ARTICULO

ZONATION BASED ON PLANKTONIC FORAMINIFERA OF MIDDLE MIOCENE TO PLIOCENE WARM-WATER SEDIMENTS

(ZONACION DEL MIOCENO MEDIO HASTA EL PLIOCENO BASADA EN FORAMINIFEROS PLANCTONICOS DE SEDIMENTOS DE AGUAS CALIDAS)

by Hans M. Bolli and Pedro J. Bermúdez

ABSTRACT

Sequences of planktonic foraminifera are described, as encountered in beds of Middle Miocene to Pliocene age in northeastern and northwestern Venezuela, Jamaica and Java. Although there are discrepancies attributable to ecologic factors, the sequences match well enough to serve as a basis for six zones, which are here formally proposed. Placement of the Miocene-Pliocene and Pliocene-Pleistocene boundaries is discussed briefly. Five new planktonic species, three of zonal value, are described and figured. They are: *Globigerina riveroae*, *Globigerina tetracamerata*, *Globigerinoides obliquus extremus*, *Globorotalia margaritae* and *Globorotalia pseudomiocenica*.

RESUMEN

Se describen unas secuencias de foraminíferos planctónicos, como encontradas en capas del intervalo Mioceno Medio hasta Plioceno en Venezuela nor-oriental y nor-occidental, Jamaica y Java. Aunque existen ciertas discrepancias que se atribuyen a factores ecológicos, las secuencias se conectan bastante bién para proveer la base de seis zonas, que se denominan formalmente aquí. Se discute brevemente la colocación de los limites Mioceno-Plioceno y Plioceno-Pleistoceno. Se describen e ilustran cinco nuevas especies planctónicas, incluyendo tres de valor en zonación: son *Globigerina riveroae*, *Globigerina tetracamerata*, *Globigerinoides obliquus extremus*, *Globorotalia margaritae* y *Globorotalia pseudomiocenica*.

INTRODUCTION

In recent years planktonic Foraminifera have been applied with increasing success to solving regional and transoceanic problems of chronostratigraphic correlation. From the Cretaceous up to the Lower Miocene a sequence of short-lived species is recognized, within which evolutionary lineages enhance the applicability of these microfossils to stratigraphy. Many zones correspond closely to the short life-ranges of their name-fossils, random examples being the zones of Porticulosphaera mexicana (Middle Eocene) and Globigerinatella insueta (Lower Miocene).

However, from the Middle Miocene onward, i.e. above the Globorotalia fohsi robusta Zone, short-ranging planktonic species become more and more difficult to find, and it becomes necessary to use longer-ranging forms, often combining the ranges of two species to define a zone. The purpose of this paper is to suggest a zonation from the higher Middle Miocene into the Pliocene, in upward continuation of the zonation proposed by Bolli (1957) up into the Middle Miocene, above which level adverse facies conditions in Trinidad did not allow the development of the planktonic Foraminifera to be followed up into younger sediments.

Six new zones are distinguished between the Globorotalia menardii Zone and the high Pliocene and it will be demonstrated that they are applicable in places as far apart as the West and East Indies. The number of zones into which this stratigraphic interval is subdivided appears to be comparable to that of earlier Tertiary intervals of similar duration.

It will be shown that the higher part of the Pozón Formation of Falcón, coastal northwestern Venezuela, because of its progressively shallowing environment above the Globorotalia menardii menardii/Globigerina nepenthes Zone of Blow (1959), is no longer suited to establish a zonation based on planktonic Foraminifera. The more open marine sediments of the Cubagua Formation, coastal northeastern Venezuela, which furthermore extends higher stratigraphically than the Pozón Formation, are much better suited to establishing such a zonation from above the Globorotalia menardii Zone into younger strata.

Conditions are not perfect even in the Cubagua Formation, however, where certain planktonic foraminiferal species were apparently quite sensitive to only slight ecologic changes. While such species as Globorotalia menardii s.l., Globorotalia dutertrei, Globoquadrina altispira altispira, etc. were not affected, one finds Globorotalia tumida s.l. and Pulleniatina obliquiloculata s.l., which are both still living today, only for a short interval in the middle part of the Cubagua Formation. Ecologic conditions must have been more constant and favorable for these species in the Bodjonegoro-1 section of Java (Bolli, 1964; in press), where they carry on throughout the section after their first occurrence.

The zonation presented here is largely based on observations made in the Cubagua Formation, in particular in the two well sections of Cubagua-1 and -2 (Kugler, 1957), and also on the section of well Bodjonegoro-1 in Java (Bolli, 1964; in press). In addition, a number of isolated observations like those made in Jamaica confirm the distribution pattern of the chosen index fossils.

It is encouraging to see that the zonation can be applied to sections so far apart and that a close biostratigraphic comparison is possible over long distances. Because of the nature of the index fossils one has, however, to be aware that the application of the proposed zonation remains restricted to sediments deposited in warm to moderately warm waters.

The authors wish to thank Dr. R. M. Stainforth for reading the manuscript and for making many valuable suggestions to improve the paper.

THE AREAS STUDIED FOR THE PROPOSED ZONATION

INCLUDING REVIEWS OF SOME PREVIOUS WORK

The zonation based on planktonic Foraminifera of the Upper Miocene to Pliocene as proposed in this paper is based primarily on a number of surface and subsurface sections of coastal northeastern Venezuela (Isla Margarita, Isla Cubagua, Península de Araya, Cumaná, Cabo Blanco); the Pozón/Ojo de Agua formations of Falcón, coastal northwestern Venezuela; some surface and subsurface information obtained from Jamaica; and the well Bodjonegoro-1 of Java. The pertinent unpublished and published data are reviewed shortly in the following section. Results of the studies in northeastern Venezuela and Java will be dealt with in more detail in forthcoming publications.

Coastal northeastern Venezuela

The two well sections Cubagua-1 and -2 which penetrated the entire Cubagua Formation were particularly useful for studying the distribution of the planktonic Foraminifera in the Upper Miocene. This formation is now the subject of detailed studies by a group of students of the Universidad Central de Venezuela. On the Península de Araya this formation can be subdivided into lower (Cerro Verde) and upper (Cerro Negro) members.

Detailed lithologic and paleontologic descriptions will be given in separate publications, and in particular the foraminiferal fauna will be described in a forthcoming paper by Bermúdez, Bolli and Fuenmayor. In this paper there will also be a discussion of the stratigraphic and zonal correlation of the various sections sections studied. Also included in this study will be a description of the foraminiferal faunas of the Pliocene Cumaná Formation of Araya, which locally overlies the Cubagua Formation with a hiatus, and of the approximately age-equivalent Cabo Blanco Formation. The basal part of the Cubagua Formation of coastal northeastern Venezuela is certainly younger than the upper part of the Lengua Formation of Trinidad (Globorotalia menardii Zone). It appears comparable, however, to the highest part of the Pozón Formation of eastern Falcón. The Carenero beds are the only sediments in coastal northeastern Venezuela which can faunistically be correlated with the Globorotalia menardii Zone of Trinidad's Lengua Formation.

Coastal northwestern Venezuela (Falcón)

Conditions for a study of planktonic Foraminifera in the higher Middle Miocene were found to be somewhat better in the Pozón Formation of Falcón than in Trinidad. Blow (1959) proposed there two additional younger zones above the Globorotalia menardii Zone (Globorotalia menardii menardii/Globigerina nepenthes Zone of Blow). They are from top to bottom:

Globigerina bulloides Zone
Sphaeroidinella seminulina Zone

The Sphaeroidinella seminulina Zone is characterized, according to Blow, by the continuing presence of both subspecies of Sphaeroidinella seminulina, i.e. Sphaeroidinella seminulina seminulina and Sphaeroidinella seminulina kochi. It seems likely, and this possibility was also pointed out by Blow himself, that the upper limit of this zone is to some extent influenced by a facies change. A similar extinction of Sphaeroidinella seminulina, also pointed out by Blow, occurs in the two subsurface sections of wells Cubagua-1 and -2 (at approx. 734' in Cubagua-1 and at approx. 532' in Cubagua-2). Though Blow claims that there is no apparent facies change in the Cubagua surface sections, the present authors noted an impoverishment of the planktonic fauna in the top parts of the two well sections.

Blow himself regards the Globigerina bulloides Zone, his highest zone in the Pozón Formation, as only a provisional solution which could eventually be replaced by a zonation based on stratigraphically more restricted planktonic index fossils, though no suitable forms are recorded in the upper part of the Pozón Formation. Globigerina bulloides s.l. prefers colder and temperate waters and shows quite a long stratigraphic range. Occasionally specimens may turn up also in warmer waters. In this respect it is of interest to note that Recent Globigerina bulloides are present quite frequently in the Gulf of Cariaco, northeastern Venezuela, indicating a colder water temperature for this area than exists normally at this latitude.

Blow also uses Globigerina nepenthes as an index fossil for distinguishing a lower Globorotalia mayeri/Globigerina nepenthes Subzone and a higher Globorotalia menardii menardii/Globigerina nepenthes Zone, Globigerina nepenthes being restricted to these two intervals in the Pozón Formation.

In both wells penetrating the Cubagua Formation, Cubagua-1 and -2, Globigerina nepenthes overlaps with Globorotalia dutertrei, indicating that the species did not in fact become extinct at the close of the Globorotalia menardii menardii/Globigerina nepenthes Zone but must have withdrawn from the Pozón area because of adverse ecologic conditions, to live on for quite some time in other areas like that occupied by the Cubagua Formation.

At least some of the benthonic foraminiferal species were similarly affected by the increasingly shallower conditions towards the top of the Pozón Formation. Marginulinopsis basispinosus, for instance, is the marker for and restricted to H. H. Renz' (1948) Marginulinopsis basispinosus Zone in the higher part of the Pozón Formation. Its range there corresponds with the upper part of Blow's Globorotalia mayeri/Globigerina nepenthes Subzone, the Globorotalia menardii menardii/Globigerina nepenthes Zone, and the basal part of Blow's Sphaeroidinella seminulina zone. In the Cubagua formation of NE Venezuela Marginulinopsis basispinosus would thus by comparison have to become extinct within the Globorotalia acostaensis Zone. Instead, the species carries on well into the overlying Globorotalia dutertrei/Globigerinoides obliquus extremus Zone.

Jamaica

A number of samples from the Bowden, Buff Bay and Manchioneal formations were kindly placed at the disposal of one of the authors (HMB) by Drs. M. H. S. Barker, H. G. Kugler and R. M. Stainforth who collected them in Jamaica. A preliminary examination of the Bowden samples yielded the following planktonic foraminiferal species:

Candeina nitida
Globigerina foliata
Globigerinoides canimarensis
Globigerinoides obliquus extremus
Globigerinoides ruber
Globigerinoides triloba s.l.
Globoquadrina altispira altispira
Globoquadrina venezuelana
Globorotalia dutertrei
Globorotalia margaritae
Globorotalia menardii s.l.
Globorotalia miocenica
Globorotalia multicamerata
Globorotalia cf. tumida
Globorotalia crassaformis
Globorotalia scitula
Hastigerina sp.
Orbulina sp.
Pulleniatina obliquiloculata s.l.
Sphaeroidinella dehiscens s.l.

Some slight variations in the composition of the assemblages were found to exist among the samples examined, which must have been collected from different outcrops within the Bowden type area. The joint occurrence of Globorotalia margaritae and Pulleniatina obliquiloculata places these Bowden samples in the Globorotalia margaritae Zone and they can be correlated with the lower part of the Cerro Negro Member of the Cubagua Formation of coastal northeastern Venezuela, also with the fauna described by Drooger (1953) from the Oranjestad beds of Aruba.

Palmer (1945) determined Globorotalia truncatulinoides from the Bowden Formation. To the authors' knowledge this species appears later stratigraphically and Palmer's determination is thought to be a misidentification of Globorotalia crassaformis. This author also noted a Globotruncana sp. whose presence, if confirmed, would be a definite indication of existing reworking in at least a part of the Bowden formation.

The examined samples from the Buff Bay Formation contain essentially the same planktonic foraminiferal assemblages. The Pulleniatinas in the Buff Bay samples are coiling at random while the few specimens seen in the Bowden samples are coiling dextrally. Though the Bowden specimens are too few for a final interpretation, it appears that the examined Bowden samples could stratigraphically be slightly higher within the Globorotalia margaritae Zone than the Buff Bay samples.

The samples examined from the Manchioneal Formation contain the following younger fauna of planktonic Foraminifera:

Candeina nitida
Globigerina foliata
Globigerina uvula
Globigerinita sp.
Globigerinoides canimarensis
Globigerinoides ruber
Globigerinoides triloba s.l.
Globigerinoides triloba fistulosa
Globoquadrina altispira altispira
Globorotalia dutertrei
Globorotalia menardii s.l.
Globorotalia miocenica
Globorotalia multicamerata
Globorotalia obesa
Globorotalia crassaformis
Globorotalia scitula
Globorotalia truncatulinoides
Hastigerina sp.
Orbulina sp.
Pulleniatina obliquiloculata
Sphaeroidinella dehiscens

Of particular significance is the joint occurrence of Globorotalia truncatulinoides and Globoquadrina altispira altispira, which places the samples in the new Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone. The planktonic foraminiferal fauna of the examined Manchioneal samples compares well with that found in the lower part (1410-1746 cm.) of the Submarex bore hole drilled off the south coast of Jamaica by the Institute of Marine Science, University of Miami.

A corresponding Manchioneal fauna is not known from coastal northeastern Venezuela. There it is thought to fall within a hiatus situated between the top of the Cerro Negro Member of the Cubagua Formation and the base of the Pliocene Cumaná Formation.

Java

An unusually complete section for studying the distribution of planktonic Foraminifera from the Lower Miocene to the top of the Upper Miocene, and probably into the Pliocene, is that of well Bodjonegoro-1 in Java. Reference is made to the publications by Boomgart (1949), who described and figured the smaller Foraminifera from this well, and Bolli (1964), who discussed and compared the ranges of selected planktonic foraminiferal species with those from the Philippines and the Caribbean. A full account of the stratigraphic distribution of the planktonic Foraminifera in well Bodjonegoro-1 is given by Bolli (in press).

As in coastal northeastern Venezuela and Falcón, a Globorotalia acostaensis Zone can clearly be distinguished in Bodjonegoro-1 between an older Globorotalia menardii Zone and a younger Globorotalia dutertrei/Globigerinoides obliquus extremus Zone. The Globorotalia acostaensis Zone is followed by a thin Globorotalia dutertrei/Globigerinoides obliquus extremus Zone, a Globorotalia margaritae Zone and a Globoquadrina altispira/Globorotalia crassaformis Zone. The upper part of the latter might in fact

already be stratigraphically equivalent to the Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone as recognized in the Caribbean. Because Globorotalia truncatulinoides is not present in the Bodjonegoro-1 section, probably for reasons of higher water temperatures than persisted at comparable times in the Caribbean, it is not possible to distinguish a younger Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone from an older Globoquadrina altispira altispira/Globorotalia crassaformis Zone. The uppermost part of Bodjonegoro-1, where Globoquadrina altispira altispira is no longer present, is possibly correlatable with the Globorotalia truncatulinoides/Globorotalia inflata Zone of the Caribbean. But this is only an assumption as, probably due to the above-mentioned higher water temperatures, these two species are not present in Bodjonegoro-1. On the other hand the tropical Globorotalia tumida is common. Compared with coastal northeastern Venezuela it would appear that parts of the Globorotalia dutertrei/Globigerinoides obliquus extremus Zone and also of the Globorotalia margaritae Zone are absent in Bodjonegoro-1.

SOME REMARKS ON ECOLOGIC FACTORS INFLUENCING THE DISTRIBUTION OF PLANKTONIC FORAMINIFERA

Although planktonic organisms are less subject to environmental control than their benthonic counterparts, ecologic factors need careful consideration also for planktonic Foraminifera. The three main factors influencing the viability of planktonic Foraminifera are temperature, depth and salinity of the sea. Temperature is well established as the cause of pronounced differences between the boreal-austral and the tropical suites, the latter being much more diversified in both fossil and modern assemblages. As a result of changes in temperature, salinity and water depth, certain species may disappear and reappear within a vertical sequence of beds, or, where an ancestral form appears to die out in one area, its descendants may take its place elsewhere. How the above mentioned factors may have their effects even within tropical and subtropical waters is shown below for three species:

Globorotalia tumida

During its range from the late Miocene to Recent Globorotalia tumida s.l. goes through a number of evolutionary stages that are of biostratigraphic significance. Such an evolution can be followed particularly clearly in well Bodjonegoro-1 of Java (Bolli, 1964; in press). But variation within the species is such that further study of the evolution of this species and its subspecies is indicated before using it for close biostratigraphic correlation. The evolution of Globorotalia tumida s.l. cannot be followed so nicely in the Cubagua Formation of coastal northeastern Venezuela as is the case in Java. Here, early Globorotalia tumida appears first in the upper part of the Cerro Verde Member of the Cubagua Formation but disappears shortly after to remain absent throughout the upper part of the formation as well as in the overlying Pliocene Cumaná and Playa Grande formations. Globorotalia tumida is, however, living today off the Venezuelan north coast. This would point towards a colder water temperature in coastal northeastern Venezuela during the uppermost Miocene and Pliocene compared with that of Java during the same time.

Globorotalia tumida s.l. was, to the authors' knowledge, also largely absent in the Gulf Coast area from the high Miocene to Pliocene/Pleistocene Because of its geographically limited occurrence, its use as a stratigraphic marker remains rather restricted.

Globorotalia truncatulinoides

Globorotalia truncatulinoides, appearing stratigraphically later than Globorotalia tumida, shows similar shortcomings. While Globorotalia tumida is definitely a warm water tropical form (distribution in the Pacific: ca. 0-20° N. and S.), Globorotalia truncatulinoides is largely found between 20 and 40° N. and S. in the Pacific, while its main distribution in the north Atlantic can seasonally extend from 20° to at least 50°, this more northern distribution being largely helped by currents such as the Gulf Stream.

Globorotalia truncatulinoides shows considerable variation which is primarily caused by an increase in the thickness of the wall. Bé and Ericson (1963) have demonstrated that the wall thickness increases while the species descends to greater depth during the later part of its life cycle, a similar phenomenon to that demonstrated by Bé (1965) for Sphaeroidinella dehiscens (see below).

After checking a number of paratypes of Globorotalia tosaensis, described from the Nobori formation of Japan and kindly supplied by Dr. Takayanagi, it is believed that this species is not only an ancestral form of Globorotalia truncatulinoides but at the same time corresponds to the type with thickened wall and thus of a late life cycle which lived in deeper water.

The presence in Pliocene to Recent sediments of Globorotalia truncatulinoides thus largely indicates an environment of only moderately warm water; abundant thick shelled specimens in addition point to deep water. Globorotalia truncatulinoides is absent in the section of Bodjonegoro-1 of Java probably for reasons of high water temperature, in the Cubagua Formation probably because these beds antedate its appearance. Thin shelled specimens occur in the Pliocene Cumaná and Playa Grande formations, indicating fairly shallow and colder water.

Globorotalia tumida and Globorotalia truncatulinoides are two examples of planktonic foraminiferal species which appear well above the Globorotalia menardii zone, with Globorotalia tumida displaying considerable evolutionary changes yet to be described. But both species are so much restricted environmentally that they often do not occur together and for this reason are not well suited as zonal markers for interregional correlations.

It may, however, be said in favor of Globorotalia truncatulinoides that during late Pliocene and Pleistocene time, i.e. during widespread periods of cooling, the species became abundant in lower latitudes. This is nicely demonstrated by its common presence in the Cumaná and Playa Grande formations and it is largely for this unique occurrence so far south that Globorotalia truncatulinoides with Globorotalia inflata have been chosen as zonal markers for these formations. Together with Globorotalia inflata and Globigerina bulloides it must in this case be regarded not so much as a time marker as an indicator for an environment that was colder then than today.

Sphaeroidinella seminulina / Sphaeroidinella dehiscens

Sphaeroidinella seminulina is regarded as the ancestor of Sphaeroidinella dehiscens. It should, therefore, not become extinct in a favorable habitat but rather develop into Sphaeroidinella dehiscens. Its disappearance in the Pozón and Cubagua formations must, therefore, be taken as evidence that Sphaeroidinella was driven out of the areas by some change in conditions that no longer agreed with the genus. Investigations on the distribution of recent Sphaeroidinella dehiscens in the Pacific (Bradshaw 1959, Prker 1962) show a latitudinal dispersion between about 30° N. and S. The disappearance of Sphaeroidinella in our sections was therefore hardly caused by water temperature. Other factors like changes in salinity or, more likely, water depth must have restricted the stratigraphic distribution of the genus.

An interesting contribution on Sphaeroidinella was recently given by Bé (1965). He attempts to prove a close relationship of Sphaeroidinella dehiscens with Globigerinoides sacculifer. According to his observations Sphaeroidinella develops from Globigerinoides sacculifer by secretion of a thick translucent calcite crust upon the test of Globigerinoides sacculifer. The thickening process starts in the epipelagic zone (0-300 m.) and reaches its maximum development at meso-and bathy-pelagic depth of 300-2000 m., This would indicate that Sphaeroidinella dehiscens, and thus most likely also its ancestor Sphaeroidinella seminulina s.l., only occur or occurred below 300 m. water depth, and should thus be absent in sediments laid down in less than 300 m. depth. This probably provides the explanation for the absence of Sphaeroidinella seminulina in the higher parts of the Pozón and Cubagua formations where a shallowing is indicated. The level of disappearance of Sphaeroidinella seminulina s.l. in the higher Pozón and Cubagua formations may still be useful for correlation within each of these formations but is of no value for interregional or worldwide zonation.

DEFINITION AND DESCRIPTION OF THE NEWLY PROPOSED ZONES

To establish a zonation of the widest possible application in an ecologic sense it is essential to choose as zonal markers such species as show a fair tolerance for changes in water temperature, salinity, water depth etc. Though a zonal marker has not to be restricted to the zone it names, a short range is desirable. These combined requirements of environmental tolerance and short stratigraphic range are unfortunately not often met. If a species with environmental tolerance is chosen, it often has to be at the expense of a longer range, or vice versa.

A good number of the planktonic foraminiferal species known from the Globorotalia menardii Zone later become extinct at various levels, while others are still living today. On the other hand several new species appeared, some of them living only for a short interval, others again going on to Recent. Thus in a marine warm to moderately warm water environment there exists no shortage of good marker fossils that can be used for the zonation of the interval post-Globorotalia menardii Zone to Pliocene.

Six zones based on planktonic Foraminifera and ranging from the uppermost Middle Miocene into the Pliocene are defined and discussed below. The observed ranges of the zonal markers and of two additional stratigraphically important species (Pulleniatina obliquiloculata, Globigerina riveroae) are shown for the following areas on Table 1:

Coastal northeastern Venezuela (1)
Coastal northwestern Venezuela (Falcon) (2)
Jamaica (3)
Java (4)

Table 2 shows the biostratigraphic correlation based on the new zones of upper Middle Miocene to Pliocene formations of these areas, and in addition also of Trinidad and Aruba (Netherlands Antilles). As can be seen, the facies of this stratigraphic interval is not suitable in Trinidad for the study of planktonic Foraminifera. It was only partially investigated in Aruba and Jamaica.

Globorotalia acostaensis Zone

Type section: From 641 to 386 meters in well Bodjonegoro-1, Java (Bolli, in press).

Definition of Zone: Interval from first occurrence of Globorotalia acostaensis to first occurrence of Globorotalia dutertrei. The zone lies between the older Globorotalia menardii Zone and the younger Globorotalia dutertrei/Globigerinoides obliquus extremuus Zone.

Globorotalia acostensis is a species which apparently had a fairly wide environmental tolerance. It was first described by Blow (1959) from the Pozón Formation in Falcón , where it appears first in the upper part of his Globorotalia menardii menardii/Globigerina nepenthes Zone and continues to the top of the Pozón and Ojo de Agua formations. The species is present practically throughout the Cubagua Formation. In well Bodjonegoro-1 of Java (Bolli i.p.) it appears first also in the interval which in Blow's terminology is the Globorotalia menardii menardii/Globigerina nepenthes Zone. The first appearance of Globorotalia acostaensis at 641 m. in Bodjonegoro-1 is now taken to delineate the top of the Globorotalia menardii Zone and at the same time the base of the new Globorotalia acostaensis Zone, which extends up to the first appearance of Globorotalia dutertrei at 386 m. (Bolli 1964; in press).

One finds Globorotalia acostaensis, with a similar assemblage as in the Globorotalia acostaensis Zone of Bodjonegoro-1, also in the lower part of the Cubagua Formation, in wells Cubagua-1 and -2, and in the upper part of Blow's Globorotalia menardii menardii/Globigerina nepenthes Zone of the Pozón formation. It is essentially a Globorotalia menardii Zone fauna plus Globorotalia acostaensis.

Therefore, the lower part of the fossiliferous interval of the Cubagua formation in wells Cubagua-1 (2904-2432') and -2 (4164-3062') is placed in the

Globorotalia acostaensis Zone and correlated with the uppermost part of Blow's Globorotalia menardii menardii/Globigerina nepenthes Zone of the Pozón formation, including possibly the whole or parts of his overlying Sphaeroidinella seminulina and Globigerina bulloides zones, should Globorotalia dutertrei be absent there not only for ecologic but also for stratigraphic reasons. The age equivalent of the Globorotalia acostaensis Zone would be found in Trinidad within the Cruse/Forest formations, which are practically devoid of planktonic Foraminifera and can thus not be directly compared faunistically.

Globorotalia dutertrei/Globigerinoides obliquus extremus Zone

Type section: From 2432-1435' in well Cubagua-1 on the island of Cubagua, Venezuela.

Definition of zone: Interval with Globorotalia dutertrei and Globigerinoides obliquus extremus but without Globorotalia margritae, Globorotalia crassaformis, Globorotalia truncatulinoides and Pulleniatina obliquiloculata (base of Globorotalia dutertrei to base of Globorotalia margaritae). The zone lies between the older Globorotalia acostaensis Zone and the younger Globorotalia margaritae Zone.

Globorotalia dutertrei is a distincitve planktonic species with apparently a fair tolerance to water temperature. In the Cubagua Formation of well Cubagua-1 it appears first at 2432' and in well Cubagua-2 at 2742', to continue in both sections to the top of the formation. The species is widespread in the Cumaná and Playa Grande formations and is living today off the north coast of Venezuela. With its fair tolerance to water temperature goes also, unfortunately, a long range that reduces its value as a stratigraphic marker. But in combination with Globigerinoides obliquus extremus, a species apparently restricted to the higher Miocene and Lower Pliocene as interpreted here (upper part Globorotalia acostaensis Zone to top Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone), Globorotalia dutertrei makes a good marker to determine an interval between the top of the Globorotalia acostaensis Zone (= base of Globorotalia dutertrei) and the base of the next higher zone, characterized by Globorotalia margaritae.

A Globorotalia dutertrei/Globigerinoides obliquus extremus Zone can also be distinguished in well Bodjonegoro-1 (from 386-354 meters), though much reduced in thickness, probably by the absence of its lower part.

Globorotalia margaritae Zone

Type section: From 1435-849' in well Cubagua-1 on the island of Cubagua, Venezuela.

Definition of zone: Range of the zonal marker Globorotalia margaritae. The zone lies between the older Globorotalia dutertrei/Globigerinoides obliquus extremus Zone and the younger Globoquadrina altispira altispira/Globorotalia crassaformis Zone.

Globorotalia margaritae is a distinctive species which is restricted in the Cubagua Formation to the uppermost part of the Cerro Verde Member and to the lowermost part of the Cerro Negro Member. It is found in surface sections of Margarita, Araya and in the wells Cubagua-1 (between 1435 and 849') and Cubagua-2 (between 2159 and 1326'). The species is also known from Bodjonegoro-1, Java, not only with a similarly short range but also in a very similar or identical stratigraphic position. In addition, Globorotalia margaritae has also been noted in the Bowden and Buff Bay formations of Jamaica and in the Gulf Coast area.

Because of its widespread occurrence, possibly even reaching into more temperate waters, and its restricted stratigraphic range, Globorotalia margaritae makes an excellent stratigraphic marker. It is therefore chosen to characterize the zone following that of Globorotalia dutertrei/Globigerinoides obliquus extremus. The Globorotalia margaritae Zone is defined by the total range of the species.

The range of Globorotalia margaritae comprises, as pointed out, the highest part of the Cerro Verde and the basal part of the Cerro Negro members of the Cubagua Formation. Field evidence in Araya shows that Pulleniatina obliquiloculata s.l. first comes in at the base of the Cerro Negro Member. It disappears again, probably for adverse ecologic conditions, after only a short but distinct show. This takes place even before the short-lived zonal marker Globorotalia margaritae becomes extinct.

Very shortly after Pulleniatina obliquiloculata s.l. appears, at about the level where the species changes from the initial sinistral to dextral coiling, Globigerina riveroae appears, to continue to the top of the Cerro Negro Member. The occurrence of this species together with Globorotalia margaritae but without Pulleniatina obliquiloculata s.l. would therefore also indicate the Cerro Negro part of the Globorotalia margaritae Zone.

It is thus possible to recognize within the Globorotalia margaritae Zone two biostratigraphic units which coincide with the lithostratigraphic subdivision of the Cubagua formation, viz.

Cerro Negro member: (base)	Globorotalia margaritae with Pulleniatina obliquiloculata and/or Globigerina riveroae
Cerro Verde member: (top)	Globorotalia margaritae without Pulleniatina obliquiloculata and Globigerina riveroae.

Globoquadrina altispira altispira/Globorotalia crassaformis Zone

Type section: From 849' to the top in well Cubagua-1 on the island of Cubagua, Venezuela.

Definition of zone: Interval with Globoquadrina altispira altispira and Globorotalia crassaformis, between extinction of Globorotalia margaritae and first appearance of Globorotalia truncatulinoides. The zone between the older Globorotalia margaritae Zone and the younger Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone.

A considerable gap apparently exists between the extinction of Globorotalia margaritae and the first appearance of Globorotalia truncatulinoides.

In absence of restricted markers within this interval it is named as a zone after two long ranging species that extend below and above it. Such a Zone is thus determined by the two zonal markers and the absence of Globorotalia margaritae and Globorotalia truncatulinoides.

The zone is of considerable thickness in the Cubagua Formation (849' in well Cubagua-1, 1326' in well Cubagua-2) where it reaches to the top of the formation and thus might not even be preserved fully.

The zone is also present within the upper part of the Bodjonegoro-1 well section in Java (305-214 m). The upper part of this interval might however already be the stratigraphic equivalent of the next younger Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone (see previous discussion of Globorotalia truncatulinoides).

Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone

Type section: Type locality area of the Manchioneal formation, Jamaica, sample R.M. Stainforth 119611.

Definition of zone: Interval with the joint occurrence of Globoquadrina altispira altispira and Globorotalia truncatulinoides. The zone lies between the older Globoquadrina altispira altispira/Globorotalia crassaformis Zone and the younger Globorotalia truncatulinoides/Globorotalia inflata Zone.

An overlap of the two zonal markers was found to exist in samples from the type locality area of the Manchioneal formation in Jamaica and also in the Submarex borehole drilled south of Jamaica by the Marine Laboratory of the University of Miami, from the bottom of the hole at 1748 cm. to 1410 cm.

An overlap of these two species was not noted in coastal northeastern Venezuela where it is assumed that such an assemblage would fall within a hiatus between the top of the Cubagua Formation (Globoquadrina altispira altispira/Globorotalia crassaformis Zone) and the base of the Cumaná Formation (Globorotalia truncatulinoides/Globorotalia inflata Zone).

The zone is also not recognizable in the Bodjonegoro-1 section of Java, there probably for ecologic reasons. The extinction of Globoquadrina altispira altispira occurs in this well at 216 m. If distribution patterns in the East Indies were the same as in the Caribbean, one would expect Globorotalia truncatulinoides to appear somewhere below this level. As pointed out in the discussion of Globorotalia truncatulinoides earlier in this paper, this species is absent in the Bodjonegoro-1 section apparently for temperature reasons.

This is a good example to show how variable even within the warm to moderately warm water limits the distribution of certain planktonic Foraminifera can be and, as a consequence, how limited their use as zonal markers may become.

Globorotalia truncatulinoides/Globorotalia inflata Zone

Type section: Playa Grande formation at Cabo Blanco, north of Maiquetía airport, Venezuela. In particular lower part of formation containing the zonal markers.

Definition of zone: Globorotalia truncatulinoides and Globorotalia inflata without Globoquadrina altispira altispira. The zone lies above the Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone. Its markers reach, under favorable ecological conditions, up to Recent.

A planktonic fauna of a colder water environment, such as existed earlier in the Miocene Cubagua Formation, is present in the Pliocene Cumaná and Playa Grande formations of coastal northeastern Venezuela. It is characterized by the zonal markers Globorotalia truncatulinoides (distribution in the N. Pacific: approx. 20-40°) and Globorotalia inflate (approx. 25-40°), further by Globigerina bulloides (approx. 30-60°) and by the absence of such warm water species as Globorotalia tumida (0-20°). Globorotalia menardii (0-30°) occurs in certain beds of the Playa Grande formation, but its presence is usually exclusive of the above-mentioned colder water species as well as the warm water Globorotalia tumida. Comparing with conditions existing today in the North Pacific (Bradshaw 1959), one can conclude that the parts of the Cumaná and Playa Grande formations containing Globorotalia truncatulinoides, Globorotalia inflata and Globigerina bulloides were laid down under water temperatures comparable to those prevailing today in the North Pacific between about 30-40°. The intervals with Globorotalia menardii would have been deposited in slightly warmer waters.

A Pliocene zone erected on species ranging from the Pliocene to Recent is difficult to use for interregional biostratigraphic correlations but may find local applications. In the present case it facilitates correlation of the above mentioned Pliocene faunas along coastal northeastern Venezuela. At the same time the zonal markers point to a colder water influx that is unusual for these low latitudes, probably reflecting one or more of the periods of increased glaciation.

In Jamaica the Globorotalia truncatulinoides/Globorotalia inflata Zone may be present in beds, not yet studied, overlying the Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone in the Manchioneal Formation. In the Submarex borehole it may represent an interval above the extinction of Globoquadrina altispira altispira at 1410 cm. The intermittent presence above this level of Globorotalia truncatulinoides and/or Globorotalia tumida and the absence there of Globorotalia inflata and Globigerina bulloides point to already warmer water conditions than existed at the same time in coastal northeastern Venezuela. More information will be required, however, to substantiate such correlations between the Pliocene of Jamaica and Venezuela.

For ecologic reasons the markers of the Globorotalia truncatulinoides/Globorotalia inflata Zone are not present in the Bodjonegoro-1 well section of Java. If the extinction levels of Globoquadrina altispira altispira are identical in the East Indies and to the Globorotalia truncatulinoides/Globorotalia inflata Zone of coastal northeastern Venezuela are approximate age-equivalents of the whole or part of the Bodjonegoro-1 interval above depth 216 m., where Globoquadrina altispira altispira is no longer present.

In conclusion it may be said that the above-defined zones can, with the exception of the Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone, clearly be recognized in coastal northeastern Venezuela, the Globorotalia truncatulinoides/Globorotalia inflata Zone in the Pliocene Cumaná and Playa Grande formations, the others in the Miocene Cubagua formation, both in well sections of Cubagua-1 and 2 and, as far as exposed, in surface sections on Margarita, Cubagua and Araya. An identical sequence of zones is also discernible in the higher part of the Bodjonegoro-1 well section of Java with the exception of the two zones. Further, there are good indications that such a proposed zonation can also be applied to the younger marine Tertiary of Jamaica where, so far, the Globorotalia margaritae and the Globoquadrina altispira altispira/Globorotalia truncatulinoides zones are recognized.

It is expected that amongst other areas such a zonation or a similar one can be carried into the Gulf Coast area. How much farther geographically this subdivision, based predominantly on warm to moderately warm water planktonic foraminiferal species, can be extended is, however, still to be determined.

THE DIRECTION OF COILING OF THE INDEX SPECIES

The patterns of coiling direction of the stratigraphically more important planktonic Foraminifera used in this study will be described in forthcoming papers on the faunas and their stratigraphic distribution. Here it need only be mentioned that practically all specimens of the following species were found to coil sinistrally within the stratigraphic interval dealt with in this paper:

Globorotalia margaritae
Globorotalia inflata
Globoquadrina altispira altispira

whereas the majority of the Globorotalia truncatulinoides display dextral coiling.

The coiling patterns of Globorotalia truncatulinoides display dextral coiling.

The coiling patterns of Globorotalia acostensis, Globorotalia dutertrei and Globorotalia crassaformis were found to show changing intervals of distinctly preferred dextral or sinistral coiling. The coiling pattern of Pulleniatina obliquiloculata was discussed by Bolli, 1964.

THE PLACEMENT OF THE MIOCENE/PLIOCENE AND PLIOCENE/PLEISTOCENE BOUNDARIES

Opinions on the placement of the Miocene/Pliocene and Pliocene/Pleistocene boundaries are still contradictory. It is not intended to enter here into a full discussion but the following remarks may suffice to point out some of the questions still to be solved and the cited references should provide a fuller insight into the existing problems.

The present authors adhere here - for convenience - to an interpretation based on macrofossil evidence of the area under study. The Cubagua Formation of coastal northeastern Venezuela is thus regarded as Middle to Upper Miocene. This is in part contrary to the views expressed by Bandy (1962, 1963a, 1963b, 1964a) and discussed by Bolli (1964). Bandy proposed - though without convincing paleontological support - to place the Miocene/Pliocene boundary at the first occurrence of Sphaeroidinella dehiscens and common Pulleniatina obliquiloculata. If this were accepted, the Cerro Negro Member of the Cubagua Formation would have to be placed in the Pliocene. Reference in this connection is also made to the discussions by Stainforth (1964) and Bandy (1964b) on the problems of Miocene subdivision.

Following **Weisbord** (1962) the age of the Playa Grande Formation of the Cabo Blanco Group, and correspondingly the Cumaná formation, is accepted as Pliocene. This is in contrast to the views expressed by Ericson et al. (1963), who define the Pliocene/Pleistocene boundary on a number of micropaleontological criteria like abundance of Globorotalia truncatulinoides, sinistral coiling of Globorotalia menardii etc. By taking those into account, the Playa Grande and its age equivalent formations would have to be placed in the Pleistocene. The conclusions of Ericson et al. were subsequently critically discussed by Riedel et al. (1963). Jenkins (1964) discusses the Pliocene/Pleistocene boundary in higher latitudes, in particular in New Zealand.

Finally, reference is made to comments by Bolli (in Drooger, 1964), where a number of problems are pointed out that will have to be dealt with in the attempt at a world-wide zonation of Miocene to Recent sediments based on planktonic Foraminifera.

DESCRIPTIONS OF NEW SPECIES

Globigerina riveroae Bolli & Bermúdez, new species

Plate 1, Figures 1 - 6

Shape of test low to medium high trochospiral, wider than high; equatorial periphery strongly lobate. Wall calcareous, perforate, surface of well preserved specimens covered with very short spines. Chambers spherical, 10-12, arranged in about 2 whorls, the 4 chambers of the last whorl, in particular the ultimate one, rapidly increasing in size. Sutures on spiral and umbilical side radial, incised. Umbilicus wide and distinct. Aperture of the last chamber a very large more or less semicircular arch bordered by a distinct though thin rim, interiomarginal, umbilical. Large aperture of penultimate chamber as a rule also clearly visible. Largest diameter of holotype 0.35 mm.

Stratigraphic range: Globorotalia margaritae Zone (upper part) and Globoquadrina altispira altispira/Globorotalia crassaformis Zone, Upper Miocene, Cerro Negro member, Cubagua formation, Venezuela.

Locality: Holotype from beds outcropping directly below the terrace on which stands the village of Araya, Península de Araya, Estado Sucre, Venezuela. Sample P.J. Bermúdez 7/64. Figured paratypes from beds outcropping in La Caldera, Isla Cubagua, Estado Nueva Esparta, Venezuela. Sample P.J. Bermúdez Cubagua 8. Types deposited at the U.S. National Museum, Washington, D.C.**

Remarks: Globigerina riveroae is characterized by its globular form and in particular by its very large, nearly semicircular aperture of the ultimate chamber. The new species most closely resembles Globigerina bulloides d'Orbigny but differs from it in the larger size of the above-mentioned aperture. Further, Globigerina riveroae is stratigraphically and geographically much more restricted than Globigerina bulloides. So far, the species has only been observed in the upper part of the Globorotalia margaritae Zone and in the Globoquadrina altispira altispira/Globorotalia crassaformis Zone of the Cerro Negro member, Cubagua formation, coastal northeastern Venezuela. It seems to have lived there under only moderately warm water conditions. Globigerina riveroae is no longer present in the Pliocene Cumaná and Playa Grande formations of the same area and is also not known from the Recent. It is possible that Globigerina riveroae branched off from Globigerina bulloides in the late Miocene under ecological conditions

** Editor's Note: USNM catalogue numbers of the types of the five new species described here had not been received up to the time of going to press. They will be listed in a future issue.

that existed, as far as known, only in a restricted area around coastal northeastern Venezuela. It became extinct there at about the close of the Miocene. Locally the new species is thus a good index fossil for the Cerro Negro member of the Cubagua Formation.

The new species is named in honor of Prof. Frances de Rivero of the Escuela de Geología, Universidad Central de Venezuela, Caracas.

Globigerina tetracamerata Bolli & Bermúdez, new species

Plate 1, Figures 7 - 9

Shape of test trochospiral; equatorial periphery strongly lobate. Wall calcareous, very finely perforate. Chambers spherical, about 10, arranged in 2 to 2 1/2 whorls; the 4 chambers of the last whorl increase rapidly in size but the final chamber may be reduced. Sutures on spiral and umbilical side radial, incised. Umbilicus distinct. Aperture of ultimate chamber a medium sized arch, often bordered by a thin lip or rim; interiomarginal, umbilical. Largest diameter of holotype: 0.23 mm.

Stratigraphic range: Globorotalia acostaensis Zone to Globorotalia truncatulinoides/Globorotalia inflata Zone, Lower Miocene to Pliocene, Cubagua and Cumaná formations, Venezuela. Catapsydrax stainforthi Zone to Globorotalia menardii Zone, Lower Miocene to Middle Miocene, Cipero and Lengua formations, Trinidad. Globigerinatella insueta Zone to Globoquadrina altispira altispira/Globorotalia crassaformis Zone, Lower Miocene to Upper Miocene, Kalibeng and Rembang beds in well Bodjonegoro-1, Java.

Locality: Holotype from La Cantera de Araya, south side of Cerro Barrigón, Península de Araya, Estado Sucre, Venezuela. Globorotalia truncatulinoides/Globorotalia inflata Zone, Cumaná formation. Sample Humberto Calderon no. 72. Holotype deposited at the U.S. National Museum, Washington, D.C.

Remarks: Globigerina tetracemerata is characterized by its small size and the four chambers in the last whorl. The general shape and apertural characteristics may be compared with those of Globigerina foliata Bolli which is, however, much larger.

Globigerinoides obliquus extremus Bolli & Bermúdez, new subspecies.

Plate 1, Figures 10 - 12

Shape of test high trochospiral; equatorial periphery distinctly lobate; axial periphery rounded. Wall calcareous, perforate, surface finely pitted. Chambers of the last whorl progressively more compressed in a lateral, oblique manner; 10 - 12, arranged in 2 to 3 whorls; the 4 chambers of the last whorl increase fairly rapidly in size, though the last chamber may be slightly reduced in some specimens. Sutures somewhat oblique on spiral and umbilical side, incised. Umbilicus rather narrow. Primary aperture a distinct arch of medium height, interiomarginal, umbilical. One supplementary aperture on last chamber often also visible on earlier ones. Largest diameter of holotype: 0.36 mm.

Stratigraphic range: Globorotalia acostaensis Zone to Globoquadrina altispira altispira/Globorotalia crassaformis Zone, Middle Miocene to Upper Miocene, Cubagua formation, Venezuela.

Locality: Holotype from core 1029-1034 feet of well Cubagua-1, Isla Cubagua, Estado Nueva Esparta, Venezuela. Globorotalia margaritae Zone, Cubagua formation. Holotype deposited at the U.S. National Museum, Washington, D.C.

Remarks: Globigerinoides obliquus extremus evolved from Globigerinoides obliquus obliquus Bolli (1957,p.113) probably in the Globorotalia acostaensis zone. It differs from Globigerinoides obliquus obliquus in that even the earlier chambers of the last whorl are compressed in a laterally oblique manner, and the compression of the final chamber is much more pronnounced than in the type subspecies. The new subspecies continues to or near the top of the Miocene. It is no longer present in the Pliocene Cumaná and Playa Grande formations of coastal northeastern Venezuela and is also not known from the Recent. Its characteristically compressed chambers and its range restricted to the uppermost Middle and the Upper Miocene make the subspecies a good index fossil. In the well section of Bodjonegoro-1, Java, it has been found in a similar stratigraphic position. The subspecies has been chosen as a comarker for the Globorotalia dutertrei/Globigerinoides obliquus extremus Zone which is defined in this paper.

Globorotalia margaritae Bolli & Bermúdez, new species.

Plate 1, Figures 16 - 18

Shape of test low trochospiral, compressed and elongate; equatorial periphery slightly lobate; axial periphery acute with a thin keel. Spiral side rounded-convex, umbilical side much less convex. Wall calcareous, finely perforate, surface smooth to very finely pitted. Chambers strongly compressed, seen from the spiral side elongate, fairly narrow and distinctly curved, about 12, arranged in 2 to 2-1/2 whorls; the usually 5 chambers of the last whorl increase fairly rapidly in size. Sutures on spiral side strongly curved but only very slightly depressed; on umbilical side radial to slightly curved, more or less depressed. Umbilicus very narrow. Aperture a slit, bordered above by a small, thin lip, interiomarginal, umbilical-extraumbilical. Coiling sinistral. Largest diameter of holotype: 0.37 mm.

Stratigraphic range: Globorotalia margaritae Zone, Upper Miocene: Upper part Cerro Verde member and lower part Cerro Negro member, Cubagua formation, Venezuela; type locality of Bowden and Buff Bay formations, Jamaica; Rembang beds between 354-305 meters in well Bodjonegoro-1, Java.

Locality: Holotype from roadcut on highway leading from Porlamar to Boca del Rio, east of Espinal and immediately west of junction where highway to Punta de Piedras branches off; Isla Margarita, Estado Nueva Esparta, Venezuela. Globorotalia margaritae Zone, Las Hernandez beds, a local equivalent of the Cubagua formation. Holotype deposited at the U.S. National Museum, Washington, D.C.

Remarks: Globorotalia margaritae differs from Globorotalia menardii d'Orbigny in the more convexly rounded spiral side, in the smaller and finer developed peripheral keel and, seen from the spiral side, in the more elongate, narrower and more strongly curved chambers. Globorotalia margaritae is restricted to the zone of the same name which is defined in this paper. It has thus a much shorter range than Globorotalia menardii and is regarded as an excellent index fossil. So far Globorotalia margaritae has been found in several parts of the Caribbean area and in Java. In all samples studied from these areas, the new species coils sinistrally whereas Globorotalia menardii strongly prefers dextral coiling in the same samples.

Globorotalia pseudomiocenica Bolli & Bermúdez, new species

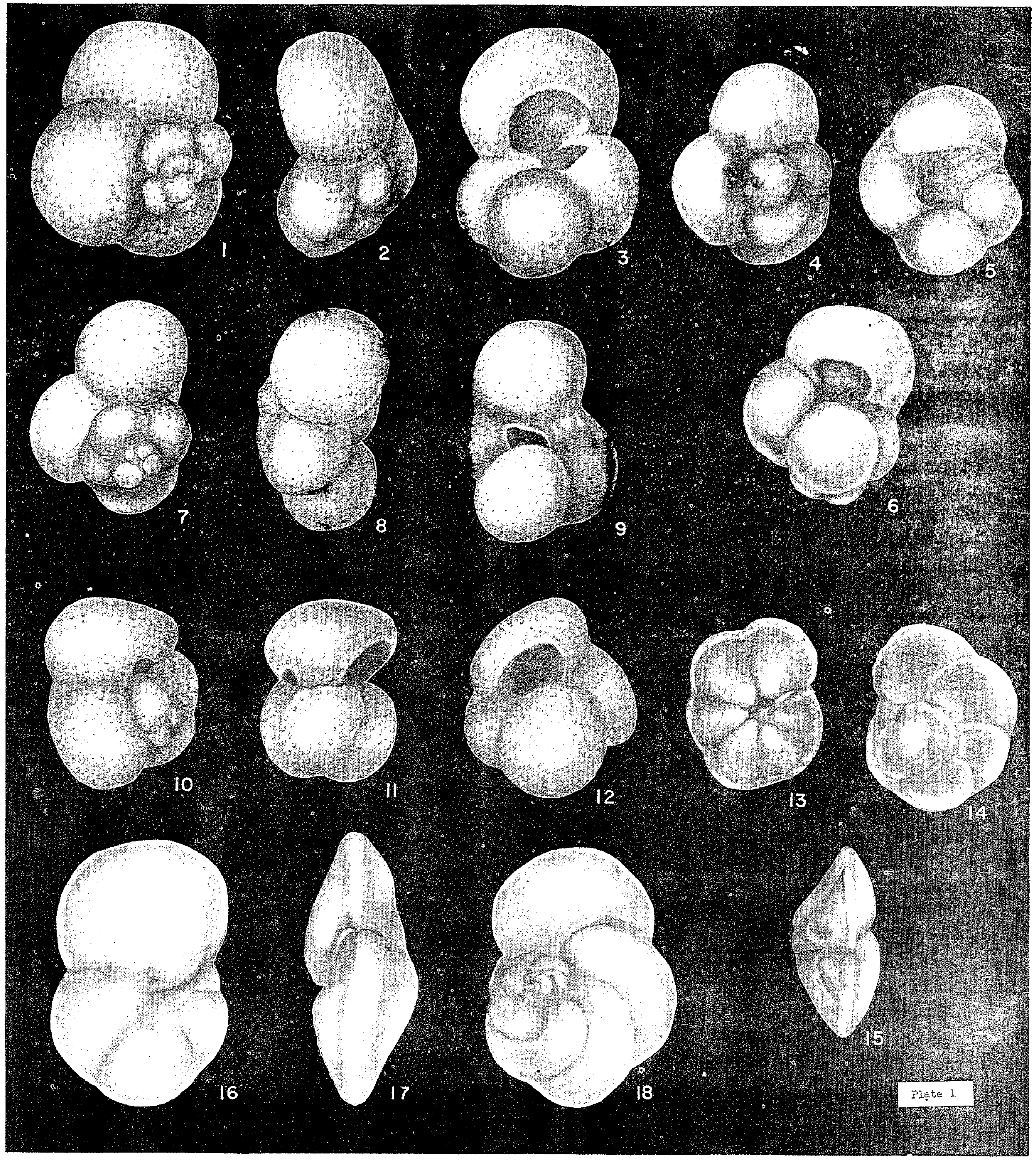
Plate 1, Figures 13 - 15

Shape of test very low trochospiral, flat to only very slightly convex on spiral side, strongly convex on umbilical side; equatorial periphery slightly lobate; axial periphery acute with a thin but distinct keel. Wall calcareous, finely perforate, surface smooth to very finely pitted. Chambers angular, more or less flat on spiral side, high on umbilical side; about 12, arranged in 2 to 2-1/2 whorls; the 4 to 5 chambers of the last whorl increase moderately in size. Sutures on spiral side curved; on umbilical side radial to slightly curved and slightly depressed. Umbilicus very narrow. Aperture a slit bordered above by a fine rim or lip; interiomarginal, umbilical-extraumbilical. Largest diameter of holotype: 0.52 mm.

Stratigraphic range: Globorotalia menardii Zone, Middle Miocene, Carenero Formation, and Globorotalia acostaensis Zone, Middle Miocene, Cubagua formation both from coastal northeastern Venezuela. Globorotalia mayeri Zone, Middle Miocene, to Globoquadrina altispira altispira/Globorotalia crassaformis Zone, Upper Miocene, Rembang and Kalibeng beds, well Bodjonegoro-1, Java.

Locality: Holotype from cut in road leading from Higuerote to Chirimena, after bridge across lagoon immediately northwest of Carenero, Estado Miranda, Venezuela. Globorotalia menardii Zone, Carenero Formation. Holotype deposited at the U.S. National Museum, Washington, D.C.

Remarks: Globorotalia pseudomiocenica differs from Globorotalia menardii (d'Orbigny) in the flatter, almost plane spiral side, in the strongly convex umbilical side, the thinner peripheral keel and often also by the smaller size of the test. The new species differs from Globorotalia miocenica Palmer in having a more lobate equatorial periphery which in typical Globorotalia miocenica is practically not lobate. The spiral side may in some specimens of Globorotalia pseudomiocenica be very slightly convex, in typical Globorotalia miocenica it is completely flat. Globorotalia pseudomiocenica has a longer range than Globorotalia miocenica, which is known in Jamaica from the Globorotalia margaritae Zone (Bowden and Buff Bay type localities) and from the Globoquadrina altispira altispira/Globorotalia truncatulinoides Zone and the Globorotalia truncatulinoides/Globorotalia inflata Zone (Submarex well 6301 of the Marine Laboratory, University of Miami). It appears that Globorotalia pseudomiocenica has also a much wider geographic distribution than Globorotalia miocenica.



EXPLANATION OF PLATE 1

Figures

1 - 3 : Globigerina riveroae Bolli & Bermúdez n. sp.
Holotype, x 120.
Upper Miocene, Cubagua Formation, Venezuela.

4 - 6 : Globigerina riveroae Bolli & Bermúdez n. sp.
Paratypes, x 120.
Upper Miocene, Cubagua Formation, Venezuela.

7 - 9 : Globigerina tetracamerata Bolli & Bermúdez n. sp.
Holotype, x 175.
Pliocene, Cumaná Formation, Venezuela.

10 - 12 : Globigerinoides obliquus extremus Bolli & Bermúdez n. subsp.
Holotype, x 96.
Upper Miocene, Cubagua Formation, Venezuela.

13 - 15 : Globorotalia pseudomiocenica Bolli & Bermúdez n. sp.
Holotype, x 66.
Middle Miocene, Carenero Formation, Venezuela.

16 - 18 : Globorotalia margaritae Bolli & Bermúdez n. sp.
Holotype, x 130.
Upper Miocene, Cubagua Formation, Venezuela.

T A B L E 1

ZONATION AND DISTRIBUTION OF ZONAL MARKERS IN MIDDLE MIOCENE TO PLIOCENE WARM-WATER SEDIMENTS

Key to sections represented in the numbered sub-columns

1. Coastal northeastern Venezuela.

Cumaná and Playa Grande formations (Zone of G. truncatulinoides/G. inflata)

Cubagua Formation (Zones of G. acostaensis to G. a. altispira/G. truncatulinoides)

Carenero Formation (Zone of G. menardii)

2. Coastal northwestern Venezuela.

Pozón Formation, upper part (Zones of G. menardii and G. acostaensis)

Higher zones may be represented in the overlying Ojo de Agua Formation, but it is a brackish-water deposit containing no significant planktonic foraminifera.

Other young Miocene/Pliocene deposits of this region, in particular the Punta Gavilán Formation, are not included in the present study.

3. Jamaica

Beds above 1410 cm. in Submarex borehole (? Zone of G. truncatulinoides/G. inflata)

Manchioneal Formation and beds at 1410-1748 cm. in Submarex borehole (Zone of G. a. altispira/G. truncatulinoides)

Bowden and Buff Bay formations at type localities (Zone of G. margaritae)

This is an incomplete sampling of the sequence in Jamaica, and the zones not mentioned may well be present there.

4. Java

Kalibeng and Rembang beds cored in well Bodjonegoro-1. (Zones of G. menardii up to G. a. altispira/G. crassaformis as in Caribbean sections; diagnostic features of the two overlying zones modified by higher water temperatures)

LEGEND

- (hatched) Hiatus
- (empty box) Species absent for stratigraphic reason
- e c Species absent for ecologic reason
- n s Interval not studied
- 1-4 See opposite page

AGE	ZONES	Globoquadrina altispira altispira 1	2	3	4	Globorotalia acostaensis 1	2	3	4	Globigerinoides obliquus extremus 1	2	3	4	Globorotalia dutertrei 1	2	3	4	Globorotalia margaritae 1	2	3	4
Pliocene	Globorotalia truncatulinoides /Globorotalia inflata														ec						
Pliocene	Globoquadrina altispira altispira /Globorotalia truncatulinoides		ec		?						ec		?		ec						
Upper Miocene	Globoquadrina altispira altispira /Globorotalia crassaformis		ec	ns			ec	ns	?ec		ec	ns			ec	ns					
Upper Miocene	Globorotalia margaritae		ec				ec		?ec		ec				ec				ec		
Upper Miocene	Globorotalia dutertrei/ Globigerinoides obliquus extremus		ec	ns			ec	ns	?ec		ec	ns			ec	ns					
Middle Miocene	Globorotalia acostaensis			ns				ns													
Middle Miocene	Globorotalia menardii			ns																	

AGE	ZONES	Globorotalia crassaformis 1	2	3	4	Pulleniatina obliquiloculata 1	2	3	4	Globigerina riveroae 1	2	3	4	Globorotalia truncatulinoides 1	2	3	4	Globorotalia inflata 1	2	3	4
Pliocene	Globorotalia truncatulinoides /Globorotalia inflata		ec				ec								ec		ec		ec	ns	ec
Pliocene	Globoquadrina altispira altispira /Globorotalia truncatulinoides		ec				ec								ec		ec		ec		ec
Upper Miocene	Globoquadrina altispira altispira /Globorotalia crassaformis		ec	ns		ec	ec	ns			ec	ns	ec								
Upper Miocene	Globorotalia margaritae		ec		?ec		ec				ec	ec	ec								
Upper Miocene	Globorotalia dutertrei/ Globigerinoides obliquus extremus																				
Middle Miocene	Globorotalia acostaensis																				
Middle Miocene	Globorotalia menardii																				

Table 1

AGE	ZONES	Trinidad	Coastal NE Venezuela	Coastal NW Venezuela	Aruba	Jamaica	Java, well Bodjonegoro-1
Pliocene	Globorotalia truncatulinoides/ Globorotalia inflata	Cruse-Forest-Morne l'Enfer-Erin formations. Facies not suitable for the study of planktonic foraminifera.	Cumaná and Playa Grande fms	? Ojo de Agua Fm. ?	not investigated		Kalibeng beds
	Globoquadrina altispira altispira /Globorotalia truncatulinoides					Manchioneal Fm.	
Upper Miocene	Globoquadrina altispira altispira /Globorotalia crassaformis		Cubagua Formation: Cerro Negro Member				
	Globorotalia margaritae		Cubagua Formation: Cerro Verde Member		Oranjestad Miocene	Bowden and Buff Bay fms.	
	Globigerina dutertrei/ Globigerinoides obliquus extremus				not investigated	not investigated	
Middle Miocene	Globorotalia acostaensis			Pozón Fm.			Kalibeng beds and/or Rembang beds
	Globorotalia menardii	Lengua Fm.	Carenero Fm.				
	Globorotalia mayeri						

Table 2 : Biostratigraphic correlation of some uppermost Middle Miocene to Pliocene formations in Trinidad, coastal northeastern Venezuela, coastal northwestern Venezuela (Falcón), Aruba, Jamaica and Java.

REFERENCES

BANDY, O.L, 1962

"Cenozoic foraminiferal zonation and basinal development for part of the Philippines"
Amer. Assoc. Petrol. Geol., Bull., vol. 46, no. 2, p. 260 (abst.)

----------- 1963a

"Cenozoic planktonic foraminiferal zonation and basinal development in the Philippines"
Idem, vol. 47, no. 9, p. 1733-1745

----------- 1963b

"Miocene-Pliocene boundary in the Philippines as related to late Tertiary stratigraphy of deep-sea sediments"
Science, vol. 142, no. 3597, p. 1290-1292

----------- 1964a

"Cenozioic planktonic foraminferal zonation"
Micropaleontology, vol. 10, no. 1, p. 1-17

----------- 1964b

"Subdivision of Miocene; reply"
Amer. Assoc. Petrol. Geol., Bull., vol. 48, no. 11, p. 1848-1850

BE, A.W.H., 1965

"The influence of depth on shell growth in Globigerinoides sacculifer"
Micropaleontology, vol. 11, no. 1, p. 81-97

---------- & ERICSON,D.B.,1963

"Aspects of calcification in planktonic foraminifera (Sarcodina)"
New York Acad. Sci., Ann., Vol. 109, art. 1, p. 65-81

BERMUDEZ, P.J. & FUENMAYOR, A., 1962

"Notas sobre los foraminíferos del Grupo Cabo Blanco, Venezuela"
Asoc. Ven. Geol. Min. Petr., Bol. Inf., vol. 5, no. 1, p. 3-16

BLOW, W.H., 1959

"Age,correlation and biostratigraphy of the upper Tocuyo (San Lorenzo) and Pozón formations, eastern Falcón, Venezuela"
Bull. Amer. Pal., vol. 39, no. 178, p. 59-251

BOLLI, H.M., 1957

"Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, B.W.I."
U.S. Nat. Mus., Bull. 215, p. 97-123

------------ 1964

"Observations on the stratigraphic distribution of some warm water planktonic foraminifera in the young Miocene to Recent"
Eclog. Geol. Helv., vol. 57, no. 2, p. 541-552

------------ (in press)

"The planktonic foraminifera in well Bodjonegoro-1, Java"
Idem, vol. 59, no. 1

BOOMGART, L., 1949

"Smaller foraminifera from Bodjonegoro (Java)"
Univ. Utrecht, Diss., p. 1-175

BRADSHAW, J.S., 1959

"Ecology of living planktonic foraminifera in the north and equatorial Pacific Ocean"
Cushman Found. Foram. Res., Contrib., vol. 10, pt.2, p. 25-64

CUSHMAN, J.A. & JARVIS, P.W., 1930

"Miocene foraminifera from Buff Bay, Jamaica"
Jour. Pal., vol. 4, no. 4, p. 353-368

------- & TODD, R., 1945

"Miocene foraminifera from Buff Bay, Jamaica"
Cushman Lab. Foram. Res., Spec. Publ. 15, p. 1-73

DROOGER, C.W., 1953

"Miocene and Pleistocene foraminifera from Oranjestad, Aruba (Netherlands Antilles)"
Cushman Found. Foram. Res., Contrib., vol. 4, p. 116-147

-------------- 1964

"Zonation of the Miocene by means of planktonic foraminifera; a review and some comments"
IN: Symposium on micropaleontological lineages and zones used for bio-stratigraphic subdivision of the Neogene, p. 20-27. Neogen Kongress Bern.

ERICSON, D.B., EWING, M. & WOLLIN, G., 1963

"Pliocene-Pleistocene boundary in deep-sea sediments"
Science, vol. 139, no. 3556, p. 727-735

JENKINS, D.G., 1964

"Location of the Pliocene-Pleistocene boundary"
Cushman Found. Foram. Res., Contrib., vol. 15, pt. 1, p. 25-27

KUGLER, H.G., 1957

"Contributions to the geology of the islands Margarita and Cubagua, Venezuela"
Geol. Soc. Am., Bull., vol. 68, p. 555-566

PALMER, D.K., 1945

"Notes on the foraminifera from Bowden, Jamaica"
Bull. Amer. Pal., vol. 29, no. 115, p. 5-82

PARKER, F.L., 1962

"Planktonic foraminiferal species in Pacific sediments"
Micropaleontology, vol. 8, no. 2, p. 219-253

RENZ, H.H., 1948

"Stratigraphy and fauna of the Agua Salada Group, State of Falcón, Venezuela"
Geol. Soc. Am., Mem. 32, p. 1-219

RIEDEL, W.R., BRAMLETTE, M.N. & PARKER, F.L., 1963

"Pliocene-Pleistocene boundary in deep-sea sediments"
Science, vol. 140, no. 3572, p. 1238-1240

STAINFORTH, R.M., 1964

"Subdivision of the Miocene"
Amer. Assoc. Petrol. Geol., Bull., vol. 48, no. 11, p. 1847-1848

TRECHMAN, C.T., 1930

"The Manchioneal beds of Jamaica"
Geol. Mag., vol. 67, p. 199-218

WEISBORD, N.E., 1962

"Late Cenozoic gastropods from northern Venezuela"
Bull. Amer. Pal., vol. 42, no. 193, p. 1-672