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Evolution and Variability of Orbulinoides beckmanni (Saito)

By FRANCA PROTO DECIMA[1]) and HANS M. BOLLI[2])

ABSTRACT

The stratigraphically significant evolutionary sequence *Globigerinatheka curryi – Globigerinatheka euganea – Orbulinoides beckmanni* is described from Middle Eocene sections in Barbados, W.I., Trinidad, W.I., and northern Italy. *G. curryi* and *G. euganea* are described as new. The non-bullate genus *Globigerapsis* BOLLI, LOEBLICH and TAPPAN 1957 is here placed into synonymy with the bullate genus *Globigerinatheka* BRÖNNIMANN 1952. *Orbulinoides*, originally described as possessing sutural apertures at the base of the last and between earlier chambers, is emended to also include forms with vestibules, bulla-like structures and areal apertures. The variability of the species under consideration, in particular of *Orbulinoides beckmanni*, is illustrated by drawings and scanning electron micrographs.

RIASSUNTO

Viene descritta, in serie stratigrafiche dell'Eocene medio delle Barbados W.I., di Trinidad W.I. e dell'Italia settentrionale, la sequenza evolutiva *Globigerinatheka curryi – Globigerinatheka euganea – Orbulinoides beckmanni* di notevole significato stratigrafico. *G. curryi* e *G. euganea* vengono descritte come specie nuove. Il genere *Globigerapsis* BOLLI, LOEBLICH e TAPPAN 1957, sprovvisto di bulle, viene considerato sinonimo del genere *Globigerinatheka* BRÖNNIMANN 1952, munito di bulle. Il genere *Orbulinoides*, originariamente descritto con aperture suturali alla base dell'ultima camera e tra le prime camere, viene emendato ad includere anche forme con vestiboli, strutture simili a bulle e aperture areali. La variabilità delle specie considerate, in particolare di *Orbulinoides beckmanni*, è illustrata da disegni e da microfotografie al microscopio elettronico a scansione.

Introduction

Orbulinoides beckmanni (SAITO) is a monotypic species restricted to the Middle Eocene zone of the same name. The forms assigned since 1962 to this species and since 1968 to this genus appeared previously in the literature as *Globigerina mexicana*, *Globigerinoides mexicana*, *Porticulasphaera mexicana* and *Porticulasphaera beckmanni*. It is shown here that *Orbulinoides beckmanni* represents the end form of a lineage developing from *Globigerinatheka curryi* via *G. euganea*, two species described as new. *Orbulinoides* was originally described as possessing sutural apertures at the base of the last and between earlier chambers. A re-study of the rich Barbados material described originally by BECKMANN (1953) has shown in numerous specimens the presence of vestibules, areal apertures in addition to sutural apertures, and bulla-like

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structures. As no stratigraphic significance for these additional features was observed, to avoid further taxonomic splitting, the definitions of the genus *Orbulinoides* and its species *beckmanni* are here emended to accommodate forms with the above mentioned features. In addition to Barbados, W.I., the same sequence *Globigerinatheka curryi – G. euganea – Orbulinoides beckmanni* is here described from Trinidad, W.I., and from the Euganei hills in northern Italy. The genus *Globigerapsis* BOLLI, LOEBLICH and TAPPAN, 1957, is placed in synonymy with *Globigerinatheka* BRÖNNIMANN, 1957. The former is the non-bullate form of the latter. It was found that both stages exist in all known species and do not significantly differ in their stratigraphic distribution. With the exception of Textfig. 15 and 15a, all specimens figured are deposited at the Museum of Natural History, Basel (C 26491–26563).

Acknowledgments

Dr. J. P. BECKMANN has checked and compared at the U.S. National Museum in Washington, D.C. holotypes, paratypes and hypotypes of a number of taxa discussed in this paper. Conclusions on several species are here based on his observations. Through his work on Barbados foraminifera of the same group as discussed here, Dr. BECKMANN has further been able to give valuable advice during the preparation of this paper. The authors wish to thank him for his constructive cooperation. They also express their gratitude to Miss RUTH TODD who kindly provided information on specimens kept in the Cushman Collection, U.S. National Museum, Washington, D.C.; to Mr. J. B. SAUNDERS for making available information on the locality and stratigraphic position of the holotype of *Globigerinatheka barri;* and to Dr. S. W. WISE, JR. for discussing various aspects of this paper. The scanning electron microscope micrographs were taken by Mr. H. E. FRANZ. Foraminiferal slides, residues and original field notes by Dr. A. SENN on the Mount Hillaby River section, Barbados, W.I., were obtained from the Museum of Natural History, Basel. This paper is part of a project on the study of Alpine/Mediterranean Paleogene microfossils, supported by the Swiss National Science Foundation. The Centenar Fonds of the Federal Institute of Technology Zurich contributed towards the publication of this paper.

Historical Review

CUSHMAN (1925) described and figured *Globigerina mexicana*, a small (max. diameter 0.36 mm) Eocene specimen of globular test shape with hemispherical final chamber, possessing at its base arched apertures of medium height. Subsequently, several authors, including CUSHMAN himself (1927), identified and figured specimens as *G. mexicana* which clearly differ from the holotype in their considerably larger size, more robustly built chamber walls, more compact spherical test shape, and differing aperture arrangement, with or without bullae. Such forms are now known as *Orbulinoides beckmanni.* BECKMANN (1953), who described and figured such larger forms from the Middle Eocene of Barbados as *Globigerinoides mexicana*, already noted the existence of an evolutionary trend (in this paper to be described as *Globigerinatheka curryi-Globigerinatheka euganea-Orbulinoides beckmanni* lineage) in stating:

Wenn man die Vertreter dieser Art im Profil stratigraphisch von unten nach oben verfolgt, so erkennt man einige charakteristische Veränderungen:

1. Eine Tendenz, die vollkommene Kugelgestalt zu erreichen. In den stratigraphisch tiefsten Proben sind die einzelnen Kammern noch leicht aufgebläht und durch deutlich vertiefte Suturen getrennt (Taf. XXV, Fig. 15, 16). Gegen oben verflachen sich die Umrisse (Taf. XXV, Fig. 17) und schliesslich wird die Form ganz kugelig (Taf. XXV, Fig. 18, 19).
2. Die Zahl der Mündungen nimmt zu. Sie liegen in den Suturen, vor allem an den Berührungspunkten von drei Kammern.
3. Die zuletzt gebildete Kammer wird immer grösser und nimmt bei kugeligen Exemplaren meist mehr als die Hälfte der Oberfläche ein.

BOLLI, LOEBLICH and TAPPAN (1957) introduced the genus *Porticulasphaera* for such large forms with numerous sutural apertures not only at the base of the last chamber but also between earlier chambers, and erroneously selected as its type species the small holotype of *Globigerina mexicana* CUSHMAN. BOLLI (1957) made it the index fossil for his Middle Eocene *Porticulasphaera mexicana* Zone. SAITO (1962) showed that the holotype of *Globigerina mexicana* does not possess the characters of the genus *Porticulasphaera* and replaced it by the new species *beckmanni*. LOEBLICH and TAPPAN (1964) pointed out that SAITO was incorrect in designating *beckmanni* as the type species of the genus *Porticulasphaera*, and BLOW and SAITO (1968) proceeded to replace *Porticulasphaera* by *Orbulinoides*, of which *P. beckmanni* SAITO is the type species. However, as is explained by BLOW and SAITO (1968a), CORDEY (1968) must, due to unintentional prior publication of the name, be regarded as the author of the genus. CORDEY gives a detailed description of the morphology of *Orbulinoides beckmanni* and discusses its phylogeny.

Discussion of the Globigerinatheka curryi – Globigerinatheka euganea – Orbulinoides beckmanni Evolution

As noted above, it was BECKMANN (1953) who first observed the evolutionary trend of the forms described here as *Globigerinatheka curryi–G. euganea–Orbulinoides beckmanni*. BOLLI (1957, p. 160) observed that "transitional specimens indicate that *Globigerapsis kugleri* BOLLI, LOEBLICH and TAPPAN branched off from the long ranging *Globigerapsis index* (FINLAY) and later developed into *Porticulasphaera mexicana* (CUSHMAN)." In the same paper he figured a specimen as hypotype of *Globigerapsis kugleri* (Pl. 36, Fig. 21a, b) that comes from the *Globorotalia lehneri* Zone and thus could be an ancestral form of the stratigraphically younger *Orbulinoides beckmanni*. It is distinctly larger (0.56 mm) and has a coarser wall composition than the holotype of *Globigerapsis kugleri* BOLLI, LOEBLICH and TAPPAN (1957, p. 34, Pl. 6, Fig. 6a–c). This holotype comes from the same locality as the hypotypes of *Porticulasphaera mexicana* (= *Orbulinoides beckmanni*) figured by BOLLI, LOEBLICH and TAPPAN (1957, Pl. 6, Fig. 8–9) and by BOLLI (1957, Pl. 37, Fig. 1a, b), that is, from a level where *Orbulinoides beckmanni* is already fully developed. This locality (sample Hg. 8581) is of *Orbulinoides beckmanni* Zone age, and not from the *Globigerinatheka barri* Zone, as was erroneously stated in BOLLI, LOEBLICH and TAPPAN's descriptions of the holotype of *G. kugleri* and the hypotypes of *P. mexicana* (1957, p. 34 and 35). A zone of the name *Globigerinatheka barri* does not exist.

The greatest diameter of the holotype of *Globigerapsis kugleri* measures 0.44 mm while paratypes range from 0.36 to 0.47 mm. The figured *Orbulinoides beckmanni* specimens from the same locality are considerably larger, 0.67 to 0.70 mm. No intermediate forms exist in the *Orbulinoides beckmanni* Zone of Trinidad that would suggest any direct relation at this stratigraphic level between *G. kugleri* and *O. beckmanni*. If *O. beckmanni* has developed from *G. kugleri s.s.*, the branching off would thus have taken place earlier, in the *Globorotalia lehneri* Zone or possibly already in the *Globigerapsis kugleri* Zone. The specimen figured by BOLLI (1957) from the *Globorotalia lehneri* Zone as *G. kugleri* could thus well be an ancestral form of *O. beckmanni*, and not identical with *G. kugleri s.s.*, whereas the holotype of *G. kugleri* from the *O. beckmanni* Zone would belong to a population that continued independently from at least the lower part of the *Globorotalia lehneri* Zone.

According to BOLLI (1957), *Globigerinatheka kugleri* originates within the *G. kugleri* Zone only very slightly before the appearance of *G. barri* which shows a more tightly coiled initial spire and more numerous bullate forms. The average size of these two species remains noticeably smaller throughout their range compared with that of *Orbulinoides beckmanni* and of its ancestral forms *Globigerinatheka curryi* and *G. euganea*. It has not yet been possible to determine from the sections investigated here where, if at all, the *G. curryi–G. euganea–O. beckmanni* lineage branched off from *G. kugleri s.s.* or *G. barri*.

BECKMANN (1953) included in *Globigerinoides mexicana* not only forms now referred to as *Orbulinoides beckmanni* but also specimens which are here assigned to *Globigerinatheka euganea*. These forms may or may not have bullae (his Pl. XXV, Fig. 15, 16). Though he acknowledges the close relation of the bullate forms to *Globigerinatheka barri*, he preferred at the time not to split his *G. mexicana* complex into more taxa.

BECKMANN's figured specimens of *Orbulinoides beckmanni* (his *Globigerinoides mexicana*, Pl. XXV, Fig. 17–19) show sutural apertures at the base of the last chamber and also between earlier chambers as typical for *Orbulinoides*. This author also noted in some specimens elongate inflated chambers (schlauchförmige Kammern) along sutures and figured such a specimen (Fig. 19). He compared this feature with similar ones in *Globigerinatella insueta*, and further pointed out the morphological similarity between the spherical shape of his *Globigerinoides mexicana* end forms and *Orbulina suturalis*. Re-examination of a large number of *Orbulinoides beckmanni* specimens from Barbados sample S 206, the same sample from which BECKMANN (1953) described and figured his *Globigerinoides mexicana*, has confirmed that numerous specimens possess low, elongate bulla-like structures that follow sutures, mostly of the final chamber. It was further observed that, in addition to the sutural apertures, small areal apertures may be present in some specimens in the wall of the last, and, more rarely, in earlier chambers as well. In view of these additional morphological features of areal apertures and bulla-like structures, a strict adherence to the taxonomic principles of BOLLI, LOEBLICH and TAPPAN (1957) would require that at least two new genera be erected: one for the forms developing areal apertures and another to accommodate the bullate forms. Such bulla-like structures may be present in specimens with and without areal apertures in the last chambers, which would lead towards further generic splitting.

This is believed to be a good example to demonstrate the drawbacks of rigidly following given taxonomic principles. For the sake of not adding still more taxa. the description of the genus *Orbulinoides* is here emended to accommodate also those forms which possess areal apertures and bulla-like structures. On the specific level, the forms that feature areal apertures and bulla-like structures are also included in the existing *Orbulinoides beckmanni* (SAITO), which is emended accordingly. Should, however, some of the additional features prove to be of stratigraphic significance, in that forms with areal apertures or with bulla-like structures have noticeably different ranges than the *O. beckmanni* as originally described, then they should be distinguished on a specific or subspecific level. *O. beckmanni* specimens that form areal apertures and/or bulla-like structures are fairly frequent in Barbados, particularly in sample S 206. In other localities, such as those examined from Trinidad and northern Italy, they are scarce or absent. The extent to which presence or absence of areal apertures and bulla-like structures is controlled by environment, state of evolution or ontogeny could not yet be determined in the investigated sections.

Among other morphological features of *Orbulinoides beckmanni*, CORDEY (1968) notes that the numerous supplementary apertures of the early stage are in no instance directly connected with the outside of the test. According to him they open into a small cavity, termed vestibule, situated between the thick outer wall and the delicate wall of the initial trochospirally arranged chambers. Examination of a number of specimens indicates that at least part of CORDEY's vestibules are to be attributed to the presence of bulla-like structures as described and figured in this paper.

Contrary to BOLLI's (1957, p. 160) view that *Globigerapsis*, *Globigerinatheka* and *Porticulasphaera* (= *Orbulinoides*) are a related group, CORDEY maintains in his discussion on phylogeny that, while the first two genera have arisen form a globigerinoid ancestral form, *Orbulinoides beckmanni* derived from a globorotaloid ancestor. CORDEY does not indicate, however, which ancestral species *O. beckmanni* evolved from. The relations here discussed and illustrated, the evolutionary development and the close stratigraphic succession of *G. curryi – G. euganea – O. beckmanni* should provide sufficient proof to confirm BECKMANN's (1953) and BOLLI's (1957) phylogenetic views and to refute those of CORDEY (1968). The short, only slightly overlapping ranges of these three morphologically characteristic taxa predestined them to be excellent, successive index fossils in the Middle Eocene.

Systematic Descriptions

The relationship between genera and species of the taxa here under consideration, the biologic meaning of accessory structures and their application for taxonomic subdivision were recently discussed by HOFKER (1959, 1962, 1969), CATI and BORSETTI (1968), and QUILTY (1969). They question the validity of taxa erected on the base of bullae. Their conclusions will be reviewed in a forthcoming paper on variability in some species of *Globigerinatheka*.

BOLLI, LOEBLICH and TAPPAN (1957), the authors of *Globigerapsis*, remarked that the genus differs from *Globigerinatheka* only in lacking the bullae covering the secondary apertures. BRÖNNIMANN (1952), the author of *Globigerinatheka*, previously figured with the bullate holotype of *G. barri* a non-bullate paratype (his textfig. 3d–f.)

Current investigations of species of the two genera confirmed that all are in fact represented by non-bullate and bullate forms. No detailed investigations, however, have yet been carried out on the non-bullate/bullate ratio in a given species. Judging from superficial estimates alone, the ratio varies greatly from species to species, and apparently also within species. For example, bullae are common in *Globigerinatheka barri* where they might be present in 50% or more of the specimens, but are very scarce in *G. semiinvoluta* where bullate forms make up less than 1%. It is quite obvious that the presence of bullae in the discussed forms merely represents a final growth stage which is not attained by all specimens, and which possibly has some reproductive significance.

Observations so far also indicate that presence or absence of bullae is not of sufficient stratigraphic significance to warrant maintaining the two genera. Any differentiation into bullate and non-bullate taxa, if thought desirable, can here be made at the specific or subspecific level. For these reasons *Globigerapsis* is included in *Globigerinatheka* as its non-bullate form, and the definition of the latter genus emended accordingly.

Ancestral forms of *Orbulinoides beckmanni* are here divided into two new species, an older *Globigerinatheka curryi* and a younger *Globigerinatheka euganea*. Each species also has a distinct stratigraphic range. As is natural in true evolutionary lineages, transitional specimens featuring intermediate characters occur and may be difficult to assign to one or the other species. This is particularly true within the genus *Globigerinatheka* as here emended.

Genus *Globigerinatheka* BRÖNNIMANN 1952, emended

Type species: *Globigerinatheka barri* BRÖNNIMANN, 1952

Globigerapsis BOLLI, LOEBLICH and TAPPAN 1957

Test free, subglobular to globular, early chambers trochospiral as in *Globigerina*, later with a large enveloping final chamber covering the umbilical area formed by the previous chambers. Sutures depressed, radial. Wall calcareous, perforate, radial in structure. Primary aperture in the early globigerinid stage interiomarginal, umbilical. In the enveloping, final chamber multiple secondary sutural apertures which may or may not be covered by bullae of varying size. Each bulla possesses one or more small infralaminal accessory apertures.

Remarks: *Globigerapsis* BOLLI, LOEBLICH and TAPPAN, 1957, is the non-bullate stage of *Globigerinatheka* and here placed in its synonymy. The type species of *Globigerinatheka*, *G. barri*, differs from the type species of *Globigerapsis*, *G. kugleri*, in a more tightly coiled and more distinctly globular test. *G. kugleri* in comparison has a larger initial spire. The holotypes of the two species can thus clearly be distinguished. Both species are represented by non-bullate and bullate forms.

The holotype of *G. kugleri* BOLLI, LOEBLICH and TAPPAN, 1957, originates from the Middle Eocene *Orbulinoides beckmanni* Zone, Navet Formation, Trinidad. The holotype of *G. barri* BRÖNNIMANN, 1952, was described from the Upper Eocene Mount Moriah Formation of Trinidad, samples TLL 158007, 158028–29. BRÖNNIMANN does not specify from which of the three samples the holotype was selected. The samples

are from the following cores of well Harmony Hall 2, drilled immediately south of Pointe-à-Pierre, Trinidad:
158007 core 10 1176–1188′
158028 core 11 1198–1212′
158029 core 11 1198–1212′
The cores of this interval consist of a rubble bed of marl boulders and calcareous clay matrix with some glauconitic sandstone fragments of Mount Moriah type. The interval is exceedingly heterogeneous with presumed Paleocene, Middle and Upper Eocene. *G. barri* is now considered to be restricted in Trinidad to the Middle Eocene and specimens that appear in the Upper Eocene Mount Moriah Formation, which often contains heterogeneous faunas, are most likely reworked. It can be assumed that the holotype and the paratypes of *G. barri* came from one of the Middle Eocene Navet Formation parts of the rubble bed. *G. barri* is particularly frequent and typical in the *Globorotalia lehneri* Zone of Trinidad. Because of the heterogeneity of the sample, such an age assignment for the holotype of *G. barri* can only be suggestive.

Globigerinatheka kugleri (Bolli, Loeblich and Tappan)

Globigerapsis kugleri Bolli, Loeblich and Tappan, 1957, Pl. 6, Fig. 6a–c (holotype)
non *Globigerapsis kugleri* Bolli, Loeblich and Tappan. Bolli, 1957, Pl. 36, Fig. 21a, b (= *Globigerinatheka curryi* n. sp.)

The morphologic differences between *Globigerinatheka kugleri* and *Globigerinatheka curryi* are explained in the description of *G. curryi*. The holotype of *G. kugleri* is from the *Orbulinoides beckmanni* Zone, that of *G. curryi* from the older *Globorotalia lehneri* Zone. The specimen figured by Bolli (1957) as hypotype of *G. kugleri* is proposed in this paper as holotype of *G. curryi*. The larger and more robust *G. curryi* in the *Globorotalia lehneri* Zone are the ancestors of *Globigerinatheka euganea* and are not directly related to the *G. kugleri* of the *Orbulinoides beckmanni* Zone. The two forms are therefore to be kept apart as separate species.

The possibility that *G. kugleri* and *G. curryi* might have a joint ancestor in the lower part of the *Globorotalia lehneri* Zone or the upper part of the *Globigerinatheka kugleri* Zone still remains to be investigated. In the light of today's closer morphological differentiation it also remains to be seen whether the specimens determined as *G. kugleri* in the *Globigerinatheka kugleri* and *Globorotalia lehneri* zones are identical with the specimens from the younger *Orbulinoides beckmanni* Zone.

Globigerinatheka curryi n. sp.

Plate I, Fig. 1–4, Plate III, Fig. 1–2, Textfig. 1–3a, 38–39b

Globigerapsis kugleri Bolli, Loeblich and Tappan, Bolli, 1957, Pl. 36, Fig. 21a, b (holotype)
Globigerapsis index (Finlay). Todd, 1966, Pl. 2, Fig. 1a–c

Test free, subglobular, early coil low trochospiral with globular chambers increasing moderately in size as added, four to five in the whorl prior to the last two, occasionally three chambers, which are becoming distinctly larger and successively begin to cover the umbilical area. Final inflated chamber slightly larger, same size or slightly smaller than penultimate, completely covering the umbilical area. Final chamber may also be rudimentary, distinctly smaller than the penultimate, and there-

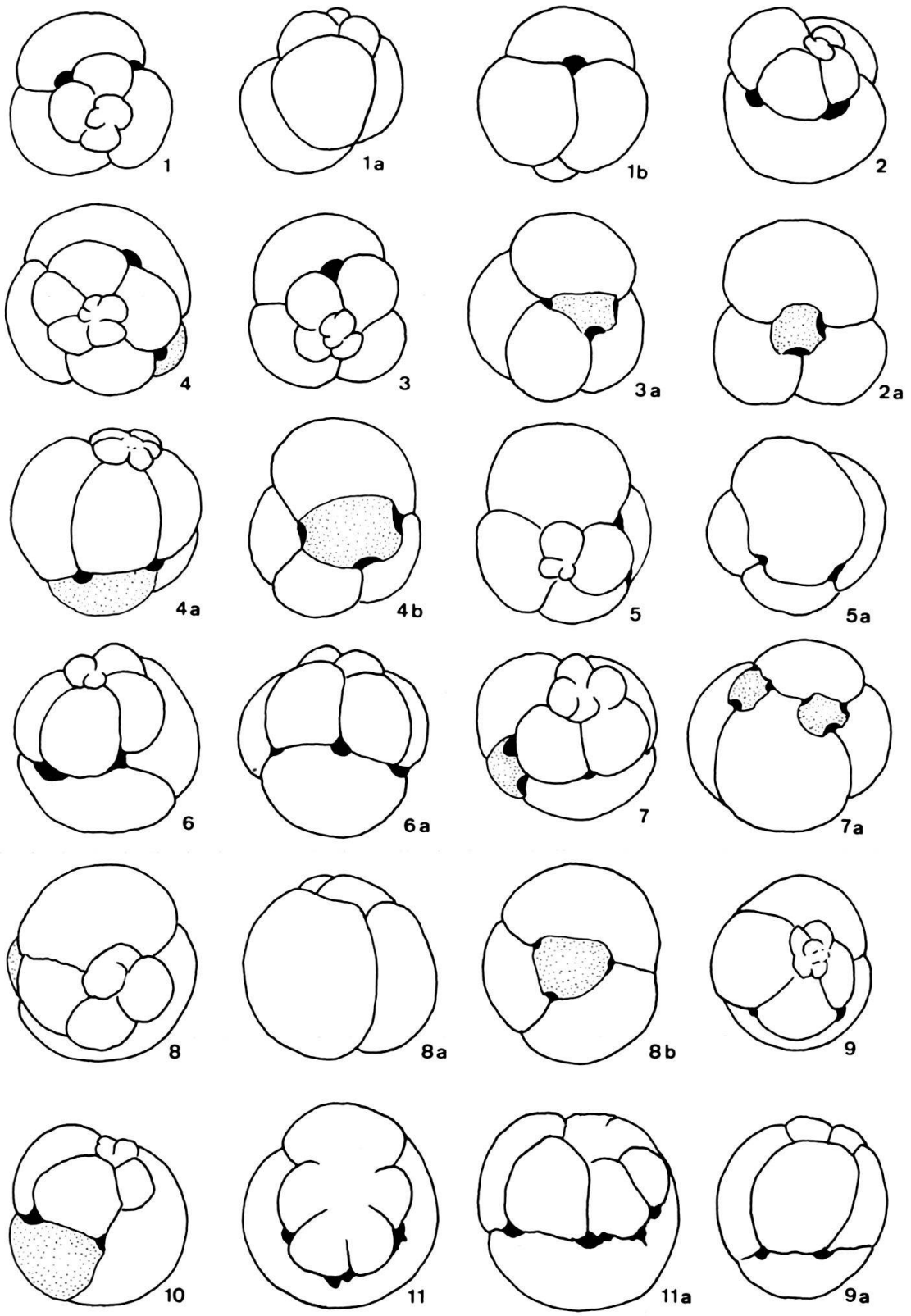

Fig. 1–11 a

fore may be difficult to distinguish from a bulla. One to four small more or less inflated bullae may be present, each covering one of the apertures of the final chamber. Sutures distinct, between last chambers deeply depressed or incised, radial to slightly curved. Wall calcareous, coarsely perforate. Aperture an interiomarginal, umbilical arch, except in the final chamber covering the umbilical area, which has two to four low arched sutural openings usually situated symmetrically above sutures between earlier chambers (as in *Globigerinoides ruber*). When rudimentary end chamber present, last normal chamber may possess additional apertures. Apertures may be bordered by a faint rim. Bullae with two to three apertures. Strong preference for dextral coiling. Greatest diameter of holotype 0.56 mm.

Remarks: The new species differs from *Globigerinatheka euganea* of which it is the ancestor, in having distinctly more incised sutures, more inflated chambers and consequently a less spherical form of the whole test. The deeper sutures are particularly apparent between the last two or three chambers which are relatively large, and bet-

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General remarks and explanation of Text Figures 1–47 b

Magnification of all specimens ×48

Bullae, bulla-like structures, and rudimentary chambers are stippled for better recognition. The small apertures, in particular of Orbulinoides, are often filled with matrix. This may affect in some specimens the shape of the apertures as drawn. To make sutures, apertures, bullae, and bulla-like structures better visible the specimens were treated with methylene blue. Numbers designated C are depository numbers of the Museum of Natural History, Basel.

Fig. 1–11a. Specimens from the Mount Hillaby River section, Barbados, W.I.

Globigerinatheka curryi, n.sp.

From S 204, *Globorotalia lehneri* Zone.

1 Spiral view, 1a side view, 1b umbilical view. Final chamber with three apertures C 26491.

2 Side view, 2a umbilical view. Final chamber with three apertures, one covered by small bulla. C 26492.

3 Spiral view, 3a umbilical view. Final chamber with two apertures, one covered by bulla. C 26493.

Specimens transitional between *Globigerinatheka curryi* and *Globigerinatheka euganea*.

Specimens 4–6 from S 593; 7 from S 204, *Globorotalia lehneri* Zone.

4 Spiral view, 4a side view, 4b umbilical view. Final chamber with two apertures, one covered by large bulla. C 26494.

5 Spiral view, 5a umbilical view. Final chamber with four apertures. C 26495.

6 Oblique spiral view, 6a side view. Final chamber with four apertures. C 26496.

7 Oblique spiral view, 7a umbilical view. Final chamber with four apertures, two covered by bullae. C 26497.

Globigerinatheka euganea, n.sp.

Specimens 8, 9, 11 from S 180; 10 from S 593, *Globorotalia lehneri* Zone.

8 Spiral view, 8a side view, 8b umbilical view. Small rudimentary final chamber with three apertures. C 26498.

9 Spiral view, 9a side view. Final chamber with three apertures. C 26499.

10 Oblique view. Small rudimentary final chamber with three apertures of which only two are visible in the figure. C 26500.

11 Spiral view, 11a side view. Large final chamber giving specimen distinctly spherical shape. C 26501.

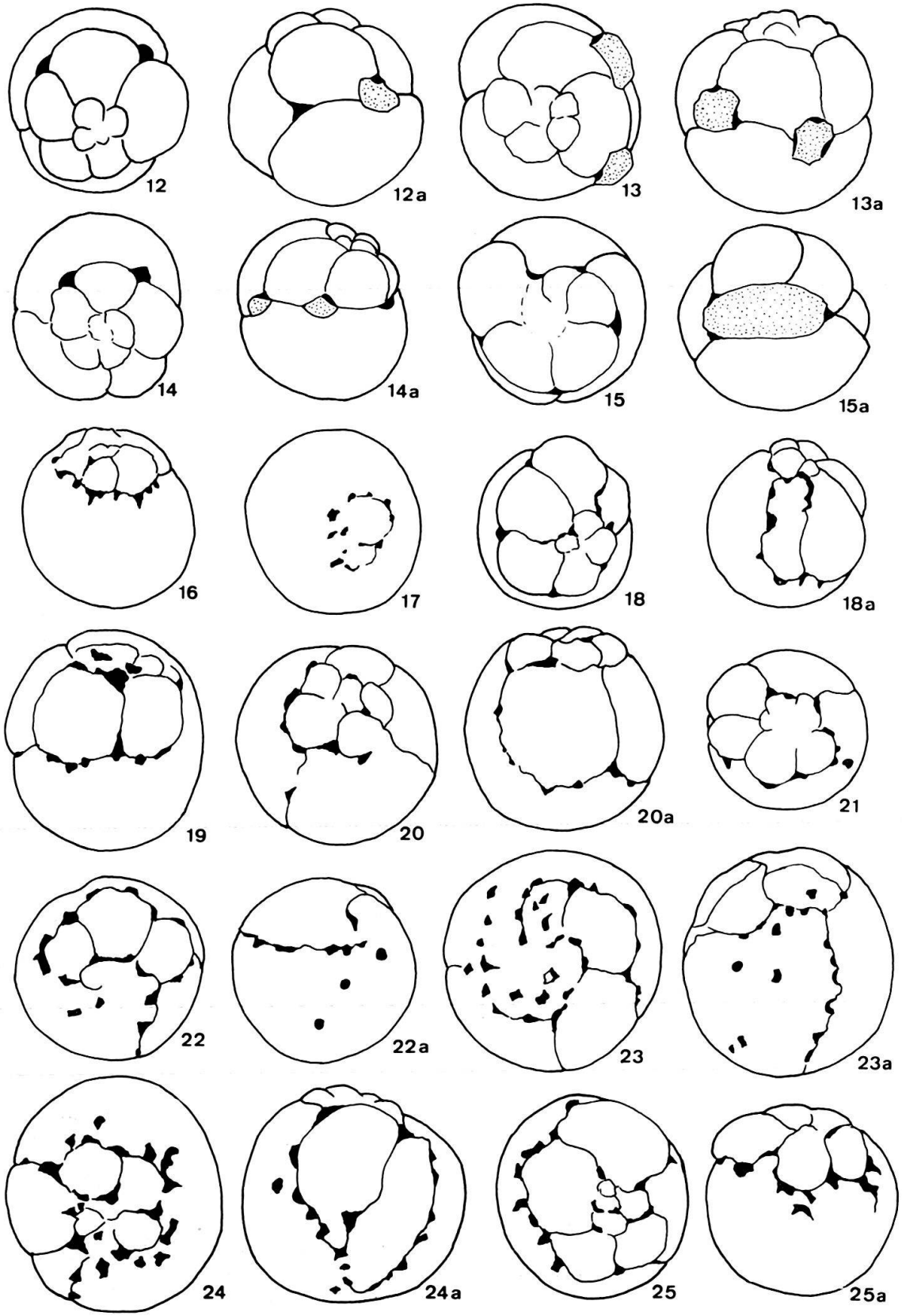
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Fig. 12–25 a

ween these chambers and the earlier coil; therefore, the latter often appears somewhat detached from the final two to three chambers. Every intermediate morphological stage exists between *G. curryi* and its successor *G. euganea.*

Though figures of *Globigerinatheka kugleri* and *Globigerinatheka curryi* look much alike (e.g., BOLLI, LOEBLICH and TAPPAN, 1957, Pl. 6, Fig. 6a–c, and BOLLI, 1957, Pl. 36, Fig. 21a, b), the latter differs in the distinctly larger size of the test (average 0.5–0.6 mm as against 0.35–0.40 mm), more robust wall structure, and in a more restricted stratigraphic range. The large specimens leading to *Globigerinatheka euganea* and finally to *Orbulinoides beckmanni* are no longer to be included in *Globigerinatheka kugleri.* The new species differs from *Globigerinatheka barri* in the larger test size and

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Fig. 12–14a, 16–25a. Specimens from the Mount Hillaby River section, Barbados, W.I.

Globigerinatheka euganea, n.sp.

Specimens 12, 14 from S 180; 13 from S 593, *Globorotalia lehneri* Zone.

12 Spiral view, 10a side view. Final chamber with four apertures, one covered by small bulla. C 26502.

13 Spiral view, 13a side view. Final chamber with three apertures, two covered by bullae. C 26503.

14 Spiral view, 14a side view. Final chamber with four apertures, two covered by very small bullae. C 26504.

Fig. 15–15a. From M-65-V, Alazan, Rio Tuxpan, crossing of road from Palo Blanco to La Noria and along Rio Pantepec about 200 m above its mouth, Mexico. Dark grey clay, some layers very full of foraminifera. Collected 1920 by Dr. VAUGHAN, now in Cushman Collection at U.S. National Museum, Washington, D.C.

15 Spiral view, 15a umbilical view. Small rudimentary final chamber with three apertures. Last three large chambers before final chamber with sutural apertures against early whorl.

Orbulinoides beckmanni (SAITO).

Specimens 16, 17, 19, 25 from S 205; 18, 20–24 from S 206, *Orbulinoides beckmanni* Zone.

16 Side view. Final chamber with numerous apertures against early whorl. Within early whorl one sutural aperture visible. C 26505.

17 Spiral view. Final chamber almost spherical, leaving small early part discernible only by the arrangement of the sutural apertures. C 26506.

18 Spiral view, 18a side view. Penultimate chamber relatively small and elongate. Sutural apertures of last chamber and within early stage. C 26507.

19 Side view. Final chamber and early whorl with numerous sutural apertures. C 26508.

20 Spiral view, 20a side view. Final chambers and early whorl with sutural apertures. C 26509.

21 Spiral view of small specimen. Final chamber and early whorl with sutural apertures; one areal aperture close to the base of last chamber. C 26510.

22 Spiral view, 22a side view. Final chamber and early whorl with sutural apertures. Sutures of earliest chambers not visible. Few areal apertures in final chamber. C 26511.

23 Spiral view, 23a side view. Final chamber and early whorl with sutural apertures. Sutures of earliest chambers not visible. Areal apertures in final chamber and in some chambers of early whorl. C 26512.

24 Spiral view, 24a side view. Final chamber and early whorl with sutural apertures. Sinistrally coiling. Few areal apertures in final chamber. C 26513.

25 Spiral view, 25a side view. Final chamber and large early whorl with sutural apertures. One areal aperture visible in final chamber. C 26514.

more deeply incised sutures which produce a less spherical test shape. Bullate specimens are not nearly as common as in *G. barri.*

Stratigraphic range: *Globorotalia lehneri* Zone to basal part of *Orbulinoides beckmanni* Zone, Middle Eocene.

Holotype: From sample K9071 (TTOC 178160), *Globorotalia lehneri* Zone, Navet Formation, Nariva River, Central Range, Trinidad, W.I. Figured in BOLLI (1957), Pl. 36, Fig. 21a, b, as *Globigerapsis kugleri* BOLLI, LOEBLICH and TAPPAN. Deposited at U.S. National Museum, Washington, D.C. (USNM P 5727).

Figured hypotypes: Plate I, Fig. 1–4; Plate III, Fig. 1–2, Textfig. 1–3a, 38–39b.

Figured specimens transitional between *Globigerinatheka curryi* and *G. euganea:* Plate I, Fig. 5; Textfig. 15, 31, 43–45.

The species is named for Mr. DENNIS CURRY in recognition of his contributions to Tertiary stratigraphy and paleontology.

Globigerinatheka euganea n.sp.

Plate I, Fig. 6–11, Plate III, Fig. 3–5, Textfig. 8–15, 31–31a, 43–45b

Globigerinoides mexicana (CUSHMAN). BECKMANN, 1953, Pl. XXV, Fig. 15, 16

Test free, subspherical to nearly spherical, early coils low trochospiral with inflated chambers increasing moderately in size as added, four to six in whorl prior to the last whorl, which normally consists of two to three distinctly larger chambers, extending over the umbilical area of the early stage, or of a single very large hemispherical chamber. The size of the ultimate chamber may vary considerably from small, rudimentary, bulla-like (Textfig. 8b) to approximately the same size as penultimate (Textfig. 45–45b) to very large, hemispherical (Textfig. 11, 11a). Small bullae may cover sutural apertures of final chamber (Textfig. 12a, 13, 13a, 14a). Sutures in early stage distinct, between large ultimate chambers little depressed and often barely visible. Wall calcareous, coarsely perforate. Aperture in early stage an interiomarginal, umbilical arch. In final hemispherical chamber covering the umbilical area, two to four, seldom more, small arched or semicircular to almost circular sutural openings (Textfig. 11, 11a). When umbilical area is covered by two to three large chambers, two to four spiral and umbilical sutural apertures are present in the ultimate; in addition, one to seldom two spiral sutural apertures may exist in each of the preceding one to three large chambers (Textfig. 45, 45a, Pl. I, Fig. 7). Rudimentary end-chambers and bullae usually have two to four small openings. Strong preference for dextral coiling. Greatest diameter of holotype 0.53 mm.

Remarks: The new species is the intermediate form between its ancestor *Globigerinatheka curryi* and its successor *Orbulinoides beckmanni.* From the former it differs in the distinctly more spherical test shape and less incised sutures, the usually slightly more numerous but smaller sutural apertures of the final chamber, and the occasional presence of spiral sutural apertures in the preceding one to three large chambers. In overall test shape *G. euganea* is similar to *O. beckmanni* from which it differs in the lack of areal apertures and spiral sutural apertures between the early chambers. In its range *G. euganea* overlaps both the older *G. curryi* and the younger *O. beckmanni.*

Every transitional morphological stage exists between *G. euganea* and its ancestor *G. curryi*.

Stratigraphic Range: Upper part *Globorotalia lehneri* Zone to lower part *Orbulinoides beckmanni* Zone, Middle Eocene.

Holotype: Plate I, Fig. 7; Plate III, Fig. 3. Paratypes: Plate I, Fig. 8; Plate III, Fig. 4; Textfig. 40–42a, from sample FPD 69/17, *Orbulinoides beckmanni* Zone, Euganei marls, Cava Zillo, Este, northern Italy (see Textfig. 50, 51). Deposited at the Museum of Natural History, Basel (holotype C 26543, paratypes C 26529–26531, 26544).

Figured hypotypes: Plate I, Fig. 6, 9–11; Plate III, Fig. 5; Textfig. 8–15, 31–31a, 43–45b.

The species name refers to the Euganei hills in northern Italy, from which the holotype originates.

Genus *Orbulinoides* CORDEY 1968 (ex BLOW and SAITO ms. 1967), emended

Type species: *Porticulasphaera beckmanni* SAITO, 1962

Test free, subglobular to globular. Low trochospiral arrangement of early chambers, four to six per whorl. Last chambers becoming considerably larger than the early part, covering its umbilical area; their place may be taken by a single very large hemispherical chamber. Wall calcareous, perforate, radial-hyaline. Surface of early chambers may have fine elongate spines, visible in well preserved specimens.

Early chambers thin walled, with umbilical primary apertures and secondary sutural apertures an spiral side. The thin walled chambers are distinctly inflated with depressed sutures. At a later stage the entire test is covered by a subspherical to spherical thick wall, in which the outlines of the spiral sutures of the early stage may be preserved clearly (Textfig. 26) or indistinctly (Textfig. 17). This thick wall adheres tightly to most of the outer surface of the earlier chambers, except at the incised sutural areas where an empty space may be left (vestibule of CORDEY, 1968). The outer thick wall has numerous apertures, some of which are positioned approximately above the spiral sutures of the early whorls (Textfig. 25). The majority of the openings however follow the outer contact of the final thick wall with the thin walled early trochospire (Textfig. 25), or lie along the sutures of the last two or three chambers (Textfig. 28a). As was already pointed out by CORDEY (his textfig. 1d), the sutural apertures of the early stage do not lead directly to the outside, but into vestibules, whose outer thick wall has separate aperures as mentioned above. The external apertures may form narrow double rows which enclose slightly inflated, bulla-like areas (Textfig. 35). More rarely such irregularly shaped bulla-like structures are present within the spiral area of the early stage (Textfig. 30). The pores of these areas are of about the same size as in the final chamber. Areal apertures may be present in the last two to three large last chambers or in the single very large final chamber (Textfig. 21–25a, 27–28, 36–37).

Remarks: Specimens with large, strongly inflated hemispherical chambers with areal apertures that cover the umbilical area of the early stage sometimes resemble *Orbulina suturalis*. Despite later thickening, the spiral part of the early stage of *O. beckmanni* remains usually distinctly visible and is considerably larger than in *Orbulina*

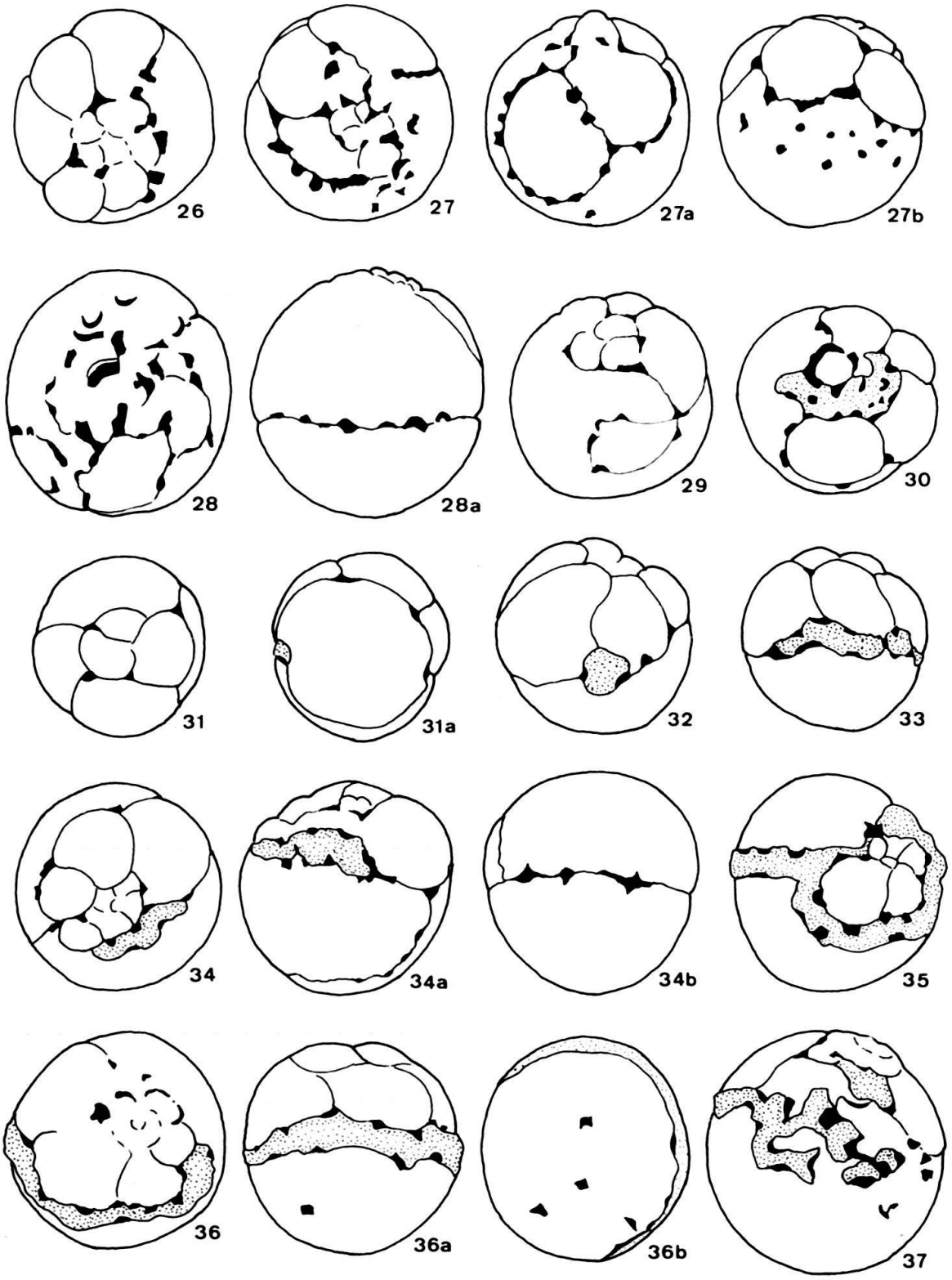

Fig. 26–37

suturalis. Further, *O. beckmanni* may possess vestibules and bulla-like structures, features not known in *O. suturalis*. The elongate and often iregular shaped sutural bulla-like inflations have some resemblance to those known in the Miocene genus *Globigerinatella*. In contrast to *Orbulinoides*, *Globigerinatella* shows areal apertures already in the early stage covered by the final chambers and possesses true sutural and areal bullae. *Orbulinoides* differs from *Globigerinatheka* in possessing 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 two to three chambers. Further it may have areal apertures in the last chambers, which are not known in *Globigerinatheka*.

Stratigraphic range: *Orbulinoides beckmanni* Zone, Middle Eocene.

Fig. 26–37. Specimens from the Mount Hillaby River section, Barbados, W.I.

Orbulinoides beckmanni (Saito).

Specimens 26–28, 30 from S 206; 29 from S 205, *Orbulinoides beckmanni* Zone.

26 Spiral view. Final chamber and large early whorl with sutural apertures. Few areal apertures in final chamber. C 26515.

27 Spiral view, 27a side view, 27b side view. Final chamber and large early whorl with sutural apertures. Numerous areal apertures in final chamber, one in third last chamber (visible in spiral view). C 26516.

28 Spiral view, 28a umbilical view. Early whorl almost completely obscured by final thick wall. Numerous sutural apertures in final chamber against early whorl area and large penultimate chamber. Early whorl area with several large apertures. C 26517.

29 Side view. Final chamber partially overgrowing penultimate. C 26518.

30 Spiral view. Elongate irregular shaped bulla-like structure with numerous sutural apertures covers large part of sutural area within early whorl. C 26519.

Globigerinatheka euganea, n.sp.

From S 180, *Globorotalia lehneri* Zone.

31 Spiral view, 31a umbilical view. Final chamber with four apertures, one covered by very small bulla. Large fourth to second last chambers with sutural openings towards early whorl. No sutural apertures within early whorl. C 26520.

Orbulinoides beckmanni (Saito).

Specimens 35, 37 from S 206; 32–34, 36 from S 205, *Orbulinoides beckmanni* Zone.

32 Side view. Final chamber with several sutural apertures, one covered by bulla. Sutural apertures within early whorl not visible in side view. C 26421.

33 Side view. Elongate, irregular shaped bulla-like structure with numerous apertures along large part of suture between early whorl and final chamber.

34 Spiral view, 34a side view, 34b umbilical view. Elongate bulla-like structure along part of sutural apertures of large penultimate chamber, 34b shows sutural apertures between penultimate and final chamber. C 26523.

35 Oblique spiral view. Elongate bulla-like structure along sutural area between early whorl and large penultimate and final chamber, also extends along suture between the two last chambers. C 26524.

36 Spiral view, 36a side view, 36b umbilical view. Elongate bulla-like structure along large portion of suture between final chamber and early whorl. Few areal apertures in final chamber. C 26525.

37 Oblique spiral view. Early whorl hardly visible, covered by final thick wall and irregular shaped small and elongate bulla-like structures. Areal apertures in final chamber. C 26526.

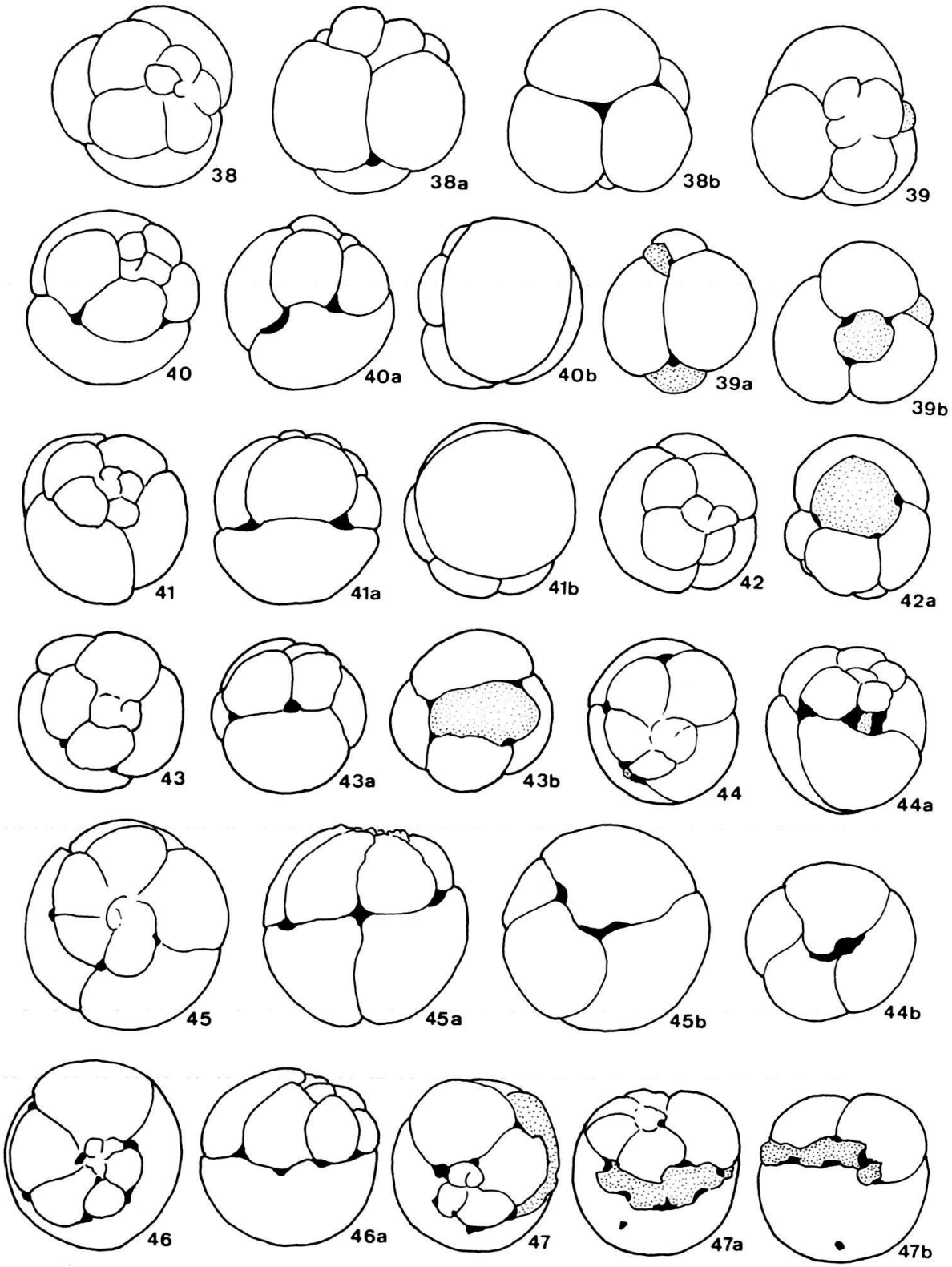
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Fig. 38–47 b

Orbulinoides beckmanni (Saito), emended

Plate I, Fig. 12; Plate II, Fig. 1–12; Plate III, Fig. 6–12; Plate IV, Fig. 1–9; Textfig. 16–30, 32–37, 46–47b

Globigerinoides mexicana (Cushman). Beckmann 1953, Pl. 25, Fig. 17–19.
Porticulasphaera mexicana (Cushman). Bolli, Loeblich and Tappan, 1957, Pl. 6, Fig;8, 9; Bolli, 1957, Pl. 37, Fig. 1.
Porticulasphaera beckmanni Saito, 1962, Pl. 34, Fig. 1a–2.
Orbulinoides beckmanni (Saito). Mohan and Soodan, 1970, Pl. 2, Fig. 11a, b.

Orbulinoides beckmanni is monotypic. Species description, remarks, and stratigraphic range are the same as given for the genus *Orbulinoides*.

Figured hypotypes: As listed above.

Fig. 38–47b. Specimens from Cava Zillo, Euganei hills, northern Italy.

Globigerinatheka curryi, n.sp.
From FPD 69/14bis, *Globorotalia lehneri* Zone.

38 Spiral view, 38a side view, 38b oblique umbilical view. Final chamber with three apertures. C 26527.

39 Spiral view, 39a side view, 39b umbilical view. Final chamber with two apertures, both covered by bullae. C 26528.

Globigerinatheka euganea, n.sp.
Paratypes, from FPD 69/17, *Orbulinoides beckmanni* Zone.

40 Spiral view, 40a side view, 40b umbilical view. Final chamber with four apertures. C 26529.

41 Spiral view, 41a side view, 41b umbilical view. Final chamber with two apertures. C 26530.

42 Spiral view, 42a umbilical view. Rudimentary final chamber with three apertures. C 26531.

Specimen 43 from FPD 69/16, 45 from FPD 69/15, *Orbulinoides beckmanni* Zone; 44 from FPD 69/14, *Globorotalia lehneri* Zone.

43 Spiral view, 43a side view, 43b umbilical view. Rudimentary final chamber with four apertures. Penultimate chamber with two apertures. C 26532.

44 Spiral view, 44a side view, 44b umbilical view. Final chamber with three apertures. Aperture of penultimate chamber partially covered by very small bulla. C 26533.

45 Spiral view, 45a side view, 45b umbilical view. Final chamber slightly smaller than penultimate, with two apertures. Sutural aperture also in penultimate and third last chamber. C 26534.

Orbulinoides beckmanni (Saito).
Specimen 46 from FPD 69/17, 47 from an outcrop between villages Cortelà and Valnogaredo, near the small valley Calto Fondo in the central-western Euganei hills (sheet 64 of Carta d'Italia, Tavoletta Lozzo Atestino), *Orbulinoides beckmanni* Zone.

46 Spiral view, 46a side view. Final chamber and early whorl with sutural apertures. C 26535.

47 Spiral view, 47a oblique spiral view, 47b side view. Final chamber and early whorl with sutural apertures. Sutural apertures of final chamber partly covered by irregular shaped, elongate bulla-like structure with numerous apertures. Few areal apertures in final chamber. C 26536.

Patterns on Chamber Surfaces

It is clearly apparent from the specimens figured by SEM microphotographs on Plates I and II, and in particular from details shown on Plate III, that the surface patterns of *Globigerinatheka curryi*, *G. euganea* and *Orbulinoides beckmanni* vary considerably. Many specimens possess a fairly regular, but distinctly and rather deeply pitted surface (II/12, detail III/12). The surface of others is covered by coarse, fairly evenly sized calcite pustules. This coverage may be dense, over the whole surface of the specimen (I/7, detail III/3), or in the form of isolated knobs, often restricted to only one or part of one chamber (II/7). Chambers with a fairly smooth original surface and regularly spaced pores may become covered partially by isolated blocky masses of calcite (I/4, detail III/2). Eventually these may partially coalesce to form a smooth surface leaving small round or larger irregular shaped depressions, resulting in a meander pattern (I/2, detail III/1, early chambers only). The coalescing process may eventually reach a stage where most of the chamber surface becomes covered by a smooth calcite crust with the pores forming only small, often irregular shaped openings (I/8, detail III/4).

Areal apertural openings are often surrounded by more prominent calcite masses (II/5, 6, detail III/7, 8, 9). The principal patterns may extend over the whole surface of a specimen (I/7, II/8), or may be present only in parts (I/4, II/7).

Sections Studied

The evolution of *Globigerinatheka curryi–G. euganea–Orbulinoides beckmanni* was studied for this paper in sections from Barbados, W.I., Trinidad, W.I., and the Euganei hills in northern Italy. Due to facies changes influencing the distribution of the species, incomplete sampling, condensation or tectonic disturbance, none of the investigated sections seems to show the entire evolutionary history. This is true particularly of the early and late part of the lineage, whereas the significant interrelation of the three species *G. curryi*, *G. euganea* and *O. beckmanni* appears to be well documented.

Barbados

The Mount Hillaby River section collected by A. SENN in the lower part of the Oceanic Formation of Barbados and described by BECKMANN (1953) shows best the evolutionary sequence of the species considered here. *Orbulinoides beckmanni* in particular occurs in great numbers. It displays considerable variability, as is shown in Textfig. 16–37. The samples and slides used here are the same ones on which BECKMANN (1953) based the original foraminiferal work on the Oceanic Formation. Textfig. 48 shows SENN's original columnar section of the Mt. Hillaby River with the position of the sample numbers and also the distribution of *Globigerinatheka curryi*, *G. euganea* and *Orbulinoides beckmanni*. The Joes River mudflow (S 268A) is overlain by 10 cm of greyish slickensided clay (S 268B), 10 cm of white weathering, light bluish marly limestone (S 268C), followed by a massive white limestone (S 593) with a 5 cm layer of grey, knobby marl (S 204). The overlying interval S 180–S 211 consists of white marly limestone layers or lenticular ledges, alternating with white or

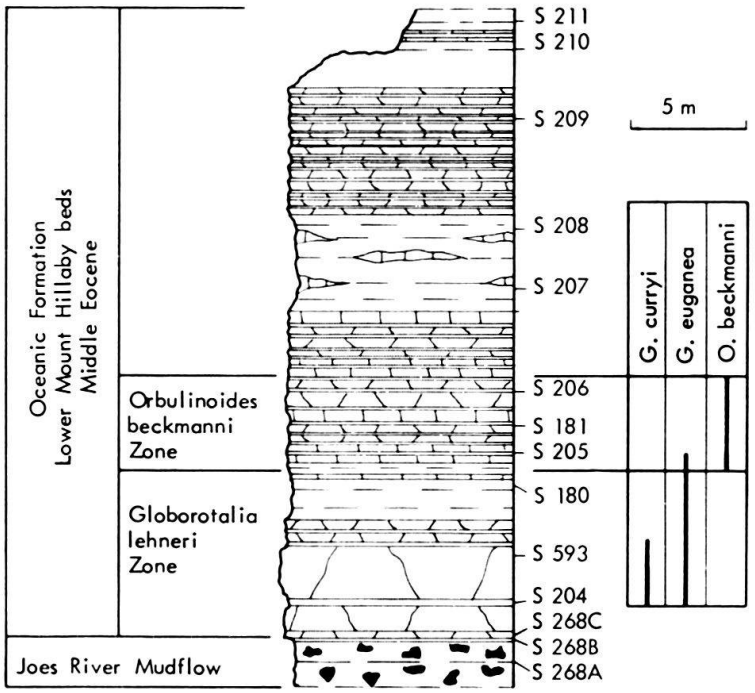

Fig. 48. Columnar section, sample position and distribution of discussed species in basal part of Oceanic Formation, northern bank of Mount Hillaby River, Barbados, W.I. Columnar section and sample position from unpublished field notes by A. Senn. For location of section see BECKMANN (1953, textfig. 2).

grey marls. While sample S 268B contains a fairly poor, predominantly benthonic foraminiferal fauna, S 268C is rich in planktonic foraminifera, mainly *Globigerina senni*. The first *Globigerinatheka curryi* occur in S 204, already together with *G. euganea*. Thus, the lower part of the *G. curryi* range is not represented in the available samples. According to SENN's field notes samples S 180 and S 205 are identical, i.e. from the same 1.5 m thick grey foraminiferal marl. Judging from the fauna of sample S 180, which contains only *G. euganea*, it is apparent that this sample must have been collected slightly below S 205 which contains *G. euganea* together with well developed *Orbulinoides beckmanni*. This species continues to be present in samples S 181 and S 206. Samples S 207 to S 211 are rich in radiolaria, and still contain planktonic foraminifera such as *Globigerina senni*, but no more *O. beckmanni*. It is possible that this species disappeared here early because of the incoming radiolarian facies.

Trinidad

Only a limited number of single outcrop samples from the *Globigerinatheka kugleri*, *Globorotalia lehneri* and *Orbulinoides beckmanni* zones were available for investigating the distribution of the species under discussion. Because of the poor outcrop conditions and tectonic disturbances no continuous surface sections are known in which these zones are exposed in a continuous sequence. Three of the six samples listed in Textfig. 49, one for each zone, are from a tectonically disturbed section in the Navet River area. The remaining three samples are from the type localities of the above mentioned three zones.

AGE FM	ZONE	LOCALITY	SAMPLE NO	G. kugleri s.l.	G. curryi	G. euganea	O. beckmanni
Middle Eocene Navet	Orbulinoides beckmanni	Type Locality	HK 408				
		Navet River area	K 8777				
	Globorotalia lehneri	Type Locality	DB 272				
		Navet River area	K 8815				
	Globigerinatheka kugleri	Type Locality	Rz 476				
		Navet River area	K 8824				

Fig. 49. Distribution of discussed species in diagnostic samples from Trinidad, W.I. For location of samples from type localities and Navet River area see Bolli (1957, p. 158 and textfig. 25).

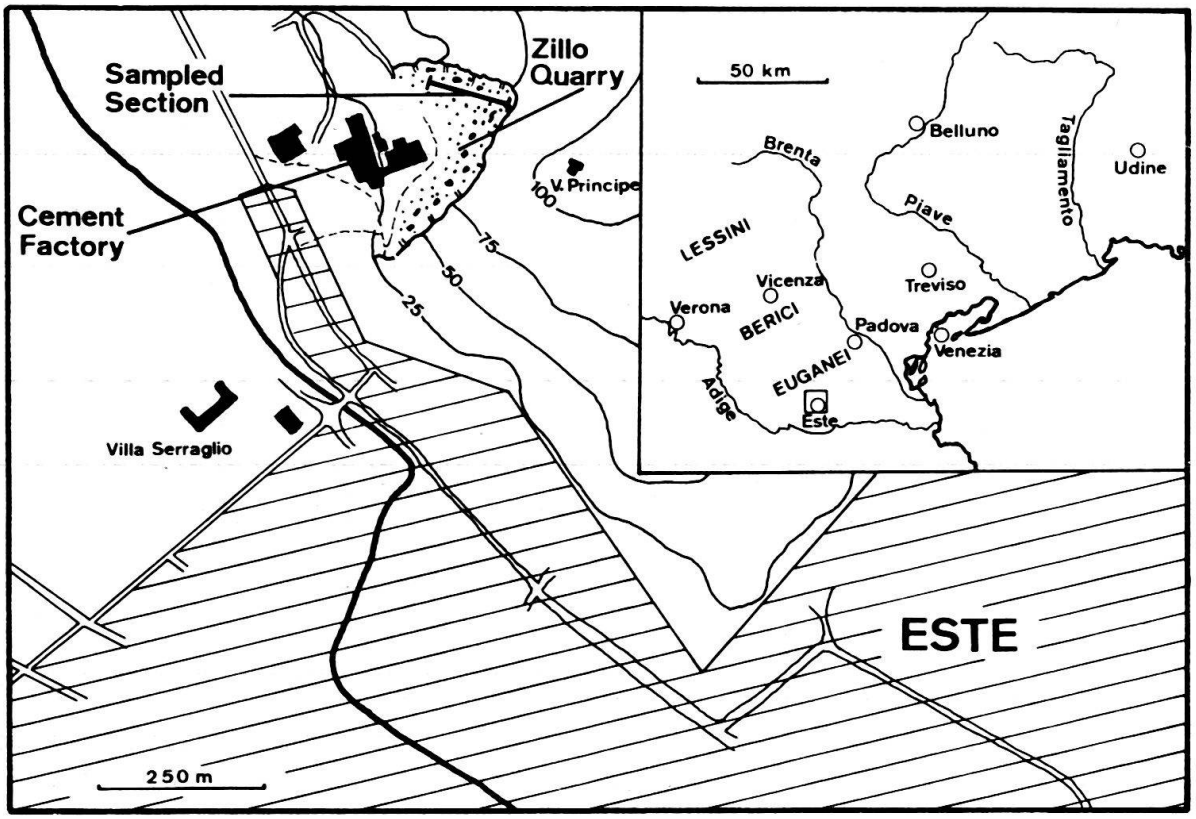

Fig. 50. Sketch map showing location of Cava Zillo section, Euganei hills, northern Italy.

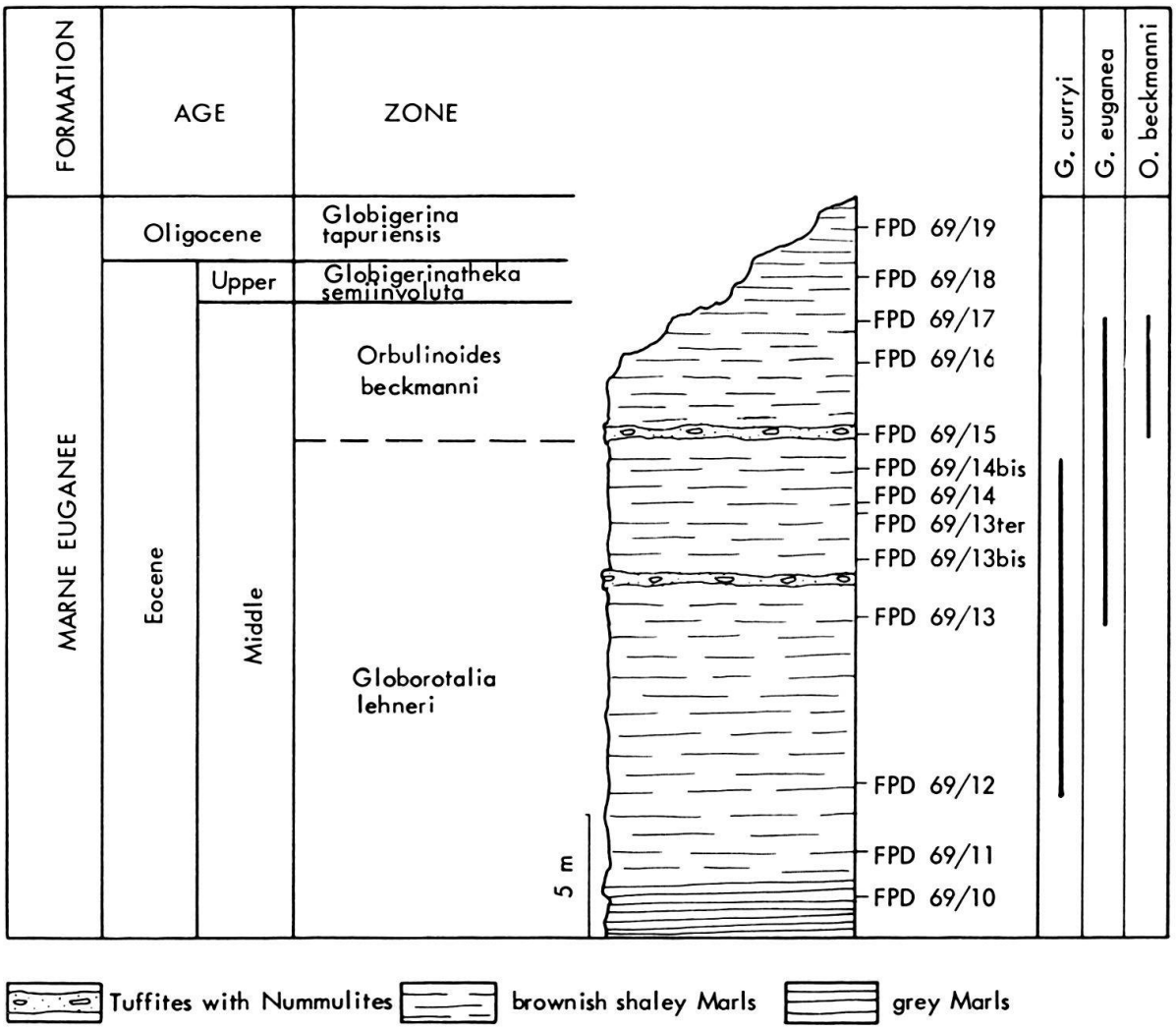

Fig. 51. Columnar section, sample position and distribution of discussed species in upper part of Euganei marls, Cava Zillo, Euganei hills, northern Italy.

Though it is not possible to show the evolutionary relationship of the three species in a continuous section, the six samples as arranged in Textfig. 49 provide a distribution pattern similar to that from the Mount Hillaby River section of Barbados. *Globigerinatheka kugleri* s.l. from the *G. kugleri* Zone listed here could be the ancestor of *G. curryi*, which is already well developed in the *Globorotalia lehneri* Zone. Investigation of closely spaced samples in a continuous section will be necessary, however, to confirm this.

Northern Italy

One of the best exposures in northern Italy, containing the Middle Eocene evolutionary sequence discussed here, is found in the southern part of the Euganei hills near the town of Este, in the Zillo cement works quarry which is cut into the western slope of the Monte Murale.

The beds exposed in this quarry range from Scaglia rossa at the base via transitional beds into the Euganei marls which form the upper part of the quarry. The exposed Scaglia measures about 40 m, of which 30 m are Upper Cretaceous (Upper Campanian-Mastrichtian), the remaining 10 m Paleocene-Lower Eocene. A hiatus does not permit observation of the complete passage from the Cretaceous to the Tertiary. The Euganei marls have a thickness of about 15 m in the southern part of the quarry and are here in their upper part of *Globorotalia lehneri* Zone age. As a result of a local fault, stratigraphically higher levels of the Euganei marls become exposed in the northern part of the quarry, where they measure about 30 m, and where the highest levels reach into the Oligocene.

The upper part of the section in this northern location of the quarry is shown in Textfig. 51. Its lower half is of *Globigerinatheka kugleri* and *Globorotalia lehneri* Zone age and consists of grey marls, with some intercalations of black shale layers, which are also transitional towards the higher shaley marls of brown color. Two tuffaceous layers, containing *Nummulites* sp. and *Discocyclina* sp., are characteristic levels in the upper part of the marls which are of *Globorotalia lehneri* to *Globigerina tapuriensis* Zone age. The upper tuffaceous layer approximately represents the boundary between the *Globorotalia lehneri* and the *Orbulinoides beckmanni* zones. Sample FPD 69/16 comes from the highest part of the quarry main slope. Samples FPD 69/17–19 were collected from a ledge above the main slope.

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Plate I

Globigerinatheka curryi n.sp.

Specimens from S 204, *Globorotalia lehneri* Zone, Mount Hillaby River section, Barbados, W.I.

Fig. 1 Spiral view. ×68. C 26537.

Fig. 2 Side view. Detail see Pl. III/1. ×68. C 26538.

Fig. 3 Umbilical view. Rudimentary final chamber. ×68. C 26539.

Fig. 4 Oblique umbilical view. Detail see Pl. III/2. ×82. C 26540.

Fig. 5 Specimen transitional between *Globigerinatheka curryi* and *Globigerinatheka euganea*.
Same locality as Fig. 1–4.
Side view. ×68. C 26541.

Globigerinatheka euganea n.sp.

Specimens 7 (holotype) and 8 (paratype) from FPD 69/17, *Orbulinoides beckmanni* Zone, Cava Zillo section, Euganei hills, northern Italy. Specimen 6 from S 204; 9 from S 593; 10 from S 180, *Globorotalia lehneri* Zone, Mount Hillaby River section, Barbados, W.I.

Fig. 6 Oblique umbilical view. Rudimentary final chamber with pore size smaller than in earlier chambers. ×60. C 26542.

Fig. 7 Oblique spiral view of holotype. Detail see Pl. III/3. ×60. C 26543.

Fig. 8 Oblique spiral view of paratype. Detail see Pl. III/4. ×64. C 26544.

Fig. 9 Side view of specimen with large penultimate and final chambers. ×60. C 26545.

Fig. 10 Side view. ×64. C 26546.

Fig. 11 Oblique side view. Specimen with two bullae, a small one at lower left, a larger one on top right. ×56. C 26547.

Orbulinoides beckmanni (SAITO)

From S 206, *Globorotalia lehneri* Zone, Mount Hillaby River section, Barbados, W.I.

Fig. 12 Spiral view. Sutural apertures of final chamber at contact with large early whorl visible. Sutural apertures within early whorl filled with matrix, indistinct on micrograph. ×60. C 26548.

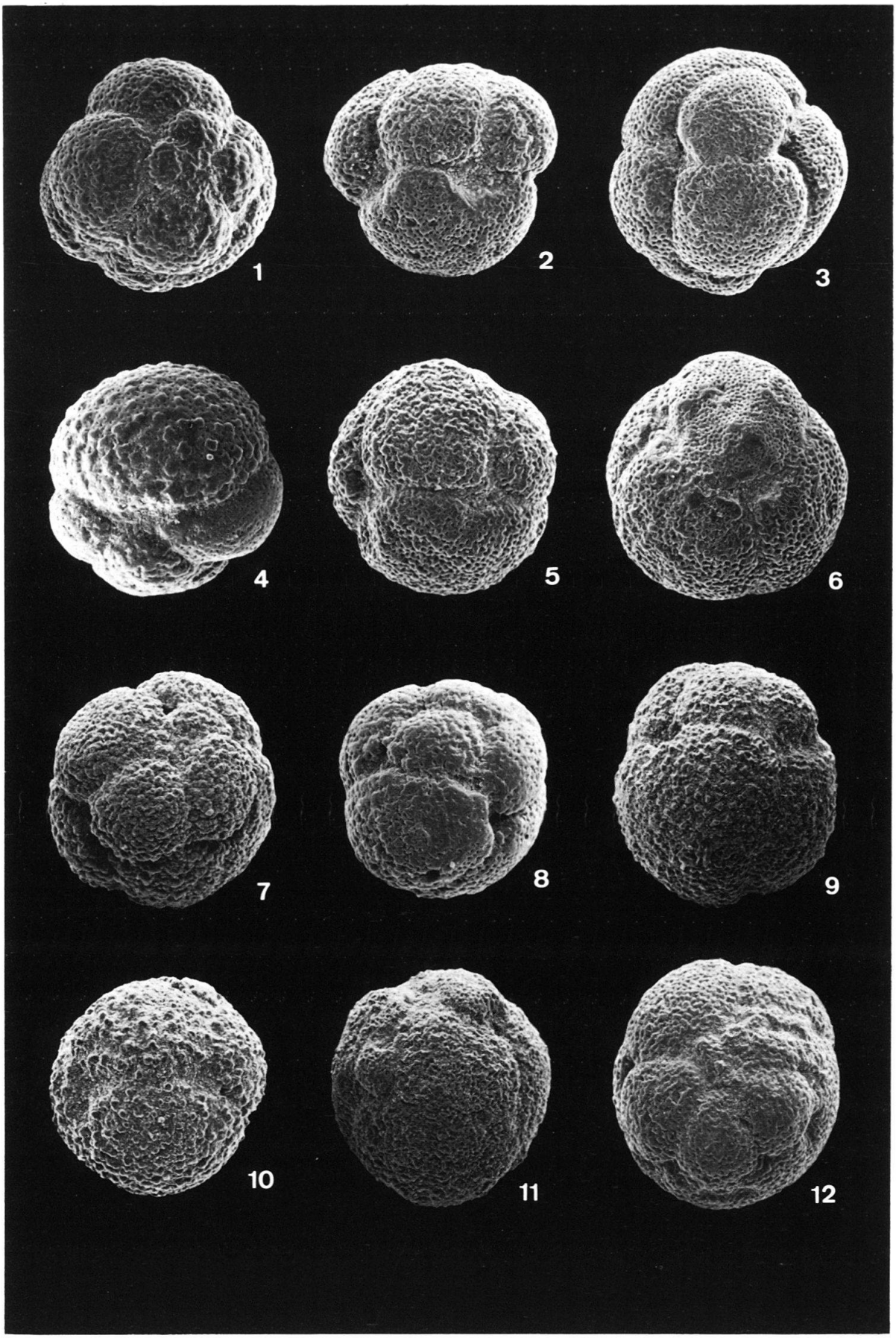
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Plate II

Orbulinoides beckmanni (SAITO)

Specimens 1, 5, 9 from S 205; 2, 6, 7, 10–12 from S 206; 3, 4, 8 from S 181, *Orbulinoides beckmanni* Zone, Mount Hillaby River section, Barbados, W.I.

Fig. 1 — Side view. Distinct sutural apertures between early whorl and final chamber. Detail see Pl. III/6. ×52. C 26549.

Fig. 2 — Side view. Large sutural apertures between early whorl and final chamber. ×56. C 26550.

Fig. 3 — Side view. Few areal apertures in final chamber. Detail see Pl. III/10. ×56. C 26551.

Fig. 4 — Oblique spiral view. Early whorl only poorly discernible. Final chamber with distinct sutural apertures. ×56. C 26552.

Fig. 5 — Side view. Penultimate large chamber (right) with one areal aperture. Detail see Pl. III/9. ×56. C 26553.

Fig. 6 — Oblique view. Final chamber with areal apertures. Details see Pl. III/7, 8. ×56. C 26554.

Fig. 7 — Side view. Large final chamber. ×64. C 26555.

Fig. 8 — Side view. Few areal apertures in final chamber. ×56. C 26556.

Fig. 9 — Side view. One sutural aperture of final chamber covered by small bulla-like structure (upper left). Few areal apertures in final chamber. ×56. C 26519.

Fig. 10 — Side view. Small elongate bulla-like structure along part of suture between early whorl and final chamber (upper left). ×60. C 26557.

Fig. 11 — Side view. Irregular shaped, elongate bulla-like structure along most of the suture between early whorl and final chamber, running parallel to and slightly above equator. Detail see Pl. III/11. ×52. C 26558.

Fig. 12 — Side view. Several small bulla-like structures on suture between early whorl and final chamber (running from upper left to lower right). Detail see Pl. III/12. ×48. C 26559.

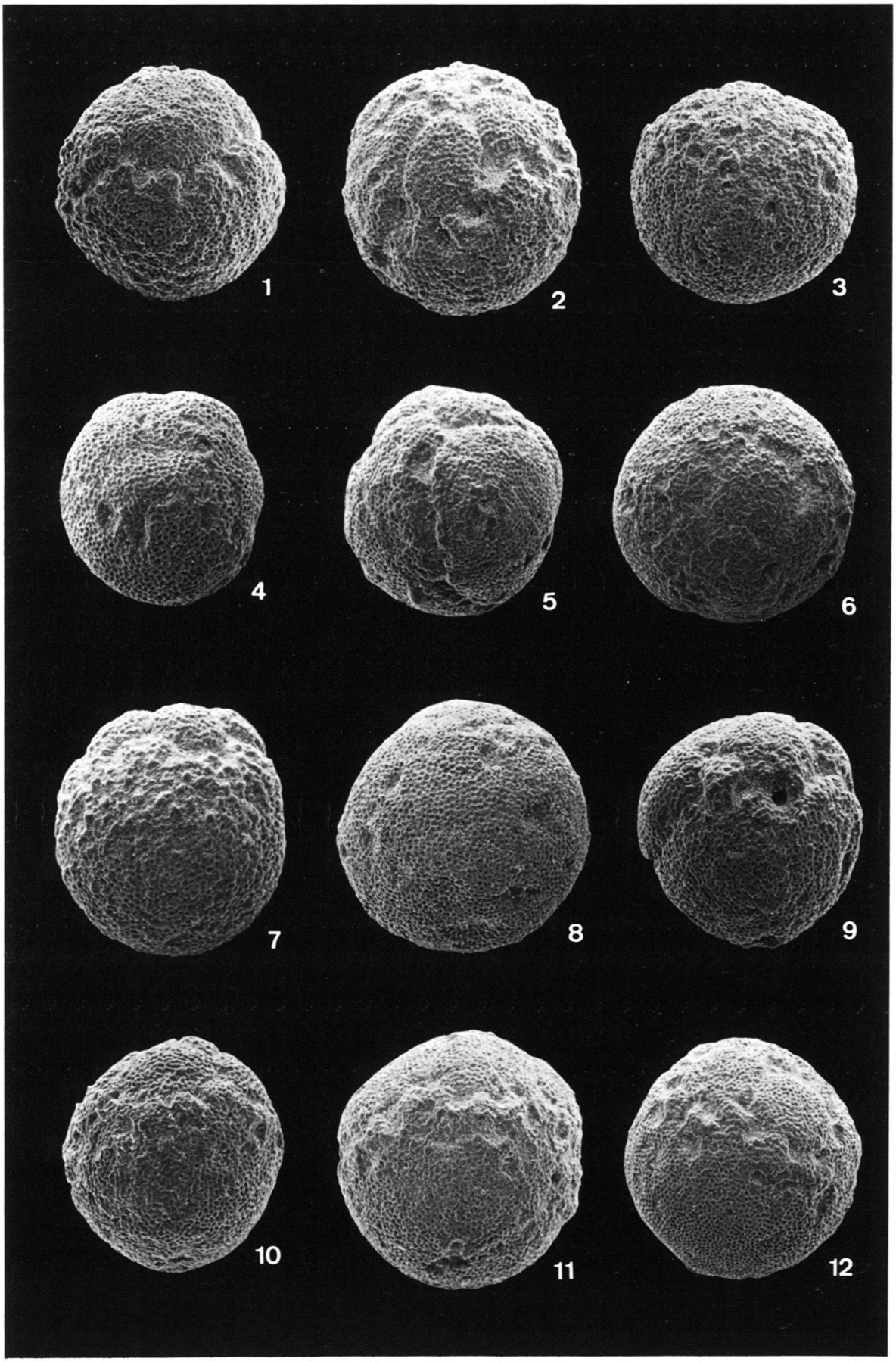
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Plate III

Surface patterns and apertures

Details of specimens figured on Plate I and II (except Fig. 5). For discussion see p. 900.

Fig. 1 Center of Pl. I/2. Aperture, meander pattern of surface in lower half. ×375.

Fig. 2 Center of Pl. I/4. Surface with isolated blocky masses of calcite. ×375.

Fig. 3 Upper left of Pl. I/7. Surface densely covered by calcite pustules. ×260.

Fig. 4 Lower right of Pl. I/8. Surface smooth with small, irregular shaped pores. ×260.

Fig. 5 Bulla on a specimen of *Globigerinatheka euganea* from S 593, *Globorotalia lehneri* Zone, Mount Hillaby River section, Barbados, W.I. ×230. C 26560.

Fig. 6 Center of Pl. II/1. Sutural apertures of final chamber. ×230.

Fig. 7 Top center of Pl. II/6. Areal apertures of final chamber. ×230.

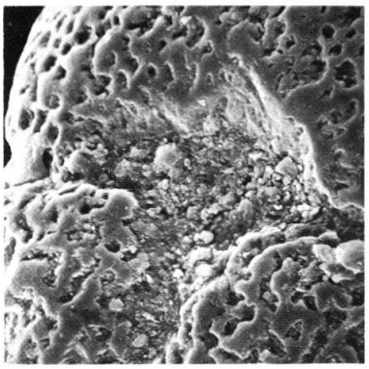
Fig. 8 Upper left of Pl. II/6. Areal aperture of final chamber. ×600.

Fig. 9 Right center of Pl. II/5. Areal aperture in penultimate chamber surrounded by prominent calcite masses. ×400.

Fig. 10 Middle right of Pl. II/3. Several areal apertures in final chamber. ×260.

Fig. 11 Central part of Pl. II/11. Elongate, irregular sutural bulla-like structures between early whorl and final chamber. ×150.

Fig. 12 Upper left of Pl. II/12. Regularly pitted surface. Small bulla-like structures. ×230.



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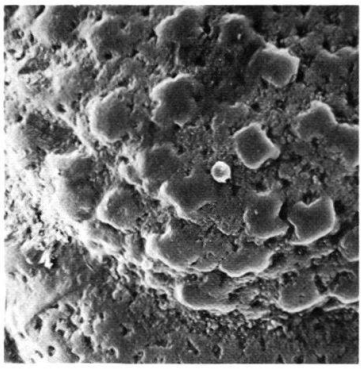

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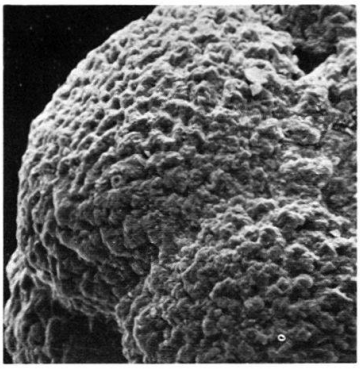

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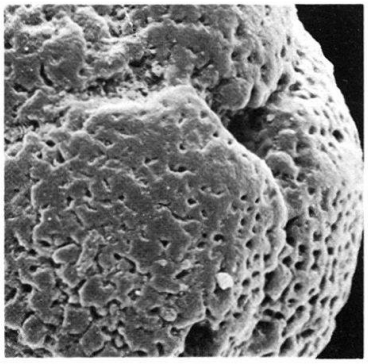

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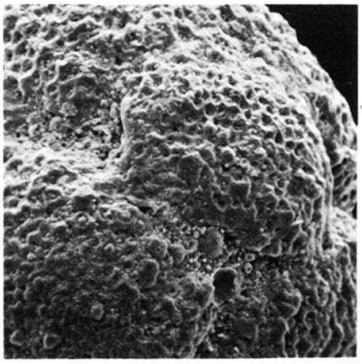

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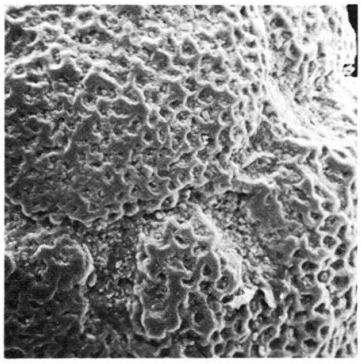

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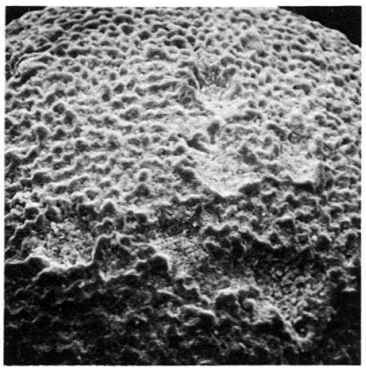

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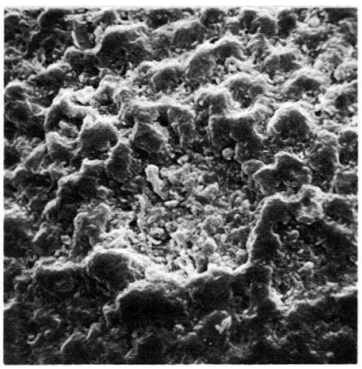

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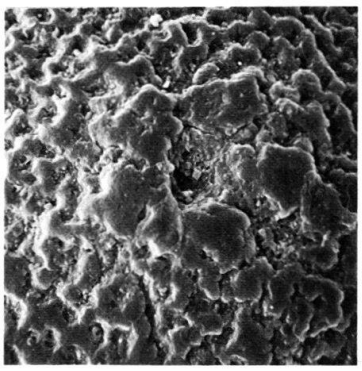

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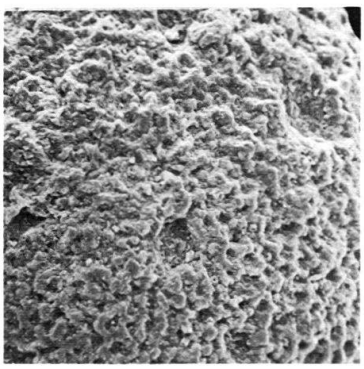

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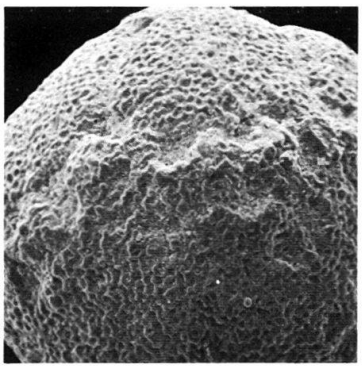

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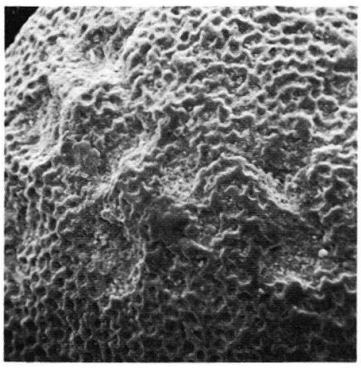

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Plate IV

Fig. 1–9 *Orbulinoides beckmanni* (SAITO) from S 206, *Orbulinoides beckmanni* Zone, Mount Hillaby River section, Barbados, W.I. Dissected specimens showing early whorl, vestibules, sutural and areal apertures, pores, and wall structure.

Fig. 1 Early whorl with delicate chamber walls. Later thickening covers spiral portion of these chambers. ×90. C 26561.

Fig. 2 Detail of Fig. 1: Four innermost visible chambers complete. Pore size increases as chambers are added. Finger shaped hollow (arrow) is caused by broken out sutural area between two early whorls. The floor of the hollow is formed by the porous inner surface of the thick outer wall that surrounds the whole specimen. Several rimmed sutural apertures of the thick outer wall, partially, filled with matrix, are situated along the contact with the early dissected chambers and one at the contact with the next later whorl (left of arrow point). A vestibule lies between the above mentioned broken out thin walled portions of the early chambers and the thick outer wall behind. ×150.

Fig. 3 Detail of upper right of Fig. 1: Sutural area of two early chambers (inside view), fused with thick outer wall, except in sutural area where a vestibule is formed. ×250.

Fig. 4 Part of early whorl (lower right) and thick walled final chamber with several areal and sutural apertures. ×80. C 26562.

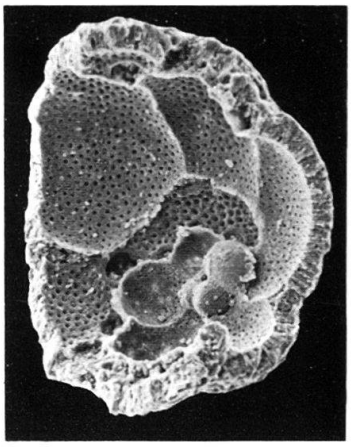
Fig. 5 Detail of lower center of Fig. 4: Four areal apertures and two sutural apertures, surrounded by smooth, non-porous rims. Sutural apertures possibly leading into a vestibule. All apertures partially filled with matrix. ×250.

Fig. 6 Detail of top left of Fig. 1: Inner view of sutural area of two early chambers; small broken portion of thick outer wall behind, with porous inner wall and sutural aperture partly filled with matrix. A vestibule occupies the space between the visible parts of the inner chambers and the outer wall. ×250.

Fig. 7 Early, thin walled chambers covered on spiral side by thick outer layer. Sutural apertures of these early chambers lead into vestibules which are situated along the outer sutural areas of the early chambers and the surrounding thick wall. ×85. C 26563.

Fig. 8 Detail of lower left of Fig. 7: Inner view of a sutural aperture, opening into a vestibule. ×250.

Fig. 9 Detail of upper right of Fig. 7: Cross section through thick wall fused to early chamber. ×500.



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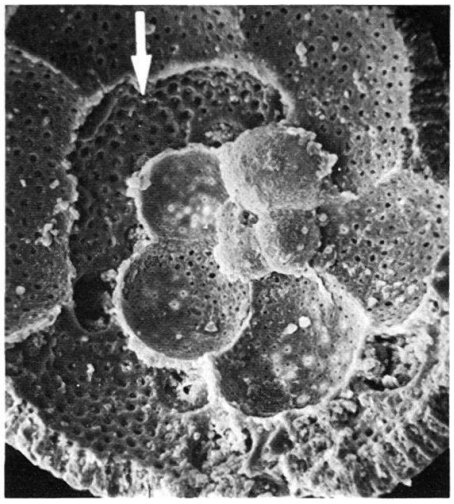

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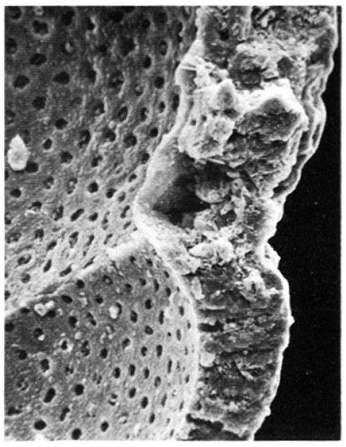

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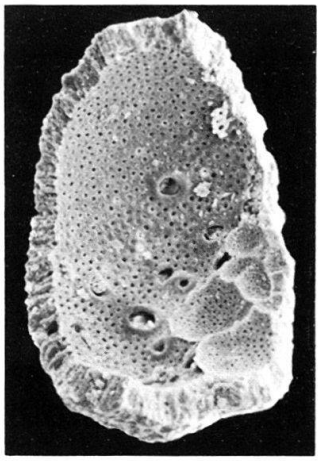

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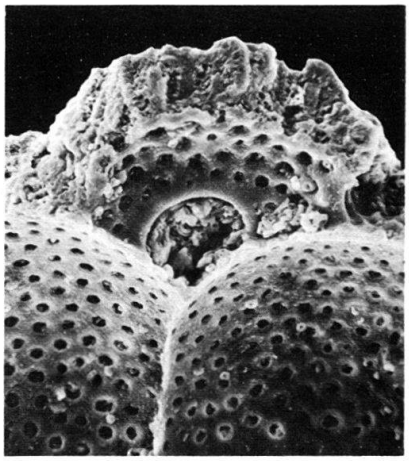

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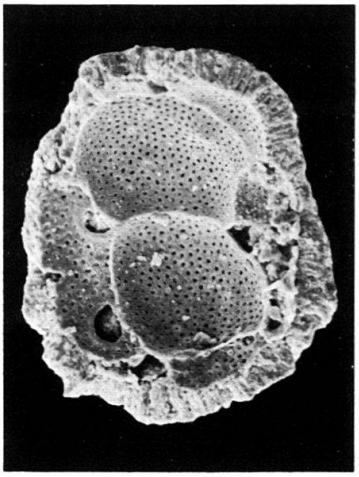

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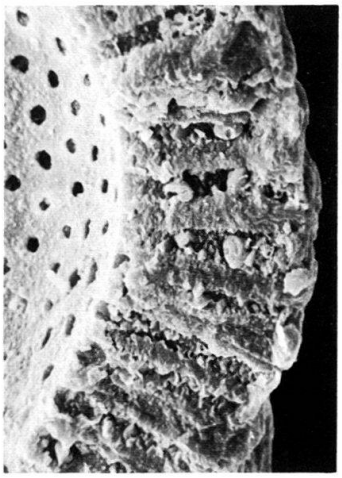

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