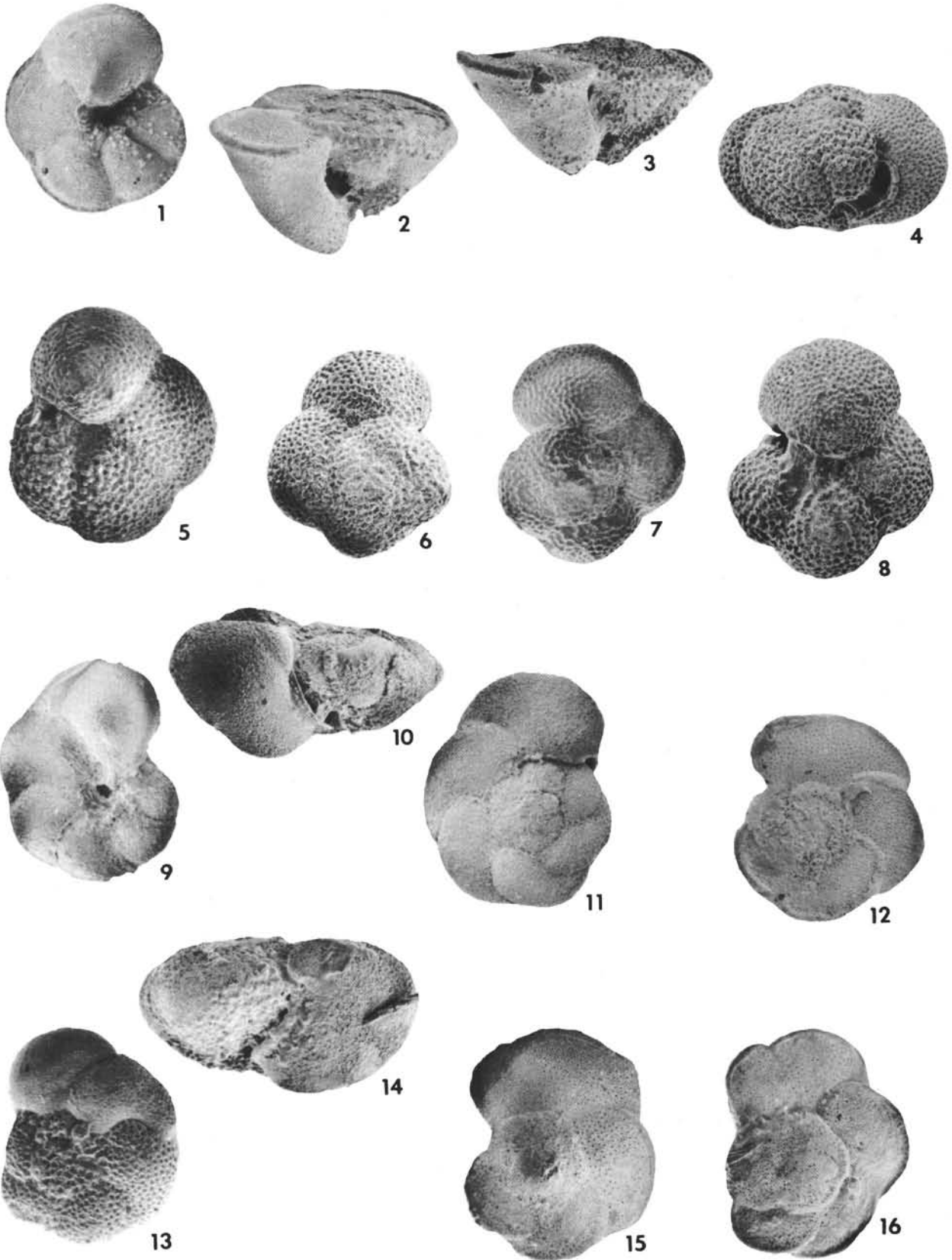


PLATE 13

- Figure 1 *Globorotalia scitula* (Brady), $\times 80$; Sample 258A-1-1, 61-63 cm; hypotype: slide FMACN 7711.
- Figure 2 *Globorotalia pseudobulloides* (Plummer), $\times 80$; Sample 253-11-2, 40-42 cm; hypotype: slide FMACN 7712.
- Figure 3 *Globorotalia pseudobulloides* (Plummer), $\times 92$; Sample 253-12-5, 40-42 cm; hypotype: slide FMACN 7712.
- Figure 4 *Globorotalia* cf. *pseudopima* Blow, $\times 80$; Sample 254-1, CC; hypotype: slide FMACN 7713.
- Figure 5 *Globorotalia tosaensis* Takayanagi and Saito, $\times 80$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7714.
- Figure 6 *Globorotalia tosaensis* Takayanagi and Saito, $\times 80$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7714.
- Figure 7 *Globorotalia tosaensis* Takayanagi and Saito, $\times 52$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7714.
- Figure 8 *Orbulina suturalis* Brönnimann, $\times 160$; Sample 251A-14-1, 10-12 cm; hypotype: slide FMACN 7715.
- Figure 9 *Globorotalia truncatulinoides* (d'Orbigny), $\times 64$; Sample 254-1-2, 115-117 cm; hypotype: slide FMACN 7716.
- Figure 10 *Globorotalia truncatulinoides* (d'Orbigny), $\times 64$; Sample 254-1-2, 115-117 cm; hypotype: slide FMACN 7716.
- Figure 11 *Globorotalia truncatulinoides* (d'Orbigny), $\times 64$; Sample 254-1-2, 115-117 cm; hypotype: slide FMACN 7716.
- Figure 12 *Sphaeroidinella subdehiscens* Blow, $\times 56$; Sample 254-3-4, 115-117 cm; hypotype: slide FMACN 7719.
- Figure 13 *Pulleniatina obliquiloculata praecursor* Banner and Blow, $\times 80$; Sample 258-3 CC; hypotype: slide FMACN 7717.
- Figure 14 *Sphaeroidinella seminulina* (Schwager), $\times 48$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7718.
- Figure 15 *Sphaeroidinella dehiscens* (Parker and Jones), $\times 44$; Sample 254-1-2, 115-117 cm; hypotype: slide FMACN 7720.
- Figure 16 *Sphaeroidinella seminulina* (Schwager), $\times 64$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7718.
- Figure 17 *Sphaeroidinella seminulina* (Schwager), $\times 54$; Sample 254-2-5, 40-42 cm; hypotype: slide FMACN 7718.

PLATE 13

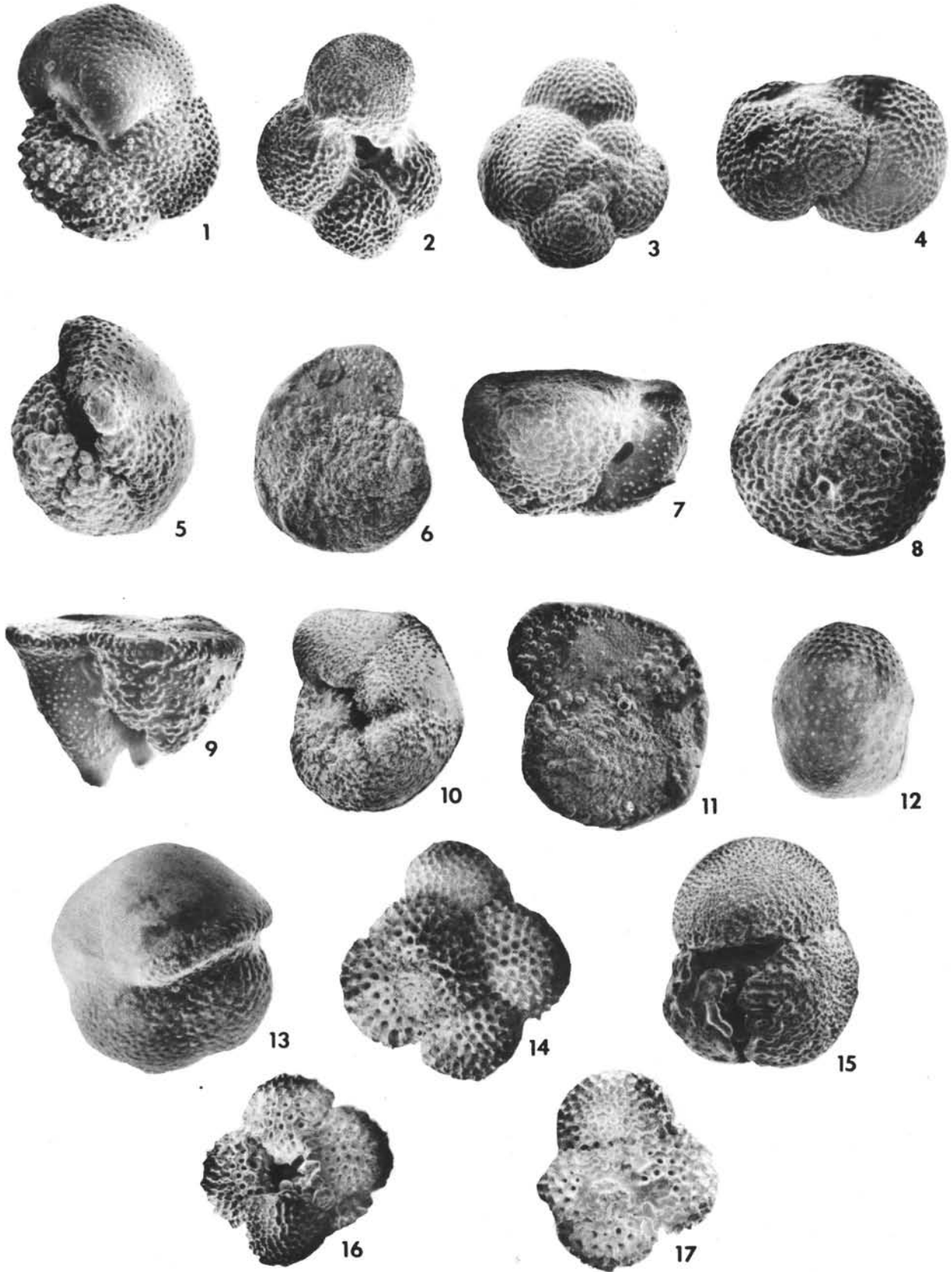


PLATE 14

Figure 1a-b *Globorotalia petaliformis* n. sp., *holospecietypus*,
×48; Sample 254-10, CC; slide FMACN 7646.

Figures 2-16 *Globorotalia petaliformis* n. sp., *paratypi*; slide
FMACN 7648

2. ×40; Sample 254-12, CC
3. ×48; Sample 254-11-2, 115-117 cm
4. ×48; Sample 254-11-2, 115-117 cm
5. ×56; Sample 254-10, CC
6. ×48; Sample 255-4-1, 40-42 cm
7. ×48; Sample 253-7-3, 40-42 cm
8. ×48; Sample 254-10-5, 115-117 cm
9. ×56; Sample 254-10-6, 40-42 cm
10. ×64; Sample 254-10-4, 40-42 cm
11. ×56; Sample 254-10-4, 40-42 cm
12. ×76; Sample 254-11-4, 115-117 cm
13. ×60; Sample 254-11-5, 115-117 cm
14. ×56; Sample 254-11, CC
15. ×40; Sample 254-12, CC
16. ×52; Sample 254-10, CC

PLATE 14

