27. LATE NEOGENE PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY OF DSDP SITE 357 (RIO GRANDE RISE)

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ABSTRACT

Late Neogene planktonic foraminiferal biostratigraphy of Site 357 on the Rio Grande Rise is discussed. The stratigraphic succession studied covers the interval from lower middle Miocene to upper Pleistocene (planktonic foraminiferal Zones N11 to N23). The lower middle Miocene (Zone N11) is separated from the upper lower Miocene (Zone N7-8) by an unconformity. Two unconformities are postulated within the studied sucession (1) one spanning early late Miocene time, (2) one spanning late Pliocene-late Pleistocene time. The Miocene/Pliocene boundary and a threefold subdivision of the lower Pliocene Zone PL1 (Berggren, 1973), recently recognized in piston cores from the Rio Grande Rise, are seen at Site 357 as well. Taxonomically and/or stratigraphically important species are illustrated by scanning electron photomicrographs.

MATERIAL

Thirty-six samples have been examined at 100-cm intervals in Cores 1-6 from DSDP Site 357 drilled on the Rio Grande Rise (latitude 30°00.25′S, longitude 35°33.59′W) in a water depth of 2086 meters. Samples were washed through a 63 μm screen after soaking in a 15% solution of hydrogen peroxide which aided in disaggregating the sediment. The washed residues were sieved into three size fractions: (1) >250 μm; (2) 250-149 μm, and (3) <149 μm. The samples from the <149 μm size fraction were then spread on a picking tray and the stratigraphically and/or taxonomically important species were picked and recorded in tabular form (see Figure 1). Preservation is generally excellent, although discoloration and abrasion were observed in Core 1, particularly near the bottom where substantial reworking occurs in connection with a probable unconformity.

BIOSTRATIGRAPHY

Cores 1-6 span the stratigraphic interval of upper lower Miocene to upper Pleistocene. Three unconformities were identified in this sequence, one definite and two probable. Their location in the stratigraphic sequence and the extent of (bio) stratigraphic separation represented by the hiatus are shown in Table 1.

Unconformity 1 is clearly seen by the abrupt replacement of such typical early Miocene taxa as *Globigerinita dissimilis, G. unicava, Globigerinoides sicanus,* and *Globorotalia praescitula* by such middle Miocene taxa as *Globorotalia peripheroacuta, G. mayeri, G. miozea, G. praemenardii, G. lenguaensis, Globigerina druryi,* and associated forms between Sections 4 and 5

of Core 6 (see Figure 1). Elements of the *Globorotalia fohsi* lineage are present within Core 6 and help in recognizing the approximate position of Zones N11-13 (Blow, 1969).

The initial appearances of *Sphaeroidinellopsis subdehiscens* in Core 5, Section 6 and *Globigerina nepenthes* in Core 5, Section 5 are considered definitive in recognizing the base of Zones N13 and N14, respectively. It should be noted that the earliest specimens referable to *Globorotalia conoidea* occur within Zone N12 and occur together with *Globorotalia fohsi* and *G. praemenardii. Globorotalia mayeri, G. siakensis, G. peripheroronda*, and *G. lenguaensis* are common components of the middle Miocene fauna between the two unconformities which occur in the lower part of Cores 5 and 6, respectively.

An unconformity is postulated between Sections 4 and 5 of Core 5 based upon the sudden appearance of *Globorotalia conomiozea* and *G. mediterranea* in Sections 4 and 3, respectively, together with a typical late Miocene fauna consisting of *i.al., Globigerinoides ruber, Neogloboquadrina acostaensis* (rare), *Globigerina decoraperta, and,* in somewhat younger levels, *Globigerinoides obliquus* and *Globorotalia exserta.*

The stratigraphic interval between Core 5, Section 4 and Core 4, Section 1 is assigned to the *Globorotalia conomiozea-G. mediterranea* Zone (as proposed here), which is interpreted here as of late Miocene age. This zone is characterized by the concurrent range of the two nominate taxa from the initial occurrence of *G. conomiozea* to the initial appearance of *Globorotalia margaritae.* The age of the base of this zone remains somewhat uncertain at the moment. Zachariasse (1975) has recorded the earliest appearance of the *Globo-*
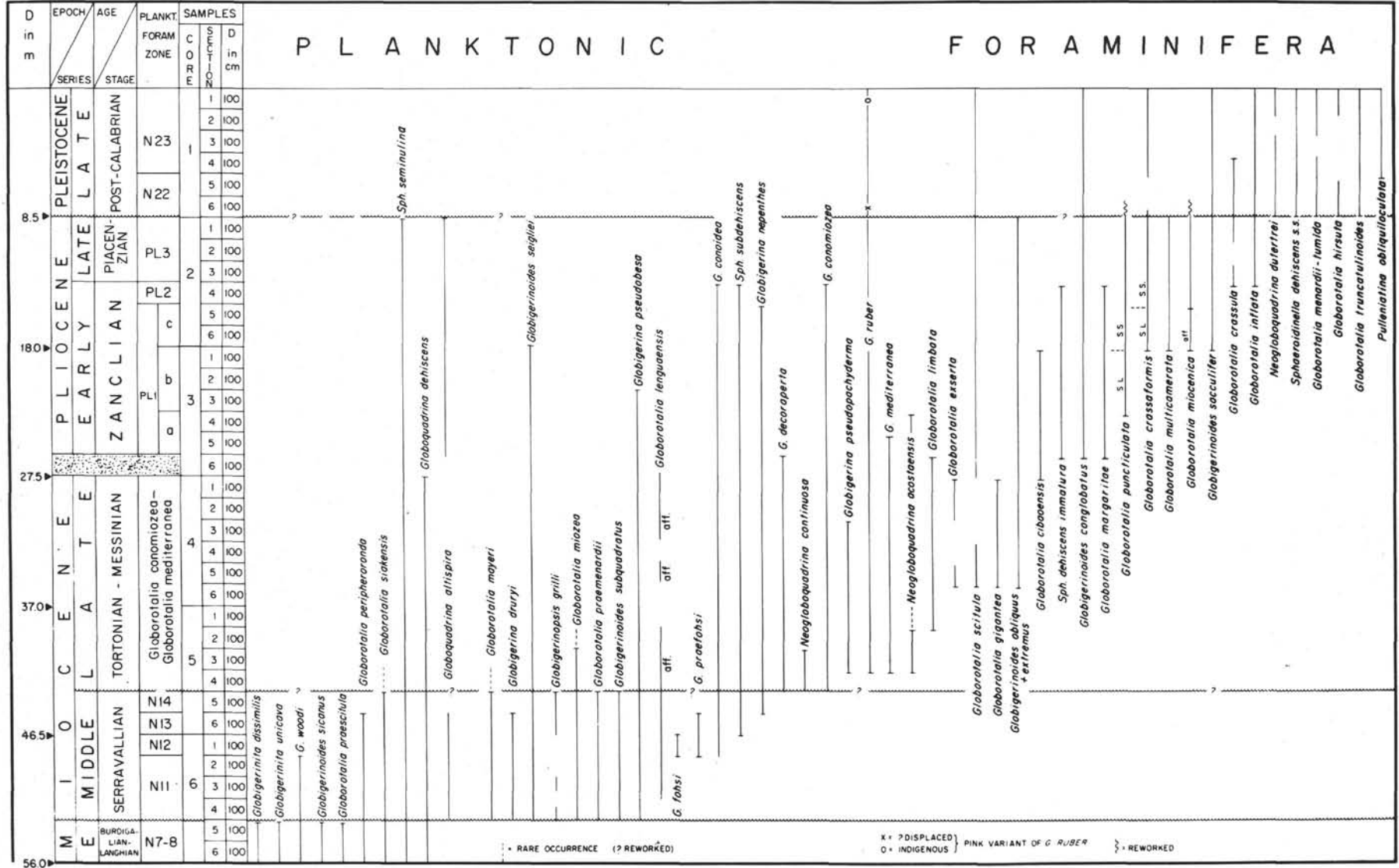
Figure 1. *Stratigraphic distribution of planktonic foraminifers at DSDP 357: Cores 1-6 (late Neogene).*

TABLE 1
Temporal and Spatial Extent of Definite (no. 1) and Probable
(no. 2 and 3) Intra-Neogene Unconformities at Site 357.

Unconformity	Approximate Depth Below Sea-Level (m)	Core & Section	Biostrat.	Separation	
				Chronologic (m.y.)	Chronostratigraphic
3	8.5	Between 1-6 and 2-1	N22/PL3	~2	Late Pleistocene/ early late Pliocene
2	43	Between 5-4 and 5-5	*G. conomiozea-G. mediterranea*/N14	~4-5	Middle late Miocene/late middle Miocene
1	53	Between 6-4 and 6-5	N11/N7-8	~2-3	Early middle Miocene/late early Miocene

NOTE: Biostratigraphic zonation schemes used are those of Blow (1969), Berggren (1973), and this paper.

rotalia conomiozea-G. mediterranea group at a stratigraphic level only slightly below the base of the stratotype Messinian. The base of the Messinian has been estimated by Ryan et al. (1974, p. 674) to lie within the uppermost part of Paleomagnetic Epoch 7 at about 6.6 m.y. and the *G. conomiozea* initial appearance datum to occur within the middle of Epoch 6 (i.e. within the Messinian) at about 6.3 m.y. (but this estimate is obviously too young). More recently the initial appearance of *Globorotalia conomiozea* and *G. mediterranea* some tens of meters *below* the level of the original definition of the Tortonian/Messinian boundary has led to the suggestion of a downward revision of the Messinian so that its lower limit coincides with the initial appearance of these taxa (d'Onofrio et al., 1975).

There are several alternatives in interpreting the age of the stratigraphic interval above Core 5, Secion 5.

1) Core 5, above Section 5, is of early late Miocene (Tortonian) age and equivalent to Zones N15 and N16 based upon the appearance of *Neogloboquadrina continuosa* in Section 4 and of *N. acostaensis* in Section 3. If this is true, then the initial appearance of *Globorotalia conomiozea* and *G. mediterranea* (in Sections 4 and 3, respectively) occurs in Zones N15 and 16, respectively. There is no evidence for the initial appearance of these taxa at such a low (i.e., early) level either in the literature or from my experience. Were it true, the *Globorotalia conomiozea-G. mediterranea* Zone would be essentially equivalent to Zone N16 and N17 of the tropical low latitude zonal scheme (Blow, 1969).

An alternative explanation would be that the presence of *G. conomiozea-G. mediterranea* is due to downhole contamination. This explanation is rejected for two reasons: (a) *G. conomiozea* and *G. mediterranea* are common and show intergradational morphologies with the associated *G. conoidea* and *G. miozea*; (b) There is no evidence (either taxonomic or preservational) of downhole contamination of other elements.

2) The virtually simultaneous initial appearance of *G. conomiozea-G. mediterranea* is real and denotes a level only slightly older than the Tortonian/Messinian boundary (say 7-7.5 m.y.), and there is an unconformity between Sections 4 and 5 of Core 5. In this case the

(rare) co-occurrence of *N. continuousa* and *N. acostaensis* would be somewhat younger than is normally seen in deep-sea sediments. The occurrence of *N. acostaensis* is sporadic in the Atlantic, although it is an abundant form in the Tortonian of the Mediterranean region.

I have chosen to adopt the second interpretation tentatively and have shown a questionable unconformity between Sections 4 and 5 of Core 5 in Figure 1.

The Miocene/Pliocene boundary is approximately denoted by the extinction of *Globoquadrina dehiscens* and the initial appearance of *Globorotalia margaritae*. In actual fact recent studies at our laboratory on a series of piston cores from the Rio Grande Rise have verified the finding of Saito et al. (1975) of a stratigraphic overlap in the upper range of *G. dehiscens* and the lower range of *G. margaritae* over the upper part of Paleomagnetic Epoch 5 (between 5.5-5.0 m.y. approximately). Thus *G. margaritae* actually makes its initial appearance in latest Miocene time and the extinction of *G. dehsicens* (at 5.0 m.y.) serves as the primary guide form for the recognition of the Miocene/Pliocene boundary (see also Berggren, 1973). We have found also that the initial appearance of *Globorotalia cibaoensis* occurs virtually simultaneously with *G. margaritae* and is followed shortly thereafter by the initial appearance of *Globigerinoides conglobatus*. This same sequential association has been found at Site 357 with the exception that the *G. margaritae-G. dehiscens* overlap has not been detected. The Miocene/Pliocene boundary is thus placed between Core 3, Section 5 and Core 4, Section 1 where these two events occur, respectively.

The lower Pliocene and the lowest part of the upper Pliocene(Zones PL1-3; Berggren, 1973) are represented by Core 2 and Core 3, Sections 1-5. Zone PL1 is further subdivided here into three subzones: (a) based on the range of *G. cibaoensis* following the extinction of *G. dehiscens*, (b) based on the initial appearance of primitive *Globorotalia puncticulata* s.l., (c) based on the initial appearance of *Globorotalia crassaformis* s.l. (see Figure 1). These three subzones will be formally described in a forthcoming paper on the late Neogene

biostratigraphy of the Rio Grand Rise. The sequential appearance of *Globorotalia multicamerata* and *G. miocenica* is similar to that seen in other cores on the Rio Grande Rise (work in progress in our laboratory) as well as in the Gulf of Mexico and Caribbean region.

An unconformity is postulated between Cores 1 and 2. This is based upon the following observations:

1) Several taxa which become extinct at about 3 m.y. disappear abruptly in Core 2, Section 1 and are replaced by

2) several typically Pleistocene taxa such as *Globorotalia truncatulinoides*, *Sphaeroidinella dehiscens excavata*, and *Neogloboquadrina dutertrei* and large robust elements of the *Globorotalia menardii-tumida* group.

3) Core 1, Section 6 contains a typically Pleistocene fauna with obvious evidence of reworking (*G. miocenica-G. puncticulata*) as seen both in preservation (discoloration, abrasion) and taxonomy.

The unconformity is believed to span about 2 m.y. (from early late Pliocene, ca. 3 m.y. to early late Pleistocene, 1 m.y.). This is based upon the absence of evidence of upper Pliocene Zones PL4-6 and the presence of *S. dehiscens excavata* in Core 1 which is the guide form of Zone N23. The presence of pink *Globigerinoides ruber* in Core 1, Section 1 and questionably in Core 1, Section 6 also indicates a late Pleistocene age.

The presence of a late Pleistocene unconformity at Site 357 is in accordance with other evidence which we have seen in the course of our current study of piston cores from the Rio Grande Rise. A late Pleistocene unconformity which has eroded down to different levels between late Pliocene to early late Miocene is seen in eight piston cores.

TAXONOMIC NOTES

A brief discussion of the taxonomy of several of the biostratigraphically more important taxa is appended here by way of explanation of Figure 1.

Globigerina druryi Akers, 1955
(Plate 1, Figure 1)

Remarks: This small species is a useful guide form for the middle Miocene. Ancestral to *G. nepenthes*, it is more compact, lower spired, and has a lower, narrower apertural arch.

Globigerina nepenthes Todd, 1957
(Plate 1, Figures 2, 3,)

Remarks: The initial appearance of this taxon in Core 5, Section 5 serves to identify the presence of Zone N14. It ranges throughout the upper Miocene at Site 357, but shows a pronounced size increase in the Pliocene. Its extinction in Core 2, Section 5 serves to denote the top of Zone PL1 (Berggren, 1973)

Globigerina pseudopachyderma Cita, Premoli-Silva, and Rossi, 1965
(Plate 1, Figures 4,5)

Remarks: This form bears a remarkable resemblance to its Pliocene-Pleistocene namesake. It may be distinguished by its considerably smaller size, more compact (tightly coiled) test, and resulting more quadrate test outline. The similar morphology suggests that perhaps it should be placed in *Neogloboquadrina*. At Site 357 this taxon ranges through the stratigraphic interval from Core 5, Section 3 to Core 4, Section 3 which is interpreted as spanning Tortonian and Messinian ages.

Globigerina pseudobesa Salvatorina, 1966
(Plate 1, Figures 6-8)

Remarks: This distinct taxon is characterized by a (generally) strongly evolute test and wide, arching aperture which, in some individuals, extends to the spiral side of the test. Specimens which appear referable to this taxon were observed throughout the middle Miocene (5-5 to 6-4). It ranges into the lower part of the Pliocene (Zone PL1b) at Site 357, a stratigraphic range which has been verified in our piston cores from the Rio Grande Rise as well. It is a common element in the upper Miocene of Andalusia, Spain (Tjalsma, 1971; Berggren and Haq, 1976).

Globigerinoides subquadratus Bronnimann, 1964
(Plate 1, Figures 9, 10)

Remarks: This is the dominant species of *Globigerinoides* in the middle Miocene unconformity-bounded interval between Core 6, Section 5 and Core 5, Section 4 at Site 357. The subquadrate outline and two discrete supplementary apertures on the spiral side are characteristic of the species.

Globigerinoides conglobatus (Brady), 1879
(Plate 1, Figures 11, 12)

Remarks: This taxon has been observed here, and in our piston cores from the Rio Grande Rise, to make its initial occurrence very near, but slightly above, the Miocene/Pliocene boundary and this appearance may serve as a useful adjunct in locating the position of the Miocene/Pliocene boundary in the Atlantic Ocean.

Globigerinoides seigliei Bermúdez and Bolli, 1969
(Plate 1, Figures 13-18)

Remarks: There is a large, strongly spinoise and relatively thin-walled species of *Globigerinoides* with a coarsely perforate test and high, arching primary aperture which appears to range from Core 6, Section 4 to Core 3, Section 1. It is generally subquadrate and has three globular chambers in the last whorl. The morphology matches that of *G. rubra* (d'Orbigny) *seigliei* Bermúdez and Bolli was originally described from the "upper Miocene" Cubagua Formation, Cerro Negro Member, and whose occurrence was said to be restricted to the *Globoquadrina altispira altispira* Zone. This zone is probably of early Pliocene age (see Berggren and Van Couvering, 1974). Associated with this morphology are forms with 4 to 5 chambers in the last whorl and in which the supplementary apertures on the spiral side often coalesce to form a large, extended opening along the spiral suture. As such, the morphology is virtually identical with the form described as *Globigerinoides kuehni* Schmid, 1967, from the "Upper Lagenid Zone" (= Zone N13) of the Vienna Basin, Austria.

These form(s) are particularly common in the upper Miocene in our Rio Grande Rise piston cores and a similar, lower Pliocene, extinction level has been ascertained there. Both types are included here under *G. seigliei* pending additional studies of the taxonomy and morphology of the group.

Sphaeroidinellopsis seminulina (Schwager), 1866
(Plate 1, Figure 19, 20)

Remarks: Large, robust 5-7 chambered forms are common elements at Site 357, particularly in the upper Miocene-lower Pliocene. The taxon extends up to the unconformity between Cores 1 and 2 within Zone PL3.

Sphaeroidinellopsis subdehiscens Blow
(Plate 1, Figure 21)

Remarks: The initial appearance of this taxon at the base of Core 5 indicates the presence of Zone N13.

Sphaeroidinella dehiscens immatura (Cushman), 1919
(Plate 2, Figures 1, 2)

Remarks: Individuals exhibiting a minute supplementary aperture on the spiral side appear in Core 3, Section 5 and range as high as Core 2, Section 4 (at least).

Sphaeroidinella dehiscens excavata Banner and Blow, 1965
(Plate 2, Figure 3)

Remarks: This is the guide form for Zone N23 (Blow, 1969). It occurs as low as Core 1, Section 4 at least, which suggests that Core 1

is predominantly late Pleistocene (i.e., within the Brunhes Epoch) in age. In Figure 1 this taxon is included under *S. dehiscens* s.s.

Globoquadrina dehiscens (Chapman, Parr, and Collins), 1934
(Plate 2, Figures 4-6)

Remarks: This is the dominant taxon in the upper Miocene of the Rio Grande Rise. Its abrupt extinction which is approximately concordant with the initial appearance of *Globorotalia margaritae*, serves to determine the stratigraphic position of the Miocene/Pliocene boundary. A similar stratigraphic range has been found by Saito et al. (1975) in the Pacific Ocean. We have not observed indigenous populations of *G. dehiscens* in the Pliocene (cf. Srnivasan and Srivastava, 1975; Kennett and Srnivasan, 1975, who record the extinction of *G. dehiscens* together with *G. altispira* at the top of Zone N19-20 in the Indian Ocean).

Globoquadrina altispira (Cushman and Jarvis), 1936
(Plate 2, Figures 7-9)

Remarks: This species occurs in the middle Miocene (Zones N11-14), is absent in the upper Miocene, and reappears in the lower Pliocene, slightly above the Miocene/Pliocene boundary. I have observed a similar stratigraphic distribution elsewhere in the Atlantic as well as in piston cores from the Rio Grande Rise. Its reappearance, just above the extinction of *Globoquadrina dehiscens* serves as a useful adjunct in determining the stratigraphic position of the Miocene/Pliocene boundary.

Globorotalia miozea Finlay, 1939
(Plate 3, Figures 1-8;
Plate 4, Figures 1-3)

Remarks: The stratigraphic sequence from Core 6, Section 4 to Core 2, Section 4 contains a group of keeled globorotaliids which may be designated, for convenience, the *Globorotalia miozea* group. Virtually flat to low-biconvex forms with predominantly 5-6 chambers are referred to *Globorotalia miozea* Finlay. This morphotype ranges from Core 6, Section 4 to Core 5, Section 3 with a questionable extension to Core 5, Section 2. It is the dominant keeled globorotaliid in the middle Miocene at Site 357 as it is in the two piston cores which penetrate middle Miocene on the Rio Grande Rise (Berggren, work in progress).

Low conical (biconvex) forms with predominantly 4-5 generally encrusted chambers appear in Core 6, Section 1 (i.e. within Zone N12) and are relatively common by Core 5, Section 5 (i.e. Zone N14). These forms are assigned to *G. conoidea* Walters and the origin here in the middle Miocene agrees well with that described from the Waiauan Stage of New Zealand by Walters (1965). Occurring together with typical *G. conoidea* are nonencrusted biconvex forms which exhibit intergradational morphology with that form. The nonencrusted forms appear to have been recorded as *G. miotumida* Jenkins by various investigators, but are included under the single name *G. conoidea* Walters.

An increase in the conical angle is seen in Core 5, Section 4 and high conical, lobulate forms with predominantly 4-1/2 to 5 chambers are referred to *Globorotalia conomiozea* Kennett. Both encrusted and nonencrusted morphologies are seen among these high conical forms. Relatively high conical forms with 5-1/2 to 6 chambers, a narrow umbilicus and weakly lobulate periphery, and oval-shaped outline appear in Core 5, Section 3 and are referred here to *Globorotalia mediterranea* Catalano and Sprovieri. Both morphologies were grouped by Zachariasse (1975) under the name *G. conomiozea* which was shown to be a distinct form in the uppermost Tortonian-basal Messinian (pre-evaporite phase) of the Mediterranean. These two morphologies are retained as distinct taxa here, primarily because a general reduction in chamber number from 5 to 4 to 4-1/2 is seen in the high conical *G. conomiozea* morphotype near the Miocene/Pliocene boundary (together with *G. conoidea*), whereas the typical *mediterranea* morphotype appears to have its upper stratigraphic limit only slightly above the Miocene/Pliocene boundary (i.e. within Zone PL1a) which agrees well with observations on our piston cores from the Rio Grande Rise. *G. conomiozea* and *G. conoidea* have their upper stratigraphic limit in Core 2, Section 4 (i.e. near the PL2/3 boundary). In actual fact, examination of piston cores from the Rio Grande Rise suggests that these two taxa became extinct within Zone PL3 at about 3.2 m.y. only slightly subsequent to the extinction of *G. margaritae*.

Globorotalia conoidea Walters, 1965
(Plate 3, Figures 9-21)

Remarks: See under *G. miozea* above.

Globorotalia conomiozea Kennett, 1966
(Plate 4, Figures 4-12; Plate 5, Figures 1-4)

Remarks: See under *G. miozea* above.

Globorotalia mediterranea Catalano and Sprovieri, 1969
(Plate 4, Figures 14-18; Plate 5, Figures 5-8)

Remarks: See under *G. miozea* above.

Globorotalia foshi Lineage
(Plate 5, Figures 9-16)

Remarks: Elements of the *Globorotalia foshi* lineage occur over the stratigraphic interval of 6/4-5/5 and aid in the recognition of Zones N11-13. Partially (*G. praefoshi*) and fully (*G. foshi*) keeled specimens were observed in Core 6, Section 1 indicating the presence of Zone N12. *G. peripheroronda* is the dominant smaller, nonkeeled globorotaliid in the middle Miocene of Site 357, although it is difficult, in some instances, to consistently separate if from *G. lenguaensis*. This was done primarily on the basis of the more circular test and low-conical umbilical side in *G. lenguaensis*.

Globorotalia praemenardii Cushman and Stainforth, 1945
(Plate 5, Figure 17)

Remarks: This species is commonly associated with *G. miozea* in the lower Miocene interval bounded by two unconformities between Core 6, Section 5 and Core 5, Section 4.

Globorotalia scitula (Brady), 1882
(Plate 5, Figures 18-20)

Remarks: Although the typical, modern form seems to appear near the Miocene/Pliocene boundary in our piston cores from the Rio Grande Rise, several individuals apparently referable to this taxon were observed over the interval Core 4, Section 5 to Core 4, Section 4. Representative specimens from this upper Miocene interval are illustrated here.

Globorotalia lenguaensis Bolli, 1957
(Plate 6, Figures 1-3)

Remarks: This taxon occurs commonly in the middle Miocene at Site 357 together with *G. peripheroronda* from which it is, at times, difficult to distinguish. Forms which range through the upper part of Core 5 and occur sporadically in Core 4 (i.e., to the top of the Miocene) are referred to this taxon as "aff." They are generally more elongate than typical forms of this taxon.

Globorotalia siakensis LeRoy, 1939
(Plate 6, Figures 14-17)

Remarks: See under *G. mayeri* below.

Globorotalia mayeri Cushman and Ellisor, 1939
(Plate 6, Figures 18-23)

Remarks: This taxon may be distinguished from the morphologically similar and stratigraphically associated (*G. siakensis* by the curved intercameral sutures on its spiral side (*G. siakensis* possesses dominantly straight radial sutures on its spiral side). Both forms apparently terminate their stratigraphic range in Core 5, Section 5, although doubtful occurrences are recorded in Core 5, Section 4 also.

Neogloboquadrina continuosa (Blow), 1959
(Plate 7, Figures 1-4)

Remarks: This taxon ranges over the interval of Core 5, Section 4 to Core 5, Section 3 is associated with *N. acostaensis* in Core 5, Section 3.

Neogloboquadrina acostaensis (Blow), 1959
(Plate 7, Figure 5-9)

Remarks: Rare specimens of this taxon occur in Core 5, Section 3; Core 5, Section 2; and questionably in Core 5, Section 1. It then reappears briefly in Core 3, Section 4 (lower Pliocene). This form is known to be rare in mid-low latitude upper Miocene sediments of the Atlantic. It is, however, a common component of the Tortonian of the Mediterranean region as well as equivalent levels in the "Atlantic fauna" of Andalusia, Spain (Tjalsma, 1971; Berggren and Haq, 1976). It is not possible to determine, with certainty, whether the

stratigraphic occurrence in Core 5, Section 2 to Core 5, Section 3 signifies Zone N16 or a younger level, equivalent to Zone N17. The occurrence of *N. continuosa* in Core 5, Section 4 to Core 5, Section 3 suggests an N15/N16 boundary (i.e., near base of Tortonian) between these two sections. However, the co-occurrence of *Globorotalia conomiozea* and *G. mediterranea* at these levels suggests a younger age (i.e., near top of Tortonian).

Globorotalia cibaoensis Bermúdez, 1949
(Plate 7, Figures 10-16)

Remarks: This form is distinguished by its smooth-walled, four-chambered test, with low, slit-like aperture, narrow umbilicus, ovate peripheral profile and low-conical to subquadrate profile in edge view. It is difficult to reconcile the disparate stratigraphic range recorded by Blow (1969; within N15-within N19) and that given by Parker (1973), Kennett (1973), and Kennett and Srnivasan (1975) who record it from latest Miocene-early Pliocene levels. The specimens referred here to *G. cibaoensis* agree well with those illustrated by these latter authors and the taxon has been seen to appear suddenly here at Site 357 Core 3, Section 6 and in our piston cores from the Rio Grande Rise in uppermost Miocene levels, where it overlaps the terminal part of the range of *Globoquadrina dehiscens.*

The taxon may be the ancestor of *G. margaritae.* I believe it is also the ancestor of *Globorotalia puncticulata* (Deshayes) within the early Pliocene.

Globorotalia margaritae Bolli and Bermúdez, 1965
(Plate 7, Figures 17-20)

Remarks: Forms referable to *G. margaritae* s.s. and *G. margaritae primitiva* Cita appear together in Core 3, Section 5. Our recent studies on the Rio Grande Rise have corroborated the demonstration by Saito et al. (1975) that *G. margaritae* makes its initial appearance within the middle of Epoch 5 (ca. 5.6 m.y.) and overlaps the uppermost part of the stratigraphic range of *Globoquadrina dehiscens.* However, we have not discerned this overlap at Site 357. This may be due to inadequate sampling or it may suggest a small hiatus in the vicinity of the Miocene/Pliocene boundary.

Globorotalia puncticulata (Deshayes), 1832
(Plate 8, Figures 1-13)

Remarks: The origin of *G. puncticulata* is being currently studied in connection with our examination of piston cores from the Rio Grande Rise. Stated briefly it appears that the compressed slightly rounded *G. cibaoensis* undergoes the following phylogenetic changes over a relatively brief time-stratigraphic interval: (1) increase in test size, (2) inflation of the chambers resulting in a more rounded axial profile, (3) development of an arched aperture. This sequence, seen in several of our Rio Grande Rise piston cores, occurs here at Site 357 between Core 3, Section 5 and Core 3, Section 3. The earliest forms in which the compressed chambers are replaced by globular, inflated chambers still retain the narrow, slit-like aperture (Core 3, Section 3) and these are referred to *Globorotalia puncticulata* s.l. The typical *G. puncticulata* with high, arched aperture appears somewhat higher (Core 2, Section 4) in Zone PL1c, at the same level in which (primitive) *G. crassaformis* s.l. makes its initial appearance.

Globorotalia inflata (d'Orbigny), 1839
(Plate 8, Figures 14-16)

Remarks: The initial occurrence of this taxon occurs in Core 2, Section 3 within Zone PL3 at the same level that *G. crassula* makes its initial appearance. It is associated with *G. puncticulata* from which it probably is descended and rapidly becomes a dominant element of the planktonic fauna, particularly in the Pleistocene (Core 1).

Gloroborotalia crassaformis (Galloway and Wissler), 1927
(Plate 8, Figures 17-23; Plate 9, Figures 1-4)

Remarks: The ancestry of *Globorotalia crassaformis* remains the subject of controversy and is being considered as part of a separate study on Rio Grande Rise piston cores (Berggren, in preparation). Basically, I believe that (primitive) forms referable to *G. crassaformis* evolve from *G. puncticulata* s.l. in the early Pliocene. These forms resemble the rounded, involute forms generally ascribed to *G. crassaformis ronda* Blow. The level of this appearance is only slightly prior to the extinction of *Globigerina nepenthes* (3.7 m.y.). At a level only slightly prior to the extinction of *Globorotalia margaritae* (3.3 m.y.), the more typical, anguloconical *G. crassaformis* s.s. develops. In some forms intraumbilical extensions of the apertural lips occur and give the test a superficial resemblance to *Globoquadrina dehiscens.*

At Site 357 *G. crassaformis* s.l. appears in Core 2, Section 6, *G. crassaformis* in Core 2, Section 4. A significant phylogenetic trend towards size increase is seen between Pliocene and Pleistocene population in *G. crassaformis* as well as a tendency to develop a quadrate, rather than elongate, rectangular, outline.

Globorotalia crassula Cushman and Stewart, 1930
(Plate 9, Figures 5-10)

Remarks: Specimens referable to this taxon are distinguished by having a low anguloconical test with a sharply keeled peripheral margin. They appear in Core 2, Section 3 and range as high as 1/4 (i.e. late Pleistocene). The only noticeable difference between Pliocene and Pleistocene individuals is the distinctly large size of the younger forms. The general resemblance to the terminal forms of *G. conomiozea* (four-chambered, showing a tendency towards reduction in height of spire) suggests a possible phylogenetic relationship.

Globorotalia limbata (Fornasini), 1902
(Plate 9, Figures 11-16)

Remarks: This form is considered a senior synonym of *Globorotalia pseudomiocenica* Bolli (cf. Blow, 1969; Parker, 1973). Circular and elongate-oval morphotypes are shown here. The form is relatively common in the upper Miocene at Site 357.

Globorotalia miocenica Palmer, 1945
(Plate 9, Figures 17-19)

Remarks: This taxon appears over the interval of the lower half of Core 2 (Zones PL1c-PL2). Large, multicamerate forms with a slight biconvexity are, in some instances, difficult to separate from the associated *G. multicamerata.* The different spiral suture pattern is usually sufficient, however, to distinguish between the two.

Globorotalia multicamerata Cushman and Jarvis, 1930
(Plate 9, Figures 20, 21)

Remarks: This taxon appears in Core 2, Section 6 and ranges up to the unconformity separating Cores 1 and 2 (within Zone PL3).

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PLATE 1

Figure 1   *Globigerina druryi* Akers.
6-4, 100 cm; ×175.

Figures 2, 3   *Globigerina nepenthes* Todd. Exhibits a significant increase in size during its stratigraphic range (compare Figures 2 and 3). The large, thumblike final chamber is characteristic of early Pliocene forms.
2. 5-5, 100 cm; ×140.
3. 3-2, 100 cm; ×100.

Figures 4, 5   *Globigerina pseudopachyderma* Cita, Premoli-Silva, and Rossi.
5-3, 100 cm.
4. ×175.
5. ×200.

Figures 6-8   *Globigerina pseudobesa* Salvatorini.
6. 6-3, 100 cm; ×55.
7, 8. 4-4, 100 cm; ×50.

Figures 9. 10   *Globigerinoides subquadratus* Bronnimann.
6-2, 100 cm.
9. ×100.
10. ×112.

Figures 11, 12   *Globigerinoides conglobatus* Brady).
11. 3-5, 100 cm; ×80.
12. 3-2, 100 cm; ×75.

Figures 13-18   *Globigerinoides seigliei* Bolli. Characterized by its large size, high, arching primary aperture which, in some instances extends to the spiral side (Figures 14, 15), and large, multiple supplementary apertures on the spiral side. Pliocene forms (Figures 17, 18) are generally larger and higher spired.
13, 14. 4-4, 100 cm; ×55.
15. 4-3, 100 cm; ×60.
16. 4-1, 100 cm; ×60.
17,18. 3-2, 100 cm.
17. ×65.
18. ×60.

Figures 19, 20   *Sphaeroidinellopsis seminulina* (Schwager).
4-4, 100 cm; ×55.

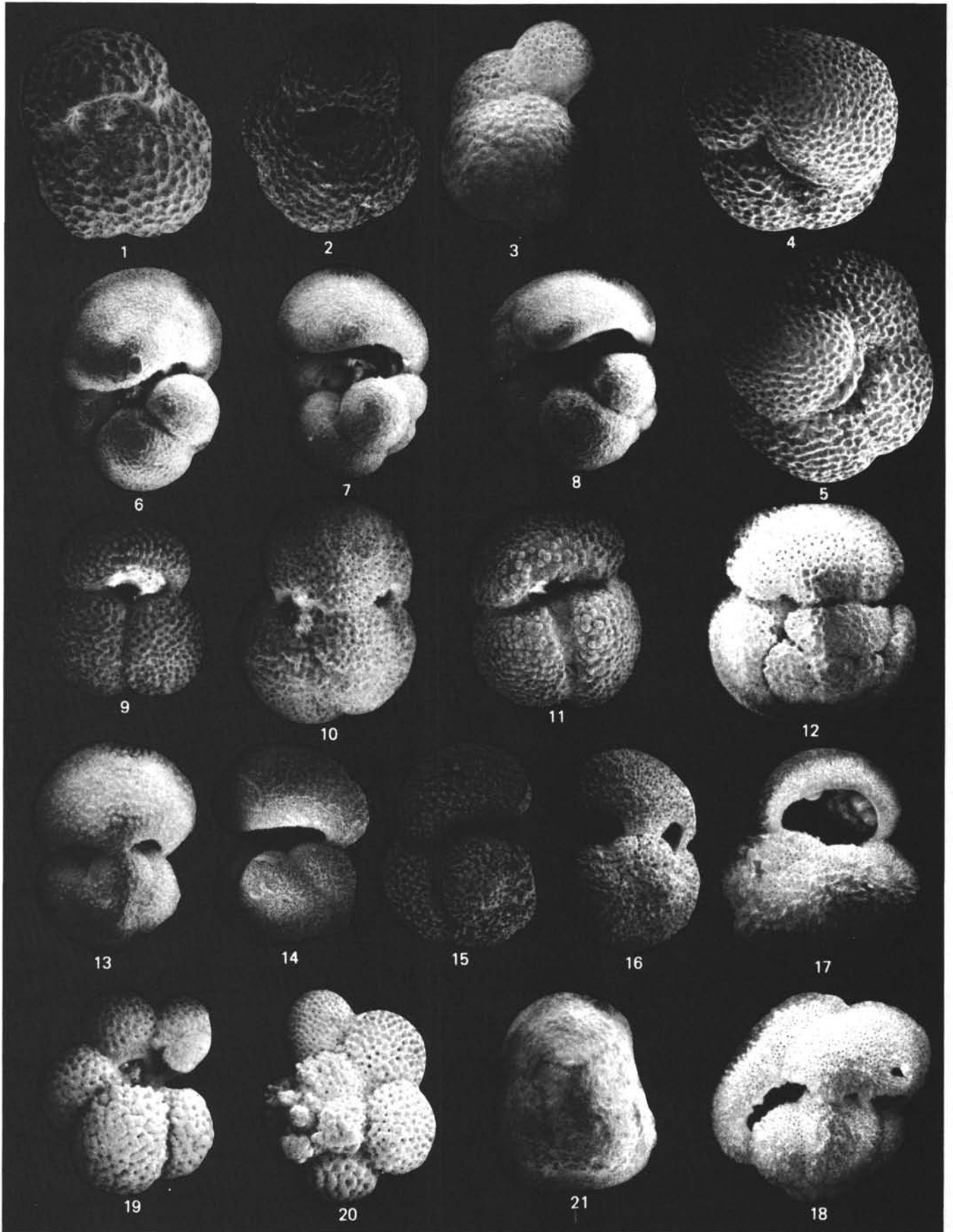Figure 21   *Sphaeroidinellopsis subdehiscens* Blow.
3-5, 100 cm; ×125.

PLATE 1

PLATE 2

Figures 1, 2   *Sphaeroidinella dehiscens immatura* (Cushman).
2-4, 100 cm.
1. ×115.
2. ×2000.

Figure 3   *Sphaeroidinella dehiscens excavata* Blow.
1-4, 100 cm; ×65.

Figures 4-6   *Globoquadrina dehiscens* (Chapman, Parr, and Collins).
4. 5-6, 100 cm; ×100.
5. 4-4, 100 cm; ×80.
6. 4-1, 100 cm; ×115.

Figures 7-9   *Globoquadrina altispira* Cushman.
7, 9. 2-3, 100 cm; ×75.
8. 3-5, 100 cm; ×100.

PLATE 3

Figures 1-8   *Globorotalia miozea* Finlay. Characterized by its low-conical test and 5-6 chambers in the last whorl. Figure 3 exhibits a morphology transitional to *G. conoidea* Walters. Figures 4 and 5 are encrusted, 6 and 7 unencrusted individuals.
1. 6-1, 100 cm; ×45.
2. 6-1, 100 cm; ×65.
3. 6-1, 100 cm; ×70.
4. 5-5, 100 cm; ×75.
5. 5-5, 100 cm; ×75.
6. 5-5, 100 cm; ×75.
7. 5-5, 100 cm; ×80.
8. 5-4, 100 cm; ×70.

Figures 9-21   *Globorotalia conoidea* Walters.
All specimens from 5-4, 100 cm. Characterized by its low to moderately high anguloconical test. Smooth and encrusted morphologies, which are a function of preservation, have often led to a variety of species names. Compare the smooth (9, 10) and encrusted (11, 12) morphology of the umbilical and spiral view. Encrustation leads to an obliteration of the sutures (11-13, 17, 19, 21), thickening (19) or burial (21) of the keel, and obliteration of pores (11-13, 17, 19, 21).
9, 10. ×100.
11, 18. ×75.
12, 13, 16, 17, 21. ×80.
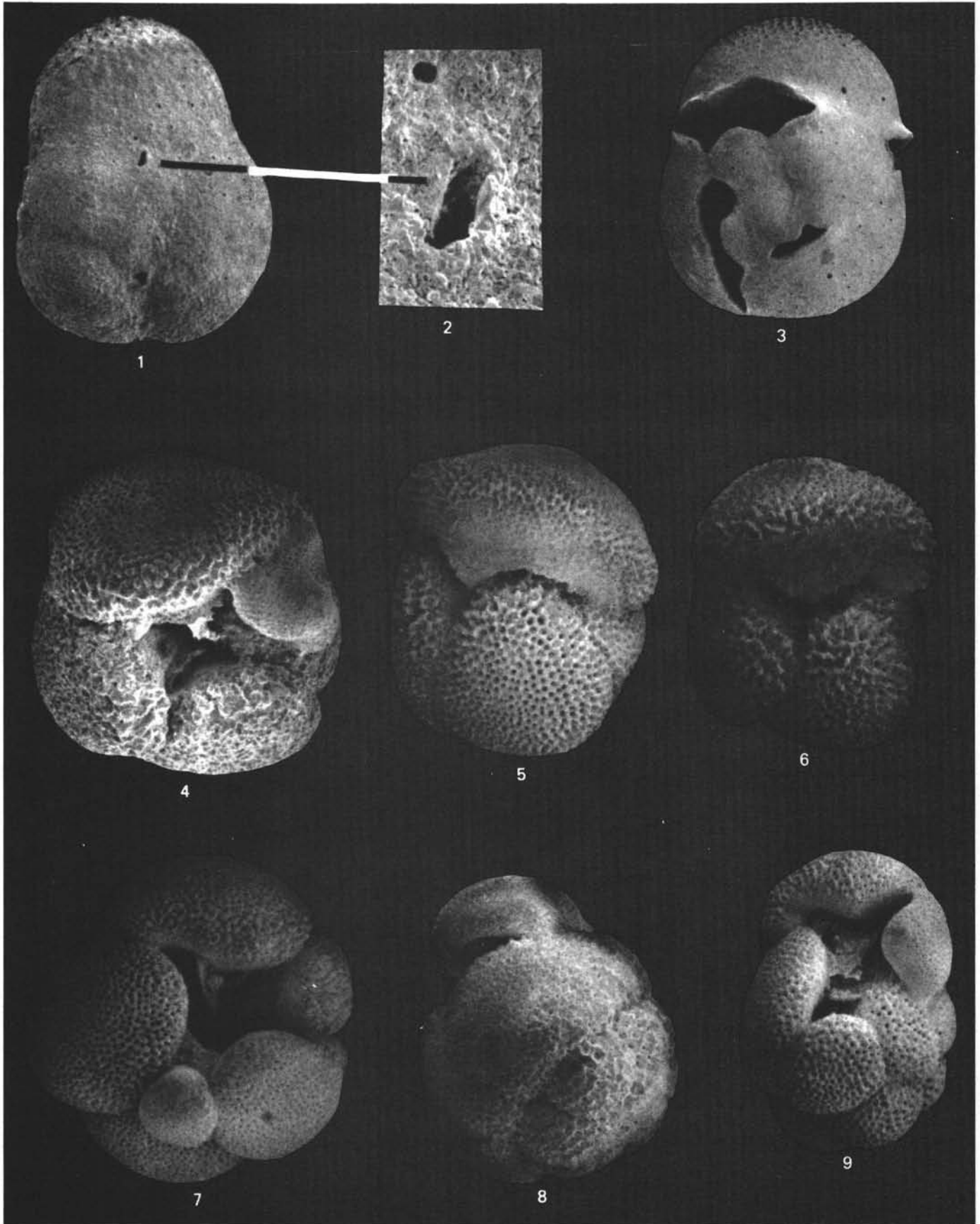14. ×125.
15. ×60.
19. ×55.
20. ×90.

PLATE 2

PLATE 3

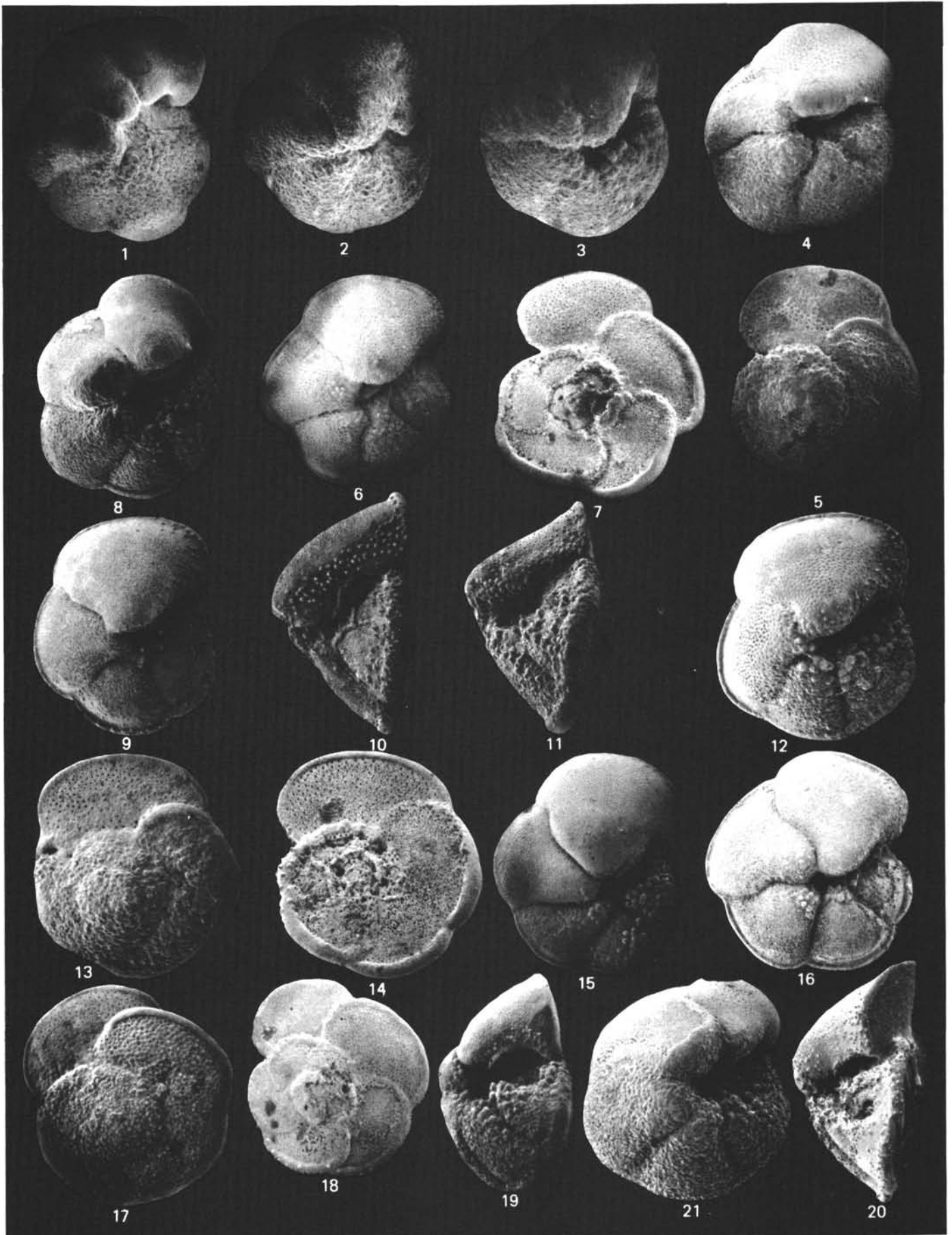## PLATE 4

Figures 1-3   *Globorotalia miozea* Finlay.
All specimens from 5-2, 100 cm; ×60.

Figures 4-12   *Globorotalia conomiozea* Kennett.
4. 4-1, 100 cm.
5- 9. 5-1, 100 cm.
10. 4-1, 100 cm; ×60.
11, 12. 2-4, 100 cm.
4, 5, 7, 8. ×75.
6. ×100.
9. ×87.
11. ×60.
12. ×50.

Figure 13   *Globorotalia* sp. specimen *ex interc G. miozea-G. mediterranea.*
5-2, 100 cm; ×60.

Figures 14-18   *Globorotalia mediterranea* Catalano and Sprovieri.
14. 5-4, 100 cm; ×60.
15- 17. 4-4, 100 cm.
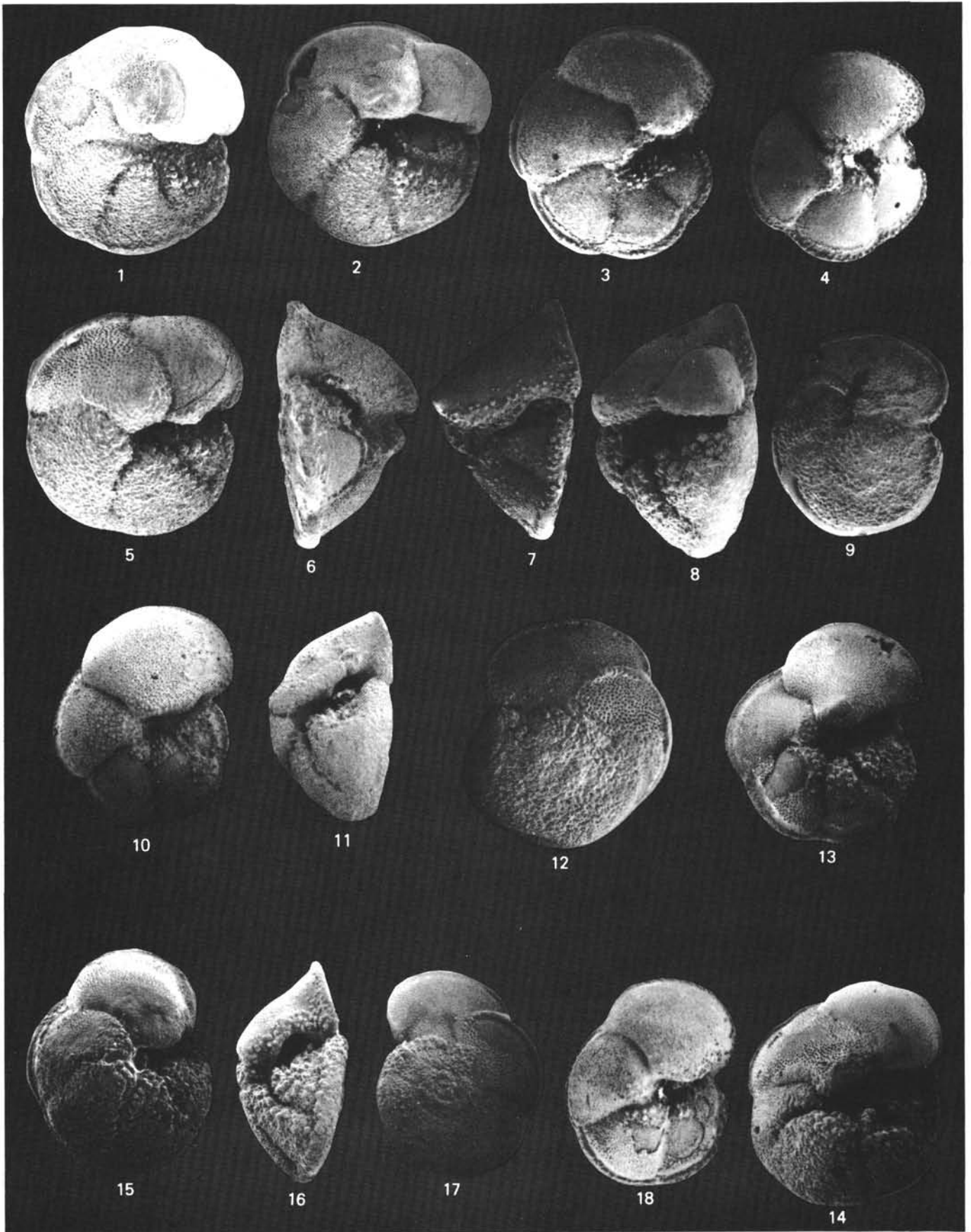15. ×60.
16. ×55.
17. ×50.
18. 4-1, 100 cm; ×70.

PLATE 4

PLATE 5

Figures 1-4   *Globorotalia conomiozea* Kennett. Unencrusted (1, 2) and encrusted (3, 4) individuals of *G. conomiozea* from a lower Pliocene level.
   1-4. 3-2, 100 cm.
   1. ×100.
   2. ×75.
   3, 4. ×90.

Figures 5-8   *Globorotalia mediterranea* Catalano and Sprovieri.
   5, 6. 4-1, 100 cm; ×60.
   7, 8. 3-6, 100 cm.
   7. ×63.
   8. ×50.

Figures 9-14   *Globorotalia peripheroronda* Blow and Banner.
   9-11. 6-4, 100 cm; ×150.
   12-14. 6-3, 100 cm.
   12. ×125.
   13, 14. ×150.

Figures 15, 16   *Globorotalia fohsi* Cushman and Ellisor
   6-1, 100 cm.
   15. ×150.
   16. ×125.

Figure 17   *Globorotalia praemenardii* Cushman and Stainforth.
   6-3, 100 cm. ×60.

Figures 18-20   *Globorotalia scitula* (Brady).
   18. 4-5, 100 cm; ×100.
   19, 20. 4-4, 100 cm.
   19. ×100.
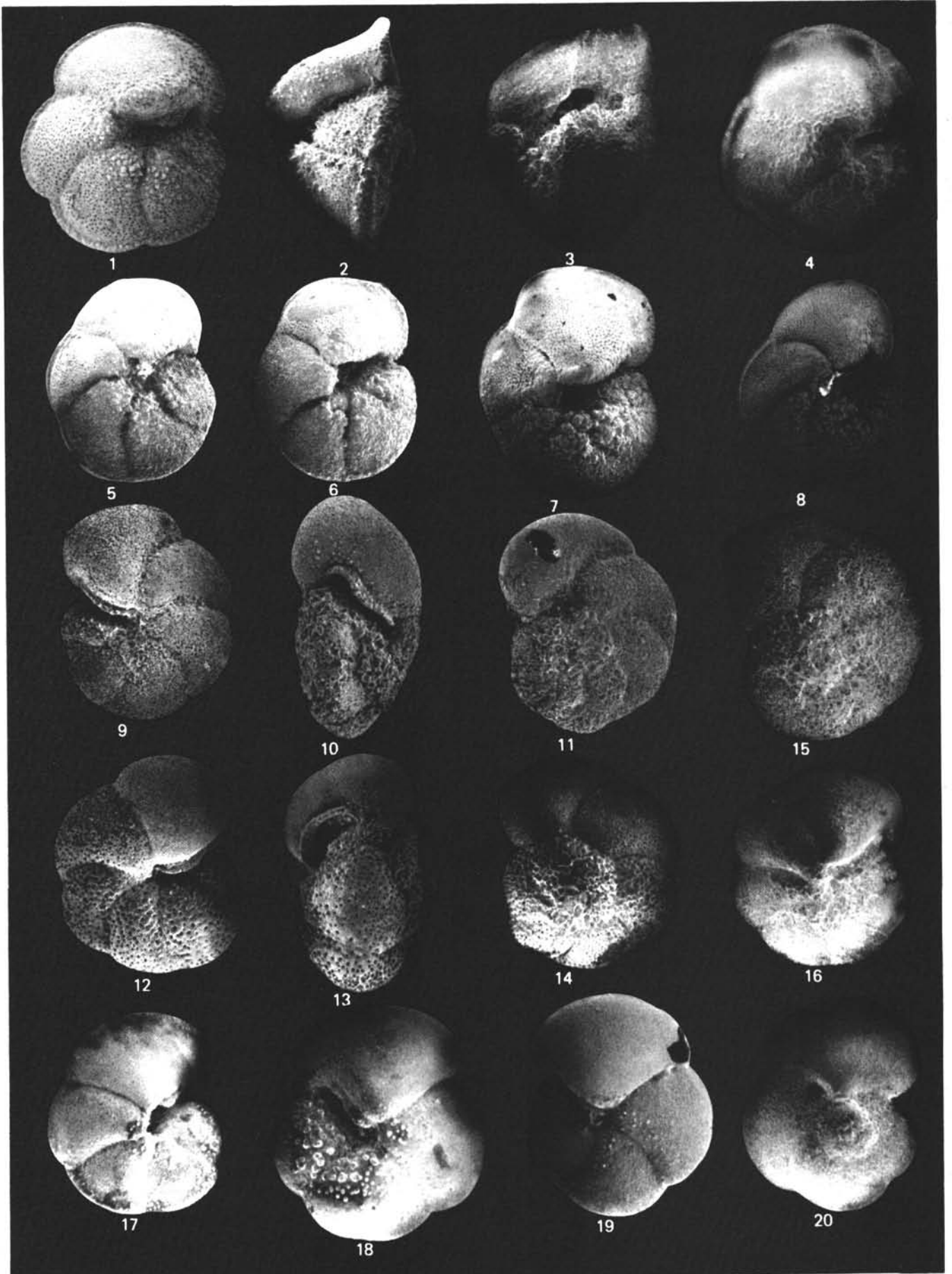   20. ×135.

PLATE 5

PLATE 6

Figures 1-3   *Globorotalia lenguaensis* Bolli.
                         1-3. 5-5, 100 cm. ×125.

Figures 4-13   *Globorotalia* sp. *aff. G. lenguaensis* Bolli.
                         4-6, 13. 4-5, 100 cm.
                         4. ×150.
                         5. ×175.
                         6. ×185.
                         13. ×165.
                         7-9. 4-2, 100 cm.
                         7. ×112.
                         8, 9. ×150.
                         10-12. 5-3, 100 cm.
                         10. ×175.
                         11, 12. ×150.

Figures 14-17   *Globorotalia siakensis* LeRoy.
                         14, 15. 6-4, 100 cm; ×125.
                         16, 17. 5-5, 100 cm; ×165.

Figures 18-23   *Globorotalia mayeri* Cushman and Ellisor.
                         18, 19. 6-1, 100 cm; ×125.
                         20, 21. 5-5, 100 cm.
                         20. ×175.
                         21. ×150.
                         22. 6-2, 100 cm; ×125.
                         23. 6-3, 100 cm; ×150.

PLATE 6

PLATE 7

Figures 1-4   *Neogloboquadrina continuosa* (Blow).
1-3. 5-4, 100 cm.
1. ×200.
2. ×150.
3. ×165.
4. 5-3, 100 cm; ×130.

Figures 5-9   *Neogloboquadrina acostaensis* (Blow).
5-7. 5-4, 100 cm.
5. ×150.
6. ×135.
7. ×112.
8. 5-3, 100 cm; ×175.
9. 3-4, 100 cm; ×150.

Figures 10-16   *Globorotalia cibaoensis* Bermúdez.
10-12. 3-6, 100 cm.
10. ×150.
11. ×160.
12. ×135.
13. 3-5, 100 cm; ×100.
14-16. 3-4, 100 cm.
14, 15. ×100.
16. ×112.

Figures 17-20   *Globorotalia margaritae* Bolli.
17. 3-4, 100 cm. ×70.
18-21. 3-5, 100 cm.
18. ×85.
19. ×90.
20. ×80.

PLATE 7

PLATE 8

Figures 1-10   *Globorotalia puncticulata* (Deshayes) s.l. The early
forms of *Globorotalia puncticulata* are character-
ized by a subangular to subrounded periphery (in
edge view) and a low narrow apertural arch in
contrast to the flaring arch of typical forms
(Figure 12).
1-3. 3-3, 100 cm.
1. ×100.
2, 3. ×125.
4-6. 3-2, 100 cm.
4, 5. 100.
6. ×112.
7-10. 3-1, 100 cm.
7, 8. ×100.
9. ×112.
10. ×130.

Figures 11-13   *Globorotalia puncticulata* Deshayes.
2-3, 100 cm; ×65.

Figures 14-16   *Globorotalia inflata* (d'Orbigny).
2-3, 100 cm. ×70.

Figures 17-23   *Globorotalia crassaformis* Galloway and Wissler.
Early forms of this species (Figures 17-19) are
characterized by a subquadrate test. Typical forms
are characterized by incised sutures (Figures 20,
21) and, in some individuals, by umbilical teeth
(Figure 21). Encrustation (Figure 22) obscures the
surface morphology and results in a general
appearance similar to *G. puncticulata*.
17-19. 2-6, 100 cm.
17, 18. ×100.
19. ×80.
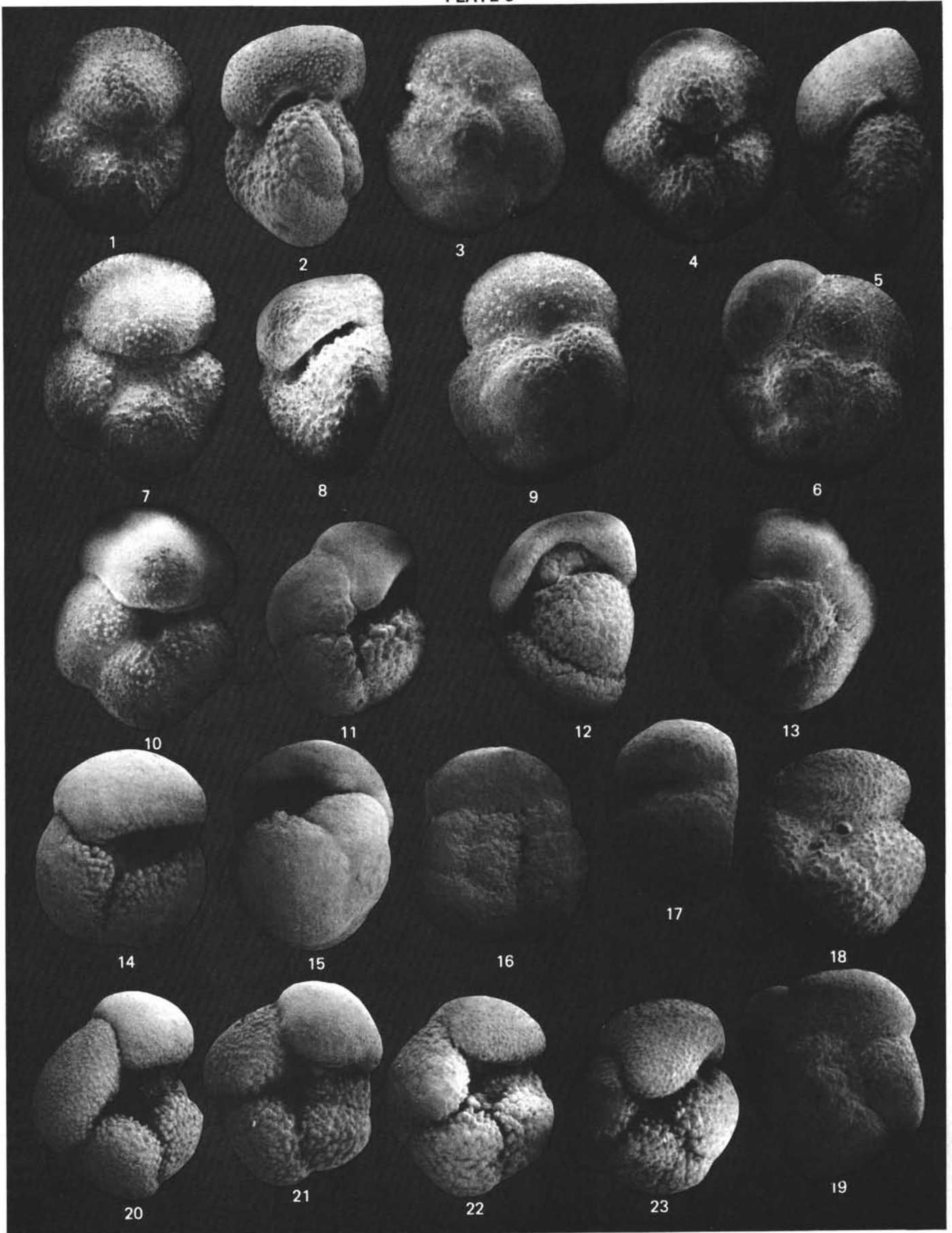20, 21. 2-3, 100 cm.
20. ×60.
21. ×80.
22, 12. 1-5, 100 cm.
22. ×60.
23. ×75.

PLATE 8

PLATE 9

Figures 1-4   *Globorotalia crassaformis* Galloway and Wissler.
1-4, 100 cm.
1, 2. ×60.
3. ×50.
4. ×65.

Figures 11-16   *Globorotalia limbata* (Fornasini). Elongate-oval (Figures 1-4) and subcircular (Figures 5, 6) forms are illustrated here. The species is characterized by strongly curved sutures on spiral side.
11-13. 3-6, 100 cm.
11. ×60.
12, 13. ×75.
14, 15. 4-4, 100 cm; ×55.
16. 6-1, 100 cm; ×75.

Figures 17-19   *Globorotalia miocenica* Palmer. Typical individuals are virtually flat on the spiral side. (cf. Figure 18).
2-3, 144 cm.
17. ×80.
18. ×83.
19. ×75.

Figures 20, 21   *Glooroxalia multicamerata* Cushman and Jarvis.
20. 2-3, 100 cm; ×45.
21. 2-1, 100 cm; ×50.

PLATE 9