CHAPTER 19. BIOSTRATIGRAPHY

Maria B. Cita, University of Milano, Italy,
Catherine Nigrini, Scripps Institution of Oceanography, La Jolla, California
and
Stefan Gartner, Institute of Marine Sciences, University of Miami, Florida

CORRELATION BETWEEN THE SITES

The five sites drilled during Leg 2 yielded 78 sediment cores, most of them highly fossiliferous, for a total thickness of about 217 meters and an average recovery of about 34 per cent.

The oldest adequately dated sediments were penetrated at Site 10 (see discussion below). From the oldest to the youngest units, the following biostratigraphic correlations can be established.

Upper Cretaceous

Upper Cretaceous fossiliferous sediments were recovered at Holes 9A and 10. At Hole 9A, Cores 2 and 3, which were cut from 758.2 to 773.8 meters below the ocean floor, yielded Upper Cretaceous microfossils as did Cores 4 to 6, which were cut from 822.8 to 835.5 meters. The thickness of the penetrated Upper Cretaceous section exceeded 77 meters.

At Hole 10, Upper Cretaceous faunas were identified in Core 10 (from 291.2 to 298.8 meters below the ocean floor) and Cores 11 to 19 (from 377.7 to 456.7 meters). The total thickness of the Upper Cretaceous section penetrated at Hole 10 is at least 165 meters.

Neither at Hole 9A nor at Hole 10 was the Cretaceous-Tertiary boundary cored. At both sites volcanic rocks were recovered from beneath the fossiliferous sediments.

A precise biostratigraphic correlation between the two sites is not possible. Foraminifera, especially the planktonic ones, are extremely scarce at Hole 9A while they are rich and abundant at Hole 10, where four biozones have been identified. Two of them are referable to the Campanian stage, two to the Maestrichtian (see discussion on Correlation with Land Sections). The Campanian-Maestrichtian boundary, considered as coincident with the boundary between the *Globotruncana calcarata* and *G. tricarinata* or corresponding zones, falls in Section 4 of Hole 13 at a depth of about 404 meters below the sea floor.

Radiolaria, on the other hand, are found at Hole 9A, but are absent at Hole 10. Nannoplankton recovered in Core 2 of Hole 9A indicate a Maestrichtian age for this level; however, these fossils probably originated from above Core 2 as they were recovered only in disturbed material, such as lumps and smears, and the same assemblages were also recovered sporadically below Core 2 at Hole 9A.

Paleocene

No fossiliferous assemblages of Paleocene age were found in the cores taken during Leg 2, even though it is likely that the Paleocene is present, at least at Holes 9 and 10, where both the uppermost Cretaceous (Maestrichtian) and the Lower Eocene have been identified.

Eocene

The Eocene is present at four of the five holes drilled (8A, 9A, 10 and 12B). In three of them (8, 9, and 12) it is represented by siliceous sediments devoid of calcareous components and fossils. The organic content is represented by Radiolaria, diatoms and sponge spicules.

The radiolarian assemblage at Hole 12B is too sparse to be included in any correlation; however, it is possible to order the material found at Holes 8, 9, and 10. There are, undoubtedly, gaps in the sequence. It is apparent (see section on Eocene Radiolaria Recovered During Leg 2) that samples from Hole 9A are the youngest, but it should be noted that only 9A-1-6, 16-18 cm is an *in situ* sample. Samples 9A-1-4, 70-74 cm is from an isolated lump of green radiolarian ooze in an otherwise barren, brown clay. Sample 9A-center bit is a chert fragment brought up with the center bit prior to coring Core 1 of Hole 9A. Samples from Holes 8 and 8A (at least down to the catcher of 8A-1) are older than Hole 9A samples and younger than Hole 10 samples. It is probable that samples from 8A-2-1, 8A-3, and 8A-4 are older than the Hole 10 samples, but their stratigraphic position is questionable because the fauna is sparse and poorly preserved. Recorded absences are not necessarily meaningful. The assemblage from Hole 10 includes the oldest, well-preserved radiolarians recovered during Leg 2. Based on co-occurring nannofossils, the age of Sample 10-9 is Lower Eocene (approximately *Globorotalia aragonensis* Zone).

Only at Hole 10, where the Lower, Middle and Upper Eocene have been identified through a total thickness of about 100 meters, do Eocene calcareous and siliceous microfossils co-occur. Cores 8 and 9 contain calcareous nannofossils and Radiolaria. The best age assignments were obtained by means of nannofossils (which allowed the assignment of Core 9 to the (*Globorotalia aragonensis* or *Globorotalia formosa formosa* Zone) and of planktonic foraminifera *(Orbulinoides beckmanni* Zone for Core 7).

The association of abundant and well-preserved Radiolaria and of rich and diversified nannofossil assemblages in Cores 8 and 9 should be pointed out. This Lower Eocene assemblage contains no foraminifera, which is difficult to explain on the basis of our present knowledge of the association of calcareous nannoplankton and planktonic foraminifera in the deep-sea sediments.

Oligocene

Fossiliferous Oligocene sediments were recovered only at Site 10, where both the Eocene-Oligocene and the Oligocene-Miocene boundaries were identified. The former falls in Core 5 and is based on nannofossils (disappearance of *Discoaster barbadiensis* and *D. saipanensis*), the latter falls in Core 2 and is based on planktonic foraminifera and nannofossils. However, this second boundary is not quite normal because the Miocene section is much reduced and probably mixed. The total thickness of the Oligocene section at Site 10 is about 30 meters. It is possible that the Oligocene section at Site 10 is also reduced and condensed, chiefly in its lower part.

Miocene

Fossiliferous sediments of Miocene age were found at Holes 8, 9, 10 and 11; however, no precise biostratigraphic correlations are possible between the sites for the following reasons:

(a) At Site 8 the fossils consist of Radiolaria and diatoms, which are lacking in this interval at the other sites.

(b) At Site 9 only the topmost part of the Miocene section has been sampled (see section on Correlation with Land Sections).

(c) At Site 10 the Miocene section is greatly reduced (about 5 meters) and, therefore, is not suitable for detailed biostratigraphic analysis.

(d) At Site 11 the Miocene section is apparently complete from the Middle Miocene up, and is very rich in calcareous microfossils (coccoliths and planktonic foraminifera). It is cored for an interval of about 50 meters, but the core recovery was very poor. The oldest sample (Core 7, Hole 11A) is Middle Miocene in age and probably belongs to the *Orbulina suturalis* Zone. Other biozones have been identified, indicating an age ranging from the Langhian to the Tortonian (see section on Correlation with Land Sections).

(e) It is possible that the Miocene is also present at Site 12, below Core 4, but the lack of any fossils, except for some scanty and dwarfed foraminifera and fish teeth, does not allow any positive statement.

Pliocene

Fossiliferous Pliocene sediments—all of them containing rich assemblages of calcareous microfossils—were cored at Sites 9, 10, 11, and 12.

At Site 9, Cores 7 and 8, cut from 194.5 to 212.6 meters below the mud line, yielded poor foraminiferal assemblages which may be referred to the lower Pliocene (see section on Correlation with Land Sections). The most significant species is *Globigerina nepenthes,* whose range crosses the Miocene-Pliocene boundary.

Better evidence is given by nannofossils and they confirm this age assignment. *Discoaster brouweri, D. pentaradiatus, D. variabilis* and *D. surculus* are present throughout Cores 7 and 8, as well as *Reticulofenestra pseudoumbilica* and *Sphenolithus abies. Ceratolithus tricorniculatus* and *Ceratolithus rugosus* are present in Core 8, indicating an age no older than early Pliocene.

At Site 10 a middle to lower Pliocene section is present in Core 1 and at the top of Core 2, for a total thickness of about 10 meters. Core 1 was cut from 29.9 to 40 meters below the mud line.

The middle Pliocene (probably Zone N.20 of Blow, 1968) is present in the upper part of Section 1, Core 1, where foraminiferal faunas with *Globoquadrina altispira, Globorotalia multicamerata, G. miocenica* (comparable with the assemblages present in Section 1 of Core 4, Hole 12C) are found. Lower in Section 1, Core 1, *Sphaeroidinellopsis* appear to be common and at 64 meters of Section 2 the last occurrence of *Globigerina nepenthes* is noted. These assemblages indicate an early Pliocene age and may be referred to Zone N.19 of Blow (1968). They may be correlated with the assemblages recovered in Sections 2 through 4 of Core 4, Hole 12C (Cape Verde).

The calcareous nannofossils also indicate a late Pliocene age for the upper part of Section 1, Core 2, which contains *Discoaster brouweri, D. surculus, D. pentaradiatus, Ceratolithus rugosus* and the placolith cf. *Coccolithus cricotus.* The last named species occurs only above 125 centimeters of Section 1, Core 1, where it is associated with *Reticulofenestra pseudoumbilica,* which does not occur in the upper Pliocene. Early to middle Pliocene nannofossils, characterized by *Ceratolithus tricorniculatus* and *Sphenolithus abies,* occur in the lower part of Core 1 and in Section 1 of Core 2. The absence of *Ceratolithus rugosus* at 143 centimeters in Section 1, Core 2 may indicate an uppermost Miocene (Messinian) age for this level (Bukry and Bramlette, 1968).

At Site 11 a mixed Pleistocene-Lower Pliocene assemblage is present in Section 4 of Core 1, which was cut from 12.2 to 21.3 meters below the mud line.

A pure Lower Pliocene foraminiferal fauna was found at 125 centimeters of Section 4, containing *Globigerina nepenthes, Globorotalia margaritae, Sphaeroidinellopsis seminulina, S. subdehiscens, Globorotalia menardii, G. multicamerata, Candeina nitida, Globoquadrina altispira, Globigerinoides obliquus extremus,* etc. This assemblage indicates a pre-*Sphaeroidinella* datum age and may be referred to the topmost part of Zone N.18 of Blow (1968). It is the oldest Pliocene which the authors were able to identify by means of planktonic foraminifera during Leg 2. The assemblage is much richer and more diversified than those in the same stratigraphic position in Sites 9, 10 and 12 and, therefore, allows a more precise age determination. This is due to the lesser water depth at Site 11, which was above the carbonate compensation depth during all of the about 14 to 18 million years in which the sedimentary sequence overlying the volcanic rock was deposited.

Section 4 of Core 1 contains Pliocene calcareous nannofossils from about 30 centimeters on down. At 65 centimeters, *Coccolithus cricotus* is well developed along with *Ceratolithus rugosus, Discoaster brouweri* and other asteroliths, thus indicating a late Pliocene age. At 85 centimeters, small specimens of *Reticulofenestra pseudoumbilica* and *Cyclococcolithus aequiscutum* are present in addition to the above specimens. probably indicating a middle Pliocene age. From 95 centimeters to 145 centimeters *Coccolithus cricotus* is lacking but *Sphenolithus abies* and *Ceratolithus tricorniculatus* are present, indicating an age no younger than early Pliocene. The absence of *Ceratolithus rugosus* at 145 centimeters may indicate this level to be of late Miocene (Messinian) age (Bukry and Bramlette, 1968).

In Site 12 it was possible to identify, by means of planktonic foraminifera, the upper, middle and lower Pliocene. However, the topmost part of the Pliocene is lacking; in fact, *Globorotalia multicamerata* and *G. miocenica,* which are known to have become extinct within the range of *Globorotalia tosaensis* a short time before the first appearance of *G. truncatulinoides,* are present up to the topmost sample referable to the Pliocene. below the disturbed interval (see below). It was not possible to document the presence of the lowermost Pliocene, but the absence of some characteristic species such as *Globigerina nepenthes* and *Globorotalia margaritae* may be related to the sparse and poorly preserved assemblages.

The total thickness of the fossiliferous Pliocene section at Cape Verde is about 13 meters, excluding the disturbed interval with mixed upper Pliocene and Pleistocene faunas. About two thirds of this thickness may be referred to the upper Pliocene (Zone N.21 of Blow, 1968) since it yields a foraminiferal assemblage with *Globorotalia tosaensis,* abundant *G. multicamerata, G. exilis* and *G. miocenica,* which is younger than the horizon of extinction of *Sphaeroidinellopsis* spp. and of *Globoquadrina altispira.*

The middle and lower Pliocene are more reduced, being represented in Section 1 (pars) to 3 of Core 4 (Hole 12C) for a total thickness of about 4 meters. Core 4 was cut from 32.6 to 41.8 meters below the mud line. The core recovery was only 50 per cent, and it was technically impossible to locate with precision the cored interval. However, a biostratigraphic correlation with Core 5 (Hole 12D) which was cut from 27.4 to 36.6 meters and had a core recovery of 100 per cent indicated that the three sections of Core 4 (Hole 12C) represent the lower part of the cored interval, since they yielded foraminiferal faunas indicating an age older than the horizon of extinction of *Sphaeroidinellopsis seminulina* and *Globoquadrina altispira.*

Since the faunal changes are gradual the authors think that, though condensed, the section has no significant gaps.

The calcareous nannofossils are essentially in agreement with the picture presented by the planktonic foraminifera, except that the topmost Pliocene may be represented near the base of Core 2R, Section 1, as indicated by cf. *Coccolithus cricotus, Discoaster brouweri* and ceratoliths transitional between *Ceratolithus rugosus* and *Ceratolithus cristatus.* This interval is above the disturbed zone in Core 2R (Hole 12C).

The oldest Pliocene sediments at Site 12 were recovered in Section 3 of Core 4 (12C). The nannofossils present at this interval include *Discoaster brouweri, D. pentaradiatus, D. surculus, D. variabilis, Reticulofenestra pseudoumbilica* and *Ceratolithus rugosus.* The complete lack of *Sphenolithus abies* and *Ceratolithus tricorniculatus* suggests that the lower part of the lower Pliocene interval is missing.

Pleistocene and the Plio-Pleistocene Boundary

Pleistocene sediments, all of them richly fossiliferous, were cored at Sites 9, 11 and 12.

A contact between the Pliocene and the Pliestocene has been identified at Sites 11 and 12, but in both cases some anomalies were observed, and a biostratigrpahically continuous, normal succession seems to be lacking.

At Site 9, six cores for a total thickness of about 80 meters were taken from the Pleistocene. However, only Core 5 had a good recovery and was investigated in some detail (see summary on Biostratigraphy of Site 9), giving assemblages of Radiolaria, foraminifera and coccoliths irregularly distributed within the sediment. The core catcher of Core 6 yielded an assemblage of planktonic foraminifera indicating the lower Pleistocene and a nannoflora with cf. *Coccolithus cricotus, Gephyrocapsa* sp. and rare *Discoaster brouweri* which indicate the proximity of the Pliocene-Pleistocene boundary. The assemblage mentioned before is the oldest recovered from the Pleistocene of the entire Leg 2 of the Atlantic cruise, expect possibly Section 1, Core 2R, at Hole 12C.

At Hole 11, one core was cut from 12.2 to 21.3 meters. yielding Pleistocene assemblages of planktonic foraminifera and coccoliths from Section 1 to 3. In Section 4, a mixture of Pleistocene and Pliocene assemblages was found from the top down to 55 centimeters. At 85 centimeters a middle Pliocene nannoflora is present, giving way to a lower Pliocene assemblage from 95 to 125 centimeters, and lower Pliocene, possibly upper Miocene (Messinian) at 145 centimeters. A rich lower Pliocene foraminiferal fauna is present at 125 centimeters.

The Pleistocene section of Site 12 was continuously cored, with a good recovery. It is very interesting for its extremely rich and diversified foraminiferal and nannofossil assemblages. However, since the cores were sealed and frozen for later shipment, it was impossible to carry on a detailed study of this section before the delivery of this report.

A Holocene-Pleistocene interval is present in the upper part of the section for about 15 meters. Lower in the section, a disturbed interval is present with mixed Pleistocene and Upper Pliocene assemblages. Species which, according to some recent and well documented biostratigraphic studies, are known to be mutually exclusive, such as *Globorotalia truncatulinoides, Pulleniatina obliquiloculata finalis, Globigerina digitata,* pink *Globigerinoides ruber* (Pleistocene) and *Globorotalia multicamerata, G. miocenica, Globigerinoides fistulosus* (Pliocene), are present in the same samples. Mixed assemblages including exclusively Pleistocene and exclusively Pliocene (or older) nannofossil species have been found in the same samples in which mixed foraminiferal faunas are present.

Two hypotheses may be advanced:

(a) The mixing has been artificially introduced by coring operations;

(b) The mixing is due to submarine slides which took place during the Pleistocene.

The Cape Verde Site was drilled several times, and a complete double set of cores was taken for its upper part. Mixed Pleistocene and upper Pliocene foraminiferal and nannofossil assemblages have been found in Section 2 of Core 2R (Hole 12C) and in Section 2 through 4 of Core 4 (Hole 12D). The mixed interval occurs between 13.4 and 23.5 meters below the sea floor in the first case and between 18.3 and 27.4 in the second.

The fact that the same kind of mixing has been found in both sites at about the same depth speaks in favor of hypothesis (b).

Since the first section of Core 2R, Hole 12C, is not contaminated, it may be assumed that the mixed interval lies below 15 meters beneath the mud line.

CORRELATION WITH LAND SECTIONS

Introduction

One of the main objectives of the Deep Sea Drilling Project is "to recover sedimentary sections for paleontologic and stratigraphic studies in areas where undisturbed sedimentation is believed to have taken place" (JOIDES, 1967). In particular, Site 12 drilled at Cape Verde during Leg 2 was chosen because the Atlantic Advisory Panel believed that it would provide a deep-sea equivalent of the Tertiary stratotypes which have been established in Western and Southern Europe.

The scientists of Leg 2 attempted to correlate the biostratigraphic sequences recorded with the known successions of faunas and/or floras on both sides of the Atlantic, from Site 12 and for all sections from other sites, integrating the data obtained from the study of foraminifera (M. B. C.), nannofossils (S. G.) and Radiolaria (C. N.).

In the following pages, comments on these correlations are arranged in stratigraphic order.

Upper Cretaceous

Cores 10 to 19 at Site 10 yielded rich assemblages of planktonic foraminifera correlative with the Campanian and Maestrichtian stages.

Four of the five foraminiferal zones known from the stratigraphic interval were recognized in their normal succession, as shown in the following chart.

Stages	Zonation Bolli 1966 (Modified)	Zones Recognized in Site 10
Maestrichtian	*Globotruncana mayaroensis*	*Globotruncana mayaroensis* (Core 10)
	Globotruncana gansseri	Not Cored
	Globotruncana tricarinata	*Globotruncana tricarinata* (or correspondent) (Core 11 to 13 pars)
Campanian	*Globotruncana calcarata*	*Globotruncana calcarata* (Core 13 pars, Core 14 and Core 15, pars)
	Globotruncana elevata	*Globotruncana elevata* (Core 15, pars to Core 19)

The first biozonations of the Upper Cretaceous by means of planktonic foraminifera were proposed in North Africa (Sigal, 1952, 1955; Dalbiez, 1955), in Trinidad (Bolli, 1957), and in the Alps (Klaus, 1959).

After more than ten years of detailed biostratigraphic investigations in different parts of the world, the present state of the zonation is satisfactory, inasmuch as there is a fairly good agreement with the data available on the planktonic foraminifera from the stratotypes of the Campanian (Van Hinte, 1965), and Maestrichtian (Hofker Sr., many papers) stages.[1]

A correlation of the North American time units (Taylor with the Campanian and Navarro with the Maestrichtian) is also usually accepted.

The Upper Cretaceous section cored on the west flank of the Mid-Atlantic Ridge confirms both the validity of the zonation and the correlation between the North American time units and the European reference sections.

The calcareous nannofossils of the Upper Cretaceous, although more than adequately represented both in number of species and in quantity of material, are insufficiently known at this time to allow making a zonation as refined as that based on planktonic foraminifera. Only one zone, the *Lithraphidites quadratus* Zone, roughly equivalent to the Maestrichtian, was identified with certainty. Presumably the sample material from Site 10 could serve as the basis for making a refined nannofossil zonation at least for part of the Upper Cretaceous interval.

The Eocene-Oligocene Boundary

The Eocene-Oligocene boundary is contained at the top of Section 5 of Core 5 at Hole 10; and, the evidence for this, based on calcareous nannofossils, is quite clear. The planktonic foraminifera, being strongly controlled by depth of deposition or carbonate compensation level, are too poor and scanty to allow any reasonable age determination and/or correlation (see Comments on Paleoenvironments).

The upper limit of the uppermost Eocene nannofossil zone, the *Isthmolithus recurvus* Zone, is defined by the last occurrence of *Discoaster barbadiensis* and *D. saipanensis.* Both of these species have their highest occurrence at the top (20 to 40 centimeters) of Section 5 of Core 5 and they are not found in Section 4 of Core 5. *Isthmolithus recurvus* and *Bramletteius serraculoides,* two characteristically upper Eocene species, continue into Section 4 of Core 5 (lowermost Oligocene).

The Upper Eocene reference section, the Priabonian, also contains a nannoflora of the *Isthmolithus recurvus* Zone, with *Discoaster barbadiensis* (see Cita *et al.*, 1968).

The calcareous nannoflora of the Oligocene stratotype in northern Germany is insufficiently known. However, Levin and Joerger (1967) found *Discoaster barbadiensis* lacking in the lowermost Oligocene of Alabama, as did Bramlette and Wilcoxon (1967), and in the Blake Plateau JOIDES Cores 3 and 4. The above authors did record *Ishmolithus recurvus* from the lower Oligocene.

Miocene

The Miocene section penetrated at Site 11 is very interesting and might be useful for correlation of Miocene transatlantic land sequences. Unfortunately, core recovery was very poor, so that there is only scattered data instead of a continuous section to examine.

The subdivision of the Miocene (and Oligocene) column by means of planktonic foraminifera started in the Caribbean area more than twenty years ago. Cushman and Stainforth (1945), Cushman and Renz (1947). and Bolli (1951 and 1957) gave more and more detailed zonations based on the sections studied in Trinidad, while Blow (1959), introducing minor modifications, applied Bolli's 1957 zonation to Venezuela.

---

[1] In the Core Description Manual the Campanian-Maestrichtian boundary is considered to be slightly above the upper boundary of the *Globotruncana calcarata* Zone. This is not in agreement with the views held by most European biostratigraphers familiar with the Upper Cretaceous. The boundary placement as discussed in the manual is based on unpublished, and as yet inadequately documented material, and, therefore, cannot be accepted without further proof.

In the meantime, investigations were made also on the planktonic foraminifera of the European stratotypes. The first correlations with the Caribbean zonations were tentative (see Cita and Premoli, 1960) because, mainly in the Middle Miocene, the species used as zonal markers, such as *Globigerinatella insueta, Globorotalia fohsi fohsi, G. fohsi lobata, G. fohsi robusta,* appear to have a limited geographical range and are restricted to tropical and/or subtropical areas.

The problem of Miocene intercontinental correlations was successively drawn to a state of great confusion by two widely read but misleading papers: Eames, *et al.* (1962) and Bandy (1964). At this point the importance of the Committee for Mediterranean Neogene Stratigraphy (CMNS) and particularly of the Working Group Micropaleontology, more especially the work of C. W. Drooger, should be pointed out. In a meeting held in Bern (1964) a rough zonation useful for the Mediterranean area and based on some datum planes which can be easily recognized both in the tropical and in the temperate areas was discussed and compared with the more refined, but in temperate areas practically unusable, Caribbean zonation (see Proceedings of the CMNS Session in Bern, 1966). These datum planes are based on the first evolutionary appearance of a genus (such as *Globigerinoides, Praeorbulina, Orbulina*) or of a species (such as *Globigerina nepenthes, Globorotalia menardii*). The position of the stratotypes in the biostratigraphical column was then discussed in terms of tropical zonation and of world-wide datum planes.

The same thinking prevailed in the CMNS 1967 Meeting held in Bologna, and the world-wide datum planes proved to be successful.

As a practical application of this method of work, we may consider Cores 2 to 7 at Hole 11A. Core 2 contains *Orbulina universa* and *Globigerina nepenthes* and thus lies above the *G. nepenthes* datum plane. Core 4 contains *Orbulina universa* and *O. suturalis* but does not contain *Globigerina nepenthes* and thus lies below the *G. nepenthes* datum and above the *Orbulina* datum. The basement (Core 7) contains *Orbulina* and, therefore, lies at or slightly above the *Orbulina* datum. The presence of *Globorotalia menardii* in Core 2 and of *Globorotalis fohsi robusta* in Core 4 gives further evidence for the position discussed above in terms of datum planes and permits zonal assignments.

The stratotypes of the Miocene stages defined in Italy and used in the Core Description Manual are clearly located with reference to the accepted datum planes. The Langhian stage, as stratotypified by Cita and Premoli (1960) starts at the *Praeorbulina* datum and contains the *Orbulina* datum plane (base of the *Orbulina suturalis* Zone of the previously named authors). The Tortonian stage, as stratotypified by Gianotti (1953) and with reference to the study of planktonic foraminifera by Cita, Premoli and Rossi (1965), starts probably above the *Globigerina nepenthes* datum.

But the Langhian and Tortonian stages are not consecutive: the stratotype sections are separated by an important body of strata (the "Elveziano" of some Italian authors) which contains planktonic foraminifera of post-*Orbulina* and pre-*Globigerina nepenthes* age comparable to the assemblages found in Core 4.

Pareto (1865), who originally defined the Langhian stage, defined a Serravallian stage consecutive to the Langhian and prior to the Tortonian. The possibility of using the term Serravallian for the stratigraphic interval involved was discussed at the CMNS Meetings in Sabadell (1961) and in Bologna (1967), but no final decision was made. At any rate, a Langhian-Tortonian boundary as indicated by Blow (1969), by Berggren (in press) and as used in the Core Description Manual is arbitrary and disregards the known stratotypes and the pertinent literature.

The Langhian stage stratotype corresponds to the *Globigerinoides bisphaericus* (pars) and *Globorotalia fohsi barisanensis* (pars) Zones of Bolli (1966); it also corresponds to the *Globigerinoides sicanus/Globigerinatella insueta* Zone N.8 of Blow (1968) and to his *Orbulina suturalis/Globorotalia peripheroronda* Zone N.9. W. H. Blow (1969) expressly considered the Cessole Formation (stratotype of the Langhian stage) as a paratype locality of both Zones N.8 and N.9.

It is strongly recommended that the term Langhian be used as a time-equivalent of the previously mentioned biostratigraphic units, and of these alone.

The Tortonian stage (stratotype) starts slightly above the *Globigerina nepenthes* datum plane, and yields *Globorotalia acostaensis* starting from Level 4 (of Cita, Premoli, Silva and Rossi, 1965). Therefore, it may be correlated, excluding the lower part, with the *Globorotalia acoustaensis* Zone of Bolli (1966) and with the *G. acostaensis acostaensis-G. merotumida* Zone N.16 of Blow (1969).

Blow's index Zones N.11 to N.14 are not represented in the type Langhian nor are they in the type Tortonian. The term Serravallian may be correctly used for this stratigraphic interval.

The Miocene-Pliocene Boundary

The Miocene-Pliocene boundary may be contained within Section 1 of Core 2 at Hole 10, where a foraminiferal fauna with *Sphaeroidinellopsis seminulina* and *S. subdehiscens,* but no true *Sphaeroidinella* and a nannoflora with *Ceratolithus tricorniculatus* are present. However, this cannot be established with absolute certainty because of problems involved in (a) reference sections and (b) world-wide zonations.

(a) The reference section for the uppermost Miocene, the Messinian, is gypsiferous and mostly barren of planktonic foraminifera. However, its topmost part (Level 7 "marne argillose superiori" of Selli, 1960) contains *Sphaeroidinellopsis seminulina* and *S. grimsdalei.*

Two reference sections for the basal Pliocene are known in Italy; the Tabianian, which conformably underlies the Piacenzian (middle Pliocene) in the north Appenninic borderland, and the Zanclian, defined in Sicily ("Trubi" formation), overlying the Messinian.

The Tabianian, at Tabiano, contains numerous planktonic foraminifera among which *Globorotalia margaritae* (*G. hirsuta* in Iaccarino, 1967) and *Globoquadrina altispira* (see Iaccarino, 1967, and Barbieri, 1967). The "Trubi" formation contains a rich planktonic fauna with *Globorotalia margaritae, Globoquadrina altispira, Sphaeroidinellopsis seminulina, Sphaeroidinella dehiscens,* etc.

(b) In the world-wide zonation proposed by Bolli (1966) the Miocene-Pliocene boundary lies between the *Globoquadrina altispira altispira* and the *Globoquadrina altispira altispira/Golborotalia truncatulinoides* Zones, whose delimitation is given by the first occurrence of *Globorotalia truncatulinoides.* This boundary is arbitrary and is not in agreement with the reference sections examined above.

In the world-wide zonation proposed by Blow (1968) the Miocene-Pliocene boundary falls within Zone N.18 (*Globorotalia tumida tumida/Sphaeroidinellopsis subdehiscens paenedehiscens*) which is defined in the Bowden formation (Buff Bay section, Jamaica). No sharp or definite break is observed within this zone, whose upper boundary is defined by the first evolutionary appearance of *Sphaeroidinella dehiscens dehiscens* (base of the *Sphaeroidinella dehiscens dehiscens/Globoquadrina altispira altispira* Zone N.19). This boundary is more reasonable, but in practice it is difficult to detect (pre-*Sphaeroidinella dehiscens* datum).

In a recent discussion of planktonic foraminiferal zonations suitable for the Mediterranean area (see Cati *et al.,* 1968), most of the authors involved were in agreement on a *Globorotalia margaritae* Zone for the Lower Pliocene, underlain by a *Sphaeroidinellopsis* Zone (or subzone) characterized by the great abundance of this genus. However, some of the authors considered this *Sphaeroidinellopsis* Zone as lowermost Pliocene, others as topmost Miocene.

As a conclusion of this discussion, the choice of the *Sphaeroidinella dehiscens* datum as the base of the Pliocene would have the advantage of a clear and easy biostratigraphic means to detect the Miocene-Pliocene boundary both in tropical and temperate areas, and would not be in conflict with the data available from the reference sections. However, at the present state of our knowledge of these sections, it seems prudent to defer making a final conclusion.

A probable late Miocene (Messinian) age may be indicated for the lower part of Section 1, Core 2, Hole 10, by the presence of well-developed *Ceratolithus tricorniculatus* and the absence of the somewhat younger *Ceratolithus rugosus.* The first species is present in the uppermost marine shale of the type Tortonian section, which is assigned to the Messinian by Italian micropaleontologists (see Bukry and Bramlette, 1968). The second species is lacking there.

In the San San clay of Jamaica, *C. tricorniculatus* first appears at the base of that unit (Blow's Zone N.17 or N.18); but, *C. rugosus* first appears at the top of the San San clay (Blow's Zone N.19).

Pliocene

A biostratigraphic subdivision of the Pliocene by means of planktonic foraminifera dates back only a few years (see Banner and Blow, 1965; Bolli and Bermudez, 1965; Bolli, 1966, etc.) and, therefore, must still be considered tentative in some aspects.

Valuable additions to our knowledge of Pliocene biostratigraphy were given by the study of deep-sea piston cores (see Parker, 1967; Saito, In Hays, *et al.,* in press etc.), most of which were from tropical areas.

The most detailed zonation now available is that of Blow (1959) which is based on land sections and on deep-sea cores. The type-localities for each zone are defined on land sections, most of them located in the Caribbean area. The zonation is as follows:

N.22 *Globorotalia truncatulinoides truncatulinoides*	PLEISTOCENE
N.21 *Globorotalia tosaensis tenuitheca*	PLIOCENE
N.20 *Globorotalia multicamerata-Pulleniatina obliquiloculata obliquiloculata*	
N.19 *Sphaeroidinella dehiscens dehiscens/Globoquadrina altispira altispira*	
N.18 *Globorotalia tumida tumida/ Sphaeroidinellopsis subdehiscens paenedehiscens*	MIOCENE

At the CMNS Meeting held in 1967, several zonations mostly based on planktonic foraminifera were proposed for the Mediterranean region, where the reference sections for the Pliocene stages may be found. Most of the authors concerned participated in a meeting in 1968, which resulted in the zonations for the Pliocene of the Mediterranean region shown in Table 1 (see paper by Cati *et al.,* 1968).

During Leg 2 the Pliocene sections penetrated at Sites 10, 11 and 12 cover most of the Pliocene, with the possible exception of the top. It was possible, therefore, to check the different zonations, particularly at the Cape Verde Site 12, the purpose of which was mainly the correlation between the tropical zonations and the Mediterranean type-sections.

As a result of these investigations, which are still preliminary, it may be said that the Mediterranean zonations are not suitable for the Atlantic sections here considered, because the definitions of the zones are based on the first appearance or on the disappearance of taxa which have different ranges in tropical or subtropical areas, and because no datum planes are defined which might be used to identify the zones to which they are referred.

The zonation originally proposed by Banner and Blow (1965) and subsequently refined by Blow (1969) proved to be useful, even though some zonal boundaries are not clearly identifiable. Particularly useful were some datum planes (such as, the horizon of extinction of *Globigerina nepenthes, Globoquadrina altispira, Globorotalia multicamerata, G. miocenica*), the position of which with reference to the zones are discussed in Parker (1967), Blow (1969) and Berggren (in press).

A valuable control is also given by the position of the considered interval with reference to two well-known evolutionary lineages: the *Sphaeroidinellopsis-Sphaeroidinella* lineage and in the *Pulleniatina* lineage.

Earlier attempts at a zonation of the Pliocene interval proved not entirely satisfactory. The zonation proposed by Hay and Schmidt and by Hay and Boudreaux (in Hay *et al,* 1967) is somewhat cumbersome.

TABLE 1.
Pliocene-Zonations

NORTHERN AND CENTRAL ITALY		GREECE, SICILY	SPAIN
Zone	Sub-Zone	Zone	Zone
Globorotalia inflata		*Globorotalia inflata/ Globorotalia tosaensis*	
Globorotalia crassaformis		*Globorotalia crassaformis* s.l.	
Globorotalia aemiliana			
Globorotalia margaritae	*Globorotalia bononiensis*	*Globorotalia puncticulata*	*Globorotalia puncticulata*
	Globorotalia puncticulata		
	Sphaeroidinellopsis	*Globorotalia margaritae*	*Globorotalia margaritae*
Not defined		*Sphaeroidinellopsis*	

COMMENTS ON PALEOENVIRONMENTS

The fossil assemblages investigated consisted of:

(a) Foraminifera, both benthonic and planktonic, the latter strongly dominating;
(b) Calcareous nannoplankton (Coccoliths, Discoasterids);
(c) Radiolaria;
(d) Diatoms;
(e) Fish teeth;
(f) Ostracodes; and
(g) Sponge spicules, etc.

The presence and relative abundance of the various groups are highly variable, according to the different ecologic conditions and/or to the different conditions of preservation during deposition or after burial.

Displaced faunas were never found, which is in agreement with the absence of true turbidites. However, single specimens of benthonic foraminifera were observed, the presence of which in deep-sea deposits is quite unusual. Quite commonly, both in the Pleistocene and in the Tertiary sediments, some specimens of corroded *Quinqueloculina* and *Triloculina* were found. It is thought that empty shells of these imperforate foraminifera, which possess a single and small aperture, may float for a long time over long distances and that they fall to the ocean floor only when holes are formed by corrosion. They may also be transported into the open ocean attached to sargassum or other floating sea weed.

Corrosion of the foraminiferal tests was often observed. especially in the Pleistocene and Pliocene deposits. Some *Sphaeroidinella* and *Sphaeroidinellopsis* lost their cortex (*sensu* Banner and Blow, 1960) showing the inner test. Also, some *Globorotalia* and *Orbulina* show a dissolution of the outer layer of the test.

Fragmentation of the tests was also commonly observed. It is thought that in most cases this is due to dissolution (see Berger, 1967) rather than to burrowing organisms because: (a) fragmentation of the foraminifera shells is common in sediments approaching the carbonate compensation depth; and (b) the fragments belong only to planktonic foraminifera, and usually are very thin and highly perforated, with pores possibly widened by dissolution, while benthonic species show entire tests.

Selection of the species of planktonic foraminifera preserved appears quite clearly in the Eocene-Oligocene section penetrated at Site 10. In the middle Eocene the assemblages are far less diversified than is common in the stratigraphic interval considered and consist mainly of the genera *Globigerinita, Globigerapsis* and *Orbulinoides,* all characterized by a subspherical shape and a massive test. Also, rare *Globigerinas* are present, always rounded. Most of the taxa known from the Middle Eocene are lacking, including the spinose *Globorotalias,* the thin-shelled *Hantkeninas,* etc. The authors have no reference in the literature to similar findings, probably because Eocene pelagic sediments deposited in water depths comparable to Site 10 have never been found on dry land. However, the experimental results obtained by Berger (1967) on the dissolution of Recent or sub-Recent planktonic foraminifera in the central Pacific are in agreement with their observations, because the highest dissolutions found by him were in species with thin or spinose shells.

The faunal diversity is also very small in the Upper Eocene and Oligocene sections, and a marked selection of the planktonic species present is thought to be related to the structure of the wall. *Globigerinita* is always the most common genus and a single species (*G. unicava*) may represent up to 90 per cent of the planktonic foraminiferal population.

Because strong differences in the assemblages–presumably related to environmental changes–were observed in the stratigraphic column, and taking into account that for the first time the possibility of investigating deep-sea sediments in a continuous sequence lasting over 80 million years is offered to scientists, the authors have analyzed in some detail the data available, starting with the youngest deposits, as follows:

Pleistocene

Cores from near the ocean floor were taken at four of the five sites drilled during Leg 2; all of them yielded calcareous microfossils, regardless of water depth, as may be seen by the following:

Site 9 (water depth, 4969 meters):
Cores 1 to 5 (0-60.5 meters) - calcareous nannofossils, foraminifera and Radiolaria (Pleistocene).

Site 10 (water depth, 4697 meters):
Abundant coccoliths and foraminifera (Pleistocene).

Site 11 (water depth, 3556 meters):
Core 11 (12.2-21.3 meters) - coccoliths and foraminifera (Pleistocene).

Site 12 (water depth 4542 meters):
Cores 1 to 4 (0 to about 40 meters) - very rich calcareous nannoplankton and foraminifera (Pleistocene-Pliocene).

At Site 8 (water depth 5169 meters) cores were not taken above - 167 meters, and the first core yielded Miocene Radiolaria and diatoms, but no calcareous microfossils. However, according to the data obtained by *Vema* at the same location, foraminifera were present at and near the surface.

The conclusion may be drawn that, according to the present investigations, during Pleistocene times all the sites, including the deepest one (5169 meters) were at or above the carbonate compensation depth.

Pliocene

At Sites 10 and 12, which were cored almost continuously in their upper parts and were drilled to similar depths (see above), the foraminiferal content decreases strongly during the Lower Pliocene, and often the assemblages consist chiefly of broken tests. A change in the carbonate compensation depth, related either to a rise of the sea floor after the Lower Pliocene or to a change in the chemistry of the water masses, seems likely. In the case of the Cape Verde Site 12, the latter hypothesis may be accepted, being related to documented volcanic activity of the area. A third hypothesis of a change due to temperature increase from the Miocene to the Pliocene is considered unlikely, because no geological evidence can be found to support this assumption.

Miocene

Environmental conditions during the Miocene appear more strictly related to the present depth of the areas investigated than do those during the intermediate periods.

At Site 8 (water depth 5169 meters) the Miocene section penetrated is devoid of calcareous microfossils; sedimentation probably took place below the carbonate compensation depth.

At Site 10 the Miocene section is strongly condensed and partly missing and, therefore, is not suitable for observations concerning the environment of deposition; however, calcareous microfossils (both coccoliths and planktonic foraminifera) are present, the latter consisting of poor assemblages composed of selected species.

At Site 11, the shallowest drilled in Leg 2, the Miocene section is very rich in planktonic foraminifera, whereas, the nannofossils, though numerous, are less diversified than usual and the discoasters especially show corrosion.

At Site 12 the probable Miocene/pre-Pliocene section penetrated was clearly deposited below the carbonate compensation depth because the organic content of calcareous fossils is extremely poor, consisting of fish teeth, sponge spicules, very rare dwarfed planktonic foraminifera, and some benthonics with arenaceous tests which are sometimes coated with manganese.

Oligocene and Eocene

The Oligocene section penetrated at Site 10 is very interesting from an environmental standpoint. The sediments are rich in calcareous nannofossils, which, although not highly diversified, are well preserved. The foraminiferal assemblages, on the contrary, are scarce and controlled by carbonate compensation depth. While the benthonic forms are relatively common, the planktonic ones belong to a small number of taxa and most of the species known from the considered stratigraphic interval are not present. The genus *Globigerinita* is the best represented. Its wall structure, which is less subject to solution, is considered to be responsible for the relative abundance. Most of the specimens have an empty test—only the outer wall being preserved. It is thought that the umbilical bulla, which characterizes the genus *Globigerinita,* played a certain role in protecting the external wall from dissolution.

Fish teeth and sponge spicules are also present; their chemical compositions make them resistant to dissolution.

In addition, in the Upper and Middle Eocene section penetrated at Site 10, the planktonic foraminifera assemblages are oligotypical, as discussed above. The benthonic forms, on the contrary, are normally diversified; the plankton/benthos ratios appears to be very low probably because most of the planktonic species underwent dissolution.

It should be pointed out that the calcareous nannofossils at this level show no evidence of corrosion by dissolution.

The great abundance of Radiolaria and other siliceous organisms in all of the Eocene sections penetrated must be pointed out. Only at Site 10 are calcareous nannofossils present with Radiolaria in the Lower Eocene. But at Sites 8, 9 and 12, that is both in the Western and Eastern Atlantic, only siliceous microfossils are present. This fact suggests a major change—possibly connected with volcanic activity—in the chemistry of the water masses during the Lower Eocene and/or a major change in the water circulation.

Cretaceous

A sharp difference between the fossil assemblages of the Lower Eocene and the Upper Cretaceous was observed both at Sites 9 and 10. According to Funnell (1964) during the Upper Cretaceous the Atlantic was one-half to two-thirds as large as it is at present. It was probably more shallow than it is at present, at least in the central part occupied by the present Mid-Atlantic Ridge. This shoaling is a possible cause for the great abundance of calcareous microfossils in the Upper Cretaceous, as found in Site 10. The diversity of the foraminiferal faunas is great and the preservation of the tests, even of the finest structures such as spines, tegillae and beads—which show no corrosion—is exceptional. Few broken tests were observed. As planktonic foraminifera tests have been shown to be most sensitive to solution effects, it may be concluded that during Upper Cretaceous times the water masses near the ocean floor were saturated with calcium carbonate or that some other condition existed which was unfavorable to solution penetration. Further evidence for a shallower deposition at Site 10 during the Upper Cretaceous is given by the rate of sedimentation which is higher in the considered stratigraphic interval than in the younger horizons.

The water depth during the Upper Cretaceous was probably greater at Site 9 than at Site 10, as it is today, since the foraminiferal assemblages are extremely poor at Site 9. However, at Site 9 the faunal and floral composition of the assemblages in the Upper Cretaceous section and in the overlying Lower Eocene, which is devoid of calcareous microfossils, is quite different from that at Site 10.

EOCENE RADIOLARIA RECOVERED DURING LEG 2

Eocene Radiolaria were recovered at 4 of the 5 sites occupied during Leg 2. They are, for the most part, well preserved, but the preservation deteriorates within the more cherty sequences. Some samples also contain abundant sponge spicules. Only in Hole 10, Core 9, were calcareous (nannofossils) and siliceous Eocene faunas found together.

Calocyclas turris Ehrenberg and *Eusyringiumf istuligerum* (Ehrenberg) were noted in only one sample, i.e., some reddish material brought up with the center bit prior to the coring of Hole 9A, Core 1. This material could have come from anywhere above the coring depth. *Podocyrtis triacantha* Ehrenberg is absent from all samples examined. These absences indicate a Middle to Lower Eocene age for all the *in situ* radiolarian assemblages recovered.

The occurrences of all other Eocene radiolarian species described in the Core Description Manual (Part VII) are shown in Table 2 along with 7 additional species not mentioned in the manual. The species included in Table 2 are:

?Pseudostaurosphaera sp. (Plate 1A):

> This species apparently belongs to the genus *Pseudostaurosphaera* of Krasheninnikov (1960). It is similar to *P. perelegans* Krasheninnikov (1960), but differs from it in having stouter spines (either 3 or 4) and both inner and outer medullary shells. *P. perelegans* is described from the Middle Eocene of the western Pre-Caucasus.
>
> *?P.* sp. has a very restricted range and is found only within Core 1 of Hole 8A. It may be a useful stratigraphic marker.

Spongatractus pachystylus (Ehrenberg) (Plate 1B):

> *Spongosphaera pachystyla* Ehrenberg, C. G. Ehrenberg 1875).
> *Spongatractus pachystylus* (Ehrenberg), Ernst Haeckel (1887).
> *S. pachystylus* is found throughout all the examined section, but only in the topmost sample does it occur with any frequency.

Lithocyclia ocellus Ehrenberg (Plate 1C):

> *Lithocyclia ocellus* Ehrenberg, (C. G. Ehrenberg, 1854).
> *Lithocyclia ocellus* Ehrenberg, (C. G. Ehrenberg, 1875).
> *Lithocyclia ocellus* Ehrenberg, Ernst Haeckel (1887).
> *L. ocellus* occurs in all samples from Holes (A and 8, in Core 1 of Hole 8A and in the core catcher sample of Core 8, Site 10. It is absent from lower samples and may be a useful stratigraphic marker.

Dictyophimus babylonis Clark and Campbell (Plate 1D):

> *Dictyophimus babylonis* Clark and Campbell, (B. L. Clark and A. S. Campbell, 1942).
> *Dictyophimus babylonis* Clark and Campbell, W. R. Riedel (1957a).
> *D. babylonis* occurs throughout all the examined sequences.

Lynchonocanium bellum Clark and Campbell (Plate1E):

> *Lychnocanium bellum* Clark and Campbell, (B. L. Clark and A. S. Campbell, 1942).
> *L. bellum* occurs throughout all the examined sequences.

Sethamphora mongolfieri (Ehrenbergi) (Plate 1F):

> *Eucyrtidium mongolfieri* Ehrenberg, (C. G. Ehrenberg, 1854).
> *Eucyrtidium mongolfieri* Ehrenberg, (C. G. Ehrenberg, 1875).
> *Sethamphora mongolfieri* (Ehrenberg), Ernst Haeckel, (1887).
> *Sethamphora costata* Haeckel, (Ernst Haeckel, 1887).
> *Sethamphora mongolfieri* (Ehrenberg), W. R. Riedel, (1957a).
> *Dethamphora mongolfieri* (Ehrenberg), W. R. Riedel. (1957b).
>
> For the present report *Sethamphora mongolfieri* is more strictly defined than it was for the unpublished shipboard reports. The species is here restricted to forms having very well defined transverse and longitudinal pore rows, separated by ridges, on the abdomen. There is a similar form, usually with a thinner shell, and with less regular rows of smaller pores

TABLE 2
Occurrences of Some Radiolaria at Sites 8, 9 and 10[a]

Sample Designation[b]	*Podocyrtis* sp. a	*Sethamphora mongolfieri*	*Lithocyclia ocellus*	*Podocyrtis mitra/ P. sinuosa*	*? Theopera fusiformis*	*Podocyrtis papalis*	*Spongatractus pachystylus*	*Anthocyrtium hispidum*	*Dictyophimus babylonis*	*Phormocyrtis embolum*	*Lithochytris* sp(p).	*Phormocyrtis striata*	*Lychnocanium bellum*	*Lophocyrtis biaurita*	*?Clathrocyclas dominasinensis*	*Theocorys* sp.	*Calocyclas casta*	*Clathrocyclas* sp.	*Lithocampe* sp.	*?Pseudostaurosphaera* sp.
9A-center bit	F	C	R	C	R	F	F	C	C	F	C	F	F	–	–	–	–	–	–	–
9A-1-4, 70-4 cm	+	+	+	+	–	–	+	+	+	+	–	+	+	R	–	–	–	–	+	–
9A-1-6, 16-8 cm	F	C	R	R	–	F	R	F	C	F	R	F	F	R	–	–	–	–	–	–
8-2-1, 81-3 cm	–	–	–	F	R	C	R	F	F	F	R	C	R	R	R	R	–	–	–	–
8-2-1, 99-100 cm	–	–	R	F	R	C	R	R	F	R	R	C	R	C	R	F	–	–	–	–
8-2-2, 0-2 cm	–	–	R	C	F	F	F	F	C	F	R	C	R	R	R	F	–	–	–	–
8-2-2, 86-8 cm	–	–	R	F	R	C	F	R	F	R	R	F	R	R	R	F	–	–	–	–
8-2-3, 0-2 cm	–	–	–	F	R	C	R	R	R	R	R	F	R	R	R	R	–	–	–	–
8-2-3, 83-5 cm	–	–	R	R	R	F	R	R	R	F	R	F	R	C	R	R	–	–	–	–
8-2-3, 150 cm	–	–	R	F	R	C	R	R	R	C	R	F	F	F	R	R	–	–	–	–
8A-1-1, 92-4 cm	–	–	R	R	R	C	R	R	R	F	R	C	F	C	R	R	–	–	–	R
8A-1-1, 108-10 cm	–	–	–	R	R	C	–	–	R	F	R	F	R	F	R	–	–	–	–	F
8A-1-2, 16-8 cm	–	–	R	F	R	C	R	–	R	F	R	F	F	F	R	R	R	–	–	F
8A-1-2, 83-5 cm	–	–	R	R	R	F	–	–	–	R	R	F	R	F	–	R	R	–	–	R
8A-1-core catcher	–	–	–	F	F	C	R	R	R	F	R	C	F	R	R	R	R	–	–	F
10-8 core catcher	–	–	R	C	–	C	R	R	C	R	R	R	C	R	F.	F	C	–	–	–
10-9-1, 20-2 cm	–	–	–	F	–	C	R	R	C	R	F	F	F	R	F	F	F	F	C	–
10-9-1, 79-81 cm	–	–	–	F	R	C	R	F	F	R	F	F	R	R	R	F	R	R	C	–
10-9-1, 100-2 cm	–	–	–	F	R	C	F	R	C	R	F	F	F	R	F	F	F	F	F	–
10-9-1, 130-2 cm	–	–	–	–	–	F	R	R	F	R	R	F	F	R	F	R	F	F	C	–
10-9-2, 0-2 cm	–	–	–	–	R	C	R	R	C	R	R	F	R	R	F	F	F	F	F	–
10-9-2, 80-2 cm	–	–	–	–	–	C	R	R	F	R	F	F	F	C	R	F	F	–	C	–
10-9-2, 100-2 cm	–	–	–	–	R	C	R	R	F	R	R	F	C	R	R	R	R	R	C	–
10-9-2, 129-32 cm	–	–	–	–	–	C	R	R	F	R	R	C	F	R	F	R	F	F	C	–
10-9-3, 0-2 cm	–	–	–	–	–	C	R	R	F	–	R	F	R	R	F	F	F	R	C	–
10-9-3, 70-2 cm	–	p	–	–	–	F	–	R	R	R	R	F	R	C	R	F	F	F	F	–
10-9 core catcher	–	–	–	–	–	C	R	R	F	–	F	C	F	R	R	F	F	R	C	–
8A-2-1, between chert	–	–	+	+	+	+	+	–	+	–	+	+	+	+	+	+	+	–	+	–
8A-3 core catcher	–	–	–	–	–	+	–	–	+	+	–	–	–	–	–	–	–	–	+	–
8A-4	–	–	–	–	+	–	–	–	–	–	+	+	+	+	–	–	–	–	–	–

---

[a] R = Rare, F = few, C = common. In four samples radiolarians are sparse and poorly preserved and therefore only presences or absences are recorded. The samples are ordered stratigraphically but gaps are probably present between samples from different sites.

[b] Hole-Core-Section-length in centimeters.

which was originally included, by the present author (C. N.), in *S. mongolfieri,* but is now thought to represent a different species. Samples from Hole 9A contain the only examples of well formed specimens of *S. mongolfieri* found during the present study.

Anthocyrtium hispidum (Ehrenberg) (Plate 1G):

Anthocyrtis hispida Ehrenberg, (C. G. Ehrenberg, 1875).
Anthocyrtium hispidum (Ehrenberg), Ernst Haeckel, (1887).
Anthocyrtium hispidum (Ehrenberg) ?, W. R. Reidel, (1957b).
A. hispidum occurs throughout the examined sequences, but only in samples from Hole 9A and in the upper part of the Hole 8 Eocene sequence does it occur with any frequency.

Podocyrtis papalis Ehrenberg (Plate 1H):

Podocyrtis papalis Ehrenberg, (C. G. Ehrenberg, (1854).
Podocyrtis papalis Ehrenberg, Ernst Haeckel, (1887).
P. papalis is a major component of the radiolarian fauna throughout the examined sequences.

Podocyrtis sp. a (Plate 1I):

Podocyrtis sp. a was recorded in samples from Leg 1 (see Cenozoic radiolarian report for Leg 1) and differs from *P. papalis* in having an externally expressed lumbar stricture, and toothed feet. In the Leg 2 material it occurs only in samples from Hole 9A and may be a useful stratigraphic marker.

Podocyrtis mitra Ehrenberg/*Podocyrtis sinuosa* Ehrenberg (Plate 1J):

Podocyrtis mirta Ehrenberg, (C. G. Ehrenberg, 1854).
Podocyrtis mitra Ehrenberg, (C. G. Ehrenberg, 1857).
Podocyrtis mitra Ehrenberg, Ernst Haeckel, (1887).
Podocyrtis sinuosa Ehrenberg, (C. G. Ehrenberg, 1875).
Podocyrtis sinuosa Ehrenberg, Butschli, (1882).
Podocyrtis sinuosa Ehrenberg, Ernst Haeckel, (1887).

This species differs from *P. papalis* in having an abdomen longer than the thorax, and a well differentiated peristome (see Cenozoic radiolarian report, Leg 1). It occurs in samples from Holes 9A and 8, Core 1 of Hole 8A and in the upper part of the Site 10 sequences and may be a useful stratigraphic marker.

?Clathrocyclas dominasinensis (Ehrenberg) (Plate 2A):

Podocyrtis dominasinensis Ehrenberg, (C. G. Ehrenberg, 1875).
Clathrocylcas domina (Ehrenberg), Ernst Haeckel, (1857).

A three-segmented shell with a trilocular (the 2 secondary lobes beneath and lateral to the primary lobe) ecphalis bearing a stout three-bladed apical horn and, sometimes, several shorter auxiliary horns. The thorax is three hemispherical with subcircular pores aligned longitudinally. The abdomen is cylindrical with pores similar to those on the thorax; termination is ragged.

The form found during the present study resembles that figured by Ehrenberg, but lacks the peristome and feet described by Haeckel. It is absent from Hole 9A samples, but is present throughout the examined sequences from Holes 8, 8A, and 10. It may be a useful stratigraphic marker.

Clathrocyclas sp. (Plate 2B):

This species is similar to *?C. dominasinensis,* but differs in having an enlarged abdomen with larger pores, irregular in size and arrangement. It occurs only in Core 9 of Site 10 and may be a useful stratigraphic marker.

?Theopera fusiformis Haeckel (Plate 2C):

Theopera fusiformis Haeckel

The form figured by Haeckel (1887) closely resembles, but has a rather larger abdomen than those specimens studied during the present investigation. Forms observed in Eocene samples known to be younger than the Leg 2 Eocene samples tend to have longer, sharply conical abdomens and may even develop a terminal spine. *?T. fusiformis* is present in the uppermost sample from Hole 9A and throughout Hole 8 and Core 1 of Hole 8A. It is scattered and sparse in samples from Hole 10. The species may be a useful stratigraphic marker particularly if it is used in conjunction with its variants as noted above.

Lithochytris sp(p) (Plate 2D&E):

This species occurs throughout the examined sequences of Eocene samples. It is worth noting that there is a considerable variation in the lengths of the feet (32-64 μ) and abdomen (56-135 μ). However, this variation does not appear to be stratigraphically significant in the intervals examined.

Phormocyrtis embolum (Ehrenberg) (Plate 2F):

Eucytridium embolum Ehrenberg, (C.G. Ehrenberg, 1875).
Phormocyrtis embolum (Ehrenberg), Ernst Haeckel, (1887).

Phormocyrtis proxima Clark and Campbell, (B. L. Clark and A. S. Campbell, 1942).
Phormocyrtis embolum (Ehrenberg), W. R. Riedel, (1957a).

P. embolum occurs throughout the examined sequences, but there is a general decrease downwards in abundance.

Phormocyrtis striata Brandt (Plate 2G):

Phormocyrtis striata Brandt, (Karl Brandt, 1935).

Specimens of *P. striata* encountered during the present study are in good agreement with the original description of the species by Brandt (1935). A form similar to *P. striata* in all respects except that the abdomen is triangular rather than circular in cross-section occurs in Paleocene sediments (Riedel, personal communication). *P. striata* occurs with some frequency in all samples examined during the present study.

Calocyclas casta Haeckel (Plate 2H):

Calocyclas casta Haeckel, (Ernst Haeckel, 1887):

A 3-segmented shell with a spherical cephalis bearing a long, conical apical horn. The thorax is conical with subcircular pores aligned longitudinally and separated by ridges. The abdomen is very inflated, almost spherical, with large subcircular pores. Needle-like spines project from between the pores; the mouth is constricted to a narrow, poreless peristome with a smooth termination.

The form found during the present study resembles closely that described and illustrated by Haeckel, except that it lacks terminal feet. The species occurs rarely in the lower part of Core 1 (Hole 8A) and more commonly throughout the Hole 10 radiolarian sequence. It may be a useful stratigraphic marker.

Lophocyrtis biaurita (Ehrenberg) (Plate 2I, J and K):

Eucyrtidium biauritum Ehrenberg, (C.G. Ehrenberg, (1875).
Lophocyrtis biaurita (Ehrenberg), Ernst Haeckel, (1887).

A 2-segmented shell with two equally stout cephalic horns. The thorax is ovate, and is sometimes quite inflated with circular to subcircular pores arranged, distally, in one to eight transverse rows. Proximal pores are scattered and sparse. The species is present throughout the examined sequence.

Theocorys sp. (Plate 2L):

This is a 3-segmented, thick-walled shell. The cephalis is simple with a robust apical horn. The thorax is inflated and conical; the abdomen is cylindrical with closely spaced longitudinal rows of circular to subcircular pores. The mouth is constricted slightly with a well differentiated, poreless persitome.

The species is absent from Hole 9A samples, but is present throughout the examined sequences from Holes 8, 8A and 10. It may be a useful stratigraphic marker.

Lithocampe sp. (Plate 2M):

This is a 4-segmented shell. The cephalis is spherical with a short, three-bladed apical horn. The thorax is reduced, conical. The abdomen is inflated and barrel-shaped with regularly spaced circular pores in transverse and diagonal rows. The fourth segment is frequently broken off, but when present it narrows distally with one to three transverse pore rows. The termination is ragged.

This species is found only in samples from Core 9 of Hole 10 and may be a useful stratigraphic marker.

Eocene Radiolarian Stratigraphy

It is thought that the order of the samples in Table 2 is stratigraphically correct, although gaps between the superimposed sites must certainly exist. The calcareous nannofossils found in the core catcher sample of Core 8 and throughout Core 9 of Hole 10 indicate that this sequence lies within the *G. aragonensis* Zone. Examination of the radiolarian fauna in Bermudez' Sample 351 (Bermudez, 1950) from the Toledo member of the Universitad Formation (Cuba) shows an assemblage intermediate between that found in Hole 9A and the uppermost sample recovered at Hole 8. Bramlette (personal communication) places the Toledo sample in his Biostratigraphic Unit 5 (Bramlette and Sullivan, 1961) which is approximately equivalent to the *H. aragonensis* Zone. The present author (C. N.) has examined material from Hole 13A (Leg 3) which appears to be younger than the Site 9A material and which, according to the calcareous nannofossil content, also belongs in the *H. aragonensis* Zone.

On the basis of this rather sketchy evidence, it appears that the Eocene radiolarian sequences recovered during Leg 2 all lie within the upper Lower Eocene and lowermost Middle Eocene between the *G. aragonensis* and *H. aragonensis* Zones. Certain radiolarian species have clearly defined ranges within this interval and may, in time, be useful in establishing a radiolarian zonation which could be correlated with existing foraminiferal and calcareous nannofossil zonations.

REFERENCES

Bandy, O. L., 1964. Cenozoic planktonic foraminiferal zonation. *Micropaleontology*. **10**, (1), 1.

PLATE 1

Radiolaria (magnification: 200 X)

A	*Pseudostaurosphaera* sp.; 8A-1-2, 16-8 cm (V23/4)
B	*Spongatractus pachystylus* (Ehrenberg); 8-2-1, 81-3 cm (S30/4)
C	*Lithocyclia ocellus* Ehrenberg; 9A-1-6, 16-8 cm (G22/3)
D	*Dictyophimus babylonis* Clark and Campbell; 8-2-3, 0-2 cm (J26/1)
E	*Lynchonocanium bellum* Clark and Campbell; 10-8, core catcher (E11/0)
F	*Sethamphora mongolfieri* (Ehrenbergi); 9A, center bit (F32/1)
G	*Anthocyrtium hispidum* (Ehrenberg); 10-9-2, 129-32 cm (Y28/2)
H	*Podocyrtis papalis* Ehrenberg; 8-22, 86-8 cm (R25/0)
I	*Podocyrtis* sp. a; 10-8, core catcher (T40/1)
J	*Podocyrtis mitra* Ehrenberg/*Podocyrtis sinuosa* Ehrenberg; 9A, center bit (N46/4)

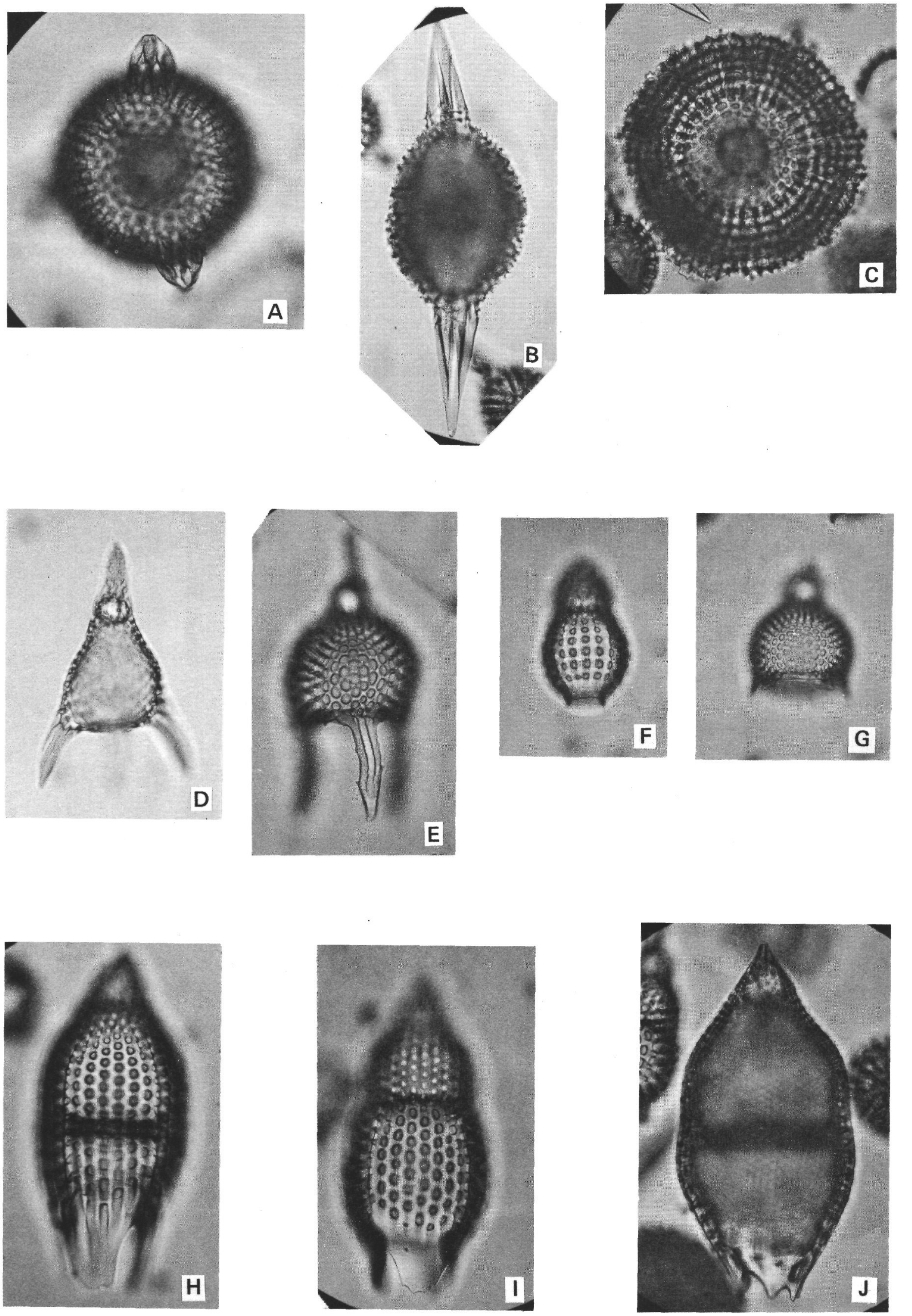
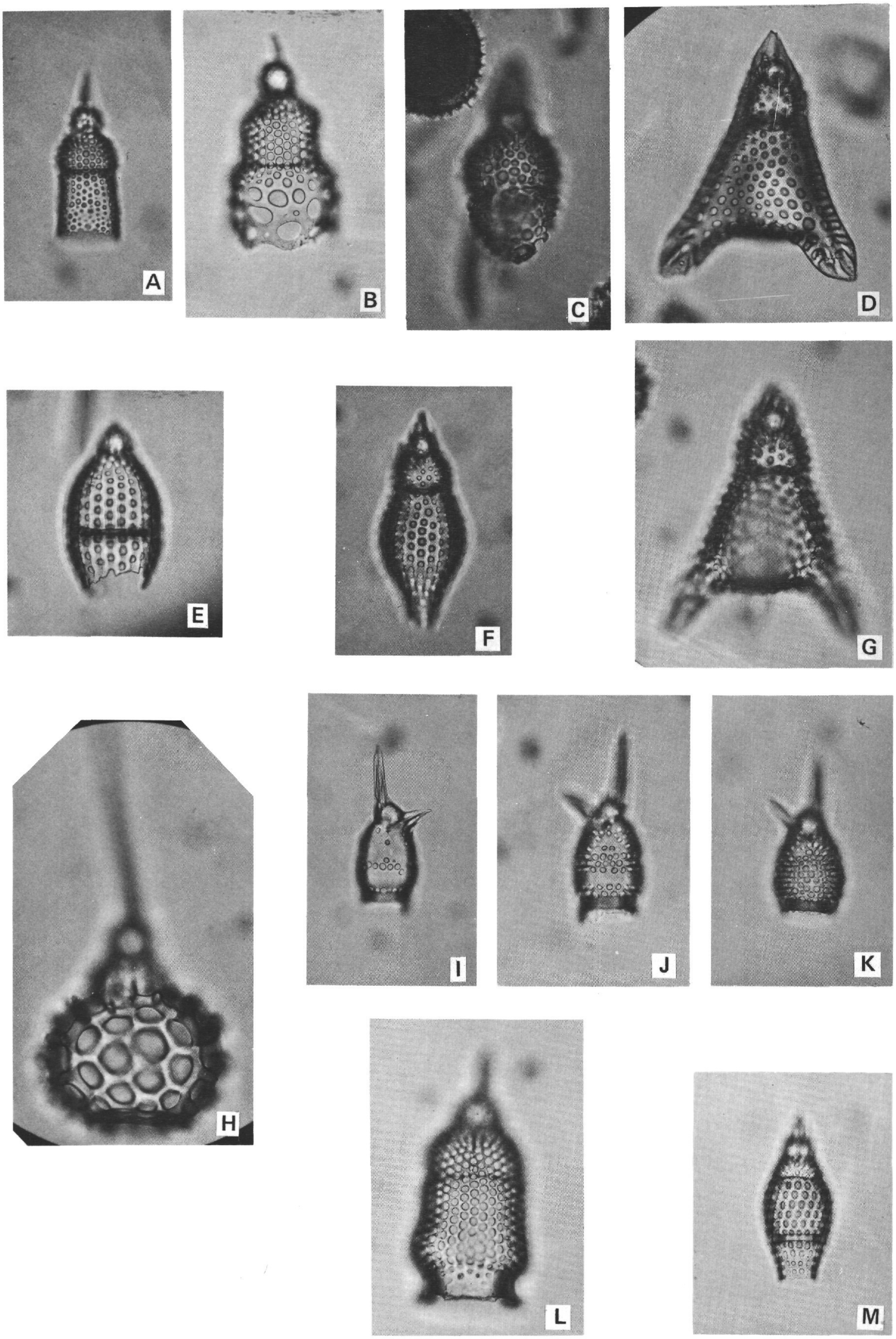

A
B
C
D
E
F
G
H
I
J

PLATE 2

Radiolarian (magnification: 200 X)

A	*?Clathrocyclas dominasinensis* (Ehrenberg); 2-8-2-1, 81-3 cm (Y57/1)
B	*Clathrocyclas* sp.; 2-10-9-1, 100-2 cm (M49/0)
C	*?Theopera fusiformis* Haeckel; 2-8-2-2, 0-2 cm (E49/3)
D	*Lithochytris* sp., with relatively short feet; 2-9A-1-6, 16-8 cm (G27/0)
E	*Lithochytris* sp., with relatively long feet; 2-8-2-3, 83-5 cm (N47/0)
F	*Phormocyrtis embolum* (Ehrenberg); 2-8-2-2, 0-2 cm (Y29/0)
G	*Phormocyrtis striata* Brandt; 2-8-2-2, 86-8 cm (X50/3)
H	*Clathrocyclas casta* Haeckel; 2-10-8, core catcher (X27/1)
I	*Lophocyrtis biaurita* (Ehrenberg) with relatively few pores; 2-10-9-2, 0-2 cm (E26/3)
J	*Lophocyrtis biaurita* (Ehrenberg), with an intermediate number of pores; 2-10-9-2, 129-32 cm (S16/0)
K	*Lophocyrtis biaurita* (Ehrenberg), with many pores; 2-8A-1-1, 92-4 cm (X54/3)
L	*Theocorys* sp.; 2-10-9, core catcher (X42/0)
M	*Lithocampe* sp.; 2-10-9-2, 0-2 cm (H47/0)


A
B
C
D
E
F
G
H
I
J
K
L
M

Banner, F. and Blow, W. H., 1960. Some primary types of species belonging to the superfamily Globigerinacea. *Contr. Cushman Lab Foram. Res.*, **11**, Pt. 1, 1.

Banner, F. T. and Blow, W. H., 1965. Progress in planktonic foraminiferal biostratigraphy of the Neogene. *Nature.* **208**, (5016), 1164.

Barbieri, F., 1967. The Foraminifera in the Pliocene section Vernasca-Castellarquato including the "Piacenzian stratotype" (Piacenza Province). *Mem. Soc. Ital. Sci. Nat.*, **15**, (3), 145.

Berger, W. H., 1967. Foraminiferal ooze: solution at depths. *Science.* **156**, (3773), 383.

Berggren, W. H., (in press). Tertiary Boundaries. *SCOR Conference (1968).*

Bermudez, P. J., 1950. Mem. Soc. Cubana Hist. Nat., vol. 19, no. 3, pp. 205-375.

Blow, W. H., 1959. Age, correlation and biostratigraphy of the upper Tucuyo (San Lorenzo) and Pozon formations, eastern Falcon, Venezuela. *Bull. Am. Paleont.* **39** (178), 59.

——————— 1969. Late-Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *Proc.* 1st. *Intern. Conf. Plankt. Microfossils.* **1**, 109. (Paper known, in manuscript, since 1968. Also cited in text as Blow (1968)).

Bolli, H. M., 1951. Notes on the direction of coiling of rotalid foraminifera. *Contr. Cushman Lab. Foram. Res.* **2**, pt. 4, 139.

——————— 1957. Planktonic Foraminifera from the Oligocene-Miocene Cipero and Leguna formations of Trinidad, B.W.I. *U.S. Nat. Museum Bull.* **215**, 97.

——————— 1959. Planktonic Foraminifera from the Cretaceous of Trinidad, B.W.I. *Bull. Am. Paleont.* **39** (179), 258.

——————— 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic Foraminifera, *Bull. Asoc. Venezolana Geol. Mineria Petrol.* **9** (1) 3.

Bolli, H. M. and Bermudez, P. J., 1965. Zonation based on planktonic foraminifera of Middle Miocene to Pliocene warm-water sediments. *Bull. Asoc. Venezolana Geol. Mineria Petrol.* **8** (5), 119.

Bramlette, M. N. and Sullivan, F. R., 1961. Coccolithophorids and related Nannoplankton of the early Tertiary in California. *Micropaleontology.* **7** (2), 129.

Bramlette, M. N. and Wilcoxon, J. A., 1967. Middle Tertiary calcareous nannoplankton of the Cipero section, Trinidad, W.I. *Tulane Studies Geology.* **5**, 93.

Brandt, Karl, 1935. Radiolaria in Wetzel, O. Die Mikropalaeontologie des Heilegenhafener Kieseltones (Ober-Eozan). *Jber. Niedersachs. Geol. Ver.* **27**, 41.

Bukry, D. and Bramlette, M. N., 1968. Stratigraphic significance of two genera of Tertiary calcareous nannofossils. *Tulane Studies Geology.* **6**, 149.

Butschli, O., 1882. Beitrage zur Kenntris der Radiolarienskelette, insbesonderi der der Cyritida. *Zeitschr. wiss Zool.* **36**, 485.

Cati, F. *et al*, 1968. Biostratigrafia del Neogene mediterraneo basata sui foraminiferi planctonici. *Boll. Soc. Geol. Ital.* **87** (3), 491.

Cita, M. B., 1968. Report of the working group micropaleontology, Committe on Mediterranean Neogene Stratigraphy Proc. IV Sess. Bologna (1967). *Geol. Ann. Museo Geol Bologna.* **35**, (2), 1.

Cita, M. B. and Premoli, S. I., 1960. Pelagic Foraminifera from the type Langhian. *Intern. Geol. Congr., Rept. XII Sess.* 22, 39.

Cita, M. B., Premoli, S. I., Rossi, R., 1965. Foraminiferi planctonici del Tortoniano-tipo. *Riv. Ital. Paleont. Strat..* **71**, (1), 217.

Cita, M. B., *et al.* 1968. Guide de l'excursion en Italie. *Comite Fransais de stratigraphie. Collque sur l'Eocene.* 1.

Clark, B. L. and Campbell, A. S., 1942. Eocene radiolarian faunas from the Mt. Diablo area, California. *Geol. Soc. Am. Spec. Papers.* (39), 1.

Cushman, J. A. and Renze, H. H., 1947. The foraminiferal fauna of the Oligocene, Ste. Croix formation of Trinidad, British West Indies. *Contr. Cushman Lab. Foram. Res. Spec. Publ.* (22), 1.

Cushman, J. A. and Stainforth, R. M., 1945. The Foraminifera of the Cipero marl formation of Trinidad, British West Indies. *Contr. Cushman Lab. Foram. Res. Spec. Publ.* (14), 1.

Dalbiez, F. 1955. The genus *Globotruncana* in Tunisia. *Micropaleontology.* **1**, (2), 161.

Eames, F. E., Banner, F. T., Blow, W. H. and Clarke W. J., 1962. *Fundamentals of Mid-Tertiary Stratigraphical Correlations.* Cambridge (Cambridge Univ. Press) 163 pp.

Ehrenberg, C. G., 1854. *Mikrogeologie Liepzig.* Fortsetzung (1958), 89 pp.

——————————— Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht der mikroskopischen Palaontologie gleichartig analysirter Gebirgsarten der Erde, mit specieller Rucksicht aug den Polycystienn-Mergel von Barbados. *Abhandl. Dent. Akad. Wiss. Berlin.* (1875), 1.

Funnell, B. M., 1964. Studies on North Atlantic geology and paleontology: 1. Upper Cretaceous. *Geol. Mag.* **101**, (5), 421.

Gianotti, A., 1953. Microfaune della serie tortoniana del Rio Mazzapiedi-Castellania (Tortona, Alessandria). *Riv. Ital. Paleont. Strat., Mem. VI,* 167.

Haeckel, Ernst, 1887. Report on the Radiolaria collected by H. M. S. *Challenger* during the years 1873-76. Rept. Voyage *Challenger. Zoologica.* **8**, 1,803 pp.

Hays, J. D., Saito, T., Opdyke, N. D. and Burckle, L. H. (in press). Pliocene-Pleistocene sediments of the

Equatorial Pacific - their paleomagnetic, biostratigraphic and climatic record. *Bull. Geol. Soc. Amer.* **80.**

Hay, W. W., *et al.,* 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean area and transoceanic correlation. *Trans. Gulf Coast Assoc. Geol. Soc.* **17,** 428.

Hofker, J., 1966. Maestrichtian, Danian and Paleocene Foraminifera. *Palaeontographica,* Bd. 10, I-II, 1.

Iaccarino, S., 1967. Les Foraminiferes du stratotype du Tabianian (Pliocene inferieur) de Tabiano Bagni (Parme). *Mem. Soc. Ital. Sci. Nat.* **15** (3), 165.

JOIDES, 1967. The Deep Sea Drilling Project. *Bull. Am. Assoc. Petrol. Geologists.* 1787.

Klaus, J., 1959. Le complexe schisteux intermediaire dans le synclinal de la Gruyere (Prealpes medianes). Stratigraphie et Micropaleontologie, avec l'etude speciale des Globotruncanides de l'Albien, du Cenomanien et du Tutonien. *Eclogue Geol. Helv.* **52** (2), 753.

Krasheninnikov, V. A., 1960. Nektorye radiolayrii nizhnego i srednego eotsena zapadnogo predkavkazya. *Tr. Vses. Neft. Nauchn. Issled Geologarazird. Inst.* **16**, 271.

Levin, H. L. and Joerger, A. P., 1967. Calcareous nannoplankton from the Tertiary of Alabama. *Micropaleontology.* **13**, 163.

Marks, P. and Webb, P., 1966. Discussion on the symposium on micropaleontological lineages and zones. Committee on Mediterranean Neogene Stratigraphy, Proc. III Sess. Berne (1964). *Brill.* 140.

Pareto, M. F., 1865. Note sur les subdivisions que l'on pourrait etblir dans les terrains tertiaires de l'Apennin septentrional. *Bull. Soc. Geol. France.* S. 2, **22,** 210.

Parker, F., 1967. Late Tertiary biostratigraphy (planktonic foraminifera) of tropical Indo-Pacific deep-sea cores. *Bull. Am. Paleont.* **52**, 115.

Riedel, W. R., 1957a. Radiolaria: a preliminary stratigraphy. *Rept. Swed. Deep Sea Exped.* **6** (3), 59.

——— 1957b. Eocene Radiolaria. *U. S. Geol. Surv. Prof. Paper 280G.* 257.

Selli, R., 1960. Il Messiniano Mayer-Eymar 1897. Proposta di un neostratotipo. *Giorn. Geol. Ann Museo Geol. Bologna.* Ser. 2, 28, 1.

Sigal, J., 1952. Apercu stratigraphique sur la micropaleontologie du Cretace. *Congr. Geol. Intern. Compt. Rend. 19 Algiers, 1952.* 26.

——— 1955. Notes micropaleontologiques nordafricaines. 1. du Cenomanien au Santonien: Zones et limites en facies pelagiques. *Compt. Rend. Soc. Geol. France.* 157.

Van Hinte, J. E., 1965. The type Campanian and its planktonic foraminifera. *Koninkl Ned. Akad. Wetenschap. Proc. B.* **68**, (1), 8.