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LATE NEOGENE PLANKTONIC FORAMINIFERS IN THE CARIBBEAN, GULF OF MEXICO, AND ITALIAN STRATOTYPES

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ABSTRACT

The late Miocene to early Pleistocene planktonic succession within standard European stages and reference sections in Italy is compared with that of the Caribbean and Gulf of Mexico to clarify stage and epoch boundaries in the latter regions. In ascending order, the stages comprise the Tortonian and Messinian (late Miocene), Tabianian and Plaisancian (early to late Pliocene), and Calabrian (early Pleistocene). Climatic criteria obtained by analysis of the planktonic fauna provide a basis for recognition of the Emilian and Sicilian stages in southern Italy. Correlation of epoch boundaries and other paleontological datums from the Italian to the Caribbean and Gulf of Mexico regions utilizes restricted occurrences of planktonic foraminiferal species common to both regions and also horizons of reference within species of the *Globorotalia crassaformis* evolutionary lineage.

Species important for this intercontinental correlation and dating include *Globorotalia acostaensis* and *Sphaeroidinellopsis sphaeroides* in late Miocene, *Globorotalia margaritae* in early Pliocene, species of the *Globorotalia crassaformis* lineage in middle and late Pliocene, and appearance of *Globorotalia truncatulinoides* and faunal evidence for onset of climatic deterioration in early Pleistocene. On the basis of these data and information obtained from many localities in the Caribbean and Gulf of Mexico, a sequence of regional planktonic zones and subzones is defined for the late Miocene to Holocene interval. These zones seemingly have broad application in warm and temperate regions from about 45° S. latitude to about 45° N. latitude.

Zonation of the late Neogene was accomplished by recording in detail the stratigraphic occurrence of approximately 40 species of planktonic foraminifers in the Caribbean and Gulf of Mexico. Photographs of these species, obtained using the Cambridge electron scanning microscope, clearly show the distinguishing features of the individual species. A brief synonymy and discussion are given for each species.

INTRODUCTION

During the past decade planktonic foraminifers have played an increasingly important role in both industry and the academic world for dating and correlating marine Cretaceous and Cenozoic strata. Virtually all Tertiary biostratigraphers now use these important marker fossils whenever possible as a basis for detailed time-stratigraphic zonation within local basins or for interregional correlations. Planktonic foraminifers are especially useful because their drifting mode of life leads to wide geographic distribution; on death they sink to the sea floor, and their presence in the sediments is little affected by varying facies that tend to cause marked lateral changes in benthonic microfaunas. Significantly, their rapid evolution makes these forms particularly useful to biostratigraphers.

Unfortunately, the voluminous literature, sometimes accompanied by inadequate illustrations, appearing in widely scattered journals both in Europe and in America over the years has led to diverse taxonomic concepts that have been particularly confusing to the nonspecialist. Nomenclatural problems have been compounded also because stratigraphic ranges of many species are poorly documented, particularly those described from only a few outcrop or well samples. Moreover, because many Tertiary type stages are represented by sections deposited in environments unfavorable for planktonic foraminifers, much confusion exists concerning correlation of the planktonic succession with the standard geologic time scale.

Recent activities of the Committee on Mediterranean Neogene Stratigraphy (CMNS) have promoted research on and documentation of planktonic foraminifers from deposits within the stratotypes of the Miocene, Pliocene, and Pleistocene stages in Italy. Hence, the reliability of extra-Mediterranean dating and correlation has improved to the point that the Neogene planktonic sequence in the Caribbean and Gulf of Mexico is related to European stage standards with a reasonable measure of confidence.

The availability of deep-sea core data has led now to a notably clearer concept of evolutionary taxonomic entities from which judicious selection of index guide species can be made. Moreover, recognition of more precise stratigraphic ranges of key species has emerged from this work because these sediments are significantly freer from effects of local environmental conditions.

In the present study the late Neogene planktonic biostratigraphy of the Caribbean and Gulf of Mexico is compared with that of the Mediterranean region to facilitate correlation of planktonic foraminiferal datums and epoch boundaries. Temperature fluctuations within the Pleistocene, and their concomitant glacioeustatic events, are suggested by marked recurring changes in the planktonic fauna. These data provide a basis for formulating a continuous succession of planktonic foraminiferal zones from late Miocene to Holocene having regional biostratigraphic significance for dating and correlation.

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PLANKTONIC SUCCESSION WITHIN STANDARD REFERENCE SECTIONS

ITALY

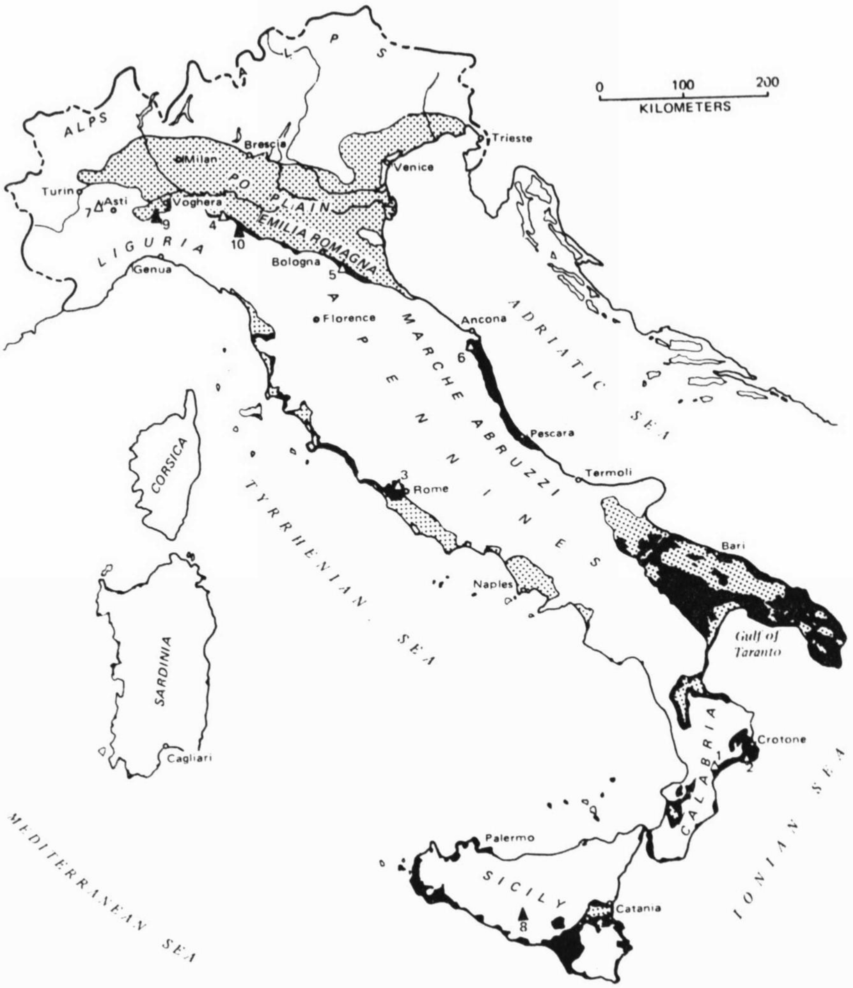
GENERAL

A brief account of some standard European marine stages (Fig. 1) is essential to understand the measure of accuracy that is implied with reference to stage and epoch boundaries in the Caribbean and Gulf of Mexico. Literature relating to the Italian late Neogene sedimentary succession is indeed voluminous and is treated in many languages. Because of its somewhat provincial character, the numerous discussions cannot be fully appreciated, however, by only casual acquaintance with some of the major works. To remedy this, the Committee on Mediterranean Neogene Stratigraphy (CMNS) at its fourth session in Bologna (1967) published, under the editorial guidance of RAIMONDO SELLI in collaboration with many recognized authorities, a multilanguage rendition in the excursion guidebooks (Nos. 1 and 2) of some historically important contributions to the understanding of type localities of the Italian Neogene succession. The full texts of the papers presented at the Bologna session are contained in volume 35 of the *Giornale di Geologia.* Of special interest is the proposal by BERTOLINO & OTHERS (1968) for a subdivision of the Italian Neogene based on planktonic foraminifers (Fig. 2).

A postsession discussion of the several Neogene planktonic zonal schemes proposed by different authors was organized by HANS BOLLI and others at Bologna University on May 15-17, 1968. A review of this meeting is given by CATI & OTHERS (1968); the stratigraphic position and correspondence of the late Miocene and Pliocene planktonic zones are shown on Figure 3. Type localities of Miocene, Pliocene, and Pleistocene stages cited in the following discussion are shown on Figure 1.

TORTONIAN STAGE (LATE MIOCENE)

The Tortonian Stage was erected by MAYER-EYMAR in 1858. The section exposed along the Castellania and Mazzapiedi Rivers, chosen as the stratotype by GIANOTTI (1953), is about 260 meters thick and extends from the Serravalian ("Helvetian" of authors) at the bottom to the Messinian at the top. Planktonic foraminifers are abundant and display a characteristic distribution. CITA, PREMOLI-SILVA, & ROSSI (1965) recognized in the type

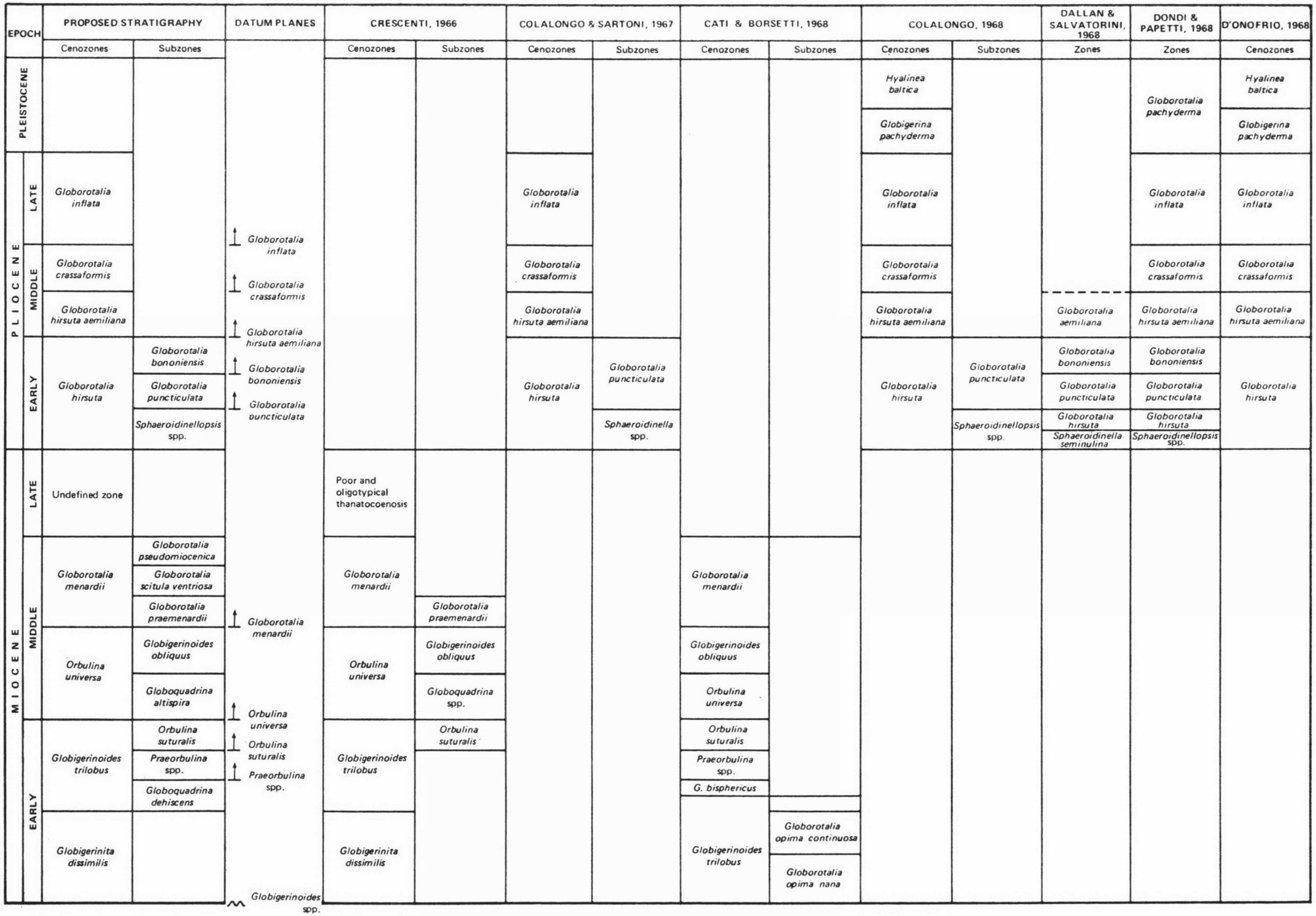


AFTER SELLI (1967)

FIG. 1. Distribution of marine Pleistocene in Italy, outcropping (black) and covered with more recent continental terrains (dotted). White triangles show localities of important sections for the Pliocene-Pleistocene boundary. Black triangles show important Miocene and Pliocene localities: 1-Santa Maria di Catanzaro ("type" Calabrian); 2-Le Castella ("type" Calabrian); 3-Monte Mario; 4-Castell 'Arquato-Vernasca (type Plaisancian); 5-Santerno; 6-Musone; 7-Villafranca d'Asti (type Villafranchian); 8-Pasquasia-Capodarso (type Messinian); 9-Rio Massapiedi-Castellania (type Tortonian); and 10-Tabiano (type Tabianian).

Tortonian the "*Globorotalia mayeri*"/*G. lenguaensis* Zone (corresponding to the lower part of the section for about 30 meters), the "*Globorotalia mayeri*"/*Globigerina nepenthes* Zone (lower-middle part), and the *Globorotalia menardii*/*Globigerina nepenthes* Zone which they extend up to the base of an interval they consider as Messinian. This planktonic zonation seemingly follows closely that which BLOW (1959) applied in zoning the planktonic sequence within the upper part of the Pozón Formation of Falcon, Venezuela, and which compares in part with, and extends upward, the Trinidad zonation of BOLLI (1957).

Additional samples were collected from the same section along the Castellania and Mazzapiedi Rivers by DERYCK D. BAYLISS and studied by CITA & BLOW (1969). They maintained that the *Globorotalia siakensis* Zone (=*Globorotalia mayeri* Zone of CITA, PREMOLI-SILVA, & ROSSI, 1965) is not represented in the section studied and that the lower 35 meters (approximately) of the stratotype Tortonian are referable to the *Globorotalia (T.) continuosa* Zone (=Zone N. 15) of BLOW (1969) and to the *Globorotalia menardii* Zone *sensu* BOLLI (1957), emend. BOLLI (1966) . They continue by saying that the *Globorotalia acostaensis* datum (earliest appearance of the species) is about 35 meters above the base of the section. Accordingly, they say that the base of the section falls within the upper limits of the *Globorotalia menardii* Zone and the upper part within the *Globorotalia acos-*



EPOCH		PROPOSED STRATIGRAPHY Cenozones	PROPOSED STRATIGRAPHY Subzones	DATUM PLANES	CRESCENTI, 1966 Cenozones	CRESCENTI, 1966 Subzones	COLALONGO & SARTONI, 1967 Cenozones	COLALONGO & SARTONI, 1967 Subzones	CATI & BORSETTI, 1968 Cenozones	CATI & BORSETTI, 1968 Subzones	COLALONGO, 1968 Cenozones	COLALONGO, 1968 Subzones	DALLAN & SALVATORINI, 1968 Zones	DONDI & PAPETTI, 1968 Zones	D'ONOFRIO, 1968 Cenozones
PLEISTOCENE											*Hyalinea baltica*			*Globorotalia pachyderma*	*Hyalinea baltica*
											Globigerina pachyderma				*Globigerina pachyderma*
PLIOCENE	LATE	*Globorotalia inflata*		*Globorotalia inflata*			*Globorotalia inflata*				*Globorotalia inflata*			*Globorotalia inflata*	*Globorotalia inflata*
	MIDDLE	*Globorotalia crassaformis*		*Globorotalia crassaformis*			*Globorotalia crassaformis*				*Globorotalia crassaformis*			*Globorotalia crassaformis*	*Globorotalia crassaformis*
		Globorotalia hirsuta aemiliana		*Globorotalia hirsuta aemiliana*			*Globorotalia hirsuta aemiliana*				*Globorotalia hirsuta aemiliana*		*Globorotalia aemiliana*	*Globorotalia hirsuta aemiliana*	*Globorotalia hirsuta aemiliana*
	EARLY	*Globorotalia hirsuta*	*Globorotalia bononiensis*	*Globorotalia bononiensis*			*Globorotalia hirsuta*	*Globorotalia puncticulata*			*Globorotalia hirsuta*	*Globorotalia puncticulata*	*Globorotalia bononiensis*	*Globorotalia bononiensis*	*Globorotalia hirsuta*
			Globorotalia puncticulata	*Globorotalia puncticulata*									*Globorotalia puncticulata*	*Globorotalia puncticulata*	
			Sphaeroidinellopsis spp.					*Sphaeroidinella* spp.				*Sphaeroidinellopsis* spp.	*Globorotalia hirsuta* *Sphaeroidinella seminulina*	*Globorotalia hirsuta* *Sphaeroidinellopsis* spp.	
MIOCENE	LATE	Undefined zone			Poor and oligotypical thanatocoenosis										
	MIDDLE	*Globorotalia menardii*	*Globorotalia pseudomiocenica*		*Globorotalia menardii*				*Globorotalia menardii*						
			Globorotalia scitula ventriosa												
			Globorotalia praemenardii	*Globorotalia menardii*		*Globorotalia praemenardii*									
		Orbulina universa	*Globigerinoides obliquus*		*Orbulina universa*	*Globigerinoides obliquus*			*Globigerinoides obliquus*						
			Globoquadrina altispira	*Orbulina universa*		*Globoquadrina* spp.			*Orbulina universa*						
	EARLY	*Globigerinoides trilobus*	*Orbulina suturalis*	*Orbulina suturalis*	*Globigerinoides trilobus*	*Orbulina suturalis*			*Orbulina suturalis*						
			Praeorbulina spp.	*Praeorbulina* spp.					*Praeorbulina* spp.						
			Globoquadrina dehiscens						*G. bisphericus*						
		Globigerinita dissimilis			*Globigerinita dissimilis*				*Globigerinoides trilobus*	*Globorotalia opima continuosa*					
				Globigerinoides spp.						*Globorotalia opima nana*					

Fig. 2. Zonal scheme for the Miocene and Pliocene of the Mediterranean area based on planktonic foraminifers (after Bertolino & others, 1968).

taensis, Globigerina dutertrei, and *Globorotalia margaritae* zones of Bolli (1966), which equate with Blow's zones N. 16 and N. 17 (in part).

If the base of the Pliocene is to be designated by the Tabianian Stage, Cita & Blow (1969) saw no need for a concept of a Messinian Stage which, according to them, is partly coeval with the Tortonian Stage. The following discussion of the Messinian Stage should convincingly show that Messinian deposits are mostly younger than those of the Tortonian and that it is highly unlikely that Tortonian and/or Messinian strata fall within the limits of the Tabianian Stage (*Globorotalia margaritae* Zone).

The base of the Tortonian Stage is, then, no older than late *Globorotalia menardii* Zone (late Zone N. 15), while the upper limit falls within the range-zone of *Globorotalia acostaensis*. It seems acceptable to follow the decision of Cita & Blow (1969) to place the Tortonian in the terminal Miocene (with the Messinian) rather than in the middle Miocene as has been the customary practice, but it should not be construed that it is the time equivalent of the Messinian.

For purposes of regional and intercontinental faunal correlation it would be desirable to designate arbitrarily the base of the range-zone of *Globorotalia acostaensis* as the base of the Tortonian Stage and the onset of the late Miocene. The first appearance of *G. acostaensis* is proving to be an excellent datum for worldwide correlation.

MESSINIAN STAGE (LATE MIOCENE)

The Messinian Stage was proposed by Mayer-Eymar (1868) to include a succession of strata near Messina in northern Sicily. Because of poor exposures and stratigraphical difficulties within this sequence, Selli (1960) designated the Pasquasia-Capodarso section in central Sicily as a neostratotype for this stage. These exposures occur between the towns of Caltanisetta and Enna. Although evaporite deposits commonly enhance recognition of the Messinian throughout Italy, the foraminiferal faunas described by d'Onofrio (1964) do not lend themselves directly to extra-Mediterranean correlation. Sulphur, gypsum, and salt are common constituents of Messinian strata in Italy and are often the sole criteria used to recognize the stage. The planktonic fauna of the early Messinian becomes impoverished upward as the evaporites are approached.

Approximately 170 meters of mostly poorly fossiliferous strata occur at the type section. An uppermost 10 meters of shale, however, are moderately rich in planktonic species and represent a deep-water environment. Samples from this interval, collected by geologists of the Esso Production Research Company, contain *Sphaeroidinellopsis sphaeroides* (=*S. seminulina* of authors) and *Globorotalia acostaensis*. In the area to the east of the type locality, between the town of Rossano and the Trionto River, widely exposed Messinian strata

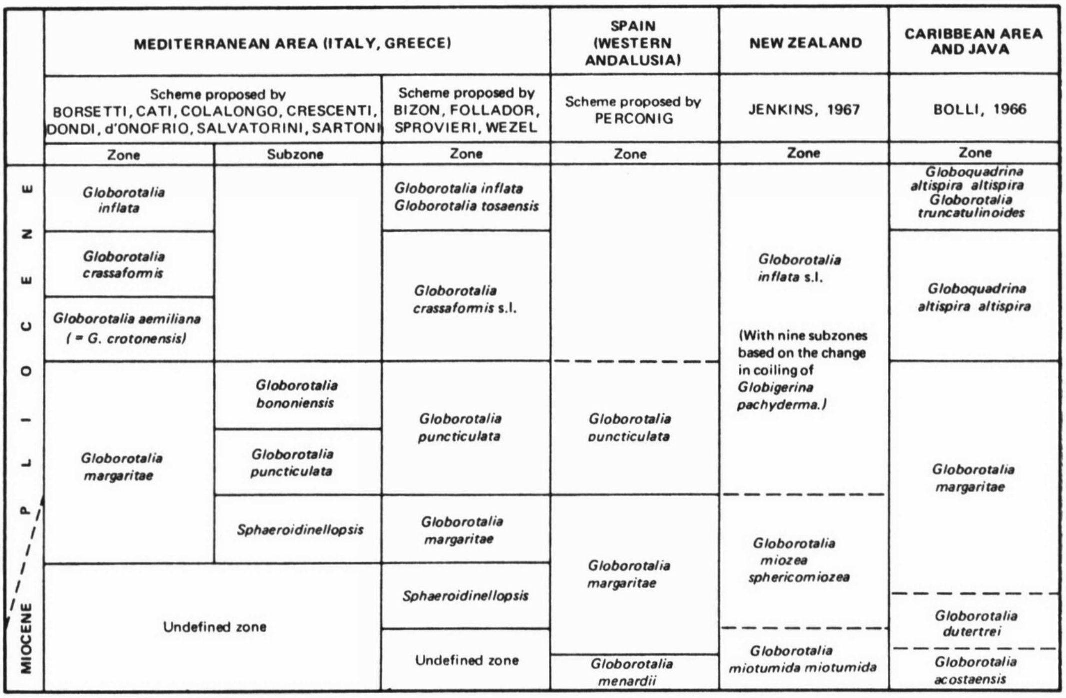


Fig. 3. Zonal scheme for the Pliocene of the Mediterranean area based on planktonic foraminifers (after Cati & others, 1968).

are overlain unconformably by Calabrian beds. From the upper portion of these Messinian strata (i.e., within the Gessi Formation) Ogniben (1962) identified a planktonic foraminiferal facies containing *Globigerinoides conglobatus, Hastigerina aequilateralis,* and *Orbulina universa.* These species are useful in correlating with the Caribbean and Gulf of Mexico, where they also occur. Italian authors define the upper limit of the Messinian as corresponding closely with the base of the *Globorotalia margaritae* (=*G. hirsuta* of authors) Zone (early Pliocene) in both southern and northern Italy.

A surprising recent find of the Deep Sea Drilling Project's (JOIDES) first Mediterranean expedition, based on 2,200 feet of sedimentary cores taken by the drilling ship *Glomar Challenger,* was that the Mediterranean Sea has filled and dried many times between 7 million and 5 million years ago or during the late Miocene (Messinian Stage). In other words, the evaporites that represent most of the land-based late Miocene sections around the Mediterranean also compose equivalent sections in deep Mediterranean basins. William B. F. Ryan, a supervising scientist for the expedition, speculated that the Straits of Gibraltar could have acted as a valve. "Over a period of 2 million years the straits might have become alternately shallow and deep-shallow by means of large tectonic upthrustings of the earth's crust there, and deep through water erosion of the newly raised rock. When the straits were shallow, the high evaporation from the Mediterranean might have exceeded the inflow from the Atlantic and the sea would have dried. Even today, if water were not pouring in from river and sea, the level of the Mediterranean would drop by 1 yard a year."

An alternative to this thesis is a worldwide lowering of sea level during the Messinian caused by mid-oceanic ridge depression or other unknown factors. Eustatics of such magnitude seemingly would influence sedimentation on a wide scale as is indicated in the Caribbean and Gulf of Mexico by interruption of late Miocene sedimentation except in deep basinal positions.

Thus, a major disruption of marine sedimentation within the Messinian in the Mediterranean has caused considerable controversy in arriving at a faunal definition for the late Miocene. Verdenius (1970), for example, goes so far as to say that this event ought to be expressed in Mediterranean biostratigraphy as a hiatus.

In searching for an alternate type locality exhibiting continuous deposition through the late Miocene Perconig (1968) proposed the Andulusian Stage from the Carmona region in southern Spain within the Guadalquivir basin. As he records planktonic species from this section that are Pliocene zonal markers in Italy, doubt has been expressed as to the Miocene age of the type Andulusian on the basis of the listed planktonic foraminifers.

Verdenius (1970) discussed the stratigraphy of the central portion of the Guadalquivir basin including that of the Carmona region which contains the stratotype of the Andalusian Stage. He strongly objected to the proposal to substitute the Andalusian for the Messinian and stated "The existence of a correlation of the strata below the Andalusian stratotype to the Tortonian stratotype and of those over the Andalusian stratotype to the 'Lower Pliocene'—thereby placing the Andalusian Stage in the supposed or real interval between the Tortonian and 'Lower Pliocene'—cannot be proved." He concluded that the Andalusian Stage is homotaxial with the Tabianian and Plaisancian Stages of Italy.

Similar conclusions were reached by Meulenkamp (1969) in his study of evolutionary lineages of the *Uvigerina melitensis* and *U. cretensis* groups from the Isle of Crete and various other localities around the Mediterranean. His data suggest tentatively that the Tortonian stratotype is in part coeval with the Messinian, and that the Andalusian stratotype contains uvigerinid species having close affinities with the Tabianian and Plaisancian stratotypes. He believes also that correlation of the marine formations of the Rethymnon region with the Tortonian, Tabianian, and Plaisancian stratotypes makes it likely that marine sedimentation started in the early-middle Tortonian and persisted without interruption into the Pliocene. This conveys the implication that the eastern Mediterranean had a somewhat different depositional history during the late Miocene than did the western Mediterranean.

Felix Gradstein (personal letter) concurs that the *"crise de salinité"* caused a complete revolution in the marine Mediterranean fauna in that typical late Miocene and Pliocene faunas can be distinguished. In his opinion, based on experience in Crete, the *crise* reflects a tectonic phase with shifting basin configurations and "locally" evaporite facies which corresponds to the time-span of the *Uvigerina lucasii* range zone.

The study by Diaz (1970) in the region of Murica, which lies to the east of the Guadalquivir basin, adds more controversy to the subject because he finds some merit in the proposals of Perconig (1968). In this region he found evidence for continuous deposition from the Tortonian to the very late Miocene and recorded a seemingly unbroken planktonic succession from the first appearance of *Globorotalia acostaensis* to the first appearance of *G. margaritae;* estimated thickness for this interval is on the order of 1,100 meters. About 800 meters of this interval he considered Tortonian and 300 meters Andalusian. The youngest horizons with *G. margaritae* he considered as Andalusian or late Miocene because the faunas have more affinity with the Miocene than with the lower Pliocene. He arbitrarily placed the Tortonian-Andalusian boundary below the first appearance of *Globigerinoides obliquus extremus* and *Orthomorphina tenuicostata* but admitted that the upper limit of the Tortonian is difficult to establish on faunal grounds.

Most would place the occurrence of *Globorotalia margaritae* exclusively in lower Pliocene, but this does not alter the fact that DIAZ described some 300 meters of section that seemingly qualify as post-Tortonian and pre-lower Pliocene or *Globorotalia margaritae* Zone.

More recently in a preliminary account of the eastern Guadalquivir basin, TJALSMA (1970) related that the eastern part of the basin rather abruptly emerged at the end of the Miocene and that in the western part of the basin (Carmona region) sedimentation lingered on but was of a more shallow character. In his section the sediments range in age from Aquitanian to upper Tortonian and possibly Messinian. Seemingly, the larger part of the section of Carmona does not have equivalents in time to the eastern part of the basin. Correlation of his section with that of DIAZ (1970) presently cannot be determined.

COLALONGO (1970) defends the status of the Messinian Stage in Italy by a restudy of planktonic foraminifers within the type section. She recognizes a sequence ranging from Tortonian to Pliocene and defines a *Globorotalia tumida plesiotumida* Zone, which is subdivided into two subzones, to encompass the Messinian. She does not offer a solution to the problem of correlating the Tortonian precisely with the Messinian, nor does she speculate on the nature of the depositional breaks within the Messinian. These issues are of current concern to stratigraphers attempting the problem of Messinian definition.

This brief summary describes some of the problems facing the Committee on Mediterranean Neogene Stratigraphy in defining a type section for a late Miocene stage in the western Mediterranean region. These are, basically:

1) Does the western Mediterranean region offer an uninterrupted depositional marine sequence from undisputed Tortonian to early Pliocene and, if not, where can a stratotype for the late Miocene be designated?
2) Should only evaporite deposits be included in a Messinian Stage?
3) Is the Messinian of sufficient time duration to be dignified as a stage, or should it be incorporated within an expanded Tortonian Stage as constituting the late Miocene?
4) Considering the above, what planktonic foraminiferal species, or zones, are best suited for defining the limits of the late Miocene?

TABIANIAN, PLAISANCIAN, AND ASTIAN STAGES (EARLY, MIDDLE, AND LATE PLIOCENE)

The Pliocene terrains exposed along the southern border of the Apennines, that is, around the towns of Tabiano, Vernasca, and Castell'Arquato, constitute the type Pliocene according to MAYER-EYMAR (1857, 1868). The Pliocene sequence in the vicinity of Vernasca and Castell'Arquato is about 950 meters thick (BARBIERI, 1967) and is represented by three stratigraphic units, which from bottom to top are as follows:

1) Vernasca Sandstone
    Sandstone and marl, light gray, with basal conglomerate.
    Thickness, about 85 meters.
    Tabianian (early Pliocene).
    Transgressive on a tectonically chaotic complex of Cretaceous to early Tertiary age.
2) Lugagnano Claystone
    Lower part: Marl and claystone, gray-blue.
        Thickness, 450 meters.
        Tabianian (early Pliocene).
    Upper part (Plaisancian stratotype): Marl and claystone, sandy, with some levels very rich in glauconite, gray-blue, very fossiliferous (pelecypods preponderant among mollusks).
        Thickness, 280 meters.
        Plaisancian (middle to late Pliocene).
3) Castell'Arquato Sandstone (Astian of authors)
    Sandstone, yellow ,with calcarenite and claystone locally; rare levels with scanty pebbles.
        Thickness, about 140 meters.
        Plaisancian (formerly Astian) (middle to late Pliocene).
        Apparently in conformable stratigraphic contact with the sandy-clayey Pleistocene (Calabrian).

BARBIERI (1967) proposed to eliminate the term "Astian" as a stage name, because of its lateral equivalent to parts of the Plaisancian and to subdivide the Pliocene into two stages, the Tabianian (early Pliocene) and Plaisancian (middle to late Pliocene).

To the east, near the town of Tabiano, the Vernasca Sandstone lies conformably on the Messinian. The maximum water depth of the seas is interpreted to have been that of outer shelf toward the slope during Tabianian time, and the minimum water depth at the end of Pliocene was within the limits of the sublittoral or littoral zone.

Planktonic foraminifers of the Tabianian stratotype (early Pliocene), as described by IACCARINO (1967), include (1) warm-water species such as *Sphaerodinellopsis sphaeroides* (=*S. seminulina* of authors) and *Globoquadrina altispira* which make their last appearance in northern Italy during the Tabianian, (2) *Globorotalia margaritae* (=*G. hirsuta* of authors) which is restricted to the Tabianian, and (3) *G. crassaformis* gens which appear first in the Tabianian. Assemblages contain common *Globigerina* spp. and *Globigerinoides* spp. *Globoro-*

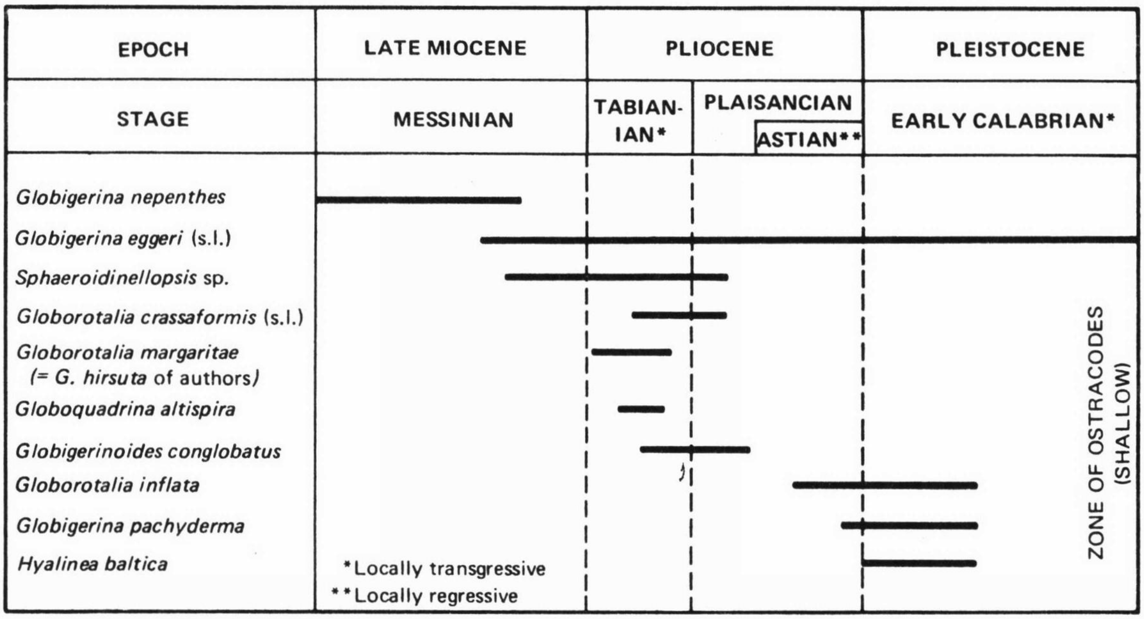


FIG. 4. Stratigraphic distribution of some planktonic foraminifers in the sub-Apennine region of northern Italy (after PEZZANI, 1963; BARBIERI, 1967; IACCARINO, 1967; and BARBIERI & PETRUCCI, 1967).

talia inflata first appears in the upper Plaisancian slightly below *Globigerina pachyderma.*

The stratigraphic distribution of important late Neogene planktonic species in northern Italy is given on Figure 4. On the planktonic scale the Tabianian is mostly equivalent to the *Globorotalia margaritae* Zone (early Pliocene) and the Plaisancian to the *G. crassaformis* and *G. inflata* Zones (middle and late Pliocene).

Although zonal nomenclature differs for the planktonic zonation of the Pliocene and Pleistocene in central and southern Italy, agreement is close for the stratigraphic succession of the planktonic species (for example, see Fig. 5-7). Of particular interest are the studies of globorotaliid lineages and their application to zonation of the Pliocene. Two parallel lineages of globorotaliids described by COLALONGO & SARTONI (1967) for Pliocene time are 1) *Globorotalia margaritae*→*G. aemiliana*→*G. crassaformis,* and 2) *G. puncticulata*→*G. bononiensis*→*G. inflata.*

CONATO & FOLLADOR (1967) propose a similar lineage, *Globorotalia crotonensis*→*G. crassacrotonensis* (=in part *G. crassaformis* of authors)→*G. crassaformis,* for the middle to late Pliocene (Fig. 4). *Globorotalia crotonensis* is a junior subjective synonym of *G. aemiliana* (*fide* MARIA LUISA COLALONGO), and *G. crassacrotonensis* is morphologically transitional between *G. aemiliana* and *G. crassaformis.* It seems quite unlikely that a nonkeeled *G. aemiliana* is an evolutionary descendant of a keeled *G. margaritae* because present knowledge suggests that keeled forms are derived mostly from nonkeeled forms and not vice versa. *Globorotalia margaritae* likely belongs to another evolutionary lineage, namely, *G. margaritae*→*G. hirsuta sensu stricto,* as suggested by PARKER (1967; see also discussion of *G. praehirsuta* by BLOW, 1969). Hence, the proper lineage designation becomes *G. aemiliana*→*G. crassacrotonensis*→*G. crassaformis.*

Although WEZEL (1968) and FOLLADOR (1967) record *Globorotalia truncatulinoides* as appearing first in the very late Pliocene, current opinion, supported by study of occurrences in the type region of the Calabrian Stage, regards this species as restricted to Calabrian and younger intervals and as first occurring commonly in the Sicilian Stage (GRADSTEIN, 1970). There is possibly some confusion among authors with *G. tosaensis,* a closely related species, which is reported to occur rarely in the late Pliocene of Italy. Although the complete bioseries leading to *Sphaeroidinella dehiscens* has not been documented in Italy, *S. dehiscens* is reported from the late Pliocene by FOLLADOR (1967) and *Sphaeroidinellopsis sphaeroides* (=*S. seminulina* of authors) from the early and early middle Pliocene by many authors. On the basis of available evidence, no occurrence for *S. dehiscens* is older than late Pliocene.

Setting aside minor nomenclatorial differences indicated on Figures 2-7, the Pliocene planktonic zones, which begin with the first appearance of the nominate species are as follows:

Upper Pliocene	*Globorotalia inflata* Zone
Middle Pliocene	*Globorotalia crassaformis* Zone (includes *G. crassacrotonensis* Range Zone in part)
	Globorotalia aemiliana Zone (corresponds closely with the lower part of the *G. crassacrotonensis* Zone of FOLLADOR, 1967)
Lower Pliocene	*Globorotalia margaritae* Zone

BANNER & BLOW (1965b) place the lower limit of the Pliocene in Sicily near the base of the Trubi beds of the Zanclian Stage and maintain that this stratigraphic horizon is characterized by the first, or evolutionary, occurrence of *Sphaeroidinella dehiscens,* which they say represents a worldwide datum of considerable importance and the base of their Zone N. 19. BLOW (1969) maintains a similar position, but CITA & BLOW (1969) qualify this by saying that the eventual choice of stages to define either the later Miocene and earlier Pliocene should be left to competent international bodies following the expression of preferences and views from as many interested workers as possible.

The 1967 meeting of the CMNS in Bologna, Italy, did not consider the Zanclian Stage as stratigraphically important to defining the Pliocene and set it aside in favor

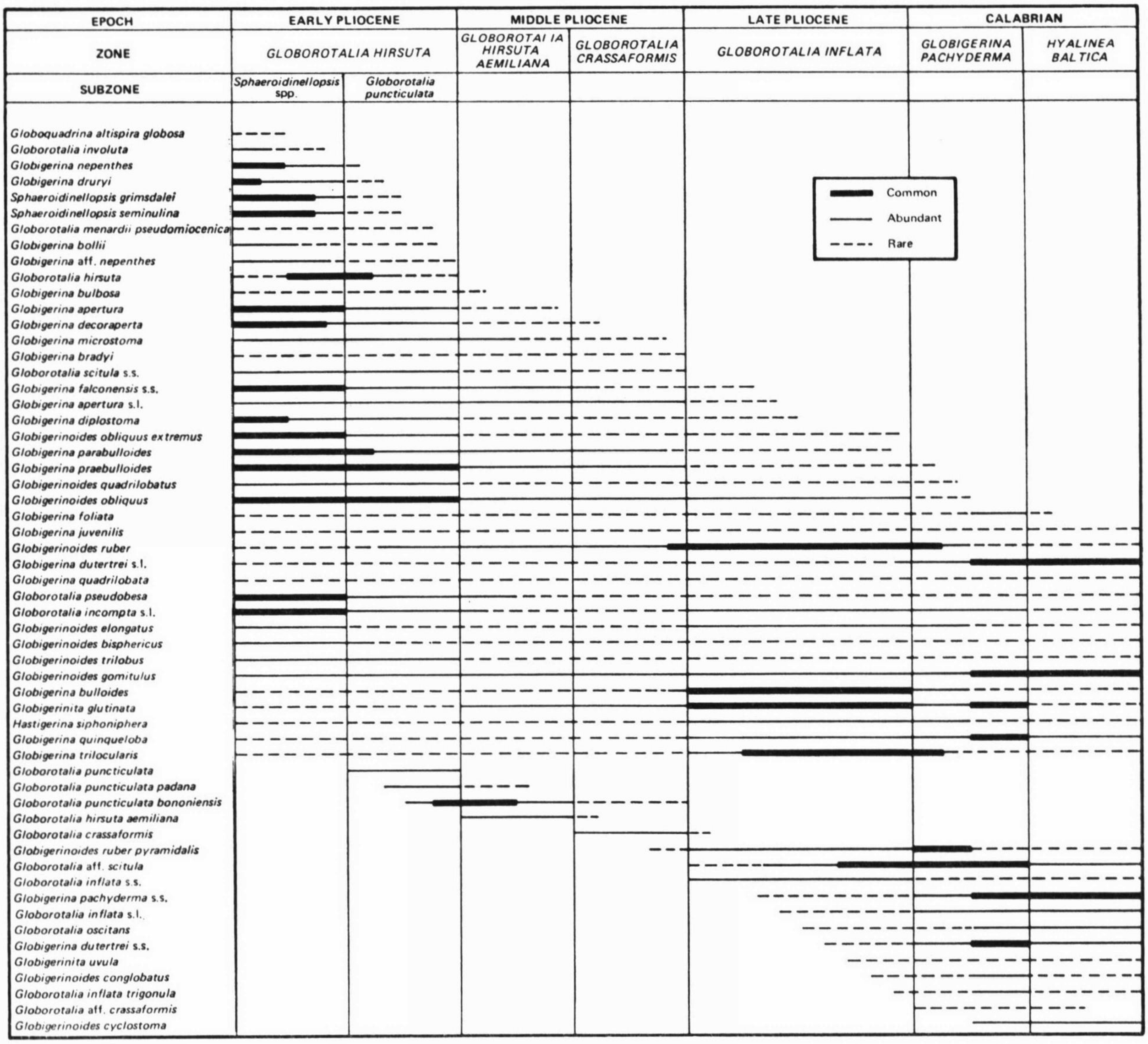


FIG. 5. **Zonation** of late Neogene sediments at Romagna Apennines, near Bologna, Italy (after COLALONGO, 1968).

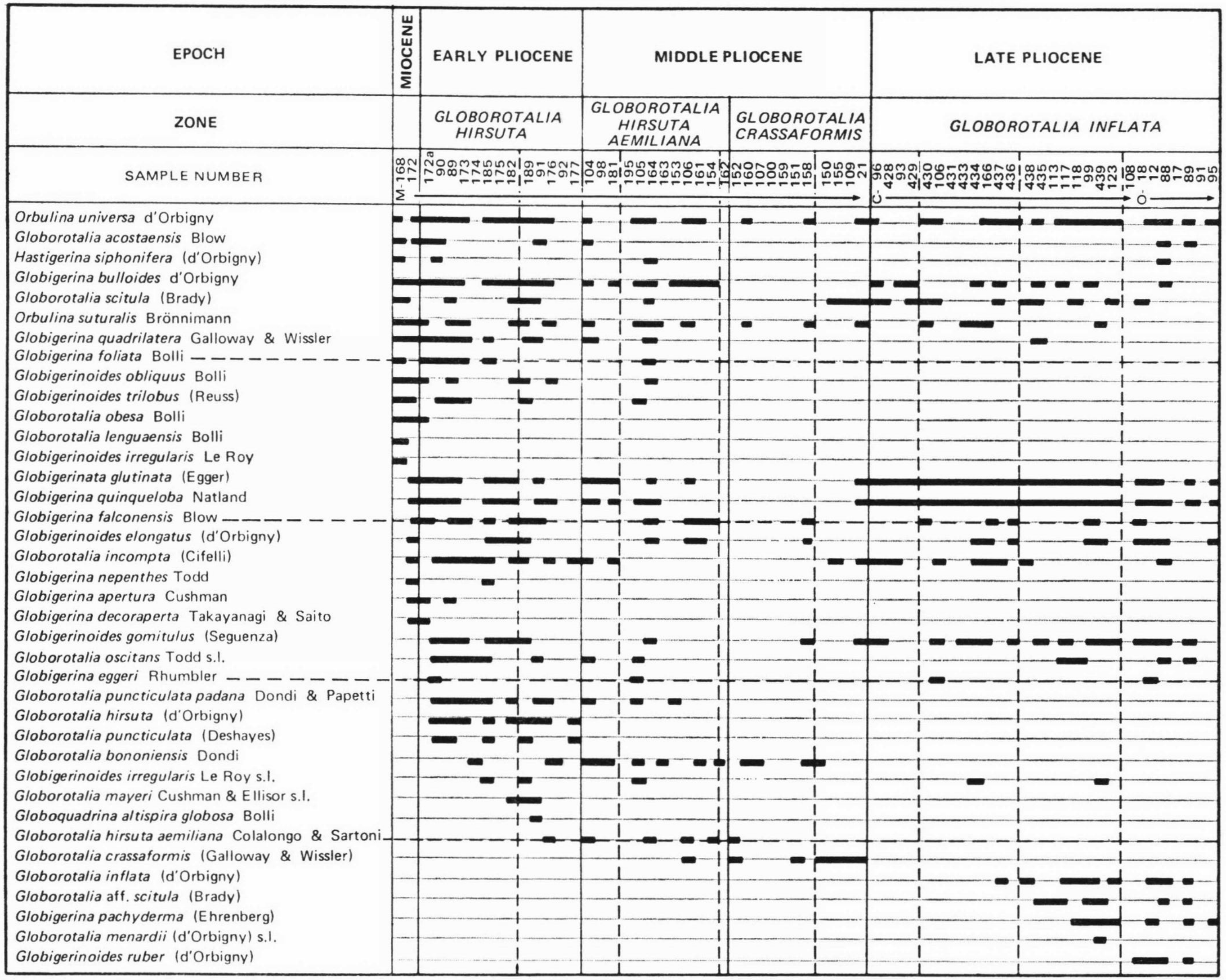


FIG. 6. Zonation of late Neogene sediments at Ostra Vetere in the Marche region, central Italy (after D'ONOFRIO, 1968).

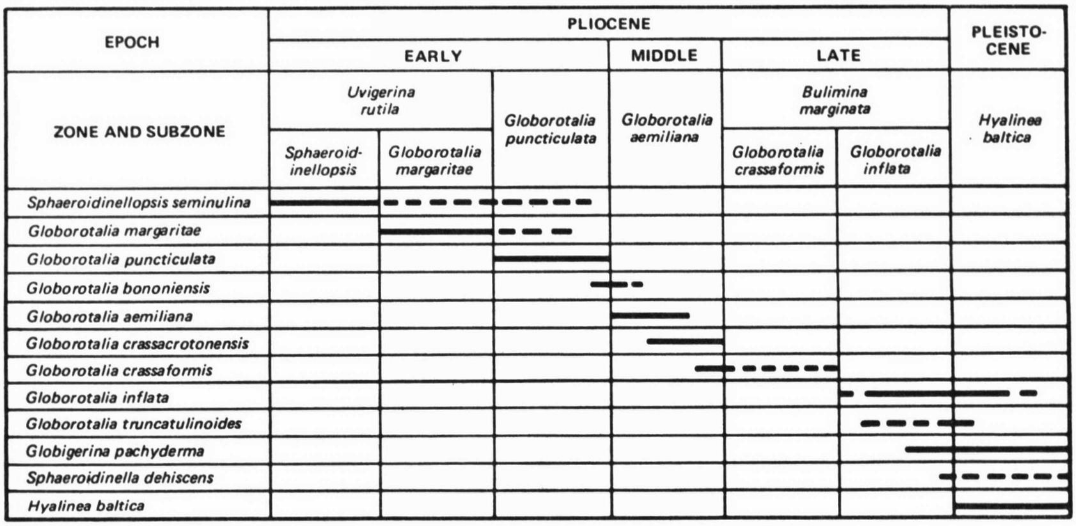


FIG. 7. Zonation of late Neogene sediments in central and southern Italy (after FOLLADOR, 1967). Dashed line indicates rare occurrence.

of the Tabianian Stage for defining earliest Pliocene and the Plaisancian Stage for defining middle and late Pliocene. In the foregoing discussion the first occurrence of *Globorotalia margaritae* is seen to fall at, or slightly above, the base of the Tabianian, and the first occurrence of *Sphaeroidinella dehiscens* to fall within late Plaisancian.

If the first occurrence of *Sphaeroidinella dehiscens* is considered as earliest Pliocene, then evidently all of the Tabianian and most of the Plaisancian must be considered Miocene. Such a concept, however, is contrary to definition of the classical Pliocene terrains in northern Italy.

In tropical regions HAYS & OTHERS (1969) showed the range of *Globorotalia margaritae* to fall within the Gilbert Event (greater than 4.5 m.y. to about 3.3 m.y.) and that of *Sphaeroidinella dehiscens* to begin at about the top of the Mammouth Event (at 3.0 m.y.). In a land-based section of the Bowden Formation on the Island of Jamaica in the Caribbean Sea, ROBINSON & LAMB (1970) also demonstrate that *S. dehiscens* first occurs near the Mammouth Event.

CALABRIAN STAGE (EARLY PLEISTOCENE)

Following recommendations of the 18th International Geological Congress (1950), the base of the Quaternary, or Pleistocene, is widely accepted as being at the horizon of the first indication of climatic deterioration in the Italian Neogene succession. The Commission recommended further that the lower Pleistocene should include as its basal member in the type area the Calabrian Formation (marine) together with its terrestrial equivalent, the Villafranchian. How the marine Calabrian of southern Italy was to be correlated with the terrestrial Villafranchian of northern Italy was not decided.

The work of GIGNOUX (1913) in the type area where he described the Calabrian Stage emphasized onset of climatic deterioration as recognized by the sudden appearance in the Mediterranean region of "northern guest" species, such as *Arctica islandica.*

Current difficulties in selecting the boundary are related more to what criteria should be considered rather than to the method employed. FLINT (1965) maintains that if we emphasize climate rather than glaciation, which is a secondary effect, we are approaching the problem more realistically. In support of pronounced climatic oscillations of very early Pleistocene age, FLINT (1965) cites climatic evidence in the Leffe Basin in the province of Bergamo in the Italian Alps. Pollen studies show a number of climatic fluctuations through and above the part of the stratigraphic section in which Villafranchian mammals are found. These lines of evidence suggest that climatic change at the base of the Quaternary was a harbinger of the "Ice Age."

The beginning of glaciation per se can be demonstrated most effectively by physical evidence, such as glacial till, in continental sequences and evidence for lowering of sea level within marine sequences in reasonably tectonically stable regions. The stratigraphic succession in northern Italy seemingly is ideal to demonstrate a relationship between the faunal (climatic) and eustatic events; namely, marine regressive upper Pliocene (Astian) strata grade upward into continental beds (Villafranchian) which precede or are laterally equivalent in part of marine Calabrian strata. Although Villafranchian and Calabrian deposits are not contiguous, it is feasible, because of their stratigraphic position above the Astian sandstones, to equate the Villafranchian with possibly upper Pliocene and also lower Pleistocene marine strata containing the cold-water immigrant species *Hyalinea baltica* and *Arctica islandica.*

The Calabrian issue would seem to be largely settled except that RUGGIERI (1965) states emphatically that *Arctica islandica* precedes *Hyalinea baltica* in the Castell'Arquato section and elsewhere and that some evidence indicates that cold climatic conditions had already been initiated before the onset of the Calabrian as defined by the first occurrence of *H. baltica. A. islandica* and *H. baltica* may not have reached Italy at the same time, and if not, which is the more reliable species for determining the base of the Calabrian? SELLI (1967) discussed this issue in some detail with respect to an inferred paleotemperature gradient for the Calabrian. He concluded that the species probably arrived together but that they are normally found separately in different facies; that is, *A. islandica* is found in shallow-water environments and *H. baltica* in deep-water environments. A pre-Calabrian cold period within the Astian of Castell'Arquato was determined palynologically by LONA (1962); this work supports the argument of RUGGIERI (1965). This so-called pre-Calabrian cooling may be represented in the planktonic foraminiferal facies by the appearance of right-coiling forms of *Globigerina pachyderma* in the late Pliocene.

If the concept of climatic change is carried a step further, it is clear from the works cited here for the late Tertiary of northern and central Italy that climatic cooling in these latitudes began during the late Miocene. This is seen by the progressive withdrawal of warm-water species such as the *Globorotalia menardii* group in late Miocene, *Globoquadrina altispira* in early Pliocene, and the appearance of the boreal species *Globigerina pachyderma* in late Pliocene. The issues here are mainly concerned with defining climatic deterioration at the end of the Pliocene and onset of a cool Pleistocene (Calabrian) climate.

The Pliocene planktonic foraminiferal zonation schemes offered by the CMNS (Fig. 2-3) reflect mostly faunal subdivisions that can be recognized in the type locality of the Pliocene stages in northern Italy (e.g., Tabianian and Plaisancian Stages), and it seems prudent to test the CMNS recommendations for defining the lower limit of the Pleistocene within the type area of the Calabrian Stage.

BAYLISS (1969) studied the stratigraphic distribution of the foraminifers *Globorotalia truncatulinoides* and *Hyalinea baltica,* together with the mollusk *Arctica islandica,* in the area of the Calabrian at Santa Maria di Catanzaro in southern Italy. He maintained that the species first appeared at different horizons. If the first occurrence of *H. baltica* is taken as the horizon to begin the Pleistocene, then the Plio-Pleistocene boundary would be below the lowest bed exposed in the Santa Maria di Catanzaro section. In this case, he argued, the boundary cannot coincide with GIGNOUX's which was determined with *A. islandica.*

It should be clearly understood that the decisions rendered by the 18th International Geological Congress (1950) and the fourth session of the CMNS (1967) effectively nullify GIGNOUX's boundary, which is a calcarenite lens or bed containing the mollusk *Arctica islandica* situated about 62 meters above the base of the post-Pliocene or "sandy Calabrian" section exposed at Santa Maria di Catanzaro.

BAYLISS' study in part supports the Committee's recommendations for recognizing certain faunal criteria in defining the upper limits of the Pliocene, which become *ipso facto* the limiting criteria for defining the lower limit of the Calabrian Stage. Some eight authors express the opinion that the upper boundary of the Pliocene corresponds with 1) the increase in frequency and change in coiling (i.e., entry of sparse left-coiling forms) of *Globigerina pachyderma,* 2) the first appearance of *Globorotalia truncatulinoides* (only in some regions), and 3) the appearance of "northern guests" or boreal species such as *Hyalinea baltica* and *Arctica islandica.*

Because BAYLISS did not discuss the occurrence of the species *Globigerina pachyderma* in his material, we examined samples from his sections along the road from Santa Maria di Catanzaro to Caraffa di Catanzaro and Cortale. *Hyalinea baltica* occurs in the lower samples of the Calabrian (i.e., the lower sandstones at this locality), whereas *Globorotalia truncatulinoides* occurs first some 30 meters higher in the section, which is some 22 meters below the horizon at which it was reported by BAYLISS. Both left- and right-coiled individuals of *Globigerina pachyderma* occur in the lower 30 meters; the latter form is distinctly dominant.

Although the base of the "sandy" Calabrian is not exposed, additional samples of some 10 meters of lower "sandy" Calabrian above a 30-meter covered interval from the churchyard of Santa Maria di Catanzaro provide data on the lower interval. Below the covered interval is more than 30 meters of highly fossiliferous siltstone considered to be Pliocene. Within the upper 10 meters of this siltstone right-coiled *Globigerina pachyderma* occurs very sparsely, *Globorotalia crassaformis* and *G. inflata* occur commonly about 30 meters below the top, and *G. pachyderma* occurs not at all. No specimens of *Hyalinea baltica* were found in this siltstone. The age of the siltstone below the "sandy" Calabrian is undoubtedly late Pliocene (*Globorotalia inflata* Zone).

Thus, on the basis of foraminiferal evidence, the base of the Calabrian Stage is not completely exposed at Santa Maria di Catazaro because it falls within the 30 meters of covered section below the lower sandstones. This covered interval has Pliocene strata below and Pleistocene strata above.

The coarse, angular, dirty sandstones at the base of the exposed section have been interpreted as being of turbidite origin (Emiliani, Mayeda, & Selli, 1961; Bayliss, 1969). The dominant benthonic foraminiferal species below, within, and above the sandstones suggest a bathyal depositional water depth. Displaced shallow-water species of foraminifers occur also within the sandstones. A reasonable explanation for genesis of these turbidites is that they were implanted in this deep basinal position during a period of low sea level following onset of climatic deterioration and concomitant continental glaciation. Such eustatism would cause severe degradation of the exposed continental shelf, with much of the sediment being carried down the slope to rest in deep water. A strong marine regression at this time is seen in terminating the Astian Stage in northern Italy and also on the coastal plain of Israel, where the first Pleistocene regression is correlated with the Calabrian and the presence of *Hyalinea baltica* (Issar, 1968).

From a study of nannofossils found in the Le Castella section, Smith (1969) determined that the interval studied by Emiliani, Mayeda, & Selli (1961) is mostly younger than the Santa Maria di Catanzaro section. That is to say, the Le Castella section contains a well-developed Emilian Stage (or warm upper Calabrian) and early Sicilian Stage above the "marker bed" (Smith's sample IT-761) which are not developed in the Catanzaro section.

Emiliani (1971) completed additional isotopic studies of the Le Castella section, which he accepts as the stratotype Calabrian, and reaffirmed his earlier contention that the "marker bed" horizon constitutes the Plio-Pleistocene boundary on evidence of the first appearance of *Hyalinea baltica*. In this he contradicts Smith (1969), who says that *H. baltica* occurs below the "marker bed," and he indicates six temperature maxima within the section based on isotopic and micropaleontological grounds (i.e., peak occurrences of *Globigerinoides ruber*). He still maintains that there are no major temperature changes across his boundary.

Bandy & Wilcoxon (1970) correlated Calabrian strata of southern Italy with that of the Wheelerian Stage of Balcom Canyon, California, utilizing mostly nannofossils and climatic implications based on coiling changes in the foraminifer *Globigerina pachyderma*. Much of their discussion is a recount of worldwide paleomagnetic, paleoclimatic, and paleoeustatic events as related to changes in the direction of coiling of *G. pachyderma*. They say the Le Castella section was deposited in water depths of 600 to 1,000 meters (or perhaps slightly more) on foraminiferal evidence and that the Santa Maria di Catanzaro section was deposited in water depths of about 200 to 500 meters. They base correlation of the two sections on nannofossil zones described by Hay & others (1967), which disagrees strongly with Smith (1969) and with Bayliss (1969). Work presently in progress by Smith will clarify usage of late Neogene nannofossil zones and will consider the conclusions made by Bandy & Wilcoxon. Because the present study has found *Hyalinea baltica* below the occurrences cited by Bandy & Wilcoxon (1970) in both the Santa Maria di Catanzaro and Le Castella sections, their lower limit for the Calabrian must be refuted.

No specific or generally accepted type section exists for the Calabrian, although the region of Calabria is the type locality. At the 19th International Geological Congress in Algiers in 1952, four type sections were proposed; Monte Mario (Roma), Castell'Arquato (Emilia), Santerno (Romagna), and Musone (Marche). None of these has received popular support, except perhaps the Castell-'Arquato by Ruggieri (1965). In the region of Calabria, Emiliani, Mayeda, & Selli (1961) selected the Le Castella section for detailed isotopic analysis, maintaining that it was more completely exposed than the Santa Maria di Catanzaro section of Gignoux (1913). They demonstrated climatic fluctuations above a proposed Pliocene-Pleistocene boundary determined by the first appearance of *Hyalinea baltica*. No detailed study was made of the foraminifers, although they were reported to be abundant in the samples collected for the study. Selli (1967) later stated a preference for the section at Santa Maria di Catanzaro which he provisionally dedicated as the stratotype. Although he discussed the incursion of boreal species as fundamental in defining the Calabrian, the planktonic biostratigraphy was not described.

Banner & Blow (1965a) said that *Globorotalia truncatulinoides* occurs in the lower part of the "stratotype" Calabrian at Santa Maria di Catanzaro, which is one of the Calabrian localities of Gignoux (1913). Blow & Banner (1966) enlarged on this by saying that *G. truncatulinoides* first appears in the Calabrian Stage of the lowest Pleistocene in Europe, immediately overlying youngest Pliocene beds with *G. tosaensis,* which they regard as the evolutionary ancestor to *G. truncatulinoides*. These authors attempt to relate the evolutionary appearance of *G. truncatulinoides* to the beginning of the Quaternary, but opinions differ slightly on this matter.

The foregoing discussion emphasizes the need for designating a stratotype for the Calabrian Stage within the type area of Calabria, thereby fixing the Plio-Pleistocene boundary at its base. Selli (1967) gives an excellent summary of different concepts applied to defining the boundary in Italy. He says the boundary, according to

Stefani, 1876, based upon the appearance in the Mediterranean of immigrants from the North Atlantic, has been accepted in Italy for 40 years. He realizes that, following the principles of stratigraphy, the Plio-Pleistocene boundary must be established at the beginning of the Calabrian in the continuous Italian deep open-marine sections. His choice for a type section at Santa Maria di Catanzaro (Selli, 1967a) has not been sanctioned by the CMNS.

Hedberg (1970) wrote "Perhaps in no phase of stratigraphic classification is there greater need for close international collaboration than in setting up standards of definition for stratigraphic units of international extent so that they will be internationally acceptable and so that the geologists of all countries will use these units in the same sense." And, "The concept of a stratigraphic unit is usually based on features of the rock strata—age or time-scope, lithology, fossil content, etc.—which are observable and verifiable in the rock strata. The stratotype of a unit, therefore, constitutes the ultimate standard of reference to which the concept of that unit is uniquely related."

A definitive stratotype for the Calabrian is necessary mainly on the grounds that international stratigraphic usage lacks provisions for defining geologic time units, such as epochs and stages, solely in terms of climatic change. Application of lithologic, biostratigraphic, climatic, paleomagnetic, and glacio-eustatic stratigraphies may all serve well in recognizing the lower limits of the Calabrian, but they should be related to specific horizons of reference in a type section. Further, the Calabrian must have an upper as well as lower limit, and this should be given consideration in selecting a type section. With these concepts we sampled the Le Castella section which seemed to offer a more complete late Pliocene and early Pleistocene sequence than did Santa Maria di Catanzaro; these sediments, also, have a fine-grained character more suitable for paleomagnetic determinations.

LE CASTELLA SECTION

Exposures of middle Pliocene to early Pleistocene strata were measured and sampled along the coast of the Ionian Sea near the town of Le Castella in southern Italy. Two sets of samples were taken, one for paleontological study and another for paleomagnetic determinations. Besides the classic section discussed by Emiliani, Mayeda, & Selli (1961), four other sections were included to gain a more complete knowledge of the Pliocene strata (Fig. 8). The sampled interval is underlain by Mio-Pliocene strata and overlain unconformably by Pleistocene terraces of Milazzian and younger ages. The lithology is dominantly clay and shale, and exact measurements of strike and dip were not always possible for each station. The paleomagnetic samples therefore were oriented in part by observing the regional strike and dip of the beds. Approximately 74 samples were collected for paleomagnetic analysis and 55 for paleontological study.

Smith (1969) described the nannofossil sequence within the Pleistocene interval of the Le Castella section and suggested a correlation with the Calabrian section at Santa Maria di Catanzaro. He gave cogent reasons for saying that Le Castella has a more extensive early Pleistocene history than does Catanzaro in that the Emilian Stage is not well exposed at Catanzaro and the Sicilian Stage not at all. Studies of the foraminifers at Catanzaro, not included here, tend to substantiate his prediction, but paleomagnetic samples were not taken there because of the occurrence of sandstones throughout much of the section. Le Castella, therefore, probably is the most advantageous place to study the planktonic biostratigraphy and paleomagnetic polarity patterns of the late Pliocene and early Pleistocene strata within the type area of the Calabrian Stage.

Benthonic foraminifers were not studied in detail, but horizons within the late Pliocene contain *Melonis pompilioides,* which indicates abyssal water depths. Pleistocene sedimentation suggests water depths of 600 to 1,000 meters, or lower to middle bathyal, as reported by Bandy & Wilcoxon (1970). Stratigraphic occurrences of *Hyalinea baltica* were recorded for defining the base of the Calabrian Stage.

Planktonic foraminifers are abundant in nearly all samples and many horizons qualify as globigerine ooze. The percentage occurrence of planktonic species in each sample is shown on Figure 9; mostly more than 300 specimens were counted. Occurrences of less than one percent are derived partly from counts of more than 300 specimens.

To understand the effect of inferred climatic fluctuations on the planktonic fauna, the species were divided into those having warm-water affinities and those having cold-water affinities, considering the present latitude. Species of uncertain temperature affinities were not considered as critical and, fortunately, do not occur in large numbers. More warm-water than cold-water species occur, but most of the specimens are on the cold side. Criteria for temperature segregation of the species follows that of Todd (1958, pl. 20) and Parker (1958) in their studies of Pleistocene cores from the western and eastern Mediterranean Sea. No good evidence suggests that their cores reached below the late Pleistocene to horizons considered in the present study, but they show that similar climatic fluctuations persisted up to the Holocene.

Todd (1958) considered her western Mediterranean fauna to be basically cold or cool, with fluctuations toward a warmer fauna that presumably are correlatable with interglacial stages. She offered two possible explanations for this increase in warm-water species. "Warm-water species from the Atlantic may have been brought in by the Mediterranean circulation system under conditions similar to those of the present. Return of glacial conditions would presumably limit the northern extension of circulation of warmer water in the central Atlantic so that the Mediterranean circulation system under its lowered level failed to bring in the warm-water planktonics from the Atlantic waters outside the Strait of Gibralter. Without taking into account the possible changes in the relationship between Mediterranean and Atlantic circulation systems, an alternative interpretation of the warm fluctuations is that the warm-water species, always present in the Mediterranean in at least minor amounts, flourished more abundantly there under warmer conditions."

We believe our present data indicate that some warm- and cold-water species were introduced into the Mediterranean in response to changes in the Atlantic circulation brought about by climatic change. This is evidenced in

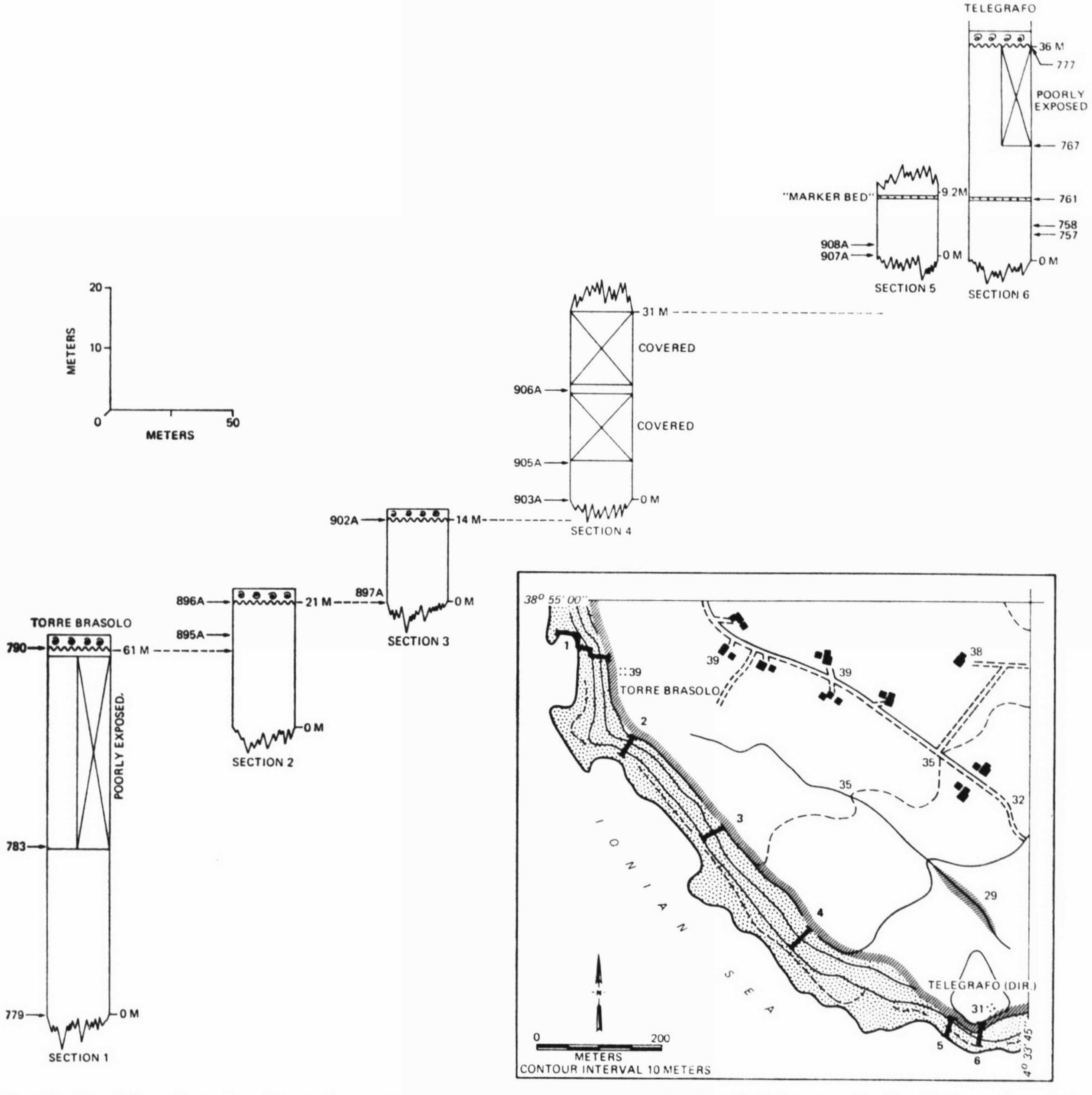


FIG. 8. Correlation of stratigraphic sections measured between Torre Brasolo and Telegrafo Point, near Le Castella in southern Italy. (Longitude is in reference to the meridian of Rome, corresponding approximately to 17°01'E of Greenwich.)

AGE		STAGE	MEDITERRANEAN PLANKTONIC ZONE	PERCENT WARM-WATER SPECIES	PERCENT COLD-WATER SPECIES	SAMPLE NUMBER	*Globorotalia bononiensis* DONDI	*Orbulina universa* (D'ORBIGNY)(W)	*Globigerina bulloides* D'ORBIGNY)(C)	*Globigerinoides quadrilobatus* (D'ORB.) (W)	*Globigerinoides sacculifer* (BRADY) (W)	*Globigerinoides ruber* (D'ORBIGNY) (W)	*Globigerinoides extremus* (BOLLI & BER.) (W)	*Globorotalia scitula* (BRADY)	*Globigerina uvula* (EHRENBERG)	*Globigerina quinqueloba* (NATLAND) (C)	*Globigerinita glutinata* (EGGER)	*Hastigerina aequilateralis* (BRADY) (W)	*Globorotalia crassaformis* (GALL. & WISS.) (W)	*Globorotalia inflata* (D'ORBIGNY) (C)	*Globigerina incompta* Cifelli (C)	*Globigerina pachyderma* (EHRENBERG) (C)	*Globigerinoides conglobatus* (BRADY) (W)	*Sphaeroidinella dehiscens* (PAR. & JONES) (W)	*Hastigerina pelagica* (D'ORBIGNY) (W)	*Globorotalia tosaensis* (TAK. & SAITO)	*Globorotalia truncatulinoides* (D'ORBIGNY)	*Hyalinea baltica* (SCHROETER)
PLEISTOCENE	EARLY	SICILIAN	NO ZONES DESIGNATED	2	91	777		2	24	0	0	0	0	4	P	44	P	P	0	1	9	13	0		0			P
				8	80	776		3	19	2	0	3	0	3	P	37	1	0	0	P	12	12	P		0			1
				7	78	775		1	15	2	P	3	0	5	P	34	2	1	0	3	11	15	0		0			1
		EMILIAN		11	71	774		9	20	0	0	2	0	9	P	33	1	P	0	P	6	12	0		P			2
				14	74	773		9	38	P	0	4	0	3	P	12	P	1	0	6	10	8	P		0			P
				33	48	772		16	26	2	1	13	0	P	P	13	1	1	P	5	6	8	P		0			P
				15	80	771		9	36	P	P	2	0	2	P	26	1	2	0	3	8	7	2		0			P
				19	71	770		9	28	P	P	9	0	1	P	10	1	1	0	P	10	23	P		0			P
				2	89	769		1	52	P	0	0	0	1	P	21	4	1	P	P	3	12	P		0			1
				21	72	768		9	8	P	0	11	0	P	P	22	1	P	0	11	3	28	1		0			P
				5	90	767		4	19	1	P	P	0	1	P	19	1	P	0	8	6	38	P		0			0
				5	89	766		1	21	1	P	1	0	1	P	33	2	P	P	8	6	21	2		0			P
				19	74	765		6	27	P	P	10	0	1	P	18	3	1	0	4	2	23	2	P	P			0
				18	78	764		5	26	1	P	10	0	P	P	13	2	1	0	2	1	36	1	0	0			P
				47	49	763		2	9	0	0	44	0	P	P	26	2	1	0	1	P	13	P	0	0			0
		CALABRIAN		12	73	762		5	21	1	P	4	1	3	1	43	8	1	0	2	P	7	P	0	0			0
				18	82	761•		2	46	4	P	2	4	P	P	6	3	1	P	20	P	10	5	0	0			P
				1	85	760		1	14	0	0	P	P	P	0	51	5	P	P	5	P	15	0	0	0			0
				2	93	759		2	7	P	0	P	P	1	P	45	9	P	0	4	1	36	P	0	0			P
				7	87	758		5	25	1	P	P	1	0	0	40	4	P	0	2	P	20	0	0	P		P	P
				14	73	757		5	24	7	P	P	1	P	P	36	11	1	0	3	1	9	P	0	P			P
				8	80	908A		3	20	1	P	1	1	P	0	36	3	1	0	7	P	17	1	0	P			0
				6	85	907A		5	36	P	P	P	1	1	P	27	3	1	0	2	1	21	P	0	P	P		P
PLIOCENE	LATE	PLAISANCIAN	*Globorotalia inflata* Zone	40	54	906A		18	32	0	0	19	3	P	P	8	1	P	P	0	5	9	0	1				
				36	53	905A		10	5	P	P	10	15	2	1	21	3	P	1	0	7	20	0	P				
				28	63	904A		2	37	P	P	1	14	P	P	13	2	1	10	0	6	7	0					
				34	61	903A		7	40	3	1	1	15	1	P	10	2	1	6	0	5	6	0					
				22	72	902A		4	46	P	0	0	6	P	P	20	1	P	12	P	4	2	0					
				21	69	901A		11	48	P	P	0	1	P	P	17	1	P	9	0	3	1	0					
				29	63	900A		2	31	3	P	2	18	P	P	7	2	P	4	0	2	23	0					
				27	63	899A		3	25	2	0	4	16	P	P	12	3	1	1	0	6	20	0					
				18	77	898A		3	40	2	1	1	9	1	P	22	2	1	1	0	8	7	0					
				15	79	897A		5	42	5	0	2	2	P	P	21	3	1	0	0	8	8	0					
				42	51	896A		10	35	24	4	2	2	0	P	12	2	P	P	0	1	3	0					
				16	69	895A		1	19	7	3	1	4	P	P	49	3	P	P	0	1	8	P					
				12	67	790		6	25	0	0	0	3	7	P	40	10	P	P	0	P	2	3					
				19	69	789		14	14	0	0	1	1	2	1	53	6	1	2	0	P	2						
				15	75	788		9	18	P	0	1	5	P	P	52	8	P	P	4	P	1						
				28	59	787		12	25	P	0	1	15	P	P	32	6	0	P	1	P	1						
				16	74	786		6	16	1	P	1	7	1	1	37	5	P	1	5	P	16						
				23	73	785	P	8	15	P	0	2	3	1	P	19	3	1	9	1	P	38						
				12	73	784	2	5	28	1	P	0	5	0	P	37	9	P	1	5	P	P						
	MIDDLE		*Globorotalia crassaformis* Zone	24	49	783	3	4	19	8	3	P	9	0	P	30	7	P	3									
				11	56	782	24	1	21	3	P	1	3	0	1	35	3	0	3									
				2	62	781	31	1	41	1	P	0	P	0	0	21	1	P										
				22	48	780	24	P	24	9	P	1	12	P	P	24	1	0										
				17	47	779	32	3	30	5	2	4	2	1	1	17	2	1										

•"MARKER BED" OF EMILIANI ET AL.,1961.

FIG. 9. Occurrence of planktonic foraminifers and the benthonic foraminifer *Hyalinea baltica* at LeCastella, Italy, with percentages of warm- and cold-water species. "Marker Bed" of EMILIANI, MAYEDA, & SELLI (1961) indicated by arrow. (P=<1%, W=warm, C=cold.)

the foraminifers and mollusks by the appearance of "northern guests" at the beginning of the Calabrian, the sudden appearance of the tropical species *Sphaeroidinella dehiscens* during the late Pliocene and Emilian, and the appearance of dominant left-coiling forms of *Globigerina pachyderma* in the Sicilian.

Todd (1958) made a point that planktonic species may provide bases for interpretation either by their abundance or by their fluctuation in abundance. This approach has been used by many workers over the past two decades to define Quaternary climatic fluctuations in different parts of the world. Following this line of reasoning, an inferred climatic curve showing the stratigraphic fluctuations in the percentages of warm-water planktonic species is shown on Figure 10.

Unfortunately, modern distribution of planktonic species in the Mediterranean, has not been studied so that we do not know for sure the current species associations. Determinations of absolute temperature values for water-masses characterizing the different stratigraphic horizons, therefore, were not attempted. It seems probable, however, that the highest water temperatures are indicated by the occurrence of *Sphaeroidinella dehiscens* in the late Pliocene and in the Emilian and the lowest by dominant left-coiling forms of *Globigerina pachyderma* in the Sicilian. These occurrences lend strong support to the validity of the curve based on fluctuating percentages of the warm-water planktonic species.

Middle Pliocene is identified on the joint occurrence of *Globorotalia bononiensis* and *G. crassaformis;* late Pliocene by the evolutionary development of *G. inflata* from *G. bononiensis;* early Pleistocene, or Calabrian, by the presence of *Hyalinea baltica,* sparse left-coiling forms of *Globigerina pachyderma,* and sharp reduction in percentage of warm-water planktonic species; Emilian by increase in percentage of warm-water planktonic species; and Sicilian by the second reduction in percentage of warm-water planktonic species and increasing dominance of left-coiling forms of *G. pachyderma* (beginning in sample 775).

Identification of the Pliocene zones follows the recommendations of the CMNS (Cati & others, 1968). The terminal Pliocene or beginning of the Calabrian follows the definition in the above citation, especially the evidence for climatic cooling based on a decrease of warm-water planktonic species following a warm late Pliocene climate and the appearance of *Hyalinea baltica.* The Emilian, interpreted following the concept of Ruggieri & Selli (1950) and Selli (1967), is evidenced by a warm upper Calabrian (Calabrian II or Emilian) separating a lower cold Calabrian from an overlying cold Sicilian. The beginning of the Sicilian is interpreted here as the horizon of reduced percentage of warm-water planktonic species following a warm Emilian and strong influx of dominantly left-coiling forms of *Globigerina pachyderma. Globorotalia tosaensis* and *G. truncatulinoides* occur sparsely for the first time in the Calabrian.

The described subdivisions of the Pleistocene follow closely those of Smith (1969), which are based partly on climatic implications of nannofossil assemblages. Material described by Gradstein (1970) from the type Sicilian Stage at Ficarazzi, Sicily, was examined and found to contain abundant specimens of *Globorotalia truncatulinoides* but no discoasters. This locality is probably slightly younger than the Sicilian identified at Le Castella, but the concept of climatic alternations within the Pleistocene is seemingly appropriate for recognition of the stage at Le Castella.

The "marker bed" or Plio-Pleistocene boundary of Emiliani, Mayeda, & Selli (1961) and Emiliani (1971) is positioned here within the very late Calabrian. It is seemingly evident from the warm-water planktonic curve presented here that no marked climatic cooling should be expected above this horizon because warm-water planktonic faunas of the Emilian Stage predominate. The isotopic values given by Emiliani (1971) agree closely with the Emilian curve of this study, probably because they both concur with peak occurrences of the warm-water planktonic species *Globigerinoides ruber.* The cool inflection of the planktonic curve for the Calabrian also agrees in part with the isotopic values except for a few stations. Contrary to the findings of Emiliani (1971), *Hyalinea baltica* occurs in four stations below the "marker bed." It must be concluded, therefore, that the "marker bed" is a dubious candidate for determining the base of the Pleistocene.

Paleomagnetic samples were demagnetized routinely at 150 oersteds to remove unstable components. Direction and intensity of magnetization were measured using a slow-spin magnetometer, and the results were processed by computer. Measured polarities of the samples are shown on Figure 10.

Covered intervals and surface weathering hamper a clear understanding of the paleomagnetic data. The entire sampled section is characterized by normal polarities with no distinct reversals. Pliocene strata, however, seem to fall within the Gauss Epoch because of the duration of the normal event. The normal polarities within the Calabrian and lower Emilian seemingly offer two possibilities for interpretation; 1) the interval falls within the Gauss, which would mean that the Gauss-Matuyama boundary is above the base of the Emilian, or 2) the interval is within the Olduvai event, which would mean that a reversed polarity interval should be expected in the covered interval between the Pliocene and Calabrian normal polarities.

This nomenclature follows that of the standard geomagnetic polarity scale of Cox (1969). It is worth men-

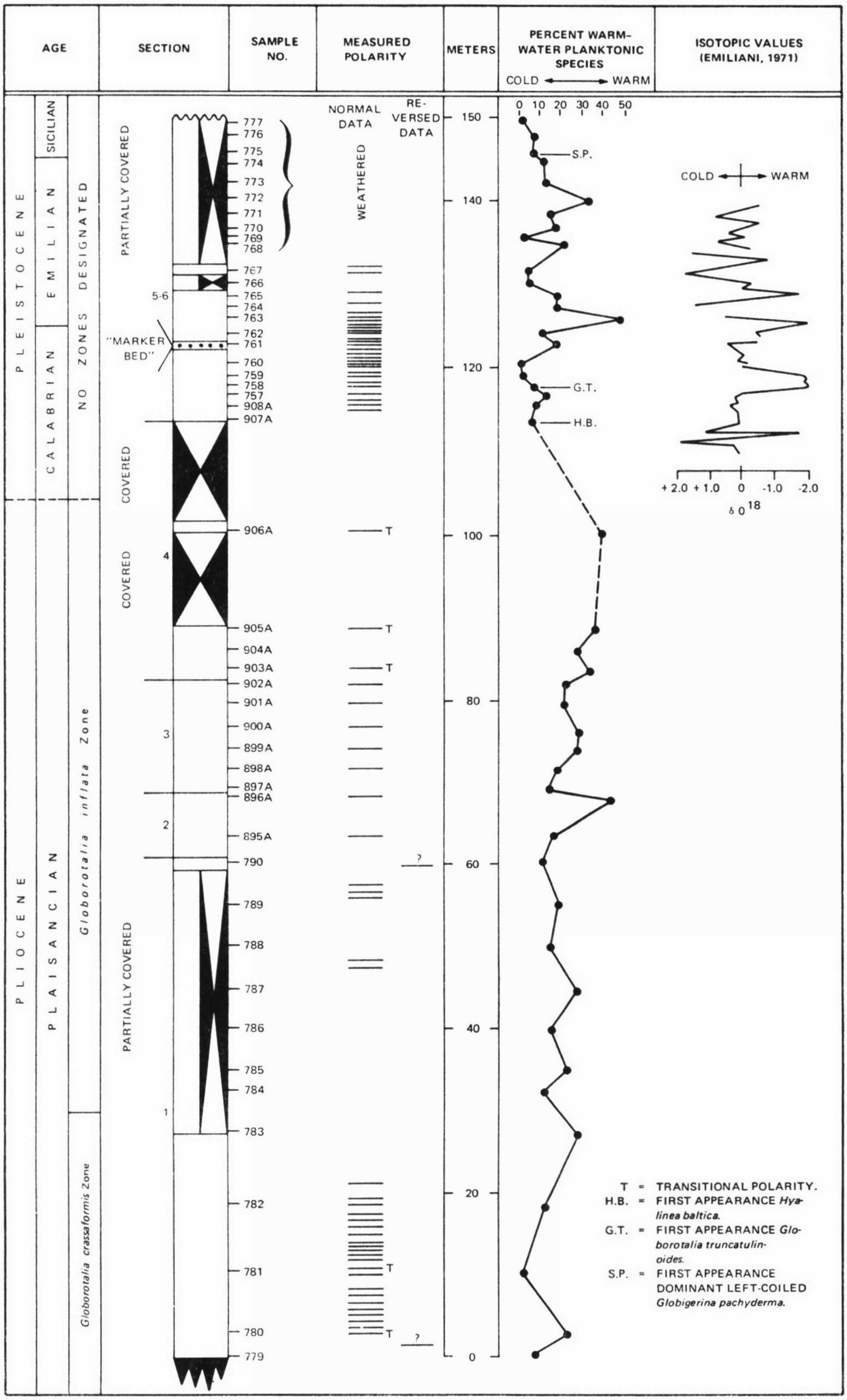


FIG. 10. Stratigraphic succession of samples at Le Castella, Italy, showing age, measured polarity, percentage of warm-water species of planktonic foraminifers, and isotopic values.

tioning, however, that Grommé & Hay (1971) present new data from Olduvai Gorge showing the Olduvai as no older than 2 million years. They maintain that all or some of the seven normally magnetized lavas having ages between 1.95 and 2.09 m.y. listed by Cox, Doel, & Dalrymple (1968) and assigned to the Olduvai event probably were erupted prior to Olduvai time. These they name the Reunion event. They also claim that the lava from which the Gilsá event was defined may have erupted during the Olduvai event and, if so, the term Gilsá should now be abandoned. The Reunion event is simply a new name for the lower split-Olduvai of Cox (1969) and does not alter his original data of having a normal event between 2.11 and 2.13 m.y. A clear understanding of the normal events within the basal part of the Matuyama Epoch is particularly important for interpreting the Le Castella section.

It is indeed unfortunate that lack of exposures and surface weathering restricts a more precise interpretation of the biostratigraphy and paleomagnetic stratigraphy at Le Castella. We believe, however, that the section is worthy of being considered as the stratotype for the Calabrian Stage because of the favorable continuity of deep marine Pliocene and Pleistocene strata, which have been shown to yield rich planktonic foraminiferal faunas and dependable measured polarities. The CMNS would do well to establish a subcommittee for the purpose of devising a program for continuously coring about 200 meters or more of the section at the Telegrafo locality in order to define clearly the paleomagnetic data and biostratigraphy and, thereby, establish a definitive lower boundary for the Calabrian Stage.

SUMMARY OF ITALIAN LATE NEOGENE PLANKTONIC SUCCESSION

The CMNS recommendation to recognize *Hyalinea baltica* in conjunction with the earliest occurrence of left-coiled forms of *Globigerina pachyderma* for defining earliest Calabrian in Italy is corroborated by biostratigraphic evidence at the type locality of the Calabrian, as well as other regions in Italy. Further, *Globorotalia truncatulinoides* appears for the first time some 40 meters above the base of the exposed Calabrian strata at Santa Maria di Catanzaro and above the base at Le Castella, apparently after lowering of sea level in early Pleistocene. At Le Castella a warm Emilian interval overlies the Calabrian and is followed upward by a cold Sicilian. These stages are identified by alternations in the percentages of warm- and cold-water planktonic species within the section. Evidence suggests that perhaps Sicilian climes were as cold, or colder, than those of the Calabrian. The first dominance of left-coiling forms of *G. pachyderma* is seen in the Sicilian as is the first abundant occurrence of *G. truncatulinoides*.

A preliminary account of nannofossils in the Santa Maria di Catanzaro and Le Castella sections is given by Smith (1969), and a more complete study is in progress. His data show that discoasters do not reach their horizon of extinction until the onset of the Sicilian Stage, and evidence is presented here that they do not occur at the type locality of the Sicilian in Sicily. There is no basis, therefore, to equate the beginning of the Calabrian or Pleistocene with extinction of the Discoasteridae, as previously inferred by Ericson, Ewing, & Wollin (1963). Seemingly cooler climes of the Sicilian were a factor in causing extinction of this phytoplankton.

The preceding discussion gives evidence for a broad subdivision of the Italian Late Neogene planktonic succession along the following lines:

1) The Tortonian (late Miocene) includes a short interval of the *Globorotalia menardii* Zone followed upward by an interval characterized by the first occurrence of *Globorotalia acostaensis* (late Zone N. 15 and Zone N. 16). For the practical purpose of faunal correlation it is desirable to begin the Tortonian Stage with the first appearance of *G. acostaensis*.

2) For reasons given, the Messinian (late Miocene) does not lend itself to extra-Mediterranean comparison on the basis of planktonic foraminifers. The lower boundary is arbitrary, as is the upper limit of the Tortonian. *Globigerinoides conglobatus, Sphaeroidinellopsis sphaeroides,* and *Globorotalia acostaensis* are among those species that occur in the late Messinian. Much of the Messinian is characterized by evaporites, and current opinion tends to include the Messinian within the Tortonian as constituting the late Miocene of the Mediterranean region.

3) The lower limit of the Tabianian (early Pliocene) corresponds closely with the earliest occurrence of *Globorotalia margaritae* followed upward by the appearance of *G. puncticulata* and *G. bononiensis. Globoquadrina altispira* and *Globigerinoides conglobatus* continue upward from the underlying Messinian.

4) The Plaisancian (middle-late Pliocene) begins with the earliest occurrence of *Globorotalia aemiliana* and *G. crassacrotonensis* followed upward by *G. crassaformis sensu stricto, G. inflata, Globigerina pachyderma, Sphaeroidinella dehiscens,* and *Globorotalia tosaensis* (reported as rare).

5) The upper limit of the Pliocene or beginning of the Calabrian Stage corresponds with the earliest occurrence of northern guest species such as *Arctica islandica, Hyalinea baltica,* left-coiling forms of *Globigerina pachyderma,* and decrease in the percentage of warm-water planktonic species. The first occurrence of *Globorotalia truncatulinoides sensu stricto* is above the base of the Calabrian.

CARIBBEAN AND GULF OF MEXICO

GENERAL

The historical development of the zonation of Cretaceous-to-Pliocene warm-water marine sediments based on planktonic foraminifers is given by Bolli (1966). He stated that the subdivision of formations into zones based on the stratigraphic ranges of planktonic foraminifers was done specifically for the practical requirements of the oil industry in Trinidad and concluded that "these zones have found widespread acceptance and application not only in the neighboring Caribbean and Gulf Coast regions but also in many other, more distant areas. This appears to be proof that most of the zones originally proposed in Trinidad are also recognizable on a world-wide scale and can be used for intercontinental stratigraphic correlation."

Although the planktonic zones defined in Trinidad by Bolli (1957) and others certainly have been used practically worldwide, more recently described Cretaceous and post-middle Miocene planktonic zones have not received widespread acceptance. Bolli's Cretaceous zones are criticized because they are not related to the standard ammonite sequence; his post-middle Miocene zones are based on preliminary data and are not demonstrably sequential in all respects.

The planktonic succession in Trinidad is not developed above the late middle Miocene *Globorotalia menardii* Zone because planktonic foraminifers are mostly excluded by unfavorable facies conditions above the Lengua Formation. Blow (1959) demonstrated that the upper portion of the Pozón Formation in eastern Falcon, Venezuela, correlates with the *Globorotalia siakensis* Zone and in part with the *G. menardii* Zone of the Lengua Formation of Trinidad and that higher stratigraphical levels of the Pozón Formation are younger than the *G. menardii* Zone of Trinidad (Fig. 11).

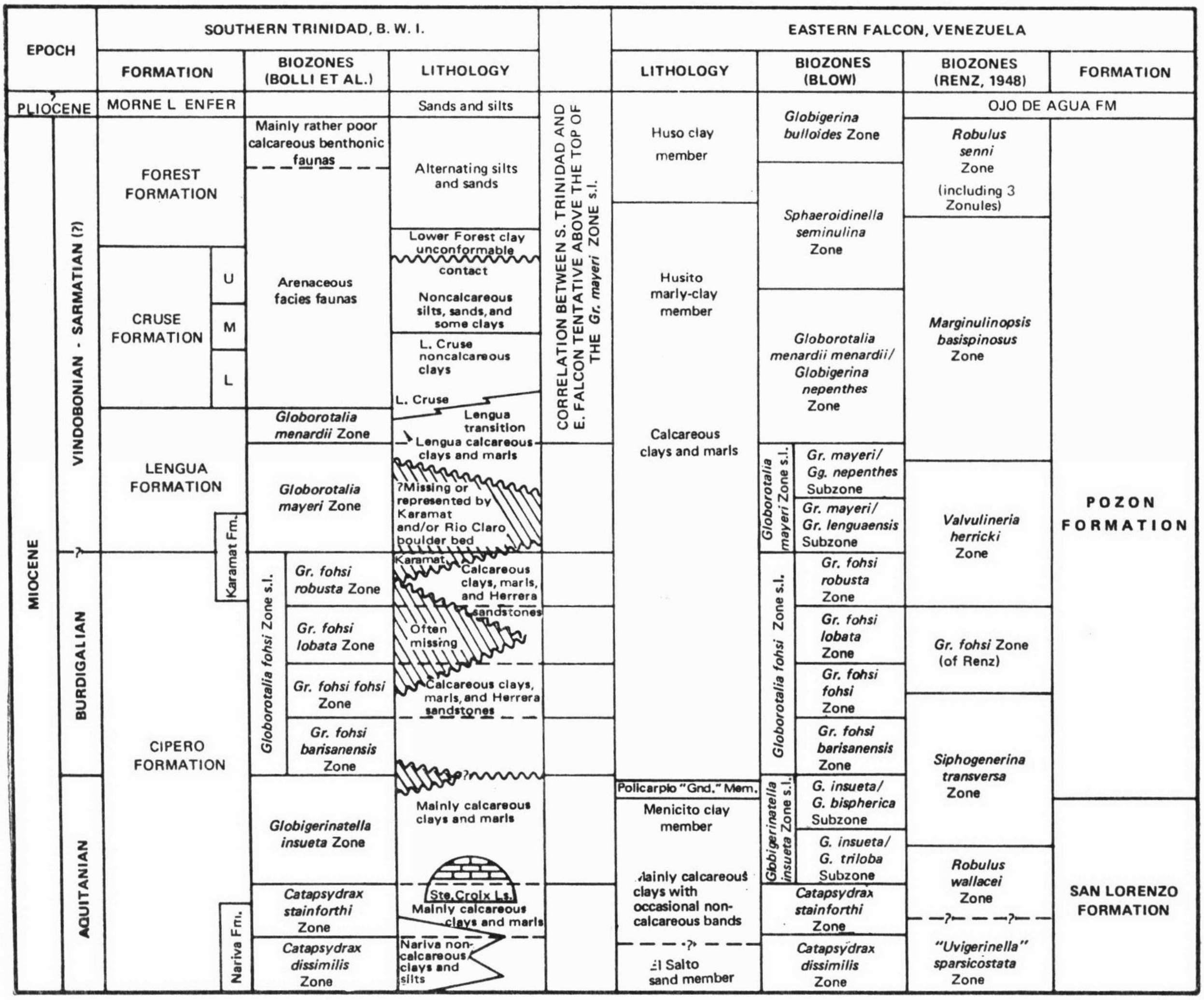


Fig. 11. Correlation of eastern Falcón, Venezuela, with southern Trinidad (after Blow, 1959).

TABLE 1. *Late Tertiary and Quaternary stratigraphy.*

AGE (millions of years)	SERIES, STAGE, AND ZONE USAGE This Paper					PLANKTONIC FORAMINIFERAL ZONES Bolli (1957, 1966), Bolli and Bermúdez (1965)		PLANKTONIC FORAMINIFERAL ZONES Banner and Blow (1965a, 1967), Blow and Banner (1966), Blow (1967)		
	EPOCH	NORTH AMERICAN STAGES	EUROPEAN STAGES	ZONE	SUBZONE					
0.007 TO 0.011	HOLOCENE	Postglacial		*Globorotalia tumida*		*Globoquadrina altispira altispira/Globorotalia truncatulinoides* SEE ROBINSON (1967)		N. 23	HOLOCENE	
	PLEISTOCENE	Wisconsinan		*Globorotalia truncatulinoides*	*Pulleniatina finalis*				PLIOCENE, PLEISTOCENE	ZANCLIAN, PLAISANCIAN, ASTIAN, CALABRIAN, POST-CALABRIAN
0.08		Sangamonian								
0.7		Illinoian			*Globoquadrina dutertrei*			N. 22		
		Yarmouthian								
		Kansan	Sicilian							
		Aftonian	Emilian		*Globorotalia tosaensis*					
2.0		Nebraskan	Villafranchian (continental) Calabrian							
2.8	PLIOCENE		Astian (regressive)	*Pulleniatina obliquiloculata*	Not subdivided			N. 19,20,21		
3.0			Plaisancian			*Globoquadrina altispira*	UPPER MIOCENE			
3.3			Tabianian	*Globorotalia margaritae*	*Pulleniatina primalis*	*Globorotalia margaritae*		N. 18	MIDDLE TO LATE MIOCENE	MESSINIAN
					Globorotalia multicamerata			N. 17		
6	MIOCENE	LATE	Messinian - Tortonian	*Globorotalia acostaensis*	*Sphaeroidinellopsis sphaeroides*	*Globigerina dutertrei*				
					Sphaeroidinellopsis seminulina	*Globorotalia acostaensis*	MIDDLE MIOCENE	N. 16		TORTONIAN
			boundary arbitrary							
		MIDDLE	"Helvetian"	*Globorotalia menardii*	Not subdivided	*Globorotalia menardii*		N. 15		
				Globorotalia siakensis	Not subdivided	*Globorotalia mayeri*		N. 14		SERRAVALLIAN
						Globigerinoides ruber		N. 13		
12				*Globorotalia fohsi robusta*	Not subdivided	*Globorotalia fohsi robusta*	LOWER MIOCENE	N. 12		
				Globorotalia fohsi lobata	Not subdivided	*Globorotalia fohsi lobata*		N. 11		

In essence, the *Globorotalia menardii/Globorotalia nepenthes* Zone of BLOW (1959) extends the *Globorotalia menardii* Zone of Trinidad upward to include the earliest occurrence of *Globorotalia acostaensis.* Although BLOW (1959) defined a provisional *Sphaeroidinella seminulina* Zone and a *Globigerina bulloides* Zone higher in the Pozón Formation, BOLLI & BERMÚDEZ (1965) and others recognized that these stratigraphic intervals are unfavorable for optimum development of a planktonic foraminiferal facies and, therefore, are unsuitable for regional zonal application.

BOLLI & BERMÚDEZ (1965) extended the Trinidad zonation of BOLLI (1957) upward from the *Globorotalia menardii* Zone to what they considered late Miocene at the time, but which BOLLI now considers to be Pliocene (see Fig. 3, right column). BANNER & BLOW (1965a, 1967) and BLOW (1967) also described a planktonic zonation for the younger Neogene, but this presently is only partially documented (Table 1). We regard the biostratigraphic framework of these authors as broadly applicable to zonation within the Caribbean and Gulf of Mexico but have found the application of their zones to detailed correlation presents many uncertainties. The present approach utilizes more of the commonly occurring and widely distributed planktonic species whose stratigraphic ranges now are precisely determined.

Although the major part of the present study focuses on the Caribbean and Gulf of Mexico regions (Fig. 12), planktonic successions within the late Neogene were studied for numerous other localities along the Pacific border of Guatemala, Nicaragua, Ecuador, and Panama. Deep-sea cores from the Atlantic Ocean also were obtained and studied. The biostratigraphy of these regions in no way controverts the data presented here.

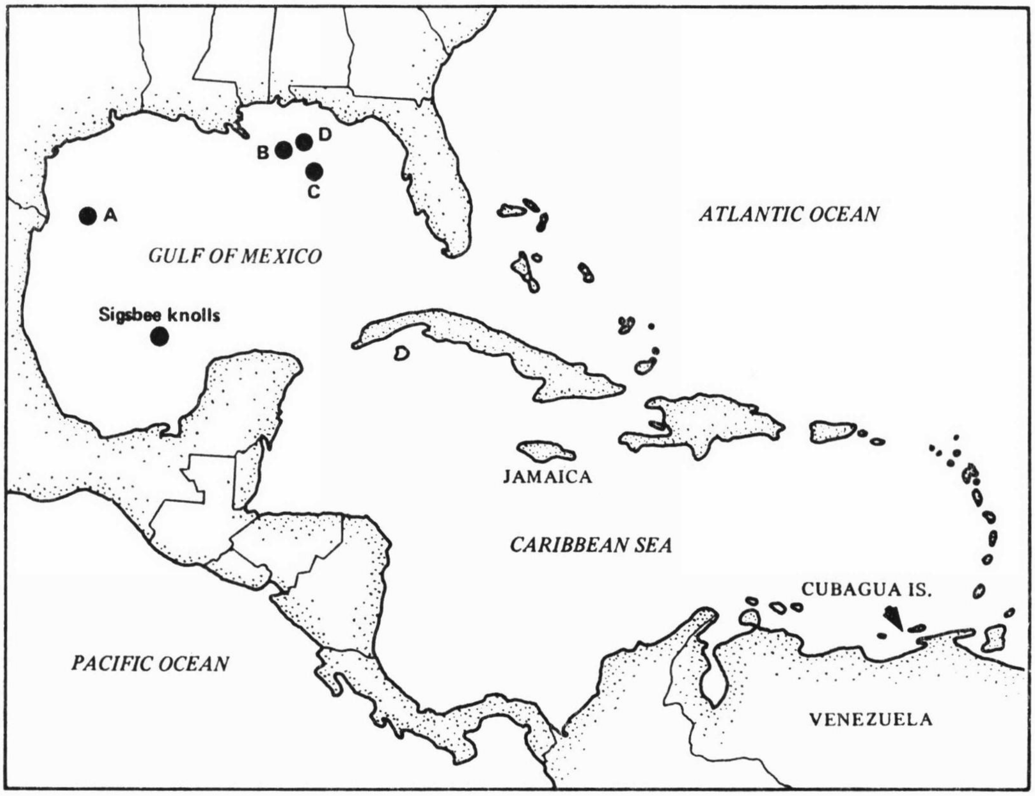


FIG. 12. Location of Caribbean and Gulf of Mexico stratigraphic sections included in present study.

NO. 1 CUBAGUA, VENEZUELA

The southern Caribbean region offers little in the way of continuous sequences of middle to late Miocene sediments containing planktonic foraminifers. In Trinidad, Venezuela, and much of Central America, marine strata of late middle Miocene age characteristically are terminated upward by shallowing of facies that are unfavorable for planktonics, and by erosional truncation or both. Late Miocene and younger sediments are rather widespread, however, and mostly lie unconformable on older rocks.

In the western end of the Araya Peninsula and on the islands of Cubagua and Margarita in eastern Venezuela, sediments of late Miocene to Pleistocene age unconformably overlie older, tectonically deformed strata. The stratigraphic column on the Araya Peninsula, as described by CALASSO (1965), is as follows:

Sequence of Stratigraphic Units on Araya Peninsula

Pliocene and Pleistocene	Marine terraces	
—— unconformity ——		
Lower Pliocene	Barrigón Formation	
Upper Miocene	Cubagua Formation	Cerro Negro Member Cerro Verde Member
Lower and middle Miocene	Basal conglomerate	
—— unconformity ——		
Pre-Miocene	Metamorphic rocks	

BERMÚDEZ (1966) and BERMÚDEZ & BOLLI (1969) discussed the regional biostratigraphic relationships of the Miocene and younger sediments of coastal Venezuela and included a review of the planktonic and benthonic foraminifers from the Socony-Vacuum Nos. 1 and 2 Cubagua drilled on Cubagua Island to the north of the Araya Peninsula. They equated the Barrigón Formation of CALASSO (1965) with the Cumaná Formation and maintained that it rests unconformably on the Cubagua Formation on both the Araya Peninsula and Cubagua Island. They dated the Cerro Verde Member of the Cubagua Formation as middle Miocene, the Cerro Negro Member as mostly late Miocene, and the Cumaná Formation as Pliocene. BOLLI (in CATI & BORSETTI, 1968), however, considered the Cerro Verde Member as late Miocene and the Cerro Negro Member as Pliocene with respect to Italian biostratigraphy. STAINFORTH (1969) evaluated the ages of Neogene formations in Venezuela with respect to the studies and recommendations of the CMNS. He

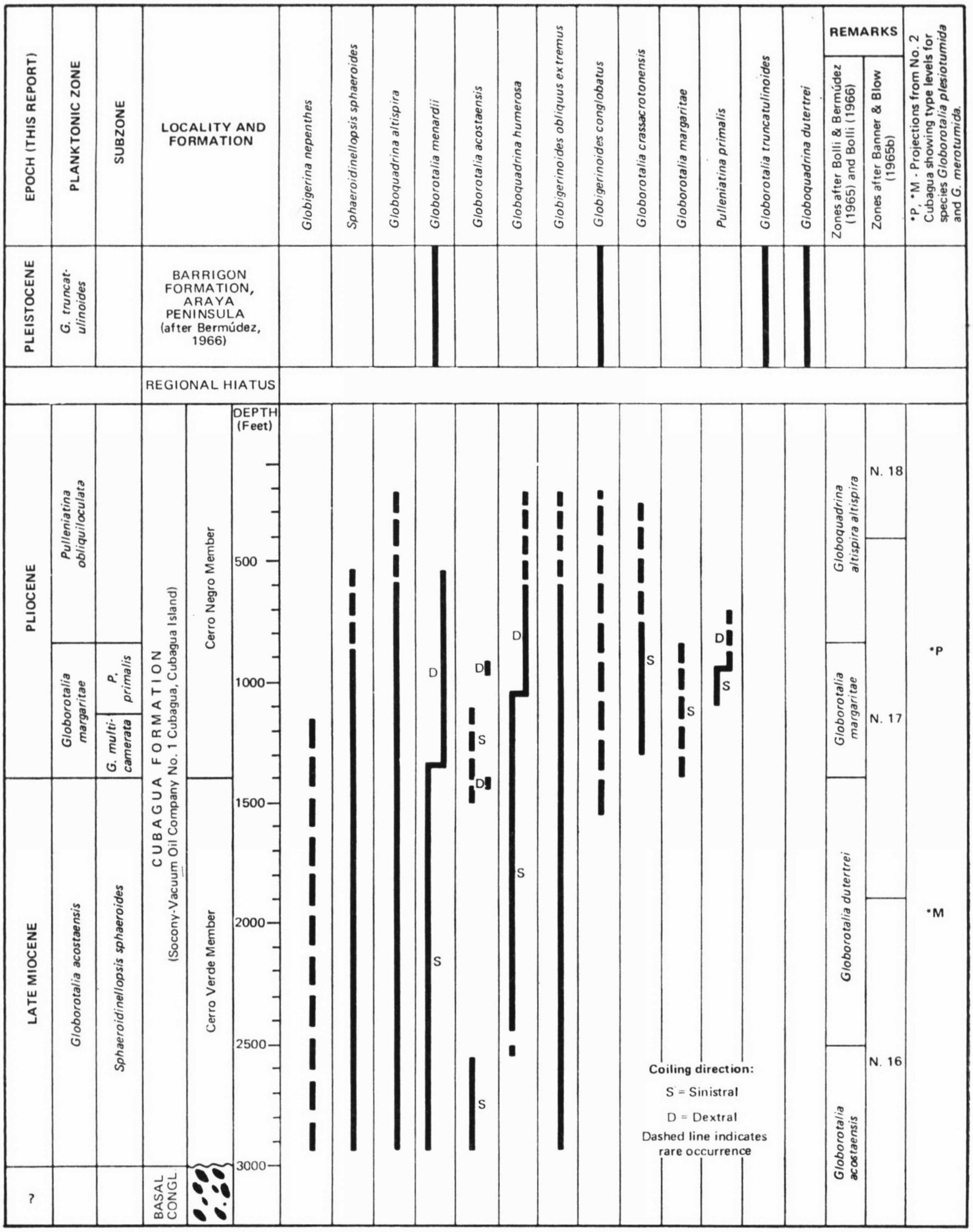


FIG. 13. Stratigraphic distribution of planktonic foraminifers from Cubagua Island and the Araya Peninsula, Venezuela.

recommended that the ages applied to late Neogene formations of coastal Venezuela be revised accordingly.

The No. 1 Cubagua penetrates approximately 3,000 feet of the Cubagua Formation, which thins to less than 300 feet on the peninsula. The Cubagua Formation was cored continuously, and most of the section is rich in planktonic foraminifers. This well is the type locality for three of the "upper Miocene" planktonic zones described by Bolli & Bermúdez (1965) and is significant as a reference section for the late Neogene succession in the southern Caribbean region.

A nearly continuous suite of cores from this well was studied, and ranges of stratigraphically important planktonics were charted (Fig. 12). On the right-hand column

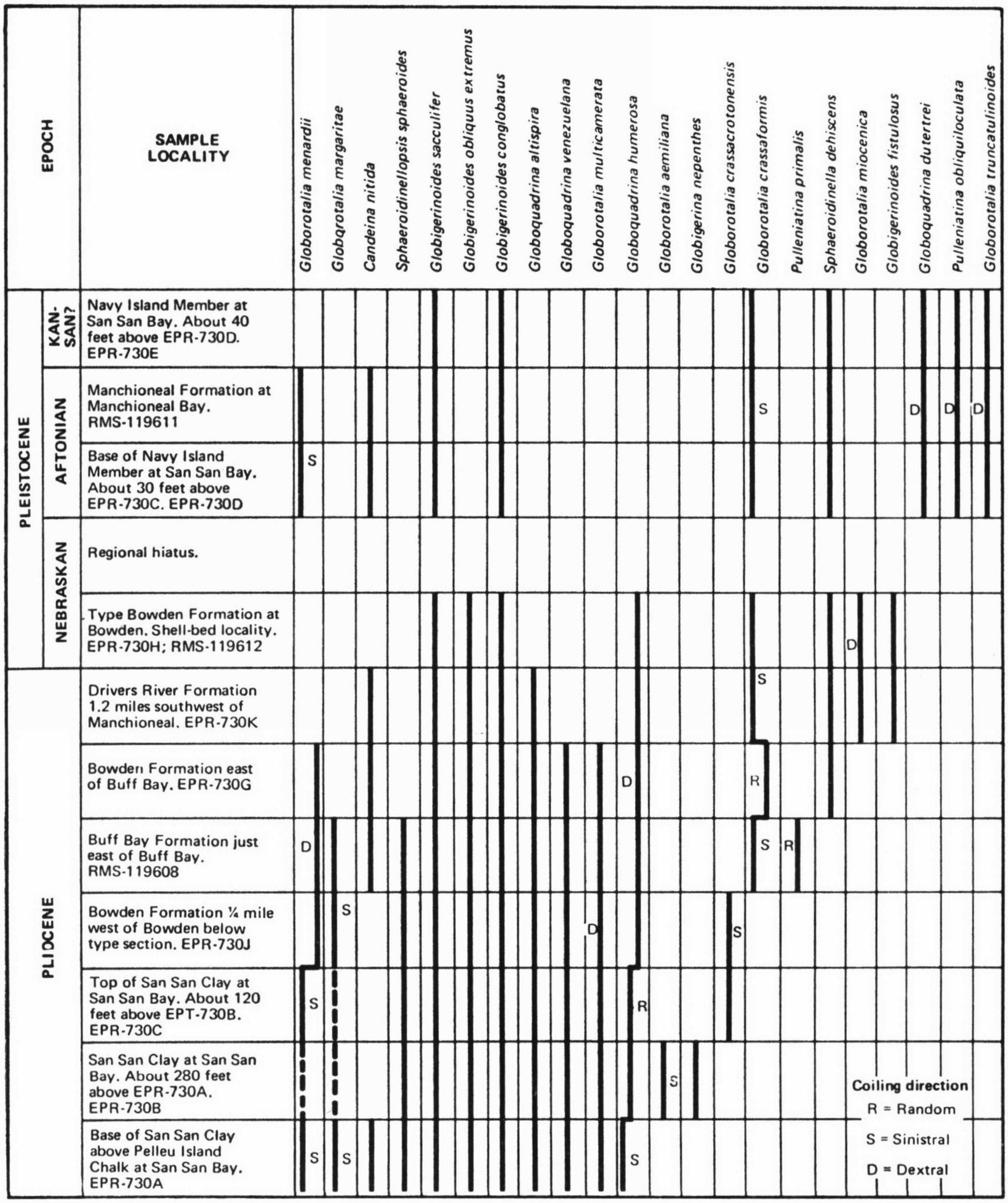


Fig. 14. Stratigraphic distribution of planktonic foraminifers from Jamaica, West Indies. Dashed lines indicate rare occurrences.

of Figure 13 several stratigraphic interpretations are explained. Nomenclatural differences are as follows:

Divergent Nomenclature of Planktonic Foraminiferal Sequences

This paper	BOLLI (in BERMÚDEZ, 1966)
Sphaeroidinellopsis sphaeroides	*Sphaeroidinella seminulina*
Globoquadrina humerosa	*Globorotalia dutertrei* (in part)
Globigerinoides conglobatus	*Globigerinoides canimarensis*
Globorotalia crassacrotonensis	*Globorotalia puncticulata*
Pulleniatina primalis	*Pulleniatina semiinvoluta*

BANNER & BLOW (1965b) described *Globorotalia merotumida* and *G. plesiotumida* from the nearby No. 2 Cubaga well, and attached significant importance in their Neogene zonation to the ranges of these species. Although these species could not be recognized in the No. 1 Cubagua well, the stratigraphic position of their type levels is projected into the section using the first appearance of *Pulleniatina primalis* (which occurs in both wells) as a reference horizon.

The late Neogene section on the island of Cubagua demonstrates 1) a late Miocene to early Pliocene passage with influx of the typical early Pliocene species *Globorotlaia margaritae, G. crassacrotonensis,* and *Pulleniatina primalis,* 2) a shallowing of facies upward in the middle Pliocene which is followed by erosional truncation, and 3) an overstep by a seemingly warm-water Pleistocene (Aftonian?) sequence around the island margin. Because the well was drilled on a structural high, young Pliocene sediments around the periphery of the island were not penetrated at the well location. The hiatus between the Pliocene and Pleistocene probably represents lowering of sea level during early Pleistocene glaciation.

COASTAL GROUP, JAMAICA, WEST INDIES

The most continuous and fossiliferous exposures of late Neogene sediments in the Caribbean region are in the Coastal Group on the island of Jamaica. These were brought to the attention of foraminifer workers by publications of CUSHMAN & JARVIS (1930), CUSHMAN & TODD (1945), PALMER (1945), and others. Presently, however, no comprehensive stratigraphic treatment of the several formations and their microfaunas has been published.

Random surface collections were made by the Creole Petroleum Corporation and Esso Production Research Company under the field guidance of Dr. EDWARD ROBINSON of the University of the West Indies; studies on these samples gives a preliminary interpretation of the planktonic succession within the late Neogene series (Fig. 14). Concurrent stratigraphical research by ROBINSON also has clarified much of the formational nomenclature of the coastal sequences and the distribution of the planktonic foraminifers.

The stratigraphic distribution and coiling directions of selected planktonic species of the Coastal Group were given by ROBINSON (1969a); he also prepared a geological guide to Neogene sections (1969b) for a field excursion to the island by 19th Annual Convention of the Gulf Coast Association of Geological Societies and the Society of Economic Paleontologists and Mineralogists. Excerpts from the stratigraphical nomenclature of this publication are shown on Figure 15.

A preliminary account of the planktonic biostratigraphy of the Coastal Group was supplied by ROBINSON for inclusion here (Fig. 16). The middle to late Miocene passage is seen in the type Buff Bay Formation with the earliest occurrence of *Globorotalia acostaensis* and *G. plesiotumida.* Within the lower part of the San San Clay *G. acostaensis* continues upward and *Sphaeroidinellopsis sphaeroides, Globoquadrina humerosa,* and *Globigerinoides conglobatus* first appear. Early Pliocene begins in the upper part with *Globorotalia margaritae, G. crassaformis* gens, and *G. multicamerata.*

Within the Upper Buff Bay Formation the early-late Pliocene passage is indicated by the last occurrence of *G. margaritae; Sphaeroidinellopsis sphaeroides* continues upward and *Pulleniatina primalis* makes its first appearance. *Sphaeroidinella dehiscens* appears in late Pliocene and is followed upward by *Globorotalia miocenica.*

Within the Drivers River Formation latest Pliocene and earliest Pleistocene are characterized by extinction of warm-water species, such as *Globoquadrina altispira* and *G. venezuelana,* and withdrawal of *Globorotalia menardii* from these latitudes. *Globorotalia multicamerata* continues upward into earliest Pleistocene whereas *G. miocenica* and *G. tosaensis* range throughout the formation. A detailed account of the biostratigraphy and paleomagnetic stratigraphy of the Drivers River Formation is given by ROBINSON & LAMB (1970). They show all of the Drivers River Formation to be within the Gauss Epoch and extinction of *G. altispira* is above the Kaena event. Thus, we see the first evidence for onset of late Neogene climatic deterioration in Jamaica within the Drivers River Formation (in the upper Gauss Epoch) at about 2.8 m.y. age.

The upper part of the Bowden Formation, including the "shell-bed locality" above the extinction horizon of *Globoquadrina altispira,* was assigned previously to the Miocene by WOODRING (1925, 1928). Although recorded by PALMER (1945) from the Bowden Formation, *Globorotalia truncatulinoides* was not found in the present study below the Manchioneal Formation or Navy Island Member. ROBINSON (1967) discussed the extinction level of *G. altispira* in Jamaica and the widespread unconformable contact between the Bowden and Manchioneal Formations. Although ROBINSON (personal communication) maintains that shallowing of facies very definitely com-

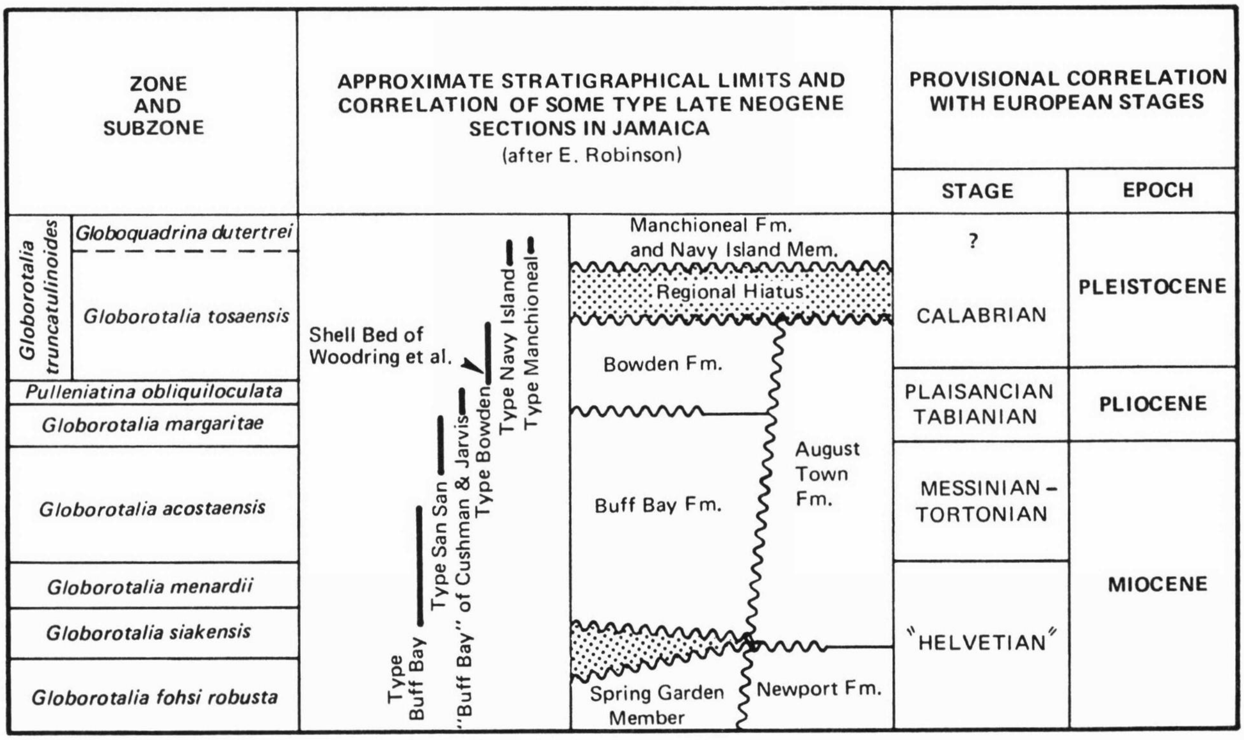


FIG. 15. Stratigraphic evaluation of some type late Neogene sections in Jamaica, West Indies.

mences some distance above the "shell-bed locality," he is not entirely convinced that a sea-level change is the sole contributing cause; regional tectonism also could be a factor.

The inference here is that the extinction level of *Globoquadrina altispira,* as well as the disappearance of other warm-water species at this stratigraphic level, is symptomatic of severe climatic deterioration in the Caribbean region. In a climatic sense, this is interpreted to be the onset of the Nebraskan Stage and of continental glaciation.

Shallowing above the Bowden shell bed seems to be glacioeustatically influenced, and the regional unconformity between the Bowden and Manchioneal Formations (including the Navy Island Member) reflects maximum lowering of sea level during the Nebraskan Stage.

Globorotalia menardii reappears a few feet above the base of the Navy Island Member of the Manchioneal Formation at San San Bay and is followed upward by the extinction of *G. tosaensis* and the first local occurrence of *G. truncatulinoides.* We concur with ROBINSON (1968) that the lower part of this member correlates with the transgressive Aftonian interglacial Stage which is followed upward by a regression corresponding to the Kansan glacial Stage.

SIGSBEE KNOLLS CORE, CENTRAL GULF OF MEXICO

According to BRYANT & PYLE (1965), "The first known occurrence of considerable thickness of non-turbidite sediment in the Sigsbee Deep of the Gulf of Mexico was sampled recently on a cruise of Texas A. & M. University's research vessel Alaminos. A 550-cm core (no. 64-A-9-5E) was collected June 5, 1964, from a depth of 3,536 m at 23°50′N., 92°24.5′W. The core was taken near the crest of one of the Sigsbee Knolls at an elevation of 152 m above the abyssal plain."

The sediment core has been the subject of several public discussions by earth scientists of the Texas A. & M. University (BRYANT & PYLE, 1965; PYLE, 1966, 1968), and of the Esso Production Research Company (GARTNER, 1967; BEARD & LAMB, 1968). Continuing attention has focused on this core because of its penetration of Pleistocene, Pliocene, and late Miocene sediment which record the late Neogene history of deposition in the central Gulf of Mexico during the past 10 million years. From faunal and physical evidence PYLE (1968) concluded that the deposition in deep water, the remarkably low rate of sedimentation, the presence of authigenic minerals, and the lack of faunal and lithologic indications of turbidites may be explained reasonably by the conclusion that the site of the deposition was on a "Sigsbee knoll" which existed in the late Miocene.

The stratigraphic distribution of species in this core (Fig. 17) is modified slightly from PYLE (1968) and BEARD & LAMB (1968) to account for new data. Interpretation of the early Pleistocene was reevaluated after discovery that the cored interval from depths of 150 to 160 cm is slightly mixed. Below 150 cm the core is regarded confidently as intact, and possible sources of contamination were carefully evaluated by visual inspection of the core, reprocessing for foraminifers at different times, and examination of nannofossil assemblages for mixing. Above 150 cm the core was disturbed in the coring process and was not studied.

The lower portion of the core which contains *Globigerinoides conglobatus* and *Globorotalia acostaensis* is dated as late Miocene. The appearance of *Globorotalia margaritae* begins the early Pliocene, and the appearance of the *G. crassaformis* lineage (i.e., the species *G. aemiliana* and *G. crassacrotonensis*) begins the middle Pliocene. An impressive number of species having modern affinities begin in the middle Pliocene, imparting a modern appearance to the assemblages.

The beginning of late Pliocene is chosen arbitrarily at the horizon of withdrawal from the region of thermophile species of the *Pulleniatina* tribe, which indicates cooling of the water mass. This horizon may correspond with a minor faunal-temperature change suggested near the end

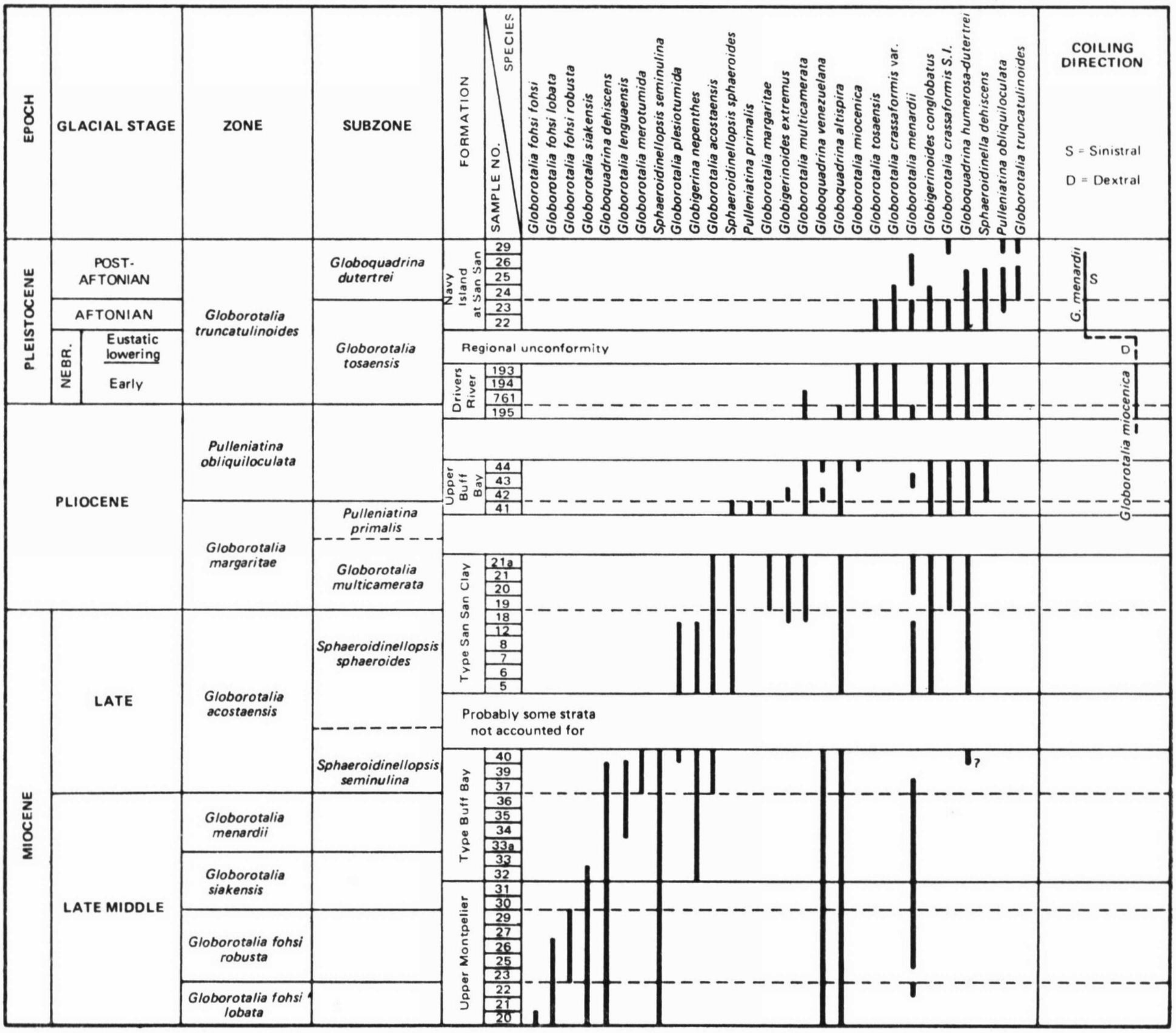


FIG. 16. Stratigraphic distribution of planktonic foraminifers in the Coastal Group of Jamaica, West Indies (after ROBINSON, personal communication).

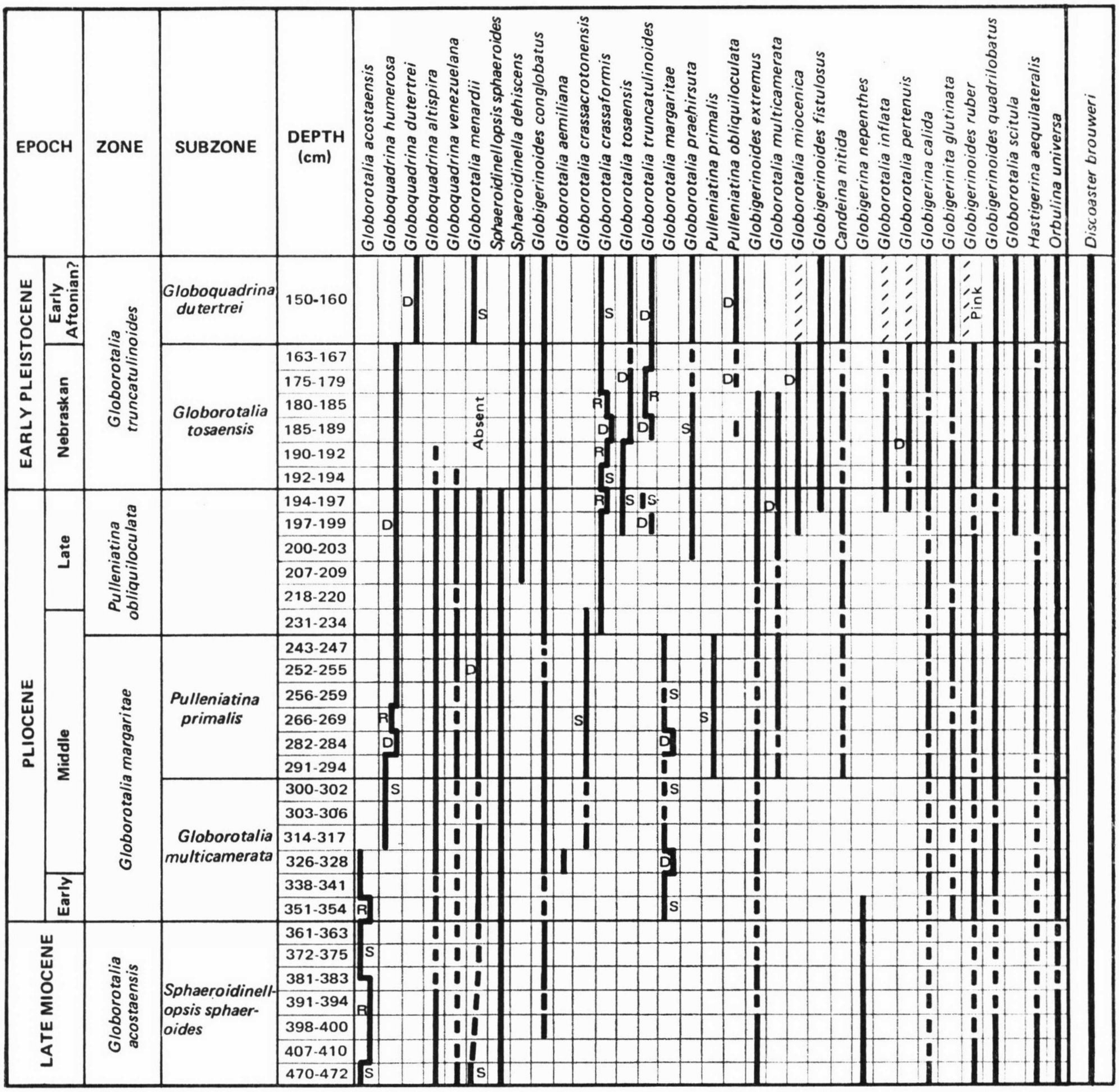


FIG. 17. Stratigraphic distribution of planktonic foraminifers in Sigsbee knolls core (64-A-9-5E), Gulf of Mexico, collected by Texas A. & M. University. Coiling direction: R—random, S—sinistral, D—dextral. Dashed line indicates very rare or discontinuous occurrence. Hachures denote contamination or mixed assemblage noted in text. (Modified after BEARD & LAMB, 1968.)

of the middle Pliocene in the Italian region (see COLALONGO, 1968, Table 1). In late Pliocene the distinctive species include *Globoquadrina altispira, G. venezuelana, Sphaeroidinella dehiscens* (with flangelike lips), *Globorotalia tosaensis* (not common), *G. miocenica,* and *G. multicamerata.* Continued cooling towards the very late Pliocene is shown by the entry of the northern cool-water immigrant species *G. inflata.* A reduction in frequency of *G. menardii* also is apparent.

The onset of severe climatic deterioration, or beginning of the Pleistocene, is clearly marked in this core by the nearly abrupt extinction of *Globoquadrina altispira* and *G. venezuelana* and withdrawal from the region of *Globorotalia menardii* (right coiled) and increase in the abundance of *G. inflata.* In terms of Gulf Coast Pleistocene nomenclature, this is the beginning of the Nebraskan glacial Stage.

Globorotalia truncatulinoides appears for the first time somewhat above the base of the Pleistocene. The rare specimens of this species found in the Pliocene interval of this core are considered contaminants because of their seemingly advanced evolutionary development. We are unable to support an earlier contention (BEARD & LAMB, 1968) that the life ranges of *Globoquadrina altispira* and *G. truncatulinoides* overlap. Their joint occurrence in rare instances seems to be best explained by mixing or contamination.

Globorotalia multicamerata and *Globigerinoides extremus* die out within the Nebraskan of this core and *Globorotalia miocenica* near the end of the Nebraskan. The end of the Nebraskan glacial and the beginning of the Aftonian interglacial is marked by the sudden and common reappearance of *G. menardii* (left coiled) and the introduction of advanced forms of *Pulleniatina obliquiloculata*. Some contaminants were identified in the upper part of this core by their coloration (i.e., pink *Globigerinoides ruber*), preservational aspect, and uncommon stratigraphic occurrence. *Discoaster brouweri* occurs in all samples.

GULF COAST SLOPE CORES, NORTHERN GULF OF MEXICO

Geological investigations along the continental slope of the northern Gulf of Mexico were initiated in January 1966 as a joint venture of Humble Oil & Refining Company, Chevron Oil Company, Gulf Oil Corporation, Socony Mobil Oil Company, and Esso Production Research Company. Core holes were drilled in water depths ranging from 2,676 to 4,384 feet; sediment penetration was about 1,000 feet.

The drilling program was designed to core 15 feet and drill 45 feet alternately, with a possible core recovery of 25 percent for the interval penetrated. About five samples from each core (297 samples in all) were processed for foraminifers and nannofossils. Four of the core holes contain a nearly complete late middle Miocene to Holocene sequence of planktonic marl; these were selected for detailed paleontological analysis (Fig. 12). Planktonic foraminifers from the greater-than-0.62 mm fraction were identified and their direction of coiling noted. Stratigraphic occurrences of *Discoaster brouweri* were charted by LEE A. SMITH.

These richly fossiliferous slope sediments provide knowledge of the successive planktonic assemblages not commonly obtainable in shallow-shelf environments. Their study, therefore, has aided materially in defining the stratigraphic distribution of planktonic foraminifers in the northern Gulf of Mexico.

The concept of alternations of glacial and interglacial stages in the marine shelfal environment of the northern Gulf of Mexico was introduced by AKERS & HOLCK (1957) and AKERS & DORMAN (1964). Although the paleobathymetric (glacioeustatic) changes reported by these authors could not be identified in the deep-slope environment of the present study, their concept of warm and cold alternations of Pleistocene stages is recognized and applied to the planktonic assemblages.

SLOPE CORE HOLE A

This site on the west side of the Gulf of Mexico about 100 nautical miles east of Brownsville, Texas (latitude 26°03.5′N; longitude 95°44.7′W), was drilled and cored alternately. The core hole is on the flank of a basin in 3,765 feet of water. Total penetration was 928 feet. A total of 16 cores were taken, and 4 to 5 samples from each core (77 in all) were processed routinely for foraminifers. At total depth the core hole had penetrated middle Eocene strata unconformably below late middle Miocene sediments. Late Eocene and early Miocene are not represented except possibly in the uncored interval below core 14 (Fig. 18).

The interval between core 12 and core 14 is late middle Miocene, being characterized by *Sphaeroidinellopsis seminulina* and *Globorotalia acostaensis* (left coiled). *Globorotalia lenguaensis* was not found above core 13.

The Miocene-Pliocene boundary (BEARD & LAMB, 1968) is between core 10 and core 11 as *Globorotalia margaritae* first occurs in core 10. At this level *Globoquadrina humerosa* and *Globorotalia multicamerata* appear. The coiling change in the *G. menardii* complex from dominantly left to dominantly right occurs within core 10. *Pulleniatina primalis* (left-coiled) and *Globorotalia crassacrotonensis* (left-coiled) occur in core 9 but were not found above or below this level.

A pronounced faunal change occurs between cores 8 and 9. *Globigerina nepenthes, Pulleniatina primalis* (right-coiled), and *Globorotalia margaritae* (left-coiled) were not found above core 9 whereas *Globorotalia tosaensis, Globorotalia miocenica s.s., Globorotalia pertenuis, Sphaeroidinella dehiscens* (with multiple flange-like apertures), *Globorotalia crassaformis* (right-coiled), and *G. inflata* first appear in core 8. The concurrent ranges of *Sphaeroidinella dehiscens* and *Globoquadrina altispira* (core 8) characterize late Pliocene in the Gulf of Mexico and Caribbean and provide an important reference horizon for worldwide correlation.

The last occurrence of *Globoquadrina altispira, Globoquadrina venezuelana,* and *Globorotalia multicamerata,* which marks the Pliocene-Pleistocene boundary, is between cores 7 and 8. *Globorotalia truncatulinoides* and *G. altispira* were not found together in this core hole. *Pulleniatina obliquiloculata* (right-coiled) occurs in reduced numbers in the top of core 7.

Globorotalia miocenica and *G. pertenuis,* which are the right-coiling members of the *G. menardii* complex, are not found above core 7. The concurrent ranges of

G. truncatulinoides and these right-coiling members of the *G. menardii* complex defines an important planktonic event in the Gulf of Mexico that is a valuable guide for correlation with other parts of the world.

The first "abundant" appearance of ***Globorotalia truncatulinoides*** (left-coiling) is in core 5. ***G. tosaensis*** and ***G. inflata*** variants were not found above **core 6.** ***Globoquadrina dutertrei*** and ***Pulleniatina obliquiloculata*** are

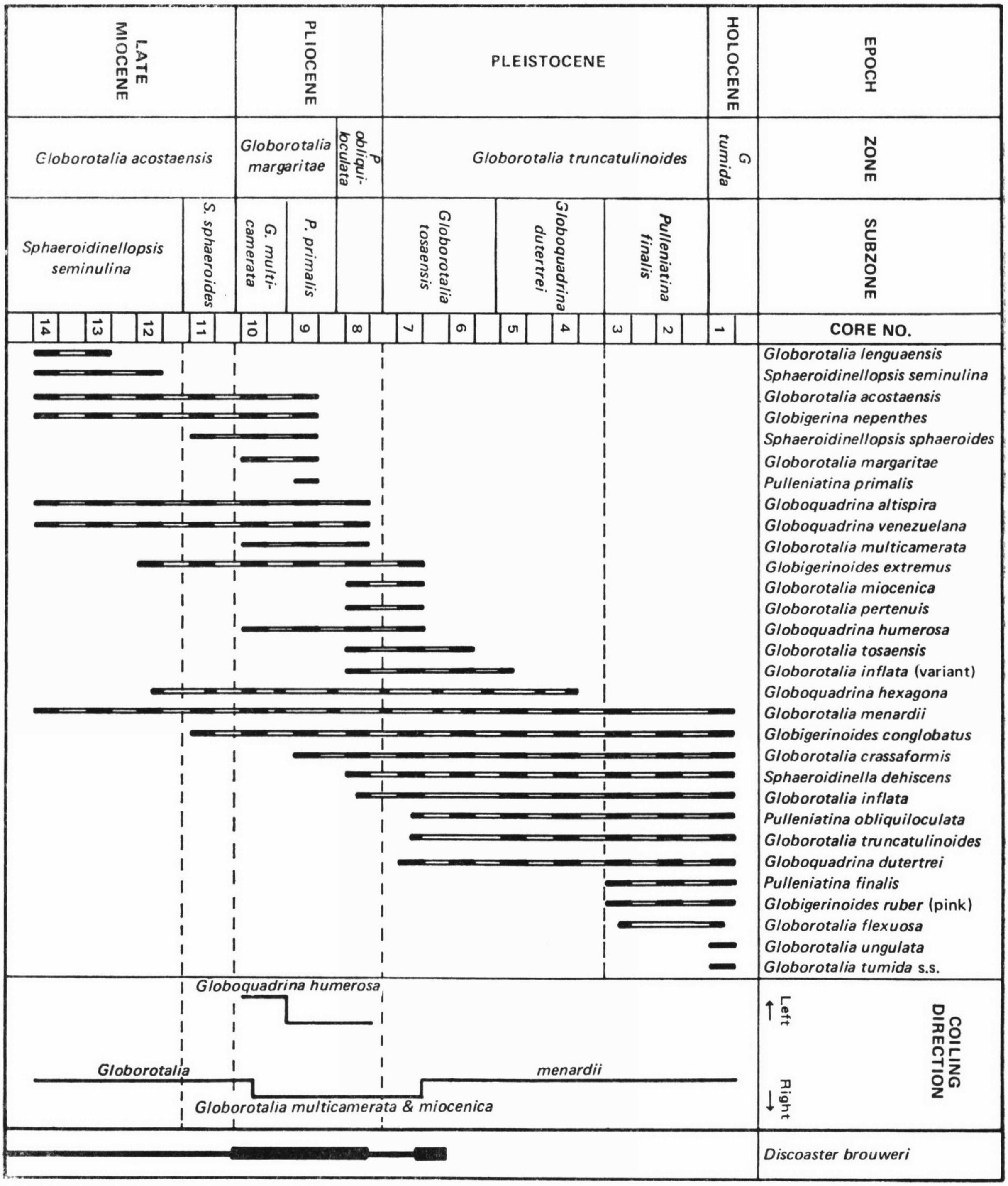


FIG. 18. Stratigraphic distribution of planktonic foraminifers in slope core hole A, Gulf of Mexico.

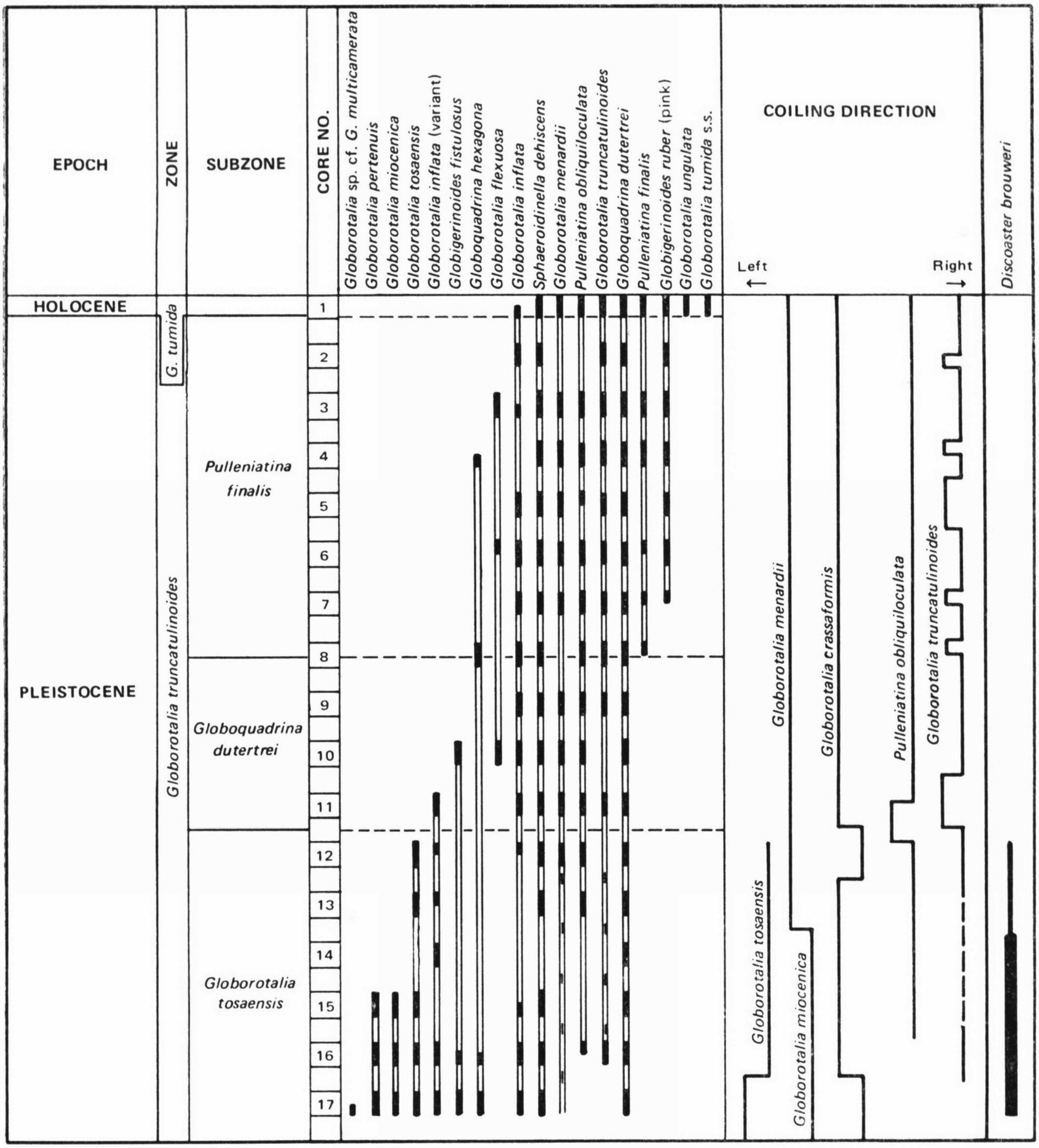


FIG. 19. Stratigraphic distribution of planktonic foraminifers in slope core hole B, Gulf of Mexico.

commonly present in cores 1 through 5, and *Globorotalia flexuosa* is restricted to this interval. *Globoquadrina hexagona* was not recorded above core 4.

Globorotalia inflata, G. tumida, and *G. ungulata* occur together in the upper part of core 1; this association characterizes the very late Pleistocene-to-Holocene transition.

SLOPE CORE HOLE B

This site was drilled and cored alternately on the lower continental slope northwest of De Soto Canyon

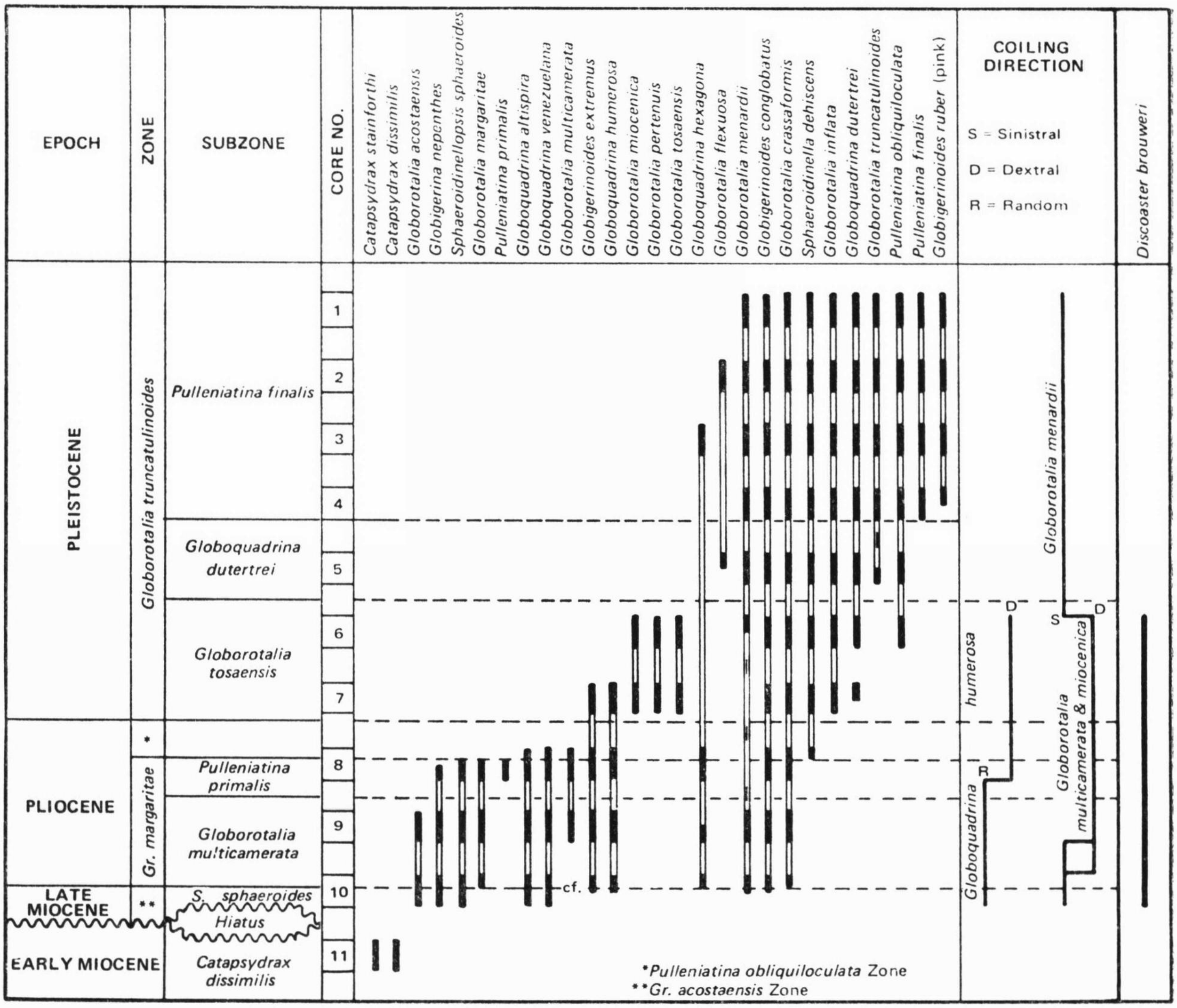


FIG. 20. Stratigraphic distribution of planktonic foraminifers in slope core hole C, Gulf of Mexico.

(latitude 29°06.5′N; longitude 87°45.3′W). Water depth at the drill site is 4,384 feet; depth of penetration was 1,000 feet. A total of 17 cores were taken and about 5 samples from each core (90 in all) were processed routinely for foraminifers.

The cores from this hole seemingly represent a nearly complete Pleistocene section which is expanded sufficiently to allow recognition of evolutionary changes in the fauna. Thus, it provides an invaluable reference for correlation with shelf deposits and for establishing a model of Pleistocene chronology.

At total depth the core hole is in Nebraskan (earliest Pleistocene) above the extinction level of *Globoquadrina altispira* and *G. venezuelana* (Fig. 19). The Pliocene-Pleistocene boundary falls below core 17. The first appearance of *Globorotalia truncatulinoides* is in core 16; no specimen of this species was found in core 17. This level is near the first evolutionary appearance of *G. truncatulinoides* (keeled) because some specimens are transitional to *Globorotalia tosaensis* (last one or two chambers not keeled). The relative abundance is low, however, when compared with later occurrences. *G. truncatulinoides* (left-coiled) is abundant in core 11 and becomes a dominant member of the planktonic assemblage in core 9. This species was not found in core 10 and in cores 12 through 15. The sporadic distribution of *G. truncatulinoides* is well demonstrated in this expanded section.

The interval from the top of core 17 to the top of core 15 consists of coarse, sandy (10 to 15 percent) clay whereas the lower part of core 17 lacks sand but contains about 10 percent planktonic foraminifers. The change from pelagic clay to coarse, sandy clay is significant as an indication of the local base of the regressive (glacio-eustatically controlled) early Pleistocene sand. In this case it is below the first occurrence of *G. truncatulinoides* and above the extinction of *Globorotalia altispira*.

Globorotalia miocenica and *G. pertenuis* (both right-coiled) are abundant in cores 14 through 17 but are not found above. Significantly, the concurrent range of *G. truncatulinoides* and the above-mentioned species covers an interval of about 175 feet. The coiling change in the *G. menardii* complex, a consistent level in the slope core holes, occurs between cores 13 and 14. *Globorotalia tosaensis* and discoasters do not occur above core 12.

The first "abundant" occurrence of *G. truncatulinoides* (left-coiled) is in core 11. *Globoquadrina dutertrei* (highly turbinate forms) occurs abundantly in core 12, and *Globorotalia inflata* variant is not found above core 11. Significantly, *Pulleniatina obliquiloculata* (left-coiled) occurs commonly in the lower part of core 11. *Globoquadrina hexagona* was not found above the lower part of core 4 and *Globorotalia flexuosa* was not found commonly above core 3. The last occurrence of *G. inflata* is in core 1; the abundance of *G. tumida* and *G. ungulata* above this indicates that several feet of Holocene (post-glacial) sediments are present at the top of the core hole.

SLOPE CORE HOLE C

This site was drilled and cored alternately off the west coast of Florida (latitude 28°45.9′N; longitude 87°20.7′W) to investigate areas where carbonate sediments now are being deposited. Depth of water at the drill site is 4,060 feet; total sediment penetration is 1,000 feet. Late Miocene to late Pleistocene strata were logged unconformably above a seemingly continuous sequence of late Eocene to early Miocene strata (Fig. 20).

In the lower part of core 10 a late Miocene assemblage includes *Sphaeroidinellopsis sphaeroides*, *Globorotalia acostaensis*, and *Globigerinoides extremus*. Higher in the same core the early Pliocene is marked by the occurrence of *Globorotalia margaritae; G. multicamerata* appears just above in core 9. In core 8 *Globigerina nepenthes*, *Globorotalia margaritae*, and *Pulleniatina primalis* are confined to the lower part, and *Sphaeroidinella dehiscens* and *Globorotalia crassaformis* appear in the upper part. The Pliocene-Pleistocene passage in this core hole is marked by the extinction of such warm-water species as *Globoquadrina altispira* and *G. venezuelana* (between cores 7 and 8) and the entry of the cold-water immigrant species *Globorotalia inflata* in core 7.

The first appearance of abundant *Globorotalia truncatulinoides* is in core 4; the first actual appearance of this species apparently was missed in uncored intervals. *Globoquadrina dutertrei*, *Globorotalia inflata*, and *Pulleniatina obliquiloculata* occur commonly in cores 1 to 5, and *Globorotalia flexuosa* is restricted to this interval. The last occurrence of *Globoquadrina hexagona* is in core 3; core 1 apparently is below Holocene (post-glacial) sediments.

SLOPE CORE HOLE D

This site was drilled and cored alternately in the northeastern part of the Gulf of Mexico in the De Soto submarine canyon (latitude 29°16.4′N; longitude 87°00.3′W) in 2,676 feet of water. Total sediment penetration was 1,000 feet. About midway in this core hole, Pleistocene beds lie unconformably upon late middle Miocene strata (Fig. 21) containing *Globorotalia fohsi* Zone *sensu lato* markers. The highest occurrence of *Globorotalia siakensis* is in core 12 and the last *G. lenguaensis* is in core 10. The bottom of core 8 contains planktonic assemblages of different ages.

An early Pleistocene assemblage with *Globorotalia miocenica*, *G. pertenuis*, and *G. tosaensis* occurs in the upper part of core 8 along with the cold-water immigrant species *G. inflata*. A coiling change in the *G. menardii* "complex" is seen between cores 7 and 8. The first appearance of *G. truncatulinoides* in abundance occurs in the top of core 7 although the earliest actual appearance of this species probably was not seen because a portion of the Pleistocene is missing in this core hole.

Globoquadrina dutertrei, *Pulleniatina obliquiloculata* (dextral), and *Globorotalia truncatulinoides* occur commonly in cores 1 to 7. *Globoquadrina hexagona* was not seen above core 3, and large forms of *Globorotalia tumida* were not encountered. Core 1 was taken apparently below Holocene (post-glacial).

PLANKTONIC ZONES

BASIS FOR ZONATION

The succession of planktonic foraminifers within the late Neogene of the Caribbean, Gulf of Mexico, and Italy is discussed in preceding parts of the present report, and stratigraphic ranges of important guide species are given in Table 2 within the framework of the standard geologic time scale as developed in Italy. Alternations of warm- and cold-water planktonic assemblages in Gulf of Mexico slope cores were determined in a separate study; relationships to the planktonic zones and to North American glacial stages are shown on Figure 22.

Not all species common to the warm-water Caribbean and Gulf of Mexico regions are represented in the late Neogene of Italy because stratigraphic distribution of such species at a particular place depends largely on the circulation of ancient oceanic water masses. Although definitive faunal correlation can be made between the American areas and Italy by utilizing common species (Fig. 23-24), criteria for dating and correlating locally (i.e., within water masses of the same temperature) obviously need to be developed using the total planktonic fauna. The Pliocene planktonic zones proposed by Italian authors, for example, can be applied partly to zonation in more southerly areas, but a local zonation based on indigenous warm-water species is more appropriate and practical. As ocean temperatures are known to influence the latitudinal distribution of modern planktonic species, a worldwide hierarchy of finely defined planktonic zones, including all known late Neogene species, cannot be compiled until the stratigraphic ranges of the species oc-

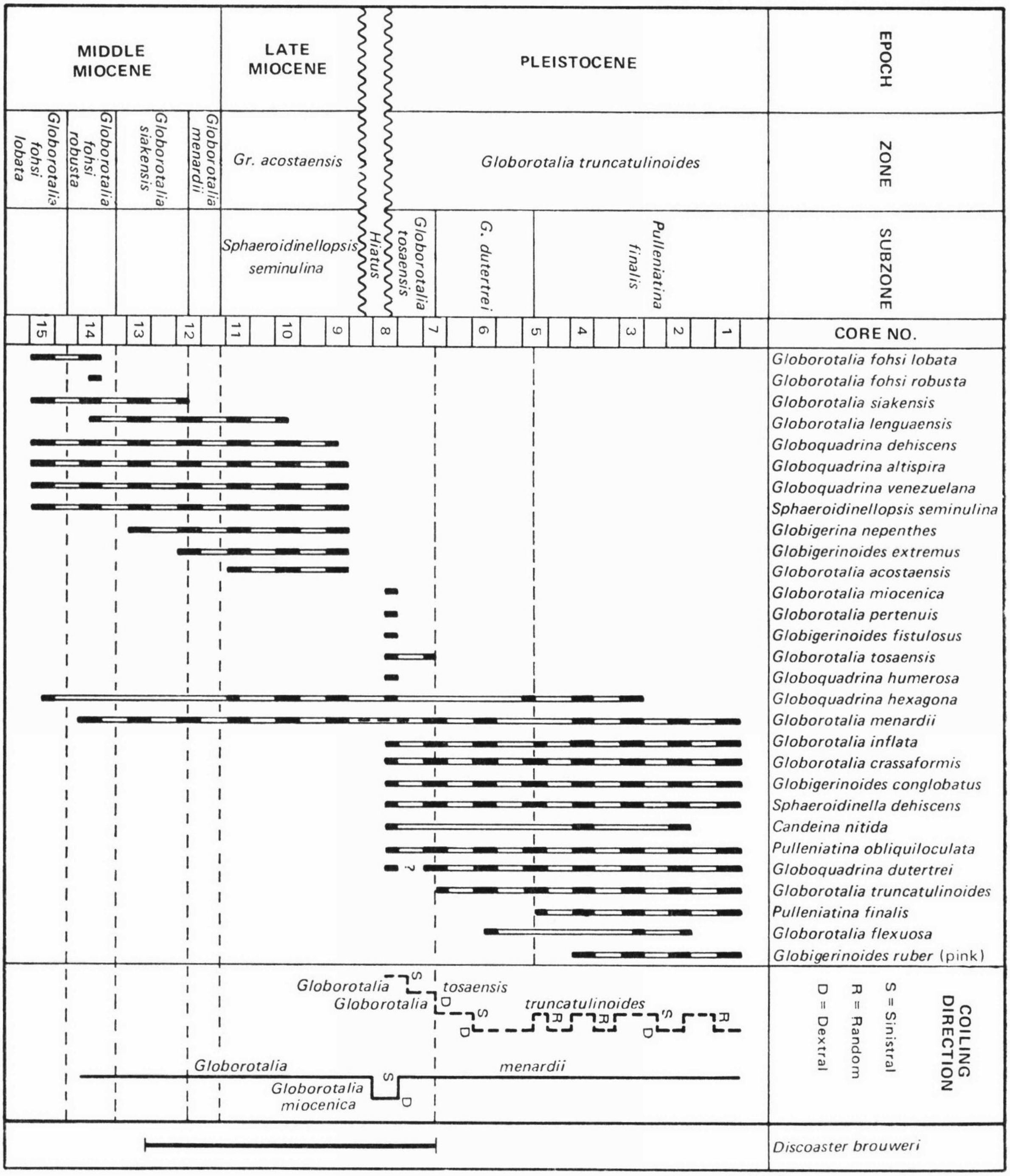


FIG. 21. Stratigraphic distribution of planktonic foraminifers in slope core hole D, Gulf of Mexico.

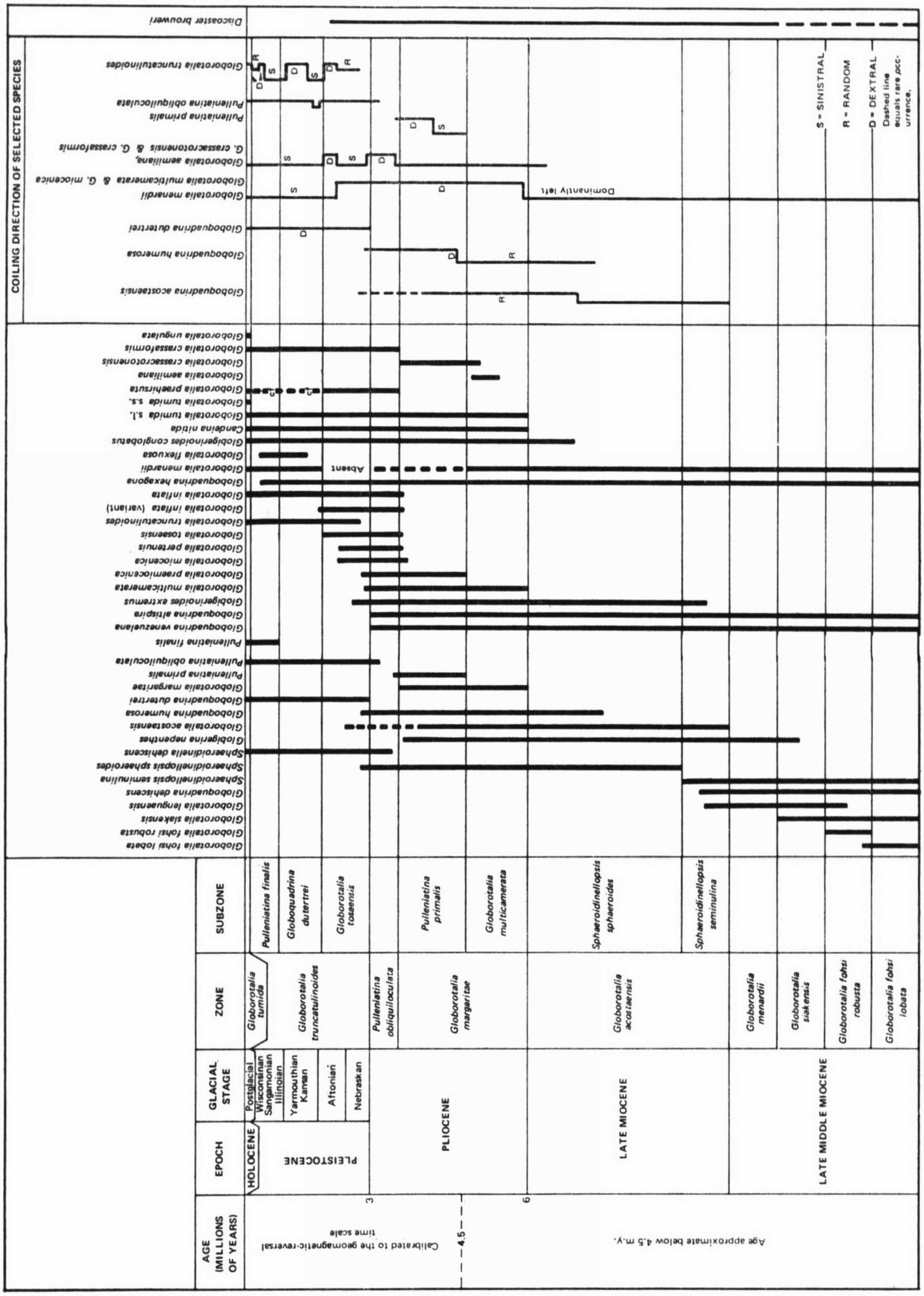


TABLE 2. *Zonation of late middle Miocene to Holocene marine sediments of the Gulf of Mexico and Caribbean region based on planktonic foraminifers.*

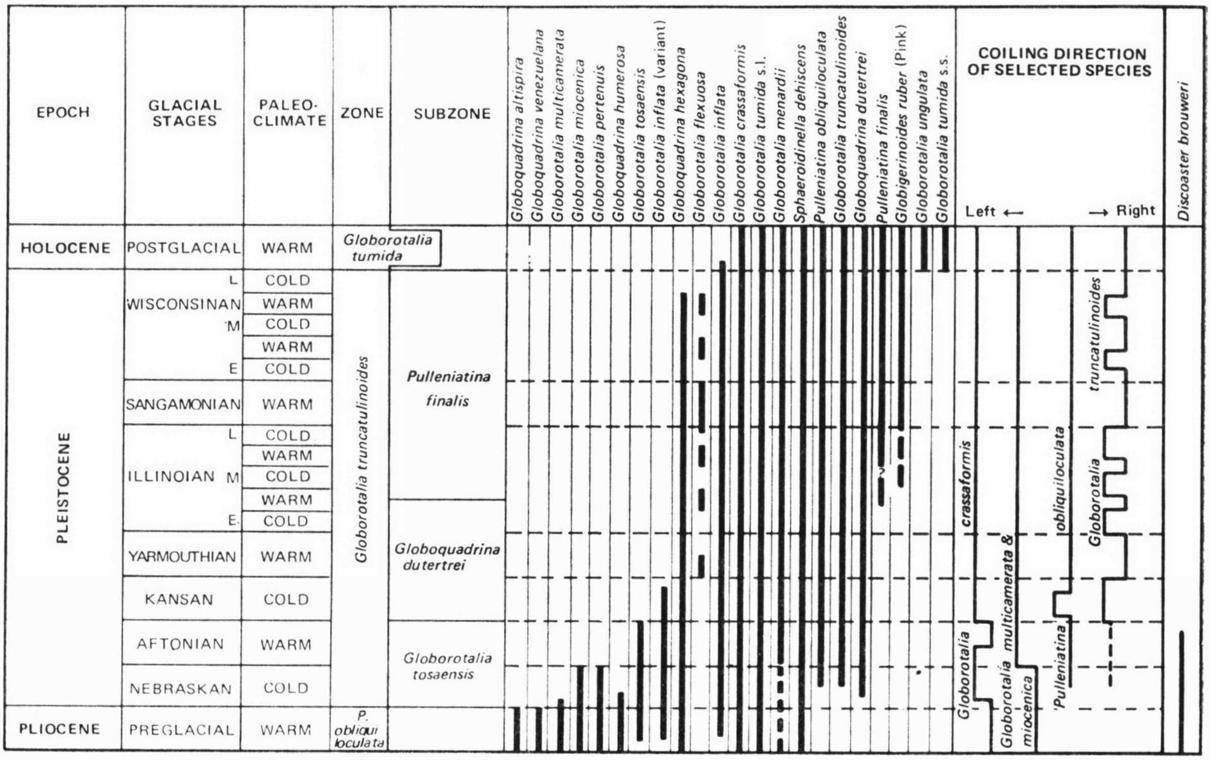


FIG. 22. Stratigraphic occurrence of late Pliocene and Pleistocene planktonic foraminifers and *Discoaster brouweri* in the Gulf of Mexico. Dashed line indicates rare occurrence.

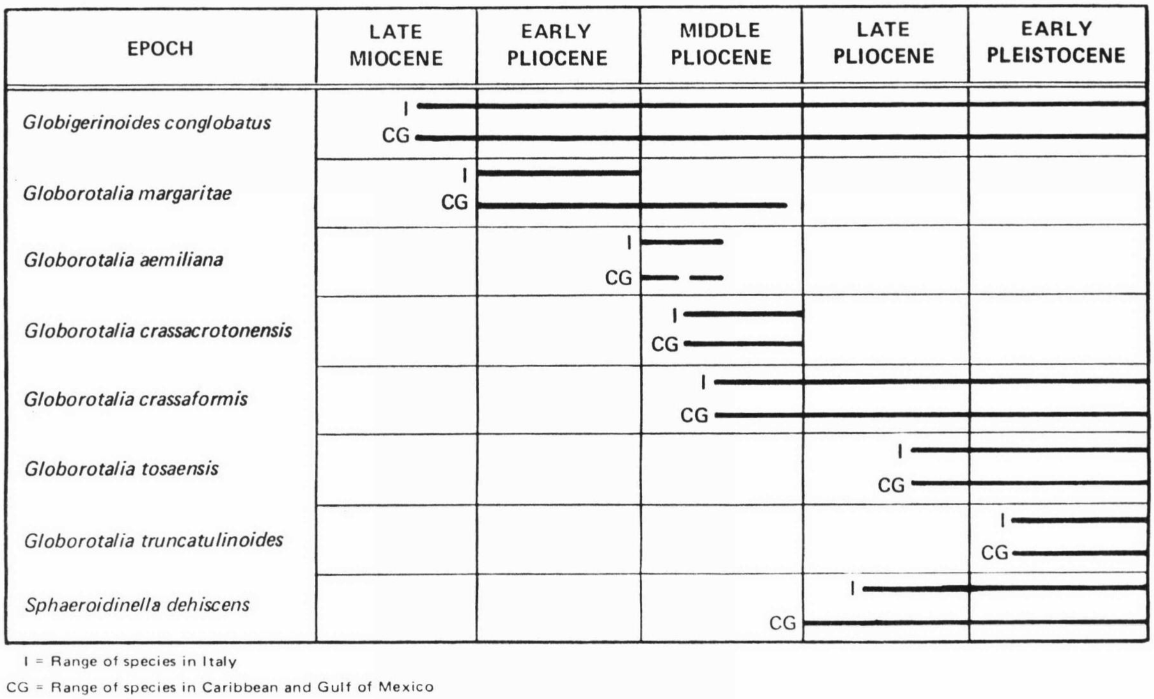


FIG. 23. Stratigraphic ranges of selected planktonic species from Italy and from the Caribbean and Gulf of Mexico (modified after BEARD & LAMB, 1968).

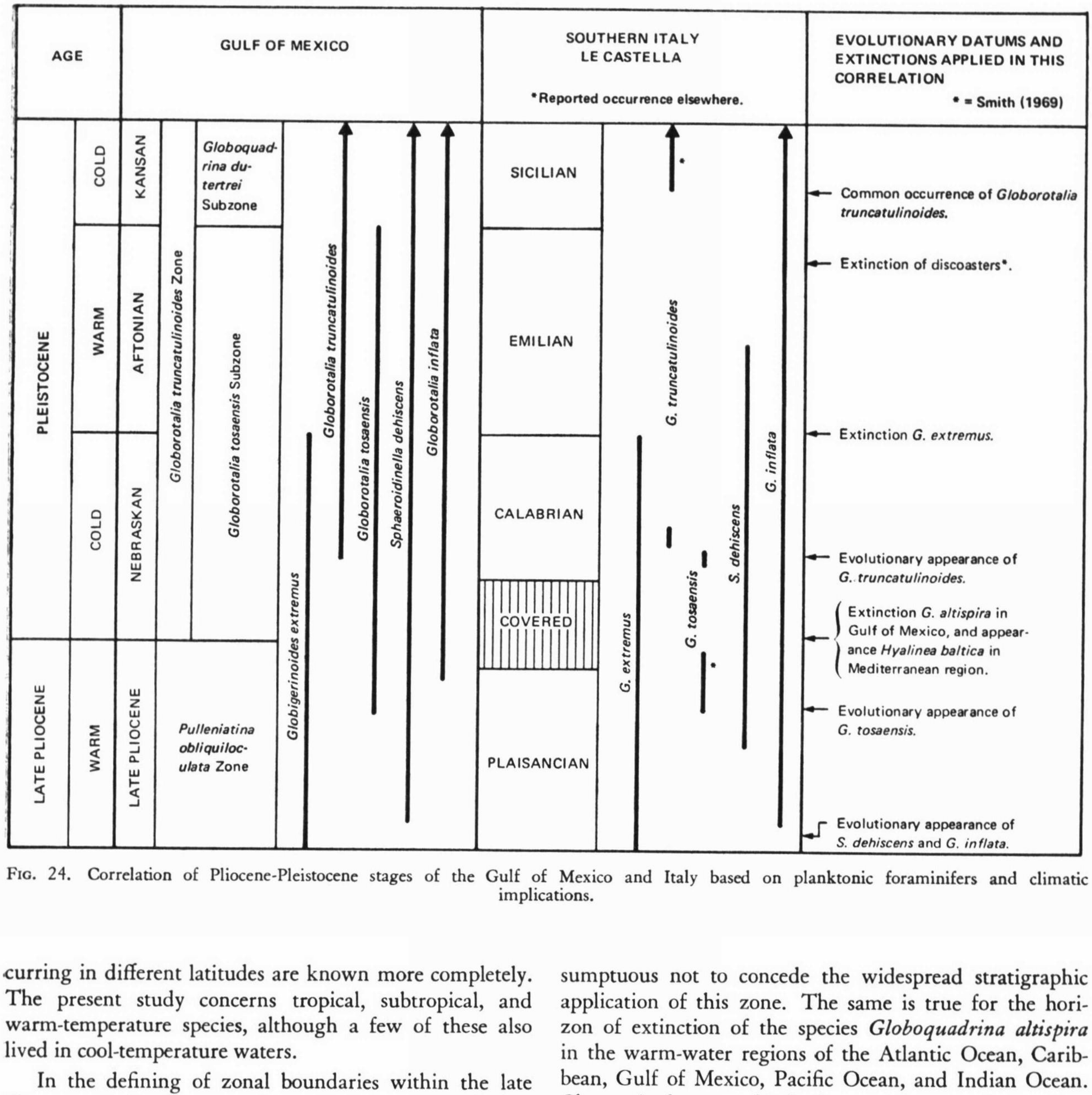


FIG. 24. Correlation of Pliocene-Pleistocene stages of the Gulf of Mexico and Italy based on planktonic foraminifers and climatic implications.

curring in different latitudes are known more completely. The present study concerns tropical, subtropical, and warm-temperature species, although a few of these also lived in cool-temperature waters.

In the defining of zonal boundaries within the late Neogene planktonic succession, reported stratigraphic occurrences of species in regions beyond the study area desirably are considered. This provides a check as to their regional stratigraphic reliability. Important horizons, such as epoch boundaries, should be based firmly on widely recognized faunal datums whenever possible. For example, the Pliocene can be subdivided or zoned in different ways by emphasizing the stratigraphic occurrences of different species. It is significant, however, that the *Globorotalia margaritae* Zone of BOLLI & BERMÚDEZ (1965) has been recognized in Italy, Caribbean and Gulf of Mexico, South Pacific, and Java; it would be presumptuous not to concede the widespread stratigraphic application of this zone. The same is true for the horizon of extinction of the species *Globoquadrina altispira* in the warm-water regions of the Atlantic Ocean, Caribbean, Gulf of Mexico, Pacific Ocean, and Indian Ocean. Change in fauna at this horizon appears mostly to reflect the onset of climatic deterioration beginning the Quaternary.

The *Sphaeroidinella dehiscens, Globorotalia crassaformis,* and *Globoquadrina dutertrei* bioseries illustrated on Plates 1-3 undoubtedly will prove essential for regional, if not worldwide, faunal correlation; thus taxa of these lineages are given special consideration in proposing the planktonic zonation of this report.

Broad subdivision of the Pleistocene in marine sections is possible using only the restricted stratigraphic occurrences of planktonic foraminifers (Fig. 25). A finer subdivision, however, is obtained locally by utilizing changes in the planktonic fauna brought about by recurrent glacial and interglacial conditions (Fig. 22; Beard, 1969, 1971). In paralic areas of the Gulf Coast, Pleistocene water-depth changes, as demonstrated by stratigraphic changes in the benthonic fauna, can be used to obtain similar results insofar as eustatic events are differentiated from local tectonic pulses (Akers & Holck, 1957; Smith, 1965). Oil-company paleontologists routinely identify glacial and interglacial events using the paleobathymetric approach.

Preferred coiling directions of several planktonic species are summarized on Table 2. Within the study area these trends have stratigraphic significance, but they should be evaluated always in conjunction with other stratigraphic data. Coiling changes of some species are known to have nearly worldwide stratigraphic significance, such as the sinistral-to-dextral change in *Pulleniatina primalis* in the upper part of the *Globorotalia margaritae* Zone and the random-to-dextral change in *Globorotalia humerosa* at about the same horizon. This aspect of biologic variability in planktonic foraminifers needs further investigation to broaden its stratigraphic application.

DESCRIPTION OF PLANKTONIC ZONES

Descriptions of the Miocene to Recent planktonic zones defined in this study are given, together with diagnoses of commonly accepted late middle Miocene zones. A comparison of the late Neogene zones of different authors is given on Table 1.

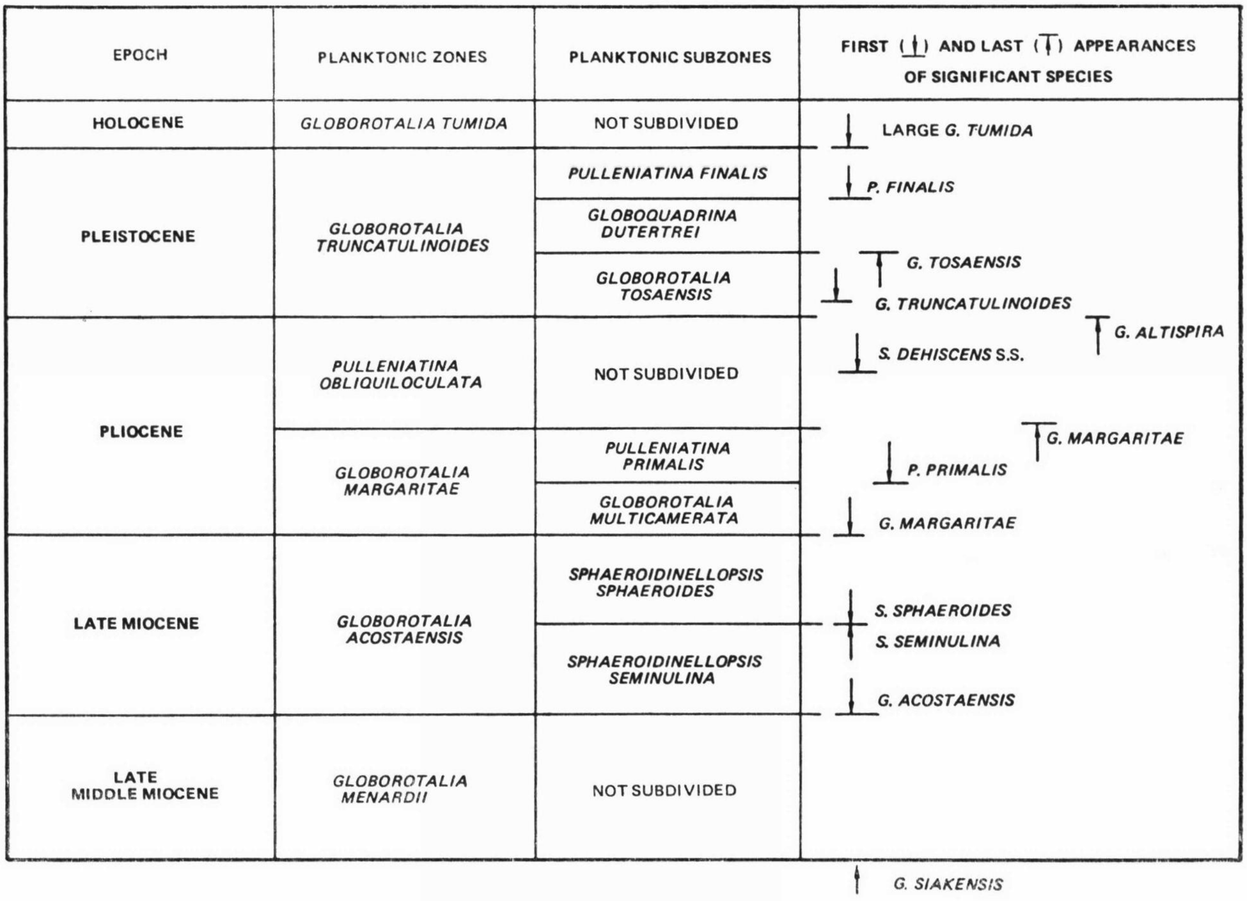
LATE MIDDLE MIOCENE

Globorotalia fohsi lobata Zone

Author: Bolli, 1957, p. 101.
Definition: Interval with zonal marker, from its first occurrence to first occurrence of *Globorotalia fohsi robusta.*

Globorotalia fohsi robusta Zone

Author: Bolli, 1957, p. 101-102.
Definition: Range of zonal marker.



EPOCH	PLANKTONIC ZONES	PLANKTONIC SUBZONES	FIRST (↓) AND LAST (⊤) APPEARANCES OF SIGNIFICANT SPECIES
HOLOCENE	*GLOBOROTALIA TUMIDA*	NOT SUBDIVIDED	
PLEISTOCENE	*GLOBOROTALIA TRUNCATULINOIDES*	*PULLENIATINA FINALIS*	
		GLOBOQUADRINA DUTERTREI	
		GLOBOROTALIA TOSAENSIS	
PLIOCENE	*PULLENIATINA OBLIQUILOCULATA*	NOT SUBDIVIDED	
	GLOBOROTALIA MARGARITAE	*PULLENIATINA PRIMALIS*	
		GLOBOROTALIA MULTICAMERATA	
LATE MIOCENE	*GLOBOROTALIA ACOSTAENSIS*	*SPHAEROIDINELLOPSIS SPHAEROIDES*	
		SPHAEROIDINELLOPSIS SEMINULINA	
LATE MIDDLE MIOCENE	*GLOBOROTALIA MENARDII*	NOT SUBDIVIDED	

Fig. 25. Miocene to Holocene planktonic zonation in the Gulf of Mexico and Caribbean.

Remarks: A clear distinction between the *Globorotalia fohsi lobata* and *Globorotalia fohsi robusta* Zones is difficult because keeled forms of this lineage seemingly appear at about the same horizon. Hyphenation, therefore, is sometimes necessary (e.g., *Globorotalia fohsi lobata-robusta* Zones).

Globorotalia siakensis Zone

Author: Brönnimann, 1951, p. 131 (same usage as Bolli, 1957, but not Bolli, 1966).

Definition: Interval with zonal marker, from the last occurrence of *Globorotalia fohsi robusta* to last occurrence of zonal marker.

Remarks: Bolli (1966) subdivided this zone into a lower *Globigerinoides ruber* Zone (interval with zonal marker, from last occurrence of *Globorotalia fohsi robusta* to last middle Miocene occurrence of zonal marker) and a more restricted *Globorotalia siakensis* Zone (interval with zonal marker, from last middle Miocene occurrence of *Globigerinoides ruber* to last occurrence of zonal marker). The objection to this subdivision is the difficulty in determining the last occurrence of *G. ruber* in pan samples. The presence of *G. ruber* in the Pliocene further complicates the recognition of this zone in ditch samples.

Globorotalia menardii Zone

Author: Stainforth, 1948, p. 1303.

Definition: Interval with zonal marker, from last occurrence of *Globorotalia siakensis* to first occurrence of *Globorotalia acostaensis.*

Remarks: Bolli (1966) stated "The Zone as defined originally included the whole Lengua Formation of Trinidad. Brönnimann (1951) subdivided Stainforth's zone into a lower, *Globorotalia siakensis* Zone and an upper, *Globorotalia menardii* Zone, with the boundary between the two zones marked by the extinction of *G. siakensis.* "Environmental changes caused a rapid disappearance of planktonic foraminifers at the top of the Lengua Formation, hence the top of the *Globorotalia menardii* Zone could not be established there. The above definition of the zone is based on more favorable sections recently investigated in coastal Eastern Venezuela by Bolli & Bermúdez (1965) and in Java by Bolli (1966)."

LATE MIOCENE

Globorotalia acostaensis Zone

Author: Lamb & Beard, new zone.

Definition: Interval with zonal marker, from its first occurrence to first occurrence of *Globorotalia margaritae.*

Sphaeroidinellopsis seminulina Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval with zonal marker, from the first occurrence of *Globorotalia acostaensis* to last occurrence of zonal marker.

Remarks: *Globorotalia lenguaensis* and *Globoquadrina dehiscens* have their last occurrence in the subzone, and *Glogiberinoides obliquus extremus* has its first occurrence in the upper part of the subzone.

Sphaeroidinellopsis sphaeroides Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval with zonal marker, from its first occurrence to first occurrence of *Globorotalia margaritae.*

Remarks: *Globoquadrina humerosa* and *Globigerinoides conglobatus* have their first occurrence in the upper part of this subzone.

PLIOCENE

Globorotalia margaritae Zone

Author: Bolli & Bermúdez, 1965, p. 132.

Definition: Range of zonal marker in the Caribbean and Gulf of Mexico regions, which seemingly ranges higher here than in Italy.

Globorotalia multicamerata Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval from first occurrence of *Globorotalia margaritae* to first occurrence of *Pulleniatina primalis.*

Remarks: *Globorotalia margaritae, G. multicamerata, G. aemiliana,* and *G. crassacrotonensis* have their first occurrence in this subzone.

Pulleniatina primalis Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval with zonal marker, from its first occurrence to the last occurrence of *Globorotalia margaritae.*

Remarks: *Globigerina nepenthes* and *Globorotalia crassacrotonensis* have their last occurrence in this subzone.

Pulleniatina obliquiloculata Zone

Author: Lamb & Beard, new zone.

Definition: Interval from last occurrence of *Globorotalia margaritae* to the extinction horizon of *Globoquadrina altispira.*

Remarks: *Globorotalia crassaformis, G. praehirsuta, G. inflata* variant, *G. tosaensis, G. pertenuis, G. miocenica, Pulleniatina obliquiloculata* (in tropical regions), and *Sphaeroidinella dehiscens* have their first occurrence in this zone, whereas *Globoquadrina altispira, G. venezuelana,* and *Sphaeroidinellopsis sphaeroides* have their last occurrence.

The few records of *Globorotalia truncatulinoides* in the uppermost part of this zone are best explained as resulting from the action of burrowing organisms or contamination.

Globorotalia menardii withdrew from the Gulf of Mexico near the climax of this zone seemingly because of onset of severe climatic deterioration beginning the Pleistocene.

PLEISTOCENE

Globorotalia truncatulinoides Zone

Author: Lamb & Beard, new zone.

Definition: Interval from the extinction horizon of *Globoquadrina altispira* to the first occurrence of large forms of the species *Globorotalia tumida* in the Gulf of Mexico region.

Globorotalia tosaensis Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval with zonal marker, from the horizon of extinction of *Globoquadrina altispira* to last occurrence of zonal marker.

Remarks: In upward fashion, *Globigerinoides obliquus extremus, Globorotalia multicamerata, G. miocenica,* and *G. pertenuis* have their last occurrence in this subzone. *Globorotalia menardii* reappears in the upper part of the subzone in the Gulf of Mexico region during the Aftonian warm interglacial period.

The horizon of extinction of *G. miocenica* within this subzone is considered by some oil-company paleontologists to mark the upper limit of the Nebraskan glacial stage. This species may prove reliable for subdividing the *G. tosaensis* Subzone.

Globoquadrina dutertrei Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval with zonal marker above last occurrence of *Globorotalia tosaensis* to first occurrence of *Pulleniatina finalis.*

Remarks: The first abundant *Globorotalia truncatulinoides* occur at the base of this subzone with large, turbinate forms of *Globoquadrina dutertrei. Globorotalia flexuosa* first occurs within this subzone.

Pulleniatina finalis Subzone

Author: Lamb & Beard, new subzone.

Definition: Interval from the first occurrence of *Pulleniatina finalis* to first occurrence of large forms of *Globorotalia tumida sensu stricto.*

Remarks: The development of *Pulleniatina finalis* from *P. obliquiloculata* characterizes the base of the zone. *Globorotalia flexuosa, G. inflata,* and *Globigerina hexagona* have their last occurrence in this subzone in the Gulf of Mexico.

HOLOCENE

Globorotalia tumida Zone (=Holocene, post-glacial)

Author: Lamb & Beard, new zone.

Definition: Interval with first abundant occurrence of very large forms of the species *Globorotalia tumida.*

Remarks: Base of zone in Gulf of Mexico is characterized by a faunal boundary between cold-water species, such as *Globorotalia inflata,* below and warm-water species, such as *G. tumida* (large forms) and common *G. menardii,* above. The boundary seems to correspond to the end of the latest glacial interval (about 7,000 to 11,000 years before present) and the beginning of the Holocene Epoch. Sparse occurrences of *G. inflata* are seen with *G. tumida* on occasion; this association is considered Holocene.

SYSTEMATIC PALEONTOLOGY

Late Neogene planktonic foraminiferal guide species discussed in this study are illustrated by notably clear and definitive photographs obtained using the Cambridge scanning electron microscope. The nomenclatural and taxonomic discussions are brief and refer mostly to current literature, as the main emphasis is in helping the practicing paleontologist derive a clear concept of the species as they appear in the Caribbean and Gulf of Mexico.

Genus CANDEINA d'Orbigny

Candeina D'ORBIGNY, 1839, p. 107, pl. 2, fig. 27-28.

Test free, trochospiral, relatively high-spired; chambers inflated; primary aperture in early stage interiomarginal, umbilical, later with tiny secondary sutural apertures on each side of primary aperture; no primary openings in adult tests, small rounded sutural secondary apertures almost completely surrounding later chambers.

TYPE-SPECIES.—*Candeina nitida* D'ORBIGNY (1839, p. 107), by monotypy. From the Holocene of Cuba and Jamaica.

CANDEINA NITIDA d'Orbigny

Plate 5, figure 5

Candeina nitida D'ORBIGNY, 1839, p. 108, pl. 2, fig. 27-28.—— PARKER, 1962, p. 253, pl. 8, fig. 27-30.

This species is seen infrequently and sparsely; not recorded below the Pliocene in the present study.

ILLUSTRATION.—Plate 5, figure 5.——Specimen from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole C, core 1, at a depth of 13.0 to 13.6 feet; ×85.

Genus GLOBIGERINA d'Orbigny

Globigerina D'ORBIGNY, 1826, p. 277, model no. 76.

Test free, trochospiral, chambers spherical to ovate; wall calcareous, perforate, radial in structure, surface in the living form with spines; aperture interiomarginal, umbilical or extraumbilical position, previous apertures opening into umbilicus.

TYPE-SPECIES.—*Globigerina bulloides* D'ORBIGNY (1826, p. 277, model no. 76), subsequent designation by PARKER, JONES, & BRADY (1865, p. 36). From the Holocene of the Adriatic Sea, close to Rimini, Italy.

GLOBIGERINA BULLOIDES d'Orbigny

Plate 5, figures 6-8

Globigerina bulloides D'ORBIGNY, 1826, p. 277 (unfigured).—— BANNER & BLOW, 1960, p. 3-4, pl. 1, fig. 1-4 (lectotype).

A simple globigerine much confused in the literature. Because its simple morphology commonly is duplicated through homeomorphy, the species name has become a wastebasket taxon. In the study area three-chambered specimens occur frequently and four-chambered specimens less frequently.

ILLUSTRATIONS.—Plate 5, figures 6-8.——Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole A, core 3, at a depth of 0-0.4 foot; ×135.

GLOBIGERINA NEPENTHES Todd

Plate 4, figures 1-8

Globigerina nepenthes TODD, 1957, p. 301, pl. 78, fig. 7.

Considerable confusion exists as to the morphology and stratigraphic range of this species, and comparative material was insufficient to prepare a meaningful synonymy. The adult hooded form was found no higher than middle Pliocene in the present study.

ILLUSTRATIONS.—Plate 4, figures 1-8.——1, 4. Typical hooded adults, ×160 and ×175.——2. Side view of typical specimen, ×95.——3. Spiral view of typical specimen, ×200.——5. Specimen showing elongated and pointed ultimate chamber, ×170.——6, 7. Juvenile four-chambered specimens, ×170; initial growth of fifth chamber shown on 6.——8. Typical adult with fifth chamber broken off, ×170.——1, 4, 6-8.——From the *Sphaeroidinellopsis seminulina* Subzone, *Globorotalia acostaensis* Zone, late Miocene in Gulf of Mexico slope core hole A, core 12, at a depth of 0-0.6 foot. ——2-3. From the *Globorotalia multicamerata* Subzone, *Globorotalia margaritae* Zone, early Pliocene, in Gulf of Mexico slope core hole A, core 10, at a depth of 7.6 to 8.0 feet.——5. From same subzone as 1 in Gulf of Mexico slope core hole A, core 12, at a depth of 2.7 to 3.1 feet.

GLOBIGERINA sp. aff. G. PACHYDERMA (Ehrenberg)

Plate 6, figures 1-3

ILLUSTRATIONS.—Plate 6, figures 1-3.——1-3. Specimens from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, early Pleistocene, in Gulf of Mexico slope core hole A, core 6, at a depth of 4.4 to 4.8 feet; ×160.

Genus GLOBIGERINITA Brönnimann

Globigerinita BRÖNNIMANN, 1951, p. 18.

Test free, trochospiral, final chamber modified and extending across umbilical region; primary aperture interiomarginal and umbilical, but in adult covered by modified final chamber which extends across umbilical region, one or more small arched supplementary apertures present at umbilical margin of final chamber.

TYPE-SPECIES.—*Globigerinita naparimaensis* BRÖNNIMANN (1951, p. 16), by original designation. From the Miocene (*Globorotalia siakensis* Zone), Cruse and Lengua Formations, Trinidad, West Indies.

GLOBIGERINITA GLUTINATA (Egger)

Plate 5, figures 1-4

Globigerina glutinata EGGER, 1893, p. 371, pl. 13, fig. 19-21.

Globigerinita glutinata (Egger). PARKER, 1962, p. 246, pl. 9, fig. 1-6.——PARKER, 1967, p. 146, pl. 17, fig. 3-5.

In a given assemblage, small finely perforate specimens of this species are found with and without a final chamber or bulla developed. Aperture singular and low-arched in specimens lacking development of final chamber; multiple in those with a final chamber.

This species may be a senior synonym of *Globigerinita naparimaensis* BRÖNNIMANN from the early and middle Miocene; the latter species, however, seemingly develops more multiple apertures on average specimens. Differentiation of randomly selected specimens, however, is difficult.

ILLUSTRATIONS.—Plate 5, figures 1-4.——Specimens from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole B, core 16, at a depth of 13.7-14.3 feet; ×160.

Genus GLOBIGERINOIDES Cushman

Globigerinoides CUSHMAN, 1927, p. 87.

Test similar to *Globigerina* but with secondary sutural apertures on spiral side.

A polyphyletic genus that developed at different times during the Tertiary from simple globigerinid stock by addition of numerous supplementary apertures around the margin of the chamber.

TYPE-SPECIES.—*Globigerina ruber* D'ORBIGNY (1839, p. 82), by original designation. From Holocene marine sands in Cuba, Jamaica, Guadeloupe, and Martinique.

GLOBIGERINOIDES CONGLOBATUS (Brady)

Plate 33, figures 4, 6-7

Globigerina conglobata BRADY, 1879, p. 286.——BRADY, 1884, p. 603, pl. 80, fig. 1-5; pl. 82, fig. 5.——BANNER & BLOW, 1960, p. 6, pl. 4, fig. 4 (lectotype).

Globigerinoides conglobatus (Brady). PARKER, 1967, p. 154, pl. 20, fig. 3-4.

This species is seen in its typical form as early as late Miocene and early Pliocene, but specimens are smaller than in the Pleistocene and Holocene. BLOW (1967) regarded this species as having developed from *Globigerinoides conglobatus canimarensis* BERMÚDEZ, which is easily confused with other species of *Globigerinoides* and, therefore, is of doubtful stratigraphic significance.

ILLUSTRATIONS.—Plate 33, figures 4, 6-7.——Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole A, core 3, at a depth of 10.0 to 12.5 feet; ×90.

GLOBIGERINOIDES EXTREMUS
Bolli & Bermúdez

Plate 32, figures 1-6

Globigerinoides obliquus extremus BOLLI & BERMÚDEZ, 1965, p. 139, pl. 1, fig. 10-12.——BLOW, 1967, p. 324, pl. 21, fig. 2-3.

Globigerinoides obliquus Bolli. PARKER, 1967, p. 155, pl. 20, fig. 5-6.——POAG & AKERS, 1967, p. 171, pl. 16, fig. 16-18.

This species is characterized through the late Miocene to earliest Pleistocene by mitered or dorsoventrally compressed chambers. Associated with typically developed specimens commonly are others having less compression of the chambers so that they are similar to *Globigerinoides obliquus*.

ILLUSTRATIONS.—Plate 32, figures 1-6.——Typical specimens from the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico core hole C, core 8, at a depth of 12.5 to 12.9 feet; ×180.

GLOBIGERINOIDES FISTULOSUS (Schubert)

Plate 31, figures 4, 7-8

Globigerina fistulosa SCHUBERT, 1910, p. 323, fig. 2.

Globigerinoides fistulosus (Schubert). PARKER, 1967, p. 154-155, fig. 4, pl. 21, fig. 3, 5, 6.

This species was found only rarely in northern Gulf of Mexico samples but was fairly common at the Sigsbee knolls location and in Jamaica in very late Pliocene and earliest Pleistocene samples.

ILLUSTRATIONS.—Plate 31, figures 4, 7-8.——4, 8. Specimens from a depth of 300 cm.——7. Specimen from depth of 220 cm. From *Pulleniatina obliquiloculata* Zone, Pliocene, in Texas A. & M. Florida Straits core 67-A3-36E; ×80.

GLOBIGERINOIDES QUADRILOBATUS
(d'Orbigny)

Plate 31, figure 1

Globigerina quadrilobata D'ORBIGNY, 1846, p. 164, pl. 9, ?fig. 7-10.

Globigerinoides quadrilobatus (d'Orbigny). BANNER & BLOW, 1960, p. 17-19, pl. 4, fig. 3 (lectotype).

PARKER (1967) discussed the *"Globigerina quadrilobatus"* problem because acceptance of BANNER & BLOW's lectotype for defining this species infers close relationship with the taxa *Globigerinoides sacculifer* (BRADY, 1877; see also pl. 27, figs. 2, 3, 5, 6) and *G. fistulosus*. The phylogeny of this group of related species is discussed in EAMES & OTHERS (1962) and in BANNER & BLOW (1960). They logically concluded that *Globigerinoides quadrilobatus* is the main-line ancestral stock from which Neogene representatives arose.

Globigerinoides quadrilobatus and *G. sacculifer* are nearly always found in association and are seemingly inseparable unless the final saclike (sacculiferous) chamber is present to distinguish *G. sacculifer*. Because the two forms have the same stratigraphic range (early Miocene to Holocene), they are referred commonly to one species, usually *G. quadrilobatus*.

ILLUSTRATIONS.—Plate 31, figure 1.——1. Specimen from the *Pulleniatina obliquiloculata* Zone, Pliocene, in Texas A. & M. Florida Straits core 67-A3-36E at a depth of 220 cm; ×80.

GLOBIGERINOIDES RUBER (d'Orbigny)

Plate 33, figures 1-3, 5

Globigerina rubra D'ORBIGNY, 1839, p. 82, pl. 4, fig. 12-14.——BANNER & BLOW, 1960, p. 19, pl. 3, fig. 8 (lectotype).

Globigerinoides ruber (d'Orbigny). PARKER, 1962, p. 230, pl. 3, fig. 11-14; pl. 4, fig. 1-10.

This form is characterized by BLOW (1967) as follows: "CORDEY (Palaeontology, vol. 10, pp. 647-59, pl. 103, 1967, and paper read to Planktonic Conference, Geneva, 1967) has already referred to the separate phylogenetic development of *G. subquadratus* and *G. ruber* both of which possess an adult morphotype which is extremely closely homeomorphic. However, as noted by CORDEY there are differences in the earlier ontogenetic stages of the two taxa which allow their separate morphological distinction. Further, the writer considers that there are also differences of wall texture and structure between the two forms. There are also minor differences of chamber shape and of arrangement of the chambers in the progression of the trochospires of the two forms. Thus, the writer agrees with CORDEY that both *G. ruber* and *G. subquadratus* can be, and should be, taxonomically differentiated notwithstanding the close homeomorphy of the adult specimens of the two taxa. The two very similar morphotypes are separated in time and do not have overlapping ranges. It would seem that *G. ruber* develops from *G. bollii* within Zone N. 16 whilst *G. subquadratus* develops from *G. quadrilobatus altiaperturus* within Zone N. 5 and becomes extinct within Zone N. 13. Range of *G. ruber,* from the middle to later part of Zone N. 16 to Zone N. 23."

ILLUSTRATIONS.—Plate 33, figures 1-3, 5.——Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole A, core 3, at a depth of 0 to 0.4 foot; ×100.

GLOBIGERINOIDES SACCULIFER (Brady)

Plate 31, figures 2-3, 5-6

See discussion for *Globigerinoides quadrilobatus* (D'ORBIGNY).

ILLUSTRATIONS.—Plate 31, figures 2-3, 5-6.——2-3, 5. Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole A, core 3, at a depth of 0 to 0.4 foot; ×85, ×85, ×100.——6. Specimen from the *Globorotalia tumida* Zone, Holocene, in the same core hole, core 1, at a depth of 0 to 0.8 foot; ×80.

Genus GLOBOQUADRINA Finlay

Globoquadrina FINLAY, 1947, p. 290.

Test free, trochospiral, umbilicate; aperture interiomarginal, umbilical, covered above by apertural flap which may vary from narrow rim to elongate toothlike projection, and in openly umbilicate forms earlier apertures remain open into umbilicus.

Species commonly have broad, flat chambers; apertural teeth, in the form of thin plates or flaps, project downward into the aperture and conceal it in some specimens. PARKER (1962, 1967) modified the generic description to include forms having pitted, nonspinose wall structure and some form of tooth or apertural flap.

TYPE-SPECIES.—*Globorotalia dehiscens* CHAPMAN, PARR, & COLLINS (1934, p. 569), by original designation. From the Miocene (Balcombian) of Australia.

GLOBOQUADRINA ALTISPIRA (Cushman & Jarvis)

Plate 9, figures 1-5

Globigerina altispira CUSHMAN & JARVIS, 1936, p. 5, pl. 1, fig. 13-14.

Globoquadrina altispira altispira (Cushman & Jarvis). BOLLI, 1959, p. 83, pl. 8, fig. 51.

Globoquadrina altispira (Cushman & Jarvis). PARKER, 1967, p. 165, pl. 25, fig. 8.

The type locality of this species was checked by AKERS & ROBINSON (in AKERS & DORMAN, 1964, p. 14), and they maintain that CUSHMAN & JARVIS erred in their locality records. They say that the original specimens probably came from the "Buff Bay" locality now considered to be Pliocene by ROBINSON and others.

The present study shows that the extinction horizon of this species in the Caribbean and Gulf of Mexico coincides closely with the onset of climatic deterioration beginning the Quaternary.

ILLUSTRATIONS.—Plate 9, figures 1-5.——1. Specimen from the *Globorotalia multicamerata* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole A, core 10, at a depth of 12.6 to 13.0 feet; ×135.——2, 4-5. Specimens from the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole C, core 8, at a depth of 12.5 to 12.9 feet; ×90.——3. Specimen from the *Globorotalia fohsi robusta* Zone, middle Miocene, in Gulf of Mexico slope core hole E, core 6, at a depth of 3.2 to 3.6 feet; ×105.

GLOBOQUADRINA DEHISCENS (Chapman, Parr, & Collins)

Plate 9, figures 6-9

Globorotalia dehiscens CHAPMAN, PARR, & COLLINS, 1934, p. 569, pl. 11, fig. 36.

Globorotalia quadraria CUSHMAN & ELLISOR, 1939, p. 11, pl. 2, fig. 5.

Globoquadrina quadraria advena BERMÚDEZ, 1949, p. 287, pl. 22, fig. 36-38.

Globoquadrina subdehiscens FINLAY, 1947, p. 291 (type not illustrated).

Globoquadrina dehiscens (Chapman, Parr, & Collins). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 31, pl. 5, fig. 5-6.——BOLLI, 1957, p. 111, pl. 24, fig. 3-4.

Specimens of this species from the type Buff Bay Formation of Jamaica have an encrusting layer or layers of secondary calcareous material covering much of the surface pore area and giving a pustulose appearance. In the present study area this species does not range above the early late Miocene, but in other areas, such as New Zealand, it is reported from younger sections.

ILLUSTRATIONS.—Plate 9, figures 6-9.——6. Specimen from the *Sphaeroidinellopsis seminulina* Subzone, *Globorotalia acostaensis* Zone, late Miocene, in Gulf of Mexico slope core hole A, core 14, at a depth of 10.1 to 10.5 feet; ×10.——7-9. Specimens from the *Globorotalia fohsi robusta* Zone, middle Miocene, in Gulf of Mexico slope core hole E, core 6, at a depth of 3.2 to 3.6 feet; ×80.

GLOBOQUADRINA DUTERTREI (d'Orbigny)

Plate 3, figures 1-3; Plate 8, figures 7-9

Globigerina dutertrei D'ORBIGNY, 1839, p. 84, pl. 4, fig. 19-21.——BANNER & BLOW, 1960, p. 11, pl. 2, fig. 1 (lectotype).

Globoquadrina dutertrei (d'Orbigny). PARKER, 1962, p. 242, pl. 7, fig. 1-13; pl. 8, fig. 1-4.——PARKER, 1967, p. 168, pl. 25, fig. 7.

The present concept of this species and a synonymy have been presented by PARKER (1962, 1967). PARKER (1962) considered this species closely related to *Globoquadrina altispira,* but she later reconsidered and now regards it as closer to *G. humerosa.* The evolutionary transition from *Globorotalia acostaensis* to *Globoquadrina humerosa* to *G. dutertrei* is illustrated on Plate 3. *Globoquadrina dutertrei* appears for the first time in the uppermost part of the *Globorotalia tosaensis* Subzone where large high-spired (turbinate) forms are seen.

Globoquadrina dutertrei differs from *G. humerosa,* its immediate ancestor, in being generally larger, having more chambers, and being higher spired with respect to coiling. It is known to have better development of apertural teeth in warm-water than in cool-water regions.

Globoquadrina dutertrei Bioseries: This lineage begins with the species *Globorotalia acostaensis,* which seemingly evolves from the simple globigerine *Globigerina continuosa* in late Miocene. *G. acostaensis* gives rise to *Globoquadrina humerosa* in late Miocene, which in turn gives rise to the modern species *G. dutertrei* in the early Pleistocene.

The evolutionary progression of this lineage follows a gradual increase in number of chambers and a gradual increase in size of the test, accompanied by a more loose and higher spired arrangement of the chambers around a developing umbilical area that is sometimes bordered by delicate fimbriate plates or apertural flaps extending downward into the umbilicus. *Globorotalia acostaensis* has usually 4.5 chambers in the last whorl arranged in a tight coil with essentially no umbilicus, and a sutural aperture with a thin lip. This develops into the slightly larger *Globoquadrina humerosa,* which has more chambers loosely arranged around a small umbilicus. The development into the modern species *G. dutertrei* is achieved by increase in overall size of the test, which has 5 or 6 chambers in the last whorl in a very loose spiral arrangement, forming a deep and open umbilicus.

ILLUSTRATIONS.—Plate 3, figures 1-3.——Same specimens as Plate 8, figures 7-9, respectively; ×43. Plate 8, figures 7-9. Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico core hole A, core 1, at a depth of 10.0 to 10.5 feet; ×85.

GLOBOQUADRINA HEXAGONA (Natland)

Plate 10, figures 1-4

Globigerina hexagona NATLAND, 1938, p. 149, pl. 7, fig. 1.

Globoquadrina hexagona (Natland). PARKER, 1962, p. 244, pl. 8, fig. 5-13.——PARKER, 1967, p. 169, pl. 25, fig. 9-10.

This small species is referred to *Globoquadrina* because of its coarsely pitted surface and nonspinose test. PARKER (1962) figured specimens furnished with umbilical teeth, but these are rare in our material. In the Gulf of Mexico this species does not occur younger than the Wisconsinan Stage, although it is living in the Pacific and Indian Oceans.

ILLUSTRATIONS.—Plate 10, figures 1-4.——Specimens from the *Globoquadrina dutertrei* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole B, core 8, at a depth of 8.0 to 8.4 feet; ×160.

GLOBOQUADRINA HUMEROSA
(Takayanagi & Saito)

Plate 3, figures 4-9; Plate 8, figures 1-6

Globorotalia humerosa TAKAYANAGI & SAITO, 1962, p. 78, pl. 28, fig. 1, 2.

Globoquadrina humerosa (Takayanagi & Saito). PARKER, 1967, p. 169, 170, pl. 25, fig. 1-6.

Globigerina altispira altispira Cushman & Jarvis. AKERS & DORMAN, 1964, p. 14, pl. 12, fig. 3-5.

Globoquadrina humerosa was described from the Nobori Formation, Shikoku, Japan. A sample collected from a block of this unit at the base of the quarry was given to W. E. FRERICHS of the University of Wyoming by J. C. INGLE, JR. FRERICHS' sample studied by us contains specimens of *G. humerosa* having a nearly flat spiral side with 4.5 to 6 chambers visible in the last whorl. Fimbriate lips and apertural teeth are lacking. Associated species in the sample include *Globorotalia tosaensis, G.* sp. cf. *G. miocenica,* and *G. truncatulinoides,* suggesting an early Pleistocene (Nebraskan) age.

In general, the species is characterized by having a nearly flat spiral side, an umbilical-extraumbilical aperture, and as many as 7 chambers in the last whorl. Apertural teeth may be visible in well-preserved specimens, but no fimbriate lip is developed as in *Globorotalia acostaensis.* This species descended from *G. acostaensis* and is ancestral to *Globoquadrina dutertrei* (see Plate 3).

A clear distinction between *Globoquadrina humerosa* and *G. dutertrei* locally is difficult in the Pleistocene (i.e., post-*Globorotalia tosaensis* Subzone). Parker's (1962) illustrations of Holocene specimens of *G. dutertrei* include specimens with umbilical-extraumbilical apertures resembling *G. humerosa*. She says, "some adults and most juveniles have such apertures, although the adults are usually more umbilicate than are specimens of *G. humerosa*. Many adult specimens, however, have an umbilical aperture and may show the typical globoquadrine teeth."

Illustrations.—Plate 8, figures 1-6.——1-3. Specimens from the *Globorotalia multicamerata* Subzone, *Globorotalia margaritae* Zone, early Pliocene, in Gulf of Mexico core hole A, core 10, at a depth of 10.1 to 10.5 feet; ×130 (same specimens shown on Plate 3, figures 7-9; ×65).——4-6. Specimens from the *Pulleniatina obliquiloculata* Zone, in same core hole, late Pliocene, core 8, at a depth of 14.7 to 15.3 feet; ×136 (same specimens shown on Plate 3, figures 4-6; ×68).

GLOBOQUADRINA VENEZUELANA (Hedberg)

Plate 10, figures 5-7

Globigerina venezuelana Hedberg, 1937, p. 681, pl. 92, fig. 7.——Bolli, 1957, p. 110, pl. 23, fig. 6-8; p. 164, pl. 35, fig. 16-17.

Globigerina altispira Cushman & Jarvis. Cushman & Todd, 1945, p. 66, pl. 11, fig. 11-12.

Globoquadrina venezuelana (Hedberg). Blow, 1959, p. 186, pl. 11, fig. 58-59.——Poag & Akers, 1967, p. 172, pl. 17, fig. 12-14.——Parker, 1967, p. 171, pl. 26, fig. 4-10.

Cf. *Globoquadrina conglomerata* (Schwager). Parker, 1962, p. 240, 242, pl. 6, fig. 11-18.

Bottom samples from the Indian Ocean, in the personal collection of W. E. Frerichs contain abundant specimens of forms seemingly conspecific with *Globoquadrina venezuelana* but which are considered *G. conglomerata* by some workers. Specimens of *G. conglomerata* from the Holocene of the Pacific Ocean, figured by Parker (1962), are also quite similar to *G. venezuelana*. It is likely, therefore, that *G. venezuelana* is a junior synonym of *G. conglomerata,* which apparently lived on in the Pacific and Indian Oceans after withdrawing from the Atlantic, Caribbean, and Gulf of Mexico regions at the end of the Pliocene.

In designating a neotype for *Globigerina conglomerata,* Banner & Blow (1960) remarked: "It seems highly likely that *Globigerina venezuelana* Hedberg, 1937, and *Globigerina rotundata* var. *jacksonensis* Bandy, 1949, should be considered as subspecies of *G. conglomerata* Schwager. However, more work on the morphology of these other forms is required before their relationships can be fully evaluated."

Illustrations.—Plate 10, figures 5-7.——5-7. Specimens from the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole C, core 8, at a depth of 12.5 to 12.9 feet; ×160, ×120, ×120.

Genus GLOBOROTALIA Cushman

Globorotalia Cushman, 1927, p. 91.

Parker (1967) included in the family Globorotaliidae trochoid genera having smooth walls, with or without coarse secondary spines, that are nonspinose when living, and coarsely or finely pitted, and have angular or ovate chambers. She further considered the genera *Globorotalia* and *Turborotalia* to be synonymous because turborotalian species appear to have been ancestral to several lineages which develop keeled forms (e.g., *G. centralis*). This usage is adopted here.

Type-species.—*Pulvinulina menardii tumida* Brady (1877, p. 535), by original designation. From the middle Pliocene of New Ireland.

GLOBOROTALIA ACOSTAENSIS Blow

Plate 6, figures 4-5; Plate 7, figures 1-11

Globorotalia acostaensis Blow, 1959, p. 208, pl. 17, fig. 106.——Cita, Premoli-Silva, & Rossi, 1965, p. 225, 226, fig. 5, pl. 18, fig. 6.——Poag & Akers, 1967, p. 171, pl. 16, fig. 22-24.

Globorotalia (Turborotalia) acostaensis Blow. Banner & Blow, 1967, p. 153, pl. 3, fig. 1 (holotype refigured).

Globoquadrina acostaensis (Blow). Parker, 1967, p. 164, 165, pl. 24, fig. 3-9.

Cf. *Globoquadrina continuosa* (Blow). Parker, 1967, p. 166, pl. 24, fig. 1-2.

Parker (1967) figured a number of specimens having "apertural teeth," but few of ours have apertural teeth or flaps on the last chamber. This small species is regarded as the ancestor of *Globoquadrina humerosa,* from which it differs in the small size and narrow fimbriate lip bordering the aperture (Pl. 3, fig. 10-12; ×95, ×86, ×86).

Random specimens that resemble closely *Globorotalia acostaensis,* except in being more tightly coiled about the umbilicus, are found in the Pleistocene. These are referred here to *Globigerina* sp. aff. *G. pachyderma* (Ehrenberg) on Plate 6, figures 1-3.

Illustrations.—Plate 6, figures 4-5.——4-5. *Globorotalia* sp. aff. *G. acostaensis* from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, from core 6, at a depth of 4.4 to 4.8 feet; ×160. These four-chambered forms are similar to *Globigerina* sp. aff. *G. pachyderma* (pl. 6, fig. 1-3) but have the umbilical flap characteristic of *G.* sp. aff. *G. acostaensis.* [From Gulf of Mexico slope core hole A.] Plate 7, figures 1-11.——1-3, 7-8. Specimens from core 12 at a depth of 10.3 to 10.7 feet; ×170.——4-6. Specimens from core 12 at a depth of 0 to 0.6 foot; ×160.——9-11. Specimens from core 14 at a depth of 10.1 to 10.5 feet; ×235, ×215, ×215. [From the *Sphaeroidinellopsis seminulina* Subzone, *Globorotalia acostaensis* Zone, late Miocene.]

GLOBOROTALIA AEMILIANA

Colalongo & Sartoni

Plate 2, figures 13-14; Plate 18, figures 7-8; Plate 20, figures 1-2

Globorotalia hirsuta aemiliana Colalongo & Sartoni, 1967, p. 267-274, pl. 30, fig. 1.

This species is characterized by its nearly flat spiral side and low arched chambers on the apertural side. The peripheral margin of the test is acute but not keeled.

Specimens identified as *Globorotalia aemiliana* by Miss Maria Luisa Colalongo for us were compared with rare specimens obtained from this study from the middle Pliocene of the Gulf of Mexico. Our specimens are slightly smaller but otherwise the same as *G. aemiliana.* This species seems ancestral to *G. crassacrotonensis,* which gave rise to *G. crassaformis* (Pl. 2, fig. 13-14).

Because of its seemingly short life-range and rare occurrence in the section, it is not a particularly useful index species.

Illustrations.—Plate 18, figures 7-8.——Topotypes (sent by M. Colalongo) from sample no. 228, middle Pliocene, from Catanzaro, Italy; ×170. Plate 20, figures 1-2.——Specimens from the *Globorotalia multicamerata* Subzone, *Globorotalia margaritae* Zone, early Pliocene, in Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 326 to 328 cm; ×110 (same specimens shown on Plate 2, figures 13-14; ×45).

GLOBOROTALIA CRASSAFORMIS
(Galloway & Wissler)

Plate 2, figures 1-9; Plate 21, figures 1-8

Globigerina crassaformis Galloway & Wissler, 1927, p. 41, pl. 7, fig. 12.

Globorotalia crassaformis (Galloway & Wissler). Parker, 1962, p. 235, pl. 4, fig. 17-18, 20-21.——Ingle, 1967, p. 357, pl. 38, fig. 3-5.

Although typological material from the early Pleistocene Lomita Marl of southern California failed to yield this species, W. E. Frerichs has assured us that our concept of the species is correct and follows closely that of Galloway & Wissler (1927) and Ingle (1967).

Globorotalia crassaformis differs from *G. crassacrotonensis* in being generally larger and in having higher arched chambers and a less acute periphery (Pl. 2, fig. 1-9).

Globorotalia crassaformis Bioseries: This lineage begins in middle Pliocene with a small low-spired species of unknown origin, *Globorotalia aemiliana. Globorotalia aemiliana* gives rise to *G. crassacrotonensis,* which shortly thereafter gives rise to *G. crassaformis.* The full development of this lineage is seen within the middle Pliocene.

In this plexus the slightly convex spiral side becomes nearly flattened; the chambers in the last whorl are reduced from a usual 4.5 to 4; the test outlines changes from symmetrically lobate to less lobate to broadly quadrate; and the umbilical region becomes deepened. Specific differences are seen in the increasingly higher vaulting of the chambers on the umbilical side from middle to late Pliocene. This character can be expressed in terms of the acute angle formed by the confluence of the chamber walls at the peripheral margin, which is smaller in more phylogenetically primitive individuals.

Illustrations.—Plate 21, figures 1-8.——1-3. Specimens from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 7 at a depth of 11.5 to 12.1 feet; ×120 (same specimens shown on Plate 2, figures 4-6; ×50).——4-5, 7-8. Specimens from the *Globoquadrina dutertrei* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 4 at a depth of 7.6 to 8.0 feet; ×110 (specimens 4, 7, and 8 are shown on Plate 2, figures 1-3).——6. Specimen from the *Globoquadrina dutertrei* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 10 at a depth of 15.0 to 15.6 feet; ×85. [1-5, 7-8. From Gulf of Mexico slope core hole A.——6. From Gulf of Mexico slope core hole B.]

GLOBOROTALIA CRASSACROTONENSIS
Conato & Follador

Plate 2, figures 10-12; Plate 20, figures 3-7

Globorotalia crassacrotonensis Conato & Follador, 1967, p. 557, 558, fig. 2, 4.3 (holotype).

Globorotalia hirsuta aemiliana Colalongo & Sartoni, 1967, pl. 30, fig. 3.

This species is usually very common in the middle Pliocene and is commonly confused with *Globorotalia crassaformis* and *G. punctulata.* It differs from *G. crassaformis* in having lower arched chambers and from *G. punctulata* in having a lower arched sutural aperture and more acute periphery.

Illustrations.—Plate 20, figures 3-7.——3, 6. Specimens from core 8 at a depth of 12.5 to 12.9 feet.——4-5, 7. Specimens from core 9 at a depth of 13.0 to 13.7 feet (specimens 4, 5, and 7 are shown on Plate 2, figures 10-12; ×50). [From the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene; ×120. Gulf of Mexico slope core hole C (3, 6) and core hole A (4-5, 7).]

GLOBOROTALIA FLEXUOSA (Koch)

Plate 12, figures 6-8

Pulvinulina tumida flexuosa Koch, 1923, p. 357, fig. 9-10.

Globorotalia tumida (Brady). Parker, 1967 (in part), p. 182, pl. 32, fig. 7.

Parker (1967) considered this species a flexuose form of *Globorotalia tumida* and gradational to the typical form. Irrespective of this consideration, the species has stratigraphic utility in characterizing late Pleistocene interglacial periods in the Atlantic Ocean and Gulf of Mexico. Similarly, *G. multicamerata* is observed locally to have an occasional flexuose development of the last chamber (see discussion under *G. tumida*).

Illustrations.—Plate 12, figures 6-8.——Specimens from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole C, core 1, at a depth of 13.0 to 13.6 feet; ×85.

GLOBOROTALIA INFLATA (d'Orbigny)

Plate 27, figures 8-11; Plate 28, figures 1-4, 6

Globigerina inflata d'Orbigny, 1839, in Barker-Webb & Berthelot, 1839, p. 134, pl. 2, fig. 7-9.——Akers & Dorman, 1964, p. 16, pl. 13, fig. 17-19.

Globorotalia sp. 1 PHLEGER, PARKER, & PEIRSON, 1953, p. 23, pl. 4, fig. 19-21.

Globorotalia inflata (d'Orbigny). PARKER, 1962, p. 236, pl. 5, fig. 6-9.——BANNER & BLOW, 1967, p. 144-146, pl. 4, fig. 1 (lectotype), 11.——PARKER, 1967, p. 179, pl. 29, fig. 1-3.——INGLE, 1967, p. 357, pl. 39, fig. 4-5; pl. 40, fig. 1.

Italian workers derive *Globorotalia inflata* from the *G. punticulata-G. bononiensis* lineage known from the early and middle Pliocene of Italy. *G. inflata* makes its evolutionary appearance in late Pliocene. Late Pliocene and early Pleistocene forms encountered in the present study are smaller generally than later forms. A variant form restricted to the very late Pliocene and early Pleistocene (commonly present in the Nebraskan) differs from the typical form in being slightly larger and having a more thickened cortex. The first appearance of *G. inflata* in the Gulf of Mexico coincides closely with onset of severe climatic cooling and is probably not the earliest evolutionary form.

ILLUSTRATIONS.—Plate 27, figures 8-11.——8. Typical form from the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 3 at a depth of 0 to 0.4 foot; ×100.——9-11. Early forms having five chambers in final whorl showing angular more compressed chambers, from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 16 at a depth of 13.7 to 14.3 feet; ×170. Plate 28, figures 1-4, 6. ——Advanced forms having four chambers in final whorl showing more inflated chambers, from the same sample as Pl. 27, fig. 8; ×100. [From Gulf of Mexico slope core hole A (Pl. 27, fig. 8; Pl. 28, fig. 1-4, 6) and B (Pl. 27, fig. 9-11).]

GLOBOROTALIA INFLATA (variant)

Plate 27, figures 1-7

Globorotalia inflata (d'Orbigny), variant PARKER, 1967, p. 179, pl. 29, fig. 3.

The proper status of this species must await close scrutiny of similar forms such as *Globorotalia inflata, G. tosaensis, G. crassaformis,* and *G. (T.) crassaformis ronda* BLOW (1967). This species is mostly restricted to the early Pleistocene (Nebraskan Stage).

ILLUSTRATIONS.—Plate 27, figures 1-7.——1-5, 7. Specimens from Gulf of Mexico slope core hole A, core 7, at a depth of 11.5 to 12.1 feet; ×90.——6. Specimen from Gulf of Mexico slope core hole B, core 17, at a depth of 0 to 0.4 foot; ×95. [From the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene.]

GLOBOROTALIA LENGUAENSIS Bolli

Plate 19, figures 1-3

Globorotalia lenguaensis BOLLI, 1957, p. 120, pl. 29, fig. 5.——BLOW, 1959, p. 213-214, pl. 17, fig. 115.

This small globorotaliid does not range above the early late Miocene in the control sections studied.

ILLUSTRATIONS.—Plate 19, figures 1-3.——Specimens from the *Sphaeroidinellopsis seminulina* Subzone, *Globorotalia acostaensis* Zone, late Miocene, in Gulf of Mexico slope core hole A, core 14, at a depth of 10.1 to 10.5 feet; ×230.

GLOBOROTALIA FOHSI LOBATA Bermúdez

Plate 19, figures 4-6

Globorotalia fohsi Cushman & Ellisor. CUSHMAN & STAINFORTH, 1945, p. 70, pl. 13, fig. 13.

Globorotalia lobata BERMÚDEZ, 1949, p. 286, pl. 22, fig. 15-17.

Globorotalia fohsi lobata Bermúdez. BOLLI, 1950, p. 88, pl. 15, fig. 7-8.——BOLLI, 1957, p. 119, pl. 28, fig. 13-14.

BLOW & BANNER (1966) regarded *Globorotalia fohsi lobata* and *G. fohsi robusta* as formae (i.e., different forms) of their emended taxon *G. (G.) fohsi* (i.e., forms possessing imperforate carina over the entire periphery of the last whorl). BOLLI (1967) countered this proposal, saying that these taxa are morphologically distinct, have different stratigraphic ranges, and are stratigraphically useful when treated as separate species. Because formae have no taxonomic status (i.e., are below subspecies) a subspecies rank is therefore preferable to maintain nomenclatorial stability under the International Code of Zoological Nomenclature.

Although distinct morphologically from *Globorotalia fohsi fohsi,* some specimens of *G. fohsi lobata* and *G. fohsi robusta* are difficult to differentiate, making it desirable sometimes to hyphenate the zones as is done in the eastern Venezuelan basin. Although the zones are not always easily separable, the usage of BOLLI (1967, fig. 3) should be followed.

ILLUSTRATIONS.—Plate 19, figures 4-6.——Specimens from the *Globorotalia fohsi lobata* Zone, middle Miocene, in Gulf of Mexico slope core hole E, core 7, at a depth of 14.4 to 14.7 feet; ×110.

GLOBOROTALIA MARGARITAE Bolli & Bermúdez

Plate 18, figures 1-6

Globorotalia margaritae BOLLI & BERMÚDEZ, 1965, p. 139, 140, pl. 1, fig. 16-18.——PARKER, 1967, p. 179, 180, pl. 32, fig. 1-2.

Globorotalia hirsuta (d'Orbigny). AGIP MINERARIA, 1957, pl. 48, fig. 4.

This small thin-keeled globorotaliid has a pronounced rounded-convex spiral side and a final pie-shaped chamber making up about one-third of the final whorl. It is descended from a nonkeeled ancestor, probably *Globorotalia juanai* BERMÚDEZ (1966), and is ancestral to *G. praehirsuta.*

Many references to *Globorotalia hirsuta* in the early Pliocene (Tabianian Stage) of Italy are regarded as *G. margaritae* (CATI & OTHERS, 1968). Samples from the type locality of the Tabianian Stage at the "New Church" locality contain this species in quantity.

ILLUSTRATIONS.—Plate 18, figures 1-6.——1, 3, 5. Specimens from core 8 at a depth of 15.0 to 15.8 feet; ×100.——2. Specimens from core 9 at a depth of 13.0 to 13.7 feet; ×90.——4. Specimens from core 10 at a depth of 10.1 to 10.5 feet; ×90.——6. Specimen from core 10 at a depth of 7.6 to 8.0 feet; ×85. [Pliocene, *Pulleniatina primalis* Subzone (1-3, 5) and *Globorotalia multicamerata* Subzone (4, 6), *Globorotalia margaritae* Zone. From Gulf of Mexico slope core hole C (1, 3, 5) and A (2, 4, 6).]

GLOBOROTALIA MENARDII (d'Orbigny)

Plate 11, figures 1-3; Plate 13, figures 1-5; Plate 14, figures 1-3; Plate 17, figure 4

Rotalia menardii d'Orbigny, 1826, p. 273, No. 26; Modèles No. 10, Ire livraison *(nomen nudum)*.——Parker, Jones, & Brady, 1865, p. 20, pl. 3, fig. 81 (no type designated).——Banner & Blow, 1960, p. 31, pl. 6, fig. 2 (lectotype).

Globorotalia menardii (d'Orbigny). Bradshaw, 1959, p. 44, pl. 8, fig. 3-4.——Bé & Hamlin, 1967, p. 103, fig. 34.

Cf. *Rotalina (Rotalina) cultrata* d'Orbigny, 1839, p. 76, pl. 5, fig. 7-9.——Banner & Blow, 1960, p. 34, pl. 6, fig. 3 (lectotype).

Globorotalia cultrata (d'Orbigny). Parker, 1962, p. 235, pl. 5, fig. 3-5.——Parker, 1967, p. 177, 178, pl. 31, fig. 2-3.

Current usage favors retaining the older name *Globorotalia menardii* rather than the proposed synonym *G. cultrata* because the former is better understood and widely recognized. This practice, moreover, is in accord with priority provisions of the International Code of Zoological Nomenclature.

A point to consider is that d'Orbigny's model of *Globorotalia menardii* is based on material from the beach of the Adriatic Sea near Rimini, Italy, not from Recent marine sediments of the West Indies from which *G. cultrata* was described. Because *G. menardii* is not known to be living in the Mediterranean Sea, the material from Rimini must be fossil—either redeposited Miocene or Pleistocene interglacial. Because *G. menardii* is not certainly known from the Italian Pleistocene, it is likely that the Rimini material is Miocene.

Banner & Blow have commented many times on the precise "stratigraphic concept" of a species; thus, a neotype of *Globorotalia menardii* (*sensu* d'Orbigny, 1826) should be selected from fossil material near Rimini. *Globorotalia menardii* (Miocene) and *G. cultrata* (Recent) differ somewhat in size and overall development of the test but here are considered synonymous. It is acknowledged that some paleontologists consider that variations in the development of this species have stratigraphic and paleoecological applications in the Pleistocene.

Illustrations.—Plate 11, figures 1-3.——Specimens, ×65, ×50, ×40. Plate 13, figures 1-5.——Specimens, ×85. Plate 14, figures 1-3.——Specimens, ×65, ×50, ×40. Plate 17, figure 4.——Specimen, ×90. [*Globorotalia tumida* Zone, Holocene, in Gulf of Mexico slope core hole A, core 1, at a depth of 0 to 0.8 foot (Pl. 11, fig. 1-3; Pl. 14, fig. 1-3) and *Globorotalia multicamerata* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole A, core 10, at a depth of 12.6 to 13.0 feet (Pl. 13, fig. 1-5; Pl. 17, fig. 4).]

GLOBOROTALIA MIOCENICA Palmer

Plate 16, figures 1-4

Globorotalia menardii miocenica Palmer, 1945, p. 70, pl. 1, fig. 10.——Akers & Dorman, 1964, p. 18, pl. 14, fig. 1-5, 19-21.

This species is characterized by a flat spiral side, thin-walled test, high chambers, and circular outline. Most observed specimens coil to the right. This species is first recorded in the present study in the late Pliocene and ranges upward through the Nebraskan (early Pleistocene). It should not be confused with *Globorotalia pertenuis,* which is biconvex and has a lobulate periphery.

The type locality of this species is within the upper part of the Bowden Formation ("shell-bed" locality), Bowden, Jamaica, West Indies, above the extinction horizon of *Globoquadrina altispira.* The type level is, therefore, early Pleistocene (Nebraskan), not middle Miocene as stated by Woodring (1925, 1928).

Illustrations.—Plate 16, figures 1-4.——1a, umbilical view; 1b-d, oblique views.——2, 4. Edge views.——3. View of spiral side. [From the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 190 to 192 cm in the Gulf of Mexico; ×90.]

GLOBOROTALIA MULTICAMERATA
Cushman & Jarvis

Plate 11, figures 4-6; Plate 12, figures 4-5; Plate 13, figures 6-8; Plate 14, figures 5-8

Globorotalia menardii multicamerata Cushman & Jarvis, 1930, p. 367, pl. 34, fig. 8.——Poag & Akers, 1967, p. 171, pl. 17, fig. 4-6.

Globorotalia menardii fijiensis Cushman, 1934, p. 136, pl. 17, fig. 5.

Globorotalia multicamerata Cushman & Jarvis. Parker, 1967, p. 180, pl. 31, fig. 5-6.

This species differs from *Globorotalia menardii* in having 6 to 8 (occasionally more) chambers in the final whorl, a more tumid test, and a thicker peripheral carina. It is mostly right coiling in the study area. Parker (1967) recorded occasional shifts to left coiling and specimens with as many as about 9.5 chambers in the final whorl. On one occasion, a specimen with 12 chambers was observed.

Illustrations.—Plate 11, figures 4-6.——Specimens, ×65. Plate 12, figures 4-5.——4. Specimen, ×60.——5. Specimen, ×90. Plate 13, figures 6-8.——Specimens identified as *Globorotalia* sp. cf. *G. multicamerata* Cushman & Jarvis that are transitional early forms just above the coiling change from left to right in the *Globorotalia menardii* complex; ×85, ×85, ×170. Plate 14, figures 5-8.——Specimens, ×85. [Pliocene, *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, in Gulf of Mexico slope core hole A, core 8, at a depth of 14.7 to 15.3 feet (Pl. 11, fig. 5-6; Pl. 12, fig. 4); *Pulleniatina obliquiloculata* Zone in Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 194 to 197 cm (Pl. 14, fig. 5-8) and *Globorotalia multicamerata* Subzone in Gulf of

Mexico slope core hole A, core 10, at a depth of 12.6 to 13.0 feet (Pl. 13, fig. 1-5).]

GLOBOROTALIA PERTENUIS Beard

Plate 14, figure 4; Plate 15, figures 1-6; Plate 16, figures 5-6; Plate 17, figures 5, 7

Globorotalia pertenuis Beard, 1969, p. 552-553, pl. 1, fig. 1-6; pl. 2, fig. 5-6.

Shape of test a very low trochospire, biconvex; equatorial periphery subcircular, lobate; axial periphery angular with a distinct imperforate keel; wall calcareous, perforate, some specimens almost transparent; chambers strongly compressed, 6 to 10 in final whorl, commonly about 7; aperture a low arch, extraumbilical-umbilical with flaring aperture flap extending onto umbilical area and becoming imbricate in final development. In some specimens extensions of flap cover the umbilical area as a plate and extend along sutures with small openings at terminal end of bullalike plate; sutures on apertural side are sinuous owing to growth of chambers over relict aperture; on some specimens chamber grows around relict aperture, leaving flaps exposed and projecting into following chambers. Largest diameter of the holotype and paratypes is about 1.0 mm.

Discussion.—This species differs from *Globorotalia miocenica* in its somewhat larger size, more lobate outline, and lenslike biconvex shape in edge view. It differs from *Globorotalia menardii* in its more circular outline, more numerous chambers, thinner walled test and keel, and relict apertural flaps which extend imbricate fashion onto the umbilical area. *Globorotalia pertenuis* differs from *Globorotalia multicamerata* in the much thinner wall of the test and keel.

Globorotalia pertenuis is considered to have descended from *G. praemiocenica* in the later Pliocene and to have reached full development in early Pleistocene time. At the time of this writing Blow (1967) described *Globorotalia exilis,* which has certain affinities with *G. pertenuis* but fewer and less lobate chambers. His figured holotype seemingly is intermediate in development between *G. praemiocenica* and *G. pertenuis. G. exilis,* therefore, is not morphologically distinct enough to have important stratigraphic usage.

This species was described from a core taken on the Sigsbee knolls, central Gulf of Mexico, by Texas A. & M. University. The type level is early Pleistocene (Nebraskan).

Illustrations.—Plate 14, figure 4.——Paratype, USNM No. 688331; ×81. Plate 15, figures 1-6.——1. Holotype, USNM No. 688324; ×50.——2-5. Paratype, USNM Nos. 688325-688328; ×80.——6. Paratype, USNM No. 688329; 6a, ×80, 6b, ×160. Plate 16, figures 5-6.——5. Oblique side view, USNM No. 688332; ×78.——6. USNM No. 688330; 6a, edge view, ×78; 6b, umbilical view, ×133. Plate 17, figures 5, 7.——5. Specimen, ×50.——7. Specimen showing extension of bulla onto dorsal side; note small aperture at terminal end; ×90. [*Globorotalia tosaensis* Subzone, *Globorotalia margaritae* Zone, Pleistocene, from Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 190 to 192 cm except Plate 17, figure 5, which is from Gulf of Mexico slope core hole C, core 7, at a depth of 10.0 to 10.4 feet.]

GLOBOROTALIA PRAEHIRSUTA Blow

Plate 18, figures 9-12

Globorotalia (Globorotalia) hirsuta praehirsuta Blow, 1967, p. 400-402, pl. 43, fig. 3-7.

Globorotalia hirsuta (d'Orbigny). Parker, 1967, p. 178-179, pl. 32, fig. 3.

This large, four-chambered, hirsute species occurs for the first time commonly in the late Pliocene. The species is characteristically biconvex with a distinct umbo on the spiral side and an imperforate peripheral carina, looking like an oversized *Globorotalia margaritae* from which it evolved. Small juvenile specimens may be mistaken for *G. margaritae.*

Illustrations.—Plate 18, figures 9-12.——Specimens from the *Pulleniatina obliquiloculata* Zone, Pliocene, in Gulf of Mexico core hole A, core 8, at a depth of 14.7 to 15.3 feet; ×110.

GLOBOROTALIA PRAEMIOCENICA
Lamb & Beard, n. sp.

Plate 17, figures 1-3, 6

Globorotalia (G.) cultrata limbata (Fornasini, 1902, *ex* d'Orbigny, 1826). Blow, 1967 (part; not Fornasini), p. 359, pl. 42, fig. 2-3; ? pl. 7, fig. 4-6.

Test average size for genus; chambers dorsoventrally compressed, finely perforate and coiled in low trochospire with 5 to 7 chambers in last whorl of adult; peripheral margin of chambers distinctly lobate and carinate; spiral side commonly strongly convex, giving biconvex appearance to test in end view; aperture single-sutural, extending from umbilicus to peripheral margin of test, and furnished with thin lip; sutures on umbilical side depressed and on spiral side strongly recurved and limbate.

Discussion.—This species developed during the early Pliocene and gave rise to *G. miocenica* in the late Pliocene. There is suspicion that it is also an evolutionary antecedent of *G. multicamerata. Globorotalia praemiocenica* differs from *G. multicamerata* in having higher arched chambers and a thin carina and from *G. miocenica* in having a distinct lobulate peripheral chamber margin and typically a strongly convex spiral side. The type locality for *G. limbata* is redeposited fossil sediment of probable middle Miocene age from near Rimini, Italy, which is also the type locality for *G. menardii.* Observable differences between these two species are negligible. Similarly, *G. pseudomiocenica* Bolli & Bermúdez (1965), described from the early late Miocene of coastal Venezuela, is more closely akin to *G. menardii* than to *G. praemiocenica,* n. sp.

Illustrations.—Plate 17, figures 1-3, 6.——Specimens from the *Pulleniatina obliquiloculata* Zone, Pliocene, in Gulf of Mexico slope core hole A, core 8, at a depth of 14.0 to 15.3 feet; ×125. Holotype figure 1; paratypes figures 2, 3, 6. Types to be deposited in the USNM collection.

GLOBOROTALIA FOHSI ROBUSTA Bolli

Plate 19, figures 7-9

Globorotalia fohsi robusta Bolli, 1950, p. 84, pl. 15, fig. 3.——Bolli, 1957, p. 119, pl. 28, fig. 16.——Blow, 1959, p. 213, pl. 16, fig. 114.

See discussion of this species under *Globorotalia fohsi lobata*.

Illustrations.—Plate 19, figures 7-9.——Specimens from the *Globorotalia fohsi robusta* Zone, middle Miocene, in Gulf of Mexico slope core hole E, core 6, at a depth of 3.2 to 3.6 feet; ×110.

GLOBOROTALIA SIAKENSIS LeRoy

Plate 6, figures 6-9

Globorotalia siakensis LeRoy, 1939, p. 39-40, pl. 3, fig. 30-31 (*fide* Blow, 1967).——Blow, 1967, p. 356, pl. 10, fig. 7-9 (holotype refigured); pl. 34, fig. 4-5 (ideotype and hypotype).

Globorotalia mayeri Cushman & Ellisor. Bolli, 1957, p. 118, pl. 28, fig. 4.——Blow, 1959, p. 214, pl. 18, fig. 116.

Globorotalia siakensis LeRoy, following the concept of Blow (1967), fits the concept of the species in this study that has been referred previously to *G. mayeri* Cushman & Ellisor by Bolli (1957), Blow (1959), and others. This species is found commonly in the *Globorotalia fohsi* Zone *sensu lato* of central Sumatra, and specimens are conspecific with Trinidad specimens.

Illustrations.—Plate 6, figures 6-9.——6. Specimens from the *Globorotalia fohsi fohsi* Zone (*sensu* Bolli, 1957), middle Miocene, in Gulf of Mexico slope core hole E, core 8, at a depth of 15.2 to 15.6 feet; ×120.——7-9. Specimens from the *Globorotalia siakensis* Zone, middle Miocene, in the same core hole, core 4, at a depth of 12.5 to 12.9 feet; ×130, ×170, ×170.

GLOBOROTALIA TOSAENSIS
Takayanagi & Saito

Plate 22, figures 1-7; Plate 23, figures 1-2

Globorotalia tosaensis Takayanagi & Saito, 1962, p. 81, pl. 28, fig. 11-12.——Parker, 1967 (part), p. 181, fig. 4-5, 7 (*not* fig. 6).

Globorotalia (T.) tosaensis tosaensis Takayanagi & Saito. Blow, 1967, p. 393, 394, pl. 4, fig. 10-12; pl. 40, fig. 4-7.

Globorotalia (T.) tosaensis tenuitheca Blow, 1967, p. 394-396, pl. 4, fig. 13-17; pl. 40, fig. 1-3.

A basic concept of this species is that it lacks a keeled margin. The degree of variability of the two subspecies designated by Blow (1967) was not considered in the present study. It is likely, however, that at least two distinct forms of this species exist; these can be explained by polyphyletic origins as suggested by Blow (1967). A perplexing problem concerning an apparent discontinuity in the stratigraphic distribution of *Globorotalia tosaensis* could possibly be explained in this manner.

Illustrations.—Plate 22, figures 1-7.——1-3. Typical specimens from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole C, core 6, at a depth of 0 to 0.6 foot; ×120.——4-5. Transitional specimens from the *Pulleniatina obliquiloculata* Zone, late Pliocene, in Gulf of Mexico slope core hole A, core 8, at a depth of 0 to 0.6 foot; ×120. Plate 23, figures 1-2.——1. Specimen showing rounded peripheral margin; ×200.——2. Specimen showing less solution than 1; 2a, b, spiral and umbilical views, ×200; 2c, enlarged view showing nonperforate and encrusted margin of earlier chambers, ×2,000. [Specimens from the Indian Ocean by the courtesy of T. Saito.]

GLOBOROTALIA TRUNCATULINOIDES
(d'Orbigny)

Plate 24, figures 1-4; Plate 25, figures 1-7; Plate 26, figures 1-3

Rotalina truncatulinoides d'Orbigny, 1839, p. 132, pl. 2, fig. 25-27.

Globorotalia truncatulinoides (d'Orbigny). Parker, 1967, p. 181, pl. 31, fig. 1.——Bolli, Loeblich, & Tappan, 1957, p. 41, pl. 10, fig. 3.——Bayliss, 1969, p. 133-134, fig. 5.

Takayanagi & Saito (1962), Banner & Blow (1965a), Parker (1967), Phillips & others (1968), and others have suggested that *Globorotalia truncatulinoides* evolved from *G. tosaensis* by developing a keeled chamber (peripheral) margin. Because the species *G. tosaensis*, as used here, includes possibly two forms (see Blow, 1967), it needs to be qualified that the ancestral form developed in late Pliocene. Phylogenetically primitive specimens of *G. truncatulinoides* in the early Pleistocene (Nebraskan Stage) are mostly tightly coiled with a shallow umbilicus, whereas younger (phylogenetically advanced) specimens mostly develop a deep umbilicus. This species has a rather discontinuous stratigraphic occurrence through the Nebraskan-Aftonian Stages within the study area and does not occur commonly until the Kansan glacial Stage.

Illustrations.—Plate 24, figures 1-4.——1. Specimen, ×190.——2-3a, 4. Typical specimens from core 1 at a depth of 10.0 to 12.5 feet; ×90.——3b. Enlarged view showing encrusted overgrowth on early keeled chamber; ×450.——3c. Enlarged view showing keeled margin of ultimate chamber; ×450. Plate 25, figures 1-7.——1. Umbilical view, ×166.——2. Edge view, ×157.——3. Umbilical view, ×170.——4. Early form; 4a, spiral view, ×160; 4b, enlarged view showing keeled margin of ultimate chamber, ×800. [From core 16 at a depth of 6.8 to 7.4 feet.]——5-7. Specimens from core 1 at a depth of 10.0 to 12.5 feet; ×90. Plate 26, figures 1-3.——1. Specimen; 1a, umbilical view, ×160; 1b, oblique view, ×185.——2. Oblique view, ×185.——3. Early transitional form having incipient keel; 3a, spiral view, ×170; 3b-d, enlarged views showing nonperforate margin of ultimate chamber, ×408, ×807, ×1615. [From core 7 at a depth of 3.0 to 3.4 feet.] [From *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, in Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 150 to 160 cm (Pl. 24, fig. 1); Gulf of Mexico slope core hole B (Pl. 25, fig. 1-4); Gulf of Mexico slope core hole A (Pl. 26, fig. 1-3). From ***Pulleniatina finalis*** Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole A (Pl. 24, fig. 2-4). From ***Globorotalia tumida*** Zone, Holocene, in Gulf of Mexico slope core hole A (Pl. 25, fig. 5-7).]

GLOBOROTALIA TUMIDA (Brady)

Plate 12, figures 1-3

Globorotalia menardii (d'Orbigny) var. ***tumida*** (Brady). BANNER & BLOW, 1960, p. 26, pl. 5, fig. 1 (lectotype).

According to BANNER & BLOW (1960), BRADY first described this form from a fragment of soft, white calcareous rock which had been found by LIVERSIDGE on a beach on the east side of New Ireland. According to PARKER (1967) the type sample is described by LIVERSIDGE (1877) as a fragment from a carved figure composed of foraminiferal "chalk" picked up on the beach on the east side of New Ireland (Bismark Archipelago) by a Wesleyan missionary, Dr. G. BROWN. The origin of the chalk carving is unknown, and the sample contains an excellent planktonic fauna identified by Miss PARKER including *Globigerina nepenthes, Globigerinoides obliquus, Globoquadrina altispira, G. dehiscens, G. humerosa, G. venezuelana, Globorotalia tumida, Pulleniatina primalis, "Sphaeroidinella seminulina,"* and *"S. subdehiscens."* PARKER (1967) considers the sample to be late Miocene; more likely, however, it represents early Pliocene, probably *Pulleniatina primalis* Subzone.

Large tumid forms of living *Globorotalia tumida* can be differentiated from the smaller, less tumid Pliocene form. Our visual and scanning electron-microscope studies suggest that *G. ungulata* is a nontumid growth form of the living large, tumid *G. tumida*. If true, this suggests the possibility that different species of globorotaliids have a tumid form, or tumid growth stage, possibly related to a mode of living such as a particular depth in the water column. The stratigraphic range of *G. tumida sensu stricto,* therefore, may be considerably confused.

ILLUSTRATIONS.—Plate 12, figures 1-3.——Specimens from the *Globorotalia tumida* Zone (Holocene) in slope core hole A, core 1, at a depth of 0-0.8 foot; ×80, ×80, ×95.

GLOBOROTALIA UNGULATA Bermúdez

Plate 11, figures 7-9

Globorotalia ungulata BERMÚDEZ, 1961, p. 1304-1305, pl. 15, fig. 6.——BLOW, 1967, p. 372, pl. 8, fig. 13-15.

This species has been found in many samples collected by the Atlantis Expedition. According to BLOW (1967), it is a very characteristic form. Although the overall test shape is reminiscent of ***Globorotalia tumida,*** the very distinctive thin, delicate, finely perforate test wall enables this form to be recognized easily.

BLOW (1967) records this species from the late Pliocene of Jamaica. In the present study, however, the species was not found below latest Wisconsinan or earliest Holocene. BLOW (1967) did not figure his late Pliocene specimens, and possibly they represent misidentifications.

Visual and scanning electron-microscope study of Holocene populations of globorotaliids suggest that ***Globorotalia ungulata*** and ***G. tumida*** are growth forms of the same species. If this is true, then the tumid character of the test may not be highly significant for specific determinations.

ILLUSTRATIONS.—Plate 11, figures 7-9.——7-9. Specimens from the *Globorotalia tumida* Zone, Holocene, in Gulf of Mexico slope core hole A, core 1, at a depth of 0 to 0.8 foot; ×85, ×100, ×100.

Genus PULLENIATINA Cushman

Pulleniatina CUSHMAN, 1927, p. 90.

Test free, globose, trochospiral to streptospiral, early portion as in *Globigerina,* with open umbilicus, later chambers completely enveloping entire umbilical side of previous trochospiral coil, and thus appearing involute; aperture interiomarginal, in young a broad umbilical arch, as in *Globigerina,* in adult a broad low extraumbilical arch at base of final enveloping chamber, bordered above by thickened lip but because of streptospiral plan of growth, not directly opening into earlier umbilicus (see emendation by BANNER & BLOW, 1967).

Until 1964 this genus contained only one described species and no subspecies, and the concept of the genus, therefore, was restricted. The characteristics of the genus have been discussed exhaustively by BANNER & BLOW (1967), who modify the definition of the genus by broadening it to include phylogenetically more primitive streptospiral forms that have a narrow slitlike umbilical-extraumbilical septal aperture in the early ontogenetic stages of some specimens but a high and arched umbilical-extraumbilical septal aperture at a slightly later ontogenetic stage.

TYPE-SPECIES.—*Pullenia sphaeroides obliquiloculata* PARKER & JONES (1865, p. 365, 368), by original designation. From the Recent of the South Atlantic Ocean.

PULLENIATINA FINALIS Banner & Blow

Plate 29, figures 5-7; Plate 30, figure 1

Pulleniatina obliquiloculata (Parker & Jones). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 33, pl. 4, fig. 3-5.——PARKER, 1967, p. 172, pl. 28, fig. 1.

Pulleniatina obliquiloculata (Parker & Jones) ***finalis*** BANNER & BLOW, 1967, p. 140-142, pl. 2, fig. 4-10; pl. 3, fig. 5; pl. 4, fig. 10.

BANNER & BLOW (1967) described this species from Holocene sediments of the South Atlantic Ocean. They claimed that it evolved from ***Pulleniatina obliquiloculata*** in the late Pleistocene and differs in having a high arched aperture, entirely extraumbilical in position, extending from the ventral surface, at a point just posterior to the posterior intercameral suture of the antepenultimate chamber, across the periphery of the test and onto the dorsal surface as far as the spiral suture of the antepenultimate chamber.

This species is first encountered in the Illinoisan Stage in the study area and is an index species for the *Pulleniatina finalis* Subzone of the *Globorotalia truncatulinoides* Zone.

Illustrations.—Plate 29, figures 5-7.——5, 7. Specimens from Gulf of Mexico slope core hole A, core 3, at a depth of 0 to 0.8 foot; ×75.——6. Specimen from slope core hole C, core 1, at a depth of 13.0 to 13.6 feet; ×85. [From the *Pulleniatina finalis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene.] Plate 30, figure 1.——Specimen from the same zone in Gulf of Mexico slope core hole A, core 1, at a depth of 0 to 0.8 foot; 1a—a representative specimen, ×75; 1b-f, successive enlargements, ×150, ×425, ×850, ×1,700, ×4,250 (note how rather large pores are considerably reduced in size by the outer layer of shell material; normally preserved specimens appear very finely perforate).

PULLENIATINA OBLIQUILOCULATA (Parker & Jones)

Plate 29, figures 1-4

Pullenia obliquiloculata Parker & Jones, in Carpenter (1862), p. 183 *(nomen nudum)*.

Pullenia sphaeroides obliquiloculata Parker & Jones, 1865, p. 365, 368, pl. 19, fig. 4.——Banner & Blow, 1960, p. 25, pl. 7, fig. 4 (lectotype designated by Bolli, Loeblich, & Tappan, 1957).

Globigerina antillensis Bermúdez, 1961, p. 1156, p. 1, fig. 1.

Pulleniatina obliquiloculata (Parker & Jones). Parker, 1962, p. 234, pl. 4, fig. 13-16, 19, 22.——Parker, 1967, p. 172, pl. 28, fig. 1.

Pulleniatina obliquiloculata trochospira Hartono, 1964, p. 10, fig. a-c.

Pulleniatina obliquiloculata obliquiloculata (Parker & Jones). Banner & Blow, 1967, p. 137, pl. 3, fig. 4 (lectotype refigured); pl. 4, fig. 9.

Banner & Blow (1967) gave a detailed discussion and emendation of this species and described its development from *Pulleniatina primalis*. Besides the subspecies listed above in the synonymy, they described *P. obliquiloculata praecursor,* which they placed as transitional between *P. primalis* and *P. obliquiloculata sensu stricto,* and *P. obliquiloculata finalis*. Parker (1967) maintained that the distinction between *P. praecursor* and *P. primalis* is negligible and rather arbitrary. Topotype material of *P. praecursor* (late Pliocene Borbon Formation of Ecuador) contains specimens showing variations from *P. primalis* to typical *P. praecursor,* thereby indicating ontogenetic as well as evolutionary variation. Adult forms of *P. praecursor* are much larger generally than typical *P. primalis* and show incipient involution of the last chamber. This is seemingly enough morphological difference to warrant specific separation of the two forms.

Pulleniatina praecursor is not recorded in this study from the Caribbean or Gulf of Mexico so that the complete evolutionary transition to *Pulleniatina obliquiloculata* is not seen. The genus seemingly is lacking in these regions during the late Pliocene because of climatic cooling. *P. obliquiloculata sensu stricto* is found infrequently in the Nebraskan but occurs commonly in the warm Aftonian. The subspecies *P. obliquiloculata finalis* is restricted to post-Yarmouthian intervals and is a marker species for the late Pleistocene and Holocene.

Illustrations.—Plate 29, figures 1-4.——Specimens from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in Gulf of Mexico slope core hole C, at a depth of 4.3 to 4.7 feet; ×85.

PULLENIATINA PRIMALIS Banner & Blow

Plate 28, figures 5, 7-9

Pulleniatina semiinvoluta Germeraad. Parker, 1965, p. 151, figs. 5, 6.

Pulleniatina primalis Banner & Blow, 1967, p. 142, pl. 1, fig. 3-8; pl. 3, fig. 2.——Parker, 1967, p. 173, pl. 27, fig. 6 (*not* fig. 5).

According to Banner & Blow (1967), "*Pulleniatina primalis* differs from *P. obliquiloculata sensu stricto* in its ventrally restricted primary aperture, which typically does not reach the periphery of the preceding whorl; in its lack of a broad umbilical depression; and in the innermost ventral ends of the adult chambers, which are narrow and meet without forming a distinct linear suture (i.e., meeting before reaching the umbilical area to form a single suture which extends into the umbilical area) between the opposed chambers. All specimens of *P. primalis* observed remain wholly evolute dorsally (with respect to the extent of the chamber lumina), and the apertural position is such that dorsal involution could not occur in normally growing specimens."

Illustrations.—Plate 28, figures 5, 7-9.——Specimens from the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole C, core 8, at a depth of 15.0 to 15.8 feet; ×90.

Genus SPHAEROIDINELLA Cushman

Sphaeroidinella Cushman, 1927, p. 90.

Early portion trochospiral, with two or three much-embracing chambers of final whorl enveloping early whorl, chambers with marginal flanges extending out toward those of opposing chambers and partially obscuring arched apertures; wall calcareous, perforate, pores extremely large and closely arranged in early stage, giving an almost latticelike appearance, area between pores raised and cancellated; in later chambers somewhat irregularly fimbriate or scalloped flange of clear shell material, relatively poreless, is formed around chamber base, tending to coalesce laterally and become much produced, exterior surface of final chambers becoming smooth and glassy due to external secondary deposit; primary aperture in young interiomarginal and umbilical, as in *Globigerina,* but later covered by embracing final chamber, and may be partially obscured by overhanging chamber flanges which parallel sutures, or chambers may be distinctly separated, with wide open area between flanges of opposing chambers, with small arched bullae crossing the sutural slit and partially covering apertural regions, walls of bullae smoothly finished and with finer pores than in chambers, although similarly spaced.

TYPE-SPECIES.—*Sphaeroidina bulloides dehiscens* PARKER & JONES (1865, p. 369), by original designation. From the Holocene.

SPHAEROIDINELLA DEHISCENS (Parker & Jones)

Plate 1, figures 1-2; Plate 34, figures 1-2

Sphaeroidina bulloides dehiscens PARKER & JONES, 1865, p. 369, pl. 19, fig. 5.——BANNER & BLOW, 1960, p. 35, pl. 7, fig. 3 (subsequent description of lectotype designated by BOLLI, LOEBLICH, & TAPPAN, 1957, p. 33).

Sphaeroidina dehiscens immatura CUSHMAN, 1919, p. 40, pl. 14, fig. 2.

Sphaeroidinella dehiscens (Parker & Jones). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 32, 33, pl. 6, fig. 1-3, 5, ?4 (lectotype designated but not described).——PARKER, 1967 (part), p. 160, pl. 23, fig. 9 (*not* fig. 8).

Cf. *Sphaeroidinella dehiscens excavata* BANNER & BLOW, 1965a, p. 1164-1165 (paratype designated fig. 8, pl. 84, in BRADY, 1884). ——BANNER & BLOW, 1967, p. 153, pl. 4, fig. 5 (holotype).

A lengthy description of this genus has been given by BOLLI, LOEBLICH, & TAPPAN (1957), and also by BANNER & BLOW (1960). The genus likely contains only the type species. Living specimens are globigerine and spinose in the juvenile (PARKER, 1962) and covered in the adult by a thick secondary layer or layers of calcareous material (coxtex), which restricts the pore openings and gives a shiny appearance in reflected light. Large aberrant end-chambers not commonly present as in *Sphaeroidinellopsis.* Genus develops from *Sphaeroidinellopsis* in the late Pliocene by addition of supplementary apertures and gradual increase in size (see Plate 1).

Sphaeroidinella dehiscens Bioseries: Species of the genus *Sphaeroidinellopsis* appear first in early Miocene, *Globigerinatella insueta* Zone. The main-line species of the lineage, *S. seminulina,* gives rise to *S. kochi* in early middle Miocene and *S. subdehiscens* in late middle Miocene. Both *S. seminulina* and *S. kochi* become extinct near the end of early late Miocene, giving rise to *S. sphaeroides. Sphaeroidinellopsis sphaeroides* continues, giving rise to the modern species *Sphaeroidinella dehiscens* in late Pliocene.

The evolutionary progression of this lineage follows (1) the reduction of number of chambers by appression of the chambers into a tighter mode of coiling, (2) development of flangelike lips, as extensions of the cortex, enclosing the aperture, and (3) development of multiple sutural apertures with flangelike lips. Specifically, the reduction in number of chambers and tighter mode of coiling distinguish *Sphaeroidinellopsis sphaeroides* from *S. seminulina;* the development of flangelike lips enclosing the aperture and gradual size increase distinguish *S. sphaeroides* from *S. subdehiscens;* and, the development of multiple apertures and gradual size increase distinguish *S. dehiscens* from *S. sphaeroides.*

ILLUSTRATIONS.—Plate 1, figures 1-2.——Specimens from Texas A. & M. Sigsbee knolls core 64-A-9-5E at a depth of 197-199 cm, *Pulleniatina obliquiloculata* Zone, Pliocene; ×32, ×34. Plate 34, figures 1-2.——1. Specimen from the *Globorotalia tosaensis* Subzone, *Globorotalia truncatulinoides* Zone, Pleistocene, in core 12 at a depth of 10.1 to 10.5 feet; ×80.——2. Specimen from the *Globorotalia tumida* Zone, Holocene, in core 1 at a depth of 0 to 0.6 foot; ×85. [From Gulf of Mexico slope core hole B.]

Genus SPHAEROIDINELLOPSIS
Banner & Blow

Sphaeroidinellopsis BANNER & BLOW, 1959, p. 15.

Test trochospiral, similar to *Globigerina,* with wall structure like that of *Sphaeroidinella,* primary wall covered by secondary layer reducing porosity; primary aperture umbilical, with bordering lip, no sutural secondary apertures.

This genus is distinguished from *Sphaeroidinella* by the lack of supplementary sutural apertures and generally smaller size.

TYPE-SPECIES.—*Sphareoidinella dehiscens subdehiscens* BLOW (1959, p. 195), by original designation. From the late middle Miocene of Falcón, Venezuela.

SPHAEROIDINELLOPSIS SEMINULINA (Schwager)

Plate 1, figures 7-8; Plate 36, figures 4-9

Globigerina seminulina SCHWAGER, 1866, p. 256, pl. 7, fig. 112. ——BANNER & BLOW, 1960, p. 24, pl. 7, fig. 2 (neotype).

Globigerina sp. KOCH, 1923, p. 355, fig. 8.

SCHWAGER's original figure of the type specimen shows the upper margin of the last chamber furnished with a flangelike lip, quite unlike middle Miocene forms usually referred to this species. Because the SCHWAGER collections in Munich are lost, BANNER & BLOW (1960) investigated metatype material in the British Museum sent by SCHWAGER to H. B. BRADY. From this they selected and described a neotype (BANNER & BLOW, 1960, p. 24, pl. 7, fig. 2) which is unlike the original figure in that it has four chambers visible from the apertural side and apertural flangelike lips restricted to the early chambers, the aperture of the final chamber(s) being formed by a thickened arch of clear shell material.

The neotype was examined by W. V. SLITER, Esso Production Research Company, who found the early chambers to have a thin flangelike lip and the final chamber(s) only a thickened apertural margin. Thus, the neotype agrees with the species placed in synonymy by PARKER (1967) except, perhaps, the type specimen designated by SCHWAGER. To avoid confusion, the neotype designated by BANNER & BLOW (1960) is accepted as it stands, irrespective of whether or not it agrees with the type specimen described by SCHWAGER.

ILLUSTRATIONS.—Plate 1, figures 7-8.——7. Same as Plate 36, figure 9; ×34.——8. Same as Plate 36, figure 7; ×50. Plate 36, figures 4-9.——4-8. Specimens from the *Globorotalia siakensis* Zone, late middle Miocene, in core 4 at a depth of 12.5 to 12.9 feet; ×100, ×100, ×100, ×125, ×112.——9. Specimen from the *Globorotalia fohsi robusta* Zone, middle Miocene, in core 6 at a depth of 3.2 to 3.6 feet; ×86. [From Gulf of Mexico slope core hole E.]

SPHAEROIDINELLOPSIS SPHAEROIDES Lamb

Plate 1, figures 3-4; Plate 34, figures 3-8; Plate 35, figures 1-7

Sphaeroidinella seminulina (Schwager). PARKER, 1967, p. 161-162, pl. 23, fig. 1-4.

Sphaeroidinellopsis seminulina (Schwager). POAG & AKERS, 1967, p. 172, pl. 17, fig. 18-20.——BERMÚDEZ, 1961, p. 1279, pl. 9, fig. 7.——INGLE, 1967, p. 357, pl. 43, fig. 7.

Sphaeroidinella subdehiscens Blow. PARKER, 1967, p. 162, pl. 23, fig. 6-7.

Sphaeroidinella dehiscens (Parker & Jones). PARKER, 1967 (part), p. 160, pl. 23, fig. 8.

Sphaeroidinellopsis sphaeroides Lamb, 1969, p. 571, 578, pl. 1, fig. 1-5; pl. 2, fig. 1-3.

Test a low trochospire, globigerine in form, commonly with three chambers in final whorl. Primary surface of chambers reticulate and pitted with deep pores; later covered by thick, smooth secondary layer or layers of calcareous material (coxtex) which constricts pores and gives shiny, finely perforate appearance. Test outline broadly oval to nearly spherical with chambers and sutures obscured by cortex and not clearly visible. Aperture single, intraumbilical with flangelike lips surrounding the apertural opening; lips developed as extensions of the cortex, projecting forward slightly, giving a puckered appearance. Aberrant chambers developed commonly, composed of coxtex and usually with no visible internal globigerine chamberine chamber. Diameter up to about 0.7 mm, generally smaller.

DISCUSSION.—This species differs from *Sphaeroidinellopsis seminulina* (SCHWAGER) and *S. subdehiscens* (BLOW) in having a more spherical test outline and flangelike, protruding lips enclosing the aperture. The species developed from either *S. seminulina* or *S. subdehiscens* in late Miocene by growth of flangelike apertural lips about the aperture, which in the former species are restricted to the early chambers. Individual specimens may show a break in the cortex, or solution pits, along the sutures on the spiral side, but these should not be mistaken for true secondary apertures as seen in *Sphaeroidinella dehiscens* (PARKER & JONES). Forms with one or more aberrant chambers may resemble *Sphaeroidinellopsis kochi* (CAUDRI, 1934).

This species was described from a core taken on the Sigsbee knolls, central Gulf of Mexico, by Texas A. & M. University. The type level is late Pliocene.

At the time of this writing the long-delayed publication by BLOW (1967) was distributed in which he describes the species *Sphaeroidinellopsis paenedehiscens.* According to the authors' concept of this species it is probably not synonymous with *S. sphaeroides,* but neither the types nor topotype material has been examined.

ILLUSTRATIONS.—Plate 1, figures 3-4.——3. Same as Plate 34, figure 7; ×82.——4. Same as Plate 34, figure 3; ×40. Plate 34, figures 3-8.——3. Specimen, ×93.——4, 5, 7. Specimens, ×136, ×150, ×205.——6. Specimen, ×85.——8. Specimen; 8a, dorsal view, ×170; 8b, enlargement showing small pore or apertural opening on dorsal side, ×1,700. Plate 35, figures 1-7.——1. Specimen, ×130.——2. Specimen, ×102.——3-4. Specimens, ×80.——5-6. Specimens, ×115.——7. Specimen, ×95. [From the *Pulleniatina primalis* Subzone, *Globorotalia margaritae* Zone, Pliocene, in Gulf of Mexico slope core hole C, core 8, at a depth of 10.5 to 15.8 feet (Pl. 34, fig. 3; Pl. 35, fig. 2-4); the *Sphaeroidinellopsis sphaeroides* Subzone, late Miocene, in Gulf of Mexico slope core hole A, core 11, at a depth of 6.4 to 7.0 feet (Pl. 34, fig. 4-5, 7); and the *Globorotalia multicamerata* Subzone, early Pliocene, in Gulf of Mexico slope core hole C, core 9, at a depth of 12.5 to 12.9 feet (Pl. 34, fig. 6, 8; Pl. 35, fig. 1, 5-7).]

SPHAEROIDINELLOPSIS SUBDEHISCENS (Blow)

Plate 1, figures 5-6; Plate 35, figures 8-9; Plate 36, figures 1-3

Sphaeroidinella rutschi CUSHMAN & RENZ, 1941 (part), p. 25, pl. 4, fig. 5c (*not* holotype, fig. 5a, b).——RENZ, 1948 (part), p. 167, pl. 10, fig. 1c (refigured paratype), *not* fig. 1a, b (refigured holotype).

Sphaeroidinella dehiscens (Parker & Jones). STAINFORTH, 1948, p. 124, pl. 26, fig. 20.——WEISS, 1955, p. 313, pl. 3, fig. 28-29.

Sphaeroidinella rutschi Cushman & Renz. BOLLI, 1957, p. 115, pl. 26, fig. 6-7.

Sphaeroidinella dehiscens subdehiscens BLOW, 1959, p. 195, pl. 12, fig. 71-72 (holotype).

Sphaeroidinellopsis subdehiscens (Blow). BANNER & BLOW, 1960, p. 15, fig. 5.

The above synonymy, except for the generic emendation, was given by BLOW in his original description of this species. A clear distinction between the three-chambered *Sphaeroidinellopsis subdehiscens* and the usually four-chambered forms referred to *S. seminulina* is difficult to make because they appear to be phenotypic variations of the same species, at least in the late middle Miocene interval studied. Separation of the two forms, therefore, was not seriously attempted.

ILLUSTRATIONS.—Plate 1, figures 5-6.——Same specimens as

Plate 35, figures 8-9 respectively, ×60. Plate 35, figures 8-9.——Specimens from core 12, at a depth of 12.2 to 12.8 feet. Plate 36, figures 1-3.——1-2. Specimens from core 12 at a depth of 2.7 to 3.1 feet.——3. Early, more lobate form from core 14 at a depth of 10.1 to 10.5 feet. [From the *Sphaeroidinellopsis seminulina* Subzone, late Miocene, in Gulf of Mexico slope core hole A, ×150.]

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EXPLANATION OF PLATES

PLATE 1

[*Sphaeroidinella dehiscens* bioseries.]

FIGURE

1-2. *Sphaeroidinella dehiscens* (Parker & Jones).
3-4. *Sphaeroidinellopsis sphaeroides* Lamb.
5-6. *Sphaeroidinellopsis subdehiscens* (Blow).
7-8. *Sphaeroidinellopsis seminulina* (Schwager).

PLATE 2

[*Globorotalia crassaformis* bioseries.]

FIGURE

1-9. *Globorotalia crassaformis* (Galloway & Wissler).
10-12. *Globorotalia crassacrotonensis* Conato & Follador.
13-14. *Globorotalia aemiliana* Colalongo & Sartoni.

PLATE 3

[*Globoquadrina dutertrei* bioseries.]

FIGURE

1-3. *Globoquadrina dutertrei* (d'Orbigny).
4-9. *Globoquadrina humerosa* (Takayanagi & Saito).
10-12. *Globorotalia acostaensis* Blow.

PLATE 4

[*Globigerina nepenthes* Todd from the Miocene and Pliocene in Gulf of Mexico slope core hole A.]

FIGURE

1,4-8. From *Sphaeroidinellopsis seminulina* Subzone, late Miocene; ×160, ×175, ×170, ×170, ×170, ×170.
2-3. From *Globorotalia multicamerata* Subzone, Pliocene, ×95, ×200.

PLATE 5

[Foraminifers from the *Globorotalia truncatulinoides* Zone, Pleistocene, in the Gulf of Mexico.]

FIGURE
1-4. *Globigerinita glutinata* (Egger), *Globorotalia tosaensis* Subzone; ×160.
5. *Candeina nitida* d'Orbigny, *Pulleniatina finalis* Subzone; ×85.
6-8. *Globigerina bulloides* d'Orbigny; *Pulleniatina finalis* Subzone; ×135.

PLATE 6

[Foraminifers in the Miocene and Pleistocene of the Gulf of Mexico.]

FIGURE
1-3. *Globigerina* sp. aff. *G. pachyderma* (Ehrenberg), *Globorotalia tosaensis* Subzone, Pleistocene; ×160.
4-5. *Globorotalia* sp. aff. *G. acostaensis* Blow, *Globorotalia tosaensis* Subzone, Pleistocene, ×160.
6. *Globorotalia siakensis* LeRoy, *Globorotalia fohsi fohsi* Zone (*sensu* Bolli, 1957), middle Miocene; ×120.
7-9. *Globorotalia siakensis* LeRoy, *Globorotalia siakensis* Zone, middle Miocene; ×130, ×170, ×170.

PLATE 7

[*Globorotalia acostaensis* Blow from the *Sphaeroidinellopsis seminulina* Subzone, late Miocene; of the Gulf of Mexico.]

FIGURE
1-3,7-8. Specimens, ×170.
4-6. Specimens, ×160.
9-11. Specimens, ×235, ×215, ×215.

PLATE 8

[*Globoquadrina* from the Pliocene and Pleistocene of the Gulf of Mexico.]

FIGURE
1-3. *Globoquadrina humerosa* (Takayanagi & Saito), *Globorotalia multicamerata* Subzone, Pliocene; ×130.
4-6. *Globoquadrina humerosa* (Takayanagi & Saito), *Pulleniatina obliquiloculata* Zone, Pliocene; ×136.
7-9. *Globoquadrina dutertrei* (d'Orbigny), *Pulleniatina finalis* Subzone, Pleistocene; ×85.

PLATE 9

[*Globoquadrina* from the Miocene and Pliocene in the Gulf of Mexico.]

FIGURE
1. *Globoquadrina altispira* (Cushman & Jarvis), *Globorotalia multicamerata* Subzone, Pliocene; ×135.
2,4-5. *Globoquadrina altispira* (Cushman & Jarvis), *Pulleniatina primalis* Subzone, Pliocene; ×90.
3. *Globoquadrina altispira* (Cushman & Jarvis), *Globorotalia fohsi robusta* Zone, middle Miocene; ×105.
6. *Globoquadrina dehiscens* (Chapman, Parr, & Collins), *Sphaeroidinellopsis seminulina* Subzone, late Miocene; ×110.
7-9. *Globoquadrina dehiscens* (Chapman, Parr, & Collins), *Globorotalia fohsi robusta* Zone, middle Miocene, ×80.

PLATE 10

[*Globoquadrina* from the Pliocene and Pleistocene in the Gulf of Mexico.]

FIGURE
1-4. *Globoquadrina hexagona* (Natland), *Globoquadrina dutertrei* Subzone, Pleistocene; ×160.
5-7. *Globoquadrina venezuelana* (Hedberg), *Pulleniatina primalis* Subzone, Pliocene; ×160, ×120, ×120.

PLATE 11

[*Globorotalia* from the Pliocene and Holocene in the Gulf of Mexico.]

FIGURE
1-3. *Globorotalia menardii* (d'Orbigny), *Globorotalia tumida* Zone, Holocene; ×65, ×50, ×40.
4. *Globorotalia multicamerata* Cushman & Jarvis, *Pulleniatina primalis* Subzone, Pliocene, ×65.
5-6. *Globorotalia multicamerata* Cushman & Jarvis, *Pulleniatina obliquiloculata* Zone, Pliocene; ×65.
7-9. *Globorotalia ungulata* Bermúdez, *Globorotalia tumida* Zone, Holocene; ×85, ×100, ×100.

PLATE 12

[*Globorotalia* from the Pliocene, Pleistocene, and Holocene in the Gulf of Mexico.]

FIGURE
1-3. *Globorotalia tumida* (Brady), *Globorotalia tumida* Zone, Holocene, ×80, ×80, ×95.
4. *Globorotalia multicamerata* Cushman & Jarvis, *Pulleniatina obliquiloculata* Zone, Pliocene; ×60.
5. *Globorotalia multicamerata* Cushman & Jarvis, *Pulleniatina primalis* Subzone, Pliocene; ×90.
6-8. *Globorotalia flexuosa* (Koch), *Pulleniatina finalis* Subzone, Pleistocene; ×85.

PLATE 13

[*Globorotalia* from the *Globorotalia multicamerata* Subzone, Pliocene, in the Gulf of Mexico.]

FIGURE
1-5. *Globorotalia menardii* (d'Orbigny), ×85.
6-8. *Globorotalia* sp. cf. *G. multicamerata* Cushman & Jarvis; ×85, ×85, ×170.

PLATE 14

[*Globorotalia* from the Pliocene, Pleistocene, and Holocene in the Gulf of Mexico.]

FIGURE
1-3. *Globorotalia menardii* (d'Orbigny), *Globorotalia tumida* Zone, Holocene; ×65, ×50, ×40.
4. *Globorotalia pertenuis* Beard, *Globorotalia tosaensis* Subzone, Pleistocene; ×81.
5-8. *Globorotalia multicamerata* Cushman & Jarvis, *Pulleniatina obliquiloculata* Zone, Pliocene; ×85.

PLATE 15

[*Globorotalia pertenuis* Beard from the *Globorotalia tosaensis* Subzone, Pleistocene in the Gulf of Mexico.]

FIGURE

1. Holotype, ×50.

2-5. Paratypes, ×80.

6. Paratype; ×80, ×160.

PLATE 16

[*Globorotalia* from the *Globorotalia tosaensis* Subzone, Pleistocene, in the Gulf of Mexico.]

FIGURE

1-4. *Globorotalia miocenica* Palmer; ×90.

5-6. *Globorotalia pertenuis* Beard; ×78, ×78, ×133.

PLATE 17

[*Globorotalia* from the Pliocene and Pleistocene of the Gulf of Mexico.]

FIGURE

1-3,6. *Globorotalia praemiocenica* Lamb & Beard, *Pulleniatina obliquiloculata* Zone, Pliocene; ×125.

4. *Globorotalia menardii* (d'Orbigny), *Globorotalia multicamerata* Subzone, Pliocene; ×90.

5,7. *Globorotalia pertenuis* Beard, *Globorotalia tosaensis* Subzone, Pleistocene; ×50, ×90.

PLATE 18

[*Globorotalia* from the Pliocene of the Gulf of Mexico and Italy.]

FIGURE

1-3,5. *Globorotalia margaritae* Bolli & Bermúdez, *Pulleniatina primalis* Subzone; ×100, ×90, ×100, ×100.

4,6. *Globorotalia margaritae* Bolli & Bermúdez, *Globorotalia multicamerata* Subzone; ×90, ×85.

7-8. *Globorotalia aemiliana* Colalongo & Sartoni, topotypes from Italy; ×170.

9-12. *Globorotalia praehirsuta* Blow, *Pulleniatina obliquiloculata* Zone; ×110.

PLATE 19

[*Globorotalia* from the middle and late Miocene in the Gulf of Mexico.]

FIGURE

1-3. *Globorotalia lenguaensis* Bolli, *Sphaeroidinellopsis seminulina* Subzone; ×230.

4-6. *Globorotalia fohsi lobata* Bermúdez, *Globorotalia fohsi lobata* Zone; ×110.

7-9. *Globorotalia fohsi robusta* Bolli, *Globorotalia fohsi robusta* Zone; ×110.

PLATE 20

[*Globorotalia* from the Pliocene and Pleistocene in the Gulf of Mexico.]

FIGURE

1-2. *Globorotalia aemiliana* Colalongo & Sartoni, *Globorotalia multicamerata* Subzone, Pliocene; ×110.

3-7. *Globorotalia crassacrotonensis* Conato & Follador, *Pulleniatina primalis* Subzone, Pliocene; ×120.

8-10. *Globorotalia scitula* (Brady), *Globorotalia tosaensis* Subzone, Pleistocene; ×110.

PLATE 21

[*Globorotalia crassaformis* (Galloway & Wissler) from the Pleistocene in the Gulf of Mexico.]

FIGURE

1-3. Specimens from the *Globorotalia tosaensis* Subzone; ×120.

4-8. Specimens from the *Globoquadrina dutertrei* Subzone; ×110 except 6 which is ×85.

PLATE 22

[*Globorotalia tosaensis* Takayanagi & Saito from the late Pliocene and Pleistocene in the Gulf of Mexico.]

FIGURE

1-5. Specimens from the *Globorotalia tosaensis* Subzone, Pleistocene; ×120.

6-7. Specimens from the *Pulleniatina obliquiloculata* Zone, late Pliocene; ×120.

PLATE 23

[*Globorotalia tosaensis* Takayanagi & Saito from the Indian Ocean.]

FIGURE

1-2a,b. Specimens, ×200.

2c,d. Specimens, ×2000.

PLATE 24

[*Globorotalia truncatulinoides* (d'Orbigny) from the Pleistocene in the Gulf of Mexico.]

FIGURE

1. Specimen from the *Globorotalia tosaensis* Subzone; ×190.

2-4. Specimens from the *Pulleniatina finalis* Subzone; ×90, ×90, ×450, ×450, ×90.

PLATE 25

[*Globorotalia truncatulinoides* (d'Orbigny) from the Pleistocene and Holocene of the Gulf of Mexico.]

FIGURE

1-4. Specimens from the *Globorotalia tosaensis* Subzone, Pleistocene; ×166, ×157, ×170, ×160, ×800.

5-7. Specimens from the *Globorotalia tumida* Zone, Holocene; ×90.

PLATE 26

[*Globorotalia truncatulinoides* (d'Orbigny) from the *Globorotalia tosaensis* Subzone, Pleistocene, in the Gulf of Mexico.]

FIGURE

1-2. Specimens; ×160, ×185, ×185.

3. Specimen; ×170, ×408, ×807, ×1615.

PLATE 27

[*Globorotalia inflata* (d'Orbigny) from the Pleistocene in the Gulf of Mexico.]

FIGURE

1-7. Specimens of variant from the *Globorotalia tosaensis* Subzone; ×80 except 5 which is ×95.

8. Specimens from the *Pulleniatina finalis* Subzone; ×100.

9-11. Specimens from the *Globorotalia tosaensis* Subzone; ×170.

PLATE 28

[Foraminifers from the Pliocene and Pleistocene in the Gulf of Mexico.]

FIGURE

1-4,6. *Globorotalia inflata* (d'Orbigny), *Pulleniatina finalis* Subzone, Pleistocene; ×100.

5,7-9. *Pulleniatina primalis* Banner & Blow, *Pulleniatina primalis* Subzone, Pliocene; ×90.

PLATE 29

[*Pulleniatina* from the Pleistocene in the Gulf of Mexico.]

FIGURE

1-4. *Pulleniatina obliquiloculata* (Parker & Jones), *Globorotalia tosaensis* Subzone; ×85.

5-7. *Pulleniatina finalis* Banner & Blow, *Pulleniatina finalis* Subzone; ×75, ×85, ×75.

PLATE 30

[*Pulleniatina finalis* Banner & Blow from the *Globorotalia truncatulinoides* Zone, Pleistocene, in the Gulf of Mexico.]

FIGURE

1. Specimen, ×75, ×150, ×425, ×850, ×1700, ×4250.

PLATE 31

[*Globigerinoides* from the Pliocene, Pleistocene, and Holocene in the Gulf of Mexico.]

FIGURE

1. *Globigerinoides quadrilobatus* (d'Orbigny), *Pulleniatina obliquiloculata* Zone, Pliocene; ×80.

2-3,5. *Globigerinoides sacculifer* (Brady), *Pulleniatina finalis* Subzone, Pleistocene; ×85, ×85, ×100.

6. *Globigerinoides sacculifer* (Brady), *Globorotalia tumida* Zone, Holocene; ×80.

4,7-8. *Globigerinoides fistulosus* (Schubert), *Pulleniatina obliquiloculata* Zone, Pliocene; ×80.

PLATE 32

[*Globigerinoides extremus* Bolli & Bermúdez from the *Pulleniatina primalis* Subzone, Pliocene, in the Gulf of Mexico.]

FIGURE

1-6. Specimens, ×180.

PLATE 33

[*Globigerinoides* from the *Pulleniatina finalis* Subzone, Pleistocene, in the Gulf of Mexico.]

FIGURE

1-3,5. *Globigerinoides ruber* (d'Orbigny); ×100.

4,6-7. *Globigerinoides conglobatus* (Brady); ×90.

PLATE 34

[Foraminifers from the Miocene, Pliocene, Pleistocene, and Holocene in the Gulf of Mexico.]

FIGURE

1. *Sphaeroidinella dehiscens* (Parker & Jones), *Globorotalia tosaensis* Subzone, Pleistocene; ×80.

2. *Sphaeroidinella dehiscens* (Parker & Jones), *Globorotalia tumida* Zone, Holocene; ×85.

3. *Sphaeroidinellopsis sphaeroides* Lamb, *Pulleniatina primalis* Subzone, Pliocene; ×93.

4-5,7. *Sphaeroidinellopsis sphaeroides* Lamb, *Sphaeroidinellopsis sphaeroides* Subzone, late Miocene; ×136, ×150, ×205.

6,8. *Sphaeroidinellopsis sphaeroides* Lamb, *Globorotalia multicamerata* Subzone, Pliocene; ×85, ×170, ×1700.

PLATE 35

[*Sphaeroidinellopsis* from the Miocene and Pliocene in the Gulf of Mexico.]

FIGURE

1,5-7. *Sphaeroidinellopsis sphaeroides* Lamb, *Globorotalia multicamerata* Subzone, Pliocene; ×130, ×115, ×115, ×95.

2-4. *Sphaeroidinellopsis sphaeroides* Lamb, *Pulleniatina primalis* Subzone, Pliocene; ×102, ×80, ×80.

8-9. *Sphaeroidinellopsis subdehiscens* (Blow), *Sphaeroidinellopsis seminulina* Subzone, late Miocene; ×150.

PLATE 36

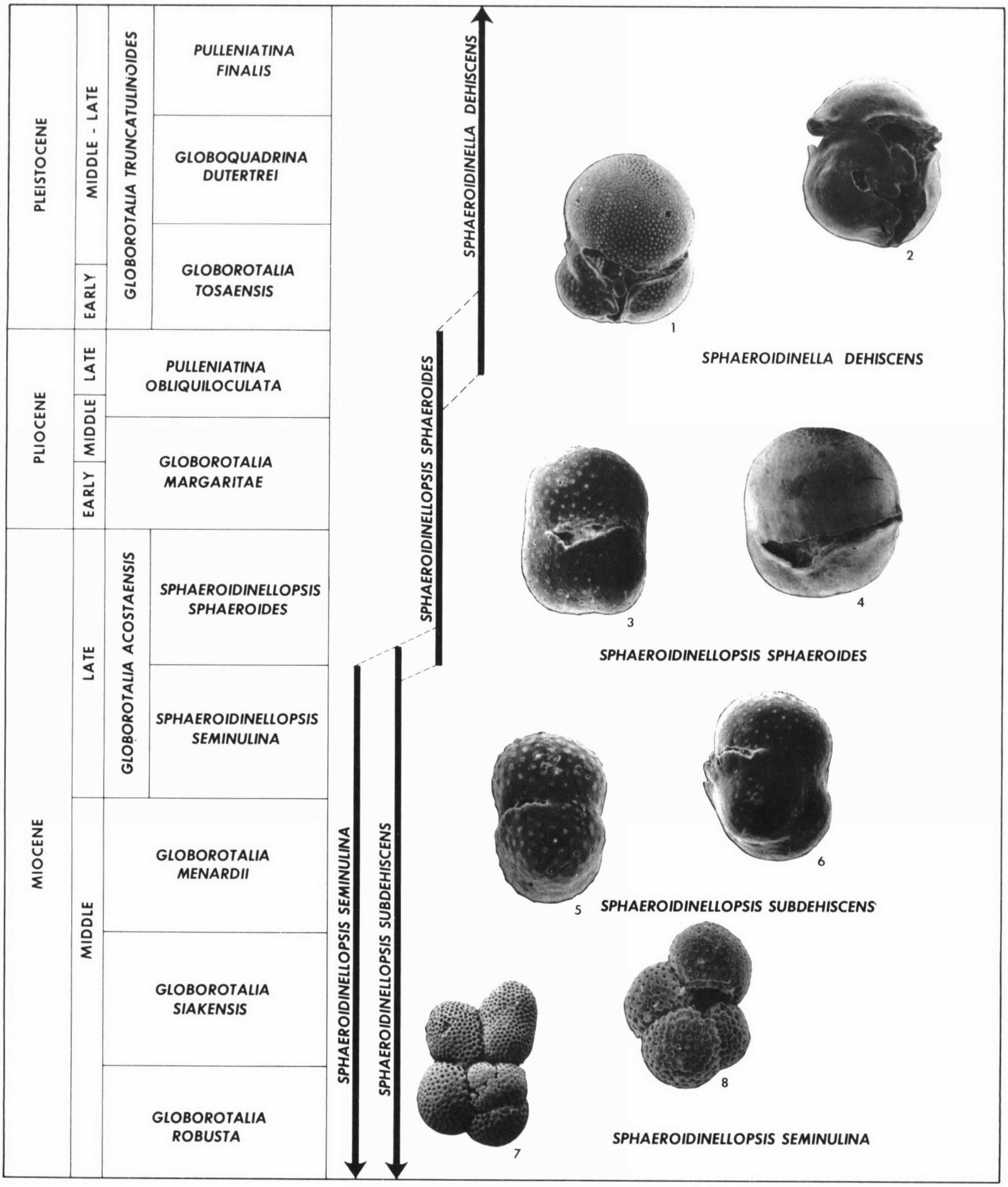
[*Sphaeroidinellopsis* from the middle and late Miocene in the Gulf of Mexico.]

FIGURE

1-3. *Sphaeroidinellopsis subdehiscens* (Blow), *Sphaeroidinellopsis seminulina* Subzone; ×150.

4-8. *Sphaeroidinellopsis seminulina* (Schwager), *Globorotalia siakensis* Zone; ×100, ×100, ×100, ×125, ×112.

9. *Sphaeroidinellopsis seminulina* (Schwager), *Globorotalia fohsi robusta* Zone; ×86.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MIDDLE - LATE
EARLY
GLOBOROTALIA TRUNCATULINOIDES
PULLENIATINA FINALIS
GLOBOQUADRINA DUTERTREI
GLOBOROTALIA TOSAENSIS
PLIOCENE
LATE
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EARLY
PULLENIATINA OBLIQUILOCULATA
GLOBOROTALIA MARGARITAE
MIOCENE
LATE
GLOBOROTALIA ACOSTAENSIS
SPHAEROIDINELLOPSIS SPHAEROIDES
SPHAEROIDINELLOPSIS SEMINULINA
MIDDLE
GLOBOROTALIA MENARDII
GLOBOROTALIA SIAKENSIS
GLOBOROTALIA ROBUSTA
SPHAEROIDINELLA DEHISCENS
SPHAEROIDINELLOPSIS SPHAEROIDES
SPHAEROIDINELLOPSIS SEMINULINA
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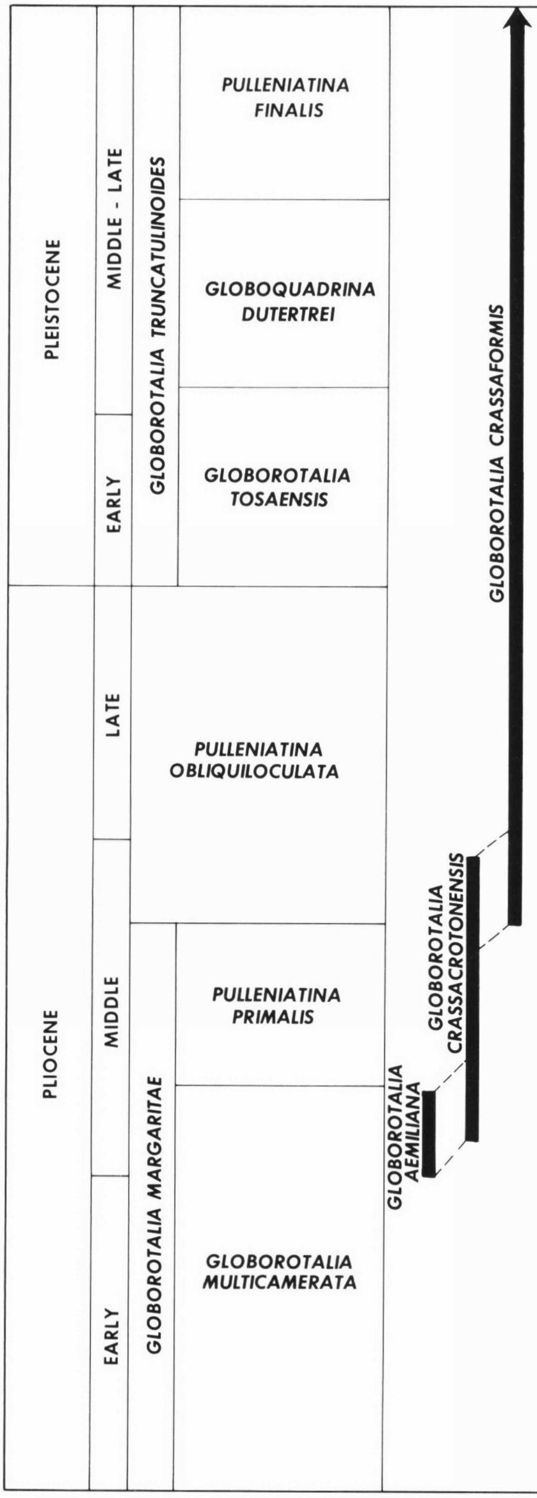
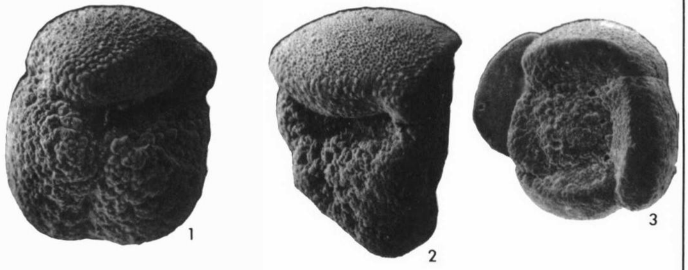
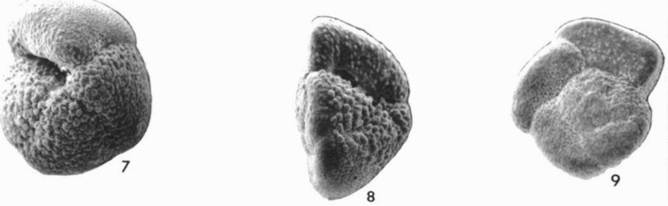
SPHAEROIDINELLOPSIS SEMINULINA





GLOBOROTALIA CRASSAFORMIS

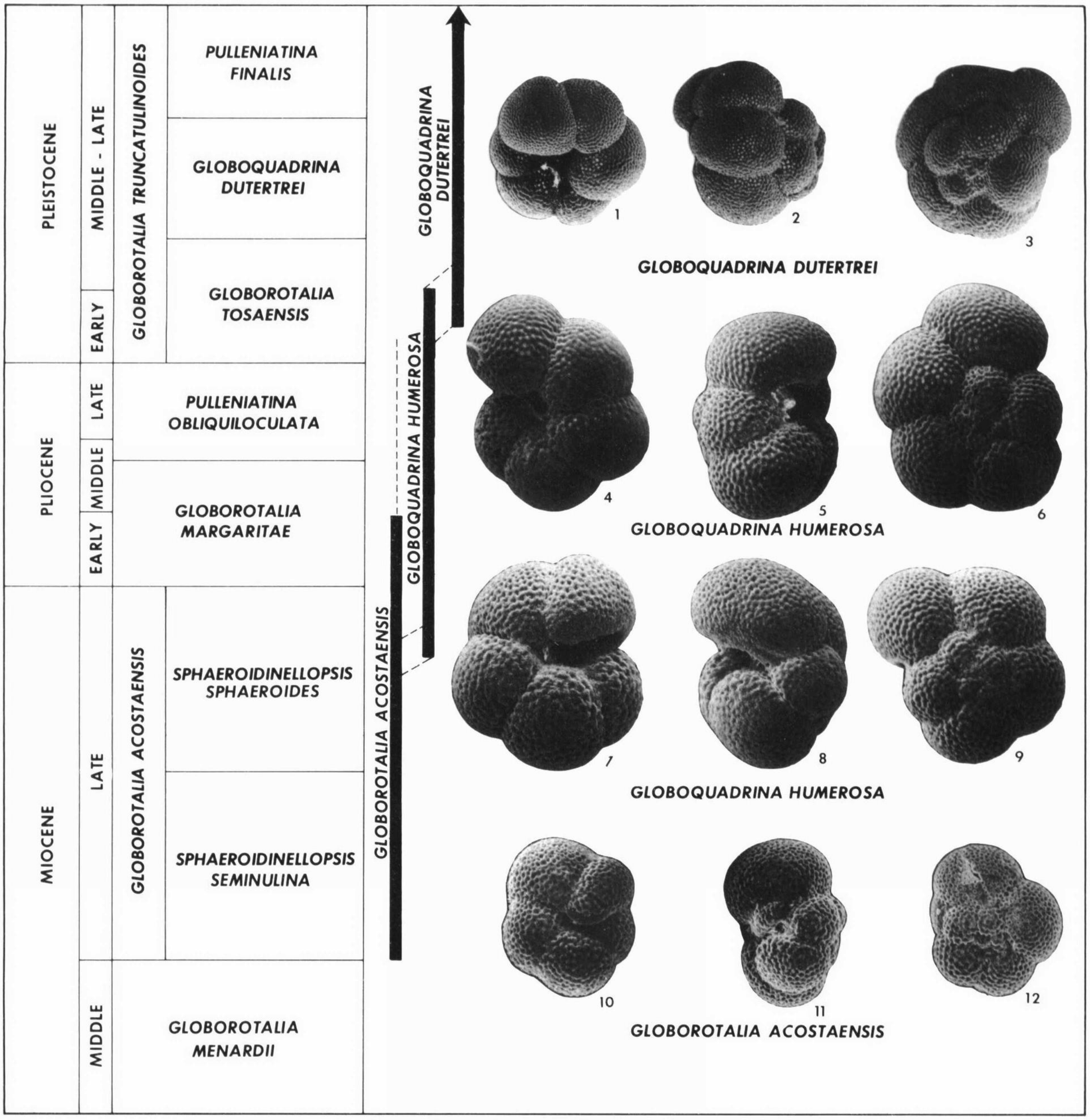
GLOBOROTALIA CRASSAFORMIS



GLOBOROTALIA CRASSAFORMIS

GLOBOROTALIA CRASSACROTONENSIS

GLOBOROTALIA AEMILIANA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PLIOCENE
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SPHAEROIDINELLOPSIS SEMINULINA
GLOBOROTALIA MENARDII
GLOBOQUADRINA DUTERTREI
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GLOBOROTALIA ACOSTAENSIS
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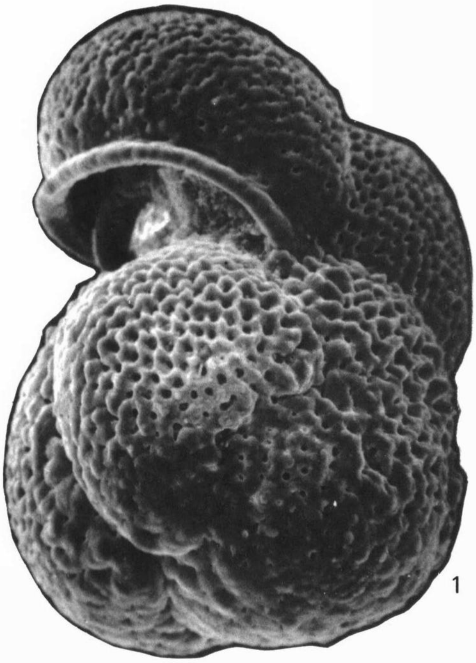
GLOBOROTALIA ACOSTAENSIS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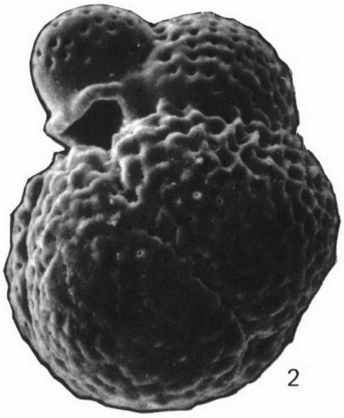
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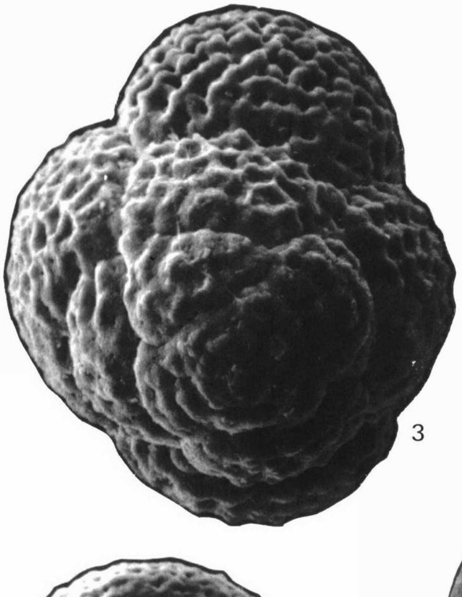
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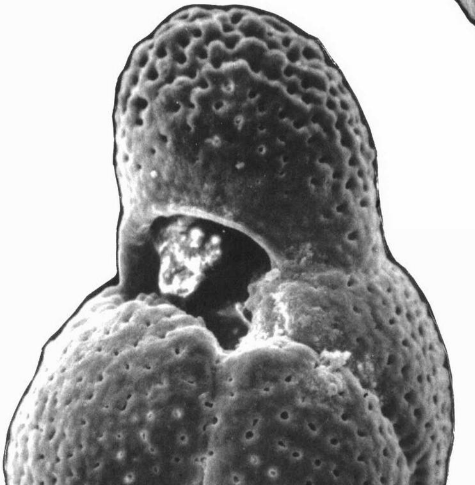
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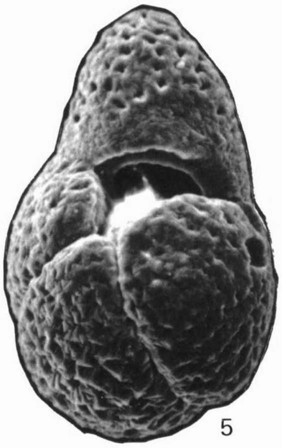
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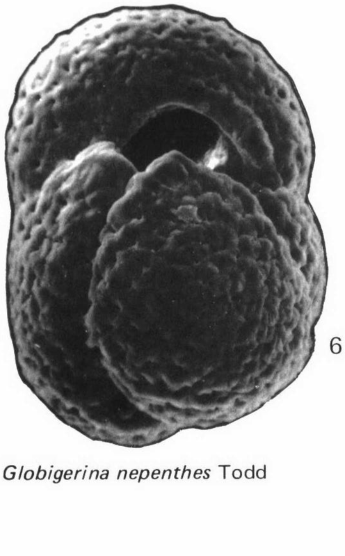
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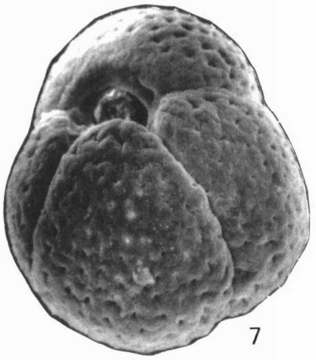
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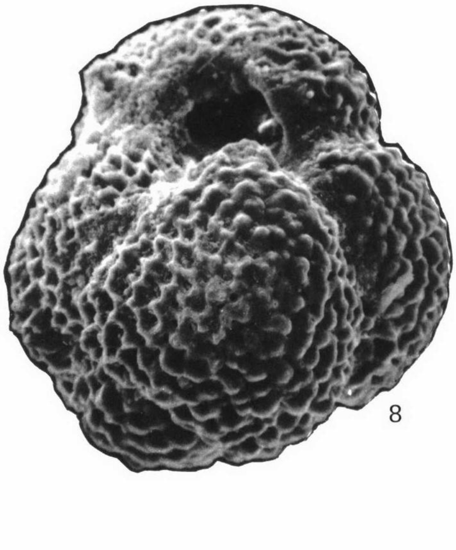
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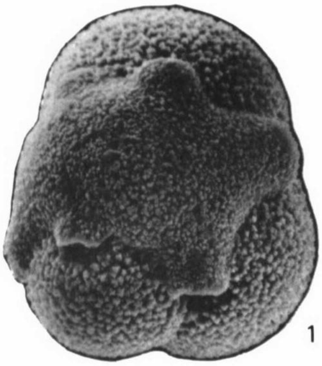
Globigerina nepenthes Todd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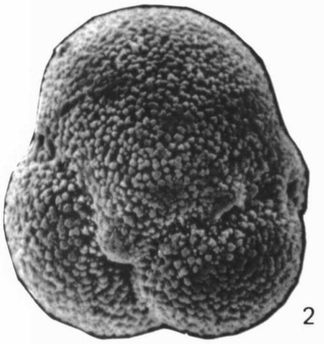
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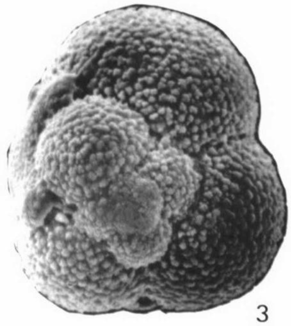
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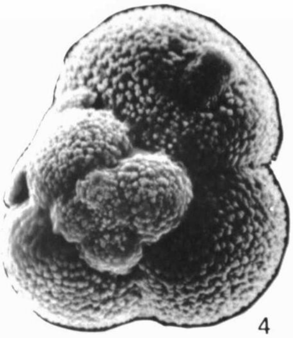
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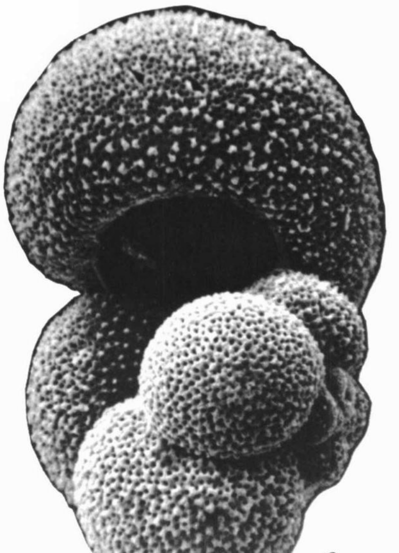
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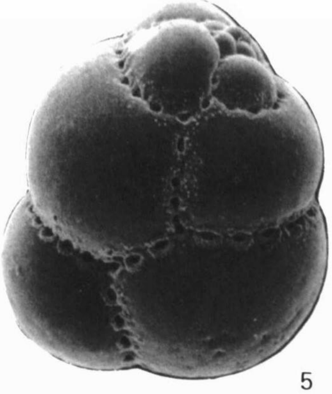
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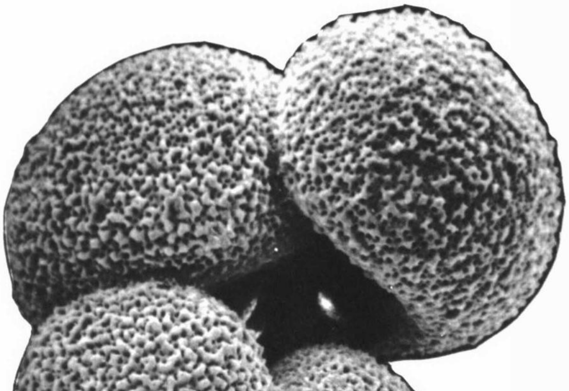
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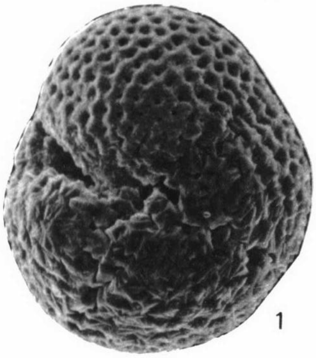
8

Globigerinita, Candeina, and *Globigerina*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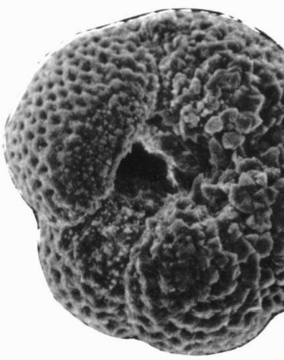
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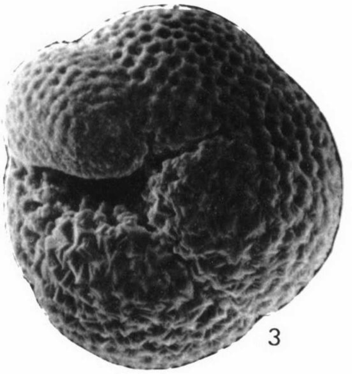
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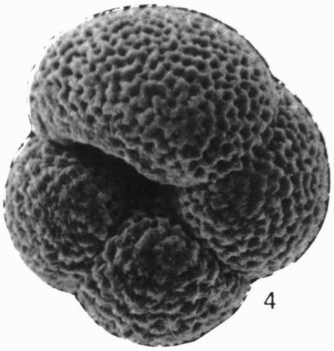
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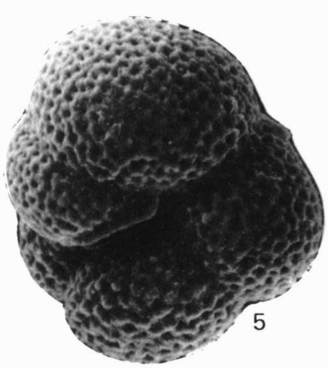
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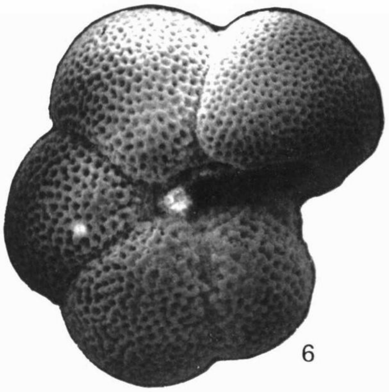
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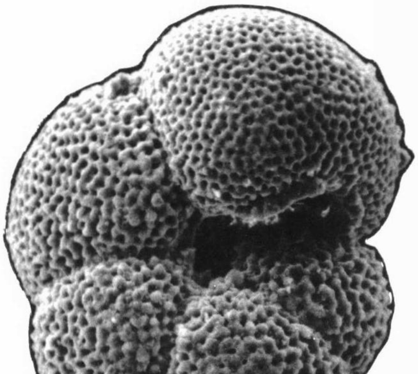
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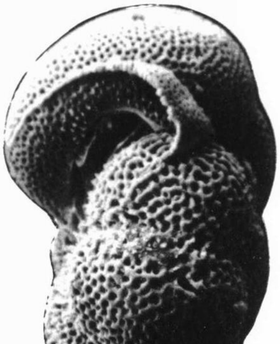
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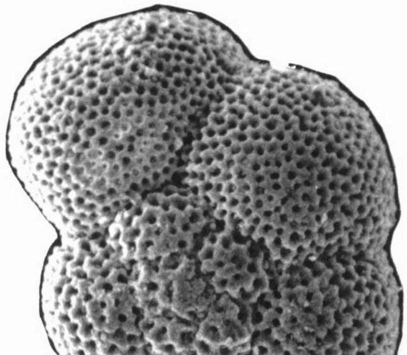
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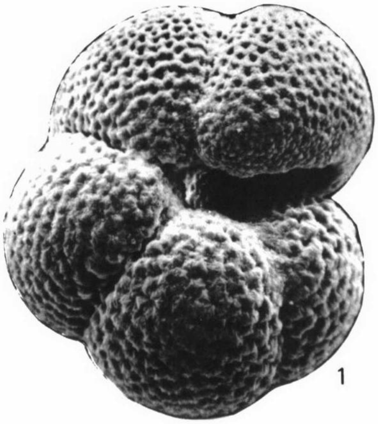
Globigerina, Globoquadrina, and *Globorotalia*

Globorotalia acostaensis (Blow)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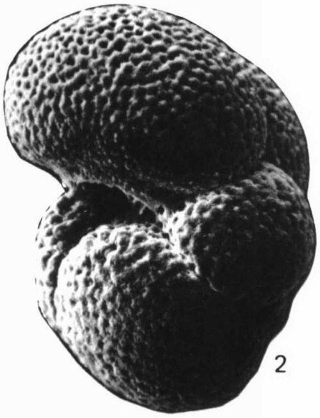
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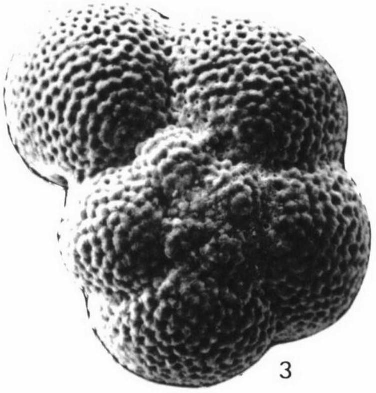
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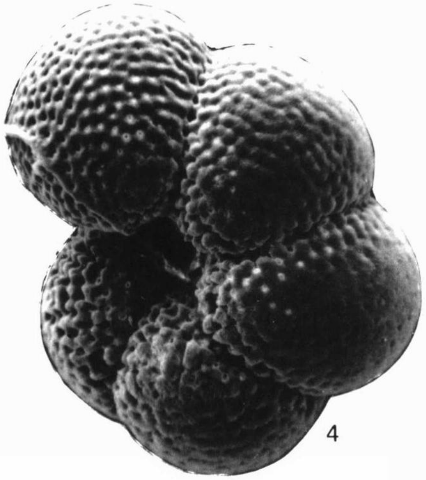
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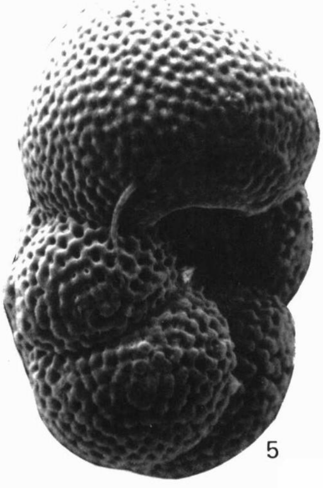
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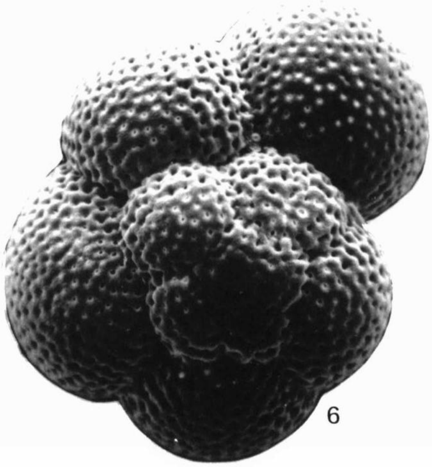
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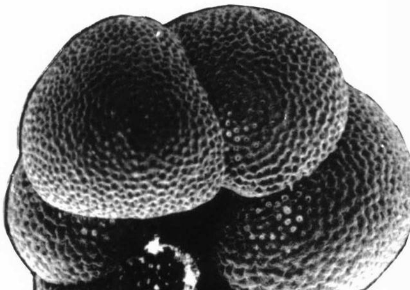
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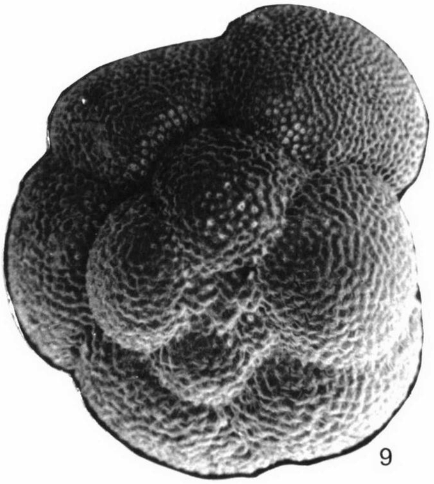
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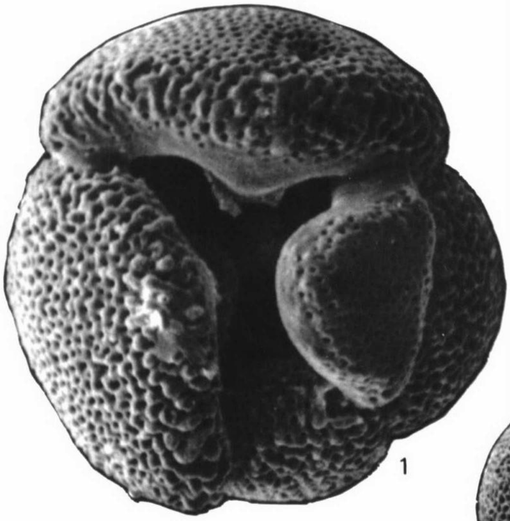
Globoquadrina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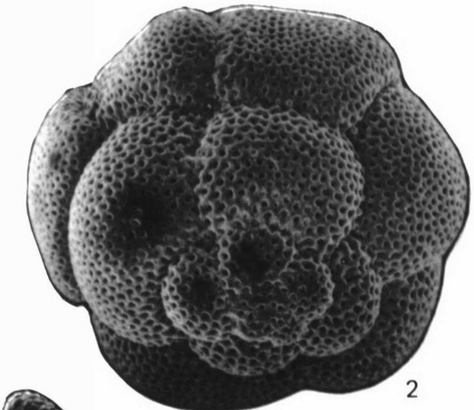
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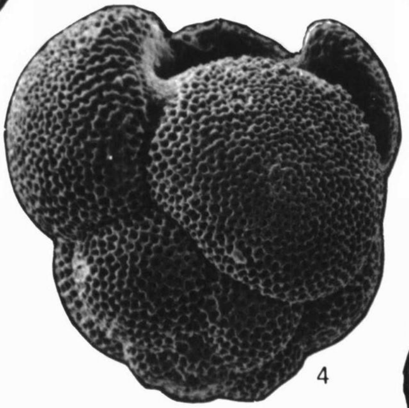
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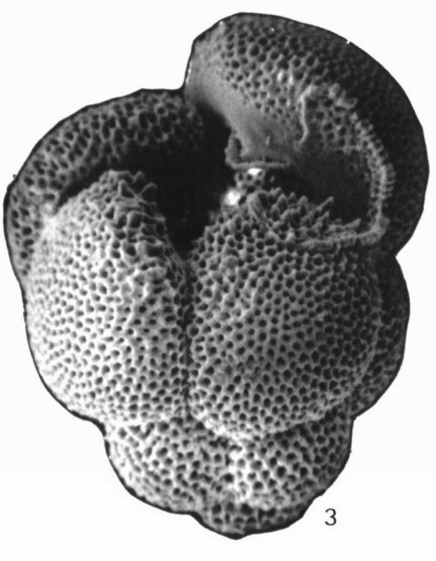
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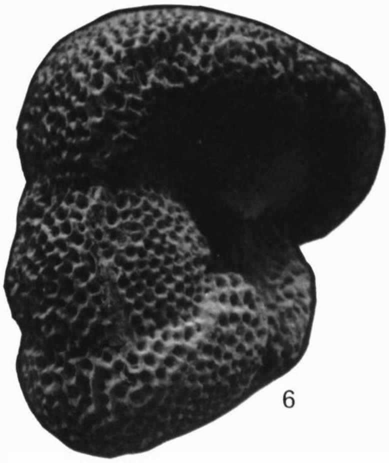
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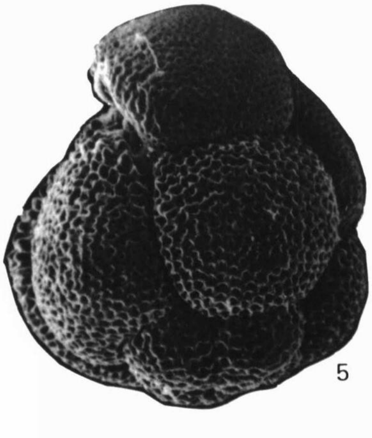
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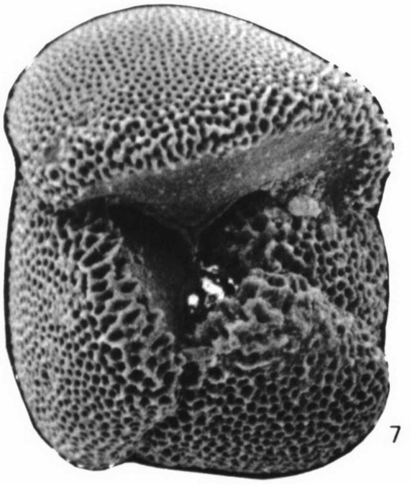
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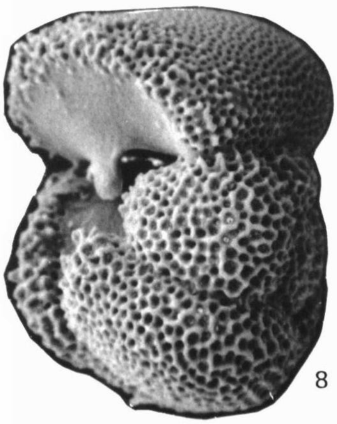
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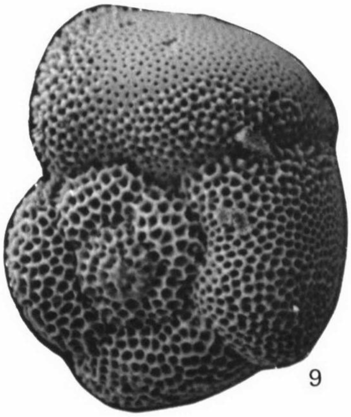
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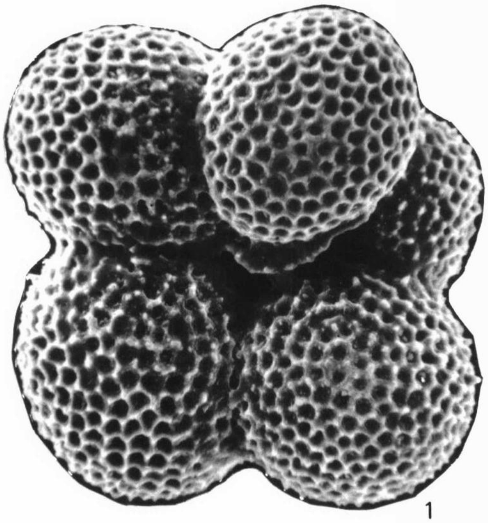
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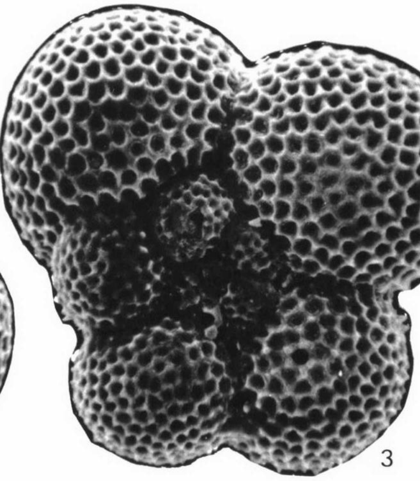
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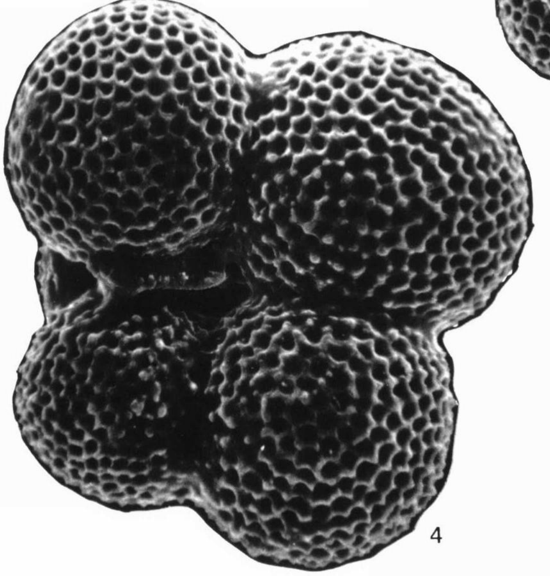
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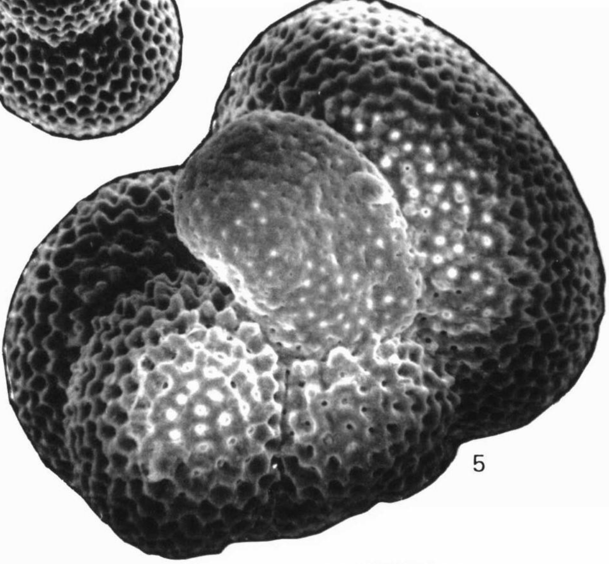
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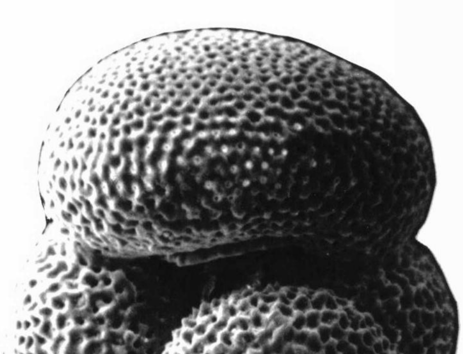
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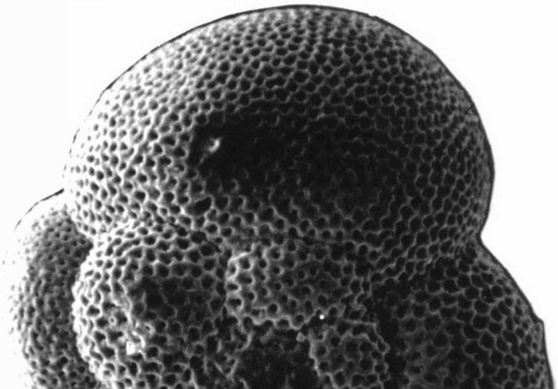
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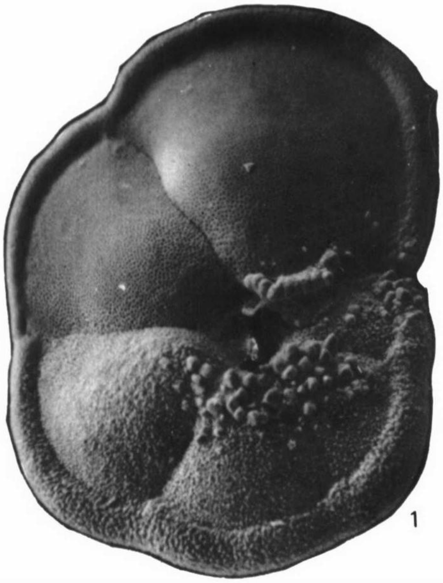
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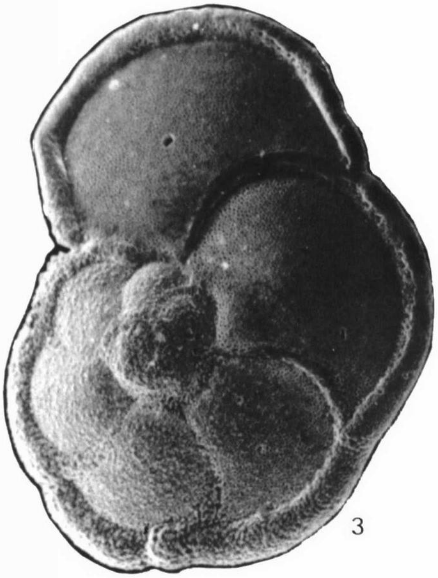
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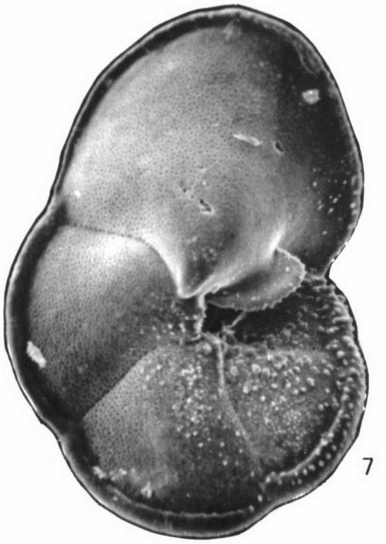
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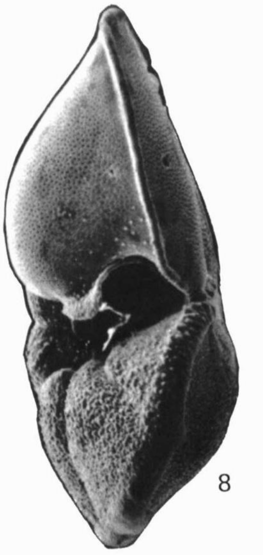
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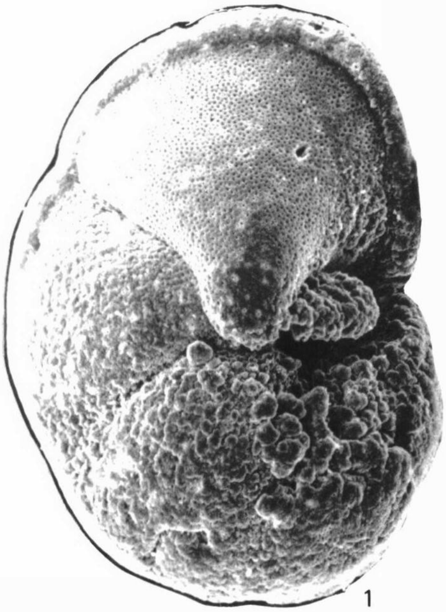
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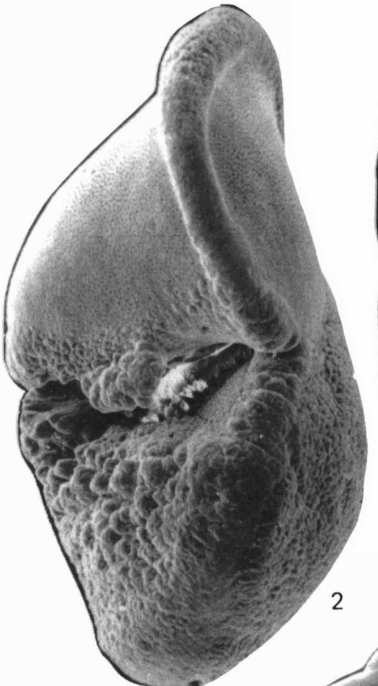
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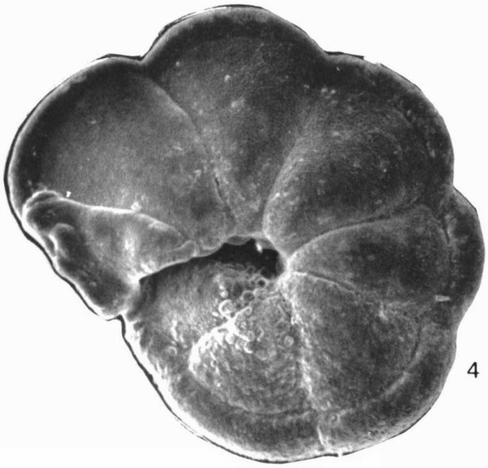
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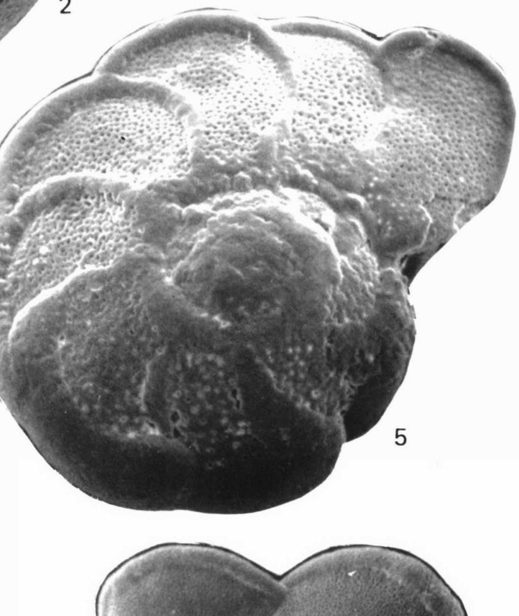
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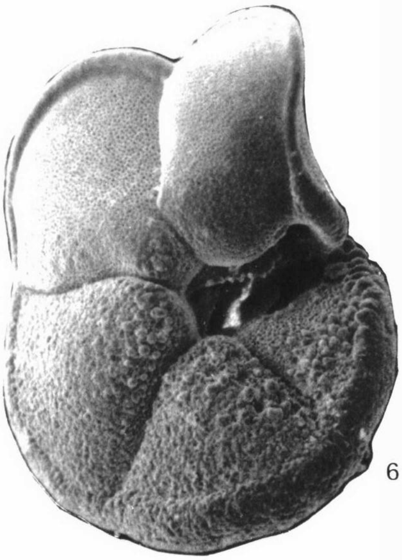
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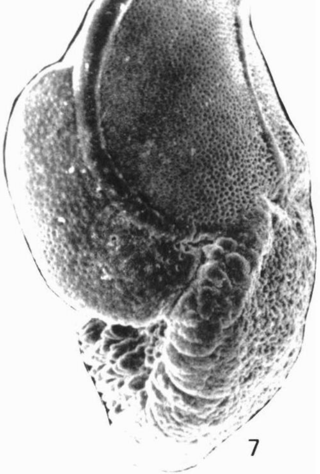
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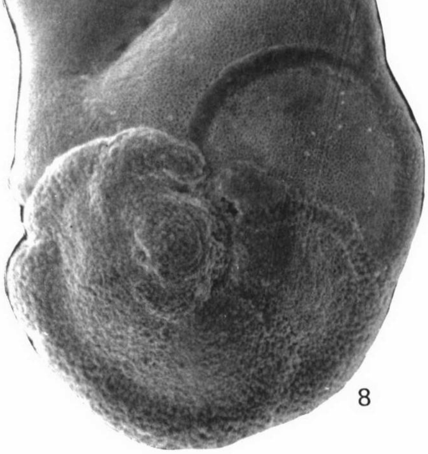
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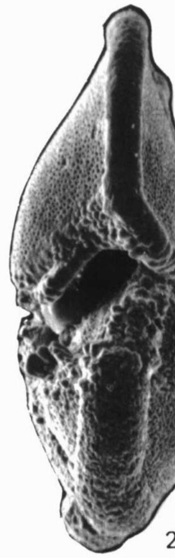
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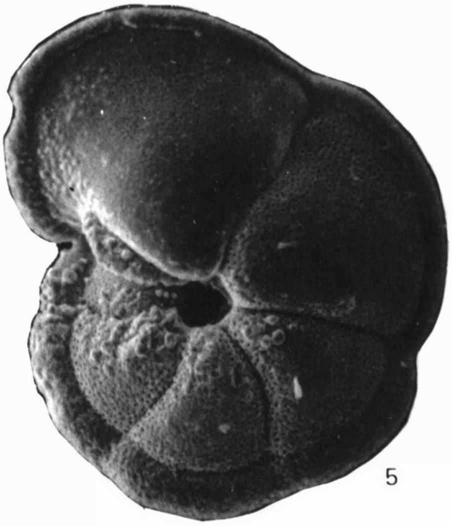
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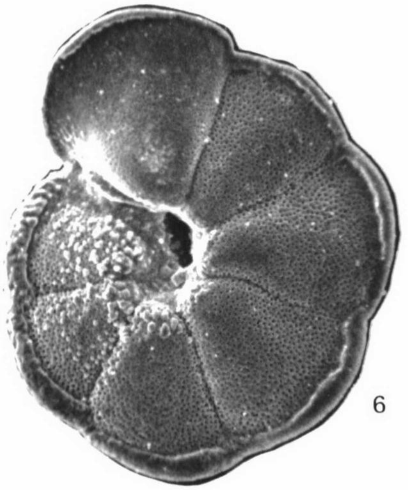
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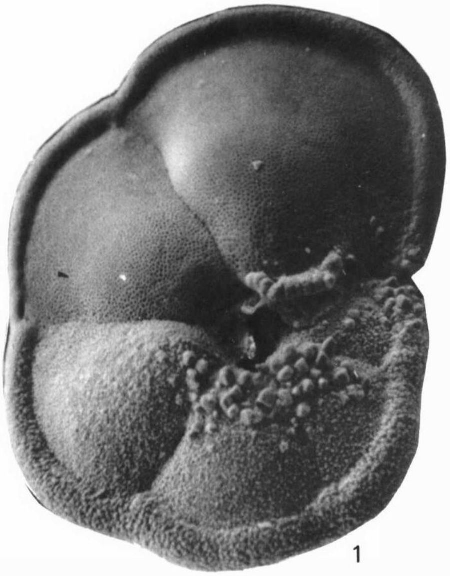
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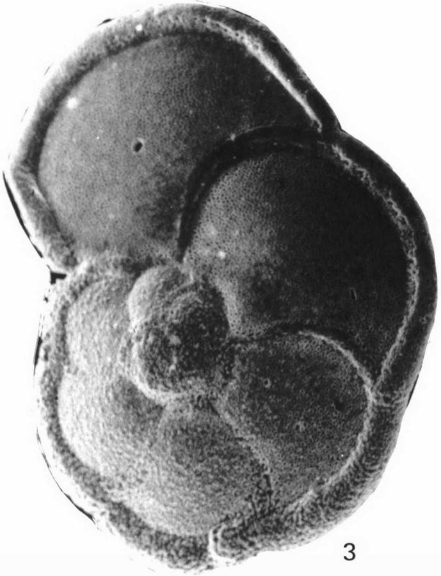
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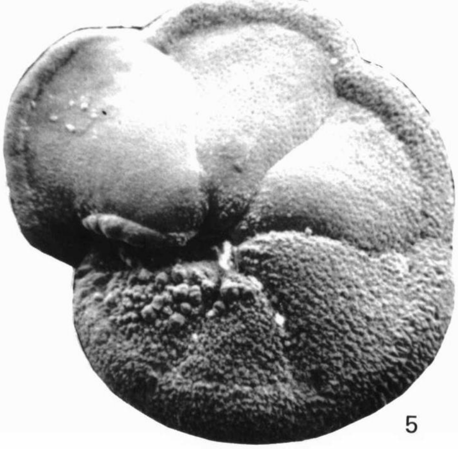
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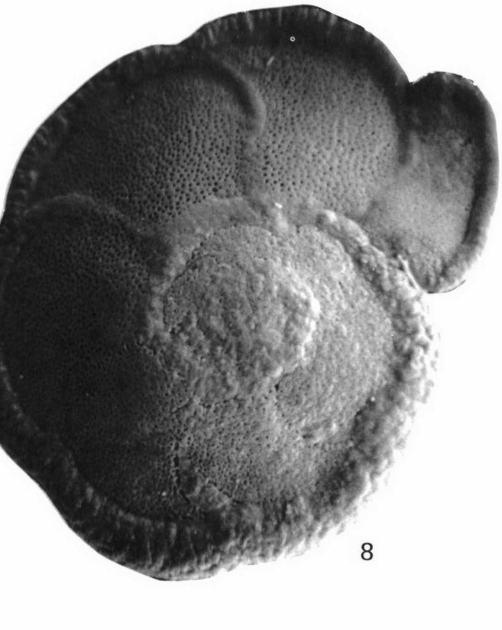
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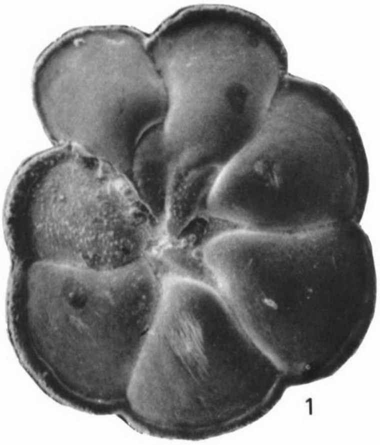
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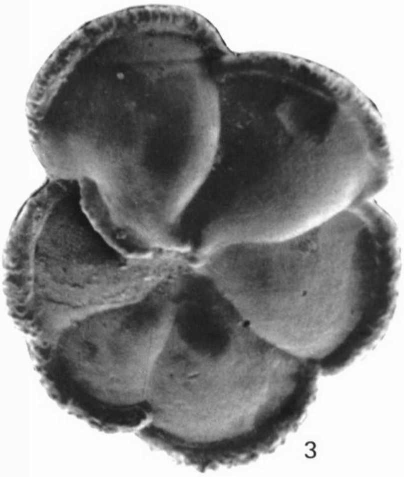
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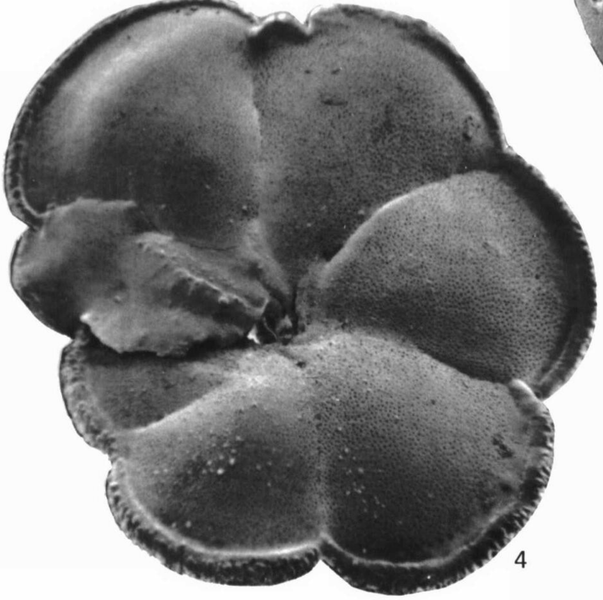
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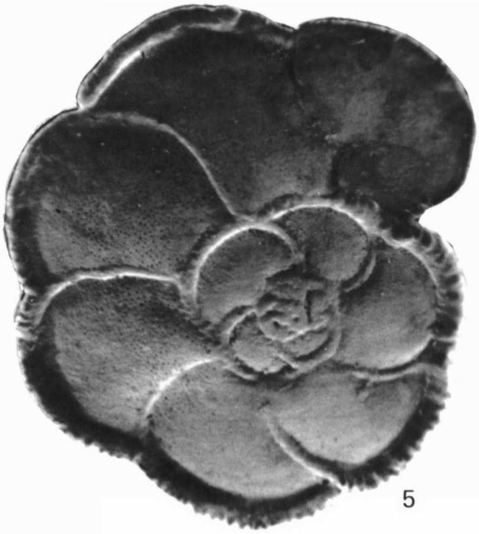
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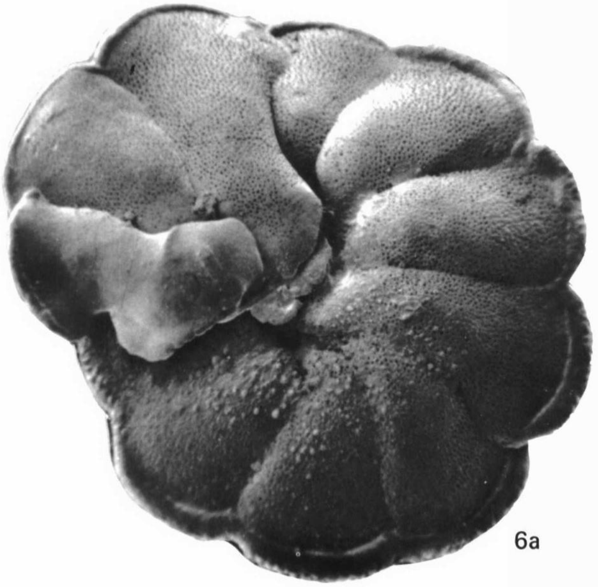
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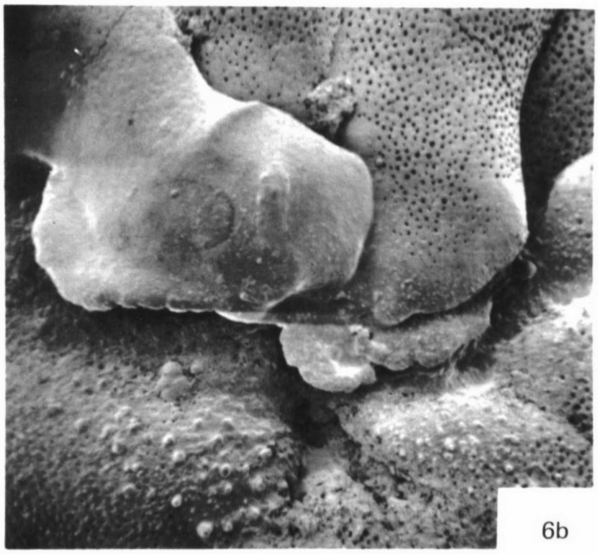
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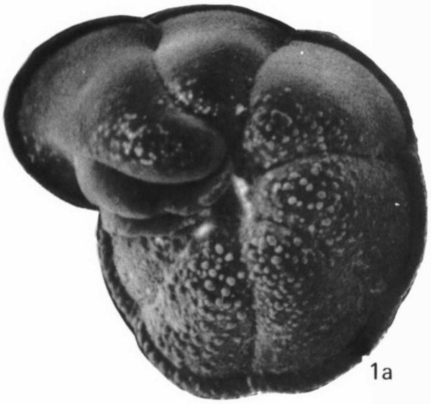
Globorotalia pertenuis Beard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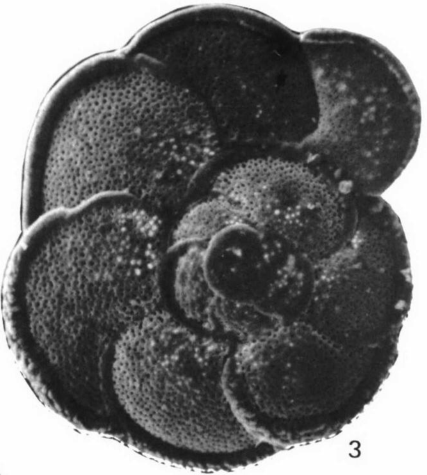
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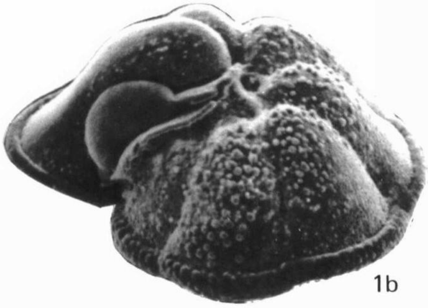
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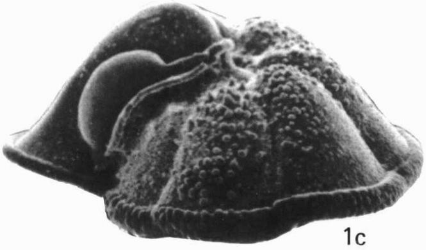
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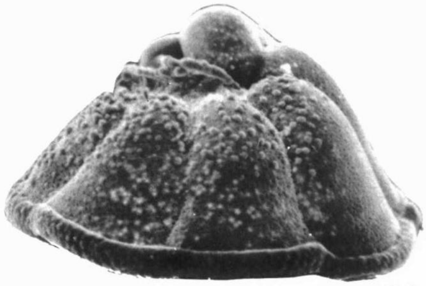
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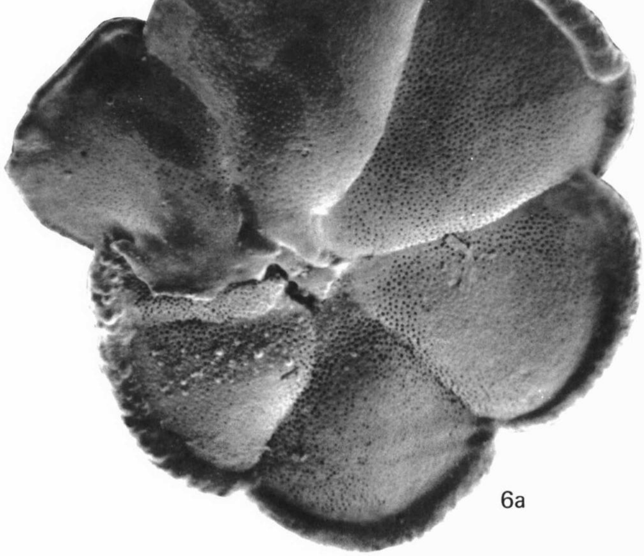
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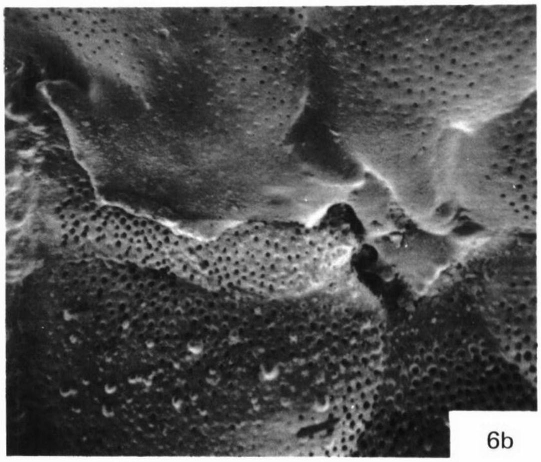
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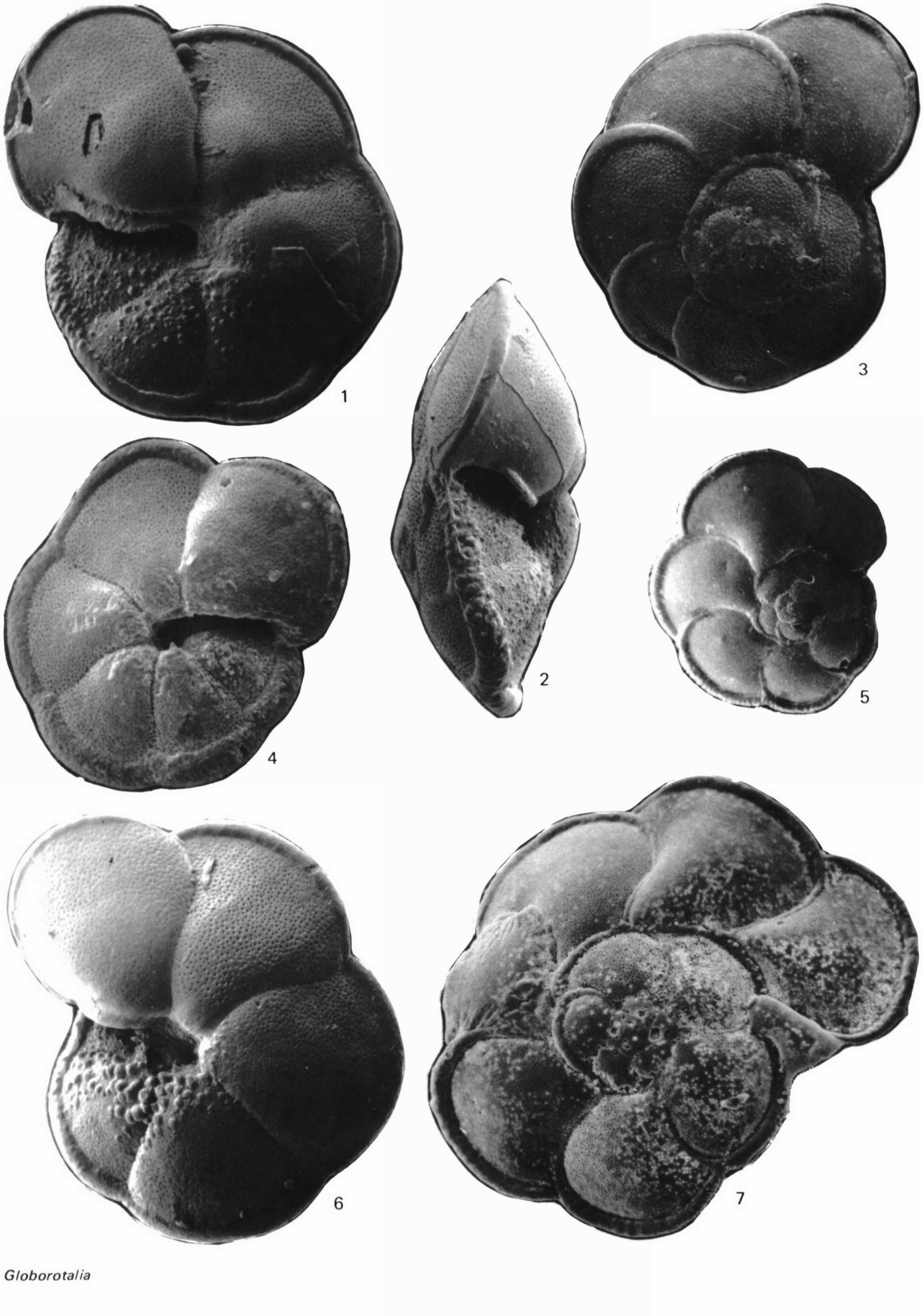

Globorotalia


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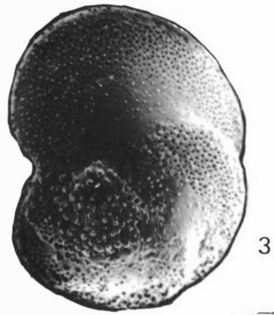
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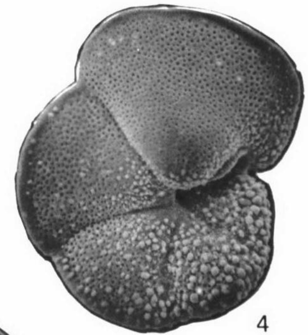
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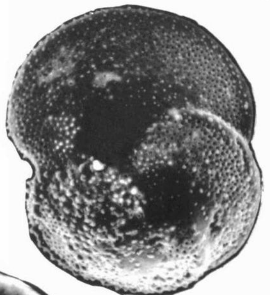
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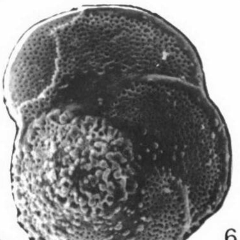
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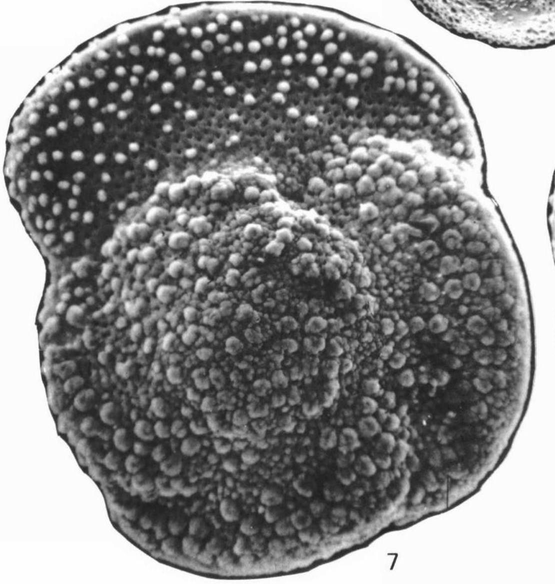
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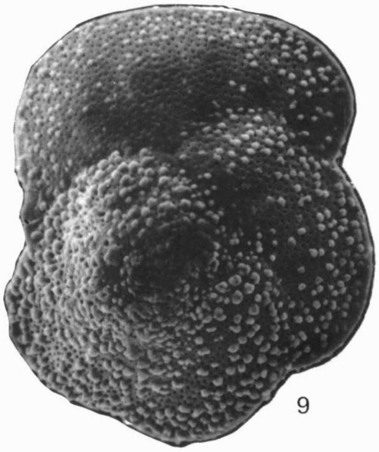
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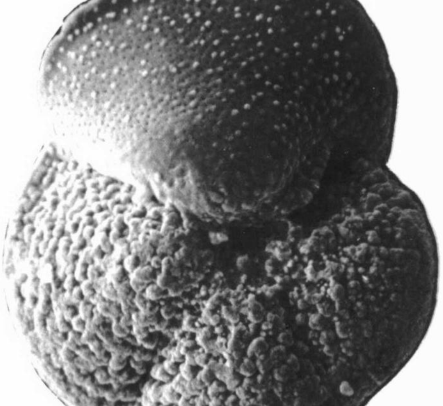
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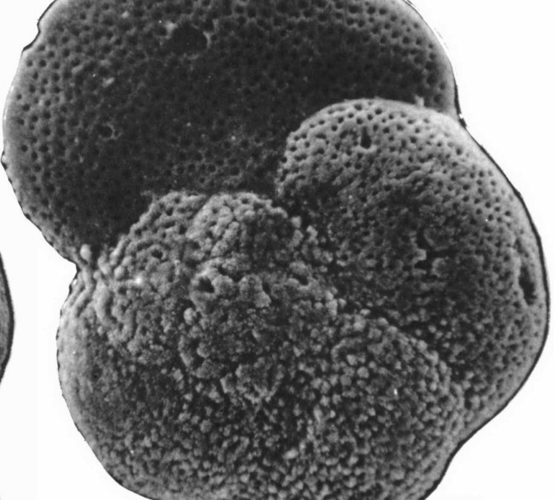
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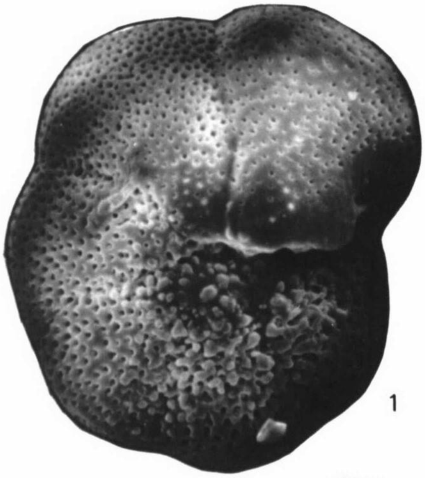
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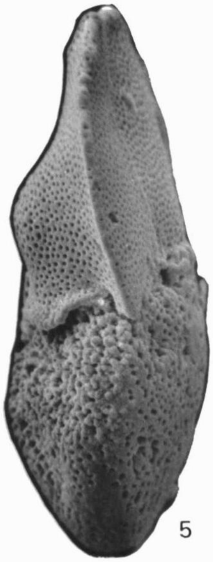
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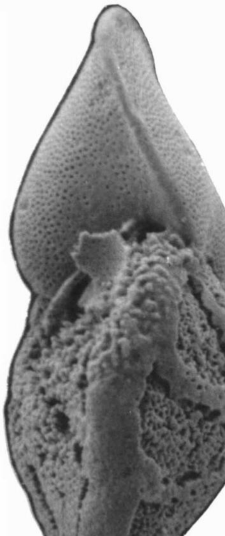
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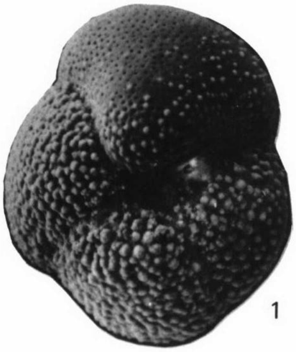
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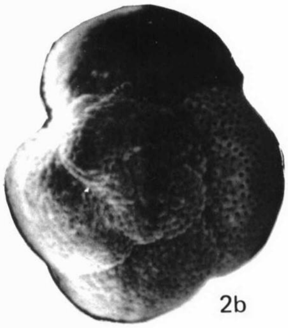
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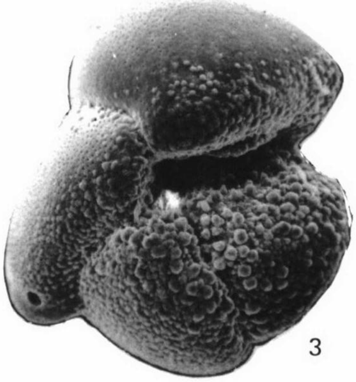
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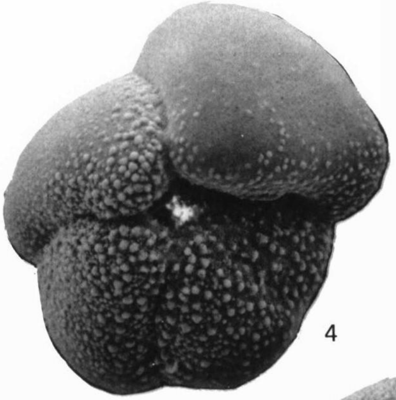
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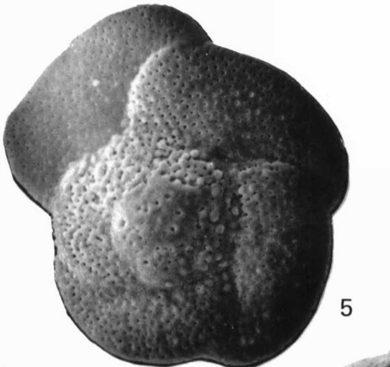
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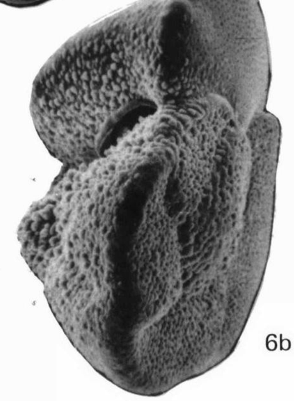
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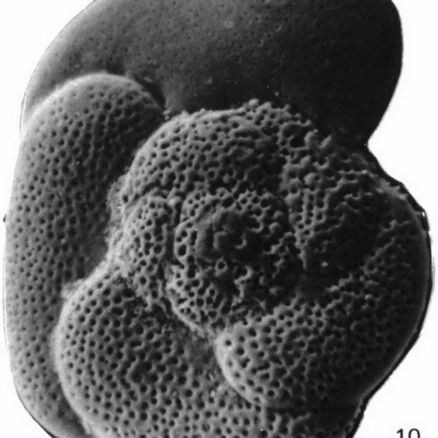
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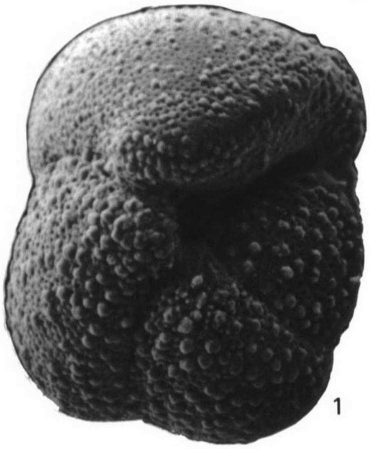
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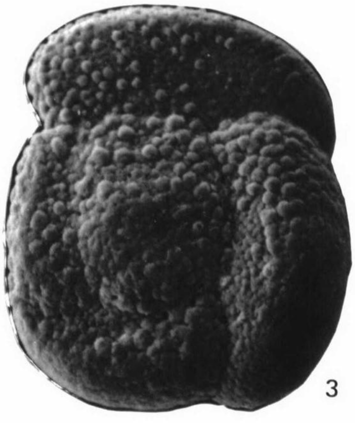
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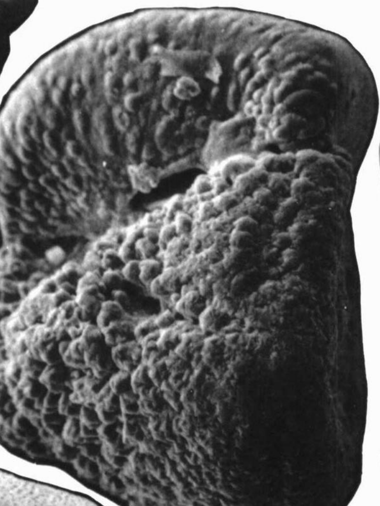
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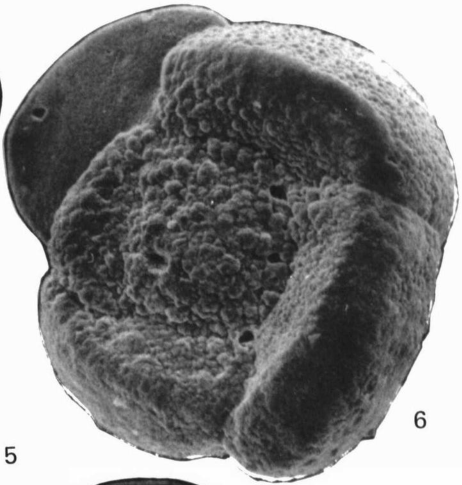
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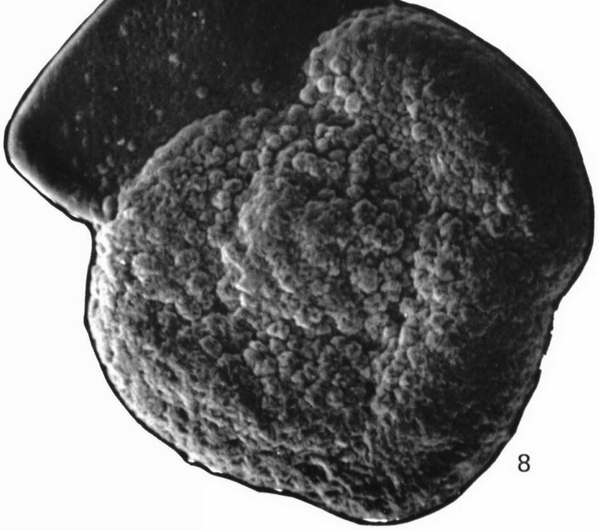
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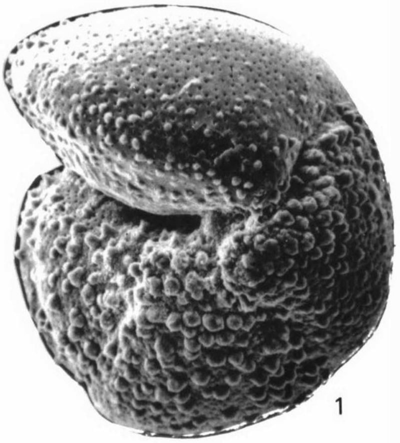
Globorotalia crassaformis (Galloway and Wissler)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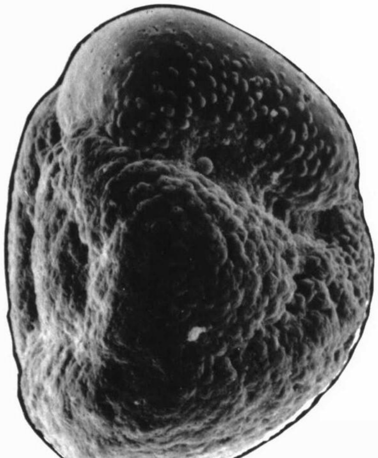
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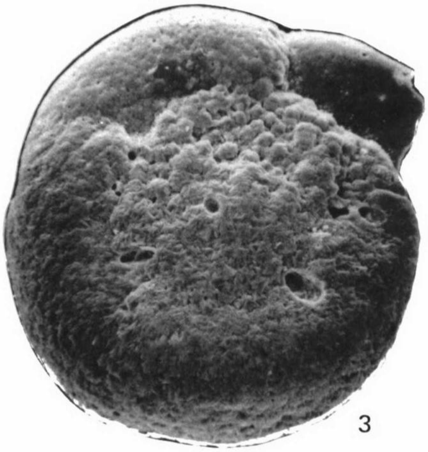
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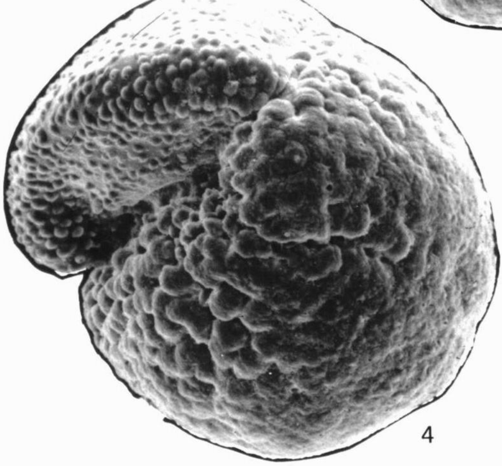
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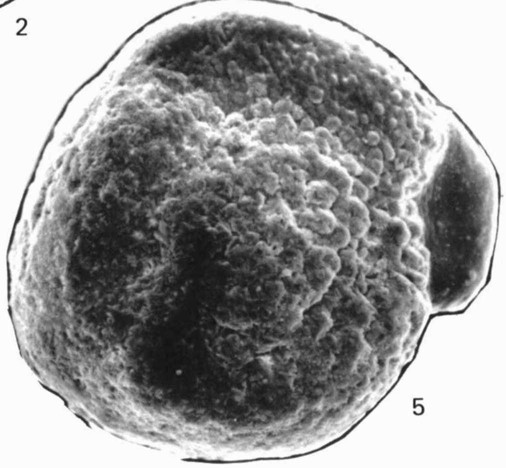
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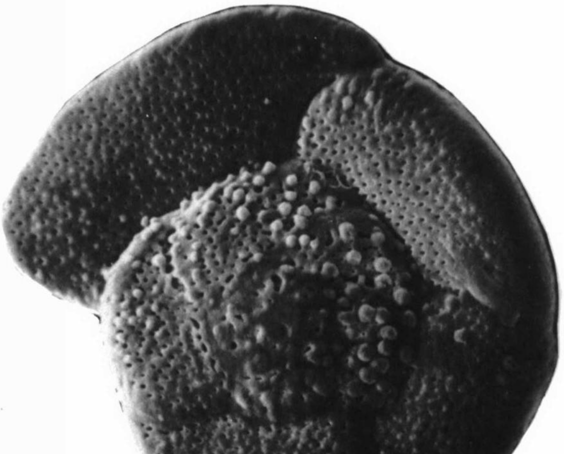
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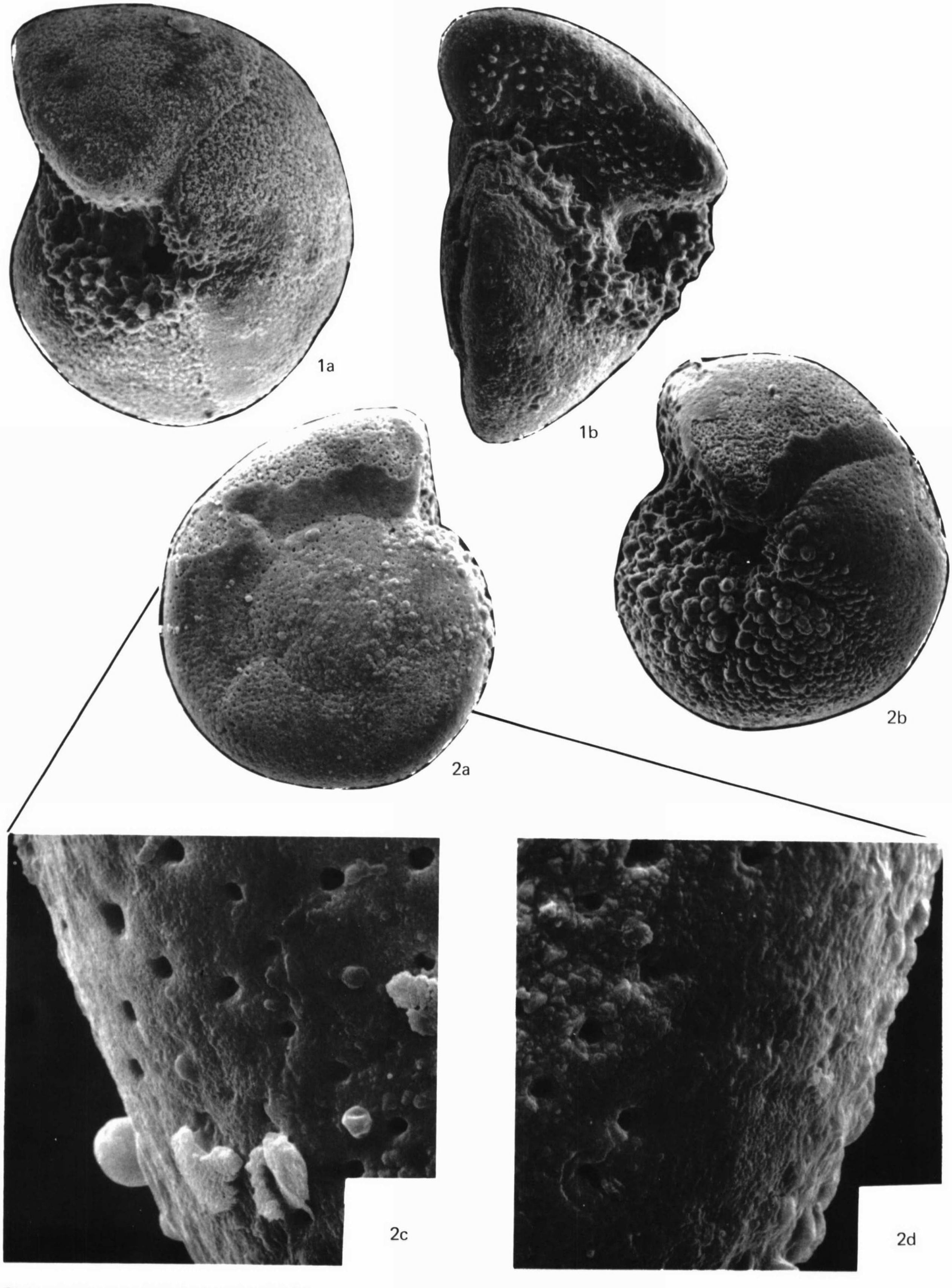
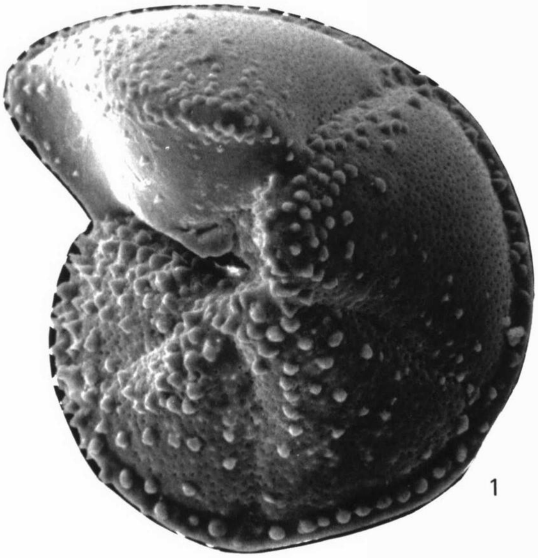
Globorotalia tosaensis Takayanagi and Saito



Globorotalia tosaensis Takayanagi and Saito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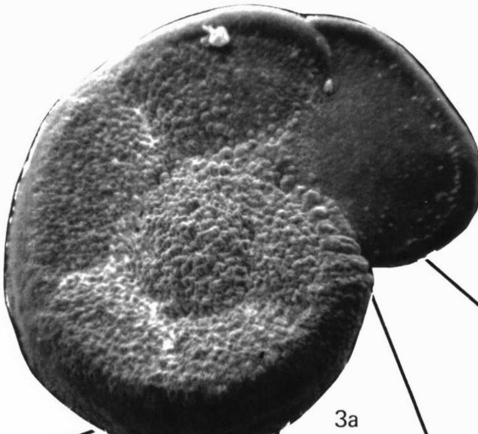
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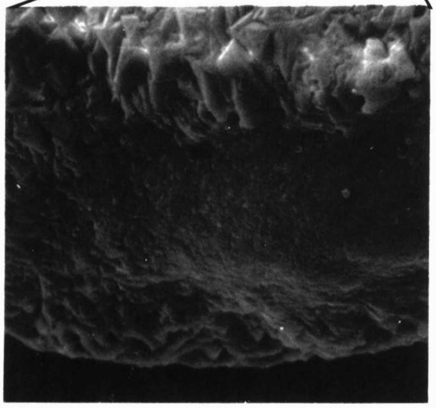
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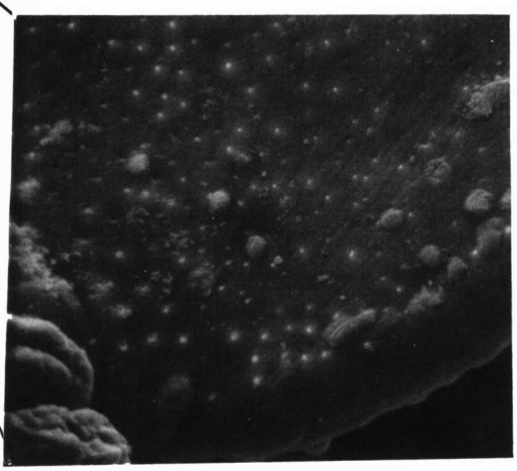
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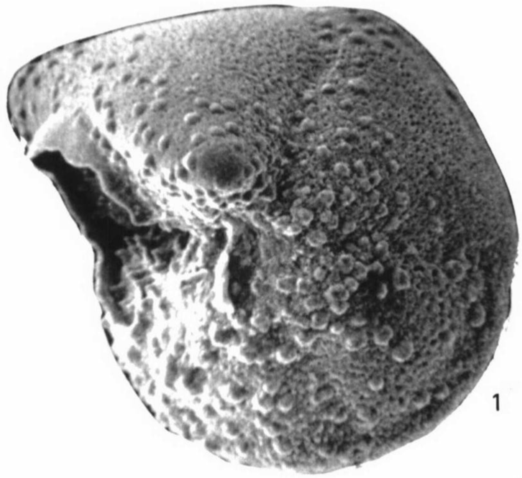
Globorotalia truncatulinoides (d' Orbigny)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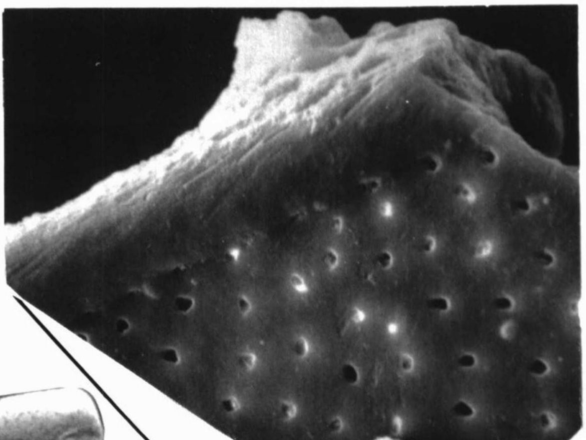
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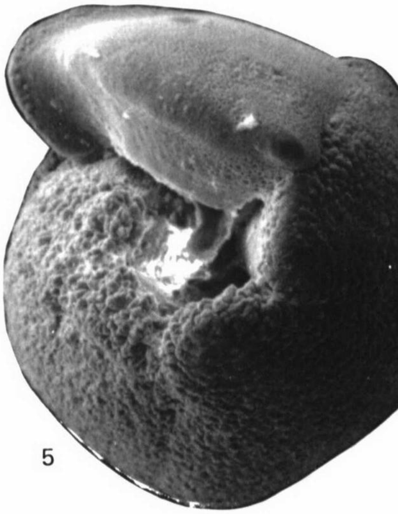
2


3


4a


6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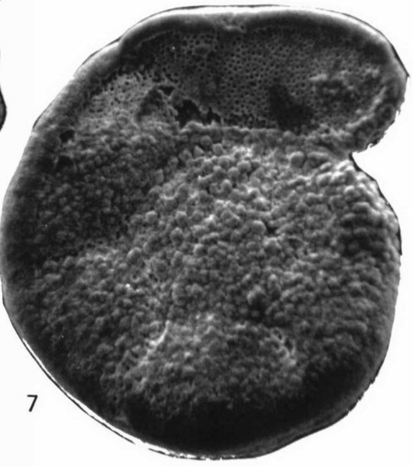
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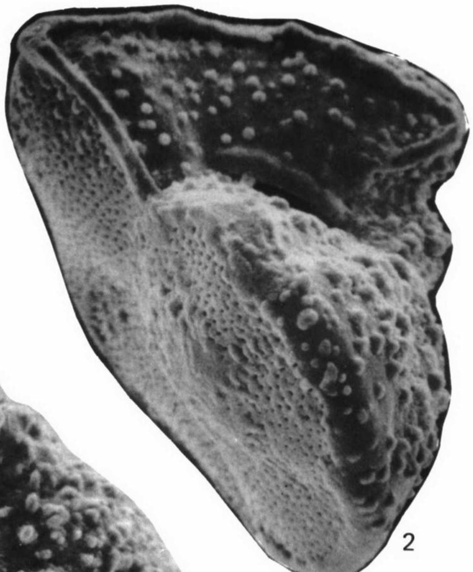
Globorotalia truncatulinoides (d'Orbigny)


1a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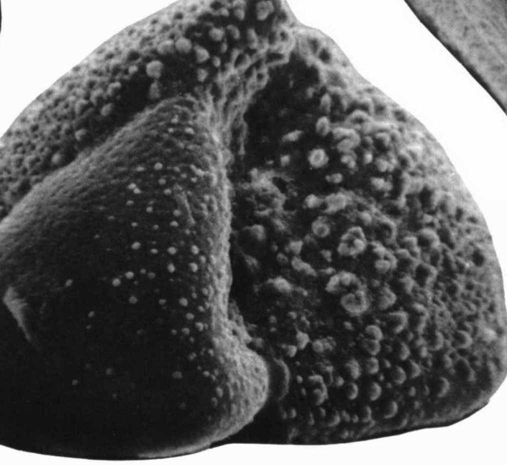
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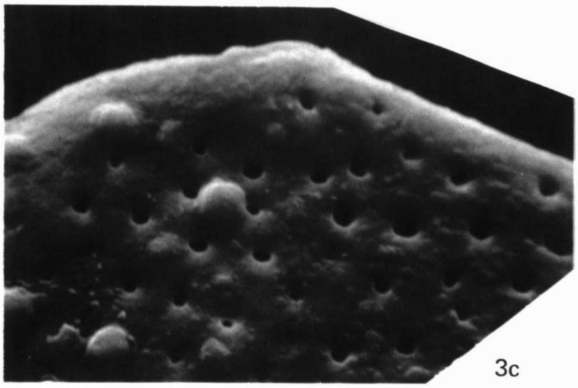
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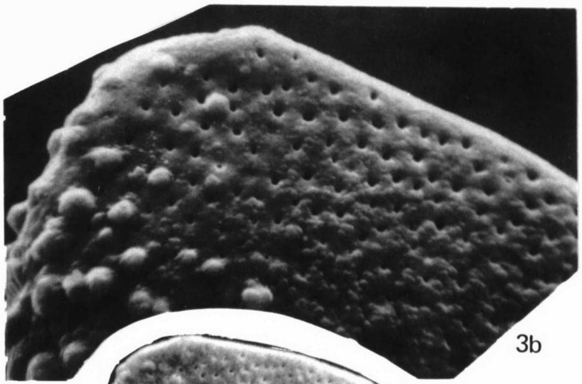
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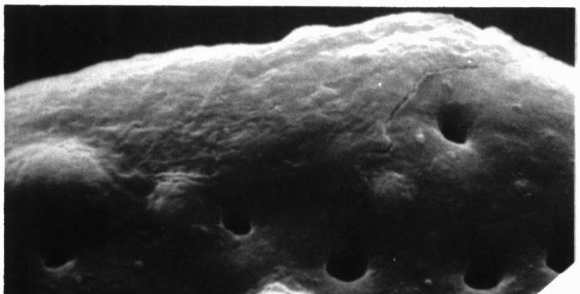
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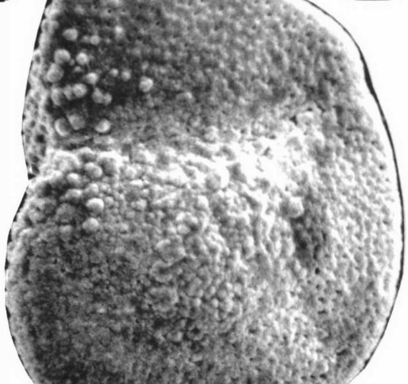
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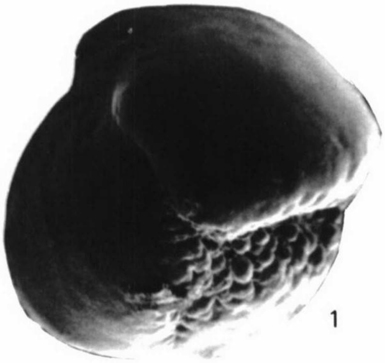
Globorotalia truncatulinoides (d' Orbigny)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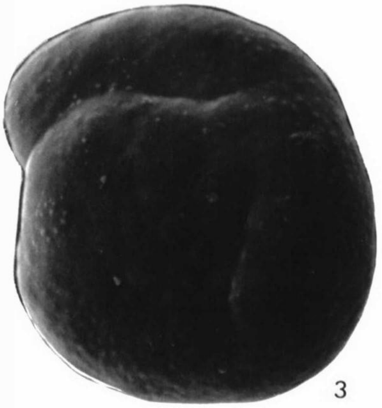
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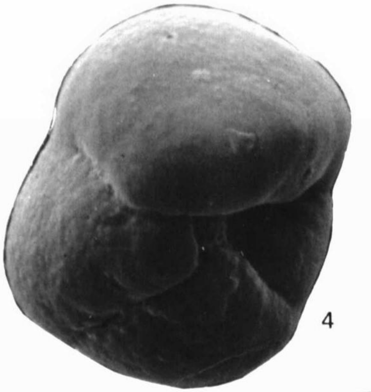
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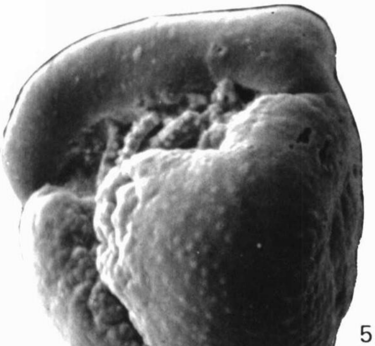
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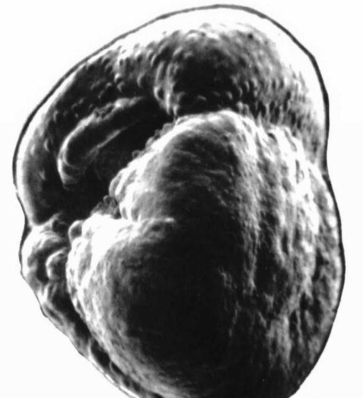
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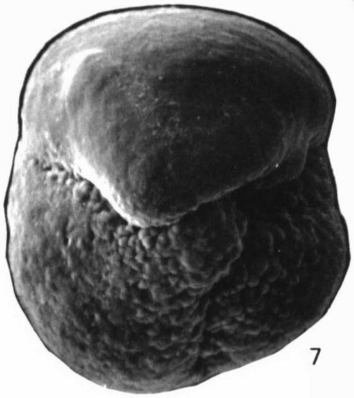
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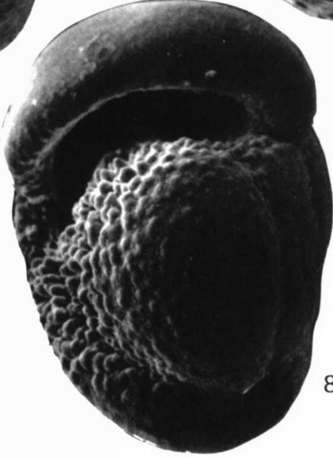
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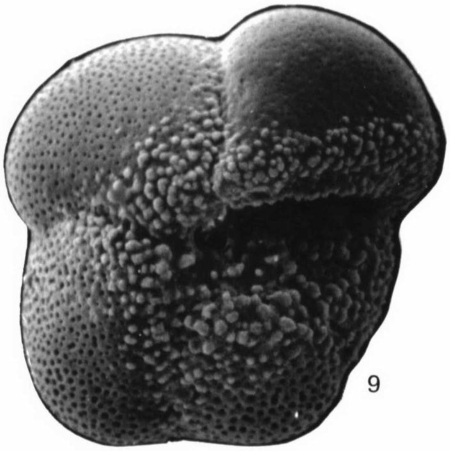
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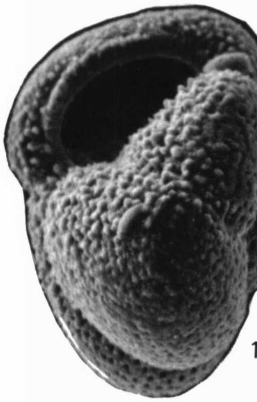
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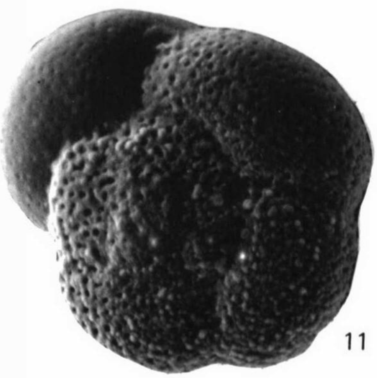
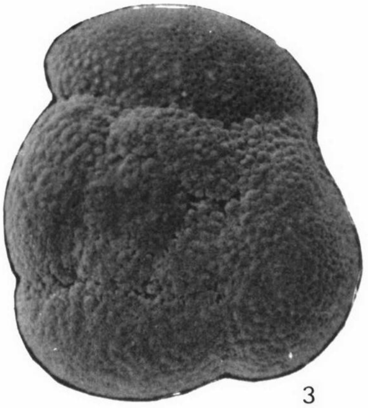

11

Globorotalia inflata (d'Orbigny)

1

2



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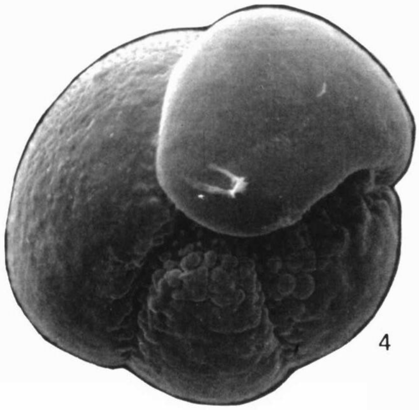

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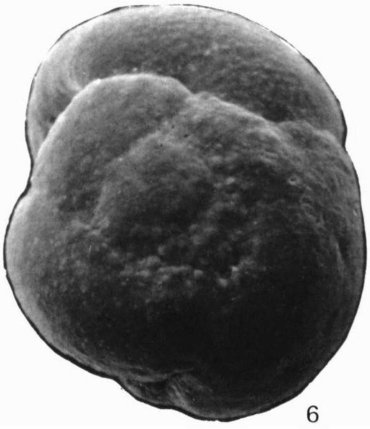

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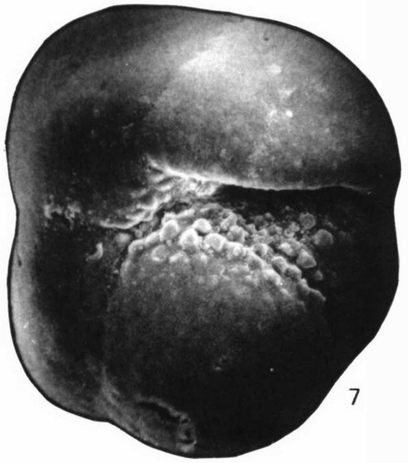

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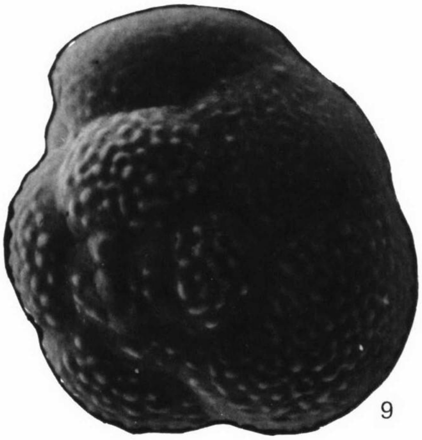
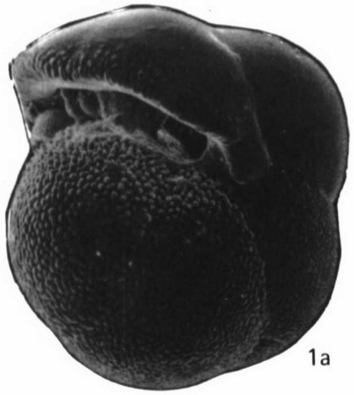


9

Globorotalia and *Pulleniatina*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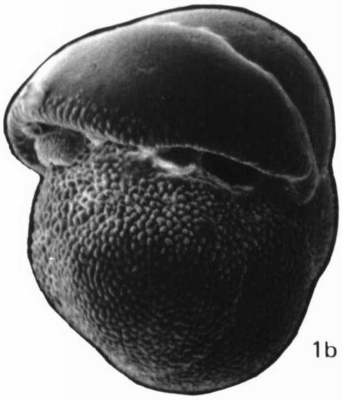
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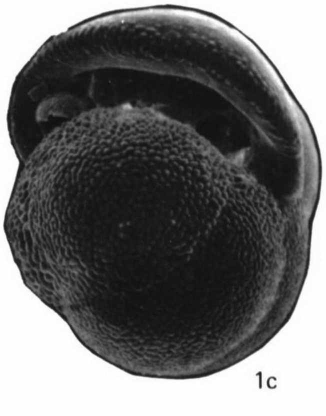
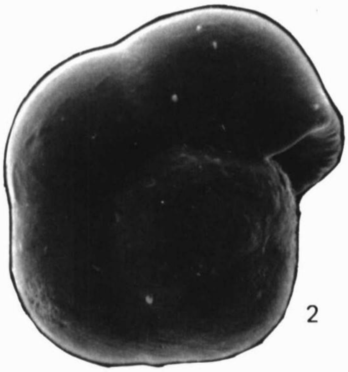

1c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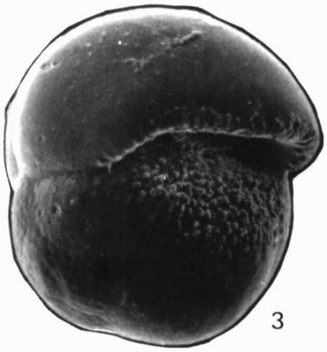
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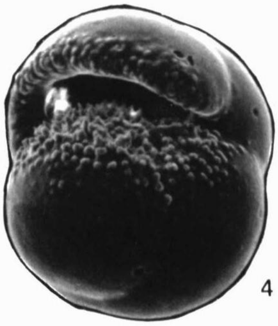
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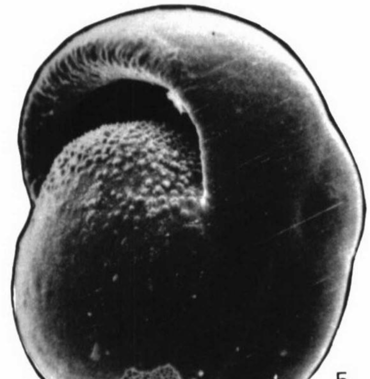
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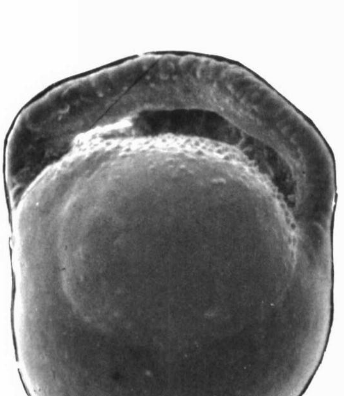
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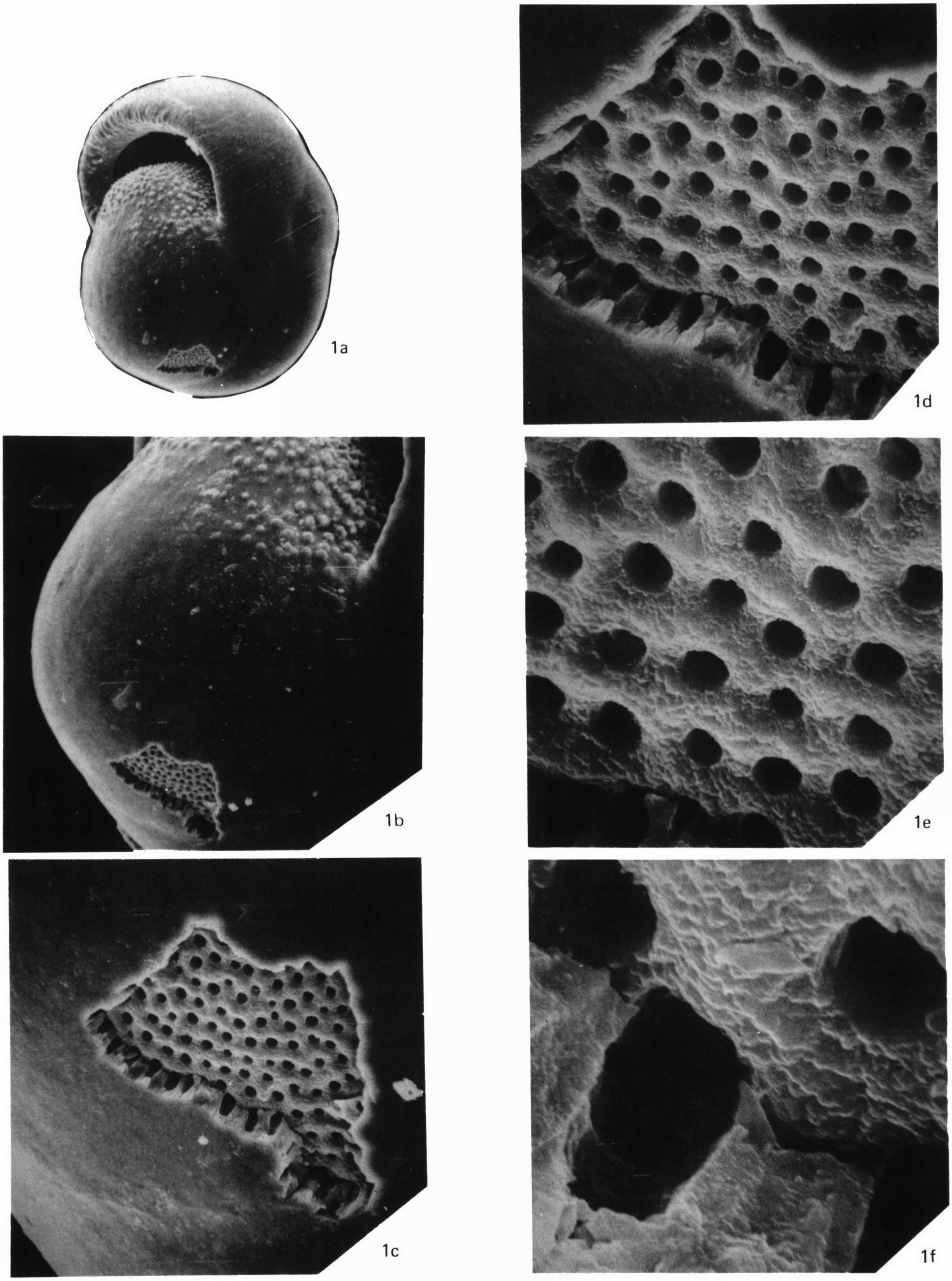
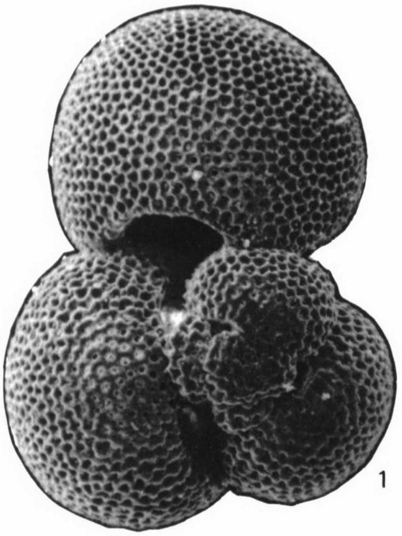
7

Pulleniatina



Pulleniatina finalis Banner and Blow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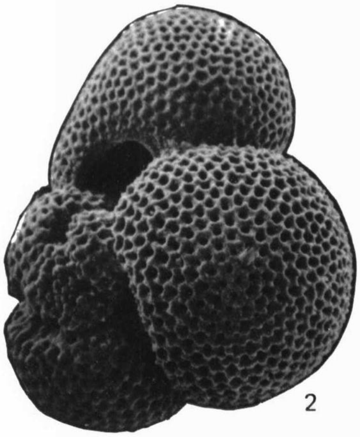
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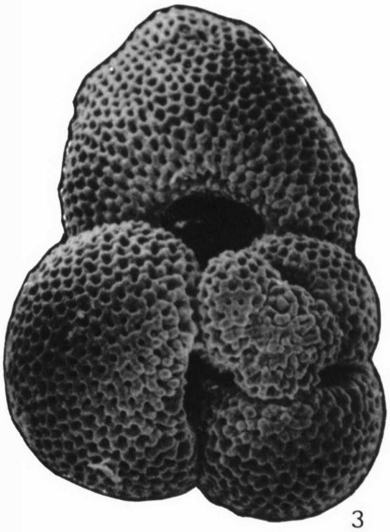
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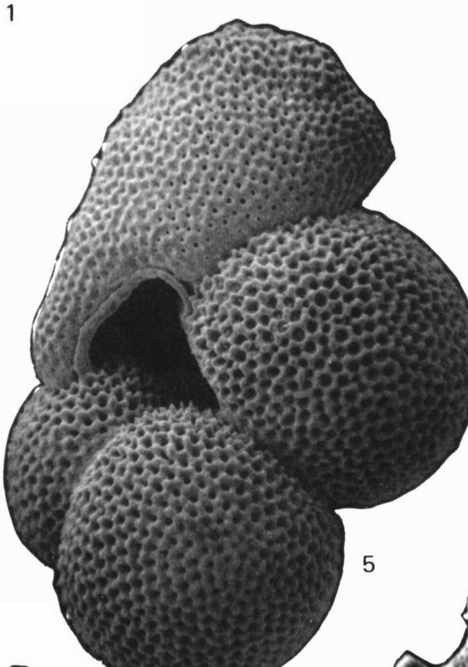
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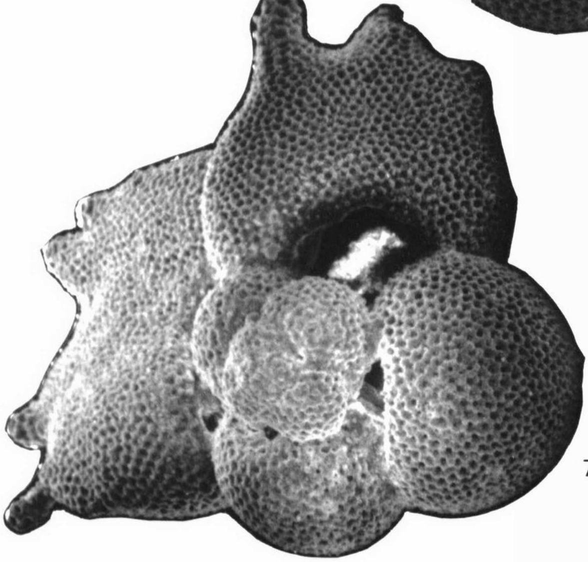
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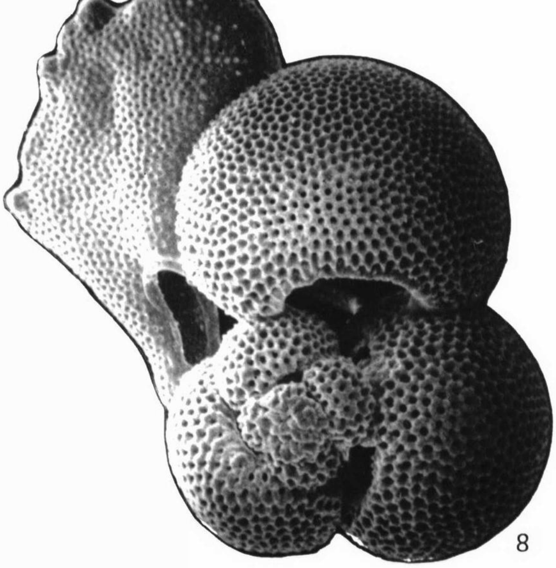
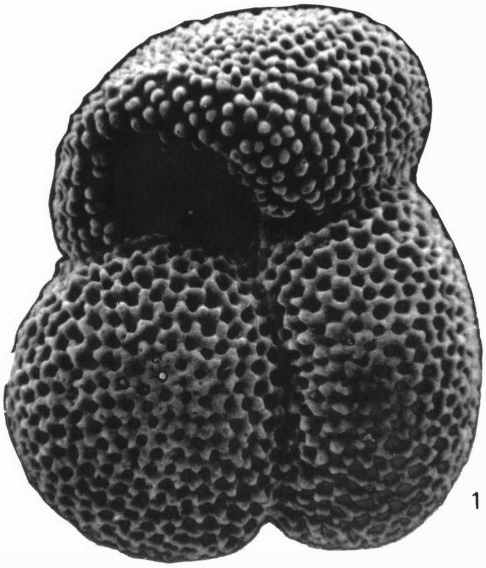

8

Globigerinoides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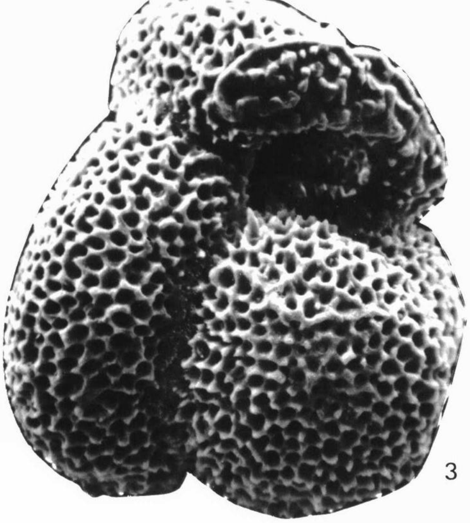
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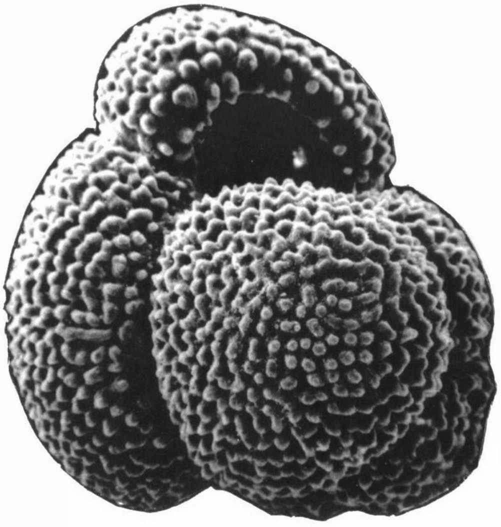
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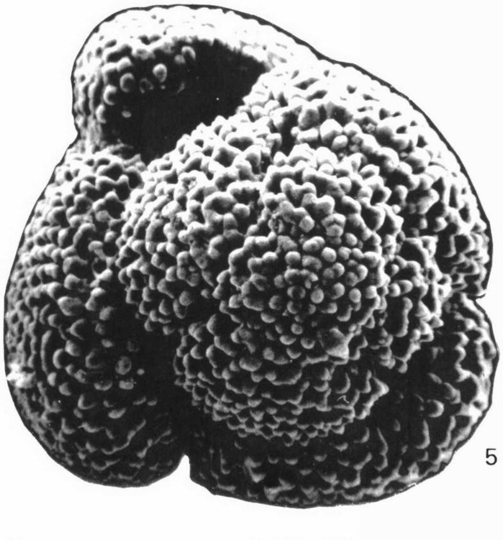
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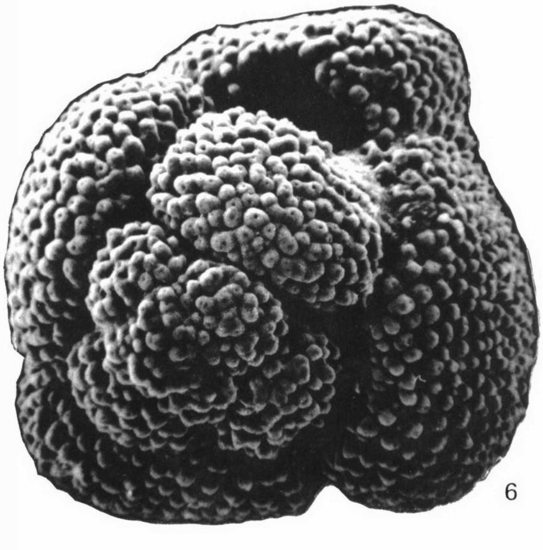
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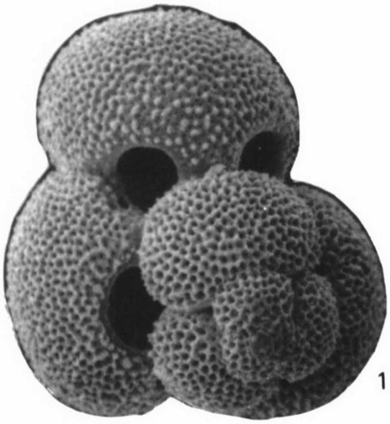
Globigerinoides extremus Bolli and Bermudez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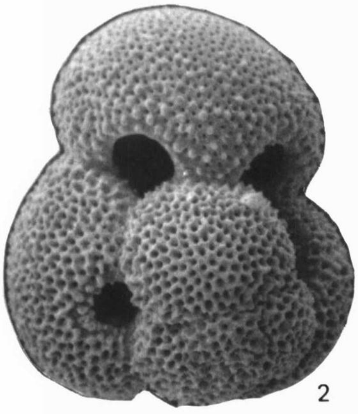
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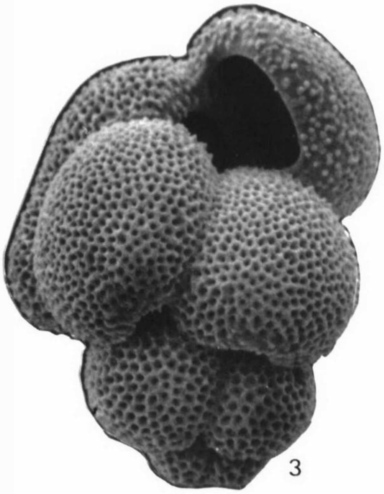
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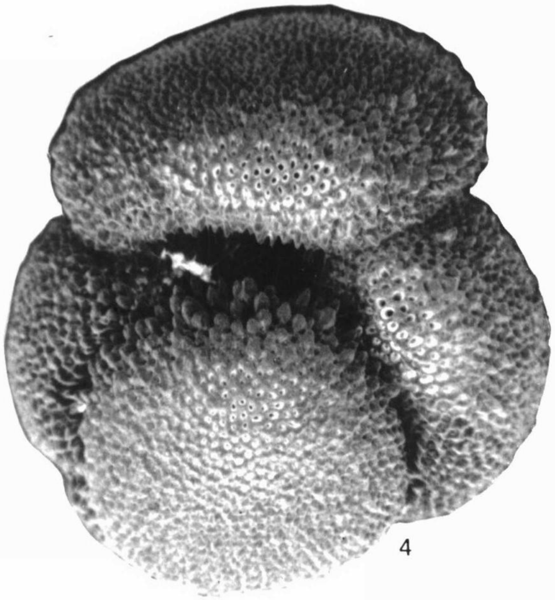
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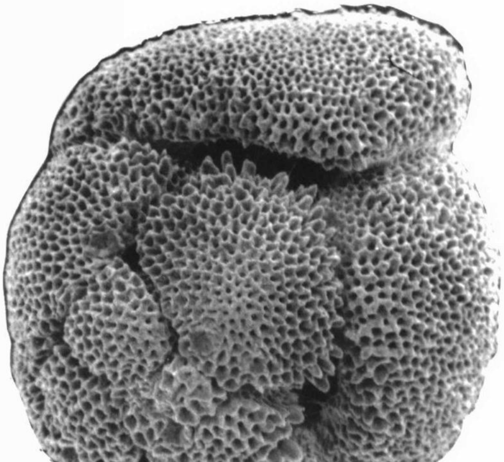
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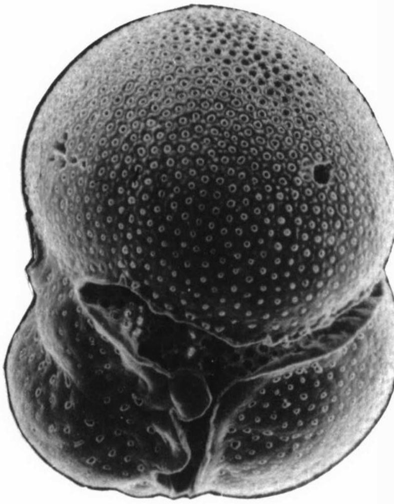
Globigerinoides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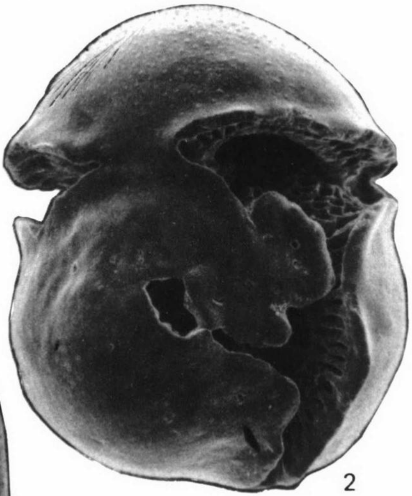
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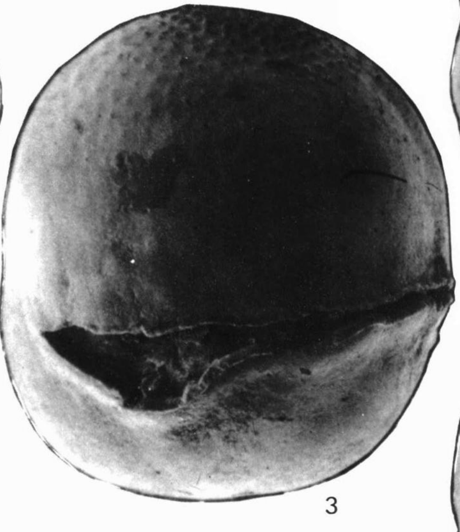
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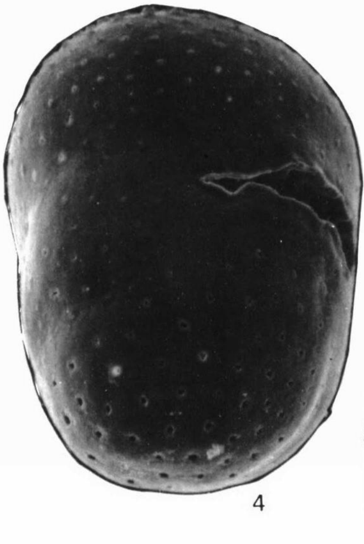
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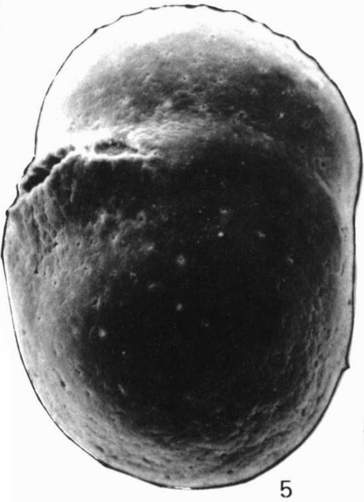
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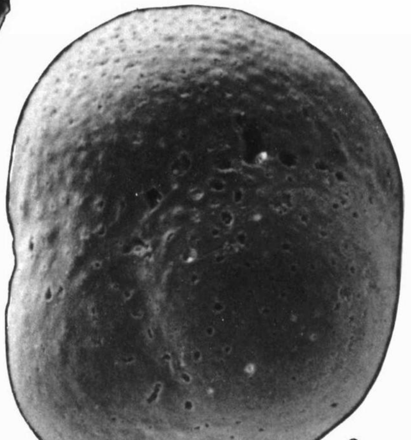
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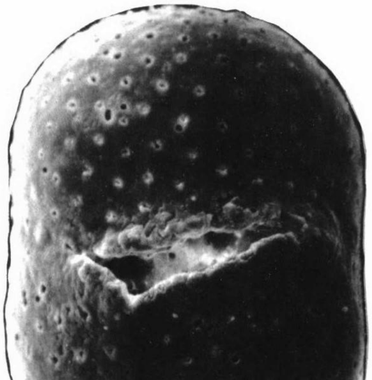
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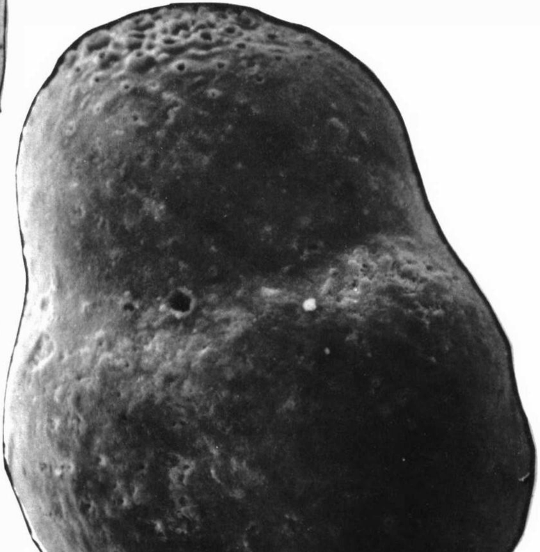
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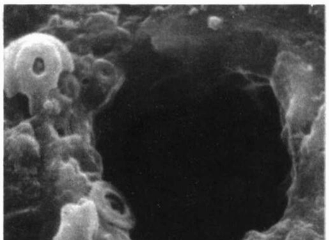
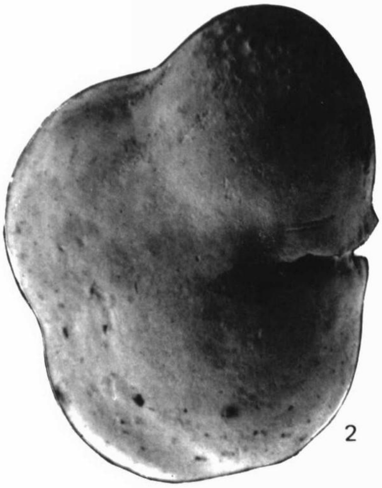

8b

Sphaeroidinella and *Sphaeroidinellopsis*


1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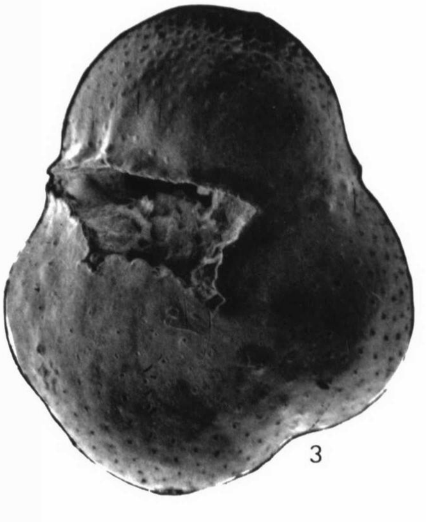
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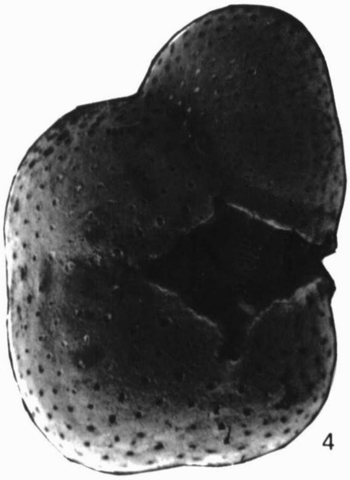
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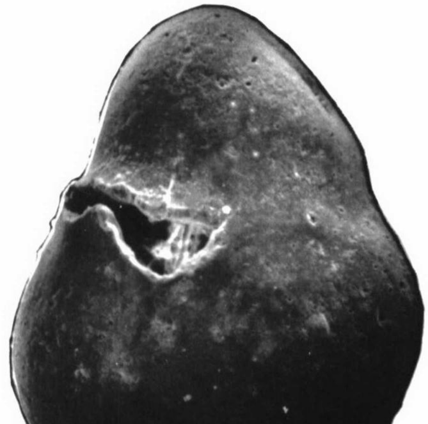
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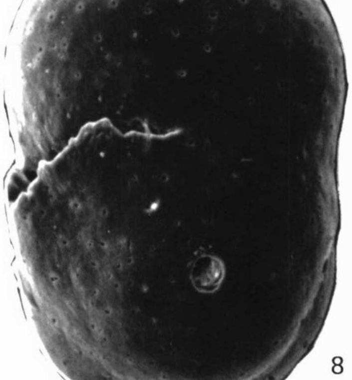
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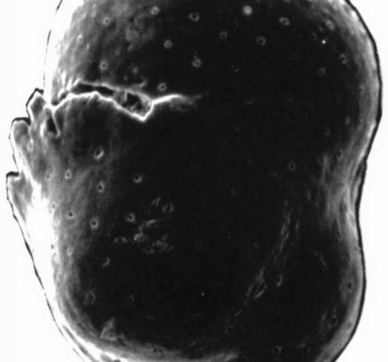
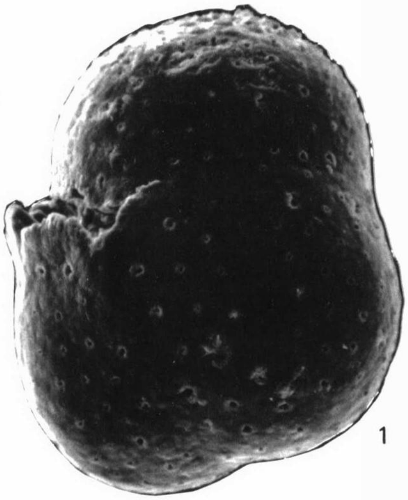

9

Sphaeroidinellopsis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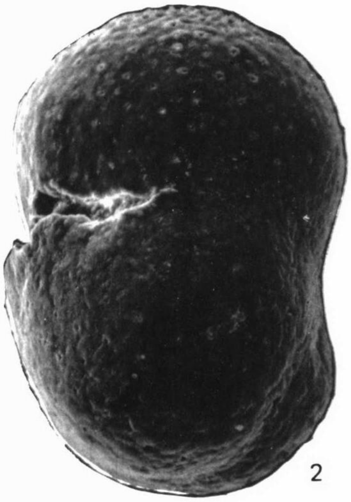
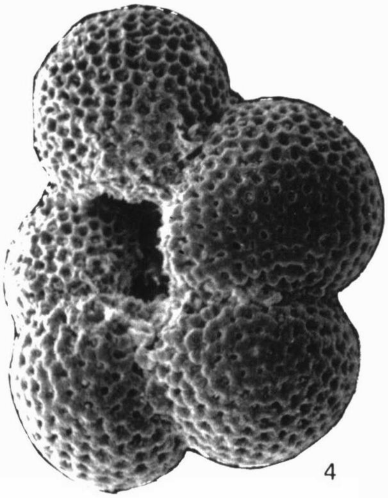

2


3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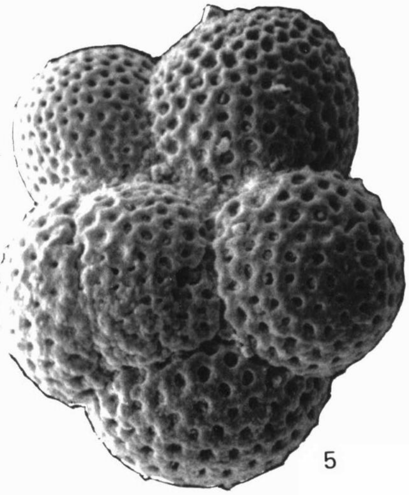
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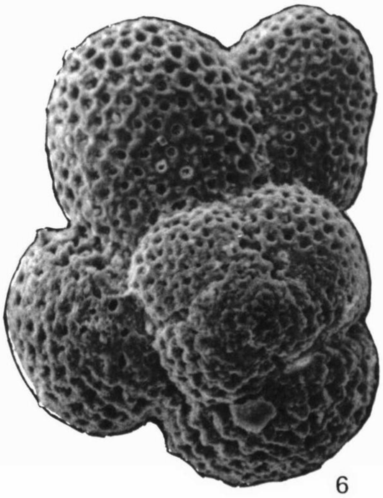
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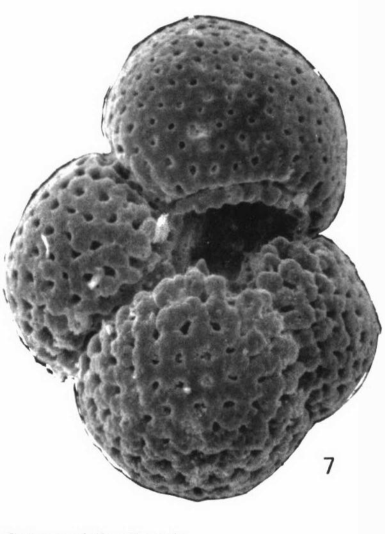
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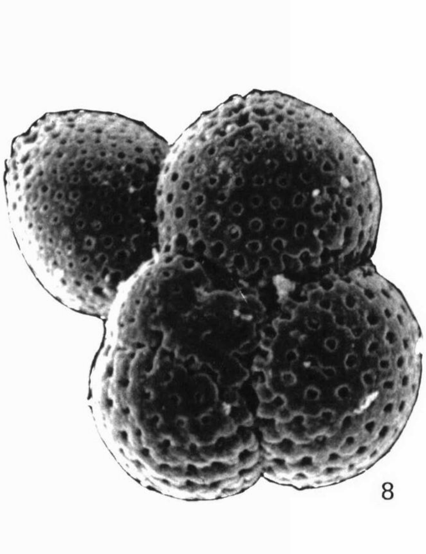
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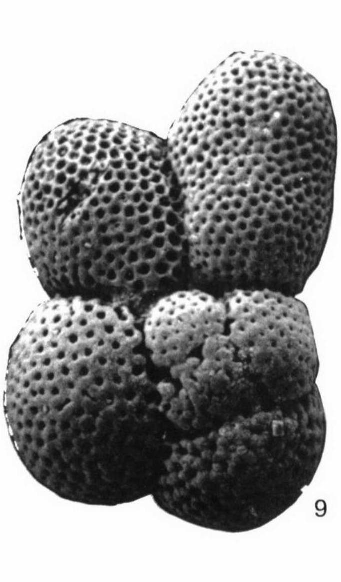
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Sphaeroidinellopsis