

of the evolution of marine sedimentation in the Mediterranean since the latest part of the Miocene is presented.

At times, the last subchapter departs from the realm of objective nonpartisan reporting. We recognize some of the writing as speculative. We will be glad if the tale woven here

elicits new avenues of attack on what is to us an intricate and fascinating history of the Mediterranean region.

W.B.F.R.

47.1. PLIOCENE BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

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INTRODUCTION

Pliocene sediments have been recovered in forty-two of the more than two hundred cores recovered during Leg 13 of the Deep Sea Drilling Project in the eastern North Atlantic and Mediterranean Sea. Fossiliferous Pliocene sediments were found at Sites 120 (Gorringe Bank), 121 (Alboran Basin), 122 and 123 (Valencia Trough), 124 (Balearic Rise), 127 (Hellenic Trench), 129 (Strabo Trench and Mountains), and 134 (Balearic Abyssal Plain). However, these sites were not continuously cored and the cored intervals were often widely separated. In some cases the material is allochthonous.

The best sections of the Pliocene were those continuously cored at Site 132 in the Tyrrhenian Basin and Site 125 in the Ionian Basin. In fact, at the latter site, the Pliocene interval was cored twice.

In the sedimentary sequence of Sites 132 and 125 the Pliocene is represented by highly calcareous deep-sea pelagic oozes with a low and constant rate of sedimentation. Planktonic foraminifera are by far the most abundant constituent of the sand-sized fraction of the sediment. Such material is ideally suited for biostratigraphic investigations. The thickness of the Pliocene section is 118 meters at Site 132, where the core recovery exceeds 86 per cent and is about 50 meters at Site 125A where the core recovery is unfortunately considerably lower, especially in the Lower Pliocene.

The planktonic foraminiferal zonation proposed here is new. To avoid duplication, reference is made to Chapter 40, Part II, point 10, for a discussion of its background and of the criteria used for the selection of the various zonal markers.

The zonation here proposed is fairly close to those recently defined for the Pliocene of Italy (Bertolino *et al.*, 1968), for the Pliocene of Greece (Bizon, 1967), for the Pliocene of Italy and other Mediterranean regions (Cati *et al.*, 1968) and can be correlated with them (see further below). The most important difference is that in the zonation here proposed for the deep-sea Mediterranean sediments we do not use as zonal markers either *Globorotalia aemiliana* (or *G. hirsuta aemiliana*, or *G. crassaformis*

aemiliana or *G. crotonensis*), or *G. crassaformis*. Both taxa have been recorded in the DSDP cores, but their occurrence, especially that of *G. crassaformis* cum var., appears strongly controlled by some ecological factors (see range charts in Chapters 7 and 13).

Globorotalia crassaformis is a mesopelagic species, living in the present seas and known in fossil sediments as old as early Pliocene (Miocene according to Blow, 1969).

The frequency curve of *G. crassaformis* (group), based on thirty samples investigated from the Pliocene section continuously cored at Site 125, does not show a correlation with the inferred climatic curve based on the occurrence of a restricted number of epipelagic, temperature-sensitive species of *Globigerinoides*, whose distribution in the present seas is limited to the tropical or subtropical areas (see Cita and Ciaranfi, 1971, and Chapter 47.3). Therefore, the factor which controls the very irregular abundance of *G. crassaformis* is not the temperature of superficial waters in the photic zone, but possibly changes in the structure of the permanent thermocline, or other ecological factors.

Although ten months have been dedicated to the investigation of the Pliocene sections under discussion, the present study is still preliminary in some aspects. Shortage of space and time have prevented a thorough documentation of the foraminiferal faunas.

The taxonomy of some groups, including the *Globorotalia crassaformis* group, is provisional. No taxonomical notes will be included here, with the exception of the *Globorotalia margaritae* group, on which statistically oriented investigations have been done (see Section on statistical investigations on this group). We had to describe two new taxa, since one of them has been used as zonal marker. Two more new taxa recorded in the Mediterranean DSDP cores will be published elsewhere, as will further paleontological investigations.

In the present chapter only the aspects of Pliocene foraminiferal biostratigraphy considered of interest for the project will be examined.

THE MIOCENE/PLIOCENE BOUNDARY

This boundary can be recognized within a single core section at Sites 134 (Balearic Abyssal Plain), 132 (Tyrrhenian Rise), and 125A (Mediterranean Ridge in the Ionian Basin). In fact, the contact is so sharp that one can put a fingernail on the visible unconformity that it represents.¹ Figures 1, 2 and 3 illustrate Sections 134-7-5, 132-21-2 and 125A-6-1 where the boundary is present; the figures are also accompanied by some biostratigraphical notes concerning the intervals investigated paleontologically.

The Miocene/Pliocene boundary coincides with the sharp sedimentary break that occurs between the evaporitic sequence below and the pelagic sediments above.

At two more sites, namely, Site 122 in the Valencia Trough and Site 124 on the Balearic Rise, south of Mallorca, the boundary is not present within a single core. It occurs somewhere in the uncored interval between two successive cores which are so different both in lithology and in fossil content, and yet so close to one another, that we can consider also in these cases that the boundary represents a dramatic change in environmental conditions.

The Pliocene pelagic oozes which overlie the Miocene evaporites correspond both in lithology and fossil content to the "Trubi" formation of Sicily, and the evaporite-pelagite contact corresponds to what may be seen in Sicily, where the "Trubi" marls directly overlie the "formazione gessoso-solfifera."²

The high-resolution biostratigraphy developed for the Pliocene indicates that the pelagic sediment immediately overlying the late Miocene (Messinian) evaporites is not of the same age in the three different basins.

The basal layer of Pliocene ooze at Site 132 in the Tyrrhenian Basin belongs to the *Sphaeroidinellopsis* Acme-zone. The basal layer at Site 134 in the Balearic Basin belongs to the *Globorotalia margaritae margaritae* Lineage-zone, and that at Site 125A in the Ionian Basin belongs to the *Globorotalia margaritae evoluta* Lineage-zone.

This observation cannot be easily explained, and was of concern to the shipboard scientists, since the deluge model which fits so much of the other data and which is attractive as a working hypothesis (see Chapter 43) would lead us to conclude that pelagic ooze should have started to accumulate in each of the basins simultaneously.

Two explanations, which are difficult to evaluate, can be offered to explain how the first ooze which was permanently preserved above the evaporites can be diachronous.

1) Vigorous submarine erosion in the early Pliocene could have prevented deposition, or could have eroded away previous loose pelagic deposits down to a firm substratum (e.g., to lithified dolomite in Core 6 of Site 125A; see Chapter 6 for documentation of just such a deep-sea erosion/nondeposition at Site 124).

2) Subsequent tectonic movements on the sea bed caused by volume change, solution, or cavern collapse in the underlying evaporite could lead to slumping or fault displacement.

In other words, although the event (Pliocene transgression or flood of the desiccated Mediterranean basin) was isochronous everywhere within the basin, the oldest sediments preserved might not necessarily be isochronous at all locations, due to more or less local factors.

As base of the Pliocene we therefore take the base of the section at which all the foraminiferal zones and all the nannofossil zones are present, namely Core DSDP 132-21-2 (see text Figure 2).

THE PLIOCENE/PLEISTOCENE BOUNDARY

The Pliocene/Pleistocene boundary (Figure 4) was cored at Sites 122 and 123 (Valencia Trough), 134E (Balearic Basin and Sardinia slope, respectively), 132 (Tyrrhenian Rise) and 125 (Mediterranean Ridge in the Ionian Basin). At other sites, particularly Sites 121 (Alboran Basin) and 124 (Balearic Rise), this boundary lies in an uncored interval between two successive cores referable to the Pleistocene and to the Pliocene respectively.

At Sites 122 and 123, the Quaternary sediments represent channel fill; an erosional surface separates them from the underlying Pliocene sediments, with an important gap in sedimentation (see Chapter 40.2, Part II, point 8). A hiatus, with hard-ground, has been recorded also at the Pliocene/Pleistocene boundary at Site 134, at the eastern edge of the Balearic Abyssal Plain (Sidewall Core 1, 134E; see Chapter 40, Plates 2 and 3).

Thus, at all these western Mediterranean sites the biostratigraphic boundary falls at a marked discontinuity. However, at both sites continuously cored from the central (132) and eastern (125) Mediterranean basins the boundary lies in an entirely uninterrupted marine succession of uniform lithology.

The boundary under discussion is defined by the (massive) extinction horizon of *Discoaster brouweri*, a biostratigraphic event which is clearly recognizable in all the Mediterranean drilling sites.

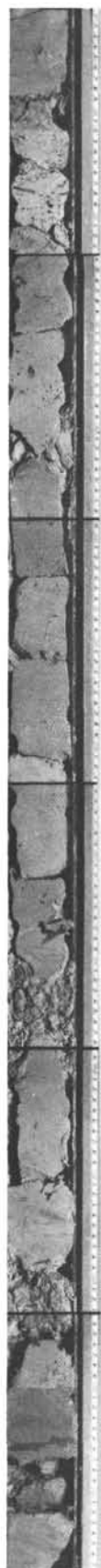
The Pliocene/Pleistocene boundary is much less clear in terms of foraminiferal biostratigraphy (Berggren, 1971). In fact, no extinction horizon or first occurrence can be used as a datum level.

Globigerina pachyderma, used sometimes as marker species in the Mediterranean, occurs below as well as above the extinction horizon of *Discoaster brouweri*. Its ratio of left to right coiling (used as the criterion for recognizing the beginning of the Quaternary by Bertolino *et al.*, 1968; Cati *et al.*, 1968) cannot be used either, since *G. pachyderma*, as recorded in Mediterranean DSDP cores, is right coiling throughout, with the exception of some of the coldest intervals recorded in the glacial Pleistocene.

The first appearance of *Globorotalia truncatulinoides*, evolving from *G. tosaensis*, is considered by Hays and Berggren (1971) to be the most reliable biostratigraphic event for recognizing the Plio/Pleistocene boundary. However, we could recognize this event only once in our cores, namely in Core 125-4 (Mediterranean Ridge), slightly below the extinction horizon of *Discoaster brouweri*. At the

¹Details of the contact in all three basins are depicted in the color frontispiece of this volume.

²Ogniben (1969, 653-654) considers an "abnormal transgression" that which leads to normal marine conditions in the evaporitic Messinian basins. "Si deve considerare l'ipotesi che questa trasgressione sia dovuta al risalire delle acque da livelli negativi al livello degli oceani, con velocità verosimilmente maggiore di quella di un fenomeno epirogenetico."



22-24 cm Sand-size fraction abundant and entirely organogenic. Planktonic foraminifera are well developed and diversified. Over ten species are recorded, including *Globorotalia margaritae margaritae*, *G. margaritae primitiva*, *Orbulina universa*, *Globigerinoides obliquus extremus*, *G. quadrilobatus* (abundant). Benthic foraminifera are extremely rare and indicate deep bathimetric conditions. Single specimens of *Uvigerina rutila* and *Lagena* sp. Also rare ostracod valves.

123-125 cm Sand-size fraction abundant; entirely consisting of shells of planktonic foraminifera, plus some organic matter, rare echinoid spines and ostracod valves. Species include *Globorotalia margaritae margaritae*, *Sphaeroidinellopsis seminulina*, *Globigerinoides obliquus extremus*. Pelagic sedimentation. Lower Pliocene, *Globorotalia margaritae margaritae* Lineage Zone.

132-135 cm Sand-size fraction very small. Planktonic foraminifera rare and partly dwarfed, indicating unfavorable life conditions. Species recorded include *Orbulina universa*, *Globigerinoides obliquus*, *Globigerina nepenthes*, *Globigerinoides trilobus*; all of them represented by single specimens. Restricted marine sedimentation. Upper Miocene, *Globorotalia plesiotumida* Zone.

144-145 cm Sand-size fraction very small. Rare planktonic foraminifera, some with pyrite fillings; recorded taxa include *Globorotalia merotumida*, *G. scitula*, *G. acostaensis*.

7,CC Sand-size fraction abundant; mostly consisting of anhydrite fragments, pyrite crystals, quartz, glauconite and other clastics. Planktonic foraminifera (extremely rare) including *Globigerina* cf. *nepenthes*, *Globorotalia acostaensis*, *Globigerina bulbosa*, *Globigerinoides obliquus*. Benthic foraminifera present; some with abraded tests.

Figure 1. The Miocene/Pliocene boundary at Site 134 (Balearic Basin). Photograph of Core 134-7-5 and biostratigraphical comments on the samples investigated.

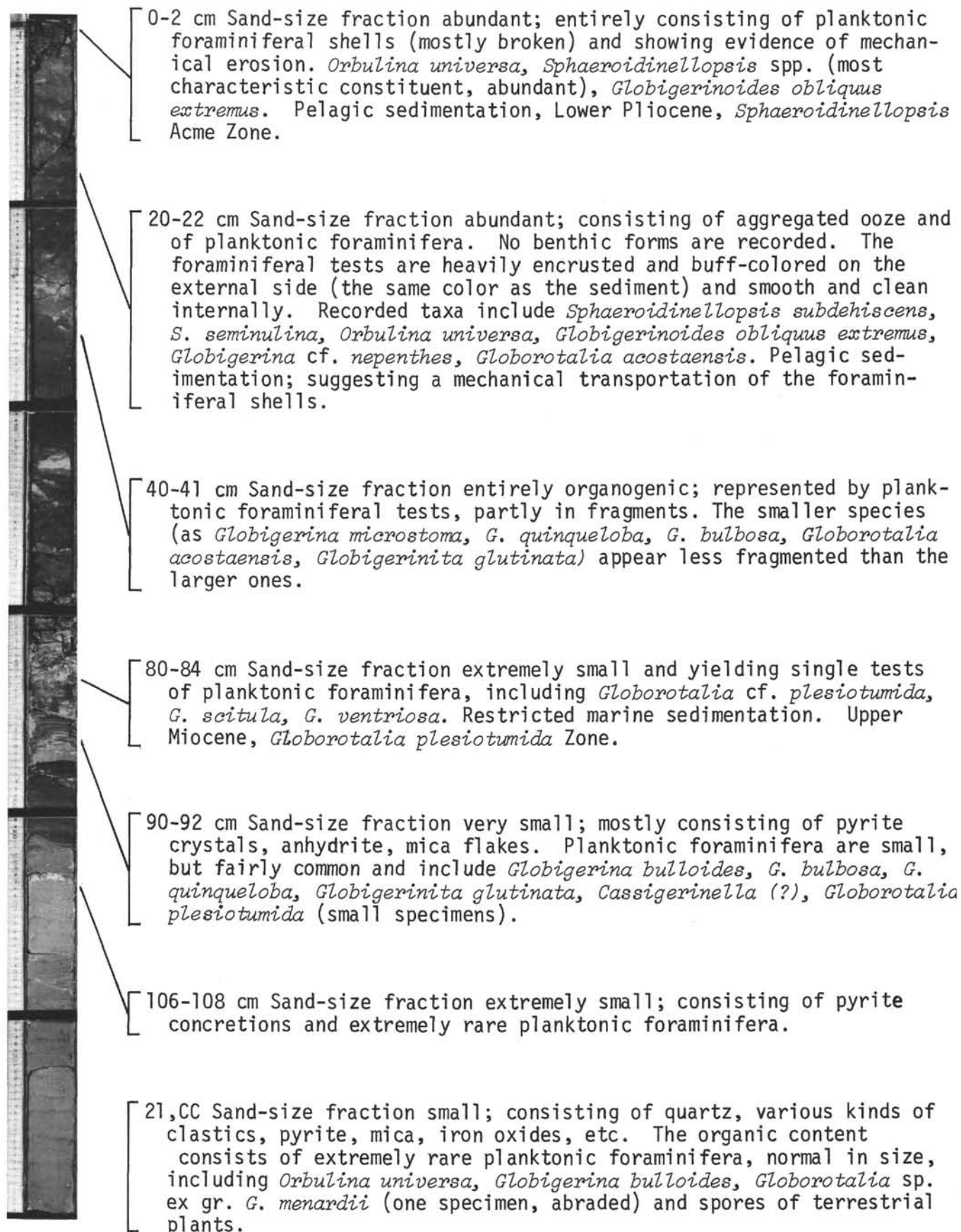


Figure 2. The Miocene/Pliocene boundary at Site 132 (Tyrrhenian Basin). Photograph of Core 132-21-2 and biostratigraphical comments on the samples investigated.



- [31-35 cm Sand-size fraction abundant; entirely consisting of foraminiferal shells. Abundant and well diversified fauna, including *Globorotalia margaritae margaritae*, *G. margaritae evoluta*, *G. puncticulata*, *Sphaeroidinellopsis seminulina*, *S. subdehiscens*, *Globigerinoides obliquus extremus*, etc. Purely pelagic sedimentation. Lower Pliocene, *Globorotalia margaritae evoluta* Lineage Zone.
- [102-105 cm Sand-size fraction abundant; pure pelagic sedimentation. Recorded taxa include *Sphaeroidinellopsis seminulina*, *Orbulina universa*, *Globigerinoides obliquus extremus*, *Globigerinita glutinata*, *Globigerina* spp. The genus *Globorotalia* is practically absent.
- [116-118 cm Sand-size fraction abundant; pure pelagic sedimentation. Fauna as above, without *Globorotalia*.
- [120-122 cm Sand-size fraction very small; almost entirely consisting of foraminiferal shells, many of which are broken and/or below their usual size. Organic matter. Fauna mostly consisting of *Globigerina* and *Globigerinoides*; not really age-diagnostic.
- [139-141 cm Sand-size fraction very large; mostly consisting of dolomite and pyrite. No fossils. Restricted marine conditions. Upper Miocene by correlation.
- [1,CC Sand-size fraction very large; mostly consisting of dolomite, anhydrite (?), organic matter, and spores of terrestrial plants(1).

In the shipboard report, a foraminiferal fauna including planktonic forms indicating a *Globorotalia margaritae* Zone age, and shallow-water benthic forams, was recorded from the Core Catcher of 125A-6. This finding of planktonic species with shallow-water benthics was puzzling, since at Sites 134 and 132 the topmost Miocene marls were devoid of normal pelagic faunas. It was suspected that possibly the planktonics were recovered in the core catcher by downhole contamination, since the overlying pelagic sequence had to pass through the fingers of the catcher before the Miocene was penetrated. To verify this suspicion, a new sample was taken from an undisturbed, homogeneous piece of dark sediment, characteristic of the dominant color of the core catcher sample. This sediment turned out to be devoid of foraminifera altogether, though it also contains the same dolomite, anhydrite(?) and organic matter as the first shipboard sample. For a description and discussion of the shallow-water faunas, see Chapter 7.

Figure 3. The Miocene/Pliocene boundary at Site 125A (Ionian Basin). Photograph of Core 125A-6-1 and biostratigraphical comments on the samples investigated.

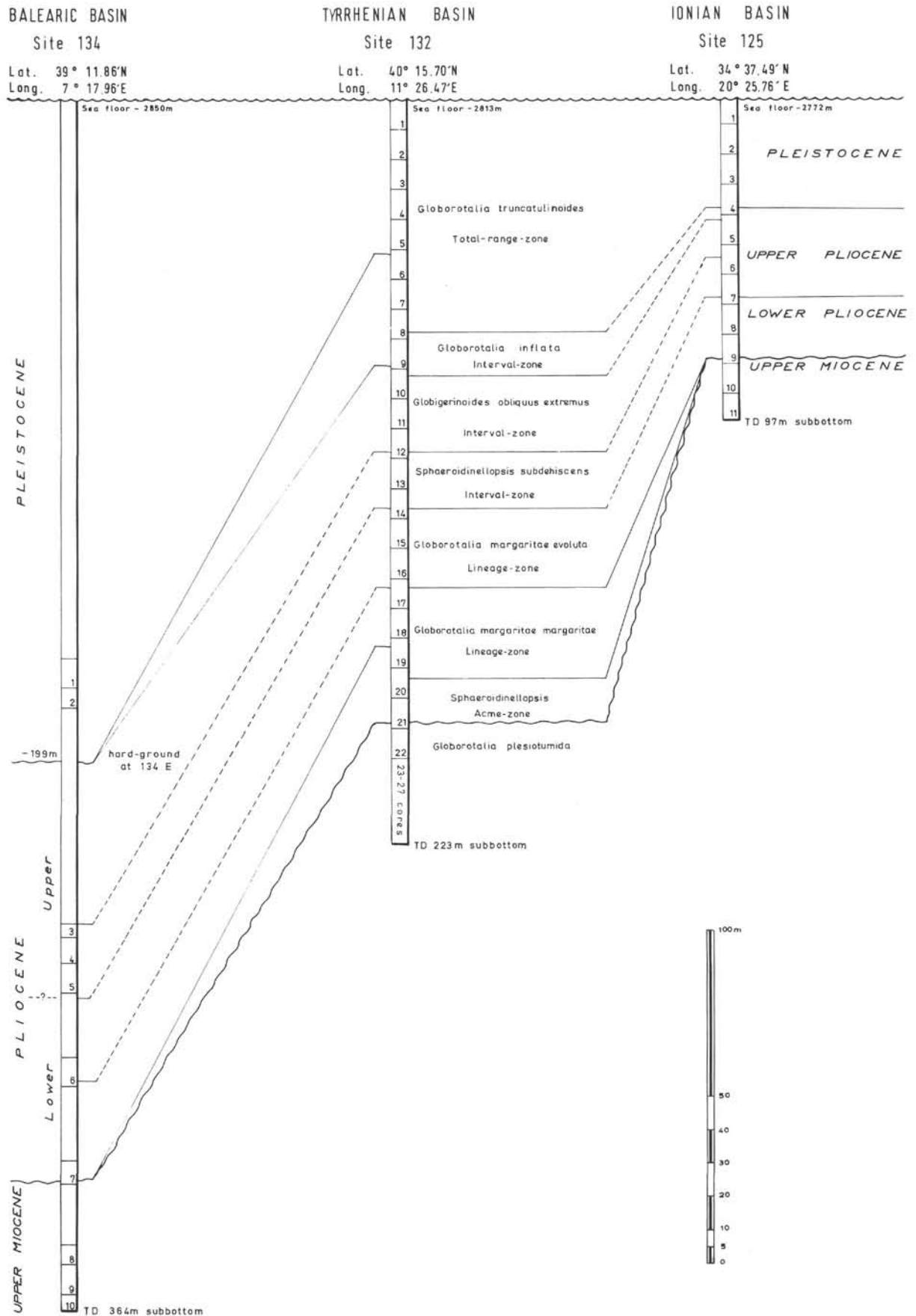


Figure 4. Pliocene boundaries, foraminiferal zones and biostratigraphic correlations in the Balearic, Tyrrhenian and Ionian basins.

remaining sites, *G. truncatulinoides* appears much higher in the succession, and *G. tosaensis* is extremely rare or absent. This demonstrates that both species are probably ecologically controlled and cannot be used as reliable zonal markers in the Mediterranean.

The almost perfect coincidence between the *Globorotalia truncatulinoides* datum and the *Discoaster* extinction datum in DSDP Core 125-4, however, allows us to check the reliability of the latter datum in order to identify the Pliocene/Pleistocene boundary in the Mediterranean.

Hyalinea baltica, the first occurrence of which in the Le Castella Section, Calabria, has been taken as marker point for the Plio/Pleistocene boundary (INQUA Congress, 1965). It was found only at two of the Mediterranean sites (121 and 122). At the latter, it is surely displaced in a channel fill deposit; in the former, our shallowest drilling site, it is possibly in place.

H. baltica was never recorded in the 220 samples from the Tyrrhenian Basin, nor in the 185 samples from the Ionian Basin, which were investigated in detail from continuously cored successions (see Chapter 46). Obviously, this benthic species, which lives in the Mediterranean at depths ranging from 60 to 1000 meters, cannot be used as a biostratigraphic indicator in pelagic deep-sea deposits.

STATISTICAL INVESTIGATIONS ON THE GLOBOROTALIA MARGARITAE GROUP

Introduction

All that lies between the *Discoaster* extinction level and the uppermost layer of the evaporites is referred to as the Pliocene. In the cores recovered from this interval, we noted an important biostratigraphic event, namely, the extinction horizon of *Globorotalia margaritae*.

Extinction levels are optimal in the biostratigraphy of cored sequences if they can be shown independently to be isochronous. This is so because drilling techniques can mix sediments downhole, thus potentially confusing first occurrences, but drilling techniques cannot mix the sediment upwards. Secondly, Hays *et al.* (1969) have demonstrated that the extinction level of *Globorotalia margaritae* occurs at the Gilbert/Gauss paleomagnetic boundary (3.32 my) in piston cores from the Pacific and Indian oceans.

Chapter 47.2 will show that the *Globorotalia margaritae* extinction level at Site 132 also occurs at this boundary. Because the *Globorotalia margaritae* extinction level lies about midway between the *Discoaster brouweri* extinction level and the evaporites, we have, in the hope of obtaining other biostratigraphic criteria to further subdivide the lower part of the Pliocene, examined the *Globorotalia margaritae* group in all of our cores.

One such anticipated criterion was a distinct morphological evolution in the *Globorotalia margaritae* group which could be considered and demonstrated to be isochronous. *Globorotalia margaritae* is the most conspicuous constituent of the foraminiferal assemblages of the Lower Pliocene of deep-sea Mediterranean deposits. It is the only keeled *Globorotalia* and is present in a majority of the samples, often with hundreds of specimens that show considerable morphological variation.

From the very beginning of our investigations on board the *Glomar Challenger*, we observed a certain evolution in

the populations referable to *Globorotalia margaritae* (broadly interpreted). Where we had samples from more than one core from the same drilling site which could be assigned to the *Globorotalia margaritae* Zone, the most obvious evolutionary trends that we could perceive were an increase in size and the acquisition of a subcircular instead of an elongate equatorial outline, resulting from a different (slower) growth pattern. Other, less obvious changes apparently concern the height of the spire and the peripheral characters.

At Site 132, *Globorotalia margaritae* has a total stratigraphic range of 50 meters. This section was therefore ideally suited to statistically oriented foraminiferal investigations.

Stratigraphic Importance of *Globorotalia margaritae*

Globorotalia margaritae Bolli and Bermudez was originally described from the Miocene of Venezuela. The Miocene age was based on the molluscan fauna of the Cubagua Formation (Cubagua Island, Peninsula Araya, Venezuela). In the world-wide zonation of Bolli (1966a) the *Globorotalia margaritae* Zone, defined as a total-range zone, is entirely confined to the Miocene, being the penultimate Miocene biozone. However, the age determination for the Cubagua formation should be considered doubtful on the basis of present knowledge.

The type locality of a part of the Pliocene biozonation of Bolli (1966a) is Margarita Island off Venezuela. *G. margaritae* has been subsequently recorded in Java (Bolli, 1966b), in the equatorial Pacific (Parker, 1967), and at many other localities. In the Mediterranean area, where it is apparently more common than in the Caribbean and Gulf of Mexico, this species was often recorded as *Globorotalia hirsuta* (d'Orbigny). At the congress on Mediterranean Neogene Stratigraphy held in Bologna (1967), it became apparent in discussions among micropaleontologists of various schools that *Globorotalia hirsuta* of the Italian workers (see for instance, AGIP Mineraria, 1957; Ruggeri, 1960; Colalongo and Sartoni, 1967; Iaccarino, 1967; Barbieri, 1967; d'Onofrio, 1968; Dondi and Papetti, 1968) is identical to *Globorotalia margaritae* Bolli and Bermudez (1965).

Globorotalia hirsuta (as interpreted by the Italian workers cited) is considered a typical Lower Pliocene marker. However, it has been at times recorded from pre-Pliocene sediments (see AGIP Mineraria, 1957 (Tortonian); d'Onofrio, 1964 (Messinian); Dondi and Papetti, 1968 (Tortonian and Messinian)).³ Colalongo (1970) recorded and illustrated *Globorotalia margaritae* from level 105 of the Messinian neostratotype ("Marne argillose superiori"). The figured specimen apparently may be identified with our *Globorotalia margaritae primitiva*. Having actually seen the locality of level 105 of the neostratotype Messinian, as well as its paleontological content, the author doubts that *Globorotalia margaritae*, as well as the *Cyprideis pannonica* and contains *Ammonia beccarii tepida*, thus indicating ipohaline conditions.

Sphaeroidinellopsis present in this level, are autochthonous constituents of the assemblage, which is extremely rich in

³The aforementioned authors pointed out that the pre-Pliocene specimens are rare and smaller than the Pliocene ones.

In the new Pliocene zonation by Bolli (1970), based on DSDP cores from Leg 4 in the Central Atlantic and Caribbean, the *Globorotalia margaritae* Zone is considered to be entirely Pliocene, its lower boundary coinciding with the Miocene/Pliocene boundary. Once again, this age assignment is conventional and not related to any defined stratotype section.

In our new deep-sea Mediterranean zonation, we use a *Globorotalia margaritae* Total-range zone, a kind of super zone to which belong our lower three zones plus an undefined interval of late Miocene age. Because of the quite abnormal ecologic conditions during the late Miocene, the Mediterranean is not a suitable area to study the first evolution of this species.

The extinction of the *Globorotalia margaritae* group, which is extremely abundant and highly evolute, is quite sudden in all the drilling sites and consistently occurs within the latest part of the *Discoaster asymmetricus* Zone. The top of this zone is defined by the extinction horizon of *Ceratolithus tricorniculatus*, according to the zonation by Martini and Worsley (1970). Thus, the extinction horizons of *C. tricorniculatus* and *G. margaritae* nearly coincide, the former being slightly higher than the latter.

Procedures Followed

For the statistical investigation of *Globorotalia margaritae*, one sample from each core of Site 132 belonging to the *Globorotalia margaritae* zones⁴ was used: 132-14, CC; 132-15-2, 35 cm; 132-16-3, 35 cm; 132-17-4, 35 cm; 132-18-4, 35 cm; and 132-19-1, 35 cm. The distance between sample levels ranges from 4.5 to 10.5 meters. The corresponding time interval (with a sedimentation rate approaching 2.8 cm/10³y) ranges from 160,000 to about 350,000, averaging 300,000.

From each level we extracted 100 specimens, at random, of *G. margaritae* s.l. The specimens are fairly variable in size but have some significant features in common, including: (a) general shape of the test elongated to subrounded, (b) more or less asymmetrically biconvex test, (c) more or less flattened, (d) fairly rapid growth of the chambers, especially in the last formed whorl, (e) subacute to faintly keeled periphery, (f) thin, uniformly perforated wall, (g) extended hispidity of the surface in the early ontogenetic stages, (h) petaloid chambers, (i) more or less lobulated periphery, (j) small and slightly depressed umbilicus, (k) radial and slightly depressed intercameral sutures on the umbilical side, (l) gently curved and more or less limbed intercameral sutures on the spiral side visible only in the last whorl, (m) slit-like umbilical-extraumbilical aperture, partly covered by a more or less extended lip, and (n) coiling dominantly left (95% of 600 measured specimens). A number of variable characteristics are apparent from this list, yet only a small number can be measured.

A limited number of statistically oriented studies of planktonic foraminifera have been published to date (e.g., Scott, 1968; Gradstein, 1971; Lindenberg, 1969). The studies indicate that it is as yet unclear which parameters of foraminiferal variability are significant from an evolutionary or taxonomical standpoint.

⁴Core 20 has been disregarded, because *G. margaritae* is present only in Section 2 with a limited number of specimens.

In the present study, the continuous and discontinuous variables measured on the test of *Globorotalia margaritae* are indicated below.

Continuous Variables: (a) equatorial diameter passing through the last formed chamber (A-A' in Figure 5), (b) equatorial diameter perpendicular to A-A' (B-B' in Figure 5), (c) width of the last-formed chamber (C-C' in Figure 5), (d) axial diameter (D-D' in Figure 5). The measurements were made on a binocular microscope, using a magnification of 100X.

Discontinuous Variables: (e) characters concerning the axial periphery. Five frequency classes were distinguished (Figure 6), ranging from a subacute periphery to a keeled periphery with a distinctly imperforate keel on three or more chambers; (f) characters concerning the equatorial periphery. Three frequency classes were distinguished: slightly lobulated, lobulated and strongly lobulated; (g) characters concerning the surface of the three frequency classes: (very hispid, hispid, moderately hispid); (h) number of chambers in the last-formed whorl: four frequency classes (from 4-1/2 to 6 chambers); (i) coiling direction (two frequency classes: left and right).

The elaboration of these measures is in progress and the results will be published later. Figure 6 illustrates the histograms concerning characters (d) and (e) of the preceding list. A distinct change is observed in both of them, especially in the axial diameter, between the populations investigated from Cores 16 and 17; it is in this interval that

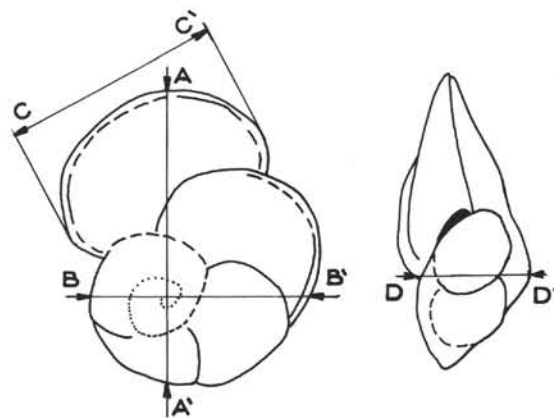


Figure 5. Continuous variables, as measured on *Globorotalia margaritae* (for further explanations, see text). A-A' = equatorial diameter (maximum) passing through the last-formed chamber, B-B' = equatorial diameter perpendicular to A-A', C-C' = width of the last-formed chamber, and D-D' = axial diameter.

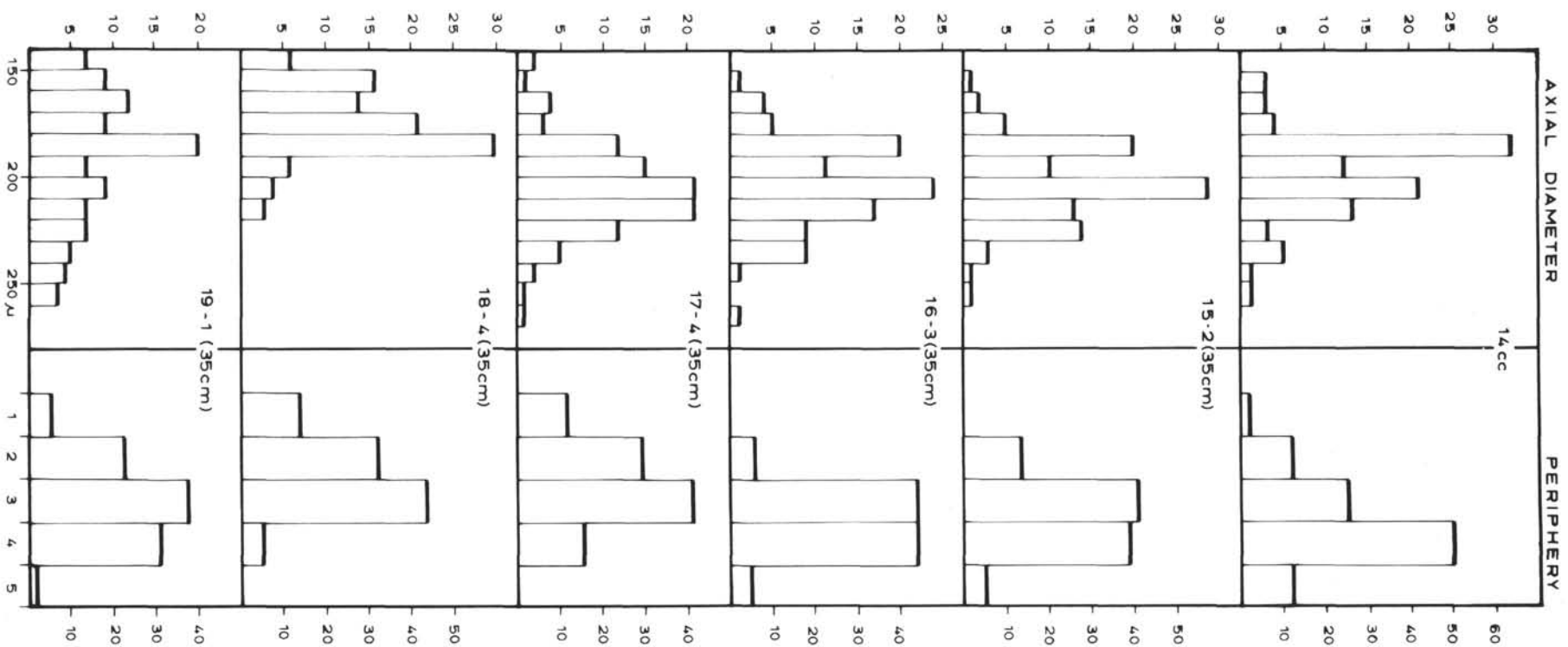


Figure 6. Histograms showing changes in the axial diameter (left) and in the periphery (right) observed in 100 random specimens of *Globorotalia margaritae* (group) from six levels investigated at Site 132 (Lower Pliocene of the Tyrrhenian Basin). The interval of each histogram class (axial diameter) is 10 μ . Interval classes concerning the periphery are as follows: (1) subacute periphery, (2) acute periphery, (3) imperforate keel in the last-formed chamber, (4) imperforate keel in the last and penultimate chambers, (5) imperforate keel on three or more chambers.

the author locates the boundary between the two lineages based on the evolution of *Globorotalia margaritae*.

It is regrettable that full documentation cannot be presented here, but the limitation of time (and also of space) was such that it was absolutely impractical; it is only possible to present the conclusions here. In fact, three taxa were distinguished by the author within the *Globorotalia margaritae* group, giving them subspecies rank; namely, *G. margaritae primitiva*, *G. margaritae margaritae*, and *G. margaritae evoluta*. They co-occur in the latest part of the range of the group, as in Sample DSDP 132-14, CC, from which come all the specimens illustrated in Plates 1-2, and which represents the type locality for the two new taxa. *G. margaritae evoluta* is common in the upper half of the range of the taxon, to which it is practically limited. Bolli (1970, p. 581) found that "...in the upper part of the *Globorotalia margaritae* Zone of Sites 29 and 31 (Venezuela Basin), they have a tendency to grow larger by adding one or two more chambers." The specimens illustrated (Plate 8, Figures 4-7) compare well with our *G. margaritae evoluta*. Beckmann (personal communication) found in the eastern North Atlantic (DSDP Leg 14) (always in the later part of the range of *G. margaritae*) a similar large form, with an equatorial periphery less elongated than in the typical form (here named *G. margaritae margaritae*). *G. margaritae primitiva* represents the most primitive type, and is more common in the lower levels.

We used these names in the range charts of the various sites, so we are obliged to describe and figure here the taxa, which otherwise should be invalidated as "nomina nuda." Further information on these taxa and on their variability will follow this first formal description.

Description of the New Taxa

Globorotalia margaritae evoluta n. subsp.

(Plate 1, Figures 1-7)

Globorotalia margaritae (large-sized specimens) of Bolli, 1970, Plate 8, Figures 4 to 7.

Description: Large and compressed form, almost symmetrically biconvex, with a low trochospire. First coils indistinct, however clearly eccentric.

Equatorial periphery subrounded to slightly elongate, lobulate. Axial periphery acute to keeled in the last whorl. A distinctly imperforate keel is visible on at least two chambers (last-formed and penultimate). Extended hispidity is observed on the early ontogenetic stages. Growth pattern regular, with a slower increase in both the height and the width of the chambers than in *G. margaritae margaritae*. An abortive (negative) final chamber is often recorded (see Plate 1, Figures 3 and 5). Chambers petaloid, separated by gently arched intercameral sutures; they are distinctly limbate in the last two or three (keeled) chambers, then become flush and are generally indistinct at the beginning of the last-formed whorl, which includes 4.5 to 6 chambers (generally 5). Intercameral sutures radial and slightly depressed on the umbilical side, which shows a narrow and shallow umbilicus. Slit-like aperture, umbilical-extraumbilical, with an apertural lip. Wall calcareous, distinctly perforate, surface smooth (in the last two or three chambers of the last-formed whorl) to hispid (in the previous ones) on the spiral side, as well as on the umbilical

side, where the hispidity is even more extended and accentuated, as evidenced by the scanning-electron photomicrographs. Coiling dominantly left.

Dimensions: Equatorial diameter (passing through the last chamber) 0.5-0.6 mm; equatorial diameter perpendicular to the above one, 0.4-0.5 mm; and axial diameter averaging 0.2 mm.

Type locality: DSDP Site 132, Tyrrhenian Basin.

Latitude: 40° 15.70'N

Longitude: 11° 26.47'E

Subbottom depth 122 meters

Type level: DSDP Core 132-14, CC.

Discussion: *Globorotalia margaritae evoluta* is considered to be phylogenetically derived from *G. margaritae margaritae* in the latest part of its evolution. It differs from the latter by its greater size, less elongated equatorial outline, slower increase in height of the chambers, and more symmetrical axial profile. *Globorotalia margaritae evoluta* also differs from *Globorotalia hirsuta prae-hirsuta* Blow in its larger size, more rounded outline, less rapid growth of the chamber height, and more distinct keel. Further comparisons with morphologically similar taxa will follow, along with a thorough documentation on the variability of the new taxon.

Globorotalia margaritae primitiva n. subsp.

(Plate 2, Figures 1-3)

Description: Fairly small form, almost symmetrically biconvex, with a low trochospire. Equatorial periphery subrounded to slightly elongate, with a faint lobulation. Axial periphery subacute, never keeled, not even in the last-formed chamber. Growth pattern regular, with a slower increase in both the height and in the width of the chambers than in *G. margaritae margaritae*. Chambers petaloid, separated by gently arched intercameral sutures, which are never limbate, but are flush to indistinct on the spiral side. Intercameral sutures subradial and slightly depressed on the umbilical side. Fairly small and shallow umbilicus; aperture slit-like, extending to the periphery, with a distinct apertural lip. Chamber wall calcareous, distinctly perforate, with an extended superficial hispidity in the early ontogenetic stages. Coiling dominantly left.

Dimensions: Equatorial diameter (passing through the last-formed chamber) 0.3-0.4 mm; equatorial diameter, perpendicular to the above, 0.25-0.35 mm; and axial diameter averaging 0.19 mm.

Type locality: DSDP Site 132, Tyrrhenian Basin.

Latitude: 40° 15.70'N

Longitude: 11° 26.47'E

Subbottom depth 122 meters.

Type level: DSDP Core 132-14, CC.

Discussion: *Globorotalia margaritae primitiva* is considered to be phylogenetically related to *G. margaritae margaritae* with which it co-occurs for most of its range in the Lower Pliocene. It differs from the latter by its smaller size, less elongate equatorial outline, slower increase in size of chambers, more symmetrical axial profile, and complete lack of a distinct keel. In addition, it differs from *Globorotalia praemargaritae* Catalano and Sprovieri for having a more elongate test, a more acute axial periphery, a more rapid growth pattern, and left coiling. Further

comparisons with morphologically similar taxa will follow, along with a thorough documentation of the variability of the new taxon.

WHY A NEW ZONATION?

A new zonation is proposed here for a number of reasons which will be discussed before defining the biozones.

1) The climatic evolution of the earth during the latest portion of its history is such that ecologically controlled variations in the planktonic foraminiferal assemblages become more and more important. Therefore, while we can accept the principle of a standard zonation for the Upper Cretaceous, it is practically meaningless to speak of a world-wide zonation for the Pliocene.

2) The crisis of salinity which occurred in the latest part of the Miocene in the Mediterranean area resulted in the extermination of the planktonic fauna living there. According to the model presented in Chapter 43 of this volume, the Pliocene fauna re-immigrated from the Atlantic into the Mediterranean in a quite unusual way. The re-immigration was not only climatically controlled, but was also controlled by the activity of geostrophic currents, influenced by the morphology of the Gibraltar threshold (see Chapters 36.2 and 40). Therefore, the Mediterranean successions, which are less diverse than the Atlantic ones and in some ways more "provincial," deserve a zonation of their own.

3) A standard zonation for the Mediterranean does not exist. A number of more or less similar zonations have been proposed since 1967, including those of Bizzi (1967) for NW Greece; Barbieri (1967) for Northern Apennines (Vernasca-Castellanquato section); Colalongo and Sartoni (1967) for Northern Apennines; Conato and Follador (1967) for Southern Italy; Colalongo (1968) for Northern Apennines; d'Onofrio (1968) for the Marche, central Italy; Mansour *et al.* (1969) for Egypt; and Mazzola (1971) for Algeria. Some of the zonations presented independently at the Fourth Congress of the Mediterranean Neogene Stratigraphy (CMNS) held in Bologna in 1967 have been integrated in a unified zonation (Bertolino *et al.*, 1968).

A comparison of the taxa, and of the range of the taxa, was requested (see Report on Micropaleontology by Cita, 1968) during the aforementioned Congress. This was promoted and actually realized by Hans Bolli, chairman of a meeting held in Bologna (May, 1968), and represented a kind of appendix to the Fourth Congress of the Mediterranean Neogene Stratigraphy (CMNS). The meeting resulted in a paper signed by 21 authors (Citi *et al.*, 1968), in which three different zonations were proposed for the Pliocene (Figure 8), since no general consensus could be reached on any one of them.

4) Most of the biostratigraphical subdivisions defined in the cited papers (Figure 8) are assemblage zones or cenozones. This is especially true of the paper by Bertolino *et al.* (1968). It includes a definition of the cenozone which is also cited in the glossary attached to Circular No. 36 of the Subcommittee on Stratigraphy Classification, IUGS (July, 1971).

Assemblage zones are obviously ecologically controlled and are a very useful tool for subdividing the stratigraphic record of epicontinental sedimentary basins. Most of the

sections investigated by Mediterranean researchers are outer shelf deposits, or in some instances inner shelf deposits. Also, subsurface sections (see Dondi and Papetti, 1968) represent sedimentation in rapidly subsiding, but certainly not deep basins.

Assemblage zones can hardly be correlated from one basin to another, and their boundaries cannot theoretically be considered isochronous over broad geographic regions.

Because the philosophic background is very different, and since for practical reasons we cannot consider the zonal boundaries as correlatable (in time-stratigraphic correlations), none of the previously defined zonations were used by the author, even in cases where the same zonal marker is used (for example, *Globorotalia margaritae* and *Globorotalia inflata*).

The author always tried to work on ranges instead of assemblages, and in deep-sea pelagic sediments certainly this is possible.

5) Some of the taxa used as zonal markers in the Mediterranean, such as *Globorotalia crassaformis* and *G. aemiliana*, appear to be strongly affected by some ecological factors (see the introduction to this chapter).

Since the assemblage-zones derive their names from these taxa and are defined in their lower boundaries by the first recorded occurrence of the zonal marker, the questions arise: are the correlations based on their first occurrences indeed isochronous, or are they diachronous, and do they only correspond to similar ecological conditions? These questions are critical for the determination of the relative ranges of *Globorotalia margaritae* (group) and *G. crassaformis* (group), as discussed on many occasions with Sartoni, Sprovieri, Crescenti, and others. The problem has been pointed out also by Ruggieri, Catalano and Sprovieri (1968) and is expressed graphically in Figure 7.

While an overlap in the ranges of the two named taxa was not found at Site 132 (Tyrrhenian Basin), it was found in the Ionian Basin (Core 125A-5-4). An overlap of these taxa has also been recorded by Catalano (1969) in Sicily. Moreover, at Anzio, the type locality of *Globorotalia hirsuta praehirsuta* Blow, there is a co-occurrence of *Globorotalia crassaformis* and *G. margaritae*.

Thus, either the extinction horizon of *Globorotalia margaritae* or the first occurrence of *G. crassaformis* is isochronous. Both biostratigraphic events cannot be isochronous, since the taxa are known to co-occur in certain outcrops and be mutually exclusive at others.

Sartoni and his colleagues believe that a correlation based on the first occurrence of *Globorotalia crassaformis* is a time correlation unlike a correlation based on the last occurrence of *G. margaritae*. It is likely that in terrigenous deposits the range of a keeled *Globorotalia* may be restricted due to a paleoenvironmental control, as is the case for the range of *G. menardii* (group) in the Serravallo-Tortonian interval of Northern Italy (Tertiary Basin of Piedmont). However, in purely pelagic sediments, such as those recovered during Leg 13, this assumption is unrealistic.

The evidence given by DSDP cores in the Mediterranean support the isochroneity of the extinction horizon of *G. margaritae*, as discussed in Chapter 40 of this volume. The consistency of the relative thickness of the overlying

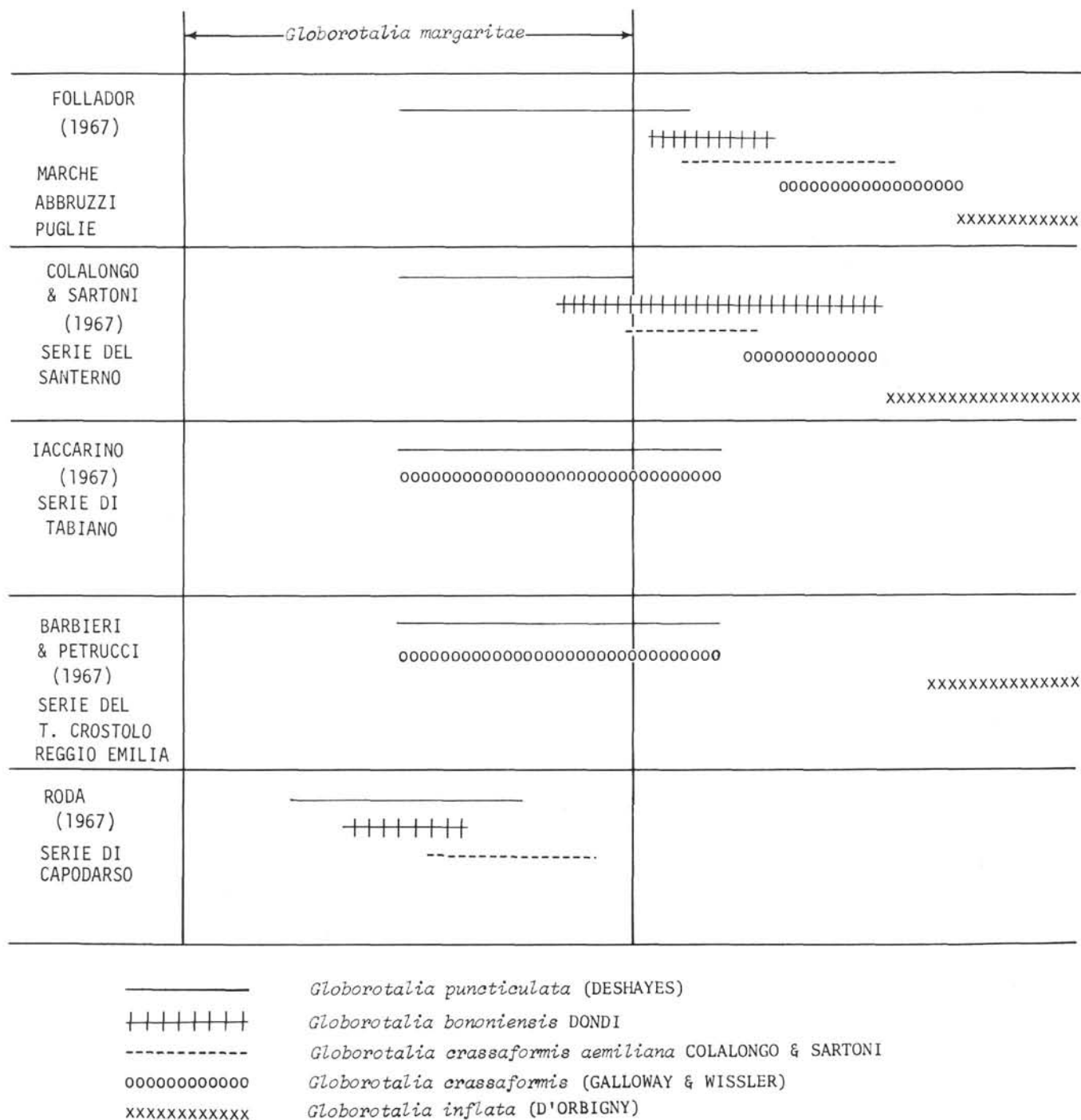


Figure 7. Range of some species of *Globorotalia* in the Pliocene of Italy as indicated by various authors, with reference to the range of *Globorotalia margaritae*. After Ruggieri, Catalano and Sprovieri (1968), slightly modified.

foraminiferal zones in the various drilling sites and the correlation, consistent everywhere with the nannofossil zones as identified by both H. Stradner and D. Bukry, are arguments in favor of this biohorizon being isochronous.

A third argument is now offered by the paleomagnetic investigations carried out on Site 132 (see Chapter 19, this volume). In fact, the Gauss/Gilbert boundary, which coincides in Pacific cores with the extinction horizon of *G.*

margaritae (see Hayes *et al.*, 1969), at Site 132 in Core 14, Section 3, falls within one meter of the last occurrence of *G. margaritae*.

DEFINITION OF THE BIOZONES

The foraminiferal zones here defined are named according to the internationally agreed-upon rules recently pro-

	AREA MEDITERRANEA (ITALIA, GRECIA)		SPAGNA (Andalusia occidentale)
	Schema proposto da BORSETTI, CATI, COLALONGO, CRESCENTI, DONDI, d'ONOFRIO, SALVATORINI, SARTONI		Schema proposto da PERCONIG
	Zone	Subzone	Zone
P L I O C E N E	Globorotalia inflata		
	Globorotalia crassaformis		
	Globorotalia aemiliana (= G. crotonensis)		
	Globorotalia margaritae	Globorotalia bononiensis	Globorotalia puncticulata
		Globorotalia puncticulata	
		Sphaeroidinellopsis	Globorotalia margaritae
	Zona non definita		
			Globorotalia menardii

Figure 8. Mediterranean foraminiferal zonations proposed for the Pliocene of Italy, Greece and Spain. After Cati et al. (1968).

posed by the Subcommittee on Stratigraphy, chaired by Prof. H. D. Hedberg (Circular No. 36, July, 1971).⁵

Six zones are distinguished in the Pliocene. One of them is an acme zone, which is characterized by the (ecologically controlled) abundance of a given taxon. Two are lineage

⁵Professor Hedberg has critically read an earlier draft of this manuscript. He has offered comments on the present zonation, with which he agrees, suggesting some more exhaustive terminology. Since zonal names have to be repeated many times and be referred to in reports, range charts, and discussions, the author believes that a complex terminology may be too cumbersome. The terms suggested by Prof. Hedberg are indicated in footnotes that follow.

zones, based on the evolution observed in the *Globorotalia margaritae* group. Three are interval zones, based on a combination of biostratigraphical events. All except the first are based on ranges of taxa, and therefore, according to the previously mentioned rules, no type section is designated. Type sections are designated only for assemblage-zones. However, some cored intervals which are considered characteristic of the various zones will be mentioned as reference sections. The present zonation is suitable for deep-sea sediments of the Mediterranean area.

Sphaeroidinellopsis Acme Zone

This interval is characterized by the abundance of

representatives of the genus *Sphaeroidinellopsis* (*S. seminulina* and *S. subdehiscens*) and is related to the catastrophic transgression which occurred after the collapse of the dam separating the desiccated Mediterranean basins from the Atlantic (see Chapter 43). The genus *Globorotalia* is represented in this interval by the species *G. acostaensis*, *G. humerosa*, *G. obesa* and *G. scitula*, none of which is common.

The *Sphaeroidinella* datum apparently falls within this zone. In fact, forms showing incipient supplementary apertures on the spiral side are recorded in Core 132-21-1, 60-62 cm (see Plate 6, Figure 5).

Discussion: The lower and upper boundaries of an acme-zone are self-explanatory. Where the acme terminates, the zone terminates. The lower boundary of the zone generally coincides with a disconformity, underlain by deposits of latest Miocene age (*Globorotalia plesiotumida* Zone [foraminiferal], *Discoaster quinqueramus* Zone [nannofossil]).

A *Sphaeroidinellopsis* Zone (or subzone) is recognized by practically all researchers in the Mediterranean region; it is assigned to either the basal Pliocene (see Bizon, 1967; Mansour *et al.*, 1969; d'Onofrio, 1968; Bertolino *et al.*, 1968; Colalongo, 1968; Dondi and Papetti, 1968) or an interval straddling the Miocene/Pliocene boundary (see Cati, *et al.*, 1968; Mazzola, 1971). For instance, Blow (1969) recorded the *Sphaeroidinella* datum, defining the Zone N.18/Zone N.19 boundary, in the lower part of the "Trubi" marls in Sicily. Bizon (1967) recorded forms transitional from *Sphaeroidinellopsis* to *Sphaeroidinella* in her *Sphaeroidinellopsis* sp. Zone in Greece. Therefore, a certain consistency appears also from the literature concerning the first evolutionary appearance of *Sphaeroidinella* in the lowermost part of the Pliocene of the Mediterranean area.

The *Sphaeroidinellopsis* Acme-zone corresponds to the lowermost part of the *Ceratolithus tricorniculatus* Zone (nannofossil), as identified by H. Stradner in the Mediterranean cores.

Thickness: The thickness of the *Sphaeroidinellopsis* Acme-zone in the Tyrrhenian Basin (Site 132) is about 10 meters.

Reference sections: DSDP Cores 132-21-1, 132-20 (Sections 3 and 4).

Globorotalia margaritae margaritae Lineage-zone⁶

Interval with the zonal marker from the end of the acme of *Sphaeroidinellopsis* to the statistically demonstrated transition toward more evolute forms of *G. margaritae* (namely, *G. margaritae evoluta*).

Discussion: *G. margaritae margaritae* is usually common to abundant in this interval, and co-occurs with *G. margaritae primitiva*. Also, forms transitional to *G. margaritae evoluta* are occasionally present, especially in the uppermost part of the zone. Other members of the genus *Globorotalia* present include *G. acostaensis*, *G. humerosa*, *G. obesa*, and *G. scitula*. The tests of *Sphaeroidinellopsis* spp. rarely occur in this zone.

⁶Or lineage-segment zone according to Hedberg (1971), since it is defined by a given part of the total evolution of the taxon.

The *Globorotalia margaritae margaritae* Lineage-zone consistently corresponds to the upper part of the *Ceratolithus tricorniculatus* Zone, as identified in the Mediterranean cores by H. Stradner.

Thickness: The thickness of the *Globorotalia margaritae margaritae* Lineage-zone in the Tyrrhenian Basin (Site 132) is 25.5 meters.

Reference sections: DSDP Cores 132-18, 132-19, 131-20 (Sections 1 and 2); 134-7 (Sections 1 and 3); 124-4.

Globorotalia margaritae evoluta Lineage-zone⁷

Interval with the zonal marker, from the statistically demonstrated transition of the taxon from *G. margaritae margaritae* upward to the extinction horizon of *Globorotalia margaritae* (group).

Discussion: This interval can easily be identified by the concurrent range of *Globorotalia margaritae* (sensu lato) and *Globorotalia puncticulata*, which usually is abundant throughout. An overlap in the ranges of *Globorotalia margaritae* (group) and of *G. crassaformis* (group) has been recorded in Core 125A-5-4.

The *Globorotalia margaritae evoluta* Lineage-zone consistently corresponds to the *Ceratolithus rugosus* Zone (nannofossil), as identified by H. Stradner in the Mediterranean cores.

Thickness: The thickness of the *Globorotalia margaritae evoluta* Lineage-zone in the Tyrrhenian Basin (Site 132) is about 27 meters.

Reference Sections: DSDP Cores 132-14, CC, 132-15, 132-16, 125A-5 (Sections 3 and 4), 125A-6-1 (upper part); 134-6; 124-3 (Section 2).

Sphaeroidinellopsis subdehiscens Interval-zone⁸

Interval with the zonal marker from the extinction horizon of *Globorotalia margaritae* (group) to the extinction horizon of representatives of the genus *Sphaeroidinellopsis*.

Discussion: The zonal marker is never abundant in this interval, nor do we find *Sphaeroidinellopsis seminulina* in abundance. *Globorotalia puncticulata* is usually well represented, and may be common, as was the case at Site 125. However, at Site 132 this species is very rare in this zone. *Globorotalia aemiliana* is represented in this zone at Site 125, but neither it nor *Globorotalia crassaformis* have been recorded in this zone at Site 132. *Globigerinoides obliquus extremus* is present throughout the interval. *Globoquadrina altispira* is commonly recorded in this zone at Site 125, but is more scarce at Site 132. It becomes extinct near the top of the zone. The extinction horizon of *Sphaeroidinellopsis* spp. consistently falls in the lower part of the *Discoaster surculus* Zone, as identified by H. Stradner in the Mediterranean cores.

⁷Since this zone virtually coincides with the total range of *G. margaritae evoluta*, which disappears along with the other subspecies of *G. margaritae* at the Gilbert/Gauss boundary, the name suggested by Prof. Hedberg is *Globorotalia margaritae evoluta* Taxon-range-Zone.

⁸Suggested name: *Globorotalia margaritae* exit-to-exit *Sphaeroidinellopsis* Interval-zone.

Thickness: The thickness of the *Sphaeroidinellopsis subdehiscens* Interval-zone in the Tyrrhenian Basin (Site 132) is 16.5 meters.

Reference sections: DSDP Cores 132-12 (Sections 5 and 6), 132-13, 132-14 (Sections 1-3); 125-6 (Section 3), 125-6; 125A, Cores 4 and 5 (Sections 1 and 2); 134-3 and 134-5; 124-3 (Section 1).

Globigerinoides obliquus extremus Interval-zone⁹

This interval with the zonal marker from the extinction horizon of *Sphaeroidinellopsis* spp. to the massive extinction of the zonal marker.

Discussion: *Globigerinoides obliquus extremus* is one of the most characteristic constituents of the Pliocene deep-sea deposits, and is common to abundant within this zone, as well as below it. The extinction horizon is clearly recognizable at all the sites investigated, and consistently falls in the lower part of the *Discoaster brouweri* Zone, as identified by H. Stradner. Single teratological specimens of the subspecies may occasionally be recorded from above the extinction horizon. The upper boundary of the zone almost coincides with the first appearance of *Globorotalia inflata*, which probably evolved from *G. punctulata*. Transitional forms are found within this zone. An overlap of *Globigerinoides obliquus extremus* in abundance and of *Globorotalia inflata* (typical form) was never seen in the DSDP Mediterranean cores.

Globorotalia tosaensis was occasionally recorded in this interval in the Ionian Basin (Holes 125, 125A). The greatest development of the *Globorotalia crassaformis* group is recorded in the present zone.

Thickness: The thickness of the *Globigerinoides obliquus extremus* Interval-zone in the Tyrrhenian Basin (Site 132) is 18 meters.

Reference sections: DSDP Cores 132-10 (Sections 2 to 6), 132-11, 132-12, 132-13, 132-14 (Sections 1 to 3); 125-5 (Sections 2 to 3), 125-6; 125A, Cores 2 and 3; 124, Core 2 (Section 4).

Globorotalia inflata Interval-zone¹⁰

Interval with the zonal marker from the extinction horizon of *Globigerinoides obliquus extremus* to the first appearance of *Globorotalia truncatulinoides* (total range).

Discussion: *Globorotalia inflata* is common in this interval, and *G. tosaensis* is present in some samples. The latter taxon is present nowhere in abundance in the Mediterranean, so that the evolution to *G. truncatulinoides* cannot be followed step by step. Only at Site 125 were we able to locate this zonal boundary directly (in Core 125-4-5) without referring to the *Discoaster brouweri* extinction horizon. Since the two biohorizons are virtually identical, in absence of *G. truncatulinoides* we can use the *Discoaster* extinction to identify the zonal boundary. When conical *Globorotalias* are absent, the transition from the latest part of the Pliocene to the earliest part of the Pleistocene is very gradational.

Globorotalia crassaformis is present in various amounts in the lower part of this zone. *Globigerina apertura* apparently becomes extinct within this zone, as does *Globigerinoides bollii*. Neither species has ever been recorded in the Pleistocene of the Mediterranean. *Globigerina pachyderma* is recorded in this zone, being represented by right-coiling specimens.

The *Globorotalia inflata* Interval-zone consistently corresponds to the latest part of the *Discoaster brouweri* Zone (nannofossil), as identified by H. Stradner in the Mediterranean cores.

Thickness: The thickness of the *Globorotalia inflata* Interval-zone is 12.5 meters in the Tyrrhenian Basin (Site 132).

Reference sections: DSDP Cores 132-9, 132-10 (Section 1); 125-4 (Section 6); 125A-1.

CORRELATION WITH OTHER ZONATIONS

A correlation with the standard zonation of Bolli (1966a) is not attempted because this zonation, which is excellent for the pre-late Miocene, seems not to be reliable in its uppermost part. Instead of the standard zonation, the new zonation proposed for the Caribbean deep-sea deposits is considered here (Bolli, 1970). Two correlations are considered as certain: that based on the first occurrence of *Globorotalia truncatulinoides* and that based on the extinction of *Globorotalia margaritae*. They are indicated with continuous lines in Figure 9. Dotted lines indicate the correlations which are probable, but not as certain as the two previously mentioned; namely, the base of the *Globorotalia margaritae* Zone, which supposedly falls in our *Globorotalia plesiotumida* Zone of late Miocene age (see previous discussion), and the top of the *Globorotalia exilis*-*G. miocenica* Zone, which is indicated as more restricted than our *Globorotalia inflata* Interval-zone. During a discussion of the new Caribbean zonation by H. Bolli (CMNS Congress, Lyon, 1971), both W. H. Blow and W.A. Berggren argued that *G. exilis* and *G. miocenica* extend to the topmost part of the Pliocene, and that even overlaps of *G. exilis* and *G. truncatulinoides* are recorded. The personal experience of the writer in the deep-sea Pliocene deposits of the Cape Verde DSDP Site 12, however, has not shown this overlap. Also Beckmann (personal communication) found in the central Atlantic a definite, though short, interval between the last occurrences of *G. exilis* and *G. miocenica* and the first occurrence of *G. truncatulinoides*. H. Bolli (personal communication), after studying the material recovered from DSDP Leg 15 has confirmed his previous observations and has found that *G. miocenica* disappears slightly earlier than *G. exilis*.

With regard to Blow's (1969) standard zonation, one correlation is considered certain — that based on the first occurrence of *Globorotalia truncatulinoides*. One more correlation is considered good — that based on the extinction horizon of *Sphaeroidinellopsis* (new zonation) and the top of Zone N 19. Two more correlations are fairly good: the base of N 21 (first occurrence of *Globorotalia tosaensis*) at about the middle of our *Globigerinoides obliquus extremus* Interval-zone, where we sometimes recorded Blow's zonal marker; and the Zone N 18/Zone N 19 boundary, based on the first occurrence of the genus

⁹Suggested name: *Sphaeroidinellopsis* exit-to-exit *Globigerinoides obliquus extremus* Interval-zone.

¹⁰Suggested name: *Globigerinoides obliquus extremus* exit-to-entry *Globorotalia truncatulinoides* Interval-zone.

AGES	PRESENT PAPER MEDITERRANEAN	BOLLI 1970 CARIBBEAN	BLOW 1969 STANDARD
PLEISTOC.	<i>Globorotalia truncatulinoides</i> Total-range-zone	<i>Globorotalia truncatulinoides</i>	N.22
PLIOCENE	<i>Globorotalia inflata</i> Interval-zone	<i>G. truncatulinoides tosaensis</i>	N.21
	<i>Globigerinoides obliquus extremus</i> Interval-zone	<i>Globorotalia exilis/</i>	N.20
	<i>Sphaeroidinellopsis subdehiscens</i> Interval-zone	<i>Globorotalia miocenica</i>	
	<i>Globorotalia margaritae evoluta</i> Lineage-zone		N.19
	<i>Globorotalia margaritae margaritae</i> Lineage-zone	<i>Globorotalia margaritae</i>	
	<i>Sphaeroidinellopsis</i> Acme-zone		
MIOCENE	<i>Globorotalia plesiotumida</i> Zone?..... <i>Globorotalia dutertrei</i>	N.18 N.17

Figure 9. Proposed correlation of various foraminiferal zonations. The Mediterranean zonation is in time-equivalent spacing.

Sphaeroidinella falling in our *Sphaeroidinellopsis* Acme-zone.

Correlations with some of the zonations recently proposed for the Mediterranean are indicated in Figure 10.

The easiest correlations are those of the lowermost zone (*Sphaeroidinellopsis* Zone) and the topmost one (*Globorotalia inflata* Zone) which are common to all of the previous zonations and are considered by everyone to be isochronous. The correlations of the zones lying in between are more or less tentative, because of the different criteria followed in the definition of the zonal boundaries. For instance, all the zonations include a *Globorotalia margaritae* (or *G. hirsuta*) Zone; however, we cannot correlate its upper boundary from one zonation to the other one, since in most cases *G. margaritae* is absent in the upper part of the zone. Further discussions of this critical argument are presented in a subsequent part of this chapter.

The best documented correlation is with the zonation of Bizon (1967): extinction of *G. margaritae* near the middle

of the *Globorotalia puncticulata* Zone; extinction of *Sphaeroidinellopsis* near the top of the *Globorotalia puncticulata* Zone.

A check of the previously discussed correlations with Bolli's (1966a, 1970) and Blow's (1969) zonations via nannoplankton, as investigated in the DSDP Legs 2, 4, 7, should be possible.

In the Pliocene succession at Cape Verde (DSDP Site 12), where the planktonic foraminifera were studied by the writer, two definite extinction horizons were recognized by Gartner (1969): the *Ceratolithus tricorniculatus* extinction horizon and that of *Reticulofenestra pseudumbilica*. The former occurs immediately above Core 12C-4-2, 100 cm. Cita (1971) recognized Datum VII of Saito (first coiling change of *Pulleniatina* from left-coiling (below) to right-coiling (above) immediately above Core DSDP 12C-4-2, 76 cm. Datum VII of Saito occurs just above event "a" of the Gilbert epoch (see Hays *et al.*, 1969). But the *Ceratolithus tricorniculatus* extinction horizon, as recorded in the

Mediterranean cores, consistently corresponds to the top-most part of the range of *Globorotalia margaritae* and almost coincides (slightly higher) with the extinction horizon of *G. margaritae* (Datum VI of Saito). This latter coincides with the Gilbert/Gauss boundary both in the equatorial Pacific (see Hayes *et al.*, 1969) and in the Mediterranean (see Chapter 47.2).

The extinction horizon of *Reticulofenestra pseudumbilica* occurs at Cape Verde above Core 12C-4-2, 2 cm (Gartner, 1969, Figure 4) which means below Datum V of Saito, as identified by Cita (1971) in Core 12C-4-1, 102 cm, based on the extinction horizon of *Sphaeroidinellopsis* (Mammoth event of the Gauss normal epoch). The relative position of the two biostratigraphic events is consistent with that found in our cores (see Figures 11 and 12). However, in the Mediterranean, *Reticulofenestra pseudumbilica* is also recorded in the Pleistocene (see observations by H. Stradner in Chapters 7, 9 and 13). At the

AGE	FORAMINIFERAL ZONES	NANNOFOSSIL ZONES	CORE NUMBER
PLEISTOCENE	<i>Globorotalia truncatulinoides</i> Total-range-zone	<i>Emiliana huxleyi</i> Zone	1
			2
		<i>Gephyrocapsa oceanica</i> Zone	3
			4
		<i>Pseudoemiliana lacunosa</i> Zone	5
			6
			7
			8
PLIOCENE	<i>Globorotalia inflata</i> Interval-zone	<i>Discoaster browneri</i> Zone	9
	<i>Globigerinoides obliquus extremus</i> Interval-zone	<i>Discoaster pentaradiatus</i> Zone	10
		<i>Discoaster surculus</i> Zone	11
UPPER	<i>Sphaeroidinellopsis subdehiscens</i> Interval-zone	<i>Reticulofenestra pseudumbilica</i> Zone	12
			13
PLIOCENE	<i>Globorotalia margaritae evoluta</i> Lineage-zone	<i>Discoaster asymmetricus</i> Zone	14
		<i>Ceratolithus rugosus</i> Zone	15
			16
	<i>Globorotalia margaritae margaritae</i> Lineage-zone	<i>Ceratolithus tricorculatus</i> Zone	17
			18
			19
LOWER	<i>Sphaeroidinellopsis acme</i> Acme-zone		20
	<i>Globorotalia plesiotumida</i> Zone	<i>Discoaster quinquarum</i> Zone	21
LATE MIOCENE			22

Figure 11. Correlation between foraminiferal zones and calcareous nannoplankton zones, as identified by H. Stradner, at Site 132 (Tyrrhenian Basin), in time-equivalent spacing.

Figure 10. Correlation between foraminiferal zonations established for the Mediterranean area. The deep-sea new zonation is in time-equivalent spacing, based on Site 132 (Tyrrhenian Basin), which was continuously cored and paleomagnetically investigated (see Chapter 19, this volume).

AGES	PRESENT Mediterranean DSDP	BIZON 1967 Greece	BARBIERI 1967 Northern Apennin	COLALONGO 1966 Northern Apennin	DONDI & PAPETTI 1968 Po Valley	D'AMOREO 1968 Marche - Italy	MANSOUR <i>et al.</i> 1969 Libya	MAZZOLA 1971 Algeria
PLIOCENE	<i>Globorotalia truncatulinoides</i> Total-range-zone							
L	<i>Globorotalia inflata</i> Interval-zone	<i>Globorotalia inflata</i>	<i>Globorotalia inflata</i>	<i>Globorotalia inflata</i>	<i>Globorotalia inflata</i>	<i>Globorotalia inflata</i>		
	<i>Globigerinoides obliquus extremus</i> Interval-zone	<i>Globorotalia crassaformis</i>	<i>Globigerina</i> spp. & <i>Globigerinoides</i> spp.	<i>Globorotalia crassaformis</i>	<i>Globorotalia crassaformis</i>	<i>Globorotalia crassaformis</i>		
P	<i>Sphaeroidinellopsis subdehiscens</i> Interval-zone		<i>Globorotalia punctulata</i>	<i>Globorotalia hirsuta</i> <i>Emiliana</i>	<i>Globorotalia hirsuta</i> <i>Emiliana</i>	<i>Globorotalia hirsuta</i> <i>Emiliana</i>		
	<i>Globorotalia margaritae evoluta</i> Lineage-zone	<i>Globorotalia punctulata</i>	<i>Globorotalia hirsuta</i>	<i>Globorotalia punctulata</i>	<i>Globorotalia punctulata</i>	<i>Globorotalia punctulata</i>		
P	<i>Globorotalia margaritae margaritae</i> Lineage-zone	<i>Globorotalia margaritae</i>						
	<i>Sphaeroidinellopsis acme</i> Acme-zone							
L	<i>Globorotalia plesiotumida</i> Zone							

AGE	FORAMINIFERAL ZONES	NANNOFOSSIL ZONES	CORE NUMBER
PLEISTOCENE	<i>Globorotalia truncatulinoides</i> Total-range-zone	? <i>Emiliania huxleyi</i> Zone	1
			2
			3
		<i>Gephyrocapsa oceanica</i> Zone	4
			5
			6
		<i>Gephyrocapsa caribbeanica</i> Subzone	7
UPPER PLIOCENE	<i>Globorotalia inflata</i> Interval-zone	<i>Cyclorococcolithina macintyreii</i> Subzone	8
			9
	<i>Globigerinoides obliquus extremus</i> Interval-zone	<i>Discoaster pentaradiatus</i> Subzone	10
			11
	<i>Sphaeroidinellopsis subdehiscens</i> Interval-zone	<i>Discoaster tamalis</i> Subzone	12
LOWER PLIOCENE			13
			14
	<i>Globorotalia margaritae evoluta</i> Lineage-zone	<i>Reticulofenestra pseudumbilica</i> Zone <i>Ceratolithus rugosus</i> Zone	15
			16
			17
	<i>Globorotalia margaritae margaritae</i> Lineage-zone	<i>Ceratolithus amplificus</i> Subzone	18
			19
LATE MIOCENE	<i>Sphaeroidinellopsis acme</i> -zone		20
			21
	<i>Globorotalia plesiotumida</i> zone		22

Figure 12. Correlation between foraminiferal zones and calcareous nannoplankton zones, as identified by D. Bukry (personal communication, 1971), at Site 132 (Tyrrhenian Basin), in time-equivalent spacing.

Hellenic Trench Sites 127 and 128, a *Reticulofenestra pseudumbilica* peak is recorded in the lower part of the *Pseudoemiliania lacunosa* Zone.

A correlation with the Caribbean based on the same criteria cannot even be attempted. In fact, Hay (1970) does not record either *Ceratolithus tricoraniculatus* or *Reticulofenestra pseudumbilica* in the Venezuela Basin (DSDP Sites 29, 30, 31).

A very interesting correlation is possible with the equatorial Pacific (DSDP Leg 7). The nannofossils there were investigated by Martini and Worsley, using their new standard zonation; the foraminiferal zonation of Bronnmann, following Blow's zonal scheme, is shown in Figure 13.

No problem exists for the N 22/N 21 zonal boundary, correlated with the *Pseudoemiliania lacunosa*/*Discoaster brouweri* zonal boundary.

Zone N 21 includes the *Discoaster brouweri* Zone, *D. pentaradiatus* Zone, and the topmost part of the *D. surculus* Zone. The base of foraminiferal Zone N 21 falls in the upper part of the *Discoaster surculus* Zone; this is consistent with our findings (see Figure 11) and with the correlation of various foraminiferal zonations here proposed (see Figure 9).

All of Zone N 20, as shown in Figure 13, falls in the *Discoaster surculus* (nannofossil) Zone. This is consistent with our findings and with the correlation proposed. There is still doubt, however, as to the exact placement of this zone, because of problems involved in the definition and recognition of its boundaries.

The top of foraminiferal Zone N 19 falls near the base of the *Discoaster surculus* Zone (nannofossil), according to the paleontologists of DSDP Leg 7. In the Mediterranean, the top of the *Sphaeroidinellopsis subdehiscens* Interval-zone falls near the base of the *Discoaster surculus* Zone (see Figure 11), and the top of Blow's Zone N 19 can be easily correlated with the extinction horizon of *Sphaeroidinellopsis* spp. (see Figure 9). In this case too, a perfect agreement exists between the Mediterranean and the equatorial Pacific.

Foraminiferal Zone N 19 falls in the *Ceratolithus tricoraniculatus* Zone instead of in the *C. rugosus* Zone (see Figure 13, correlation a').

The above discussion indicates that on the basis of available data, the correlation between foraminiferal zones and nannofossil zones has to be carefully established in one basin, but that it cannot be readily extrapolated to other basins without a critical check.

CORRELATION WITH THE STRATOTYPE SECTIONS OF THE PLIOCENE OF ITALY

Italian stratigraphers commonly use either an informal threefold subdivision of the Pliocene (Figure 14), following Ruggieri and Selli (1948), which is now supported by a detailed biostratigraphic zonation; or a subdivision in two stages (Tabianian for the lower Pliocene and Piacenzian for the middle-upper Pliocene), in agreement with the definition of the stratotypes proposed at the CMNS Congress (Bologna, 1967).

Reference is made to the recently issued volume on stratotypes of the Neogene stages (1971, edited by Carloni, Marks, Rutsch and Selli), where coordinate information on the original definition, type section, and fossil content of each Mediterranean Neogene stage may be found.

In terms of planktonic foraminifera, the Astian cannot be stratigraphically located with any degree of accuracy. It yields stratigraphically insignificant species associated with probably reworked ones (see Sampedo, Zappi and Caretto, 1968). Moreover, it has been used less and less in the last years and will not be used here.

The Piacenzian, as stratotyped by Barbieri (1967) in the Arda Valley, includes perhaps the most classical Pliocene localities of the world and also includes significant planktonic foraminifera which allow long-range correlations. Barbieri (1967, 1971a, 1971b) distinguishes the following zones from bottom to top: *Globorotalia crassa-formis-puncticulata* Zone (extending downwards to the upper part of the Tabianian), *Globorotalia crotonensis*

NN 21	<i>Emiliana huxleyi</i>	N. 23
NN 20	<i>Gephyrocapsa oceanica</i>	
NN 19	<i>Pseudoemiliana lacunosa</i>	N. 22
NN 18	<i>Discoaster brouweri</i>	
NN 17	<i>Discoaster pentaradiatus</i>	N. 21
NN 16	<i>Discoaster surculus</i>	N. 20
NN 15	<i>Reticulofenestra pseudumbilica</i>	
NN 14	<i>Discoaster asymmetricus</i>	N. 19
NN 13	<i>Ceratolithus rugosus</i>	a
NN 12	<i>Ceratolithus tricorniculatus</i>	N. 18 a'
NN 11	<i>Discoaster quinqueramus</i>	N. 17
NN 10	<i>Discoaster calcaris</i>	N. 16

Figure 13. Correlation between calcareous nannoplankton zones and foraminiferal zones, according to Martini (1971), in time-equivalent spacing. a = correlation proposed by Martini; a' = correlation here proposed, based on the Mediterranean DSDP cores.

DSDP TIME-STRATIGRAPHIC FRAMEWORK, 1970-71 BERGGREN, 1971	RUGGIERI AND SELLI, 1948	BARBIERI, 1967 1971
ASTIAN	UPPER	PIACENZIAN
PIACENZIAN	MIDDLE	
ZANCLIAN	LOWER	TABIANIAN

Figure 14. Subdivisions of the Pliocene.

Zone, *Globorotalia crassula* Zone, and *Globorotalia inflata* Zone. The Piacenzian, as stratotyped by Barbieri, corresponds to the middle and the upper Pliocene of a number of Italian researchers (see, for instance, Colalongo and Sartoni, 1967; Crescenti, 1971a, *inter alia*), and extends upward to the base of the Calabrian, which is locally represented by sands yielding *Arctica islandica*.

The Tabianian, as stratotyped by Iaccarino (1967) is well defined biostratigraphically in terms of planktonic foraminifera. It yields *Globorotalia margaritae* (recorded as *G. hirsuta*) from the base to near the top; this species has never been recorded in the overlying Piacenzian, neither at Tabiano, nor in the type section in Arda Valley. Other planktonic fossils recorded include *Globoquadrina altispira*, *Sphaeroidinellopsis seminulina* and *Globorotalia puncticulata*. The last species is recorded from about 50 meters from the base of the section upward. According to Barbieri and Selli (1971), the Tabianian may be subdivided into the *Globorotalia margaritae* Zone (below) and the *Globorotalia crassaformis-puncticulata* Zone (above); the latter zone extends upward to the lowermost part of the Piacenzian (see above). Though Iaccarino (1967) recorded *Sphaeroidinellopsis seminulina* and *Sphaeroidinellopsis* sp. from the base of the Tabianian, the *Sphaeroidinellopsis* Acme-zone apparently is not represented there.

This argument is used critically by Crescenti (1971a and b) against the use of the Tabianian stage. Blow (1969) indicated that the Tabianian extends downward further than the Zanclean (see *op. cit.*, Figure 19), reaching down to the Zone N 17/Zone N 18 boundary. This indication is repeated by Cita and Blow (1969, p. 593), but it is not supported by convincing arguments.

The lowermost part of the Pliocene succession is probably missing at Tabiano, but this is not sufficient reason for rejecting the use of this stage. In fact, most of the Lower Pliocene is represented by richly fossiliferous sediments, which also include some of the planktonic foraminifera commonly used for long-range correlations.

The Zanclean (the name derives from the Latin appellation of Messina, Sicily) has never been stratotyped. It is represented essentially by the "Trubi" marl ("marnes blanches a foraminifères" in Seguenza, 1868), a formation which has not yet been formally defined. The area of Messina is considered unsuitable for the definition of a type section (Roda, 1971). One of the most classical localities for the "Trubi" outcrops is Buonfornello, near Palermo, Sicily. A number of stratigraphically significant taxa are

recorded from this locality, including *Globorotalia margaritae* (= *G. hirsuta* in Ruggieri, 1960), *Globoquadrina altispira*, and *Ceratolithus tricorniculatus* (Martini, 1971a).

Blow (*op. cit.*, p. 418) states that the evolution of *Sphaeroidinella* from *Sphaeroidinellopsis* occurs 40 feet above the base of the "Trubi" in Sicily, but no precise location is given.

The Zanclean stage appears theoretically preferable to the Tabianian, but its use is hampered by the lack of definition of a type section.

From the above discussion we conclude that a convincing correlation is possible between our Pliocene reference section (Site 132) and the stratotype sections of the Pliocene stages. The correlation is illustrated in Figure 15. The terms Lower Pliocene and Upper Pliocene are here used (capitalized) in a formal sense, as synonymous of Tabianian and Piacenzian respectively.

We do not use here, as we did not use in the site chapters and graphical core summaries in Part I of this volume the term "middle Pliocene," commonly used in Italy by a group of scientists, following Ruggieri and Selli (1948).

The writer prefers not to use the more or less informal geochronological units, and wishes to avoid the acceptance of "floating boundaries." If we have no type sections to

which reference can be made, and if we do not have a well-defined biostratigraphy, then the age determinations based on our sections will always be conflicting and confusing.

THE PROBLEM OF THE ANDALUSIAN

The Andalusian stage was proposed by Perconig at the Third Congress on Mediterranean Neogene Stratigraphy at Berne, 1964, to fill a gap existing in the succession of marine stages. The gap corresponds to the Messinian, which is mostly represented by evaporites in its type section (Selli, 1960), and is not considered suitable for long-range correlations, because of its poor fossil content.

The type area of the Andalusian stage is Andalusia, and the type section designated is at Carmona, near Sevilla. The area was an Atlantic gulf, not connected with the Mediterranean.

The stratigraphic section of Carmona includes the following units, from bottom to top: (a) blue marls; (b) "calizas toscas," calcarenites and sands; and (c) olive-grey marls.

The fossil content of the section originally designated (Perconig, 1966), as presented at the Fourth Congress on Mediterranean Neogene Stratigraphy (Bologna, 1967) (see Perconig 1968a and b), indicates a Pliocene age for most of the section (see Verdenius 1970; see also discussion by Selli and Cita reported in Carloni and Selli, 1971).

Later, the type section of the Andalusian was extended downward into the marls of unit 1 and the late Miocene age of these marls became more evident.

At the Fifth Congress on Mediterranean Neogene Stratigraphy (Lyon, September, 1971), Martini (1971b) demonstrated that the "caliza toska" unit belongs to the *Ceratolithus tricorniculatus* Zone (nannofossil),¹¹ but that the *Discoaster quinqueramus* Zone is present in Unit 1, which also includes the *D. calcaris* Zone, found in the type Tortonian. With this extended Andalusian, an overlap with the type Tortonian exists (see also Chapter 40).

The presence of a continuous, marine section straddling the Miocene/Pliocene boundary in an embayment of the Atlantic is not surprising. Bizon and Bizon (in Bizon, Bizon and Montenat, 1971) point out some "Atlantic" features observed in the foraminiferal assemblages of the Guadalquivir basin, including:

1) Occurrence in the terminal Miocene of Carmona of *Globoquadrina altispira* in abundance. This species is never recorded in sediments of this age in the Mediterranean, though it is recorded in the Lower Pliocene there;

2) Persistence of forms of the *Globorotalia menardii* group in the Pliocene, unlike in the Mediterranean;

3) Absence, in the terminal Miocene of Andalusia, of umbilico-convex, conical *Globorotalia* as *G. mediterranea*, *G. conomiozea*, etc., which appear to be limited to the late Miocene of the Mediterranean.

Points 1 and 2 have been discussed in Chapter 40 (differences between Atlantic and Mediterranean faunas) since observations similar to those made by the Bizons on

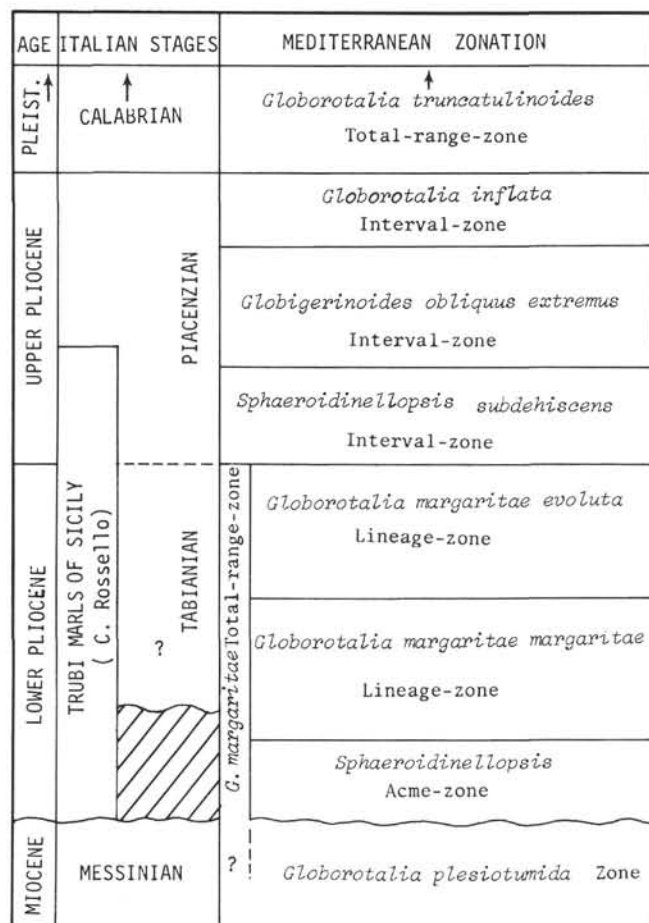


Figure 15. The new deep-sea Mediterranean zonation (in time-equivalent spacing) correlated with the stratotype sections of Italy.

¹¹ Recorded in Mediterranean DSDP cores at the base of the Pliocene.

the type Andalusian versus Mediterranean faunas have been done by us for the deep-sea North Atlantic versus deep-sea Mediterranean faunas.

We have no arguments in favor of observation 3 since our limited penetration in late Miocene sediments prevented the recovery of fossiliferous sediments of early Messinian age, where the mentioned taxa are usually recorded.

The occurrence of Andalusian outcrops in the area of southern Spain facing the Mediterranean (prov. Murcia and Alicante) appears questionable. In light of the desiccation model for the origin of the late Miocene (Messinian) evaporites of the Mediterranean (see Chapter 43, this volume), it is difficult to admit in southern Spain, facing the Mediterranean, continuous marine deposition, uninterrupted from the Tortonian to the Tabianian. However, the data presented by Montenat (in Bizon, Bizon and Montenat, 1971) do not exclude gaps in sedimentation since every marine invasion would carry in faunas of a single biozone. His section across the basin of Murcia-Alicante is in good agreement with our model. In fact, evaporites occur, with increasing thickness, toward the open sea, and they are overlain by marine deposits of early Pliocene age. The Pliocene is incomplete in its lower part, and unconformably overlies brackish-water sediments (marnes a Huitres) in the internal part of the basin.

Continental deposits are also recorded in the internal outcrops. At La Alberca, near Murcia, yellow sands interbedded in the "Marnes de Torremendo" yielded a Mammalian fauna referred by Montenat and Crusafont (1970) to the Vallesian (=fauna of Pikermi). The Torremendo marls are late Miocene in age and yield *Globigerinoides obliquus extremus*, *Globorotalia humerosa*, and others. The same situation found by De Bruijn, Sondaar and Zachariasse (1971) in Crete seems to be repeated near Murcia, some 3000 km to the west.

The above discussion indicates that the time represented by the type Andalusian, as originally defined, corresponds in part to the Messinian (Unit 1, *pro parte*) and in part to the Tabianian (extreme top of Unit 1, and all of Unit 2 "caliza tosca"; see Bizon, Bizon, and Montenat, 1971; Verdenius, 1970).

The outcrops of Spain that belong to the Alicante-Murcia basins show lithologic and paleontologic features significantly different from those in outcrops on the Atlantic side at Guadalquivir. Thus the Andalusian is not a suitable chronostratigraphic unit for the Mediterranean area, and the utility of introducing a new geochronological subdivision for this interval appears very doubtful inasmuch as a stage that straddles an epoch boundary is considered unsuitable.

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PLATE 1

Globorotalia margaritae evoluta n. subsp. Lower Pliocene of the Tyrrhenian Basin, *Globorotalia margaritae evoluta* Lineage-zone, immediately below the *Globorotalia margaritae evoluta* extinction horizon. Sample: DSDP 13-132-14, CC.

- Figure 1 Spiral view of the holotype; X150. A distinct imperforate keel is visible in the three last-formed chambers. Buttresses are limited to the early ontogenetic stage.
- Figure 2 Spiral view of a large, flat specimen with a fairly thick imperforate keel in the ultimate and penultimate chambers; X150.
- Figure 3 Umbilical view of a specimen with an abortive final chamber, a rather common feature of the latest evolutionary stages of *G. margaritae*. The umbilicus is narrow and distinct; the intercameral sutures are depressed and gently curved (almost radial), the slit-like umbilical-extraumbilical aperture shows an extended lip; X75.
- Figure 4 Side view (opposite to the apertural face) of a large specimen, showing a distinct imperforate keel in the last three chambers, the smooth and highly perforated surface of the chamber walls in the last whorl, and the obliterated and pitted initial whorls; X150.
- Figure 5 Spiral view of a specimen with an abortive final chamber, which shows a smoother and less perforated wall than the preceding chambers of the last whorl; X153.
- Figure 6 Spiral view of a specimen transitional to *Globorotalia margaritae margaritae*; the equatorial periphery is slightly more elongated than in the specimens illustrated in Figures 1, 2, 5. The imperforate keel is visible in the ultimate and penultimate chambers. Buttresses are not limited to the initial whorls, but are frequent (though smaller) also in the penultimate chamber (see Figure 7); X153.
- Figure 7 Detail of the surface of the penultimate chamber of the specimen shown in Figure 6; X850.

All the specimens illustrated in this plate, as well as in the following ones, are deposited in the Collection of the Laboratory of Micropaleontology, University of Milano. Photographs SEM by G. Gabriele (Institute of Geology, University of Milano).

PLATE 1

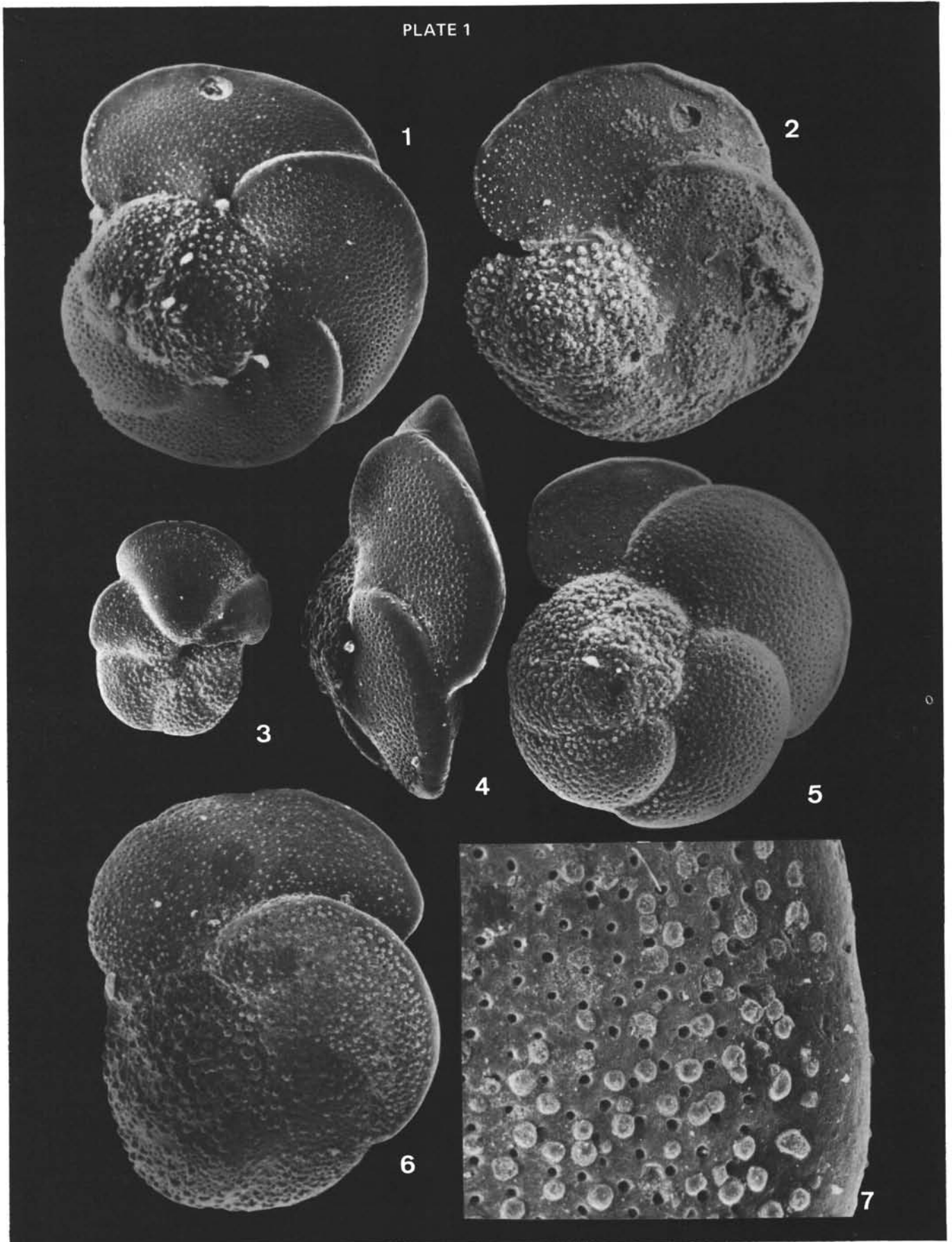


PLATE 2

All the specimens are from Sample DSDP 13-132-14, CC.
Lower Pliocene of the Tyrrhenian Basin, *Globorotalia margaritae evoluta*
Lineage-zone

- Figures 1-3 *Globorotalia margaritae primitiva* n. subsp.
1. Spiral view of a specimen showing the absence of a distinct imperforate keel, little lobulated periphery and small size of the test; $\times 160$.
 2. Umbilical view of the holotype, showing the slightly lobulated, subcircular equatorial periphery, slightly depressed radial sutures, fairly large and deep umbilicus, and slit-like umbilical-extraumbilical aperture, with a thin lip; $\times 157$.
 3. Apertural view of the holotype, showing the subacute periphery, slightly inflated chambers, spinose chamber walls; $\times 160$.
- Figures 4-6 *Globorotalia margaritae margaritae* Bolli and Bermudez.
4. Spiral view of a specimen showing a rapid increase of the chamber height in the last whorl, a distinct imperforate keel in the last and penultimate chambers, and a fairly elevated, eccentric spire; $\times 157$.
 5. Spiral view of a typical specimen; $\times 165$.
 6. Umbilical view of a typical specimen, showing how the width of the last chamber may be greater than the equatorial diameter A-A'; $\times 157$.

PLATE 2

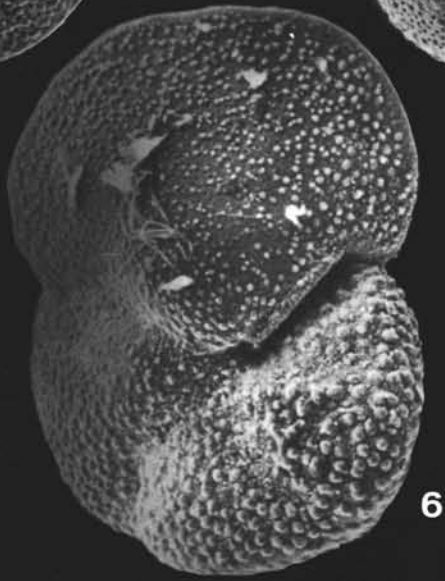
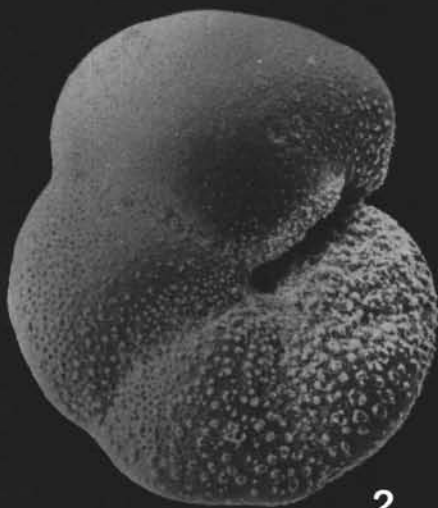
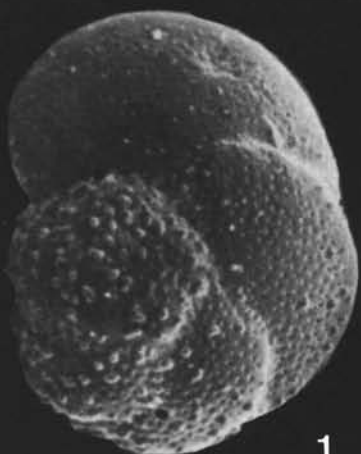


PLATE 3

Globorotalia puncticulata (Deshayes). Sample DSDP 13-132-14, CC.
Lower Pliocene of the Tyrrhenian Basin, *Globorotalia margaritae evoluta*
Lineage-zone, immediately prior to the extinction horizon of
Globorotalia margaritae (group).

- Figure 1 Spiral view of a large, typical specimen, $\times 153$.
- Figure 2 Spiral view of a small specimen; $\times 153$.
- Figure 3 Umbilical view, showing the large umbilical-extra-umbilical aperture, with a thin but distinct rim. The last-formed chamber has smaller pores than the preceding ones, and its surface is smoother; $\times 165$.
- Figure 4 Side view, slightly oblique; $\times 185$.
- Figure 5 Umbilical view of a small specimen; $\times 135$.
- Figure 6 Side view of a small specimen, showing a highly pitted surface and wide aperture, surrounded by a distinct rim; $\times 153$.

PLATE 3

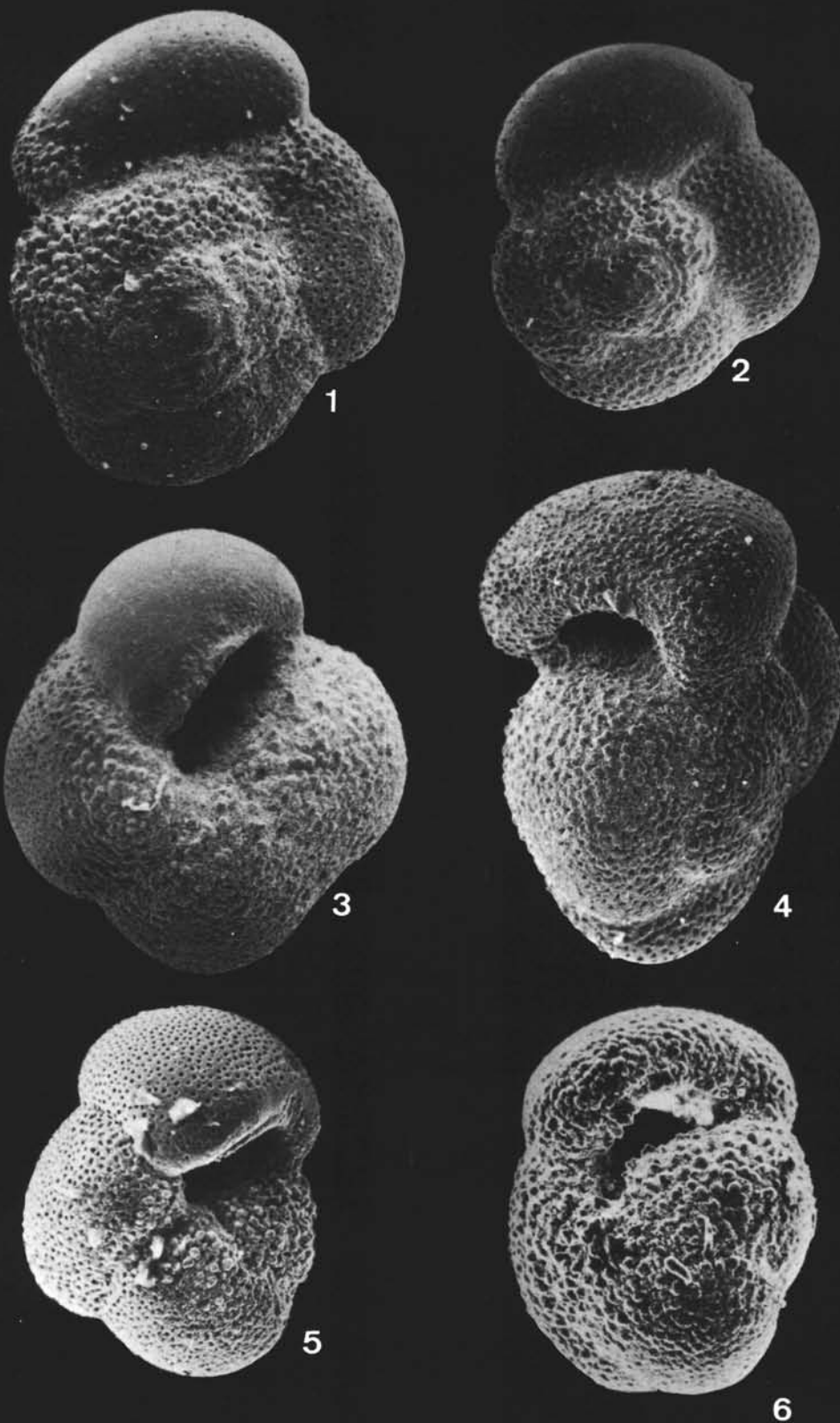


PLATE 4

Figures 1-6

Globorotalia crassaformis (Galloway and Wissler). Sample: DSDP 134E, SWC 1, Upper Pliocene of the Balearic Basin, *Globigerinoides obliquus extremus* Interval-zone.

1. Spiral view of a specimen with four chambers in the last whorl; the last formed chamber has an acute periphery, however no imperforate keel is visible; X135.

2. Spiral view of a large specimen with five chambers in the last whorl and an abortive final chamber. Subacute periphery, no peripheral keel; X120.

3. Spiral view of a large specimen with 4-1/2 chambers in the last whorl and subacute periphery; X120.

4. Umbilical view of a typical specimen, showing the fairly large umbilicus, conical shape of the chambers; depressed, radial sutures; X170.

5. A detail of Figure 4, showing the evenly spaced pores and pronounced buttresses. A number of coccoliths are visible, on the right; X1530.

6. A detail of Figure 4, showing the umbilical-extraumbilical aperture, with a faint apertural lip; X390.

Figure 7

Globorotalia scitula (Brady). Umbilical view of a right-coiling specimen, showing a smooth surface of the chambers, rare and evenly spaced pores, gently curved and depressed intercameral sutures, wide and flat umbilicus, slit-like umbilical-extraumbilical aperture, with a distinct apertural lip; X170. Sample: DSDP 13-132-14, CC. Lower Pliocene of the Tyrrhenian Basin. *Globorotalia margaritae evoluta* Lineage-zone.

PLATE 4

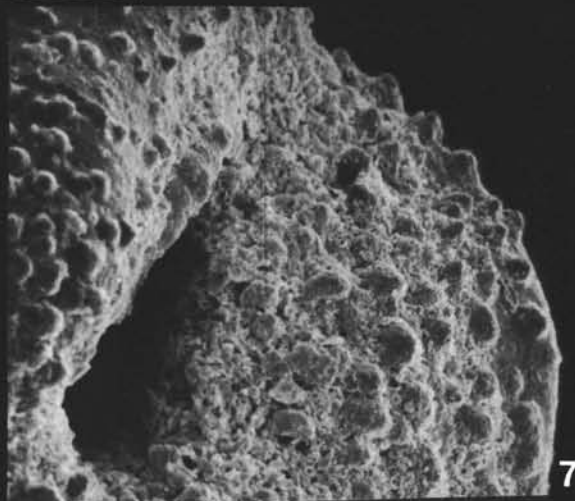
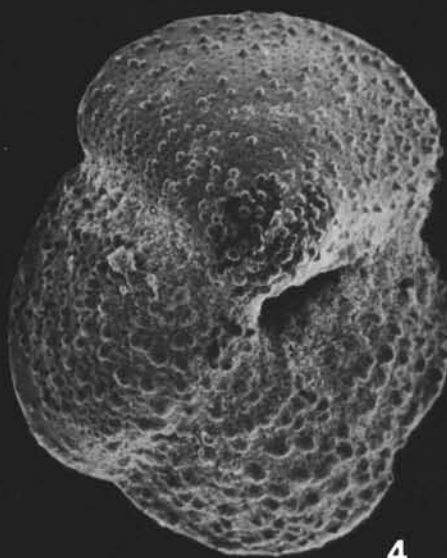
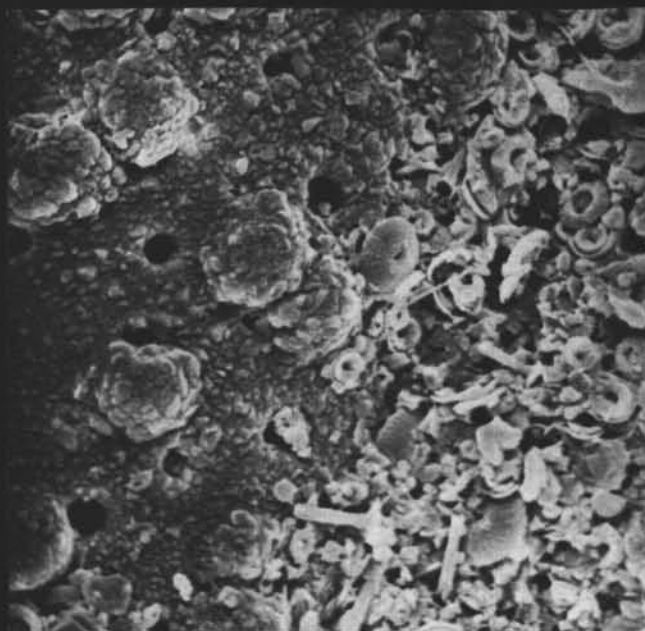
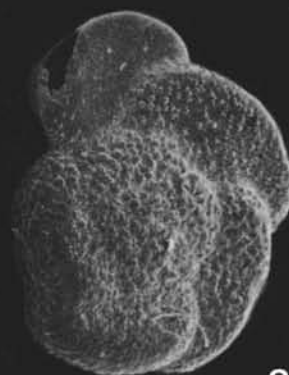
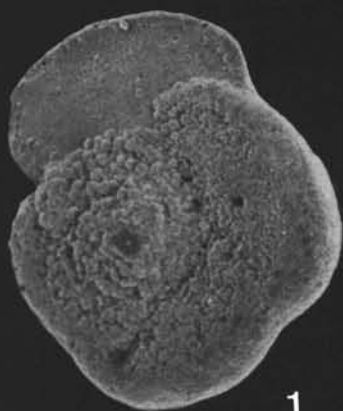


PLATE 5

All figures $\times 128$. In all figures a = spiral view; b = side view;
c = umbilical view. Camera lucida drawings by
J. van den Linden, Utrecht.

- Figure 1 (a-c) *Globorotalia crassaformis viola* Blow. Upper Pliocene,
Sphaeroidinellopsis subdehiscens Interval-zone of the
Tyrrhenian Basin. Sample: DSDP 13-132-11, CC.
- Figure 2 (a-c) *Globorotalia aemiliana* Colalongo and Sartoni. Upper
Pliocene, *Sphaeroidinellopsis subdehiscens* Interval-
zone of the Tyrrhenian Basin. Sample: DSDP 13-
132-11, CC.
- Figure 3 (a-c) *Globorotalia menardii* (d'Orbigny). Upper Pliocene,
Sphaeroidinellopsis subdehiscens Interval-zone of the
Ionian Basin. Sample: DSDP 125A-5-1, 108-110 cm.

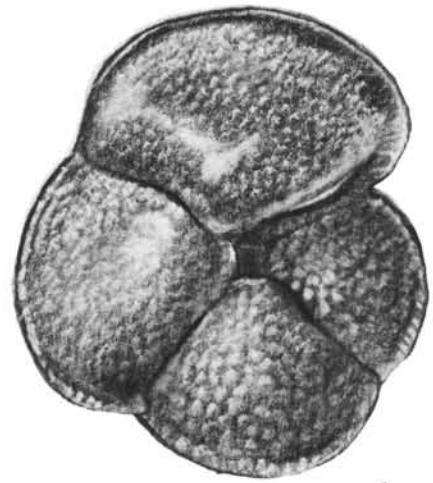
PLATE 5



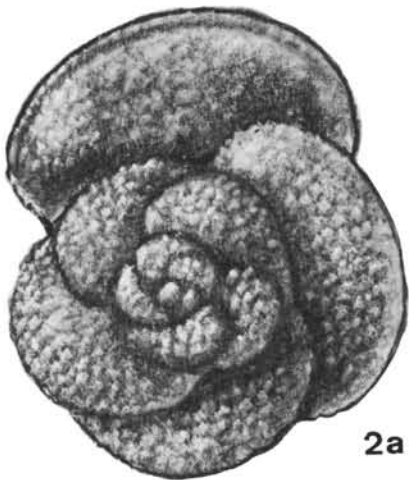
1a



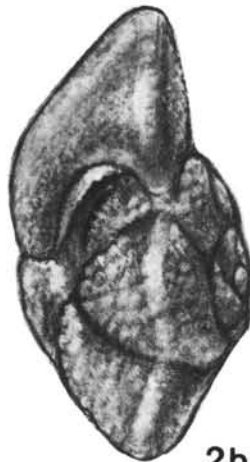
1b



1c



2a



2b



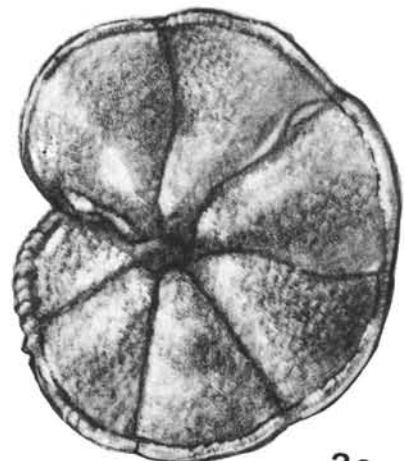
2c



3a



3b



3c

0 250 500 μ

PLATE 6

All specimens illustrated are from Sample DSDP 13-132-21-1, 60-62 cm. Lowermost Pliocene of the Tyrrhenian Basin, *Sphaeroidinellopsis* Acme-zone. This level lies some 165 cm above the Miocene/Pliocene boundary (see Figure 2, this Chapter) and can be identified with the *Sphaeroidinella*-datum.

- Figure 1 *Sphaeroidinellopsis subdehiscens* Blow. Umbilical view; X115.
- Figure 2 A detail of Figure 1, showing the primary aperture with an enclosed unidentified planktonic foraminifer; X435.
- Figure 3 *Sphaeroidinellopsis seminulina* (Koch). Spiral view; X185.
- Figure 4 Detail of Figure 3, showing the heavily calcified cortex; X425.
- Figure 5 *Sphaeroidinella dehiscens immatura* Blow; X160. Spiral view of a specimen showing incipient supplementary apertures on both sides.
- Figure 6 *Sphaeroidinellopsis seminulina* (Koch). Spiral view; X160.
- Figure 7 *Sphaeroidinellopsis subdehiscens* Blow. Umbilical view of a specimen with a very large primary aperture; X75.

PLATE 6



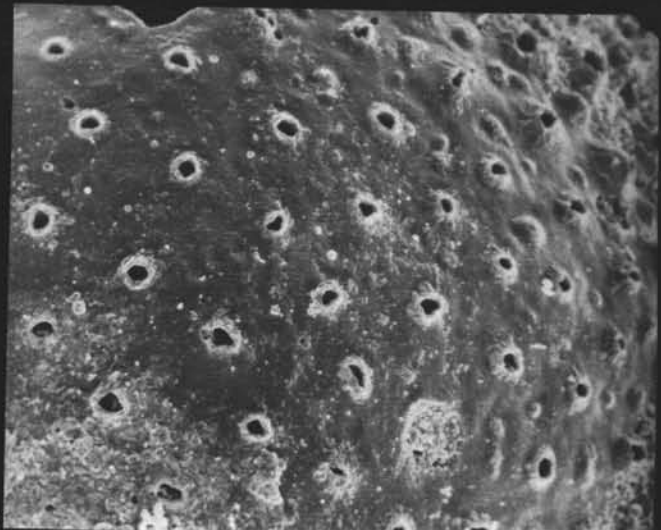
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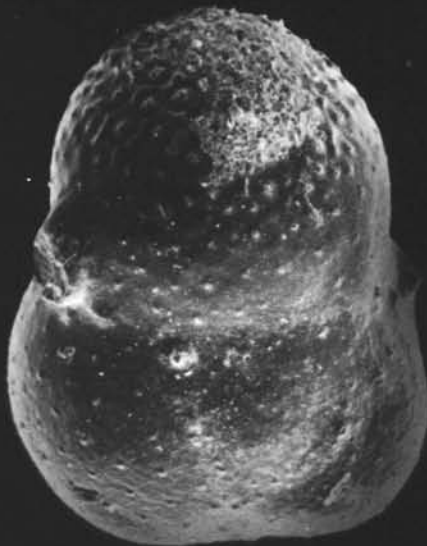
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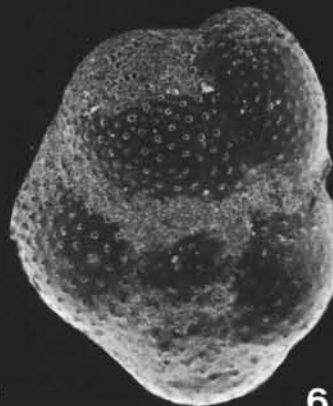
3



4



5



6



7

PLATE 7

- Figure 1 *Globigerinoides sacculifer* (Brady). Spiral view; X115. Sample: DSDP 13-132-14, CC. Lower Pliocene of the Tyrrhenian Basin. *Globorotalia margaritae evoluta* Lineage-zone.
- Figure 2 *Globigerinoides obliquus extremus* Bolli. Umbilical view, passing to side-view; X153. Sample DSDP 13-134E-SWC1. Upper Pliocene of the Balearic Basin.
- Globigerinoides obliquus extremus* Interval-zone.
- Figure 3 A detail of Figure 2, showing the cancellated surface, with funnel-shaped cavities and opened pores. Coccoliths are visible on the test surface; X765.
- Figure 4 *Globigerinoides conglobatus* (Brady). Side view; X75. Sample: DSDP 13-134E-SWC1. Upper Pliocene of the Balearic Basin. *Globigerinoides obliquus extremus* Interval-zone.
- Figure 5 A detail of Figure 4, showing thick, heavily calcified wall and well-spaced, mostly filled pores; X765.

PLATE 7

