

NEW LATE MIOCENE AND PLIOCENE OCCURRENCES OF *GLOBOROTALIA* SPECIES FROM THE NORTH ATLANTIC; AND A PALEOGEOGRAPHIC REVIEW

RICHARD CIFELLI¹ and GEORGETTE GLAÇON²

ABSTRACT

Late Miocene-Pliocene menardiform and crassaform species of *Globorotalia* are recorded and figured from a sampling site on the west flank of the Mid-Atlantic Ridge, in the southern Sargasso Sea near the core of the North Atlantic Gyre. At the present time menardiform and other endemic tropical species occur sparsely in this part of the ocean, but they are abundantly represented in the late Miocene and Pliocene. In sediments of late Miocene age menardiform species are widely distributed in the North Atlantic and Mediterranean, suggesting that tropical and warm gyral waters were greatly expanded at that time. A retraction of menardiforms towards the south occurred in

the early Pliocene, but only on the eastern side of the ocean. A speculative comparison between modern and Pliocene circulation in the North Atlantic is shown by sketches.

Some remarks are made on the taxonomy and relationships of the menardiform and crassaform species. Ontogenetic development appears to provide a means of defining these groups and establishing their relationships. On Miocene forms of *Globorotalia menardii* an imperforate band joins the keel on the umbilical face of the final chambers, a feature that disappears in younger forms.

INTRODUCTION

In this paper we record and describe late Tertiary species of *Globorotalia* from an isolated area in the southern part of the North Atlantic Ocean. The species belong to two distinct groups: the menardiforms (centered around *G. menardii*) and the crassaforms (centered around *G. crassaformis*). These groups radiated at separate times during the Cenozoic and have exploited overlapping habitats. The menardiforms, endemic to tropical waters, began their radiation in the middle Miocene, while the more ubiquitous crassaforms did not originate and expand until about the beginning of the Pliocene. An understanding of the historic development of these groups is impor-

tant not only for biostratigraphic correlations, but also for the interpretation of the evolution of ocean climate. However, documentation of their time-space relationships is handicapped by large sampling gaps in the oceans. Samples from DSDP and IPOD continue to fill in many empty spaces, but important segments of the North Atlantic and other oceans remain unsampled below the Pleistocene. Here we propose to fill a late Miocene-Pliocene gap in the North Atlantic, from a sampling site in the southern Sargasso Sea, near the core of the present North Atlantic Gyre (Fig. 1). Waters of this region now support a distinctly warm-water subtropical fauna, but are sufficiently far removed from the tropics so that menardiforms and other tropical expatriates are excluded (Cifelli and Smith, 1974; Phleger and others, 1953). A review of the relationships between the distribution of living planktonic foraminifera and circulation is given by Cifelli (in press).

¹ National Museum of Natural History, Washington, D.C. 20560, U.S.A.

² Département de Géologie Structurale, Université Pierre et Marie Curie. 4 Place Jussieu—75230 Paris, France.

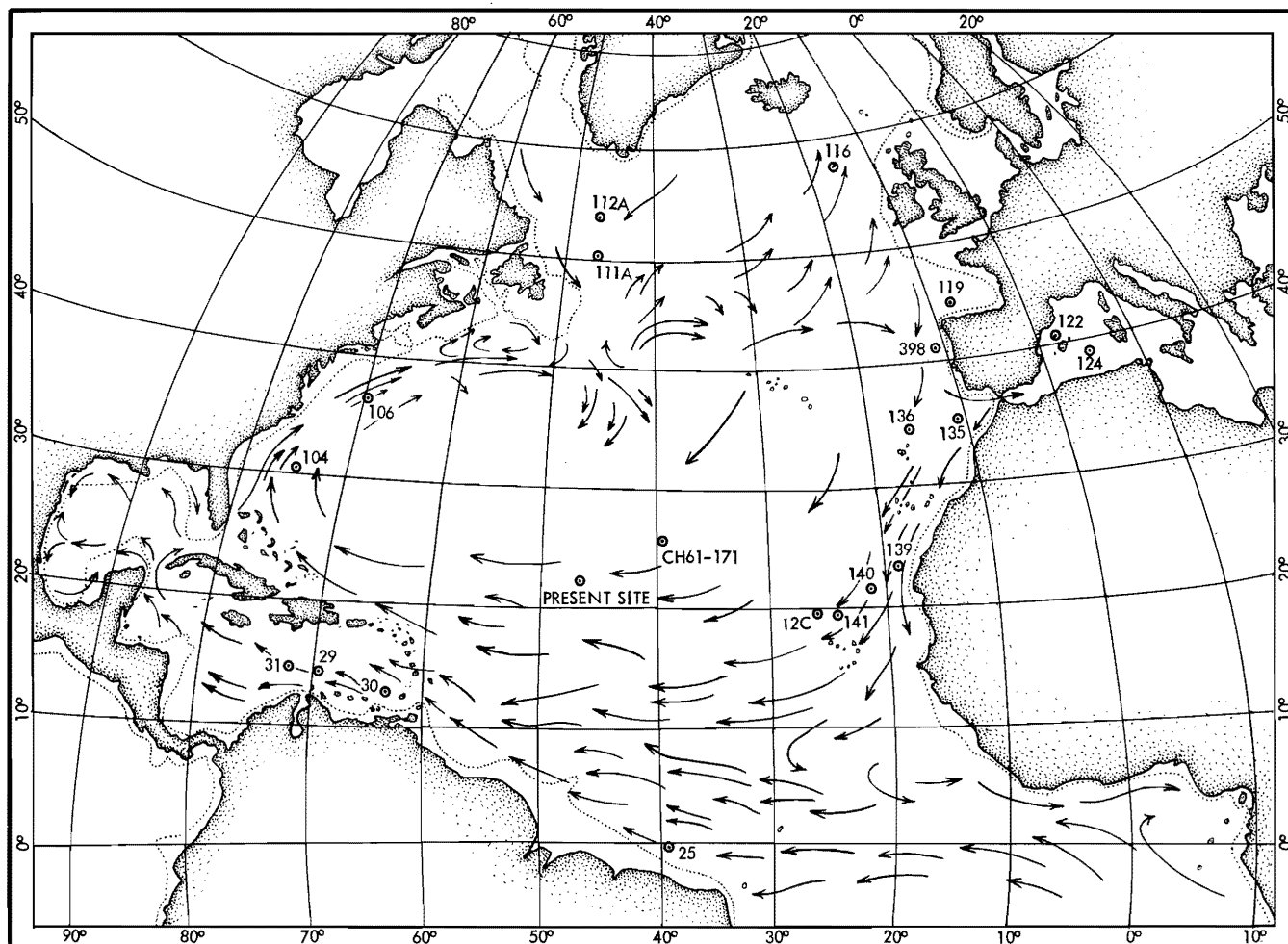


FIGURE 1

Location of present sampling site and DSDP sites against background of North Atlantic circulation (from the files of The Woods Hole Oceanographic Institution).

Faunas of the present sampling site and late Miocene-Pliocene faunas from various North Atlantic sites are reviewed and compared with modern faunas within the framework of North Atlantic circulation. Special emphasis is placed on the menardiform species, because of their close tropical affinities and common occurrence both in the Pliocene and Miocene. As previously noted (Cifelli, 1976) the distributional pattern of menardiforms has changed markedly since the Miocene, suggesting a major change in the distribution of surface water masses since that time.

The state of menardiform and crassaform taxonomy does not permit full synonymization of species at the present time. It is clear, however, that the species *Globorotalia menardii* has been interpreted in too

broad a sense (e.g., Cifelli, 1976). We follow the recommendation of Stainforth and others (1975) in limiting *G. menardii* to Miocene forms that are represented commonly in the Mediterranean. The modern menardiform *G. cultrata*, appears to be of relatively recent origin, probably dating back no further than Pleistocene. We cannot be positive of this assertion at the present time, but so far we have encountered no pre-Pleistocene menardiforms that are strictly referable to the modern *G. cultrata*.

SAMPLING SITE

The three samples recorded here come from the west flank of the Mid-Atlantic Ridge, between latitudes 22°–23°N (Fig. 2). Two of the samples were re-

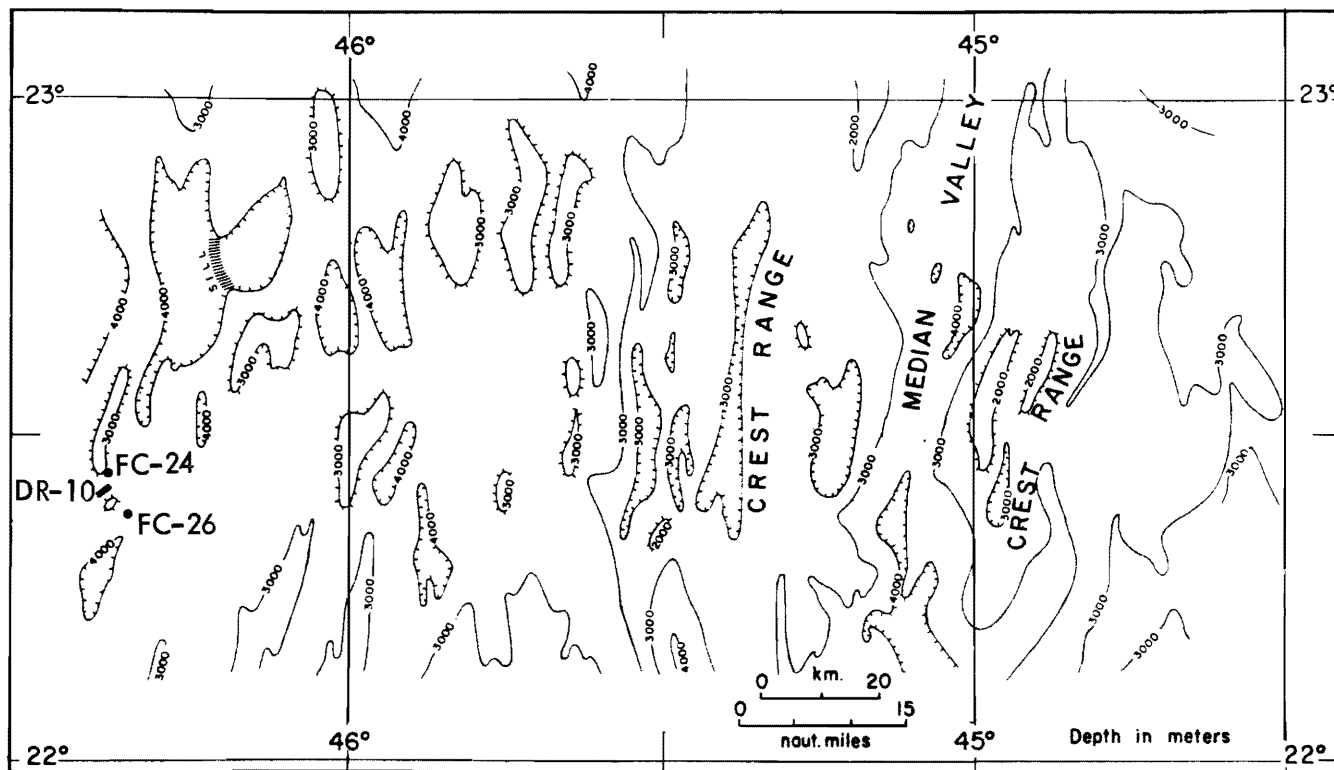


FIGURE 2

Location of samples on the flank of the Mid-Atlantic Ridge (after Cifelli, 1970).

covered by free-fall corers (FC 24, 26), the other by dredge (Dr. 10). A preliminary account of the age relationships of the sediments and the planktonic foraminifera has been given previously (Cifelli and others, 1966; Cifelli, 1970). The sediment consists of loosely consolidated foraminiferal ooze, often containing fragments of volcanic debris. The slightly indurated sediment is exposed at the flanks of valleys that contain loose ponded sediments. A full account of the sediments of the Ridge flank is given by van Andel and Bowin (1968).

PRESENT BIOGEOGRAPHIC SETTING

Figure 1 shows the sampling site in relation to the gyral circulation of the North Atlantic. It lies in the Southern Sargasso Sea, near the core of the Gyre, about midway between the American and African continents. Circulation in this part of the ocean is very weak, and there are only minor incursions of water from the North Equatorial Current. There is very little opportunity for expatriated species to reach the core of the Gyre and the fauna is a "pure" subtropical one,

i.e., warm-water assemblage but lacking species indigenous to the tropics (Cifelli and Smith, 1974). Importantly, the menardiform species (*Globorotalia "menardii," G. tumida, G. unguolata*) are virtually absent in the water column of this part of the ocean today. Individuals may be captured in net tows on rare instances, but the waters around the core of the Gyre are not a normal habitat for the menardiforms at the present time. In Quaternary sediments menardiforms are somewhat more common because they have accumulated there over many years. According to Kipp (1976), frequencies of *G. menardii* range from 0.1–2% in the total interior area of the Gyre. The Quaternary distributional pattern given by Kipp agrees well with the plankton distribution, showing impoverishment in the gyral core and concentration around the southern and western margins. The most important species in the modern North Atlantic subtropical fauna include:

Globigerinoides ruber
Globigerinoides trilobus
Globigerinoides conglobatus

Globigerinoides aequilateralis
Globorotalia hirsuta
Globorotalia truncatulinoides
Globorotalia crassaformis
Orbulina universa
Globigerina dutertrei
Hastigerina pelagica

Composition of planktonic assemblages outside of the gyral core is strongly influenced by the clockwise motion of the circulation. Not only is there considerable faunal mixing around the margins of the Gyre, but also a pronounced latitudinal asymmetry in distribution of tropical forms (Cifelli and Bénier, 1976). On the eastern side of the ocean the northern limit of tropical forms occurs between the Cape Verde and Canary Islands, or at about latitude 22°N (near Sites 139, 140). However, on the ocean's western side tropical forms are carried by the Gulf Stream as far north as the slope waters, in the vicinity of latitude 42°N (north of Site 106). Therefore, there is a displacement of tropical forms 20° northward on the ocean's western side. The clockwise spin of the circulation also causes a southward displacement of northern forms on the ocean's eastern side. Faunas along the Iberian coast (area of Sites 119, 398B, 135, 136) and the Mediterranean (Sites 122, 124) consist of mixtures of northern and subtropical species (Cifelli, 1974).

At high latitudes, beyond the North Atlantic Gyre, circulation is counterclockwise and displacement occurs in an opposite direction. The Hatton-Rockall Basin (Site 116), at latitude 55°N, supports a fauna similar in composition to that of the western slope waters at a latitude of about 44°N. No subtropical species occurs here, but neither does the polar species, *Globigerina pachyderma*. The fauna consists of *G. bulloides*, *G. incompta*, *G. egelida* and *Globorotalia inflata*. On the other hand, the Labrador Sea (Sites 111A, 112A) on the western ocean side, fed by the southward moving Labrador Current, supports a typically polar fauna consisting almost entirely of *Globigerina pachyderma*.

Except for piston core CH-61 described by Berggren (1968) there is a total absence of described fossil planktonic successions from sediments in the interior of the Gyre. Tertiary planktonic successions have been established from surface sections mainly from two regions, the Caribbean and the Mediterranean. Both of these regions lie outside of the North Atlantic proper. The Caribbean is located in the tropics, adjacent to the southwestern side of the Gyre and serves a feeder of water to the northward flowing Gulf Stream. The Mediterranean is located diametrically opposite, in the temperate region on the eastern side

of the Gyre. It forms a partial detour for the southward moving currents along the European and African coasts.

Sampling gaps between these remotely separated regions are being filled by DSDP. Thus far, the DSDP sites tend to follow the margin of the Gyre with important extensions to the north (Sites 111, 112) and into the Mediterranean. Legs 4 and 37 of the DSDP crossed the Gyre, but only a few late Tertiary species were reported. Some sediments of late Tertiary age have been recovered by piston cores (Saito and others, 1966), but faunas have not been described.

AGE AND FAUNAL COMPOSITION OF SAMPLES

The free fall and dredge samples from the present site yielded the following assemblages of planktonic foraminifera (number of specimens observed and picked shown in brackets):

FC 24 (late Pliocene)

Globigerina praebulloides Blow (2)
Globigerinella aequilateralis (Brady) (1)
Globigerinoides elongatus (d'Orbigny) (33)
ruber (d'Orbigny) (2)
sicanus De Stephani—*transitorius* Blow homeomorphs (2)
trilobus (Reuss) (2)
Globorotalia crassaformis Galloway and Wissler *sensu lato* (12)
miocenica Palmer (16)
obesa Bolli (3)
pertenuis Beard (15)
scitula (Brady) (2)
truncatulinoides (d'Orbigny) (1)
Orbulina universa d'Orbigny (2)
Sphaeroidinella dehiscens dehiscens Parker and Jones (1)
immatura Cushman (1)

FC 26 (? early Pliocene)

Globigerina nepenthes Todd (6)
Globigerinoides trilobus (Reuss) (20)
Globoquadrina altispira (Cushman and Jarvis) (6)
Globorotalia menardii (Parker, Jones and Brady) (32)
scitula (Brady) (2)
Orbulina universa d'Orbigny (1)
Sphaeroidinellopsis seminulina (Schwager) (9)

Dr 10-P1 (early Pliocene)

Globigerina nepenthes Todd (21)
Globigerinella aequilateralis (Brady) (2)

- Globigerinoides obliquus* Bolli (10)
sicanus De Stephani homeomorphs (3)
trilobus (Brady) (6)
Globoquadrina altispira (Cushman and Jarvis) (3)
Globorotalia crassaformis Galloway and Wissler
sensu lato (2)
multicamerata Cushman and Jarvis (3)
praemiocenica Lamb and Beard (4)
scitula (Brady) (1)
Orbulina universa d'Orbigny (2)
Sphaeroidinellopsis seminulina (Schwager) (3)
sphaeroides Lamb and Beard (4)
subdehiscens Blow (5)

Dr 10-P2 (late Miocene)

- Globigerina nepenthes* Todd (7)
Globigerinella aequilateralis (Brady) (4)
Globigerinoides obliquus Bolli (10)
subsacculifer Cita, Premoli-Silva and Rossi (3)
trilobus (Reuss) (18)
Globoquadrina dehiscens Chapman, Parr and
Collins (30)
Globorotalia menardii (Parker, Jones and Brady)
(6)
merotumida Blow and Banner (3)
pseudotumida Blow and Banner (4)
Orbulina universa d'Orbigny (8)
Sphaeroidinellopsis seminulina Schwager (16)

Sample FC 24 contains the richest assemblage of planktonic foraminifera with the menardiform and crassaform groups occurring in abundance. The menardiforms are represented by *Globorotalia miocenica* and *G. pertenuis* indicating a late Pliocene age. A diverse range of morphology is displayed by the crassaform group (Pl. 3, Figs. 1–5) but all forms are grouped here under *G. crassaformis sensu lato* and *G. crotonensis* because of uncertainties in crassaform taxonomy. Species that have been subdivided from *G. crassaformis* are very variable, and so far have not proved stratigraphically useful (Glaçon, Vergnaud and others, 1973). Rare specimens of *G. truncatulinoides* occur in the assemblage but may be contaminants, since, to our knowledge, there are no previous records of that species occurring in association with Pliocene-restricted menardiforms such as *G. miocenica* and *G. pertenuis*. The assemblage also contains some forms of *Globigerinoides* that closely resemble the middle Miocene *G. sicanus* group. As discussed in an earlier paper (Cifelli and others, 1966), we regard these forms as heterochronous homeomorphs. Sample FC 24 was recovered from the flank of the Mid-Atlantic Ridge, not far from the crest range (Fig. 2) so there seems no

possibility that these forms could have been reworked from a middle Miocene source.

Sample FC 26 contains fewer planktonic foraminifera than FC 24 and preservation is not as good. Species are stratigraphically undiagnostic beyond indicating an undifferentiated age of late–middle Miocene to early Pliocene. The menardiforms are represented by *Globorotalia menardii*, a long-ranging species that had a peak development in the late Miocene. However, Miocene forms have an imperforate band adjacent to the keel on the umbilical side of all test chambers (Cifelli and Glaçon, 1978). All specimens in the FC 26 assemblage lack the imperforate band on the chambers of the last whorl (i.e., the chamber perforations abut against the keel). Loss of the imperforate band is a development that apparently began in late Miocene and becomes common after the Miocene (Cifelli and Glaçon, 1978). Identical forms of *G. menardii* lacking the imperforate band have been figured by Lamb and Beard (1972) from the early Pliocene of the Gulf of Mexico. Therefore, we are inclined to regard FC 26 as early Pliocene, although determination is not certain.

Sample Dr 10 P1 contains a more diverse assemblage of planktonic foraminifera than does FC 26. An early Pliocene age is indicated by the presence of *Globigerina nepenthes*, *Globorotalia multicamerata* and *G. praemiocenica*. In DR 10-P2, the menardiforms are represented by *G. merotumida*, *G. pseudotumida* and *G. menardii*, indicating a late Miocene age. In contrast to the menardiforms found in the Pliocene assemblage, these forms have imperforate bands adjacent to the keel of the final test chambers.

PALEOBIOGEOGRAPHY

The present samples are late Pliocene (FC 24–5), early Pliocene (Dr 10-P1, FC 26) and late Miocene (DR 10-P2) in age. All of the faunal assemblages display strong warm-water affinities, allowing for the fact that a number of the species are extinct and their actual habitat preferences are not known. Among the Pliocene assemblages there are appreciable numbers of extant species, which now occupy the warm subtropical waters and the tropical waters farther south. These species include *Globigerinoides ruber*, *G. trilobus*, *G. conglobatus*, *Globigerinella aequilateralis*, *Orbulina universa*, *Globorotalia crassaformis*. In addition, there also occurs *Sphaeroidinella dehiscens*, a modern species presently restricted to tropical waters. Importantly, menardiform species are abundantly represented. These species include *G. miocenica*, and *G. pertenuis* in the late Pliocene and *G. mul-*

ticamerata, *G. praemiocenica* in the early Pliocene. None of these species is extant, but they are morphologically close to the modern menardiform species *G. cultrata* which is a tropical inhabitant. The Pliocene assemblages, therefore, can be classified as tropical in contrast to the living fauna of this region which is subtropical (Cifelli and Bénier, 1976).

The late Miocene assemblage (Dr 10-P2) contains fewer extant species, so that analogy with living faunas is less clear-cut. Nevertheless, the general aspect of the assemblage is very similar to that of the Pliocene. Among the extant species are *Globigerinoides trilobus*, *Globigerinella aequilateralis* and *Orbulina universa*. The genus *Globigerinoides* is also represented by the extinct form *G. obliquus* and the *Sphaeroidinella* group by *Sphaeroidinellopsis seminulina*, the antecedent of *Sphaeroidinella dehiscentis*. In addition, menardiform species also are well represented by *G. plesiotumida*, *G. menardii*, *G. merotumida*. They are not as abundant as in the Pliocene, but totaled together they make up about 8% of the assemblage, a frequency that is comparable with modern tropical assemblages (Kipp, 1976).

In comparing these assemblages with others of similar age we will start with the relatively nearby CH61 core, proceed to the Caribbean and equatorial regions, and then continue counterclockwise around the ocean.

RELATIONSHIPS WITH DATA FROM PREVIOUSLY DESCRIBED SAMPLES

Gyral core (CH61-171). On cruise 61 of the R/V CHAIN a piston core was raised approximately 520 miles NE of the present site that contained some sections of late Pliocene age. The lower part of the core (below 580 cm) appears approximately correlative with the late Pliocene of the present site. Berggren (1968) reports assemblages similar to those recorded here, with abundant *Globigerinoides ruber* and *Orbulina universa*. The CH61-171 assemblages also contain *Globorotalia miocenica*, *G. multicamerata*, *G. fimbriata* and the extant tropical species *Sphaeroidinella dehiscentis* and *Pulleniatina obliquiloculata*. The Pliocene of the CH61-171 core, therefore is distinctly tropical in aspect.

Caribbean (Sites 29, 30, 31). Mostly late Pliocene was represented at the Caribbean sites with some middle Pliocene and Miocene. Parker (1973) recorded rich faunas which, in the Pliocene, include numerous extant species; among them are the subtropical-tropical forms *Globigerinoides ruber*, *G. trilobus*, *G. conglobatus* and *Globigerinella aequilateralis*, *Orbulina universa* and the more tropically restricted *Sphaeroidi-*

nella dehiscentis, *Pulleniatina obliquiloculata*, *Candeina nitida*, *Globorotalia tumida*. Parker also recorded *G. cultrata*, but according to our present views of the menardiforms, Parker's form may not be the same as the modern *G. cultrata* which appears to be of post-Pliocene origin. However, the menardiforms are well represented in the Caribbean Pliocene by *G. miocenica*, *G. multicamerata*, *G. limbata*, *G. exilis*. The crassaform species are also well represented by *G. crassaformis*, *G. crotonensis*, *R. ronda*.

The late Miocene contains fewer extant species than the Pliocene but include the modern warm water forms *G. ruber*, *G. trilobus*, *G. conglobatus*, *Globigerinella aequilateralis*, *Candeina nitida*, *Orbulina universa*. Menardiform species are represented by *G. "cultrata"*, *G. merotumida*, *G. plesiotumida*, *G. limbata*. Parker also recorded *Globigerina praebulloides* from the late Miocene.

The Miocene and Pliocene faunas of the present site are very similar to the Caribbean faunas, although the Caribbean faunas are somewhat richer in species. One of the principal differences, biogeographically, is that *Pulleniatina obliquiloculata* is absent at the present site but rather common in the late Pliocene of the Caribbean sites.

South of gyral margin: equatorial current (Site 25). Site 25 was drilled on the western side of the equatorial region, in the present pathway of the South Equatorial Current. Lower to middle Pliocene and upper Miocene were recovered in the cores, with some suspected reworking and contamination in the Pliocene section (Parker, 1973). The faunas are very similar in general composition to those of the Caribbean sites; *Globigerinoides ruber*, *G. trilobus*, *G. conglobatus*, *Globigerinella aequilateralis*, *Orbulina universa* are all present. Curiously, however, extant tropical species are not quite as well represented as in the Caribbean Pliocene. For example, *Sphaeroidinella dehiscentis* is scarce, while *Pulleniatina obliquiloculata* and *Candeina nitida* were not recorded at all. It is difficult to think of an environmental reason for this discrepancy, because Site 25 is situated almost on the equator where the faunas should contain as many tropical species as the Caribbean. Postdepositional processes affecting the composition of faunal assemblages are probably involved, but the nature of these processes is not all clear.

The menardiforms are well represented in the Pliocene section where Parker recognized the following species: *G. merotumida*, *G. miocenica*, *G. multicamerata*, *G. limbata*, *G. plesiotumida*. The latter species as figured in Parker is, in our view, closer to

G. praemiocenica Lamb and Beard. Crassaform species are also represented in the Pliocene and include *Globorotalia crassaformis*, *G. ronda*, *G. crotonensis*, *G. viola*. The late Miocene assemblages recorded by Parker are very similar in general composition to those of the Pliocene and include the menardiform species *G. merotumida*, *G. "plesiotumida"*, *G. limbata*, *G. "pseudomiocenica"*. *Globigerina apertura*, *G. praebulloides*, *G. falconensis* were recorded from the late Miocene, although they are not common.

Southeastern gyral margin (Sites 12C, 139–141). Sites 12C, and 139–141 are located off the West African coast between the Canary and Cape Verde Islands. At the present time this region marks the northern limits of menardiform and other tropical species on the eastern side of the North Atlantic. Near the north African coast, living assemblages include, along with the tropical and subtropical forms, numerous northern high-latitude forms which are displaced to the south by the clockwise movement of the Gyre (Cifelli and Bénier, 1976).

From Site 12C, Parker (1973) records early and middle Pliocene, but no late Miocene. From the Pliocene the same tropical associations occur here as in the equatorial and Caribbean sites. *Pulleniatina obliquiloculata* and *Candeina nitida*, not recorded at equatorial Site 25, are reported from Site 12C. The menardiforms are well represented by *G. tumida*, *G. miocenica*, *G. multicamerata*, *G. cultrata*, *G. exilis*. Crassaform species are also well represented and include *G. crassaformis*, *G. crotonensis*, *G. ronda*, *G. viola*. There are also *Globigerina* species present, including the high-latitude type form *G. falconensis*. However, as in the Pliocene tropical sites farther west, this species is sporadic in occurrence, never forming an important component of the assemblages. At Site 12C, Pliocene assemblages have the same tropical aspect as those at the tropical sites farther west. They are not comparable to mixed, northern, tropical assemblages that inhabit the southeastern gyral margin today.

The faunal lists given by Beckmann (1972) for Sites 139–141 were prepared for a DSDP report and therefore are only partial. However, his lists do indicate the same type of tropical associations for the Pliocene as in Site 12C and previous tropical areas. The menardiforms are represented by *G. miocenica*, *G. pertenuis*, *G. multicamerata* and *G. tumida*. Crassaform species are also present. Some middle to late Miocene was recorded from Site 141 where Beckmann recorded the menardiform species *Globorotalia "cultrata"*.

Eastern gyral margin and Mediterranean (Sites 135, 136, 122, 124, 119). This region extends from the northern part of the north African coast to the Bay of Biscay. It also includes the Mediterranean, which serves as a "bypass" for the southward flowing currents of the eastern margin of the ocean. The modern planktonic faunal composition of the Mediterranean is the same as that of the adjacent North Atlantic waters except that the Mediterranean supports somewhat fewer species (Cifelli, 1974). The fauna consists of a mixture of subtropical species characteristic of the North Atlantic Gyre and high-latitude, northern species that are displaced by the southward moving currents. Importantly, at these latitudes there is an absence of menardiform and other tropical species, except for rare expatriates. As mentioned previously, the northern limits of menardiform and other tropical species occur between the Cape Verde and Canary Islands on the eastern side of the North Atlantic.

Menardiform species are also lacking throughout the Pliocene in the mid-latitude portion of the eastern north Atlantic and Mediterranean, according to the records presently available from DSDP sites (Beckmann, 1972; Cita, 1973; Berggren, 1972; Iaccarino and Salvatorini, in press). During the Pliocene, the menardiform boundary on the eastern margin of the North Atlantic appears to have been located close to where it is today, between the Canary and Cape Verde Islands.

Excellent lower and upper Pliocene sections were recovered from Mediterranean Sites 122–124 and the faunas were recorded in detail by Cita (1973). These faunas consist of a rich association of extant and extinct species showing a subtropical-northern aspect similar to what is found in the Mediterranean today. Cita reported the following extant species from the Mediterranean sites:

Northern	Subtropical
<i>Globigerina</i>	<i>Globigerinella</i>
<i>bulloides</i>	<i>aequilateralis</i>
<i>Globigerina</i>	<i>Globigerinoides</i>
<i>quingueloba</i>	<i>conglobatus</i>
<i>Globigerina</i>	<i>Globigerinoides</i>
<i>pachyderma</i>	<i>ruber</i>
(sensu lato)	<i>Globigerinoides</i>
<i>Globorotalia</i>	<i>trilobus</i>
<i>inflata</i>	<i>Globorotalia</i>
	<i>crassaformis</i>
	<i>Orbulina</i>
	<i>universa</i>

All of the northern forms found in the Pliocene in-

habit the Mediterranean today. Among the subtropical forms, however, *Globigerinoides conglobatus* and *Globorotalia crassaformis* are presently excluded. It is not clear why these species disappeared from the Mediterranean since the end of the Pliocene, but they may have been victims of increasing stress conditions that inhibit diversity. During the Pliocene, the Mediterranean supported a higher diversity than it does today if total fauna (extant plus extinct species) is considered. For example, the Pliocene assemblages recorded by Cita (1973) from Site 124 contain between 16–24 species, while the living assemblage from the western Mediterranean contains only 16 species (Cifelli, 1974).

Tropical forms have not been completely excluded from this region since the Miocene. *Sphaeroidinella dehiscens* occurs sporadically in the Pliocene of the Mediterranean and rare species of *Globorotalia menardii* (*sensu lato*) have been recovered there in plankton tows (Cifelli, 1974). Also, *Sphaeroidinella dehiscens*, *Pulleniatina obliquiloculata* and *Globorotalia tumida* have been recorded sporadically in the Pleistocene at Site 398 near the Iberian Coast (Iaccarino and Salvatorini, in press). However, the occasional intrusion of these southern expatriates should not detract from the dominantly non-tropical aspect of the post-Miocene faunas. Indeed, considering the mixing possibility of the ocean, it is somewhat surprising that they are not found more commonly.

The Miocene faunas differ markedly from those of the Pliocene because they have distinct tropical affinities, with a strong development of menardiform species. Mazzola (1971) lists *G. cultrata*, *G. miozea*, *G. cibaoensis*, *G. merotumida*, *G. menardii* for the late Miocene (Tortonian). Menardiform taxonomy is in a state of flux, but Mazzola's list and figures give an idea of the diversity of the group in the late Miocene. Menardiforms persist in the Mediterranean into the Messinian (Glaçon and Rehault, 1973). During the Messinian, the *G. conomiozea* makes a brief, enigmatic appearance (d'Onofrio and others, 1975).

Outside of the Mediterranean, in the adjacent North Atlantic waters, some upper Miocene was recovered at Site 135. Only a partial faunal list was given, but the late Miocene association recorded by Beckmann (1972) appears of tropical aspect, similar to those of other regions, and includes the menardiform *G. "cultrata."*

The upper Miocene from the Bay of Biscay (Site 119) yielded mostly undiagnostic assemblages that were impoverished in species. Berggren (1972) recorded *Orbulina universa*, *Globigerinoides* sp., *Globige-*

rina bulloides. Berggren also recorded *Globorotalia miozea*, *G. conoidea*, but no true, flattened, menardiform species. However, in the more recent drilling at Site 398, *Globorotalia merotumida* and *G. "cultrata"* have been reported from the late Miocene (Iaccarino and Salvatorini, in press).

North of gyral margin: eastern side (Site 116). The region north of the North Atlantic Gyre on the eastern side of the ocean is represented by Site 116 in the Hatton-Rockall Basin, located to the northwest of the British Isles. This region lies in the path of the North Atlantic Current which is formed from the northern branch of the Gulf Stream. The North Atlantic Current is the eastern arm of the counterclockwise circulation of the high latitudes in the North Atlantic. At the present time these waters support a typically northern fauna composed of *Globigerina bulloides*, *G. incompta*, *G. egelida* and *Globorotalia inflata*. The fauna differs from the one farther south, on the eastern margin of the Gyre, in its lack of subtropical forms (Cifelli, 1974). Also lacking is the polar species *G. pachyderma* (*sensu* Cifelli, 1974) which characterizes the fauna of high-latitude waters on the western side of the ocean.

At Site 116, early and late Pliocene planktonic assemblages were recorded in detail by Poore and Berggren (1975). The assemblages closely resemble the living assemblages of the region and show a strong dominance of *Globigerina* species which include the extant forms *G. bulloides*, *G. pachyderma* (*sensu lato*), *G. quinqueloba* (= *G. egelida*). *Globorotalia inflata* also is present, but only in the uppermost part of the Pliocene. Unlike the modern fauna of this region, however, the Pliocene also includes some extant subtropical forms. Among these are *Globorotalia crassaformis*, *Orbulina universa*, *Globigerinella aequilateralis*. In addition, *Globorotalia margaritae*, an extinct species very close morphologically to *G. hirsuta*, was recorded. *Globigerinoides* is represented only by the extinct species *G. obliquus*. Subtropical species are less well represented in the Pliocene of Site 116 than in the Pliocene of the Mediterranean, or possibly, Sites 119 and 398 in the Bay of Biscay. Nevertheless, they are conspicuous faunal elements that are lacking in waters of this region today.

In the late Miocene, *Globigerina* species are also important components of the assemblages. However, warm-water forms are better represented than in the Pliocene. *Globigerinoides trilobus* was recorded, along with *Orbulina universa*. Importantly, menardiforms also occur in the late Miocene, represented by *Globorotalia menardii* (*sensu lato*).

North of gyral margin; western side (Sites 111A,

112A). The western side of the high-latitude North Atlantic is represented by Sites 111A, 112A, located in the Labrador Sea. This side of the ocean is presently more frigid than the eastern side, as it is fed by the southward flow of the Labrador current, and is isolated from Gulf Stream influence. The living fauna is typically polar, consisting predominantly of *Globigerina pachyderma* (*sensu stricto*) with few individuals of *G. bulloides* and *G. egelida*. *G. incompta* and *Globorotalia inflata* have not been observed in these polar waters (Cifelli, 1973).

The early and late Pliocene assemblages recorded from Sites 111A, 112A by Poore and Berggren (1974) are remarkable for their striking contrast to the modern fauna of the Labrador Sea. Far from polar in aspect, these assemblages show strong tropical affinities for much of the Pliocene, especially in the early part. Menardiforms occur in variety, and include *Globorotalia multicamerata*, *G. miocenica*, *G. pseudomiocenica*, *G. exilis*, *G. menardii* (*sensu lato*). Also, early Pliocene assemblages include the extant tropical species *G. tumida* and *Sphaeroidinella dehiscens*. Crassaform species are represented by *G. crassaformis* and *G. crassula*. *Globigerinoides* species include *G. trilobus*, *G. ruber*, *G. conglobatus*. *Globigerinella aequilateralis* was also recorded.

Associated with the above warm-water species are numerous representatives of *Globigerina*, most notably *G. bulloides* and the extinct form *G. atlantica*. Through the early Pliocene and part of the late Pliocene the assemblages appear to be composed of tropical, subtropical and northern mixtures, like those found in the present Gulf Stream, presently located over 10° farther to the south.

In the late Pliocene the warm-water forms diminish, but do not disappear. Only at one interval, at Site 111A in part of core 6, do the assemblages approach a polar aspect. Above core 6, however, the assemblages revert to a non-polar aspect; for example, *Globigerina pachyderma* (left-coiled) is not the dominant species and the assemblages more closely resemble modern slope-water types. In Core 112, a polar aspect appears to be lacking throughout.

Western gyral margin (Sites 102, 103, 106). The gap between Labrador and the Caribbean on the eastern side of the ocean is filled by Sites 102, 103, 106 which lie close to the present path of the Gulf Stream. Sediments of late Miocene and Pliocene age recovered from these sites consist of stiff, dark-colored mud, apparently deposited close to the continental margin at a rapid rate. Foraminifera are generally scarce, but show tropical affinities. At Site 106 the Pliocene men-

ardiforms are represented by *Globorotalia miocenica* and *G. multicamerata* (Poag, 1972). In addition, *Globigerinoides trilobus*, *G. ruber*, *G. crassaformis* and, importantly, *Sphaeroidinella dehiscens* are also present, although not listed in the DSDP report. In the late Miocene the menardiforms include *Globorotalia cibaoensis* and *G. plesiotumida*. Sites 102 and 103 contain more diverse assemblages than does Site 106. The Pliocene menardiforms include *G. multicamerata*, *G. limbata*, *G. miocenica*, *G. "cultrata"*. Late Miocene menardiforms are represented by *G. cibaoensis*, *G. plesiotumida*, *G. merotumida*.

SUMMARY

Much more information on faunal assemblages from key parts of the circulation is necessary before the oceanographic conditions of the North Atlantic during the late Cenozoic can be confidently assessed. Nevertheless, even at this early stage of investigation it is clear that the distributional patterns of planktonic foraminifera have changed dramatically in the North Atlantic since the late Miocene (Cifelli, 1976). Interpretations of the changes may differ, but there is no denying that important changes have occurred.

During the late Miocene, and earlier too, the menardiform species extended far beyond their present range. Not only do they occur in the tropics and along the western margin of the ocean, where they might be expected, but also in the core of the present Gyre and, moreover, at high latitudes on the eastern margin of the ocean. They flourished in the Mediterranean and are well represented in the adjacent eastern North Atlantic waters. They also occur in the Miocene near the Bay of Biscay and as far north as lat 57°N. in the Hatton-Rockall Basin.

Importantly, the late Miocene menardiforms occur in association with other warm-water types of species, even at high latitudes. Only at the northernmost recorded locality (Site 116) do high-latitude types of species dominate the assemblages. But even there, warm-water forms are well represented. Therefore, there appears to be no reason to suspect that the habitat preference of menardiforms has changed appreciably since the Miocene.

The extended range of menardiforms implies that the limits of warm gyral and tropical waters were greatly expanded during the late Miocene with the Hatton-Rockall Basin (Site 116) located near the gyral margin, but with such a northerly gyral margin, where could cold waters (comparable, say, to present slope waters) have existed? To our knowledge, late Miocene

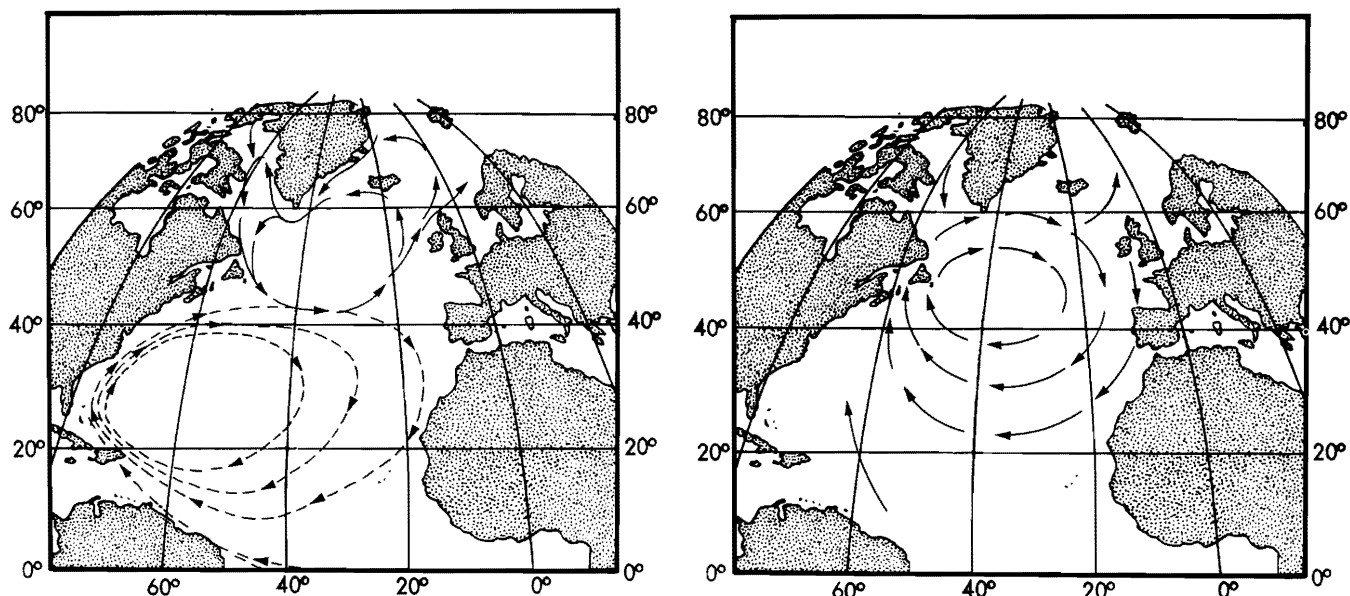


FIGURE 3a

Present gyral circulation of the North Atlantic (After Tchernia, 1969, *Océan Atlantique*, figs. 8–18)

FIGURE 3b

Inferred circulation of the North Atlantic during the Pliocene.

assemblages that could be classified as polar, or even truly temperate (i.e., totally lacking in subtropical forms), have not yet been recognized in the North Atlantic. The North Sea region seems the most likely place for their occurrence. North of the Hatton-Rockall Basin the ocean tends to become land-locked and space that might have been occupied by cold water is restricted.

A retreat of the menardiforms to lower latitudes becomes clearly visible in the early Pliocene, although it probably started towards the close of the Miocene. Termination of menardiforms and tropical affinities in the Mediterranean at the end of the Miocene has been reorganized for a number of years. Beginning in the Pliocene, Mediterranean faunas display a modern type of association, consisting of a mixture of subtropical and northern species. It was once thought that menardiform termination was due to Mediterranean isolation, but the menardiforms also disappeared along the entire eastern margin of the ocean north of the Canary Islands. Pliocene faunas of this region consist of a mixture of subtropical and northern species. Subtropical species persist as far north as the Hatton-Rockall Basin, so that the fauna of that northerly region still showed a warmer aspect than it does today, though less so than in the late Miocene.

Menardiform limits on the eastern margin of the

ocean during the Pliocene were located close to their present position, between the Canary and Cape Verde Islands. Faunas from this region have a distinctly tropical aspect and are fully comparable to Pliocene faunas of the equatorial and Caribbean regions.

In the western part of the ocean, menardiform distribution remained extended, and early Pliocene faunas have the same tropical character as in the late Miocene. Early and late Pliocene faunas in the core of the present Gyre are distinctly tropical, with abundant menardiforms, suggesting a tropical displacement of about 10° since the beginning of the Recent. Menardiform and other tropical species extend all along the western margin of the ocean, as far north as the Labrador Sea. The faunal contrast during the Pliocene between the western margin of the ocean, with a distinct tropical aspect and the eastern margin with a non-tropical aspect is very striking. Latitude is generally regarded as the limiting factor in plankton distribution but longitude is equally important in the North Atlantic for the Pliocene, especially the early Pliocene. The modern fauna, of course, shows a similar asymmetry in distribution of tropical forms around the margin of the ocean but there is considerably less northward displacement along the western side. The early Pliocene assemblages in the Labrador Sea are Gulf-Stream type associations (Poore and Berggren, 1974) which implies

that the western gyral margin was located about 10° or more farther north than it is now. Therefore, modernization in plankton biogeography occurred during the early Pliocene, but in a rather distorted fashion, as conditions on the western side of the ocean appear to have remained largely the same as they were in the late Miocene. Retraction on the western side occurred in the late Pliocene, but it appears that it was not until the Pleistocene that warm-water forms completely ceased penetrating into the Labrador Sea.

In Fig. 3 we attempt a rough approximation of early Pliocene circulation and a comparison with modern circulation. The core of the Gyre must have been located well north, and probably east, of its present position. The western boundary may have been located in the present Labrador Sea, while the eastern margin was diffuse, as it is today. Probably some allowance should be made for the more pronounced asymmetry in distribution of tropical forms in the early Pliocene, but assessment at this time is difficult. As in the late Miocene, truly cold-water faunas have not yet been recorded in the North Atlantic early Pliocene. The Hatton-Rockall Basin faunas contain appreciable numbers of subtropical forms, and that area must have been relatively close to the Gyre during the early Pliocene. Because of the lack of cold-water faunas, we suspect that thermal gradients were weaker, and circulation not as intense during the early Pliocene.

SYSTEMATIC PALEONTOLOGY

SOME REMARKS ON THE MENARDIFORM AND CRASSAFORM SPECIES

Stainforth and others (1975) used the term "menardiform" for a "group of Globorotalias having many features in common yet differing widely in aspects." The term "crassaform" can be used in a similar fashion for another group of Globorotalias but in both instances the difficulty is to define those features that

characterize all species of each group. In our opinion, the clue to definition lies in ontogenetic development of chambers, as viewed from the spiral side. Viewed this way, a case can be made for ancestry of both groups from scituliform ancestors; the menardiforms from *G. praescitula* in the middle Miocene, the crassaforms from *G. scitula* (indirectly) in the early Pliocene. The ancestral condition represented by *G. scitula* is shown in Pl. 1, Fig. 1a, where chambers are isometric, i.e., there is no relative increase in chamber height with respect to test size as chambers are added. Chambers are symmetrical and crescent shaped throughout the entire test. This kind of chamber is found in the early ontogenetic stages of both menardiforms and crassaforms (Cifelli and Glaçon, 1978). In the crassaforms, very little deviation from isometric shape occurs, and only in the chambers of the peripheral whorl. In the menardiforms, however, chamber shape quickly becomes allometric during ontogeny, i.e., chamber height increases relative to the test size. Chambers are no longer symmetrical, but become expanded, as the axial height of the chambers tends to project towards the direction of coiling (Pl. 1, Figs. 2c, 3c, 4c, 5b, 6c; Pl. 2, Figs. 1a, 2a, 3a, 4b, 5a).

Globorotalia scitula (Brady)

Pl. 1, Fig. 1a–c

Pulvinulina scitula BRADY, 1882, p. 716–717 (no figure).

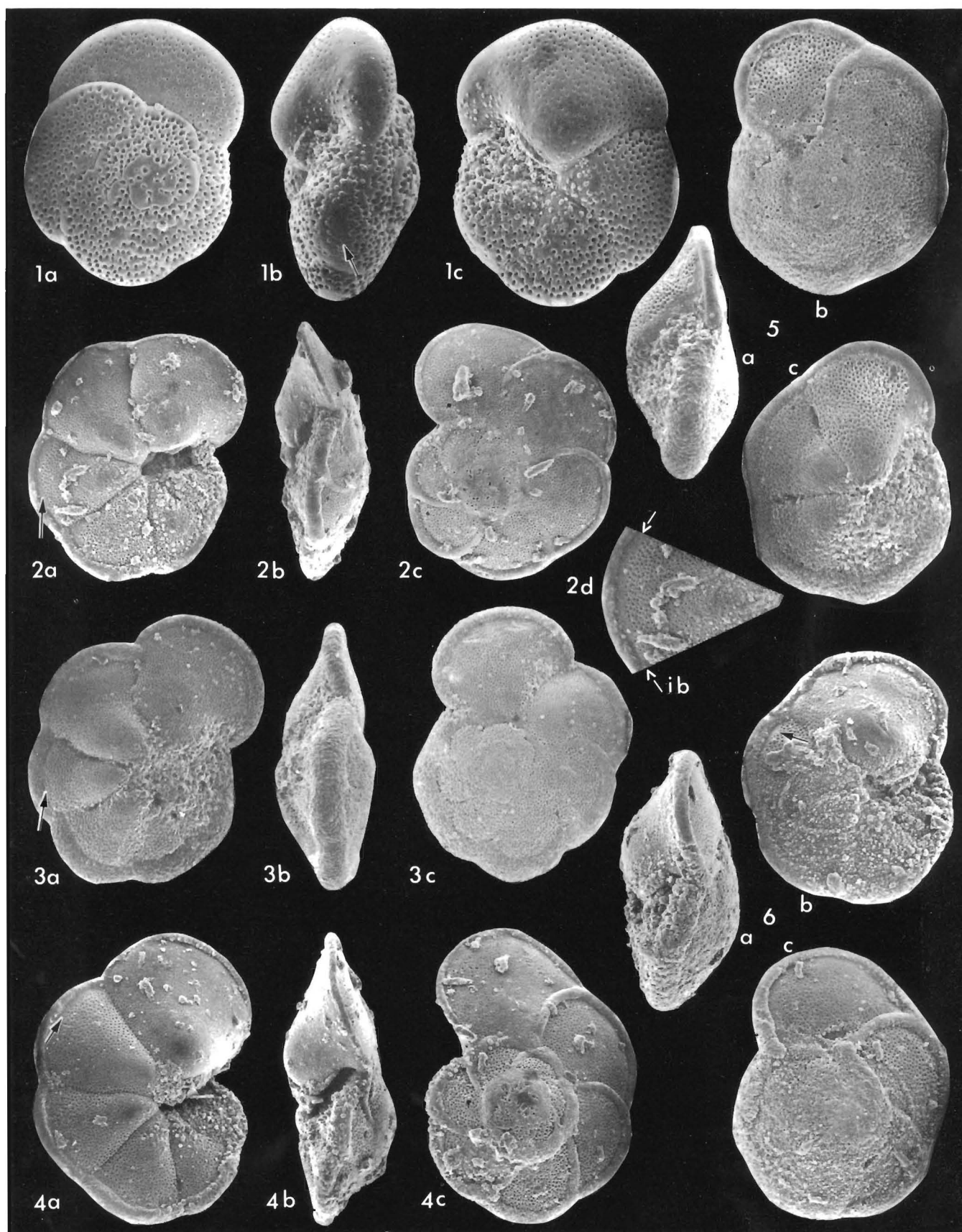
Globorotalia scitula (Brady). BANNER and BLOW, 1960, p. 27, pl. 5, fig. 5a–c (lectotype).

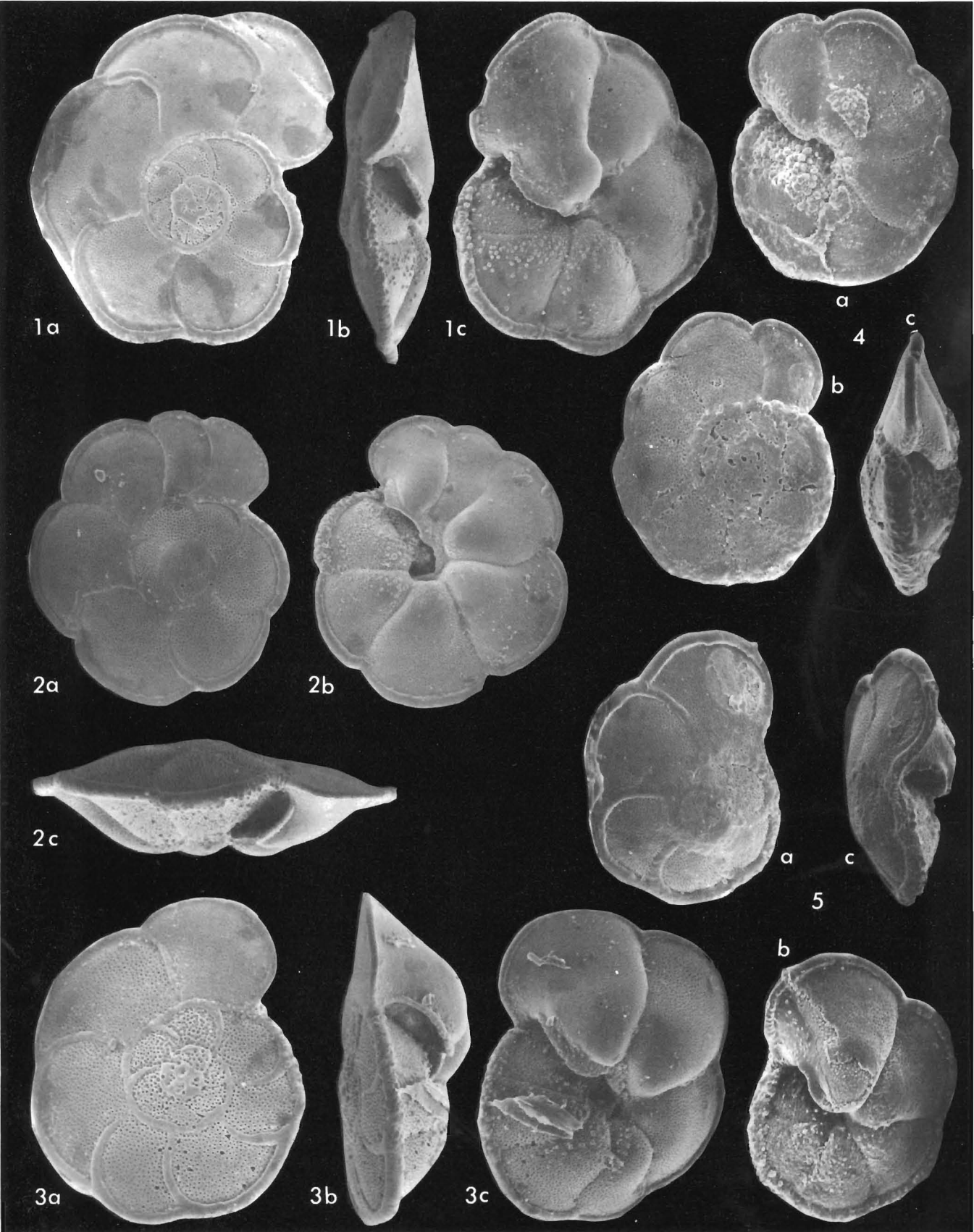
Globorotalia scitula retains the ancestral characters of *G. praescitula*. Chambers are symmetrical and crescent shaped throughout the test and a partially imperforate band is developed. However, in *G. scitula* the imperforate band surrounds the periphery (Pl. 1, Fig. 1b) while in *G. praescitula* it occurs adjacent to the periphery on the umbilical side (Bizon and Glaçon, 1978, pl. 1, fig. 1).

PLATE 1

- 1a–c *Globorotalia scitula* (Brady). FC 24. Late Pliocene. a. Spiral view. b. Profile. Arrow points to partially imperforate band surrounding peripheral margin. c. Umbilical view. $\times 109$. USNM 282803.
- 2a–d *Globorotalia menardii* (Parker, Jones and Brady). Dr 10-P2. Late Miocene. 2a. Umbilical view. Arrow points to imperforate band. 2b. Profile. 2c. Spiral view. 2d. Part of (N-2) chamber enlarged to show imperforate band (ib). 2a–c. $\times 80$. 2d. $\times 133$. USNM 282804.
- 3, 5 *Globorotalia menardii* (Parker, Jones and Brady). FC 26. Early Pliocene. 3. 3a. Umbilical view. Arrow points to mar-

- gin of keel showing absence of imperforate band. 3b. Profile view. 3c. Spiral view. $\times 77$. 5. 5a. Profile. 5b. Spiral view. 5c. Umbilical view. $\times 99$. USNM 282805, 282806.
- 4a–c *Globorotalia plesiotumida* Banner and Blow. Dr 10-P2. Late Miocene. 4a. Umbilical view. Arrow points to partially imperforate band. 4b. Profile. 4c. Spiral view. $\times 100$. USNM 282807.
- 6a–c *Globorotalia merotumida* Banner and Blow. Dr 10-P2. Late Miocene. 6a. Profile. 6b. Umbilical view. Arrow points to partially imperforate band. 6c. Spiral view. $\times 115$. USNM 282808.





***Globorotalia menardii* (Parker,
Jones and Brady, 1865)
ex d'Orbigny
Pl. 1, Figs. 2a-d, 3a-c, 5a-c**

Rotalia (Rotalie) menardii D'ORBIGNY, 1826, p. 273 (*nomen nudum*).

Rotalia menardii PARKER, JONES and BRADY, 1865, p. 20, pl. 3, fig. 81 (part).

Globorotalia menardii (Parker, Jones and Brady). STAINFORTH and others, 1975, p. 371, figs. 178, 179.

We support the proposal of Stainforth and others (1975) to retain *Globorotalia menardii* as the name "for the Miocene (and younger) menardiform species commonly recorded under this name in the Mediterranean area." This species is distinguished from the modern menardiform *G. cultrata* by its more tightly coiled chambers, thicker profile and less lobulate outline, particularly in the first chambers of the peripheral whorl. *Globorotalia cultrata* appears to be a species of quite recent origin, probably no older than Pleistocene.

Globorotalia menardii was recorded from sediments of both late Miocene and early Pliocene age at the present site. Specimens compare very well with *Globorotalia* form 5 of Tjalsma (1971) from the late Miocene of Guadalquivir Basin, Spain. At the present site the Pliocene specimens are slightly more lobulate and loosely coiled, but difficult to distinguish from the Miocene form. However, the Pliocene form lacks the imperforate band, which is clearly seen in the Miocene form. Possibly a taxonomic distinction should be made on this basis, but additional material needs to be examined.

***Globorotalia plesiotumida* Banner and Blow
Pl. 1, Fig. 4a-c**

Globorotalia tumida plesiotumida BLOW AND BANNER in Banner and Blow, 1965, p. 1,353, fig. 2a-c.

Some individuals from Dr 10-P2 appear referable to this species. The ovate outline, with somewhat elongated final chambers is in close agreement with the

holotype. In the present specimens, however, the umbilicus is slightly more open than in the holotype. An imperforate band is visible, but weakly developed on the keel margin of the umbilical side of the final chambers.

***Globorotalia merotumida* Blow and Banner
Pl. 1, Fig. 6a-c**

Globorotalia merotumida BLOW AND BANNER in Banner and Blow, 1965, p. 1,352, fig. 1a-c.

This species closely resembles the young stages of *Globorotalia menardii*, and distinction is sometimes difficult. However, some of our specimens appear identical with the holotype of *G. merotumida* and we assign them to that species. The imperforate band along the keel margin is sharply defined, but intermittent in occurrence on the final chambers.

***Globorotalia pertenuis* Beard
Pl. 2, Fig. 1a-c**

Globorotalia pertenuis BEARD, 1969, p. 552-553, pl. 1, figs. 1-6; pl. 2, figs. 5-6.

Like *Globorotalia exilis* Blow and *G. multicamerata* Cushman and Jarvis, this species is characterized by having more than five chambers in the peripheral whorl. However, it can be distinguished from the latter two species by its flaring apertural lip which extends into the umbilical area (Pl. 2, Fig. 2a-c). It also has a thinner test and more lobate keel.

***Globorotalia pertenuis-exilis*
intermediate form
Pl. 2, Fig. 2a-c**

Some individuals closely resemble *Globorotalia pertenuis* and have a projecting lip on the final chamber, but this lip does not quite extend to the umbilical area. Also, limbate portion of septal sutures on the spiral side is concealed by overlap of succeeding chambers in the final portion of the test. This feature

←

PLATE 2

1a-c *Globorotalia pertenuis* Beard. FC 24. Late Pliocene. 1a. Spiral view. 1b. Profile. 1c. Umbilical view. ×70. USNM 282809.

2a-c *Globorotalia pertenuis-exilis* intermediate. FC 24. Late Pliocene. 2a. Spiral view. 2b. Umbilical view. 2c. Profile. 2a-b. ×77. 2c. ×93. USNM 282810.

3a-c *Globorotalia miocenica* Palmer. FC 24. Late Pliocene. 3a.

Spiral view. 3b. Profile. 3c. Umbilical view. ×93. USNM 282811.

4a-c *Globorotalia multicamerata* Cushman and Jarvis. Dr 10-P1. Early Pliocene. 4a. Umbilical view. 4b. Spiral view. 4c. Profile. ×80. USNM 282812.

5a-c *Globorotalia praemiocenica* Lamb and Beard. Dr 10-P1. Early Pliocene. 5a. Spiral view. 5b. Umbilical view. 5c. Profile. ×90. USNM 282813.

characterizes *G. exilis* (Stainforth and others, 1975, p. 349).

***Globorotalia multicamerata* Cushman
and Jarvis
Pl. 2, Fig. 4a–c**

Globorotalia multicamerata CUSHMAN AND JARVIS, 1930, p. 367, pl. 34, fig. 8.

Specimens show some signs of dissolution but are distinguishable from *G. pertenuis* by their thicker, more compact test and more robust keel which is rounded in early part of peripheral whorl.

***Gloroborotalia praemiocenica* Lamb and Beard
Pl. 2, Fig. 5a–c**

Gloroborotalia praemiocenica LAMB AND BEARD, 1972, p. 55, pl. 17, figs. 1–3, 6.

Specimens mostly lack the final chamber, but they all have a conical spiral face, strong limbation of the spiral suture and they closely resemble the holotype of *Globorotalia praemiocenica*.

***Globorotalia miocenica* Palmer
Pl. 2, Fig. 3a–c**

Globorotalia miocenica PALMER, 1945, p. 70, pl. 1, fig. 10.

The present specimens have a distinct open umbilicus, but otherwise agree well with the holotype figure. The present individuals appear especially close to specimens of *G. miocenica* figured by Lamb and Beard (1972, pl. 16, fig. 1–4). Those specimens also show an open umbilicus.

***Globorotalia crassaformis*
(Galloway and Wissler)
sensu lato
Pl. 3, Figs. 1–4**

Globigerina crassaformis GALLOWAY AND WISSLER, 1927, p. 41, pl. 7, fig. 12.

The crassaform group is highly variable, but is not nearly as easy to divide taxonomically as the menardiforms. All crassaforms are characterized by a quadrate arrangement of quasi-scituline shaped chambers throughout all or most of the test; that is, there are four chambers per whorl and the chambers are symmetrically shaped, with no tendency towards allometry. Only in the final one or two chambers is there a deviation from this pattern. Final chambers may become kummerform, lobulate or even somewhat enlarged. The change in shape of the last chamber often gives a different appearance to the whole test. For example, the specimens shown in Pl. 3, Figs. 1a–c and 2a–c compare favorably with *Globorotalia crassaformis hessi* Bolli and Premoli Silva (1973, p. 476). However, if these specimens are viewed without the final chamber, they are inseparable from the specimen figured in Pl. 3, Fig. 3a–c which compares favorably with *Globorotalia crassacrotonensis* Conato and Follador (1967, p. 36–37, figs. 3, 4). Also, the specimen shown in Pl. 3, Fig. 4a–c has five chambers in the peripheral whorl and compares favorably with *Globorotalia crassaformis ronda* Blow (1969, p. 388, fig. 4–6; pl. 37, fig. 6–9). However, if the final chamber is removed, the specimen becomes inseparable from the *Globorotalia crassacrotonensis* type shown in Pl. 3, Fig. 3a–c.

***Globorotalia crotonensis*
Conato and Follador
Pl. 3, Fig. 5a–c**

Globorotalia crotonensis CONATO AND FOLLADOR, 1967, p. 556, fig. 1; figs. n-1, 2.

In the material studied most of the crassaforms are thick walled and encrusted to some degree. The thin-walled crassaforms tend to be rather small and less umbilically conical than the thickened forms. The thin-walled form shown in Pl. 3, Fig. 5a–c, compares favorably with the figure of the holotype of *Globorotalia crotonensis*. Like the holotype, this form is slightly

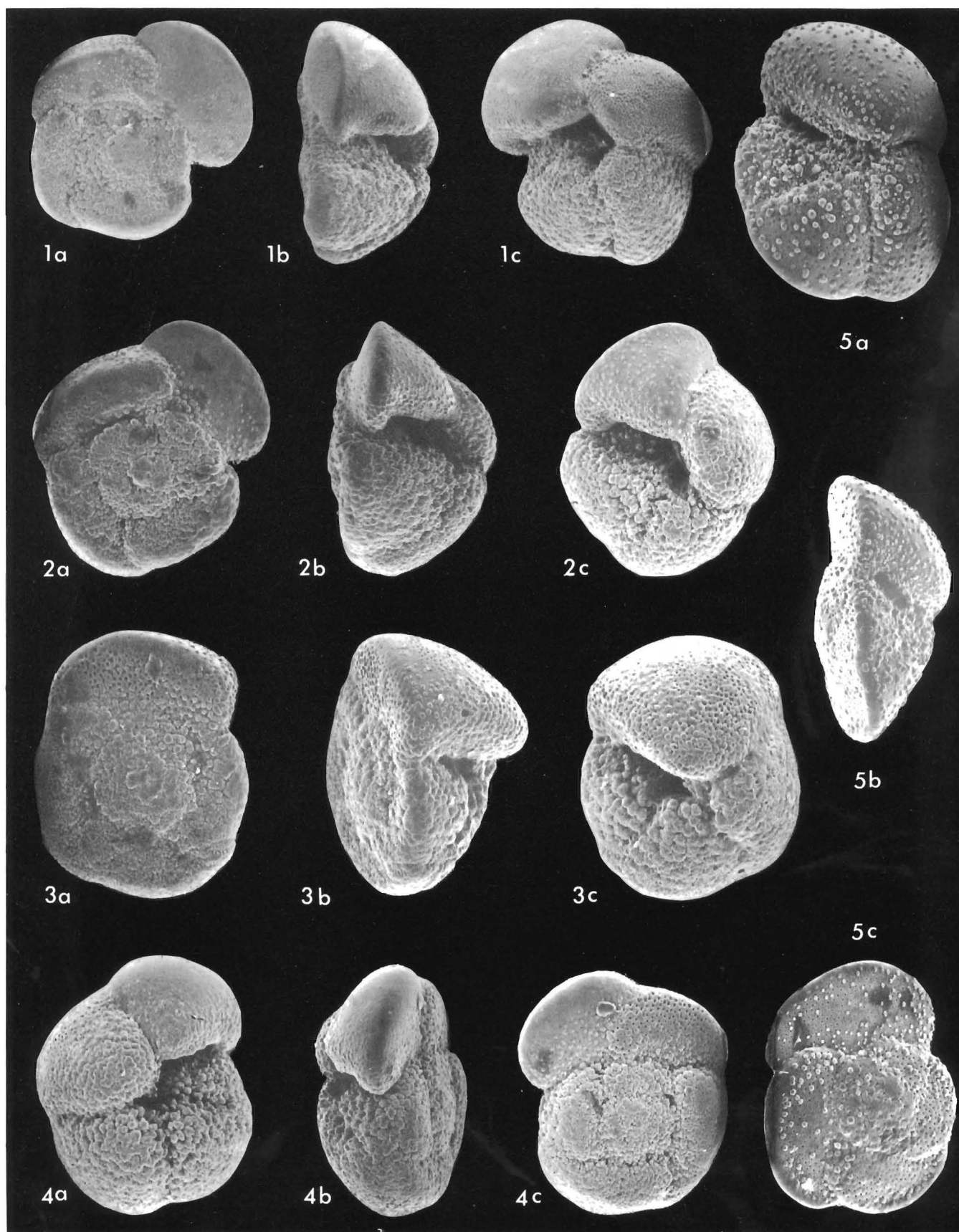
PLATE 3

- 1a–c *Globorotalia crassaformis* Galloway and Wissler *sensu lato*. FC 24. Late Pliocene. 1a. Spiral view. 1b. Profile. 1c. Umbilical view. $\times 67$. This specimen resembles but is not identical with *Globorotalia crassaformis hessi* Bolli and Premoli Silva. USNM 282814.
- 2a–c *Globorotalia crassaformis* Galloway and Wissler *sensu lato*. FC. 24. Late Pliocene. 2a. Spiral view. 2b. Profile. 2c. Umbilical view. $\times 100$. This specimen resembles but is not identical with *Globorotalia crassaformis hessi* Billi and Premoli Silva. USNM 282815.
- 3a–c *Globorotalia crassaformis* Galloway and Wissler *sensu lato*. FC 24. Late Pliocene. 3a. Spiral view. 3b. Profile. 3c. Um-

bilical view. $\times 107$. This specimen compares well with *Globorotalia crassacrotonensis* Conato and Follador. USNM 282816.

- 4a–c *Globorotalia crassaformis* Galloway and Wissler *sensu lato*. FC 24. Late Pliocene. 4a. Umbilical view. 4b. Profile. 4c. Spiral view. $\times 100$. This specimen resembles but is not identical with *Globorotalia crassaformis ronda* Blow. USNM 282817.

- 5a–c *Globorotalia crotonensis* Conato and Follador. FC 24. Late Pliocene. 5a. Umbilical view. 5b. Profile. 5c. Spiral view. $\times 134$. USNM 282818.



biconvex. However, the relationships of *Globorotalia crotonensis* are not clear. This species occurs commonly in association with *Globorotalia crassaformis* and may represent an uncrusted form of that species. Both Stainforth and others (1975) and Barbieri (1971) consider *G. crotonensis* and *G. aemiliana* to be synonyms.

ACKNOWLEDGMENTS

Reference samples from the Deep Sea Drilling Project were provided by the National Science Foundation. We are grateful to C. W. Poag for allowing us to examine his material from DSDP Leg 11. The SEM photographs were prepared by W. Brown, M. J. Mann and S. Braden, SEM laboratory, Smithsonian Institution. We are especially indebted to M. Lee for her continued help and friendly discussions during preparation of the manuscript.

REFERENCES

- BANNER, F. T., and BLOW, W. H., 1960, Some primary types of species belonging to the Superfamily Globigerinaceae: Contributions from the Cushman Foundation for Foraminiferal Research, v. 11, no. 1, p. 1-41.
- , and ———, 1965, Two new taxa of the Globorotaliinae (Globigerinaceae, Foraminifera) assisting determination of the late Miocene/middle Miocene boundary: *Nature*, v. 207, p. 1,351-1,354.
- BARBIERI, F., 1971, Comments on some Pliocene stages and on the taxonomy of a few species of *Globorotalia*: *L'Ateneo Parmense*, *Acta Naturalia*, v. 7, fasc. 1, p. 1-24.
- BEARD, J. H., 1969, Pleistocene paleotemperature record based on planktonic foraminifers, Gulf of Mexico: *Gulf Coast Association of Geologic Societies, Transactions*, v. 19, p. 535-553.
- BECKMANN, J. P., 1972, The foraminifera and some associated microfossils of Sites 135-144: Initial Reports of the Deep Sea Drilling Project, v. 14, p. 389-420.
- BERGGREN, W. A., 1968, Micropaleontology and the Pliocene/Pleistocene boundary in a deep sea core from the South-Central-North Atlantic: *Giornale Geologia*, XXV, fasc. II, p. 291-312.
- , 1972, Cenozoic biostratigraphy and paleobiogeography of the North Atlantic: leg 12, DSDP: Initial Reports of the Deep Sea Drilling Project, v. 12, p. 965-1,001.
- BIZON, G., and GLAÇON, G., 1978, Morphological investigations on the genus *Globorotalia* from Site 372: Initial Reports of the Deep Sea Drilling Project, v. 42, pt. 1, p. 687-707.
- BLOW, W. H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy: Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967, v. 1, p. 199-422.
- BOLLI, H. M., and PREMOLI SILVA, I., 1973, Oligocene to Recent planktonic foraminifera and stratigraphy of Leg 15 sites in the Caribbean Sea: Initial Reports of the Deep Sea Drilling Project, v. 15, p. 475-498.
- BRADY, H. B., 1882, Report on the Foraminifera, in Tizard and Murray, Exploration of the Faroe Channel, during the summer of 1880, in H.M.S. "Knight Errant," with subsidiary reports: Proceedings of the Royal Society of Edinburgh, v. 11 (1880-1882), no. 111, p. 708-717.
- CIFELLI, R., 1970, Age relationships of Mid-Atlantic Ridge Sediments in Radiometric dating and paleontologic zonation: Geological Society of America, Special Paper 124, p. 47-69.
- , 1973, Observation on *Globigerina pachyderma* (Ehrenberg) and *Globigerina incompta* Cifelli from the North Atlantic: *Journal of Foraminiferal Research*, v. 3, no. 4, p. 157-166.
- , 1974, Planktonic foraminifera from the Mediterranean and adjacent Atlantic waters (cruise 49 of the Atlantis II, 1969): *Journal of Foraminiferal Research*, v. 4, no. 4, p. 171-183.
- , 1976, Evolution of ocean climate and planktonic foraminifera: *Nature*, v. 264, no. 5,585, p. 431-432.
- , (in press), The role of circulation in the parcelling and dispersal of North Atlantic planktonic foraminifera, in Gray, J., and Boucot, A. J., eds., *Historical Biogeography, Plate Tectonics and the Changing Environment*: Corvallis, Oregon State University Press.
- CIFELLI, R., and BENIÉR, C. S., 1976, Planktonic foraminifera from near the West African coast and a consideration of faunal parcelling in the North Atlantic: *Journal of Foraminiferal Research*, v. 6, no. 4, p. 258-273.
- , BOWEN, V. T., and SIEVER, R., 1966, Cemented foraminiferal oozes from the Mid-Atlantic Ridge: *Nature*, v. 209, no. 5,018, p. 32-34.
- , and GLAÇON, G., 1978, Récapitulation ontogénétique des caractères ancestraux chez *Globorotalia* (Foraminifère): *Académie des Sciences, Paris, Comptes Rendus*, v. 277, série D, t. 286, p. 286-1,667.
- , and SMITH, R. K., 1974, Distributional patterns of planktonic foraminifera in the Western North Atlantic: *Journal of Foraminiferal Research*, v. 4, no. 3, p. 112-125.
- CITA, M. B., 1973, Sites 122, 124, leg 13, DSDP: Initial Reports of the Deep Sea Drilling Project, v. 13, p. 91-105, 133-174.
- CONATO, V., and FOLLADOR, U., 1967, *Globorotalia crotonensis* e *Globorotalia crassaformis*, nuove specie del Pliocene Italiano: *Società Geologica Italiana, Bolletino*, Roma, v. 86, p. 555-563.
- CUSHMAN, J. A., and JARVIS, P. W., 1930, Miocene Foraminifera from Buff Bay, Jamaica: *Journal of Paleontology*, v. 4, p. 353-368.
- D'ONOFRIO, S., GIANNELLI, L., and others, 1975, Planktonic foraminifera of the Upper Miocene from some Italian sections and the problem of the lower boundary of the Messinian: *Società Paleontologica Italiana, Bolletino*, v. 14, n. 2, p. 177-196.
- GALLOWAY, J. J., and WISSLER, S. G., 1927, Pleistocene Foraminifera from the Lomita Quarry, Palos Verdes Hills, California: *Journal of Paleontology*, v. 1, p. 35-87.
- GLAÇON, G., and REHAULT, G. P., 1973, Le Messinien marin de la pente continentale ligure (-1750 m) (Italie): *Académie des Sciences, Paris, Comptes Rendus*, t. 277, série D, p. 625-628.
- , VERGNAUD-GRAZZINI, C., LECLAIRE, L., and SIGAL, L., 1973, Présence des Foraminifères: *Globorotalia crassaformis* Cushman and Stewart et *Globorotalia hirsuta* (d'Orbigny) en Mer Méditerranée: *Revista Española de Micropaleontología*, v. 5, no. 3, p. 373-401.
- IACCARINO, S., and SALVATORINI, G., (in press), Planktonic foraminiferal biostratigraphy of Neogene and Quaternary of Site 398 of leg 41B DSDP: Initial Reports of the Deep Sea Drilling Project.
- KIPP, N. G., 1976, New transfer functions for estimating past sea-

- surface conditions from sea-bed distribution of planktonic foraminiferal assemblages in the North Atlantic: Geological Society of America Memoir 145, p. 3-41.
- LAMB, J. L., and BEARD, J. H., 1972, Late Neogene planktonic foraminifers in the Caribbean, Gulf of Mexico, and Italian stratotypes: University of Kansas Paleontological Contributions, Art. 57 (Protozoa 8), 67 p., 25 fig.
- MAZZOLA, G., 1971, Les foraminifères planctoniques de Mio-Pliocène de l'Algérie nord-occidentale: Proceedings of the II Planktonic Conference, Rome, 1970, Edizione Technoscienza, p. 787-812.
- ORBIGNY, A. D', 1826, Tableau méthodique de la classe des Céphalopodes: *Annals des Sciences Naturelles*, sér. 1, t. 7, p. 96-314.
- PALMER, D. K., 1945, Notes on the Foraminifera from Bowden, Jamaica: *Bulletins of American Paleontology*, v. 29, no. 115, p. 5-82.
- PARKER, J. L., 1973, Late Cenozoic biostratigraphy (planktonic foraminifera) of tropical Atlantic deep-sea sections: *Revista Española de Micropaleontología*, v. 5, no. 2, p. 253-289.
- PARKER, W. K., JONES, T. R., and BRADY, H. B., 1865, On the nomenclature of the Foraminifera; pt. 10 (cont.). The species enumerated by d'Orbigny in the "Annales des Sciences Naturelles": *Annals and Magazine of Natural History*, ser. 3, v. 16, no. 91, p. 15-41, pl. 1-3.
- PHLEGER, F. B., PARKER, F. L., and PIERSON, J. F., 1953, North Atlantic Foraminifera: Swedish Deep-Sea Expedition Reports, v. 7, no. 1, p. 3-122.
- POAG, C. W., 1972, Neogene planktonic foraminiferal biostratigraphy of the Western North-Atlantic: leg 11, DSDP: Initial Reports of the Deep Sea Drilling Project, v. 11, p. 483-543.
- POORE, R. Z., and BERGGREN, W. A., 1974, Pliocene biostratigraphy of the Labrador Sea: calcareous plankton: *Journal of Foraminiferal Research*, v. 4, no. 3, p. 91-108.
- , and ———, 1975, Late Cenozoic planktonic foraminiferal biostratigraphy and paleoclimatology of Hatton-Rockall Basin, DSDP Site 116: *Journal of Foraminiferal Research*, v. 5, no. 4, p. 270-293, pl. 1-5.
- SAITO, T., EWING, M., and BURCKLE, L. H., 1966, Tertiary sediment from the Mid-Atlantic Ridge: *Science*, v. 151, no. 3,714, p. 1,075-1,079.
- STAINFORTH, R. M., LAMB, J. L., and others, 1975, Cenozoic planktonic foraminiferal zonation and characteristics of index forms: University of Kansas Paleontological Contributions, Art. 62, p. 13-425.
- TCHERNIA, P., 1969, Cours d'Océanographie régionale. Océan Atlantique. Cours Polycopié: Service Hydrographique de la Marine, Paris.
- TJALSMA, R. C., 1971, Stratigraphy and Foraminifera of the Neogene of the Eastern Guadalquivir Basin (Southern Spain): *Utrecht Micropaleontological Bulletins*, no. 4, 161 p.
- VAN ANDEL, T. H., and BOWIN, C. D., 1968, The Mid-Atlantic Ridge between 22° and 23° north latitude and the tectonics of mid-ocean rises: *Journal of Geophysical Research*, v. 73, no. 4, p. 1,279-1,298.

Revised Ms accepted October 1978