

THE GENUS *GLOBIGERINATHEKA* BRÖNNIMANN

HANS M. BOLLI

Swiss Federal Institute of Technology, Zurich, Switzerland

ABSTRACT

Morphological characters, interrelations, evolutionary trends, synonymies, stratigraphic and paleogeographic distribution of 15 species here included in *Globigerinatheka* are discussed and illustrated by line drawings and SEM micrographs. In order to stress their interrelations, all taxa—with the exception of *G. semiinvoluta*—are given subspecific rank in a trinomial system. Holotypes and some additional types of the taxa discussed, which originally were published at widely varying magnifications, are reproduced at a uniform scale to facilitate

their comparison. By this procedure alone the four species *subconglobata*, *index*, *mexicana* and *semiinvoluta* become clearly distinct. The final chamber/bulla problem, of some importance in the genus, is discussed and illustrated. Evidence is given that *G. semiinvoluta* is a valid species, and not a synonym of *G. mexicana mexicana*. Its variability is demonstrated by a series of SEM micrographs. One subspecies, *G. subconglobata luterbacheri*, is described as new.

INTRODUCTION

The strict application to the systematic treatment of planktonic foraminifera of such morphologic characters as bullae or peripheral keels often results in artificial subdivisions, masking true relationships. As a consequence, certain closely related forms belonging to phylogenetic lineages became placed not only in different genera but in some cases even in different subfamilies. The non-bullate genus *Globigerapsis* and its bullate form the genus *Globigerinatheka*, for example, were originally included by Bolli, Loeblich and Tappan (1957) on the bulla criterion in the two subfamilies Orbulininae and Catapsydracinae respectively. The question now arises whether in cases of this kind a less rigorous system could be adopted in which both biologic and stratigraphic criteria might be combined in a more natural way. Such a middle-of-the-road approach would cut phylogenetic lineages less drastically into different higher taxa, while at the same time characteristic test changes that are also of stratigraphic significance could be maintained and be expressed at lower taxonomic levels. Such an approach would give more justice to the natural biologic

system without sacrificing the essential needs of the stratigrapher.

The biologist's view that opposes many of the taxa erected by micropaleontologists is propagated most strongly by Hofker. In his papers of 1959, 1962, and 1969, he places a large number of older and more recently erected planktonic foraminiferal genera in synonymy with *Globigerina*, claiming that they "have no taxonomic value in a natural system of foraminifera and thus must be abandoned." One group of taxa that come under attack not only by Hofker, but also by others such as Blow and Banner (1962), Cati and Borsetti (1968), and Quilty (1969) are those based on the presence of bullae. Criticism of some of the taxa is justified and a reduction in genera and species is desirable. Blow and Banner, for instance, place *Catapsydrax* and *Tinophodella* in *Globigerinita*, reasoning that maintaining these genera is unreal "insofar as distinctions between them are biologically, stratigraphically and taxonomically impractical and/or insignificant." However, rather than abolishing in globo all genera and species based on bullae, as proposed by some authors, one

should examine each taxon independently to determine whether biologic and stratigraphic criteria justify such a step.

Hofker (1962), for instance, places *Globigerinatheka mexicana*, *G. index*, *G. kugleri*, *G. barri* and *Porticulasphaera mexicana* (= *Orbulinoides beckmanni*) in synonymy with *Globigerina turgida*. Hofker's species concept is rejected because morphologically interrelated forms—particularly if they succeed each other in time—can represent different species or subspecies, each with a distinct range. In accepting Hofker's lumping of taxa so morphologically different as those cited above, one would no longer be able to make use of their individual and differing ranges for stratigraphic purposes. Naturally one could distinguish the morphologic differences of the above forms at the species or even subspecies level and include all in *Globigerina* without loss of biostratigraphic resolution. Some of the genera placed by Hofker in synonymy with *Globigerina*, such as *Globigerinoides*, *Globigerinatella*, *Globigerinatheka* and *Porticulasphaera* (= *Orbulinoides*) are, however, not only very characteristic morphologically but have also distinct and restricted stratigraphic ranges. They clearly represent cases where for both morphologic and biostratigraphic reasons the genera should be maintained.

Two closely related genera to be examined in the above sense are the Middle to Late Eocene *Globigerapsis* Bolli, Loeblich and Tappan (1957) and its bullate form *Globigerinatheka* Brönnimann (1952). In 1970 Proto Decima and Bolli included *Globigerapsis* in *Globigerinatheka*, whose definition was emended accordingly. Brönnimann, the author of *Globigerinatheka*, had in fact, figured a non-bullate paratype. All species described under these two genera are represented by non-bullate and bullate forms, with the percentage of the latter varying from 50% or more in *G. barri* to less than 1% in *G. semiinvoluta*. There remains little doubt, therefore, that the non-bullate and bullate forms previously separated in two genera are a biologic unit. Further, the stratigraphic range of the two genera is practically identical and there is thus no reason from this point of view to retain them both. On these grounds the single genus *Globigerinatheka* is now recognized and stages in its evolution may be separated at the species or subspecies level, as deemed appropriate.

The genus *Globigerinatheka*, ranging from the basal Middle Eocene into the Late Eocene, is of stratigraphic importance, some species having been used as zonal markers. Despite the distinct characters of the genus, widely differing interpretations of some of its species have led to confusions which in turn adversely affected

the true stratigraphic value of certain taxa. Morphological characteristics of the *Globigerinatheka* species and subspecies, their interrelations and their stratigraphic significance are discussed here with the help of line drawings and SEM micrographs. Particular attention is paid to *Globigerinatheka semiinvoluta*, a species with characteristic morphology and an index fossil for the early Late Eocene. Evidence is given that it is not synonymous with *G. mexicana* as postulated by some authors. To emphasize relationships and evolutionary trends between taxa a trinomial nomenclature is proposed for most *Globigerinatheka* species.

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to Drs. Franca Proto Decima, J. P. Beckmann, H. P. Luterbacher and R. M. Stainforth for constructive discussions and numerous suggestions for manuscript improvement. Dr. Beckmann also checked and compared a number of original types at the U.S. National Museum, Washington, D.C., and Dr. Luterbacher provided information on literature and Eocene stratigraphy in the USSR. Through the kind cooperation of Drs. Isabella Premoli-Silva, C. W. Drooger, and P. Marks, it was possible to locate Keijzer's original *Globigerinoides semiinvolutus* material in the collections of the Utrecht Geological Institute. Dr. F. Keijzer himself was helpful in providing information on the whereabouts and the way he had prepared his collection of *semiinvoluta* specimens; with Dr. W. H. Blow the author discussed questions concerning their nomenclatural status. The following persons have kindly provided specimens for comparison: Drs. N. N. Subbotina, D. M. Chalilov, H. Hagn, N. de B. Hornibrook, D. G. Jenkins, and H. P. Luterbacher (from collections received through V. A. Krasheninnikov). The Natural History Museum, Basel, made available the Eckert collection from which *Globigerinatheka subconglobata luterbacheri* n. subsp. was selected. Much use was made of the collections from the Possagno section prepared by Dr. Monique Toumarkine. A special word of thanks goes to Mrs. Marla Forristall who, with much patience, prepared most of the text figures and typed the manuscript. The SEM micrographs were taken by Mr. H. E. Franz; Mr. U. Gerber, photographer, helped in the preparation of the plates. This paper is part of a project on the study of Alpine/Mediterranean Paleogene microfossils, supported by the Swiss National Science Foundation. The author wishes to thank all these persons and institutions for their kind cooperation.

FINAL GLOBIGERINATHEKA CHAMBER AND BULLA

Bolli, Loeblich and Tappan (1957, p. 13), introduced the term bulla and defined it as "Accessory structures which in general are not closely related to the primary chambers, but are instead related only to the apertures." They distinguished four different types of bullae: umbilical, sutural, umbilical-sutural, and areal. Banner and Blow (1959, p. 5-6) re-defined a bulla as "a swollen perforate plate (bulla) or a bulla-like extension of the last chamber, and which opens to the exterior by accessory apertures at the margins of, or within the area of, the bulla." According to these authors a bulla can be similar in structure to the primary wall in *Catapsydrax* or be less coarsely perforated as in *Tinophodella*. Later, Blow and Banner (1962) included these two genera in *Globigerinita*.

None of these authors included size limits or characteristics of the wall in their definition of a bulla. Consequently, the last formed chamber of *Orbulina* could be regarded as an extremely large bulla. With no restrictive definition on wall structure and size, one could, therefore, also regard the final chamber of *Globigerinatheka*, covering the umbilical area of the globigerinitid stage as a large umbilical bulla (e.g. *G. semiinvoluta*) whose sutural apertures may be covered by secondary sutural bullae as in the case of *G. mexicana barri*.

Typical *Globigerinita*-type umbilical bullae are normally distinctly smaller in size compared with the prior last formed chamber and are placed over the umbilicus with no apparent relation to the coiling mode of the test (e.g. in *G. dissimilis*). In *Globigerinatheka*, on the other hand, the final chamber covering the umbilical area is normally larger than the penultimate and may also remain part of the general spiral arrangement. A good example for this is *G. semiinvoluta* (e.g. text figs. 72, 75).

There are other forms assigned to *Globigerinatheka*, however, particularly those belonging to the species *mexicana* and *index*, where the last chamber covering the umbilicus may vary considerably in size and shape, from larger than penultimate (text fig. 4) to smaller and more irregular shaped (text figs. 8, 10).

Also, the structure of a bulla may vary from thin walled with fine pores, clearly contrasting with earlier chambers, to thick and coarsely pored, like preceding chambers, the distinction between an umbilical bulla and a final chamber in the same position clearly rests on size alone. Normal usage has been to term the addition a "final chamber" if it is about the same or is larger

in size than the last previously formed element in the coil, but to call it an "umbilical bulla" if it is appreciably smaller. In most species this criterion is easily applicable, as in *G. dissimilis* with umbilical bulla always considerably smaller than preceding last chambers in contrast to *G. semiinvoluta* with its large, hemispherical final chambers. Nevertheless some difficulties may arise, as in the species *Globigerinita howei* Blow and Banner (1962, pl. 14, figs. Q, R) with its exceptionally large bulla.

Specimens are encountered among some species and subspecies assigned to *Globigerinatheka* which defy clear-cut assignment of the structure covering the umbilical area to either "bulla" or "chamber." In fact, the intraspecific variability may include every transition from small bulla-like addition to one distinctly larger than the preceding normal chamber, and its wall may vary from thin and finely perforate to thick with large pores. From these variabilities in the last-formed element stem most of the difficulties in distinguishing clearly between some of the established taxa. In the following paragraphs this point is discussed further with the aid of illustrations.

Such variabilities are demonstrated in some detail for *Globigerinatheka index tropicalis* on plate 3, and for *G. subconglobata luterbacheri* n. subsp. on plate 7. Plate 3, figs. 1-20 show the variability of the final structure in *G. index tropicalis*, from small finely perforated bullae to large coarsely perforated chambers. All figured specimens are from the same sample Bo 536, type locality of the Upper Eocene *Globigerinatheka semiinvoluta* Zone, Navet Formation, Trinidad, W.I. Specimens on plate 3, figs. 1-8, plate 4, fig. 7, possess thin-walled, finely perforated final structures covering the umbilical area. Those of figs. 1-5 are smaller than the last chamber and can be regarded as typical bullae and thus should be included in *Globigerinita*. The final structures of figs. 6-8 on the other hand are distinctly larger than the previous chamber, and the specimens therefore should be placed in *Globigerinatheka*.

The last formed bullae/chambers of the specimens on plate 3, figs. 9-14, plate 4, figs. 9-11 possess a wall structure that is intermediate between the thin walled finely perforated of figs. 1-8 and the thick, coarsely perforated of figs. 16-20. The size of the final element of figs. 9 and 10 is small bulla-like, that of figs. 11-14, large, chamber-sized. Accordingly, figs. 9 and 10 should be included in *Globigerinita*, figs. 11-14 in *Globigerinatheka*.

The final growth of specimens plate 3, figs. 16-20

is thick walled, coarsely perforate, like the earlier chambers, and in size equal to or larger than those. They are without hesitation regarded as final chambers and the specimens included in *Globigerinatheka*. Plate 3, fig. 15 shows a specimens where the final umbilical chamber is covered by small, delicately built bulla. It may be regarded as a bullate *Globigerinatheka index tropicalis*, which occurs rarely in the *Globigerinatheka semiinvoluta* Zone, but it is difficult to distinguish it from *G. mexicana barri* of the Middle Eocene.

Globigerinatheka subconglobata luterbacheri n. subsp. (plate 7, figs. 1–17) exhibits similar variabilities in the size of the end chamber. Specimens may possess large final chambers (figs. 3, 4, 7, 8), the apertures of which are often covered by bullae (figs. 12–17), whereas other specimens are characterized by a final chamber distinctly smaller than the penultimate and, as such, often difficult to distinguish from an umbilical bulla (figs. 5, 6, 9–11).

By adhering strictly to the existing definitions of a bulla, irrespective of size and wall structure, all species of *Globigerinatheka* hitherto included in *Globigerapsis* could, without emendation, be accommodated in *Globigerinita*. To include in *Globigerinita* also the *Globigerinatheka* forms with secondary sutural bullae (*barri* type), one could easily emend the genus accordingly. However, the size of the final growth in most species, structurally comparable with and often considerably larger in size than the previous chamber, as well as the stratigraphic restriction of such forms to the Middle Eocene and lower part of the Late Eocene, makes it preferable to retain such forms in *Globigerinatheka*, even though specimens with small end structures covering the umbilical area would fall in *Globigerinita*.

THE SPECIES INCLUDED IN *GLOBIGERINATHEKA*

The following species, listed in order of publication and with genus name given by the original author, are included here in *Globigerinatheka*:

- Globigerina mexicana* Cushman 1925
- Globigerinoides index* Finlay 1939
- Globigerinoides semiinvolutus* Keijzer 1945
- Globigerinoides korotkovi* Keller 1946
- Globigerinatheka barri* Brönnimann 1952
- Globigerinoides rubrifformis* Subbotina 1953
- Globigerinoides macrostoma* Hagn 1956
- Globigerapsis kugleri* Bolli, Loeblich and Tappan 1957

Globigerinoides subconglobatus var. *subconglobata* Shutsкая 1958

Globigerinoides subconglobatus var. *micra* Shutsкая 1958

Globigerapsis tropicalis Blow and Banner 1962

Globigerinatheka lindiensis Blow and Banner 1962

Globigerinatheka curryi Proto Decima and Bolli 1970

Globigerinatheka euganea Proto Decima and Bolli 1970

Globigerinatheka subconglobata luterbacheri n. subsp.

These published taxa are here retained with the following exceptions: *G. macrostoma* is placed in synonymy with *G. index index* and *G. lindiensis* is regarded as a bullate *G. index tropicalis*. The Eocene forms published by Glaessner (1937), Subbotina (1953, see also text figs. 65–68 in this paper), and Shutsкая (1958) as *Globigerinoides conglobatus* (Brady) are here included in *Globigerinatheka index s.l.*

COMPARISON OF MORPHOLOGY AND TEST SIZE OF *GLOBIGERINATHEKA* SPECIES

Magnifications of originally published figures of the species discussed here vary between $\times 25$ and $\times 174$. Such size difference can be misleading not only in the interpretation of a given species but particularly in interspecific comparison. To facilitate such comparisons, by showing size and morphology at the same magnification, all holotype and some paratype and hypotype figures of the species discussed here are reproduced as line drawings at approximately $\times 75$ on text figures 1–81.

This adjustment of magnification leads to the following conclusions where interrelations between species are concerned:

1. The uniformly small size of the *G. mexicana mexicana/kugleri/barri* group (text figs. 1–23) contrasts with the much larger *G. subconglobata curryi/euganea* (text figs. 27–42), representatives of which were published on several occasions as *G. mexicana* (text figs. 35–42).
2. *G. subconglobata micra* (text figs. 24–26) appears stratigraphically prior to *G. subconglobata subconglobata* (text figs. 43–46). It is similar to it in test shape, but distinctly smaller, measuring only about .35 mm. Following Shutsкая (1958) *G. subconglobata micra* is here regarded as the ancestral form of *G. subconglobata subconglobata*.

3. *G. subconglobata subconglobata* measuring between .5 mm and .6 mm (text figs. 43–46) fits, where test size and general shape are concerned, into the *curryi/euganea* lineage (text figs. 27–42) and is here regarded as its ancestral form.
4. The contrast in size and morphological characters such as shape of last chamber and apertures between the holotypes of *G. mexicana mexicana* (text figs. 1–6) and *G. semiinvoluta* (text figs. 72–76) shows that the two species are not synonymous.
5. Text figs. 51–71 show that *G. index index/tropicalis/korotkovi/macrostoma/rubriiformis* are closely related. Test shape, general arrangement of chambers and their growth patterns, including size of the end chamber in comparison with early part of the test, are about the same in all. Only *G. index rubriiformis* (text figs. 69–71) has an initial spire that is considerably higher compared with other subspecies. High arched apertures mostly surrounded by a distinct rim are typical for all subspecies of *G. index*. There is, however, a distinct variation in overall test size in the figured specimens varying from .35 mm in text fig. 60 to .59 mm in text fig. 65. Similar variations were observed in our material, for instance in *G. index tropicalis* from both Trinidad (plate 3, figs. 1–20) and Possagno (plate 3, figs. 21–24). The subspecies differences lie in wall thickness and sutures (*G. index index/tropicalis*) or in higher spire (*G. index rubriiformis*).

While adjusting published figures to a uniform magnification it was found that in two instances the stated magnification of the original figures was incorrect. Text figures 18–20 represent the original holotype figures of *G. mexicana barri* which, according to Brönnimann, were reproduced at $\times 75$, giving the specimen a size of .65 mm. Re-measurement of the holotype by Dr. J. P. Beckmann gave a value of .39 mm which agrees better with the dimensions given by Brönnimann. Text figure 35 represents a specimen of *G. subconglobata euganea* of which Cushman's figure, published as *Globigerina mexicana*, measures 4 cm at a given magnification of $\times 30$. This would imply the unlikely size of 1.33 mm for the specimen, but from illustrations of other species on the same plate it appears that the magnification should correctly read $\times 60$.

SPECIES INTERRELATIONS, PROPOSED TAXONOMY

The published record shows that different approaches exist in the identification of *Globigerinatheka* species, resulting in erroneous stratigraphic interpretations.

Species often overlap in their characters, making it difficult to assign morphologically intermediate specimens. Reason for this are intergrading characters such as growth rhythm of early spire (*G. mexicana mexicana/kugleri*), wall thickness and sutural intersections (*G. index index/tropicalis*), test size (*G. mexicana kugleri/G. subconglobata curryi*), varying size, shape and wall thickness of the final structure covering the umbilical area of the globigerinid stage (*G. index index/G. index tropicalis/G. subconglobata subconglobata*), often making it difficult to decide whether one is dealing with a chamber or a bulla. Even though central forms of individual subspecies are distinct, one may, based on intergrading specimens, question the justification for maintaining all as separate taxa. This is particularly true where no significant difference exists in stratigraphic ranges.

For a better indication of morphologically interrelated groups of taxa, the following trinomial system—except for *G. semiinvoluta*—is here proposed:

Globigerinatheka index index
tropicalis
korotkovi
rubriformis
mexicana mexicana
kugleri
barri
subconglobata subconglobata
micra
curryi
euganea
luterbacheri n. subsp.
semiinvoluta

The four species are morphologically distinct, *index* by its elongate species shape and apertures usually not covered by bullae, *mexicana* by its small size, more or less globular test and frequent presence of bullae, *subconglobata* by its large (except the ancestral *subconglobata micra*) globular test size, robust walls and occasional presence of bullae, and *semiinvoluta* by its large, regularly dome shaped final chamber, making up half or more of the test volume, and high, arched to circular apertures.

The *subconglobata* lineage led to more elaborate forms with a more embracing final chamber, more complex system of multiple sutural apertures, and secondary thickening of the wall. These are assigned to the monospecific genus *Orbulinoides* Cordey (1968) whose relationships with *Globigerinatheka* are discussed and illustrated in detail by Proto Decima and Bolli (1970).

EVOLUTIONARY TRENDS

Globigerinatheka subconglobata subconglobata is regarded as the central form, developing according to Shutsкая (1958) in the uppermost part of the Tcherkess Horizon (*Hantkenina aragonensis* Zone) from the ancestral small sized *G. subconglobata micra*. From observations in the Possagno section, the *G. mexicana* group of subspecies, *mexicana*, *barri* and *kugleri* in that

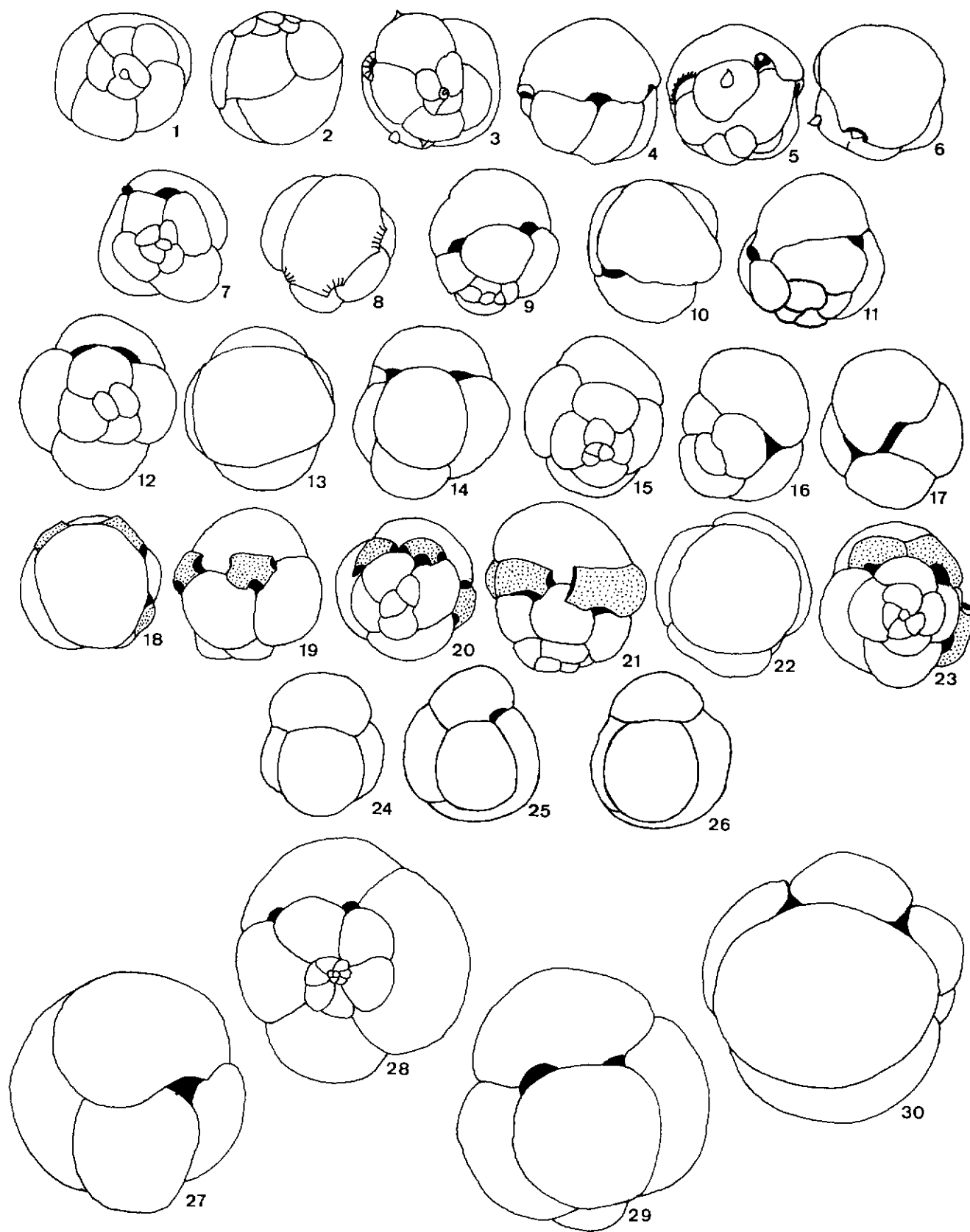
order, branched off from *G. subconglobata micra* near the base of the *Globigerinatheka subconglobata subconglobata* Zone. In the lower part of the same zone also sets in the evolution from *G. subconglobata* of the *G. index* subspecies with *rubrifformis*, followed by *index* in the upper part of the *Globigerinatheka subconglobata subconglobata* Zone which in turn gave rise to *tropicalis* close to the top of the *Truncorotaloides rohri* Zone.

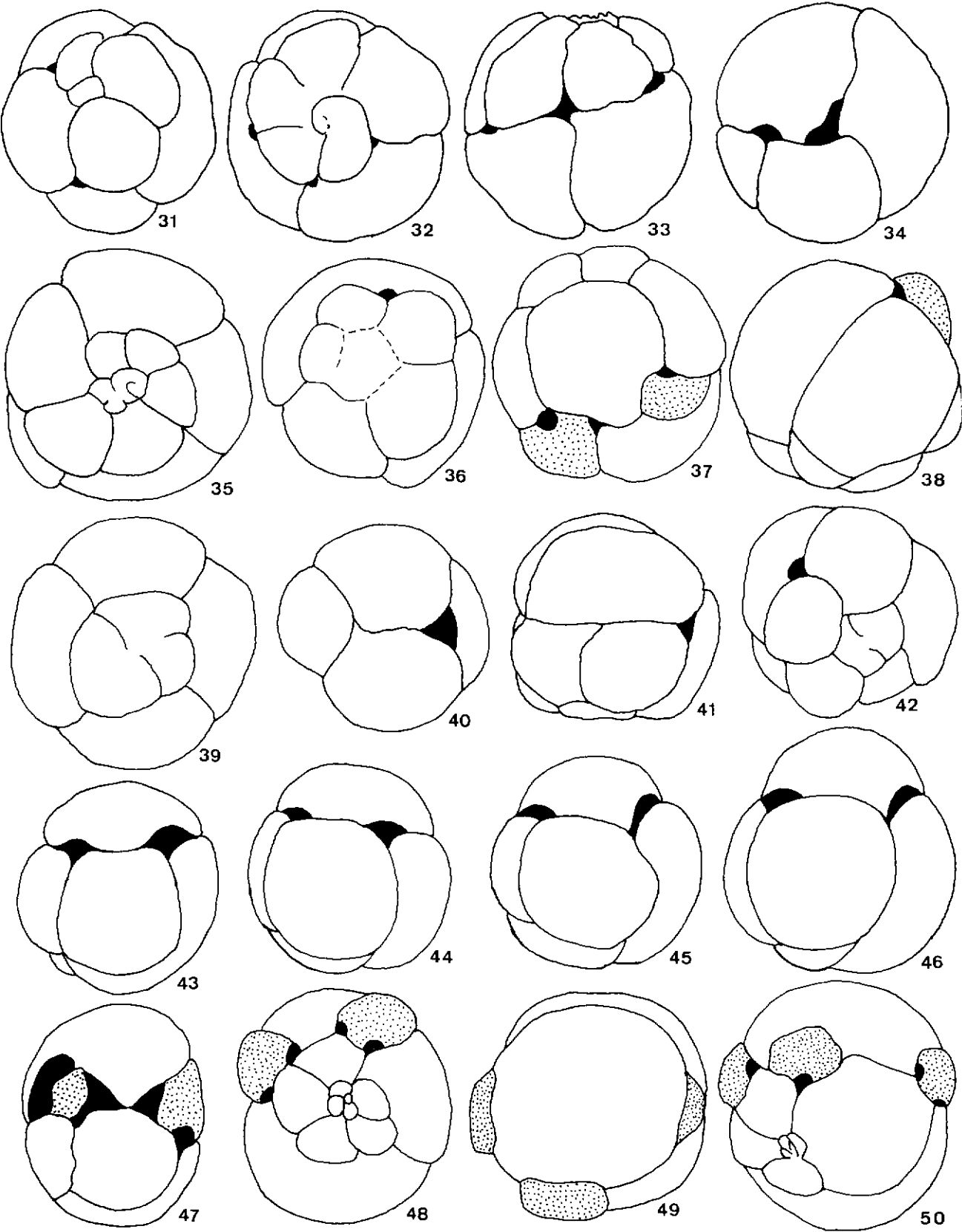
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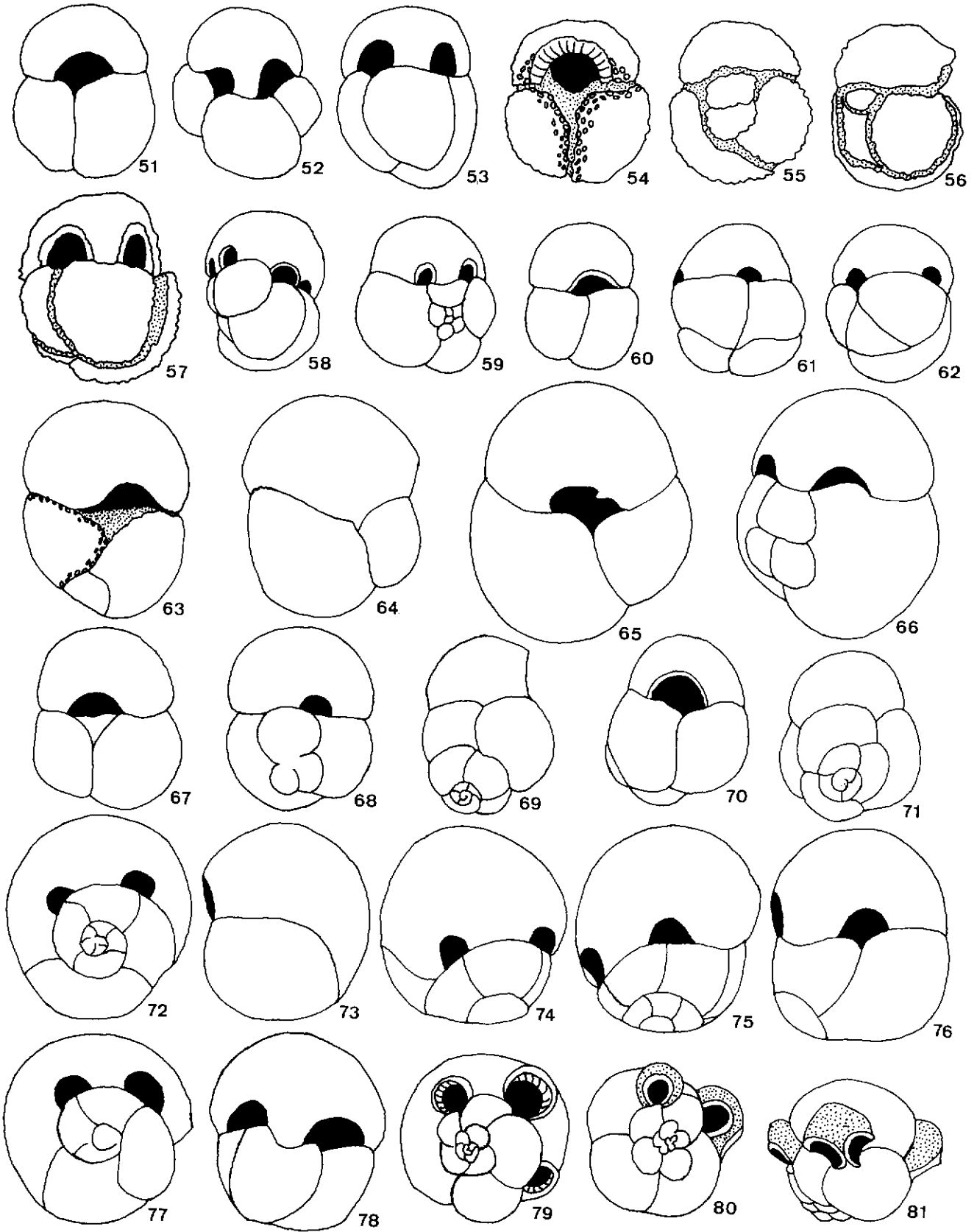
TEXT FIGURES 1-81

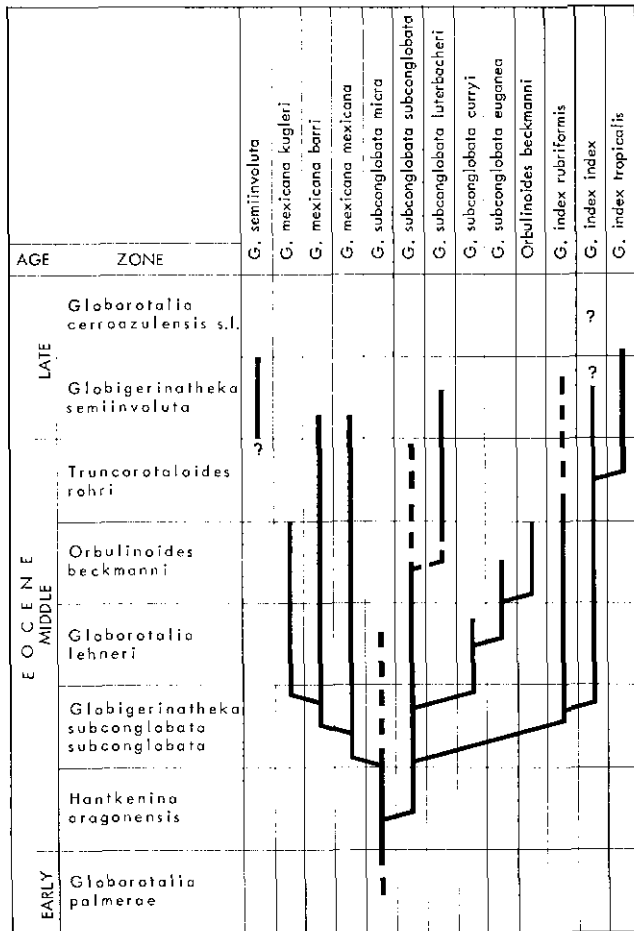
Test size and morphology of *Globigerinatheka* species and subspecies. Holo-, para-, and hypotype line drawings of original figures are all at the magnification of approximately $\times 75$. Terminology of original authors and references in brackets.

- 1-11 *G. mexicana mexicana* (Cushman)
 - 1-2 [*Globigerina mexicana* Cushman, 1925, pl. 1, fig. 8a, b] Holotype.
 - 3-6 [*Globigerapsis mexicana*,—Blow and Saito, 1968, Text fig. 1-4] Holotype redrawn.
 - 7-9 [*Globigerinatheka barri* Brönnimann,—Brönnimann, 1952, Text fig. 3d-f, Paratype of Brönnimann's *G. barri*] Hypotype.
 - 10-11 [*Globigerapsis mexicana* (Cushman),—Saito, 1962, pl. 34, fig. 6a, b] Hypotype.
- 12-17 *G. mexicana kugleri* (Bolli, Loeblich and Tappan)
 - 12-14 [*Globigerapsis kugleri* Bolli, Loeblich and Tappan, 1957, pl. 6, fig. 6a-c] Holotype.
 - 15-17 [*Globigerina mexicana* Cushman,—Mallory, 1959, pl. 22, fig. 9a-c] Hypotype.
- 18-23 *G. mexicana barri* (Brönnimann)
 - 18-20 [*Globigerinatheka barri* Brönnimann, 1952, Text fig. 3a-c] Holotype.
 - 21-23 [*Globigerinatheka barri* Brönnimann, Bolli, Loeblich and Tappan, 1957, pl. 7, fig. 12a-c] Hypotype.
- 24-26 *G. subconglobata micra* (Shutsкая)
 - 24 [*Globigerinoides subconglobatus* Chalilov var. *micra* Shutsкая, 1958, pl. 1, fig. 1] Holotype.
 - 25-26 [do., pl. 1, fig. 2, 3] Paratypes.
- 27-30 *G. subconglobata curryi* Proto Decima and Bolli
 - 27-28 [*Globigerinatheka curryi* Proto Decima and Bolli, 1970] Holotype.
 - 29-30 [*Globigerapsis kugleri* Bolli, Loeblich and Tappan, Postuma, 1971, p. 139] Hypotype.
- 31-42 *G. subconglobata euganea* Proto Decima and Bolli
 - 31 [*Globigerinatheka euganea* Proto Decima and Bolli, 1970, pl. 1, fig. 7] Holotype.
 - 32-34 [do., Text fig. 45a, b] Hypotype.
 - 35 [*Globigerina mexicana* Cushman,—Cushman, 1927, pl. 26, fig. 16] Hypotype.
 - 36-38 [*Globigerinoides mexicana* (Cushman),—Beckmann, 1953, pl. 25, fig. 15, 16] Hypotype.
 - 39 [*Globigerapsis mexicana* (Cushman),—Todd and Low, 1960, pl. 259, fig. 7] Hypotype.
- 40-42 [*Globigerapsis mexicana* (Cushman),—Saito, 1962, pl. 34, fig. 7a-c] Hypotype.
- 43-46 *G. subconglobata subconglobata* (Shutsкая). [*Globigerinoides subconglobatus* Chalilov, var. *subconglobata* Chalilov (msc), in Shutsкая, 1958, pl. 87, fig. 4, 8, 5, 7, no holotype designated]. Fig. 44 (fig. 8 of Shutsкая) is here designated as lectotype.
- 47-50 *G. subconglobata luterbacheri* n. subsp.,
 - 47 Holotype (see also this paper pl. 7, fig. 13).
 - 48-50 [*Globigerinatheka barri* Brönnimann,—Eckert, 1963, pl. 7, fig. 4a-c] Paratype.
- 51-57 *G. index index* (Finlay)
 - 51 [*Globigerinoides index* Finlay, 1939, pl. 14, fig. 85] Holotype.
 - 52-53 [do., pl. 14, fig. 87, 88] Paratypes.
 - 54-56 [*Globigerinoides index* Finlay,—Hornibrook, 1958, pl. 1, fig. 11-13] Holotype redrawn.
 - 57 [do., pl. 1, fig. 14] Paratype redrawn.
- 58-60 *G. index tropicalis* (Blow and Banner)
 - 58-59 [*Globigerapsis tropicalis* Blow and Banner, 1962, pl. 15, fig. D, E] Holotype.
 - 60 [do., pl. 15, fig. F] Paratype.
- 61-62 *G. index korotkovi* (Keller). [*Globigerinoides korotkovi* Keller, 1946,—Subbotina, 1953, pl. 14, fig. 1a, b] refigured Holotype.
- 63-64 *G. index index* (Finlay). [*Globigerinoides macrostoma* Hagn, 1956, pl. 16, fig. 11a, b] Hypotype.
- 65-68 *G. index s.l.* (Finlay). [*Globigerinoides conglobatus* (Brady),—Subbotina, 1953, pl. 14, fig. 2b, a; 3b, a] Hypotype.
- 69-71 *G. index rubrifformis* (Subbotina). [*Globigerinoides rubrifformis* Subbotina, 1953, pl. 14, fig. 6A-C] Holotype.
- 72-79 *G. semiinvoluta* (Keijzer)
 - 72-76 [*Globigerinoides semiinvolutus* Keijzer, 1945, pl. 4, fig. 58a-e] Holotype.
 - 77-78 [*Globigerapsis semiinvoluta* (Keijzer),—Bolli, Loeblich and Tappan, 1957, pl. 6, fig. 7a, c] Hypotype.
 - 79 [*Globigerapsis semiinvoluta* (Keijzer),—Blow and Banner, 1962, pl. 15, fig. J, K] Hypotype.
- 80-81 *G. index tropicalis* (Blow and Banner). [*Globigerinatheka lindiensis* Blow and Banner, 1962, pl. 15, fig. O, P] Hypotype.



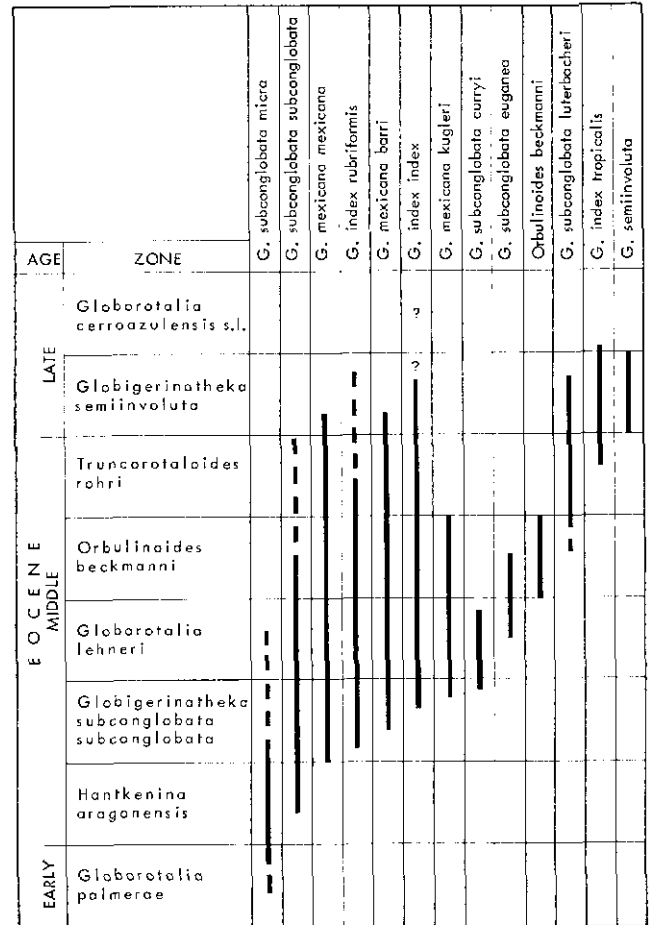






TEXT FIGURE 82

Tentative evolution of *Globigerinatheka* and *Orbulinoides*.



TEXT FIGURE 83

Distribution of *Globigerinatheka* species and subspecies, and *Orbulinoides beckmanni*.

The latter subspecies ranges into the lower part of the *Globorotalia cerroazulensis* s.l. Zone. The *G. subconglobata curryi/euganea/Orbulinoides beckmanni* lineage is assumed to have branched off *G. subconglobata subconglobata* near the top of the *Globigerinatheka subconglobata subconglobata* Zone to become extinct at the top of the *Orbulinoides beckmanni* Zone. The subspecies *luterbacheri* appears to have originated in the *Orbulinoides beckmanni* Zone, and continues well into the *Globigerinatheka semiinvoluta* Zone. It is here shown to have branched off from *G. subconglobata subconglobata* but its origin from *G. index index* is also regarded as possible. Blow and Banner (1962, p. 125) state that "it is highly likely that *G. tropicalis* is ancestral to *G. semiinvoluta*." Though a relation to the *G.*

index index/tropicalis complex is possible, it seems just as likely that *G. semiinvoluta* could have descended from the *mexicana* group. Such an assumption would be more in agreement with Blow and Banner (1968) and fit the evolutionary picture in that the early Late Eocene *G. semiinvoluta* would then represent the continuation of the *mexicana* group which has its main development in the higher Middle Eocene. *G. index tropicalis* on the other hand ranges from the late Middle Eocene to at least the top of the early Late Eocene *Globigerinatheka semiinvoluta* Zone with its maximum development in that zone, i.e. at the same time as *G. semiinvoluta*, the form which, according to Blow and Banner, should have developed from it. The evolutionary trends discussed are shown on text fig. 82.

AGE	BOLLI present paper	TOUMARKINE & BOLLI 1970 Passagno	BOLLI 1957 Trinidad	BOLLI 1966 Caribbean	BANNER & BLOW 1962 world wide	BLOW 1969 world wide	BAUMANN 1970 Central Apennine	SUBBOTINA 1953 Caucasus	STRAT. COMM. USSR 1963/1967 Caucasus	KRASHENINNIKOV 1965 Syria	JENKINS 1965/1970 New Zealand
LATE	<i>Globorotalia cerroazulensis</i> s.l.	<i>Globorotalia cerroazulensis</i> cunctalis	<i>Globorotalia cocoaensis</i>	<i>Globorotalia cerroazulensis</i>	<i>Cribranhantkenina danvillensis</i>	<i>Globigerina gortanii gortanii</i> / <i>Globorotalia</i> (T) <i>centralis</i>	<i>Globorotalia cerroazulensis</i>	Bolivina ↑	Bolivina ↑		<i>Globigerina</i> (G) <i>brevis</i>
	<i>Globigerinatheka semiinvoluta</i>	<i>Globorotalia cerroazulensis</i> cocoaensis			<i>Cribranhantkenina danvillensis</i>		<i>Globigerapsis mexicana</i>	<i>Globigerinoides conglobatus</i> and large <i>Globigerina</i>	large <i>Globigerinoides conglobatus</i>	<i>Globigerina</i> <i>corpulenta</i>	
MIDDLE	<i>Truncorotaloides rohri</i>	<i>Globorotalia c. cerroazulensis</i> / <i>Globorotalia c. pomeroli</i>	<i>Truncorotaloides rohri</i>	<i>Truncorotaloides rohri</i>	<i>Truncorotaloides rohri</i>	<i>Truncorotaloides rohri</i> / <i>Globigerinita howei</i>	<i>Truncorotaloides rohri</i>	thin walled pelagic Foraminifera	<i>Globigerina turmenica</i> (thin walled pelagic Foraminifera)	<i>Truncorotaloides rohri</i>	<i>Globigerina</i> (S) <i>linaperta</i>
	<i>Orbulinoides beckmanni</i>	<i>Globorotalia cerroazulensis</i> pomeroli	<i>Particulosphæra mexicana</i>	<i>Particulosphæra mexicana</i>		<i>Orbulinoides beckmanni</i>	<i>Orbulinoides beckmanni</i>		<i>Hantkenina alabamensis</i> / <i>Globigerinoides subconglobatus</i>	<i>Hantkenina alabamensis</i>	<i>Globorotalia</i> (T) <i>incorpua</i>
	<i>Globorotalia lehneri</i>	<i>Globorotalia cerroazulensis</i> passagnoensis	<i>Globorotalia lehneri</i>	<i>Globorotalia lehneri</i>			<i>Globorotalia centralis</i>	<i>Acarinina rotundimarginata</i>	<i>Acarinina rotundimarginata</i>	<i>Acarinina rotundimarginata</i>	<i>Globigerina</i> (G) <i>index</i> <i>index</i>
	<i>Globigerinatheka subconglobata</i> <i>subconglobata</i>		<i>Globigerapsis kugleri</i>	<i>Globigerapsis kugleri</i>			<i>Globigerapsis subconglobata</i>	<i>Acarinina</i>		<i>Globigerapsis kugleri</i>	
	<i>Hantkenina aragonensis</i>	<i>Globorotalia cerroazulensis</i> frontosa	<i>Hantkenina aragonensis</i>	<i>Hantkenina aragonensis</i>			<i>Hantkenina aragonensis</i>	<i>Acarinina crassaformis</i>	<i>Acarinina crassaformis</i>	<i>Acarinina bullbrookii</i>	<i>Pseudoglobobadrina primitiva</i>
	<i>Globorotalia palmerae</i>		<i>Globorotalia palmerae</i>	<i>Globorotalia palmerae</i>			<i>Globorotalia pentaamerata</i>	conical <i>Globorotalia</i>	<i>Globorotalia aragonensis</i>	<i>Globorotalia aragonensis</i> & <i>Acarinina penta-camerata</i>	<i>Globorotalia</i> (M) <i>crater crater</i>
EARLY											

TEXT FIGURE 84

Correlation of some Eocene zonal subdivisions based on planktonic foraminifera.

STRATIGRAPHIC DISTRIBUTION

The correlation of some Eocene zonal subdivisions as shown on text fig. 84 are given to aid comparison of the zones used here on text fig. 82 and 83. The zonal system of Bolli (1957/1966) is here changed on text figs. 82 and 83, insofar as the name *Globigerapsis kugleri* has been replaced by *Globigerinatheka subconglobata subconglobata*. The reason for this is that the forms earlier regarded as *G. kugleri* in the zone of that name are now rather to be placed in *G. subconglobata subconglobata*, with typical *kugleri* forms appearing only within the *Globorotalia lehneri* Zone. Baumann (1970, fig. 25) has already introduced a *Globigerapsis subconglobata* Zone in replacement of the *Globigerapsis kugleri*

Zone and lowermost portion of the *Globorotalia lehneri* Zone. The zonal definition remains unchanged from that given by Bolli (1966): Interval between last occurrence of *Hantkenina aragonensis* and last occurrence of *Globorotalia aragonensis*. The zonal marker occurs throughout the zone but is not restricted to it.

To comply with the zonal system proposed by Toumarkine and Bolli (1970) for the Middle-Late Eocene based on the subspecies of *Globorotalia cerroazulensis*, the *Globorotalia cerroazulensis* Zone of Bolli (1957), changed to *Globorotalia cocoaensis* Zone in 1966, is here given as *Globorotalia cerroazulensis* s.l. Zone. The definition of the zone, interval with zonal marker, from last occurrence of *Globigerinatheka semiinvoluta* to last occurrence of zonal marker, remains unchanged.

REMARKS ON A PROPOSED SYNONYMY OF
GLOBIGERINATHEKA SEMIINVOLUTA WITH
GLOBIGERINATHEKA MEXICANA MEXICANA

In their paper "The morphology and taxonomy of *Globigerina mexicana* Cushman 1925" Blow and Saito (1968) place *G. semiinvoluta* in synonymy with *G. mexicana* and regard both as restricted to the Late Eocene. In the present author's opinion the two species are morphologically distinct and have also different stratigraphic ranges. Further, *G. semiinvoluta* is an excellent short-lived index fossil well established in the literature as a zonal marker. The following critical review of Blow and Saito's proposed synonymy should serve, therefore, to show that *G. semiinvoluta* is a valid species.

Blow and Saito base their conclusion on the following statements:

1. "We have found that *G. mexicana* Cushman 1925, is a prior synonym of *Globigerinoides semiinvolutus* Keijzer, 1945, which both Bolli (1957, p. 165) and Bolli, Loeblich and Tappan (1957, p. 34) ascribed to their new genus *Globigerapsis*."

2. "As stated above, our re-examination of the holotype of *Globigerina mexicana* Cushman shows that it possesses the same essential morphology as that previously recognized for *Globigerinoides semiinvolutus* Keijzer, 1945, later known as *Globigerapsis semiinvoluta* (Keijzer)," and "we are firmly of the opinion that *Globigerina mexicana* Cushman, 1925, and *Globigerinoides semiinvolutus* Keijzer, 1945, are fully conspecific and that the latter taxon must be regarded as a junior synonym of the former taxon. In consequence of the synonymy, *Globigerapsis mexicana* (Cushman) must now be considered as an index fossil for part of the Late Eocene and not, as given under the invalid combination *Porticulasphaera mexicana* (Cushman) of Bolli, Loeblich and Tappan (not *Globigerina mexicana* Cushman), an index fossil for part of the Middle Eocene."

The above statements were based on a re-examination of the *G. mexicana* holotype which resulted in an emended species description and re-drawing of the holotype. Not available however to Blow and Saito was Keijzer's original *Globigerinoides semiinvolutus* material. Their claim for synonymy of the two species is based therefore, not on a direct examination and comparison of both holotypes, but rather on an identification of *G. semiinvolutus* with *G. mexicana* by means of description and holotype figures of the former.

While the holotype of *G. mexicana* is deposited in

the Cushman Collection as No. 4334 at the U.S. National Museum, the depository of Keijzer's original *Globigerinoides semiinvolutus* material could only be re-established in early 1970, i.e. some time after publication of Blow and Saito's 1968 paper claiming synonymy of the two taxa. For the record, the following can be said on the depository of the *G. semiinvolutus* holotype: Keijzer (1945) does not state where his collection and specimens described in his University of Utrecht doctoral thesis are deposited. The Catalogue of Foraminifera mentions under "type specimens" of *Globigerinoides semiinvolutus*: "Depository not given (Holotype probably deposited in the collection of the Geological Institute, University of Utrecht, Netherlands)." Through the courtesy of Drs. C. W. Drooger, and P. Marks of the Geological Institute of the University of Utrecht, and Isabella Premoli-Silva while on a temporary assignment there, the Keijzer collection was located in Utrecht. In a search for the holotype of *Globigerinoides semiinvolutus*, a single slide containing 23 loose specimens was found and kindly made available to the author for examination. The reason Keijzer placed all his *G. semiinvolutus* specimens, including the holotype, in a single slide was blamed in a private communication by Dr. Drooger on the difficult working conditions and shortage of slides in Utrecht during and shortly after the second world war, when Keijzer worked on his thesis. The slide has the following labelling: *Globigerinoides semiinvolutus* Keijzer; Cuba D 26798; F286, V339, V400. The 23 specimens come from four different Upper Eocene localities, including the type locality F286.

Of the 23 specimens, 13 are of a whitish color, 9 are yellowish-brown and one is pink. The marls from the Eocene in the northern region (Middle-Upper Eocene) and the type sample F286, particularly, are described as white. The three other samples mentioned on the slide are all from the synclinal area of the Eocene San Luis Formation which lies further to the south (see geographical map in Keijzer, 1945). Of this formation Keijzer says: "In the centre of the synclorium the white marls and limestones of the basal parts of the San Luis Formation grade upwards into a series of grey and brown shales and sandstones. . . ." If the holotype is included in the slide, which can reasonably be assumed inasmuch as there are no other separated *G. semiinvoluta* specimens in the collection, it should be one of the whitish specimens from the northern Eocene, the colored ones probably having been obtained from the southern San Luis Formation.

An examination of these 23 specimens and a com-

parison with Keijzer's holotype figure and description reveals that none of the colored specimens and only one of the white ones can be identified with the holotype. The others differ in the number of apertures (1, 2, 4, instead of 3 in the holotype), preservation (some are broken, deformed or partially covered by matrix), size, or overall test shape. This single specimen, regarded with the highest probability as the holotype selected by Keijzer, fits his description and figures well.

It is from locality F286 in the northern Eocene section E. of Mayari, which is shown on the small sketch map of figure 7, p. 60 in Keijzer (1945). On his geological map (in back pocket), Keijzer does not actually show locality F286, which lies between the indicated F285 and F288. Keijzer correctly figured and described the holotype, including locality, collector's number, stratigraphic position and age, but has not separated and labelled the specimen as such and also has not given a depository. Consequently, he did not conform in this respect with Recommendations 72B-C and 73C(7) of the IRZN.

The specimen is now kept in a separate slide labelled *Globigerinoides semiinvolutus* Keijzer, 1945, Lectotype, (probably Keijzer's holotype specimen from locality F286, N-Eocene section E. of Mayari, Cuba) and is deposited in the collections of the Geological Institute, Utrecht, Holland. Its essential features are those described and figured by Keijzer (1945) as holotype of *Globigerinoides semiinvolutus*.

THE MORPHOLOGICAL DIFFERENCES BETWEEN *GLOBIGERINATHEKA SEMIINVOLUTA* AND *GLOBIGERINATHEKA MEXICANA*

In addition to a different stratigraphic distribution, (see following discussion) distinct morphological differences exist between *G. semiinvoluta* and *G. mexicana* in average test size, shape and perforation of the last chamber, degree of depression of sutures, and shape of apertures in the last chamber.

The largest diameter of the holotype of *mexicana* is .35 mm against .5 mm in *semiinvoluta*. Observations on the size variability of *mexicana* specimens show a range between .3 mm and .4 mm. The holotype of *G. barri*, a form closely related to *mexicana*, measures .39 mm, paratypes .35 mm–.36 mm. Keijzer mentions a variability of *semiinvoluta* from .37 mm to .55 mm, the specimens figured here on plate 5 and 6 vary from .17 mm to .54 mm. From these figures it can be deduced that, where size is concerned, tests of *mexicana* as a

rule do not exceed .4 mm, whereas *semiinvoluta* frequently grows larger with many specimens reaching more than .52 mm.

The last chamber of the re-drawn holotype of *mexicana* is irregularly shaped and the specimen figured as *mexicana* by Saito (1962, plate 34, fig. 6) possesses a fairly small end chamber, which, seen from the top, is triangularly shaped. In contrast, the last chamber of *semiinvoluta* is, as shown in Keijzer's holotype drawings and on the numerous specimens figured here on plate 5 and 6, very regularly dome-shaped and, in the average specimen, more or less hemispherical. With few exceptions the sutures of *semiinvoluta* specimens, including the holotype according to Keijzer's drawings, are very faintly depressed and hardly visible, in particular between early chambers (plate 5, figs. 13, 18, 24). Only occasionally are they well developed (plate 5, figs. 14, 21). According to Blow and Saito the intercameral sutures of the *mexicana* holotype are "shallowly but distinctly depressed." This is also clearly shown on their re-drawn holotype figures. Because of its more regularly dome-shaped final chamber and less incised sutures between early chambers, the average test of *semiinvoluta* is thus more smoothly spherical than *mexicana*.

Though not apparent from their re-drawn holotype figures of *mexicana*, its last chamber, according to Blow and Saito, is "smoother and less coarsely perforate than the surface of the earlier chambers." With the exception of one specimen (plate 5, figs. 16, 17) none of the *semiinvoluta* figured on plates 5 and 6 shows such differences between early and last chambers.

Dr. J. P. Beckmann has had the opportunity to examine both the holotype of *mexicana* (at the U.S. National Museum) and Keijzer's original *semiinvoluta* material while on loan at the Geological Institute, ETH, Zürich. He has recognized the same morphological differences between the two species as those expressed above, and he has strongly supported the findings expressed in this paper that *semiinvoluta* is a form clearly distinct from *mexicana* in its morphology and thus must be retained as a valid species and index fossil. The opinion that *semiinvoluta* is a valid species and not a synonym of *mexicana* was already expressed by Toumarkine and Bolli (1970), and Baumann (1970, footnote, p. 1175).

AGE OF *GLOBIGERINATHEKA MEXICANA*

In addition to the forms published as *semiinvoluta* by Keijzer (1945), Bolli, Loeblich and Tappan (1957),

and Blow and Banner (1962), Blow and Saito (1968) also placed the two specimens figured by Saito (1962) as *Globigerapsis mexicana* from the Middle Eocene of Japan in synonymy with *Globigerina mexicana* Cushman (see under *G. mexicana mexicana* of this paper). This is in contradiction with their claim that *G. mexicana* is a Late Eocene index fossil.

In this context the question of a Middle or Late Eocene age of the type locality of *G. mexicana* must be raised again. To Blow and Saito's remarks on this, from which they conclude a Late Eocene age, the following observations supporting Middle Eocene are added: Of the species described in Cushman's (1925) paper "New Foraminifera from the Upper Eocene of Mexico" only two of them are planktonic, *Globigerina mexicana* and *Globigerina topilensis*. The latter is a characteristic spinose form now assigned to the genus *Truncorotaloides*, not known in strata younger than Middle Eocene. From this alone it may be deduced that the holotype of *G. mexicana* is also Middle Eocene in age and not Late Eocene as Cushman originally stated.

Blow and Saito were aware of the concurrence of the Middle Eocene *T. topilensis* in the type sample of *G. mexicana*. They reasoned, however, that *G. mexicana* is Late Eocene in age based on the following information by Dr. R. W. Barker: "It would appear that the Tantoyuca Formation does not occur in the area of the Palacho Hacienda" (from where Cushman described the fauna) but that "derived blocks of Eocene are present in these post-Eocene beds and that it is very probable that Cushman obtained his sample from such a block, or from a heterogeneous sample." From this they conclude that the associated fauna from Cushman's Palacho Hacienda cannot be used to date the occurrence of *G. mexicana*, and continue "As yet '*Globigerina mexicana*' has not been observed in the *in situ* Tantoyuca Formation, although it occurs commonly in the light colored marls of the Chapapote Formation. It may well be that Cushman's sample included derived material from the Chapapote Formation."

On this the following is said:

1. Even if Cushman's Palacho Hacienda sample comes from a derived block, its fauna can still be homogeneous.

2. Tantoyuca and Chapapote are said to represent two different facies of the same Late Eocene age (Congr. Geol. Int., Excursion C-16, p. 47-53, Mexico, 1956; Muir, 1936). A comparison of the evolutionary stages of *Globorotalia cerroazulensis* subspecies in type locality samples from the Tantoyuca and Chapapote formations

indicates, however, that the Tantoyuca can be slightly older than the Chapapote—though still Late Eocene. The shallow water, nearshore facies of the Tantoyuca Formation contains a predominantly benthonic foraminiferal fauna with larger foraminifera and only few planktonic specimens. Globotruncanas and a Middle Eocene *Globigerinatheka subconglobata curryi* specimen in a sample from the type locality of the Tantoyuca Formation indicate reworking, possibly also of the youngest faunal components *Globorotalia cerroazulensis cerroazulensis* and *G. cerroazulensis cocoaensis*. Presence in the Tantoyuca of other reworked Middle Eocene faunas, including *G. mexicana*, is thus entirely possible.

The open sea marls of the Chapapote Formation show a strong predominance of planktonic foraminifera. Samples collected by the writer (Bo 67/17-20) at its type locality on the Rio Tuxpan (an outcrop about 80 m long on the river bank with a dip of approx. 30° E, see fig. 7 of above-mentioned Congress Guide) contain *Cribohantkenina inflata* and *Globorotalia cerroazulensis cocoaensis*, and *G. cerroazulensis cunialensis* particularly in the highest part of the section. This indicates a stratigraphic extension of the type locality from the upper part of the *Globorotalia cerroazulensis cocoaensis* Zone into the *Globorotalia cerroazulensis cunialensis* Zone, upper part of the Late Eocene (Toumarkine and Bolli, 1970). This position of the Chapapote type locality explains the absence there not only of the Middle Eocene *G. mexicana* but also of *G. semiinvoluta*, which is restricted to the lower part of the Late Eocene.

3. Unless the lower parts of the Tantoyuca and/or Chapapote Formations reach into the Middle Eocene, it must be assumed that Cushman's Palacho Hacienda sample is not from *in situ* Tantoyuca, as was also suggested by Barker (quoted above). The type locality of *Globigerina mexicana mexicana* and *Truncorotaloides topilensis* rather belongs to the Middle Eocene Guayabal Formation (*in situ* or in block form) or contains material derived from it.

Until more convincing evidence to the contrary can be offered than that given by Blow and Saito (1968), *G. mexicana mexicana* is to be regarded as of Middle Eocene age, which is also in agreement with the opinion expressed by Saito (1962), and it is therefore stratigraphically older than *G. semiinvoluta*.

PALEOGEOGRAPHIC DISTRIBUTION OF *GLOBIGERINATHEKA*

Based on published records from tropical regions (Caribbean and East Africa) and temperate regions

(Alpine-Mediterranean, Caucasus and New Zealand/Australia), and from my own, unpublished observations in the Caribbean and Alpine-Mediterranean regions, the paleogeographic distribution pattern of the taxa listed here is as follows:

1. Tropical and temperate regions:
G. mexicana mexicana/barri/, *G. index tropicalis*
2. Tropical, grading into progressively less distinct and smaller forms towards temperate regions:
G. mexicana kugleri, *G. subconglobata curryi/euganea* (leading to *O. beckmanni*), *G. semiinvoluta*
3. Temperate, grading into progressively less distinct forms towards tropical regions:
G. subconglobata micra/subconglobata
4. Temperate:
G. index index/rubriformis, *G. subconglobata luterbacheri*

It appears that certain subspecies may replace each other in different latitudes by changing morphological characters. This was already suggested by Jenkins (1971), who believes that *G. index tropicalis* is the tropical equivalent of *G. index index*. While all taxa known from tropical areas have been recorded also in at least the more southern temperate areas (e.g. *G. semiinvoluta* in the Southern Alps, but not yet north of the Alps or in the Caucasus), the temperate *G. index index*, *G. index rubriformis*, and *G. subconglobata luterbacheri* are unknown so far from the tropical belt.

FAUNAS STUDIED

Material from the following areas was used for this study:

Italy: Possagno section (Cita et al, 1968; Toumarkine and Bolli, 1970), *Hantkenina aragonensis* Zone to *Globorotalia cerroazulensis* Zone. Various species and subspecies from this interval are figured on plates 1 and 3.

Switzerland: Looegg section, W. of Pilatus (Eckert, 1963). Variability of *G. subconglobata luterbacheri* n. subsp. (plate 7).

Trinidad, W.I.: Type locality and additional samples from the *Globigerinatheka subconglobata subconglobata* Zone to the *Globigerinatheka semiinvoluta* Zone (Bolli, 1957). The well preserved specimens of *Globigerinatheka mexicana mexicana*, *G. mexicana kugleri* and *G. mexicana barri* (plates 2, 4) used for variability studies

come from the *Orbulinoides beckmanni* Zone, those of *G. index tropicalis* and *G. semiinvoluta* (plates 3–6) from the *Globigerinatheka semiinvoluta* Zone.

Available for direct comparison were specimens of *G. index index* from New Zealand, the holotype and paratypes of *G. macrostoma* from Northern Italy, Keijzer's original *G. semiinvoluta* material from Cuba, *G. index rubriformis*, *G. subconglobata micra*, and *G. subconglobata subconglobata* specimens from the Caucasus, USSR. Faunas for comparison were available from sections collected along the Kheu and Kuban River of the Caucasus; further from Barbados, W.I., and the Cava Zillo section, Northern Italy. Checked and compared at the U.S. National Museum in Washington, D.C. were holo-, para- and hypotypes of *G. mexicana*, *G. kugleri*, *G. barri* and *G. curryi*. Holo- and paratypes of *G. tropicalis* and *G. lindiensis* were seen at the British Museum, London, and those of *G. euganea* at the Natural History Museum, Basel.

The specimens figured on plates 1–7 are deposited in the Museum of Natural History, Basel (C26655–26770).

Genus *Globigerinatheka* Brönnimann 1952, emended
Proto Decima and Bolli, 1970

Genotype: *Globigerinatheka barri* Brönnimann, 1952, p. 27, text figs. 3a–c

Reference is made for the genus description to Brönnimann (1952) and to Proto Decima and Bolli (1970) who included *Globigerapsis* in *Globigerinatheka* as its non-bullate stage. In *Globigerinatheka* thus are included all Middle to Late Eocene planktonic foraminifera that possess a trochospiral globigerinid stage whose umbilical area is covered by a final chamber with two or more sutural apertures which may or may not be covered by bullae. Typical for the genus is the position of the apertures of the last chamber which are as a rule placed symmetrically above the sutures between earlier chambers. In this respect the *G. index* subspecies (plate 3; text figs. 51–71) compares with *Globigerinoides ruber* (Bolli, 1957a, text fig. 21, p. 113) which displays a similar arrangement and growth rate of chambers, but differs in having a less umbilical position of the final chamber in relation to the early whorl, and in possessing sutural apertures also in earlier chambers. As can be seen from the illustrations in this paper, the same apertural positions symmetrically above sutures between earlier chambers, are also apparent in the other *Globigerinatheka* species. Where bullae are present, the

same applies to the position of their apertures in relation to sutures between underlying chambers (e.g. text figs. 19–21, 37, 48, 50).

Orbulinoides Cordey, 1968, evolved from *Globigerinatheka* (*G. subconglobata euganea*) in acquiring spiral sutural apertures in the early chambers which connect via vestibules with apertures of the covering thick wall. *Orbulinoides* also possesses a greater number of sutural apertures in the last three chambers and may have areal apertures in the last chamber, which are not known in *Globigerinatheka* (Proto Decima and Bolli, 1970).

Reference is made to the original species and subspecies descriptions. Translations in French and some in English are available for the taxa originally published in Russian (see references Subbotina, Shutskaia). Remarks on the species and subspecies comprise particular morphological characteristics, variability, differential analysis, interrelations between taxa, synonymies, and stratigraphic ranges.

Globigerinatheka index index (Finlay)

Plate 1, figures 1–4, 6, 7; Text figures 51–57, 63, 64

Globigerinoides index FINLAY, 1939, p. 125, pl. 14, fig. 85, (holotype), fig. 86–88 (paratypes). HORNIBROOK, 1958, pl. 1, figs. 11–13 (redrawn holotype), fig. 14 (paratype).

Globigerapsis index (Finlay). QUILTY, 1969, text fig. 7, no. 42.48. BAUMANN, 1970, pl. 1, figs. 12a–c.

Globigerinatheka (Globigerapsis) index index (Finlay). JENKINS, 1971, pl. 22, figs. 641–645.

Globigerinoides macrostoma HAGN, 1956, p. 173–174, pl. 16, figs. 11a, b (holotype).

Globigerinoita index (Finlay). MYATLYUK, 1970, pl. 53, figs. 1a–c.

For additional synonymies see Quilty (1969), and Jenkins (1971).

The holotype contains only one aperture in the final chamber and is therefore atypical of the genus *Globigerinatheka*, and also of *Globigerinoides* in which the species was originally placed. The figured paratypes (text figs. 52, 53, 57), however, possess two apertures in the last chamber. The essential differences between

PLATE 1

All figures $\times 80$

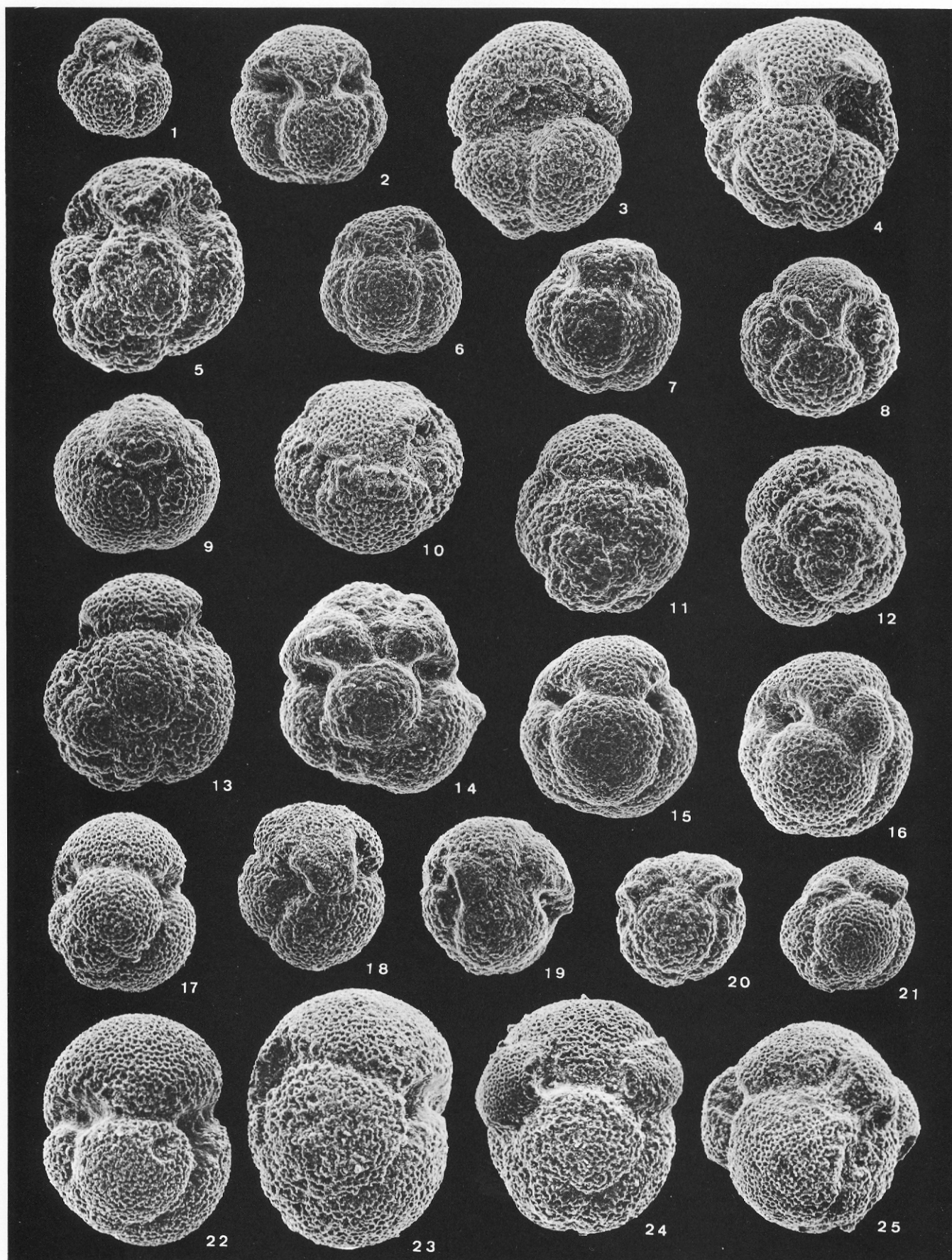
Globigerinatheka index index, *G. index rubrifformis*, *G. subconglobata subconglobata*, *G. subconglobata curryi*, *G. mexicana barri*, *G. subconglobata luterbacheri* n. subsp. from Posagno section, Northern Italy

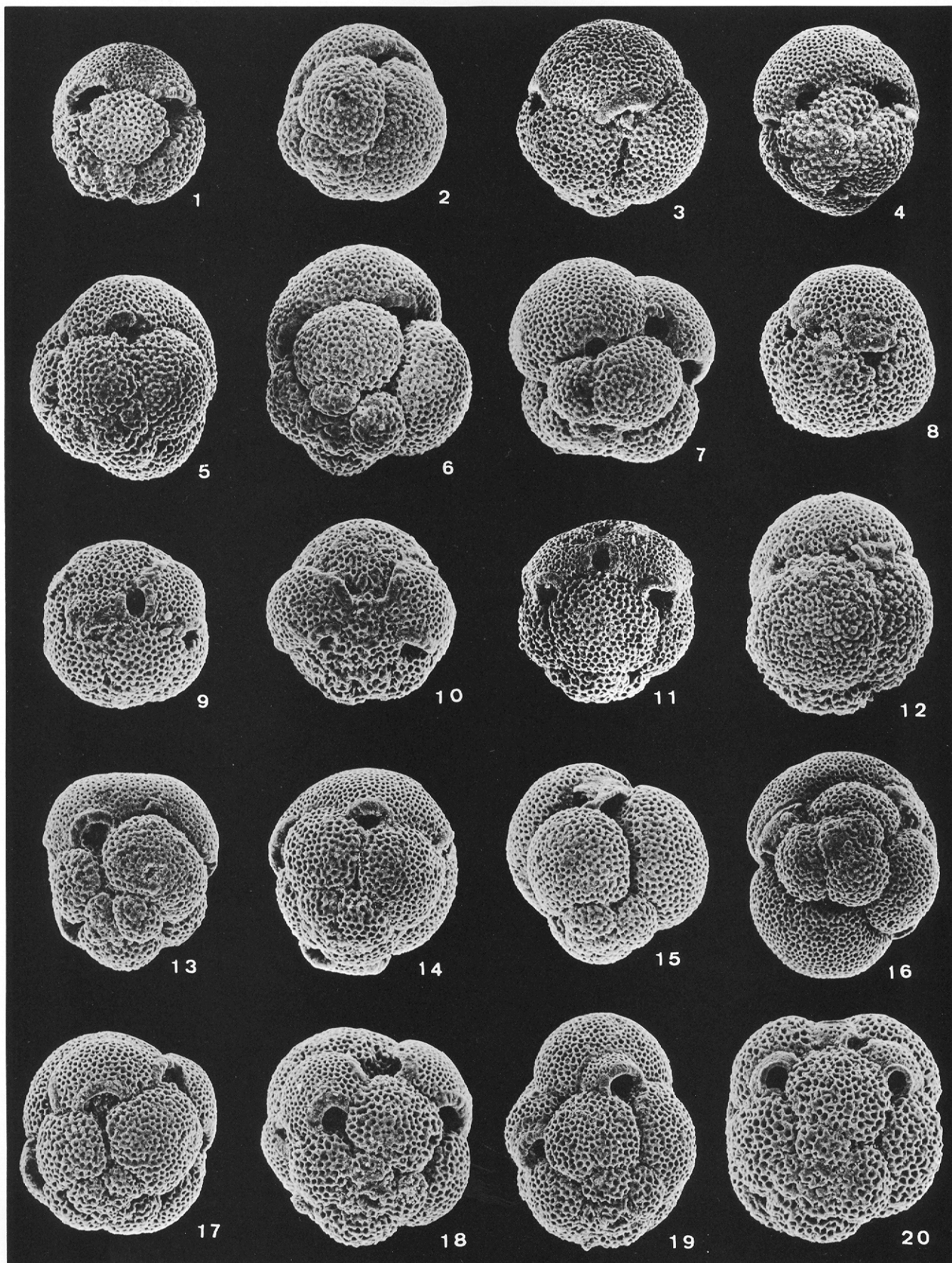
For localities of sample numbers see Cita, 1968, figs. 25, 27, and Toumarkine and Bolli, 1970, figs. 1, 3.

Samples 632–635, 638: *Globigerinatheka subconglobata subconglobata* Zone; 641–642: *Globorotalia lehneri* Zone; 643: *Orbulinoides beckmanni* or *Truncorotaloides rohri* Zone; 68/68: *Globigerinatheka semiinvoluta* Zone.

- 1–4, 6, 7, *Globigerinatheka index index*
 1 Small specimen with two apertures in last chamber. 634. C26655
 2 Medium sized specimen with two apertures. 638. C26656
 3, 4 Large specimens with two apertures (only one visible in 3) 634. C26657, C26658
 6, 7 Specimens with ultimate chamber smaller than penultimate, both with two apertures. 633, 632. C26659, C26660
 5, 11–13 *Globigerinatheka index rubrifformis*
 5 Side view, last chamber with two large apertures. 633. C26661
 11 Oblique spiral view, last chamber with three apertures, two visible on figure. 633. C26662
 12 Spiral view, last chamber with two apertures, not visible on figure. 633. C26663

- 13 Oblique spiral view. Last chamber smaller, with two apertures. 633. C26664
 8–10, 15, 16 *Globigerinatheka subconglobata subconglobata*
 8, 9 Small specimens with ultimate chamber smaller than penultimate, both with two apertures with thick rims. 633, 632. C26665, C26666
 10 Specimen with flat last chamber, possessing three apertures, two of which are visible. 634. C26667
 15, 16 Specimens with two apertures in last chamber, in 16 one covered by bulla. 633. C26668, C26669
 14 *Globigerinatheka subconglobata curryi*
 14 Large specimen with two bullae. 635. C26670
 18–21 *Globigerinatheka mexicana barri*
 18 Last chamber with two apertures, the one visible on figure with bulla like extension of last chamber. 638. C26671
 19 Two bullae, small one on center left, large one at right. 638. C26672
 20, 21 Specimens with two bullae. 641. C26673, C26674
 17, 22–25 *Globigerinatheka subconglobata luterbacheri*, n. subsp., all from 68/68
 17 Juvenile, specimen with two apertures in last chamber. C26675
 22 Medium sized specimen, two apertures in last chamber. C26676
 23, 24 Large specimens with two apertures in last chamber, in 24 both covered by bullae. C26677, C26678
 25 Specimen with three apertures in last chamber, all covered by bullae. C26679





the subspecies *index* and *tropicalis* lie in the thicker walls, more deeply incised crevice-like sutures, and granular surface of the former. It is often difficult, however, to assign specimens of intermediate character to one of the two species. Specimens also exist that appear intermediate between *G. index index*, *G. index rubrifformis* (high initial spire) and *G. subconglobata subconglobata* (small end chamber). Such variabilities are shown on plate 1, figs. 1–13, 15–16.

Since the original description by Finlay, the species has been dealt with by several authors, of whom Hornibrook (1958) offers more accurate re-drawings of holotype and paratype, and Quilty (1969) an up-to-date description.

Globigerinoides macrostoma described by Hagn (1956), is here placed in synonymy with *G. index index*. A comparison of the holotype of *G. macrostoma* kindly made available by its author, with types of *G. index index* from New Zealand received from Drs. Jenkins and Hornibrook, shows that *macrostoma* has similarly thick chambers with partially deep cut sutures, surrounded by granular surface as is typical for *index index*. Hagn, himself, describes the sutures on the ventral side as "stärker eingesenkt," "zuweilen zerschlitzt

wie bei *Sphaeroidinella*," and "die Obertfläche ist ziemlich rau und weist grubige Vertiefungen auf." These are just the characters typical for *G. index index*.

G. index index is regarded by Blow (1969) as a form that was largely restricted to cooler water habitat with only comparatively rare and sporadic invasions into tropical regions. Jenkins (1971) is of the opinion that *G. index tropicalis* is the tropical equivalent of the cooler water *G. index index*. Blow and Banner (1962) note that *G. index index* occurs abundantly in the Middle Eocene of Tanganyika but appears to be absent in the Late Eocene of East Africa and Trinidad, and they add that other records of *G. index index* from the Late Eocene (Cuba, Syria, Israel, SE Australia) should refer to *G. index tropicalis*. Observations in the Possagno section (Cita, 1968; Toumarkine and Bolli, 1970) indicate that typical *G. index index* range well into the *Globigerinatheka semiinvoluta* Zone together with *G. subconglobata luterbacheri*. Both disappear simultaneously within the higher part of that zone, while *G. index tropicalis* continues into the basalmost part of the *Globorotalia cerroazulensis* s.l. Zone to become extinct there as the last representative of the genus *Globigerinatheka*.

PLATE 2

All figures $\times 100$

Globigerinatheka mexicana mexicana, *G. mexicana kugleri*,
G. mexicana barri

All specimens from sample HK 408, *Orbulinoides beckmanni* Zone, Navet Formation, Middle Eocene, Pointe-à-Pierre, Trinidad, W.I. (Same locality as Hg. 8581 in Bolli, 1957, p. 159).

1–5 *Globigerinatheka mexicana mexicana*

1, 5 Specimen with three apertures in last chamber of which two are visible on figures. C26680, C26684

2, 3 Specimens with two apertures, both visible on figure. C26681, C26682

4 Specimen with three apertures, all visible. C26683

6–7 *Globigerinatheka mexicana kugleri*

6 Specimen with two apertures in last chamber, both visible. C26685

7 Specimen with fairly small end chamber of which two apertures are visible on figure. Penultimate, larger chamber with two apertures, one visible on figure, the other covered by ultimate chamber. C26686

8–20 *Globigerinatheka mexicana barri*

8 Specimen with two apertures, one partially covered by small bulla. C26687

9, 10, 11 Specimens with two bullae, which have thick aper-

tural rims and coarsely perforated wall. Enlargement of 10, pl. 4, fig. 4. C26688, C26689, C26690
Specimen with two apertures, covered by minute, delicate bullae. C26691

13, 14 Specimens with one large (top) and one small (lower left and lower center) bulla, both with strong apertural rims. Large chamber-like bulla of 13 with fine pores (Enlargement pl. 4, fig. 2), of 14 with larger pores. C26692, C26693

15 Specimen with small, delicate bulla covering one aperture (bullate *kugleri*). Enlargement pl. 4, fig. 1. C26694

16 Specimen with two apertures covered by small, delicate bullae (bullate *kugleri*). C26695

17 Specimen with two thick walled, coarsely perforated bullae, both with thick apertural rims. C26696

18 Specimen with three bullae as in 17. Enlargement pl. 4, fig. 3. C26697

19 Specimen with one large and one small bulla. Large bulla with small secondary, finer perforated thick rimmed bulla. Enlargement pl. 4, fig. 6. C26698

20 Specimen with two thick walled, coarsely perforated bullae, their apertures covered by finer perforated secondary bullae. Enlargement pl. 4, fig. 5. C26699

This top compares closely with that found in Trinidad by Bolli (1957). *G. index tropicalis* ranges to the top of the *Globigerinatheka semiinvoluta* Zone, also according to Blow and Banner (1962), whereas *G. index index* does not occur above the Middle Eocene.

Subbotina's (1953) *Globigerinoides conglobatus* Zone and therefore the range of the zonal marker (= *G. index s.l.*) has a similar stratigraphic position approximating that of the *Globigerinatheka semiinvoluta* Zone.

This evidence indicates that *G. index s.l.* became extinct at approximately the top of the *Globigerinatheka semiinvoluta* Zone. Following others, however, the species and in particular *G. index index* continues to the top of the Eocene or even into the basal Oligocene:

Blow (1969) mentions under *G. index*: "Recently, the writer has been shown samples by Dr. Berggren which contain typically developed specimens of this form which occur in the Late Eocene and/or earliest Oligocene of Denmark." On table 3 of Berggren (1971), *G. index* ranges to the top of the *Globigerina gortanii*/*Globorotalia centralis* Zone, Late Eocene, in the North Sea Basin. According to Jenkins (1971), *G. index* extends in New Zealand to the lower part of the *Globigerina brevis* Zone, which approximately corresponds with his Eocene/Oligocene boundary.

It would appear from this, assuming the stratigraphic

correlations are correct, that in tropical regions *G. index index* does not extend beyond the Middle Eocene (Tanganyika, Trinidad), that it ranges into the lower part of the Late Eocene in more temperate regions (Possagno), and that it continues to the top of the Eocene in still higher latitudes (North Sea Basin, New Zealand).

Globigerinatheka index korotkovi (Keller)

Text figures 61–62

Globigerinoides korotkovi KELLER, 1946, p. 98, pl. 2, figs. 14–16 (holotype).

Globigerinoides korotkovi Keller. SUBBOTINA, 1953, pl. 14, figs. 1a, b.

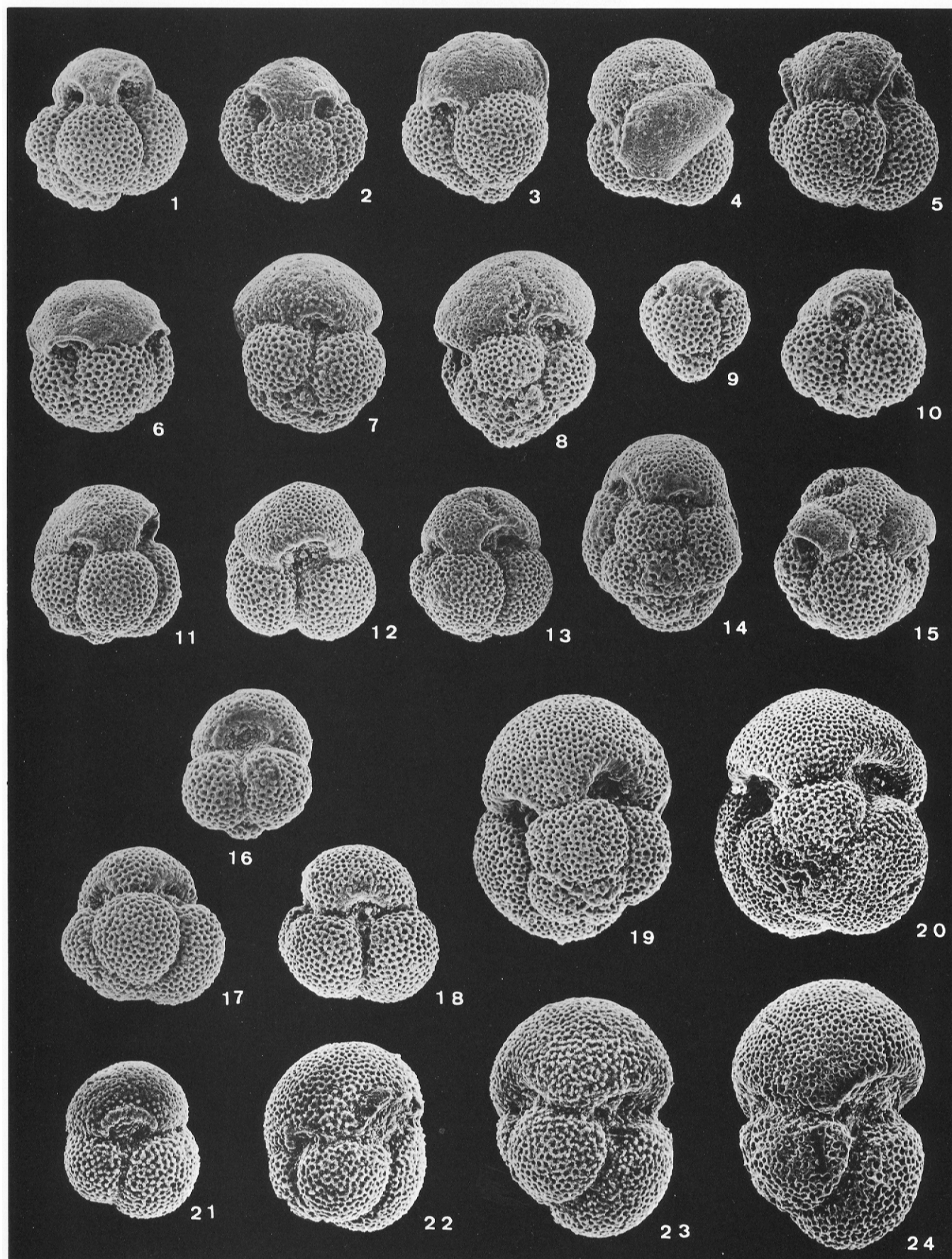
Judging from the species description and the holotype figure reproduced by Subbotina (1953) (text figs. 61, 62 in this paper), it is assumed that *korotkovi* is very close to or identical with *index* or *tropicalis*. Should the latter become verified by a comparison of the original types, *tropicalis* would then become a junior synonym of *korotkovi*. The species has originally been reported to occur in the early Senonian of the southwest slope of the Caucasus. Such an age assignment is apparently not correct and requires revision. Based on the description and figures, *korotkovi* is here regarded as a subspecies of *G. index*.

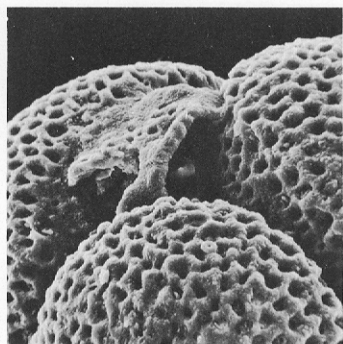
PLATE 3

All figures $\times 100$

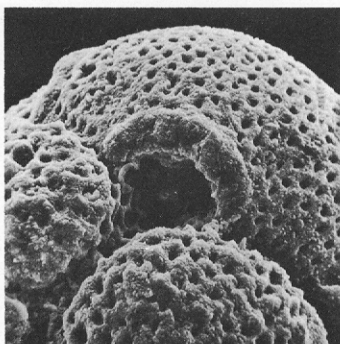
Globigerinatheka index tropicalis

- 1–20 Specimens showing variability of shape, size, wall thickness and pore size of last chamber.
All from sample Bo 536, type locality of *Globigerinatheka semiinvoluta* Zone, Hospital Hill Marl, Navet Formation, Late Eocene, Trinidad, W.I. (Bolli, 1957, p. 159–160).
- 21–23 Sample 68/65, *Globorotalia cerroazulensis cocouensis* Zone, Possagno Marl, Late Eocene, Possagno, Northern Italy. (Toumarkine and Bolli, 1970, figs. 1, 3).
- 24 Sample 650, *Globigerinatheka semiinvoluta* Zone, Possagno Marl, Late Eocene, Possagno, Northern Italy. (Cita et al., figs. 24, 27).
- 1–5 Specimens with thin walled, finely perforated, somewhat irregular shaped bulla like end chambers smaller than penultimate. Last chambers with 2–3 high arched, distinctly rimmed apertures. 3 and 4 are different views of same specimen. C26700, C26701, C26702, C26703
- 6–8 Same as 1–5 but final chamber larger than penultimate and more regular dome shaped. Apertural rims finer. C26704, C26705, C26706
- 9–10 Specimens with end chamber bulla like, smaller than penultimate, and with its wall slightly thicker and pores slightly coarser than in 1–8. Distinct apertural rims. C26707, C26708
- 11–14 As 9–10 but last chamber larger than penultimate. 11 and 12 are different views of the same specimen. C26709, C26710, C26711
- 15 Specimen with two delicate, finely pored bullae covering apertures of final chamber (bullate *tropicalis*). C26712
- 16–20 Specimens with last chamber equal or larger than penultimate, wall thickness and pore size comparable with that of earlier chambers. 17 and 18 are different views of same specimen. 16–18: last chamber with two apertures, 19, 20 are large specimens with three apertures, of which two are visible on figure. Apertural rims poorly developed or non-existent. C26713, C26714, C26715, C26716
- 21–22 Small specimens with two rimmed apertures in last chamber. C26717, C26718
- 23–24 Large, elongate specimens with three apertures of which two without rims are visible on figures. C26719, C26720

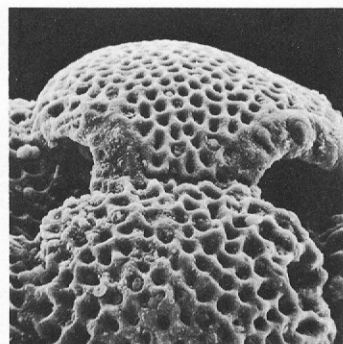




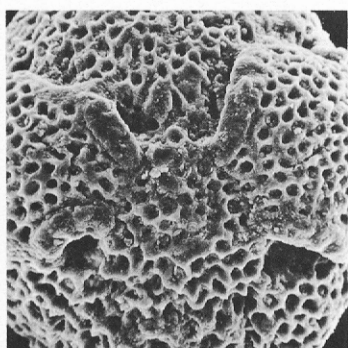
1



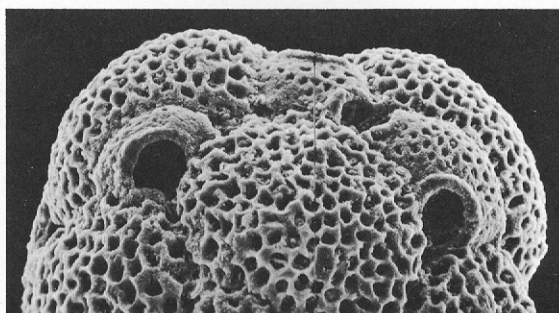
2



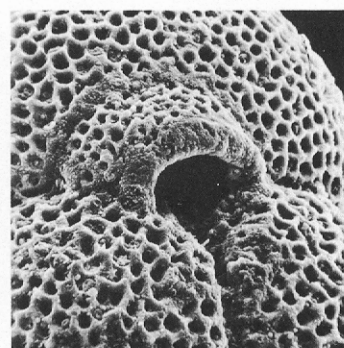
3



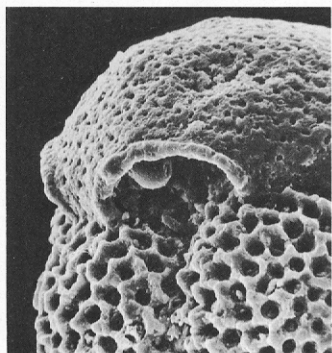
4



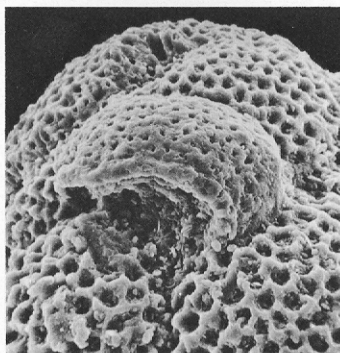
5



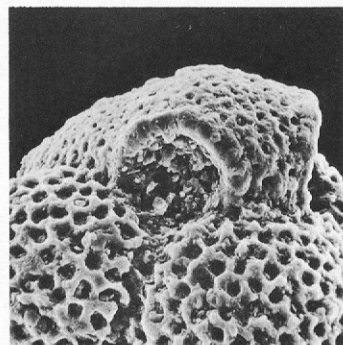
6



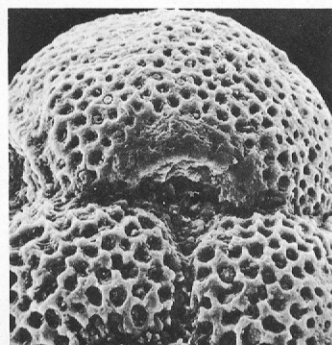
7



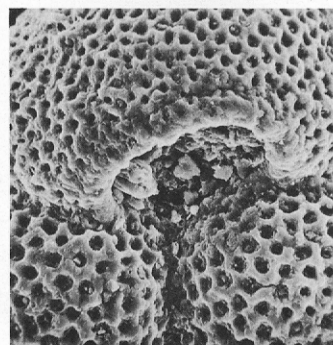
8



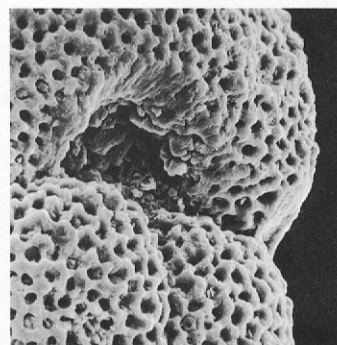
9



10



11



12

Globigerinatheka index rubriformis (Subbotina)

Plate 1, figures 5, 11–13; Text figures 69–71

Globigerinoides rubriformis SUBBOTINA, 1953, p. 92, 93, pl. 13, fig. 19; pl. 14, figs. 6–9, (holotype, pl. 14, fig. 6).

Globigerinoides index (Finlay). MYATLYUK, 1970, pl. 53, figs. 5a–c.

Of the large variability given for this species by Subbotina, Berggren (1960) includes those with a low trochospire in *G. index*. However, in comparing *rubriformis* specimens kindly made available by Dr. Subbotina with *index* from the New Zealand collections of Drs. Jenkins and Hornibrook, it becomes apparent that *rubriformis* lacks the characters of *index*, i.e. the very thick wall with granular surface and the deeply incised sutures but possesses rather those of *tropicalis* which would then be the low spired equivalent of *rubriformis*. This also fits the age assignment for *rubriformis* given by Subbotina as occurring on the limit between the Late Eocene "Zone with *Globigerinoides conglobatus* and large *Globigerina*" and the "Bolivina" Zone.

High spired specimens of the *rubriformis* type (plate 1, figs. 11–13), some with the characters of *index* (plate 1, fig. 5), also occur in the *Globigerinatheka subconglobata subconglobata* Zone of the Possagno section, concurring there with *index*. Accordingly, the *rubriformis* type thus occurs in the Middle and Late Eocene and may be regarded as a high spired variant of *index* and *tropicalis*. Therefore, it is treated here as a subspecies of *G. index*.

Globigerinatheka index tropicalis (Blow and Banner)

Plate 3, figures 1–24; Plate 4, figures 7–12;

Text figures 58–60

Globigerapsis tropicalis BLOW and BANNER, 1962, p. 124–125, pl. 15, D, E (holotype), F (paratype). BAUMANN, 1970, pl. 3, figs. 6a–c.

Globigerapsis cf. tropicalis Blow and Banner. RAJU, 1971, pl. 11, figs. 7a, b.

Globigerapsis index (Finlay). BOLLI, 1957, pl. 36, figs. 14a–16.

Globigerinoides index Finlay. HAGN, 1956, pl. 16, figs. 6–8.

Globigerinoides conglobatus (Brady). GLAESSNER, 1937, pl. 1, fig. 3. SUBBOTINA, 1953, pl. 14, figs. 2–5. SHUTSKAYA, 1958, pl. 2, figs. 1–5.

Globigerinatheka lindiensis BLOW and BANNER, 1962, pl. 15, figs. O, P (holotype), text figs. 11 (6–8).

The general test shape and arrangement of chambers is about the same as in the other subspecies of *G. index*. It differs from *G. index index* in having a more delicate wall and an absence of the deeply incised angular sutures, but specimens intermediate in character exist and it is likely that *tropicalis* has evolved from *index index*. It is for this reason that it is treated here as a subspecies of *index*.

The size of the holotype is given as 0.37 mm, but specimens of up to 0.5 mm maximum diameter are found, e.g. at Possagno and at the type locality of the *Globigerinatheka semiinvoluta* Zone of Trinidad, from which Blow and Banner (1962) also reported the subspecies. Size variations from these two localities are shown on plate 3.

PLATE 4

All figures $\times 200$

1–6 Details of bullae of *Globigerinatheka mexicana harri* specimens figured on Plate 2

1 Pl. 2, fig. 15. Very small, thin walled, finely pored bulla, aperture on right with delicate rim.

2 Pl. 2, fig. 13. Bulla with fine pores and thick apertural rim.

3 Pl. 2, fig. 18. Thick walled bulla with pore size about equal to that of earlier chambers and apertural rims.

4 Pl. 2, fig. 10. Partial view of the two thick walled, coarsely pored bullae with distinct apertural rims.

5 Pl. 2, fig. 20. Specimen with two regular sized thick walled, coarsely pored bullae. The apertures of these bullae are covered by small secondary bullae of thinner walls and finer perforation and with high arched, rimmed apertures. One of the three secondary bullae visible in the figure, bridges the two bullae, apparently covering apertures of these bullae facing each other.

6 Pl. 2, fig. 19. Partial view of large, thick walled, coarsely perforated bulla with small, secondary bulla, also fairly thick walled, coarsely perforated and with high arched, rimmed aperture.

All figures $\times 200$

7–12 Details of final chambers of *Globigerinatheka index tropicalis* specimens figures on Plate 3

7 Pl. 3, fig. 6. Thin walled, finely perforated bulla like ultimate chamber with distinct apertural rim, in contrast to thick, coarsely perforated early chambers.

8 Pl. 3, fig. 15. One of the two delicate, finely pored bullae.

9 Pl. 3, fig. 10. Small, irregular shaped, bulla like end chamber. Wall thickness and pore size intermediate between those of Fig. 7 and 12 of this plate.

10, 11 Pl. 3, fig. 14, 12. Large end chambers with wall thickness and pore size intermediate as in Fig. 9.

12 Pl. 3, fig. 19. Large end chamber with wall thickness and pore size equal to that of earlier chambers.

Blow and Banner (1962, p. 125–126, plate 15, O, P, text figs. 11, 6–8), describe *Globigerinatheka lindiensis*, a bullate form, as “closely related to, and very probably directly descended from, *Globigerapsis semiinvoluta* (Keijzer); the structure, form and disposition of the primary chambers is closely similar in the two species . . .” They also point out that “throughout later ontogeny, the chambers of *G. lindiensis* are more depressed, embracing, and more tightly coiled than in *Globigerapsis semiinvoluta*.” The range is given as limited to the *Globigerapsis semiinvoluta* Zone, Late Eocene. The bullae covering the multiple apertures of the last chamber are described as strongly inflated, subglobular, their walls being similar to those of the primary chambers but distinctly thinner. The holotype is from the *Globigerinatheka semiinvoluta* Zone, Late Eocene, Lindi area, but the species is also mentioned as apparently limited to this zone in southern Trinidad. Blow and Banner also point out the characters that distinguish *G. lindiensis* from *G. barri*.

From a comparison of the original description and figures of *G. lindiensis* with bullate *G. semiinvoluta* specimens investigated from the *Globigerinatheka semiinvoluta* Zone of Trinidad (plate 6, figs. 4–12) it would appear that most of the bullate specimens of this species are not strongly inflated (4, 12), and their wall thickness is close or equal to that of earlier chambers (5, 9), though specimens with more inflated bullae also exist (7, 10).

In comparing the holotype figure of Blow and Banner's (1962, plate 15, fig. O) *G. lindiensis* (see text fig. 80) with that of the holotype of *G. tropicalis* Blow and Banner (1962, plate 15, fig. D) (see text fig. 59), a close resemblance of the test size and shape, growth rate and arrangement of chambers, and kind of sutures can not be denied. Further, the shape and size of the final chamber and the surface texture of the test appear about the same from the figures, the only difference being the bullae in *G. lindiensis* which covers the apertures of the last chamber.

On the other hand, when the holotype figure of *G. lindiensis* is compared with that of a *Globigerinatheka semiinvoluta* as shown by Blow and Banner on plate 15, fig. J (see text fig. 79), it is apparent that the final chamber of the latter is considerably larger, more regularly circular in outline and with much larger, almost circular apertures than can possibly be present in the holotype of *G. lindiensis*.

A closer relationship of *G. lindiensis* to *G. index tropicalis* also seems apparent from the specimen shown on plate 3, fig. 15 of this paper, which is regarded as one of the rare bullate *G. index tropicalis*, possessing

strongly inflated, thin walled bullae, also typical for *G. lindiensis*. It is from these considerations that *G. lindiensis* is here not maintained as a separate taxon, descended from *G. semiinvoluta*, but rather treated as a bullate *G. index tropicalis*. Bullate forms of *G. semiinvoluta* and *G. index tropicalis* are apparently scarce and their range is not known to be different from that of the non-bullate forms.

The forms published by Glaessner (1937), Subbotina (1953), and Shutskaia (1958) as *Globigerinoides conglobatus* from the Late Eocene of the Caucasus are here included in *Globigerinatheka index s.l.* There is certainly no relation of these forms to *Globigerinoides conglobatus* Brady originally described from the Recent.

With the exception of Shutskaia (1958), who reports *conglobatus* from the Early Oligocene, the other authors give a Late Eocene age for their specimens. According to the USSR Stratigraphic Commission (1963) *conglobata* is typical of the “Late Eocene Zone of large *Globigerina* and *Globigerinoides conglobatus*.”

***Globigerinatheka mexicana barri* Brönnimann, 1952**
Plate 1, figures 18–21; Plate 2, figures 8–20; Plate 4, figures 1–6; Text figures 21–26

Globigerinatheka barri BRÖNNIMANN, 1952, p. 27–28, text figs. 3a–c (holotype) 3g, h (paratypes) (not 3d–f). BOLLI, LOEBLICH and TAPPAN, 1957, pl. 7, figs. 12a–c. BOLLI, 1957, pl. 37, figs. 8, 9. MOHAN and SOODAN, 1970, pl. 1, fig. 6. POSTUMA, 1971, p. 165.

Globigerinatheka (Globigerinatheka) index barri Brönnimann. JENKINS, 1971, pl. 21, fig. 632.

Globigerinoita index (Finlay). MYATLYUK, 1970, pl. 53, figs. 2a–c.

Reference is made to Proto Decima and Bolli's (1970) comments on the relation of *barri* with *kugleri*, and on the age assignments of the holotype and paratypes (Middle Eocene instead of the originally proposed Late Eocene). Reference is also made to the subspecies *mexicana* and *kugleri* in this paper under which headings interrelations with *G. mexicana barri* are discussed.

Globigerinatheka mexicana kugleri
(Bolli, Loeblich and Tappan)

Plate 2, figures 6–7; Text figures 12–17

Globigerapsis kugleri BOLLI, LOEBLICH and TAPPAN, 1957, p. 34, pl. 6, figs. 6a–c, (holotype).

Globigerina mexicana Cushman. MALLORY, 1959, pl. 22, figs. 9a–c.

The placing by Saito (1962) of *G. kugleri* in synonymy with *G. mexicana* is not followed here but it is agreed that the two species are closely related. Reference is made to the discussion of *G. mexicana mexicana*

in this paper where the relationships of *kugleri* with the *mexicana* and *barri* subspecies are discussed. In comparison with these taxa, *kugleri* is characterized by the larger and looser coiled initial spire more globular chambers, and resulting less compact test shape (plate 2, figs. 6, 7). Specimens with this typical *kugleri* morphology often also possess bullae (plate 2, figs. 15, 16). They are here included in *G. mexicana barri*. The stratigraphic distribution of the bullate and non-bullate forms is about the same: questionably present in the *Globigerinatheka subconglobata subconglobata* Zone, scarce in the *Globorotalia lehneri* Zone (where *mexicana mexicana* predominates), and frequent in the *Orbulinoides beckmanni* Zone, from which the holotype is described. The *kugleri* specimen figured by Bolli (1957, pl. 36, figs. 21a, b) from the *Globorotalia lehneri* Zone of Trinidad is considerably larger and more robust than the younger holotype. It is now the holotype of *G. subconglobata curryi* Proto Decima and Bolli (text figs. 27, 28).

***Globigerinatheka mexicana mexicana* (Cushman)**

Plate 2, figures 1–5; Plate 4, figures 1–6;

Text figures 1–11

Globigerina mexicana CUSHMAN, 1925, p. 61, pl. 1, figs. 8a–b, (holotype).

Globigerinatheka barri BRÖNNIMANN, 1952, text figs. 3d–f (not 3a–c, g, h).

Globigerapsis mexicana (Cushman). SAITO, 1962, p. 219, pl. 34, figs. 6a–b (not 7a–c). BLOW and SAITO, 1968, text figs. 1–4 (refigured holotype).

Globigerinoides kugleri (Bolli, Loeblich and Tappan). MOHAN and SOODAN, 1970, pl. 1, figs. 10a–b.

Globigerinoides mexicana Cushman (1925) has been misinterpreted more than any other of the *Globigerinatheka* species discussed here. This has stemmed from the original description and figures of this small species being inadequate by today's standards, and from the fact that Cushman himself (1927) and other authors have subsequently figured under this name specimens which are much larger and have partly different features, and which therefore do not belong to *G. mexicana s.s.* but rather to the *G. subconglobata curryi/euganea* lineage. To demonstrate these differences, the original holotype figures of Cushman (1925), and those re-drawn by Blow and Saito (1968) are here shown on text figs. 1–6 along with specimens figured later as *G. mexicana* by Cushman (1927, same locality as holotype), Beckmann (1953), Saito (1962), and Todd and Low (1960), on text figs. 35–42. All line drawings have been made from the published figures and they are presented here to facilitate comparison at a uniform magnification of approximately $\times 75$.

Bolli, Loeblich and Tappan (1957) were misled by some of these later published figures of "large" *mexicana* in that they based their genotype of *Porticulasphaera* (now *Orbulinoides*) on this species; see Saito (1962), Loeblich and Tappan (1964), Blow and Saito (1968), and Proto Decima and Bolli (1970).

Saito (1962), in reviewing and emending the genera *Globigerapsis* and *Globigerinatheka*, also emended *G. mexicana*. He included in this species not only the above quoted "large mexicanas" by Cushman, Beckmann, and Todd and Low but also of Hamilton (1953) and Weiss (1955), further the non-bullate paratype of *G. barri* Brönnimann, 1952, text figs. 3d, f), the holotypes of *G. kugleri* and the hypotype of this species figured by Bolli (1957, plate 36 figs. 21a, b) which has since become the holotype of *G. subconglobata curryi*, the *G. mexicana* of Stainforth (1953), and of Mallory (1959, plate 22, figs. 9a–c) here regarded as *G. mexicana kugleri*. Saito figures on his plate 34 two specimens. That of his text figs. 6a, b (text figs. 10, 11 of this paper) measure .34 mm, its chambers are arranged in a compact way, the surface is finely perforate and the last chamber covering the umbilical area is somewhat irregularly shaped and comparable with Cushman's original *G. mexicana*. The specimen of his text figs. 7a–c (text figs. 40–42 of this paper), on the other hand, measures .53 mm and is thus much larger and more robust, with more coarsely perforated walls. It is here placed in *Globigerinatheka subconglobata euganea*. Though Saito was first to realize that the large forms described by Bolli, Loeblich and Tappan as *Porticulasphaera* (now *Orbulinoides*) are not comparable with the small *G. mexicana* holotype, he continued to include in *mexicana* many large forms now assigned to the *G. subconglobata curryi/euganea/O. beckmanni* lineage.

Saito set a precedent for regarding *G. mexicana* and *G. barri* as very closely related, *mexicana* being the non-bullate form. This concept found support in comparisons by Dr. J. P. Beckmann of the original types at the U.S. National Museum. He notes that, compared with *mexicana*, *barri* has slightly more inflated chambers, a smaller final chamber, and a more delicate aspect. He concluded, however, that it would be difficult to distinguish between these forms in practice, hence it only appears justified to separate them—if at all—at the subspecies level.

On the other hand, according to Dr. Beckmann *G. kugleri* can be distinguished more readily from *G. barri* by its much larger initial spire. In his opinion it may belong to an altogether different group and thus should not be placed in synonymy with *G. mexicana*. Nevertheless the present author's investigations of may suites

of specimens indicate that intermediate forms also exist between *kugleri* and *mexicana* and make a strict distinction between these forms difficult. Bullate specimens encountered in the wider-spined range are here included in *barri* (see plate 2, figs. 15, 16).

In their paper "The morphology and taxonomy of *Globigerina mexicana* Cushman, 1925," Blow and Saito (1968) list a synonymy quite different from that of Saito (1962). Of the *mexicana* listed by Saito, only Cushman's holotype and the two specimens figured by Saito (1962) remain. Among the omissions are the non-bullate *G. barri* paratype and the holotype of *G. kugleri*. On the other hand, the holotype of *G. semiinvoluta* and numerous specimens correctly figured under this name are included by Blow and Saito in the synonymy of *G. mexicana*. Such a proposed synonymy of *G. semiinvoluta* with *G. mexicana* is critically discussed on p. 120–122 of this paper.

Blow and Saito (1968) gave a much needed re-description and re-illustration of the holotype of *G. mexicana*. From a comparison of their illustrations with

the original type, the apertural lips, according to Dr. J. P. Beckmann, may not protrude as far as is shown on the figures. Further, a less coarse perforation of the last chamber compared with the earlier ones, as described by Blow and Saito, does not show on the drawings.

Based on original types, *G. mexicana* is here regarded as almost identical with *barri* except for the bullae of the latter. *G. kugleri* differs from *G. mexicana* in its larger initial spire and its more globular chambers with deeper sutures, resulting in a less compact test. Intermediate forms exist between all three extremes and a subspecific scheme of nomenclature is therefore considered appropriate. *G. mexicana* is taken as the central species in which *mexicana*, *barri*, and *kugleri* are included as intergrading subspecies.

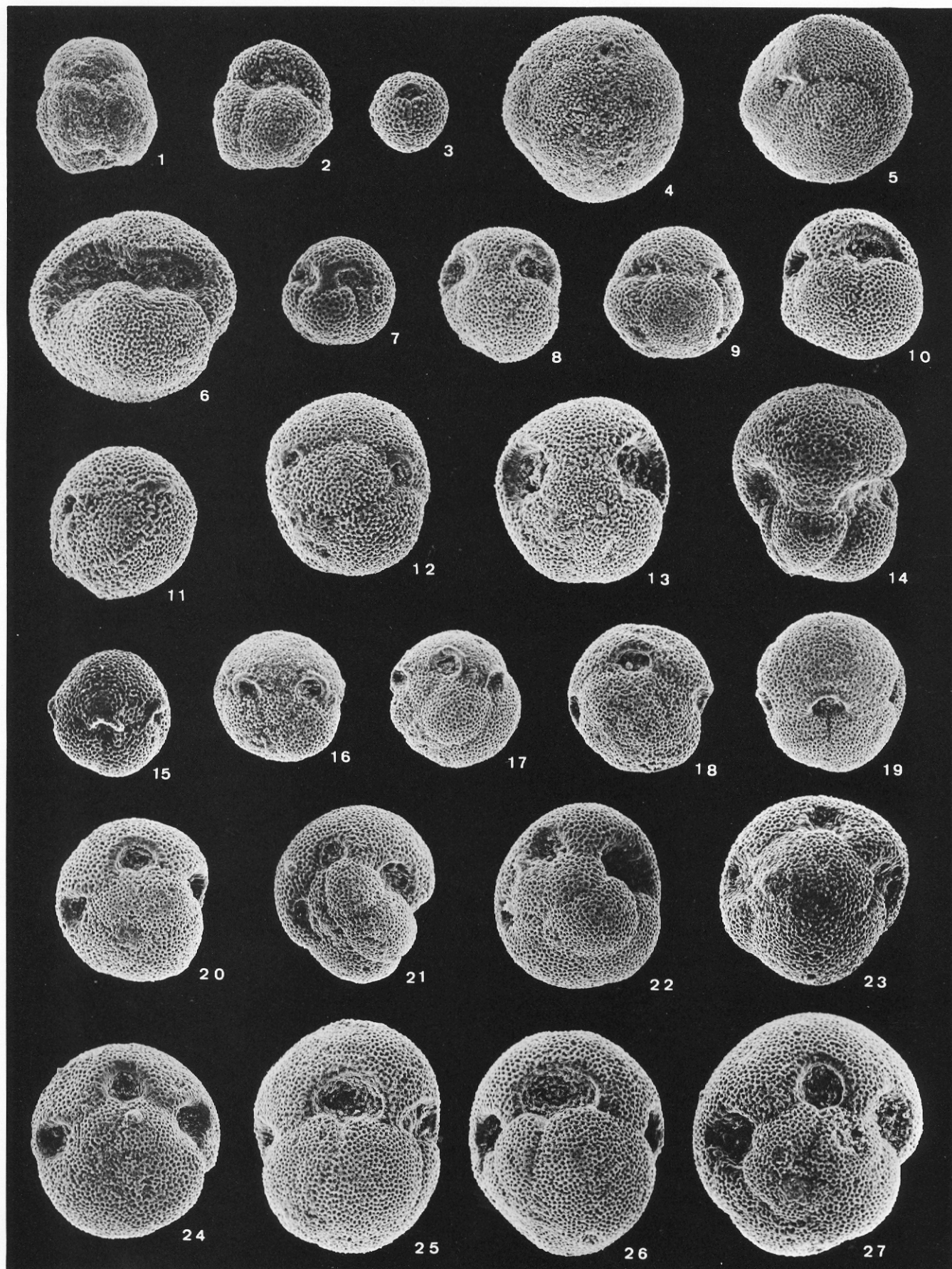
G. mexicana mexicana is frequent in the *Globorotalia lehneri* Zone (type locality of that zone in Trinidad, W.I., Bolli, 1957; Cava Zillo, Italy, Proto Decima and Bolli, 1970; Possagno, Italy, Toumarkine and Bolli, 1970) and continues into the *Orbulinoides beckmanni*

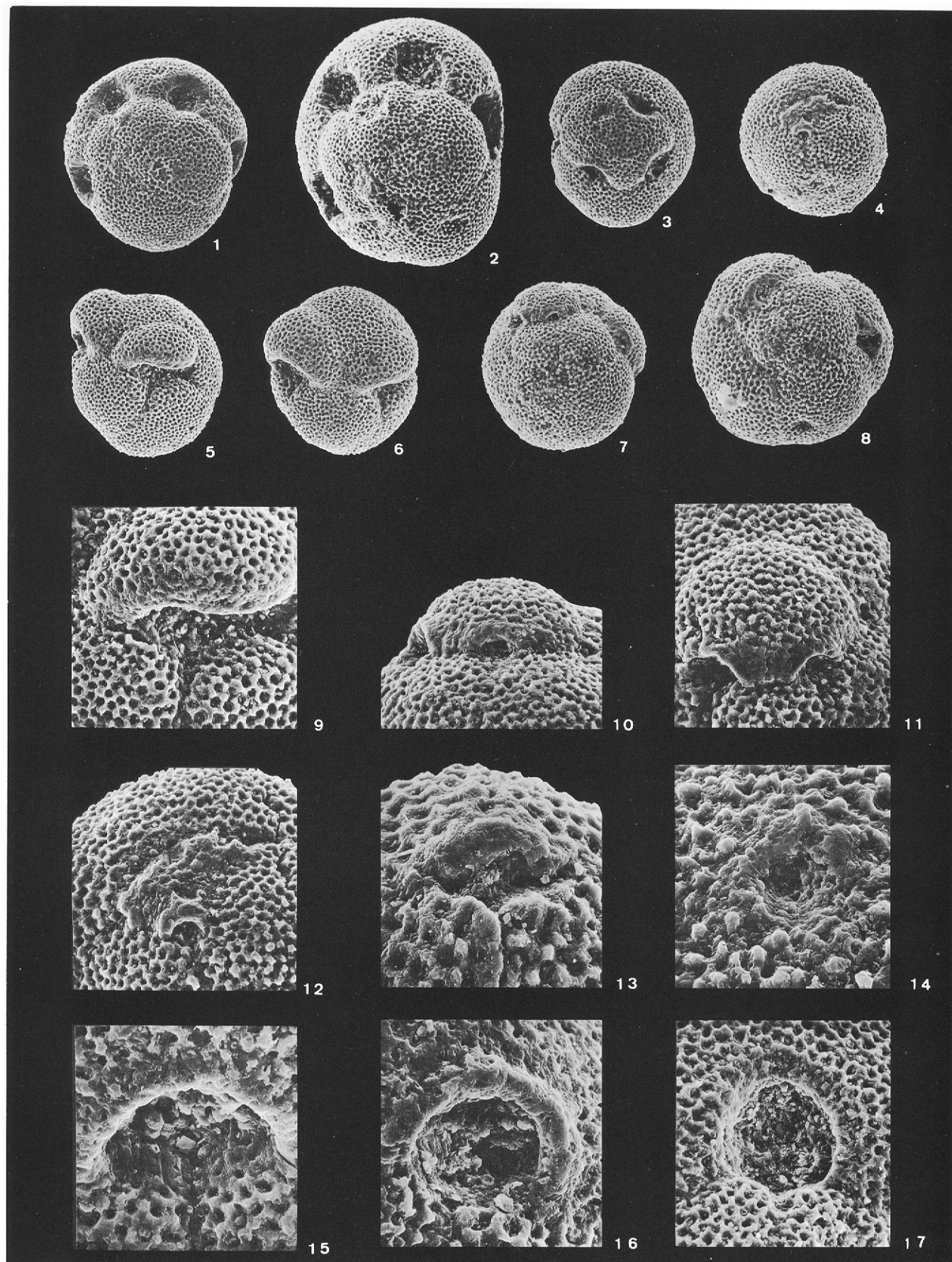
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PLATE 5

All figures $\times 80$ *Globigerinatheka semiinvoluta*

- | | | | |
|------|---|--------|---|
| 1–27 | Variability in test size and shape, number and size of apertures. All specimens from sample Bo 536, type locality of <i>Globigerinatheka semiinvoluta</i> Zone, Hospital Hill Marl, Navet Formation, Late Eocene Trinidad, W.I. (Bolli, 1957, p. 159, 160). | 12 | Spherical specimen with small, rimmed apertures. C26732 |
| 1–6 | Specimens with one aperture in last chamber. | 13 | Specimen with extremely large apertures with no rims. C26733 |
| 1, 2 | Juvenile stages of medium to large size end-forms. 1, spiral view, 2, umbilical view with large, low arched single aperture. C26721, C26722 | 14 | Large, elongate specimen with large apertures and early chambers clearly separated by fairly deep sutures. C26734 |
| 3 | Minute spherical specimen with one distinct, rimmed aperture. Aperture detail Pl. 6/13. C26723 | 15–27 | Specimens with three apertures in last chamber. |
| 4, 5 | Spherical specimens, each with one very small aperture. Aperture detail of 4: Pl. 6/14. C26724, C26725 | 15 | Small specimen with distinct apertural rims. C26735 |
| 6 | Large specimen with extremely wide aperture, central portion of which is less high, giving the impression that originally there may have been two apertures, with the dividing wall part possibly dissolved. Several such specimens were observed. C26726 | 16, 17 | Two views of same small specimen with almost circular, distinctly rimmed apertures. Last chamber with thinner wall and finer pores than earlier ones. Detail of aperture on right of 16: Pl. 6/16. C26736 |
| 7–14 | Specimens with two apertures in last chamber. | 18–20 | Specimens with average sized apertures, some with rims. 20: Early whorl in lower center, hardly discernable because of weakly developed sutures. Detail of central aperture of 19: Pl. 6/15. C26737, C26738, C26739 |
| 7 | Very small specimen with average sized aperture. C26727 | 21 | Medium sized specimen with end chamber larger than early portion whose chambers are clearly separated by fairly deep sutures. C26740 |
| 8 | Small specimen with large apertures. C26728 | 22 | Specimens with one large and two average size apertures. Early whorl visible in center of figure. C26741 |
| 9 | Small specimen with one very small and one average aperture. C26729 | 23 | Specimen with last chamber larger and partially involving early portion. C26742 |
| 10 | Specimen with large apertures. C26730 | 24 | Spherical specimen with very high arched, almost circular apertures. C26743 |
| 11 | Spherical specimen with minute apertures, one with distinct rim. C26731 | 25, 26 | Large, slightly elongate specimens. C26744, C26745 |
| | | 27 | Very large specimen with high, almost circular apertures. Detail of middle aperture: Pl. 6/17. C26746 |





Zone (Trinidad, Cava Zillo) but becomes very scarce to absent in the *Truncorotaloides rohri* Zone and the *Globigerinatheka semiinvoluta* Zone (Trinidad, Possagno). By comparison, *G. mexicana kugleri* is more poorly represented in the *Globorotalia lehneri* Zone in Trinidad but frequent in the *Orbulinoides beckmanni* Zone, above which it is apparently not recorded.

***Globigerinatheka semiinvoluta* (Keijzer)**

Plate 5, figures 1–27; Plate 6, figures 1–17;

Text figures 72–79

Globigerinoides semiinvolutus KEIJZER, 1945, p. 206, pl. 4, figs. 58a–e, (holotype).

Globigerinoides index Finlay. BECKMANN, 1954, pl. 25, fig. 14.

Globigerapsis semiinvoluta (Keijzer). BOLLI, LOEBLICH and TAPPAN, 1957, p. 34, pl. 6, figs. 7a–c. BOLLI, 1957, pl. 36, figs. 19–20. BLOW and BANNER, 1962, p. 125, pl. 15, figs. J–L.

Globigerapsis mexicana (Cushman). POSTUMA, 1971, p. 141. RAJU, 1971, pl. 11, figs. 1–6.

The original species definition of *Globigerinoides semiinvolutus* by Keijzer (1945) was later slightly emended by Bolli (1957), and Blow and Banner (1962). Despite the characteristic test shape, high arched sub-circular apertures of the final regular-shaped hemispherical chamber, fairly large average size, and stratigraphic restriction to the lower part of the Late Eocene, the species has on occasions been misidentified, e.g. by Eckert (1963, see comments in this paper under *G. subconglobata luterbacheri* n. subsp.), or erroneously placed in synonymy with *G. mexicana* by Blow and Saito (1968). The specimens here figured on plates 5 and 6 show the variability of the species in size, shape of test, number and form of apertures in final chamber, and occasional

presence of small bullae. The test size varies in the specimens figured here from 0.17 mm (plate 1, fig. 3) to 0.54 mm (plate 2, fig. 2), and the number of apertures in the final chamber from one to four. This variability is demonstrated by specimens coming from a single level, sample Bo 536, the type locality of the Late Eocene *Globigerinatheka semiinvoluta* Zone, Navet Formation, Trinidad, W.I. (Bolli, 1957), where the species is abundant. In the section of Possagno, Northern Italy, the Late Eocene *Globigerinatheka semiinvoluta* Zone measures about 100 meters (Toumarkine and Bolli, 1970). Here *G. semiinvoluta* is much less common and also of an inferior preservation compared with Trinidad. General test size and aperture variation are about the same as observed in Trinidad, though no specimens with four apertures or with bullae were seen. Further, no evidence could be found that any of the morphologic features such as test size or number of apertures are stratigraphically restricted to parts of the thick *Globigerinatheka semiinvoluta* Zone of Possagno. Unless it can be shown from other sections that some of the variable characters are related to stratigraphic levels, no reason is seen to split the species into more taxa.

The test shape of *G. semiinvoluta* is close to spherical, often also somewhat elongate up to a length/width ratio of 5:4. The last chamber is regularly rounded and in most specimens close to hemispherical, making up about half of the test volume, as can be seen from most specimens figured on plate 5. Occasionally the final chamber may be smaller (fig. 9) or larger (fig. 27) than half the test volume and rarely of only rudimentary size (plate 6, fig. 3). As a rule, the wall of the ultimate chamber

←
PLATE 6

Figures 1–8 ×80

9–12 ×200

13–16 ×400

Globigerinatheka semiinvoluta

- 1–17 Continued from Plate 5 (all specimens from locality Bo 536)
- 1–3 Specimens with four apertures in last chamber.
- 1 Large specimen with almost circular apertures. C26747
- 2 Very large, elongate specimen with almost circular apertures. C26748
- 3 Specimen with small bulla like end chamber. Fourth aperture on left of small chamber, not visible in figure. C26749
- 4, 12 Spherical specimen with one small aperture covered by thin walled finely pored, not inflated bulla with three rimmed apertures. Detail: Fig. 12. C26750

- 5, 6, 9 Specimen with two bullae protecting apertures of last chamber. They are thick walled, coarsely pored like the chambers of the specimen, each possessing one wide aperture. 9: Detail of right bulla on 5. C26751
- 7, 10, 11 Specimen with two inflated bullae covering apertures of final chamber. Wall thickness and pore size of bullae only very slightly finer than in earlier chambers, each with two rimmed apertures. 10, 11: Detail views of bulla on upper left of 7. C26752
- 8 Large specimen with two bullae similar to those of 7. C26753
- 13 Aperture detail of pl. 5, fig. 3.
- 14 Aperture detail of pl. 5, fig. 4.
- 15 Aperture detail of pl. 5, fig. 19.
- 16 Aperture detail of pl. 5, fig. 16.
- 17 Aperture detail of pl. 5, fig. 27.

compares in thickness and pore size with that of early chambers. Only very exceptionally are the pores of the last chamber finer (plate 5, figs. 16, 17). The sutures are normally quite weakly incised between early chambers, but better visible between the last and earlier chambers. Only where early chambers are more globular than usual are the sutures clearly discernible between them.

Figs. 1 and 2 of plate 5 are spiral and umbilical views of specimens which lack the final chamber covering the umbilical area. The number of apertures is not directly related to the size of the specimen. Those with two (plate 5, figs. 7–14) or three (figs. 15–27) are much more common than those with only one (figs. 1–6) or four (plate 6, figs. 1–2). Small specimens may have two (plate 5, figs. 7–9) or three (figs. 15–18) apertures, large ones only one (figs. 4–6) or two (figs. 12–14). Considerable variation also exists in size and shape of apertures. Except for some of the very small apertures (plate 5, fig. 5) they are distinctly high-arched (figs. 25, 26) to circular (figs. 17, 27). Apertures may be framed by distinct rims (plate 5, figs. 16, 17; plate 6, fig. 16), or be without (plate 5, figs. 22, 27; plate 6, fig. 17). They may be so minute that they are difficult to discern (plate 5, figs. 4, 5, 11; plate 6, figs. 13, 14) or become very large (plate 5, figs. 6, 13, 22). The size of the apertures may be fairly constant in a given specimen (plate 5, figs. 16, 24) or differ considerably (figs. 10, 22). Specimens with normal size or larger than average apertures are much more common than those with extremely small ones.

Specimens otherwise indistinguishable from *G. semiinvoluta* occasionally possess bullae covering the apertures of the final chamber (plate 6, figs. 4–12). They may be very small and not inflated, with one or more openings and with a pore size finer than in previous chambers (figs. 4, 12), or be somewhat larger and inflated with nearly equal pore size (figs. 7, 8, 10, 11), or become fairly large and with a wall thickness and pore size indistinguishable from earlier chambers (figs. 5, 6, 9).

Globigerinatheka subconglobata curryi

Proto Decima and Bolli

Plate 1, figure 14; Text figures 27–30

Globigerapsis kugleri Bolli, Loeblich and Tappan. BOLLI, 1957, pl. 36, figs. 21a, b, hypotype (later designated as holotype of *Globigerinatheka curryi* by Proto Decima and Bolli, 1970, p. 889, 891, 893–894). POSTUMA, 1971, p. 139.

Globigerapsis index (Finlay). TODD, 1966, pl. 2, figs. 1a–c.

Globigerinatheka curryi PROTO DECIMA and BOLLI, 1970, pl. 1, figs. 1–4, pl. 3, figs. 1–2, text figs. 1–3a, 38–39b.

Proto Decima and Bolli (1970) described and

illustrated the evolutionary lineage *Globigerinatheka curryi*—*G. euganea*—*Orbulinoides beckmanni*, observed in the Middle Eocene of Barbados, Trinidad, and Northern Italy. This lineage is here regarded as having its origin in *Globigerinatheka subconglobata*; consequently *G. curryi* and *G. euganea* are treated as subspecies of *subconglobata*. *G. subconglobata curryi*, assumed to have branched off from *G. subconglobata subconglobata* late in the *Globigerinatheka subconglobata subconglobata* Zone differs from it in a wider initial spire, that is in a more rapid increase in size of succeeding chambers, and in the final chamber, umbilical in position, usually being larger and more inflated. Further, *curryi* specimens may possess bullae (plate 1, fig. 14) a feature not reported from *G. subconglobata subconglobata*.

Globigerinatheka subconglobata euganea

Proto Decima and Bolli

Text figures 31–42

Globigerinatheka euganea PROTO DECIMA and BOLLI, 1970, p. 894–895, pl. 1, figs. 6–11, (fig. 7: holotype), pl. 3, figs. 3–5, text figs. 8–15, 31–31a, 43–45b.

Globigerina mexicana Cushman. CUSHMAN, 1927, pl. 26, figs. 16, 17.

Globigerinoides mexicana (Cushman). BECKMANN, 1953, pl. 25, figs. 15, 16.

Globigerapsis mexicana (Cushman). TODD and LOW, 1960, pl. 259, fig. 7. SAITO, 1962, pl. 34, figs. 7a–c (not 6a–b).

Globigerapsis cf kugleri Bolli, Loeblich and Tappan. BAUMANN, 1970, pl. 1, figs. 13a, b.

Globigerinatheka barri Brönnimann. BAUMANN, 1970, pl. 3, fig. 1.

G. subconglobata euganea is considered to have evolved from *G. subconglobata curryi* (see above) and to be the ancestral form of *Orbulinoides beckmanni*. In comparison with *curryi*, *euganea* possesses sutures that are less incised and consequently a more spherical test, usually more numerous but smaller sutural apertures in the final chamber and occasional spiral sutural apertures in the preceding one to three large chambers. *G. subconglobata euganea* is similar to *Orbulinoides beckmanni* in overall test shape, but it differs in the lack of areal apertures and spiral sutural apertures between the early chambers. It ranges from within the *Globorotalia lehneri* Zone to within the *Orbulinoides beckmanni* Zone and overlaps both, *G. subconglobata curryi* and *O. beckmanni*.

Globigerinatheka subconglobata luterbacheri

n. subsp.

Plate 1, figures 17, 22–25; Plate 7, figures 1–17; (figure 13: holotype), Text figures 47–50

Globigerapsis semiinvoluta (Keijzer). ECKERT, 1963, pl. 7, figs. 1a–3c.

Globigerinatheka barri Brönnimann. ECKERT, 1963, pl. 7, figs. 4a-d.

Globigerinoita index (Finlay). MYATLYUK, 1970, pl. 53, figs. 3a, b, 4a, b.

Test free, compact, subglobular to almost globular to slightly elongate. Early coil low trochospiral, single chambers poorly visible because of strong thickening of wall. Two or three chambers prior to ultimate one are distinctly larger, three forming a whorl. Final chamber may be up to half the size of the test volume, covering the umbilical region of the early coil, but may also be only slightly larger or smaller than penultimate chamber in which case it may become difficult to distinguish it from a bulla. Wall calcareous, thick, coarsely perforate. Aperture in small early stage single, interiomarginal-umbilical, low-arched, slitlike, fairly wide. In medium sized and larger specimens last chamber with 2-3, seldom 4, sutural apertures, which are low-arched in specimens with small ultimate chamber, medium to fairly high-arched and wide in specimens with larger sized end chambers. Apertures may be bordered by a distinct rim. Apertures in particular of larger specimens may be covered by bullae, each again with 2-3 subsidiary apertures. The size of the bullae may vary considerably, from very small, often covering only part of a large aperture, to a size so large that it may become difficult to decide whether it is a large bulla or a rudimentary sized end chamber.

Coiling: Predominantly dextral.

Greatest diameter: Holotype (pl. 7, fig. 13), 0.55 mm; figured paratypes, 0.4 to 0.6 mm.

Remarks: With both subspecies having a maximum test size of about .6 mm, *luterbacheri* resembles at first sight *G. subconglobata euganea*; but differs from it in often having a more elongate test (plate 7, figs. 3, 4, 7, 8, 13). The sutures between the last chambers are often fairly deeply cut and somewhat angular (fig. 9) in contrast to the much less pronounced ones in *euganea*, giving the whole test surface a more rugged appearance compared to the smoother, more rounded aspect of *euganea*. In particular the surface of the coil appears coarser in *luterbacheri* and the bullae vary more in size. Bullae covering only part of an aperture, as is not uncommon in *luterbacheri*, were so far not seen in *euganea*. Stratigraphically, *euganea* occurs from the upper part of the *Globorotalia lehneri* Zone to the lower part of the *Orbulinoides beckmanni* Zone, *luterbacheri* ranges from probably within the *Orbulinoides beckmanni* Zone into the *Globigerinatheka semiinvoluta* Zone.

G. subconglobata luterbacheri differs from *G. mexicana kugleri* in its more robustly built wall, more globu-

lar and compact test shape and larger size, from *G. mexicana mexicana/barri* in the more robust wall and distinctly larger test size, and from *G. semiinvoluta* in its coarser surface, generally larger size, and less highly arched apertures on the last chamber, which are often almost circular in *semiinvoluta*. Bullate forms are frequent in *luterbacheri*, very scarce in *semiinvoluta*.

It appears that *luterbacheri* branched off from the *subconglobata* stock within *Orbulinoides beckmanni* time, but may possibly also have originated from *G. index index*. Eckert (1963) regards the specimens figured on his plate 7, figs. 1-4, as an evolutionary sequence (Entwicklungsreihe) from *G. semiinvoluta* to *G. barri*. He assigns the forms without bulla (figs. 1a-c), and those with one and two bullae (figs. 2a-3c), or with not all apertures of the last chamber covered by bullae, to *semiinvoluta*, and those with three bullae, covering all apertures of the last chamber, to *barri*. The specimens of Eckert compare well in morphology and large size with those illustrated here as *G. subconglobata luterbacheri*, which were selected from his own original sample AA3858. Further examination of this sample did not reveal any *G. semiinvoluta*. Ecker's concept of an evolution from *semiinvoluta* to *barri* can also not be accepted for *barri* occurs earlier and has its peak development in the Middle Eocene *Globorotalia lehneri* and *Orbulinoides beckmanni* zones, while *G. semiinvoluta* is restricted to the lower part of the Late Eocene.

Stratigraphic range: ? *Orbulinoides beckmanni* Zone, *Truncorotaloides rohri* Zone to within *Globigerinatheka semiinvoluta* Zone.

Holotype: Plate 7, fig. 13; paratypes: plate 7, figs. 1-12, 14-17, from sample AA3858, *Globorotalia cerroazulensis coccaensis*/*Globigerinatheka semiinvoluta* Zone, Globigerina-marls of the Niederhorn-Pilatus nappe, Switzerland. Locality: Outcrop No. 2 of Eckert (1963, figs. 6 and 7, p. 1016; Level 32, p. 1019), in a small gully approximately 200 m. NNE of the barns of Alp Unter-Looegg (1373 m), on the south slope of the Schimbrig, valley of the Grosse Entlen, Central Switzerland (Map: Landeskarte der Schweiz, 1:25000, Schüpheim, Blatt 1169).

Globigerinatheka subconglobata micra (Shutsкая) Text figures 18-20

Globigerinoides subconglobatus Chalilov var. *micra* SHUTSKAYA, 1958, p. 87, 88, pl. 1, figs. 1-3, (holotype, fig. 1).

Distribution according to Shutsкая (1958): "In contrast to other representatives of fossil plankton, this is a relatively rare form. It was only found in the Nagutskii

standard well of the Mineralvodskii region in the beds with *Globorotalia aragonensis* of the Tcherkessk Horizon (Middle Eocene), in the age-equivalent beds of the Sunski river section of the Groznenski region and in the Nagypskii section of the Feodosia region in the eastern Crimea."

The Tcherkessk Horizon contains in Soviet terms the *Globorotalia aragonensis* and the *Acarinina crassaformis* zones. The former correlates with the *Globorotalia aragonensis* Zone of Bolli (1957, 1966) and possibly with part of the *Globorotalia palmerae* Zone (*Acarinina pentacamerata* Zone of Krasheninnikov, 1965). The *Acarinina crassaformis* Zone equals the *Hantkenina aragonensis* Zone of Bolli, possibly reaching in its lower part into the *Globorotalia palmerae* Zone. On her range chart Shutskeya (1958, fig. 1) lets the subspecies begin in the upper part of the Tcherkessk Horizon. It is thus possible that it already appears in beds that correspond with the Early Eocene *Globorotalia palmerae* Zone. Upwards, Shutskeya extends the likely range into the lower part of the Kerestinsk Horizon. Following Shutskeya, *G. subconglobata micra* is the small (0.3–0.4 mm) ancestral form of *G. subconglobata subconglobata* (0.5–0.65 mm).

Dr. J. P. Beckmann has compared *G. subconglobata micra* specimens from the Caucasus with similar forms from the Early Middle Eocene of Egypt, and also with the holotype of *Globigerina orbiformis* Cole from the Middle Eocene Guayabal Formation of Mexico. They both show, according to him, some affinities to the *Globigerina senni* group where wall structure is concerned (comparatively thick, with fine spinose projections in the umbilical area).

G. subconglobata micra has so far not been recorded from the late Early Eocene and Middle Eocene of the Possagno section, Italy, and therefore a descentance of *G. subconglobata subconglobata* from *G. subconglobata micra* could not be confirmed there.

Globigerinatheka subconglobata subconglobata
(Shutskeya)

Plate 1, figures 8–10, 15, 16; Text figures 43–46

Globigerinoides subconglobatus Chalilov var. *subconglobata*
Chalilov (ms.). SHUTSKAYA, 1958, p. 86, 87, pl. 1, figs. 4–11 (no holotype designated).

Though the taxon was first published by Shutskeya she gives Chalilov (ms.) as author of the species and subspecies. However, according to Article 50 of the International Code of Zoological Nomenclature, Shutskeya the person who first published the name, is to be regarded as its author.

She correctly described (p. 86, 87) and figured (plate 1, figs. 4–11) the subspecies but failed to designate a holotype from the 8 illustrated specimens. Following Article 74 of the ICZN the specimen of Shutskeya's fig. 8 is here designated as lectotype of *G. subconglobata subconglobata*.

Distribution according to Shutskeya (1958): Widely occurring in the Kerestinsk Horizon, the lower Horizon of the Late Eocene (Middle Eocene for most workers outside the Soviet Union) immediately below the Kumsk Horizon (Beds with *Lyrolepis caucasica* Roman), northern Caucasus, Crimea, southern Yergenei and northwest Prekasian regions. This variety occurs consistently in the Kerestinsk Horizon of these regions, but in the sections it is unevenly distributed. In some beds it is found in massive numbers, in others it is found only scattered, whereas it may be completely absent in still others.

In Soviet terms the Kerestinsk Horizon includes the *Hantkenina alabamensis*/*Globigerinoides subconglobata* Zone which correlates with the *Globorotalia lehneri* and *Orbulinoides beckmanni* zones, and possibly also with part of the *Globigerinatheka subconglobata subconglobata* Zone of this paper. Shutskeya (1958, text fig. 1) extends the likely range of *G. subconglobata subconglobata* to the top of the Kumsk Horizon which in our terms reaches to the top of the *Truncorotaloides rohri* Zone. The subspecies develops according to Shutskeya from *G. subconglobata micra* near the top of the Tcherkessk Horizon.

Specimens seen from the Kuban River section (Caucasus), occurring with "*Globigerinoides*" *higginsii* and *Globorotalia cerroazulensis frontosa* are closely comparable with the published figures of *G. subconglobata subconglobata*.

However, some, with larger, higher domed shaped end chambers and higher arched apertures would instead need to be regarded as *G. index index*. Based on published figures and the specimens seen from the Caucasus, the subspecies also occurs in the Middle Eocene of the Possagno section, Italy (plate 1, figs. 8–10, 15, 16). There it occurs in the upper part of the *Hantkenina aragonensis* Zone, to continue at least to the top of the *Globorotalia lehneri* Zone.

REFERENCES

- BANNER, F. T., and BLOW, W. H., 1959, The classification and stratigraphical distribution of the Globigerinaceae, Part 1: Paleontology, v. 2, pt. 1, p. 1–27, figs. 1–5, pls. 1–3.
BAUMANN, P., 1970, Mikropaläontologische und stratigraphische Untersuchungen der obereozänen-oligozänen Scaglia im zentralen Apennin (Italien): Eclogae Geol. Helv., v. 63, no. 3, p. 1133–1211, figs. 1–27, pls. 1–7.

- BECKMANN, J. P., 1953, Die Foraminiferen der Oceanic Formation (Eocaen-Oligocaen) von Barbados, Kl. Antillen: *Eclogae Geol. Helv.*, v. 46, no. 2, p. 301-412, figs. 1-29, pls. 16-30, 1 table.
- BERGGREN, W. A., 1960, Paleogene biostratigraphy and planktonic foraminifera of the Southwestern Soviet Union—an analysis of recent Soviet investigations: *Stockholm Contr. Geology*, v. 6, no. 5, p. 64-128, figs. 1-2, tables 1-8.
- , 1971, Tertiary boundaries and correlations: *The Micropaleontology of Oceans* edited by B. M. Funell and W. R. Riedel: Cambridge Univ. Press, p. 693-809, tables 52.1-52.40.
- BLOW, W. H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy: *Proc. 1st Int. Conf. Plankt. Microfossils*, p. 199-422, figs. 1-43, pls. 1-53.
- BLOW, W. H., and BANNER, F. T., 1962, The Mid-Tertiary (Upper Eocene to Aquitanian) Globigerinaceae: In Eames, Banner, Blow and Clarke, *Fundamentals of Mid-Tertiary stratigraphical correlation*: Cambridge Univ. Press, p. 61-151, figs. 6-19, pls. 8-17.
- BLOW, W. H., and SAITO, T., 1968, The morphology and taxonomy of *Globigerina mexicana* Cushman, 1925: *Micropaleontology*, v. 14, no. 3, p. 357-360, figs. 1-4.
- , 1968a, Comments and errata: *Micropaleontology*, v. 14, no. 4, p. 505.
- BOLLI, H. M., 1957, Planktonic foraminifera from the Eocene Navet and San Fernando formations of Trinidad, W.I.: *U.S. Natl. Mus. Bull.* 215, p. 155-172, figs. 25-55, pls. 35-39.
- , 1957a, Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, B. W. I.: *ibid.*, p. 97-123, figs. 18-21, pls. 22-29.
- , 1966, Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera: *Bol. Inf., Asoc. Ven. Geol., Min. y Petr.*, v. 9, no. 1, p. 3-32, tables 1-4.
- BOLLI, H. M., LOEBLICH, A. R., and TAPPAN, HELEN, 1957, Planktonic foraminiferal families Hantkeninidae, Orbulinidae, Globorotaliidae and Globotruncanidae: *U.S. Natl. Mus. Bull.* 215, p. 3-50, figs. 1-9, pls. 1-11.
- BRÖNNIMANN, P., 1952, *Globigerinoita* and *Globigerinatheka*, new genera from the Tertiary of Trinidad, W.I.: *Cushman Found. Foram. Research Contr.*, v. 3, pt. 1, p. 25-28, figs. 2-3.
- CATI, F., and BORSETTI, A. M., 1968, The accessory structures in Tertiary planktonic foraminifera: *Giorn. Geol.*, p. 387-400, figs. 1-64.
- CITA, MARIA BIANCA, 1968, Guide de l'Excursion en Italie, 1968: Comité Français de Strat., Coll. sur l'Eocène, édité par l'Ist. di Pal. Univ. Milano, p. 1-82, figs. 1-30.
- COLE, W. S., 1927, A foraminiferal fauna from the Guayabal Formation in Mexico: *Bull. Am. Pal.*, v. 14, no. 51, p. 1-46, pls. 1-5.
- CONGRESO GEOLOGICO INTERNACIONAL, Vigésima Sesión, 1956, Excursion C-16, p. 1-94, figs. 1-18.
- CUSHMAN, J. A., 1925, New foraminifera from the Upper Eocene of Mexico: *Cushman Lab. Foram. Research Contr.*, v. 1, p. 4-8.
- , 1927, Some characteristic Mexican fossil foraminifera: *Jour. Paleontology*, v. 1, no. 2, p. 147-172, pls. 23-28.
- ECKERT, H. R., 1963, Die obereozänen Globigerinen-Schiefer (Stadund Schimbergschiefer) zwischen Pilatus und Schrattefluh: *Eclogae Geol. Helv.*, v. 56, no. 2, p. 1001-1072, figs. 1-35, pls. 1-7.
- FINLAY, H. J., 1939, New Zealand foraminifera: Key species in stratigraphy—No. 2, *Roy. Soc. New Zealand, Trans. Proc.*, v. 69, pt. 1, p. 89-128, pls.
- GLAESSNER, M. F., 1937, Plankton Foraminiferen aus Kreide und dem Eozän und ihre stratigraphische Bedeutung: *Moscow Univ. Paleont. Lab. Publ. Studies Micropaleont.*, v. 1, p. 27-52, pls. 1-2 (in German and Russian).
- HAMILTON, E. L., 1953, Upper Cretaceous, Tertiary, and Recent planktonic foraminifera from Mid-Pacific flat topped seamounts: *Jour. Paleontology*, v. 27, no. 2, p. 204-237, figs. 1-4b, pls. 29-32.
- HAGN, H., 1956, Geologische und paläontologische Untersuchungen im Tertiär des Monte Brione und seiner Umgebung (Gardasee, Ober-Italien): *Palaeontographica*, v. 107, Abb. A, p. 67-210, figs. 1-8, pls. 1-12.
- HOFKER, J., 1959, On the splitting of *Globigerina*: *Cushman Found. Foram. Research Contr.*, v. 10, p. 1-9.
- , 1962, Studien an planktonischen Foraminiferen: *N. Jb. Geol. Pal. Abh.*, v. 114, p. 81-134, figs. 1-25.
- , 1969, Have the genera *Porticulasphaera*, *Orbulina* (*Candorbulina*) and *Biorbulina* a biologic meaning?: *Proc. 1st Int. Conf. Plankt. Microfossils*, p. 279-286, pls. 1-3.
- HORNIBROOK, N. DE B., 1958, New Zealand Upper Cretaceous and Tertiary foraminiferal zones and some overseas correlations: *Micropaleontology*, v. 4, no. 1, p. 25-38, pl. 1, tables 1-2.
- JENKINS, D. G., 1965, Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand: *New Zealand Jour. Geol. and Geophys.*, v. 8, no. 6, p. 1088-1126, figs. 1-15.
- , 1971, New Zealand Cenozoic planktonic foraminifera: *N.Z. Geol. Survey, Pal. Bull.* 42, p. 1-278, pls. 1-23, tables 1-54, stratigr. columns 1-32 (in pocket).
- KELLER, B. M., 1946, Foraminifera of the Late Cretaceous deposits of the Sochi region: *Biull. Mosk. obshch. isp. prirody, otd. geol.*, v. 21, no. 3, p. 83-108, pls. 1-3 (in Russian).
- KEIJZER, F. G., 1945, Outline of the Eastern part of the Province of Oriente, Cuba: *Geogr. en Geol. Med., Phys.-Geol. Reeks, ser. II*, no. 6, p. 1-216, figs. 1-33, pls. 1-11, map.
- KRASHENINNIKOV, V. A., 1965, Zonal stratigraphy of Paleogene deposits: *Internat. Geol. Cong. XXII session, Doklady Soviet. Geol.*, probl. 16, i, p. 37-61, 2 figs. (in Russian and English).
- , 1965a, Zonal stratigraphy of the Paleogene of the Eastern Mediterranean: *Akad. Sci. USSR, Geol. Inst., Trudy*, no. 133, 76 p., 9 figs. (in Russian).
- MALLORY, V. S., 1959, Lower Tertiary biostratigraphy of the California Coastal Ranges: *A. A. P. G.*, p. I-VIII, 1-416, figs. 1-7, pls. 1-42, tables, 1-19.
- MOHAN, M., and SOODAN, K. S., 1970, Middle Eocene planktonic foraminiferal zonation of Kutch, India: *Micropaleontology*, v. 16, p. 37-46, figs. 1-3, pls. 1-2.
- MUIR, J. M., 1936, Geology of the Tampico Region Mexico: *A. A. P. G.*, p. 1-280, figs. 1-40, pls. 1-15.
- MYATLYUK, E. V., 1970, Foraminifera from Flysch deposits of the Eastern Karpathians (Cretaceous-Paleogene): *VNIGRI Trudy*, v. 282, p. 1-360, pls. 1-66 (in Russian).

- POSTUMA, S. A., 1971, Manual of planktonic foraminifera: Elsevier, p. I-VI, 1-420, 3 charts.
- PROTO DECIMA, FRANCA, and BOLLI, H. M., 1970, Evolution and variability of *Orbulinoides beckmanni* (Saito): *Eclogae Geol. Helv.*, v. 63, no. 3, p. 883-905, figs. 1-51, pls. 1-4.
- QUILTY, P. G., 1969, Upper Eocene planktonic foraminifera from Albany, Western Australia: *J. Royal Soc. Western Australia*, v. 52, p. 41-58, figs. 1-7.
- RAJU, D. S. N., 1971, Upper Eocene to Early Miocene planktonic foraminifera from the subsurface sediments in Cauvery Basin, South India: *Jb. Geol. B. A.*, special v. 17, p. 7-68, figs. 1-14, pls. 1-13.
- SAITO, T., 1962, Eocene planktonic foraminifera from Hahajima (Hillsborough Island): *Trans. Pal. Soc. Japan*, N. S., no. 45, p. 209-225, pls. 32-34, 1 table.
- SHUTSKAYA, E. K., 1958, Variation of some Lower Paleogene planktonic foraminifera of the Northern Caucasus: *Voprosi Mikropaleont.*, Akad. Nauk SSSR, Otdel. Geol.-Geog. Nauk, Geol. Inst., no. 2, p. 84-90, pls. 1-3, (in Russian).
- , 1960, Variabilité de quelques Foraminifères planctoniques du Paléogène inférieur du Caucase septentrional. Translation of 1958 paper by S. and J. Sigal, in *Questions de Micropaléontologie*, B. R. G. M., Service d'Inf. Géol., p. 93-103, 1 fig., pls. 1-3.
- STAINFORTH, R. M., 1953, *Globigerina mexicana* Cushman, an Eocene index fossil: *The Micropaleontologist*, v. 7, no. 4, p. 22-23, figs. 1-3.
- SUBBOTINA, N. N., 1953, Fossil foraminifera of the USSR, Globigerinidae, Hantkeninidae and Globorotaliidae: *VNIGRI Trudy*, no. 76, 296 p., 8 figs., 40 pls., (in Russian).
- , 1960, Foraminifères fossiles d'U. R. S. S., Globigerinidae, Globorotaliidae, Hantkeninidae. Translation of 1953 paper by M. Sigal, B. R. G. M., Service d'Inf. Géol., Traduction no. 2239, p. 1-144, pls. 1-15. le partie: Globigerinidae, et Hantkeninidae.
- , 1971, Fossil foraminifera of the USSR, Globigerinidae, Hantkeninidae, and Globorotaliidae. Translation of 1953 paper by E. Lees. Collet's (Publishers) Ltd., London and Wellingborough, p. 1-320, figs. 1-8, 40 pls.
- TODD, RUTH, and LOW, DORIS, 1960, Smaller foraminifera from Eniwetok drill hole: *Geol. Survey Prof. Paper* 260-x, p. I-IV, 799-861, figs. 256-259, pls. 255-264, tables 1-7.
- TOUMARKINE, MONIQUE, and BOLLI, H. M., 1970, Evolution de *Globorotalia cerroazulensis* (Cole) dans l'Eocène Moyen et Supérieur de Possagno (Italie): *Rev. de Micropaléontologie*, v. 13, no. 3, p. 131-145, figs. 1-7, pls. 1-2.
- WEISS, L., 1955, Planktonic index foraminifera of Northwestern Peru: *Micropaleontology*, v. 1, no. 4, p. 301-319, fig. 1, tables 1-2, pls. 1-3.

Ms submitted January 1972

PLATE 7

All figures $\times 80$

Globigerinatheka subconglobata luterbacheri n. subsp.

All specimens from sample AA 3858 of Eckert (1963), Globigerina marls of *Globorotalia cerroazulensis* Zone, Late Eocene, Looegg, Central Switzerland.

- 1 Juvenile specimens with one aperture in last chamber. C26754
- 2 Small specimen with two apertures in last chamber. C26755
- 3, 4, 7, 8 Medium to large specimens with two apertures in last chamber. In 8 lower center early spire visible. C26756, C26757, C26760, C26761
- 5, 6 Small, almost spherical specimens with small last chamber which possesses in both specimens three apertures of which two are visible in the figures. C26758, C26759
- 9, 11 Medium to large spherical specimens with small, bulla like end chambers, each with three apertures of which one is visible in 9 and all three in 11 (one each on left and right end of elongate bulla, one on upper right). C26762, C26764
- 10 Spiral view of large, spherical specimen. Early spire in center and lower part of figure, dextrally coiling. Poorly visible sutures between early chambers. Deep

- open crevace like sutures between early stage and last two chambers (upper left and top to right side of figure). Last chamber with three apertures. C26763
- 12 Large specimen with three apertures in last chamber of which two are covered by bullae (a smaller one on left periphery, a larger one with three apertures bordered by thick rims in the center). C26765
- 13 Holotype. Slightly elongate with three apertures in last chamber, two of them covered by bullae of which a very small one only partially covers the larger aperture on the left. The other visible aperture on the right is covered by a larger bulla which has three apertures of which two are visible on the figure. Early chambers in lower half of figure. C26766
- 14 Similar to 13 but with aperture on right covered by large, inflated chamber like bulla. C26767
- 15 Large specimen with three apertures in last chamber, two of them covered by regular sized bullae, both visible in figure. C26769
- 16 Similar to 15, but aperture on right covered by large bulla. C26769
- 17 Specimen with four apertures in last chamber, three of them covered by distinctly inflated bullae, all visible on figure. Fourth uncovered aperture not visible on figure. C26770

