

Chapter 3

WALL TEXTURES OF OLIGOCENE NORMAL PERFORATE PLANKTONIC FORAMINIFERA

CHRISTOPH HEMLEBEN¹, RICHARD K. OLSSON², VLASTA PREMEC FUCEK³, MORANA HERNITZ KUCENJAK³

¹Department of Geoscience, Sand 6/7 Kernlabor und –Lager, D-72076 Tübingen, FR Germany.
Email: christoph.hemleben@uni-tuebingen.de

²Department of Earth and Planetary Sciences, Busch Campus, Rutgers University, Piscataway, NJ 08854, U.S.A.
Email: olsson@rci.rutgers.edu

³INA – industrija nafte d.d., Exploration and Production, Lovinciceva 4, 10002, Zagreb, Croatia.
Email: vlasta.premec-fucek@ina.hr; morana.hernitz-kucenjask@ina.hr

ABSTRACT

The work of Bé (1968) and Bé and others (1969) on the shell porosity of modern planktonic foraminifera provides additional criteria for categorizing the taxonomy of Oligocene genera and even species according to their test pore size and concentration. Use of these criteria in addition to the type of wall texture provides further information for the separation of groups of normal perforate

Oligocene planktonic foraminifera for phylogeny and classification. In addition to wall textures recognized in the Eocene (Hemleben and Olsson, 2006) two types of wall texture are recognized in Oligocene spinose planktonic foraminifera: a *Neogloboquadrina*-type which occurs in the new genus *Ciperoella* and a *conglobatus*-type which occurs in two species of *Dentoglobigerina*.

INTRODUCTION

Oligocene species of planktonic foraminifera are characterized by generalized globular morphologies exhibiting widespread homeomorphy between spinose and nonspinose species that can often make identification difficult. In addition, preservation of Oligocene planktonic foraminifera is generally poor in many localities around the world. Gametogenetic calcification and the addition of a calcite crust on some species covers underlying wall texture, making it difficult to observe spines or spine holes, i.e., whether a species is spinose or nonspinose. We have relied on well preserved specimens that have been carefully cleaned to reveal the surface texture. The descriptive method used to analyze wall textures in planktonic foraminifera is based on extant species and interpreted, based on environmental observations, measurements, and experiments (Hemleben and others, 1989).

The work of Bé (1968) and Bé and others (1969) on the shell porosity of modern planktonic foraminifera provides additional criteria for categorizing the taxonomy of Oligocene genera and even species according to their test pore size and concentration. Bé used the light microscope and x-ray to measure pore size and concentration on fragments of the test wall and gave the results as the pore concentration and size of a 25 µm x 25 µm area of the test wall. He showed by this method that modern genera and species plotted within certain separate domains (Fig. 3.1). Bé (1968) identified four clusters that formed the major species groups based on similarities in shell microstructures (*Globigerina*, *Globorotalia*, *Globoquadrina*, and *Globigerinoides*). His work was done during the early stages of the use of the scanning electron microscope (SEM) and he predicted its extensive use in future studies of shell porosity. Unfortunately, his death prevented further shell porosity study and no further study by workers was completed

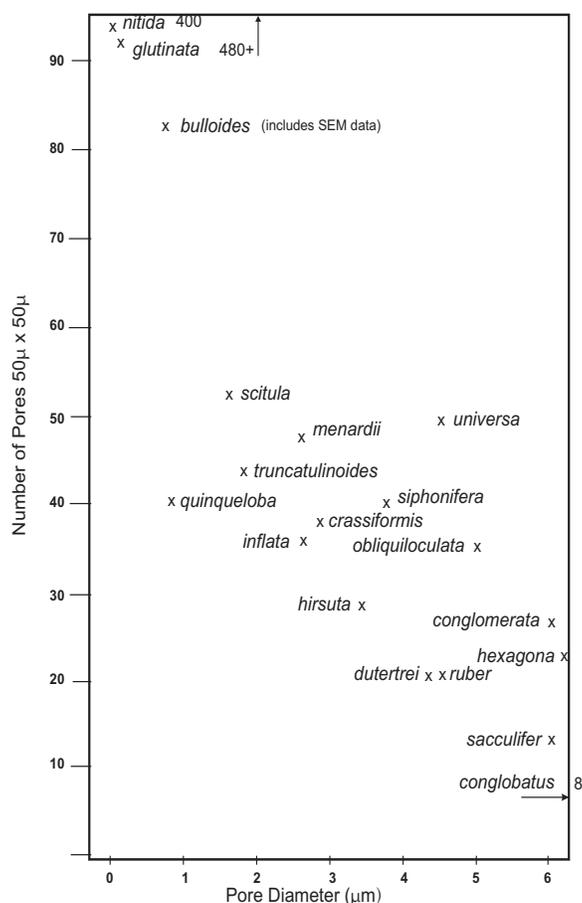


FIGURE 3.1. Pore concentration and pore size of modern species of planktonic foraminifera, from Bé and others (1969). Plot of *bulloides* includes additional measurements on Recent specimens.

using the SEM.

We have followed the lead of Bé by applying his method to the study of wall texture of Oligocene planktonic foraminifera using SEM. A 50 µm square area is cropped from a micrograph and the number and size of pores is measured. We use a 50 µm instead of a 25 µm square area as being more accurate in estimating the number of pores due to the variation of number of pores in the smaller area. Measuring the diameter of pores is more difficult due to the adding of wall layers during the formation of each chamber during ontogeny of the individual. The pore lies at the base of these ontogenetic wall layers and is usually at the base of a pit. Pores penetrating the test wall of a species, as noted by Bé, are not constant in diameter but, nevertheless, the

difference in diameter is slight. We have averaged the measurements of pore diameters to help overcome the difference. The pore diameter is measured at the base of pore pits as can be observed in cross-sections of the test wall.

There is a wide range of pore concentrations and pore diameters in Oligocene genera and species. Pore concentrations range from a little as 10 to over 90 pores per 50 µm square area of test wall surface in normal perforate planktonic foraminifera. Pore diameters range from 0.6 µm to over 4.0 µm. The specifics of these measurements are included in the discussion of wall texture below.

WALL TEXTURE AND PORE CONCENTRATION

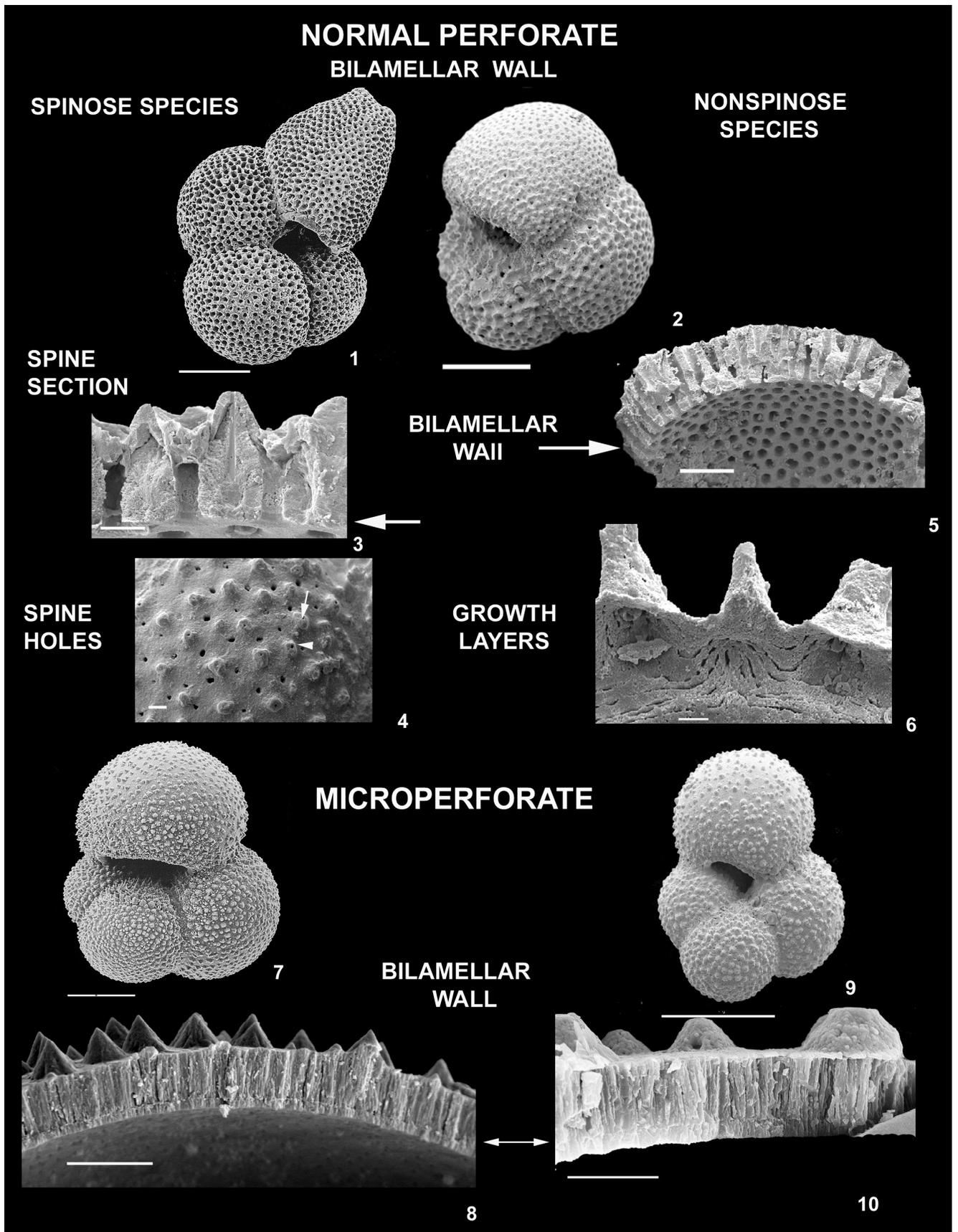
Wall textures of Oligocene planktonic foraminifera are similar to that encountered in the Eocene (Hemleben and Olsson, 2006) except for the wall texture associated with extinct Eocene genera (e.g. *Hantkenina*, *Morozovella*). The pore diameter and concentration determines the type of wall texture that develops during ontogeny. A small number of pores allows a more symmetrical cancellate texture and also a larger pore size. As the pore concentration increases the pore size becomes smaller and the wall texture becomes less symmetrical. Inter-pore ridges become elongated and somewhat parallel. Finally, with pore concentrations greater than around 60 pores per 50 µm square area of test wall the smallest pore diameters are observed and discontinuous inter-pore ridges develop in the tiny space between pores. These observations are added to the definition of wall texture types in normal perforate planktonic foraminifera.

SPINOSE

Spinose wall texture exhibits the widest range of pore concentrations and diameter whereas the non-spinose exhibits the smallest range.

sacculifer-type: as observed in the modern *Trilobatus sacculifer* as described in Hemleben and others (1991). The pores are equally distributed and the wall has a typical cancellate structure that is strongly

FIGURE 3.2. Wall types of planktonic foraminifera: 1, 3 *Trilobatus sacculifer*, 3 cross-section showing spine holes and pores, Recent; 2 *Turborotalia increbescens*, 5 cross-section of nonspinose wall, Zone O2; 4 *Globigerina officinalis* wall showing spine holes and pores, Zone O2; 6 *Morozovella aequa*, pustules showing growth layers, Zone E1; 7, 8 *Globigerinita glutinata*, 8 cross-section showing bilamellar wall and conical surface pustules, Recent; 9, 10 *Tenuitella clemenciae*, 10 cross-section showing bilamellar wall and conical surface pustule, Oligocene. Scale bar: 1 = 100 µm, 2, 7, 9 = 50 µm, 5 = 20 µm, 6, 8, 10 = 10 µm, 3 = 5 µm, 4 = 2 µm.



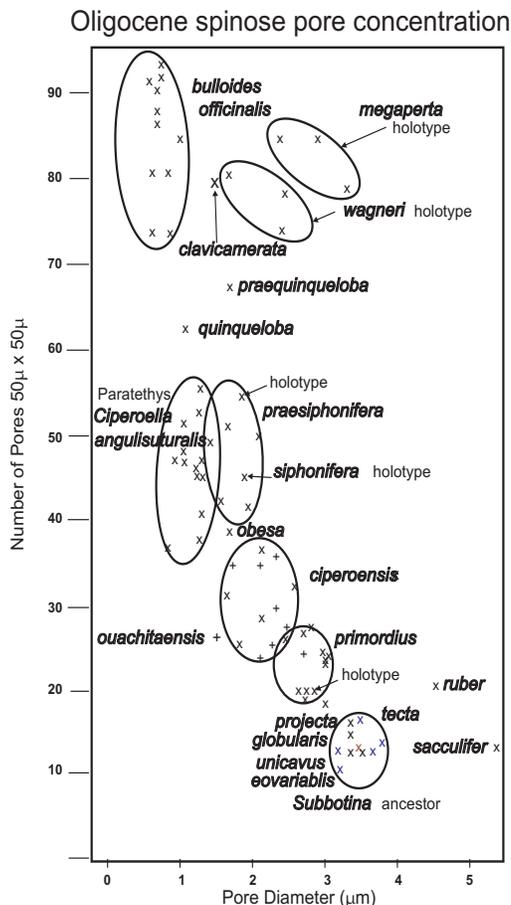


FIGURE 3.3. Pore concentration and pore size of Oligocene and later spinose species of planktonic foraminifera.

symmetrically oriented (honeycomb structure). In the Oligocene this wall texture is observed in some species of *Subbotina* and in *Catapsydrax*, *Globorotaloides*, and *Globoturborotalita* (Pl. 3.1, Figs. 1-3). Oligocene species with this type of wall texture have pore concentrations between 10 and less than 20 pores/50 μm^2 test surface area and pore diameters between 3.0 μm and 4.0 μm . Modern *T. sacculifer* has about 12 pores/50 μm^2 test surface area and a pore diameter over 5.0 μm (Bé and others, 1969).

ruber/sacculifer-type: in this type of wall texture the cancellate structure may be strongly symmetrical on some parts of the test wall and somewhat asymmetrical on other parts of the test wall. This type of wall texture is observed in some species of *Globoturborotalita* (Pl. 3.2, Figs. 1-11), *Paragloborotalia* (Pl. 3.3), and *Subbotina* (Pl. 3.1, Figs. 4-17). The first species of the genus

Trilobatus (*T. primordius*) has this type of wall texture (Pl. 3.2, Figs. 12-24). *Trilobatus primordius* has pore concentrations ranging from around 20 to 28 pores/50 μm^2 test surface area and pore diameters from around 2.5 μm to 3.0 μm . Modern *Globigerinoides ruber* has around 20 pores/50 μm^2 test surface area and a pore diameter around 4.5 μm (Bé and others, 1969).

When Cifelli (1982) erected the genus *Paragloborotalia* he illustrated SEM images of two specimens of the genotype species, *Globorotalia opima*, from Bolli's type locality in Trinidad (pl. 2, figs. 1, 1a, 2, 2a)¹. Cifelli separated *Paragloborotalia* from *Globorotalia* on the basis of a spine bearing test in his new genus. He based this interpretation on his plate 2, fig. 2a where he reported spine collars and one possible hollow (spine) hole. It is unfortunate that this specimen, apparently, is lost or misplaced because the supposed spine collar (his Fig. 2a) appears to be, in fact, deposits of gametogenetic calcite and it is unclear that there is a spine hole present. Nevertheless, Cifelli is correct that *Paragloborotalia* is a spinose genus. The spines are without spine collars, are very thin and project from a *ruber/sacculifer*-type wall texture along the honeycomb ridges (Pl. 3.3, Figs. 13-19). Spine holes can also be observed in the first paragloborotaliid species in the Eocene, *Paragloborotalia griffinoides* (Pl. 3.3, Figs. 18, 19). Spine holes are difficult to detect in *P. opima* due to deposition of gametogenetic calcite that tends to smooth the primary wall covering the tiny spine holes (Pl. 3.3, Fig. 17). A crust-like calcite layer with euhedral crystal facies may thicken the wall surrounding the umbilicus (Pl. 3.3, Fig. 13). Pore concentrations of Oligocene species of *Paragloborotalia* average about 20/50 μm^2 test surface area and pore diameters of around 2.5 μm .

Neogloboquadrina-type: Rögl (1996) examined type material from Trinidad of *Globorotalia kugleri* Bolli and *Globorotalia pseudokugleri* Blow and showed the two species were spinose and placed them in the genus *Paragloborotalia*. *Paragloborotalia kugleri* and *P. pseudokugleri* have an underlying *ruber/sacculifer*-type wall texture like the genotype species, *Paragloborotalia opima*, but develop in the adult stage a *Neogloboquadrina*-type wall where elongate parallel ridges with short connecting ridges appear more prominent on the umbilical surface (Pl. 3.4, Figs. 1-12).

¹ Two specimens from Cifelli's work deposited in the Smithsonian Cushman collections (USNM 431651 and USNM 431652) show that USNM 431652 is the same specimen illustrated by Cifelli on pl. 2, figs. 1 and 1a. USNM 431651 is a different specimen from that illustrated by Cifelli on pl. 2, figs. 2 and 2a (see Pl. 3.3).

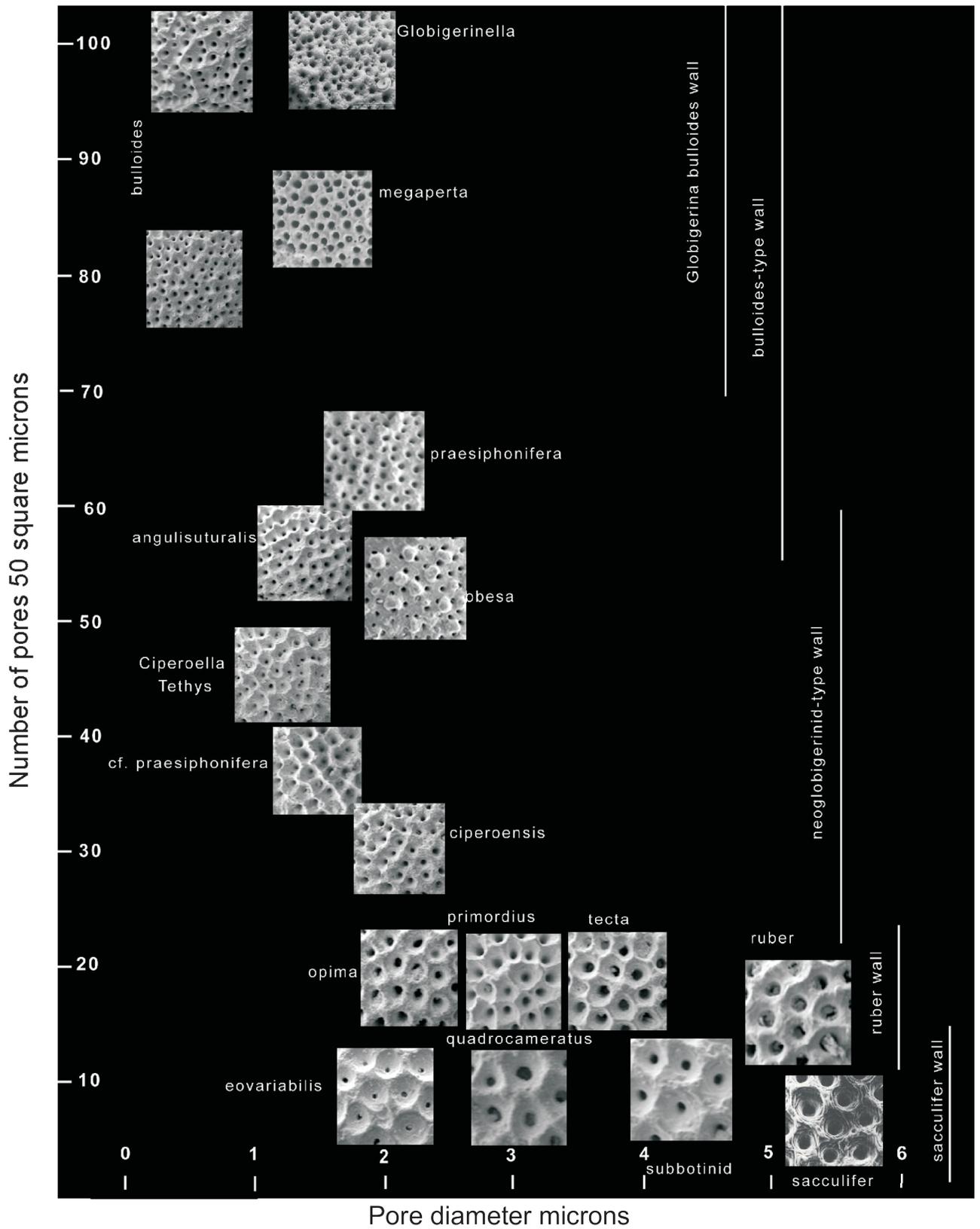


FIGURE 3.4. SEM images of wall texture of Oligocene species of planktonic foraminifera. Not to scale (see Fig. 3.3 for scale)

Pore concentrations range from around 40 to less than 70 pores/50 μm^2 test surface area with *P. kugleri* having the higher range of pore concentrations. Pore diameters are within a narrow range between 1.5 μm and 2.0 μm .

Turborotalita-type: this type of wall texture occurs in the modern *Turborotalita quinqueloba*, which has a rather smooth primary wall on which a *ruber/sacculifer* arrangement is developed (Pl. 3.5, Figs. 1-9). In the adult and terminal stages of ontogeny a calcite crust may form, enveloping the whole test (Pl. 3.5, Figs. 7, 8). These features are characteristic of all species of *Turborotalita*. It has 40 pores/50 μm^2 test surface area and a pore diameter averaging 1 μm (Fig. 3.1; Pl. 3.5).

conglobatus-type: this type of wall texture occurs in the species *Dentoglobigerina baroemoensis* and *D. globularis* and is named after the spinose modern species *Globigerinoides conglobatus*. *Globigerinoides conglobatus* is a subtropical species that lives in the photic zone and sinks to deeper water forming a thick calcite crust prior to gametogenesis. *Globigerinoides conglobatus* has a *ruber/sacculifer* wall texture (Pl. 3.6, Figs. 1-3). The species has a high density of thin spines supported by short spine collars (Pl. 3.6, Figs. 3-6). As a calcite crust develops the spine collars are covered but spine holes remain open on parts of some chambers, suggesting that spines are discarded during this stage prior to gametogenesis. This stage of crust development produces a hummocky texture of overgrown spine collars which occasionally show spine holes (Pl. 3.6, Figs. 4-6). In the terminal stage prior to gametogenesis a thick euhedral calcite crust has developed. The crust is thickest on the penultimate and prepenultimate chambers obscuring the underlying wall texture. In *D. baroemoensis* and *D. globularis* the euhedral crust is thinner. Spine holes are visible on some chamber areas similar to that observed in Recent *Globigerinoides conglobatus* (Pl. 3.7). A high density of spines is indicated by the closeness of spine holes. Average pore concentrations and pore diameters are 13 pores/50 μm^2 test surface area and 3.47 μm , respectively.

Formation of the calcite crust:

After the initial formation of the bilamellar wall and additional thickening of the lamellar wall on the outer surface, euhedral crystals of calcite form on the outer surface and gradually thicken to form a robust

final layer with a rough textured surface (Hemleben and others, 1989). The appearance of this secondary wall or calcite crust is induced in spinose and nonspinose species when subjected to low temperatures, when they sink into deeper colder waters. Cold water produces slow crystal growth and good crystallinity; whereas warm water produces faster crystal growth and poor crystallinity (Hemleben and others, 1989). Gametogenic calcification then completes the life cycle. The amount of gametogenetic calcite deposited on the test depends on the calcium budget of the organism during gametogenesis (Schiebel and Hemleben, 2017).

Ciperoella-type: this type of wall texture occurs in the new genus *Ciperoella* (Pl. 3.8). It is similar to the wall texture of the nonspinose genus *Neogloboquadrina*. It has an underlying *ruber* or *sacculifer*-type wall texture but develops longer or shorter subparallel low ridges often oriented towards the aperture. As in *Neogloboquadrina* the short ridges are less developed and may extend only part way between the longer ones. Species with this type of wall texture include *C. angulisuturalis*, *C. anguliofficialis*, *C. ciperoensis*, and *C. fariasi*. Pore concentrations range from around 25 to around 60 pores/50 μm^2 test surface area and pore diameters from around 0.9 μm to around 2.5 μm (Figures 3.3, 3.4).

bulloides-type: this type of wall texture occurs in the modern *Globigerina bulloides* and first appears in the Eocene-Oligocene species *G. officinalis* (Pl. 3.9). The pore pattern is irregular and the spine collars are connected with short and long irregular ridges. *Globigerina bulloides* evolved in the late Oligocene from *Globigerina archaeobulloides*. The pore concentration ranges from around 75 to over 90 pores/50 μm^2 test surface area and pore diameter from 0.6 to 0.9 μm . A subtype of the *bulloides*-type wall texture appears in the Oligocene species *Globigerinella praesiphonifera* and *G. obesa* (Pl. 3.9, Figs. 11-19) but the pore concentration ranges from a little over 40 to less than 60 pores/50 μm^2 test surface area and pore diameter is larger from approximately 1.6 μm to around 2.0 μm , showing a clear distinction between these two species and *G. bulloides* (Figs. 3.3, 3.4). Pore density may be a controlling factor in the development of this type of wall texture in preventing a more cancellate texture to develop due to less surface area for a cancellate arrangement to form.

NONSPINOSE/SPINOSE

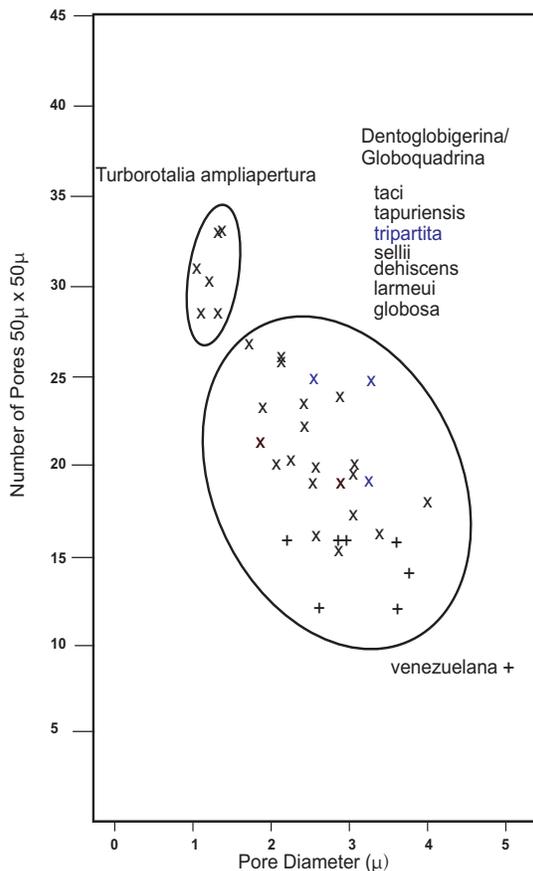


FIGURE 3.5. Pore concentration and pore size of Oligocene and early Miocene species of *Turborotalia*, *Dentoglobigerina* and *Globoquadrina*.

Quiltyella/Beella-type: this type of wall texture may have developed in the Eocene in the evolution of the genera *Clavigerinella* and *Pseudoglobigerinella* (Hemleben and Olsson, 2006). A dense pore pattern is developed within a wall with narrow cancellate ridges (Pl. 3.10, Figs. 1-16). This leads to a characteristic reticulate wall texture with a smooth surface. In the Oligocene this type of wall texture is observed in some species of *Globigerinella* and in *Quiltyella* (Pl. 3.10, Figs. 9-16). This type of wall texture is observed in the late Miocene genus *Beella* which may be a nearly identical homeomorph of *Quiltyella*.

There are two groups of Oligocene nonspino­se planktonic foraminifera, one with pustule growth during ontogeny and the other smooth-walled. These wall textures are explained in Hemleben and Olsson (2006). Smooth-walled *Pseudohastigerina* and *Turborotalia* morphology became extinct in the lower Oligocene.

The generic name of *Dentoglobigerina* is based on the presence of a triangular tooth that borders the aperture in the holotype, *Dentoglobigerina galavisi*. Umbilical teeth are present in many species but often not in all specimens in a species population. In the species discussed below umbilical teeth are less prominent and in many cases absent. These species are still placed in this genus as they are closely related to the central type and because an umbilical tooth is not a consistent morphologic feature in the ontogenetic development of species of this genus (see Chapter 11, this volume).

The derivation of the genus *Dentoglobigerina* which first appears in the middle Eocene (Zone E12) was not established by Olsson and others (2006). At the time they regarded the genus as nonspino­se due to pustule growth concentrated in the apertural area of *Dentoglobigerina* which may be a nonspino­se feeding adaptation for attachment of rhizopods. It is now evident that several species of Oligocene *Dentoglobigerina* exhibit evidence of having possessed spines. The occurrence of this evidence (holes in the wall) is sparse to abundant, and not evident in some species. Further investigations are needed to determine whether some species of *Dentoglobigerina* were nonspino­se. Species exhibit two types of wall texture. Most of the species in *Dentoglobigerina* have a *Globoquadrina*-type wall texture and two species (*D. baroemoenensis* and *D. globularis*) have a *conglobatus*-type wall texture. This, plus the possibility of some nonspino­se species suggests a somewhat complicated phylogenetic linkage. A radiation of this genus led to a number of species in the Oligocene and, in turn, led to the development of the genus *Globoquadrina*.

Globoquadrina-type: this type of wall texture has a geometrically oriented, high porosity test. The pores are evenly distributed and pustules of various morphologic types may develop in the interpore area. However, in the majority of cases the interpore area is too small to develop pustules in large quantities. In most cases the larger pustules are distributed around

the aperture. In the final growth stage the pustules grow together and thicken the wall. Species of *Dentoglobigerina* and *Globoquadrina* exhibit this wall texture type (Pl. 3.11, Figs. 1-20; Pl. 3.12, Figs. 1-16). Pore concentrations range between 15 and 30 pores/50 μm^2 test surface area but are mainly concentrated below 25. Pore diameters range between 1.5 and 4.5 μm (Fig. 3.5).

In the evolution of *Globoquadrina* from *Dentoglobigerina*, the lineage consists of *D. galavisi* - *D. larmeu* - *G. dehiscens*. It consists of 3½ to 4 chambered low trochospiral tests where the ultimate chamber becomes increasingly compressed and bent into the umbilicus. A broad apertural face develops with a sharp triangular tooth and the apertural face becomes imperforate (Pl. 3.12, Figs. 12, 14, 15).

MICROPERFORATE

The wall of this group is very finely perforate with pores that are less than 1.0 μm in diameter, in the range from 0.1 μm to 0.6 μm . The pores are scattered over the wall surface and can be overgrown by pustules in contrast to most normal perforate foraminifera. Pore concentration ranges from around 200 to over 400 pores/50 μm^2 test surface area (Pl. 3.13).

See Chapter 15 (this volume) for discussion of wall texture types of the microperforate group.

DIAGENESIS

Pustule-like additions to the test wall are quite common in the Oligocene (Pl. 3.14). They resemble pustules in morphology in that they generally do not have a crystalline surface. However, they are not part of the wall and do not show evidence of layered growth. These features may be lightly scattered on the test wall or they can be very densely distributed. They differ from pustules because they occur on gametogenetic calcite as well as on areas which lack gametogenetic calcite. This indicates (using the principle of superposition) that they formed post gametogenetic-stage or post reproductive cycle after the release of gametes. These diagenetic features have a pointed morphology like many pustules and vary in size and density on the test wall. Other diagenetic features are described in Hemleben and Olsson (2006).

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Plate 3.1 *sacculifer* and *ruber/sacculifer*-type wall texture

1-4, *Globoturborotalita cancellata*, 1, Zone O1, ASP 5B/30A/0-6", western North Atlantic slope, 2-4, Zone O2, Palma Real Fm., type locality, Tampico, Mexico; **5-8**, *Subbotina tecta*, 5, 6, 8, *nagewichiensis* Zone, AGS 66, 9A-1A, Shubuta, Alabama, 7, Zone E15/16, Tanzania (Pearson and Wade, 2015, fig. 13.4a); **9-14**, *Subbotina projecta* n. sp., 9-12, Zone E15/16, Shubuta Clay, Mississippi, 13, 14, Zone O1, TDP 17/25/3 44-58 cm, Tanzania; **15-17**, *Subbotina eocaena*, Zone O6, ASP 5A/0-6", western North Atlantic Slope. Scale bar: **1, 2, 5-7, 9, 10, 13, 15, 16** = 100 μm , **3, 4, 8, 11, 12, 14, 17** = 30 μm .

Plate 3.2 *Globoturborotalita-Trilobatus* wall textures

1-9, *Globoturborotalita paracancellata*, Zone O1, AGS 66, 9A-1A, Shubuta, Alabama; **10, 11**, *Globoturborotalita cancellata*, Zone O1, AGS 66, 9A-1A, Shubuta Fm., Alabama; **12-24**, *Trilobatus primordius*, 12-18, Zone O7, ASP 5B/16B/29-35", western North Atlantic slope, 19-24, Subzone M1a, *Globorotalia kugleri* zone, Mosquito Creek, Trinidad, RDL sample 463. Scale bar: **1, 2, 4, 7, 11, 12, 17-20, 24** = 100 μm , **8, 13** = 20 μm , **3, 5, 6, 9, 10, 14-16, 21-23**, 50 μm^2 surface area showing pore concentration and *ruber/sacculifer*-type wall texture.

Plate 3.3 *Paragloborotalia* wall texture

1-12, *Paragloborotalia opima*, hypotypes Cifelli (1982), Zone O5, *Globorotalia opima* type locality, Trinidad, 1-5, USNM 431651 (not specimen figured in Cifelli, 1982, pl. 2, figs. 2a, b), 6-8, new SEMs of USNM 431652, 9, 10 (same specimen as 6-8), reproduced from Cifelli (1982) pl. 2, fig. 2, 2a, 11, 12, reproduced from Cifelli (1982) pl. 2, fig. 1, 1a; **13-15**, *Paragloborotalia opima*, Zone O5, DSDP Site 112, Labrador Sea; **16-19**, *Paragloborotalia griffinoides*, Zone E1, Bass River, ODP 174AX, New Jersey coastal plain. Scale bar: **1-3, 6, 7, 13, 16, 18** = 100 μm , **4, 5, 8, 17** = 10 μm , **15** = 20 μm , **19** = 30 μm , **14**, 50 μm^2 surface area showing pore concentration and *ruber/sacculifer*-type wall texture.

Plate 3.4 *Neogloboquadrina*-type wall texture

1-6, *Paragloborotalia pseudokugleri*, 1-3, Zone O7, Trinidad (from Pearson and Wade, 2009, pl. 6, figs. 4a, c, 6e), 4-6, Zone M1, ODP Site 904/34/5, 144", New Jersey slope; **7-14**, *Paragloborotalia kugleri*, 7-10, 13, 14, Zone M1, *Globorotalia kugleri* type locality, Trinidad, 11, 12, Zone M1, Mosquito Creek, Trinidad, 13, 14, wall sections from Rögl (1996) showing spine holes and embedded spine. Scale bar: **1, 2, 4-7, 9, 11, 12** = 100 μm , **3** = 30 μm , **8, 10, 13, 14** = 10 μm .

Plate 3.5 *Turborotalita* wall texture

1-10, *Turborotalita quinqueloba*, 1, 2, 7-10, Recent, eastern North Atlantic Ocean; 4, 25 μm square surface area view of wall of second chamber of fig. 3; 5, 25 μm square surface area view of wall of second chamber of fig. 8; 10, 25 μm square surface area view of wall of fig. 9 showing spine hole and spine collars, 3, 6, Holocene, eastern North Atlantic Ocean; **11-18**, *Turborotalita praequinqueloba*, 11-14, 16, 17, Zone E15/16, Shubuta Clay, Mississippi, 17, 18, 25 μm square surface area and 25 μm x 50 μm surface area views of wall of ultimate and penultimate chamber of fig. 16 (11-14 from Olsson and others, 2006, pl. 6.20); 15-18 Zone O1, Shubuta Clay, Alabama. Scale bar: **1-3, 6-9, 11-16** = 50 μm .

Plate 3.6 *Globigerinoides conglobatus* wall texture

1-19, *Globigerinoides conglobatus*, Recent, Blake Escarpment, 1692 fathoms, 1, 2, pregametogenic specimen showing *ruber/sacculifer*-type wall texture showing spine holes with short spine collars, 3-6, specimen showing early development of crust with spines, 7-9, specimen showing advanced thicker development of crust with euhedral crust on penultimate chambers and spine holes on ultimate chamber, 10, specimen with last chamber removed showing the thick calcite crust, 11-19; specimens showing the thick euhedral calcite crust and thin deep sutural valley. Scale bar: **1, 3, 7, 10, 11, 14, 16, 17** = 100 μm , **2, 4-6, 8, 9, 12, 13, 15, 18, 19** = 10 μm .

Plate 3.7 *conglobatus*-type wall texture

1-24, *Dentoglobigerina globularis*, Zone M1, ODP Site 904/33/1-3, New Jersey slope, showing *conglobatus*-type wall texture. Note development of crust with thin deep sutural valley and still visible spine holes in overgrown spine collars. Scale bar: **1, 2, 5, 9, 12, 14, 17, 20, 23** = 100 μm , **3, 4, 24** = 20 μm , **7, 8, 10, 11, 13, 15, 16, 18, 19, 21, 22** = 10 μm , **6** = 2 μm .

Plate 3.8 *Ciperoella* wall texture

1-4, *Ciperoella angulisuturalis*, 1, 2, Zone O6, ODP Hole 872C/16H/1, 20-22 cm, Lo-En Guyot, northern Marshall Islands, western Pacific Ocean, 3, 4, Zone O4, Alazan Fm., type locality, Tuxpam, Tampico, Mexico; **5-8**, *Ciperoella anguliofficialis*, *nagewichiensis* Zone, AGS 66, 9A-1A, Shubuta Fm., Alabama; **9-12**, *Ciperoella fariasi*, Zone M1, ODP Site 904/34/4, New Jersey slope; **13-16**, *Ciperoella ciperoensis*, 13, *Globigerina ciperoensis* type locality, Trinidad, 14-16, *Globigerina ciperoensis* Zone, Trinidad. Scale bar: **5, 6, 8-10, 12-14** = 100 μm , **1-3** = 50 μm , **16** = 20 μm ; **4, 7, 11, 15**, 50 μm^2 surface area showing pore concentration with prominent elongate interpore ridges with short connecting incomplete ridges, typical of *Ciperoella* wall texture.

Plate 3.9 *bulloides*-type wall texture

1-4, *Globigerina officinalis*, 1, 2, Zone O2, Waschberg unit, lower Austria, Rögl sample 4-91, 2 wall view showing spine collars with spine holes, 3, 4, Zone O1, Shubuta Fm., AGS 66, 9A-1A, Alabama sample 4-91; **5-10**, *Globigerina bulloides*, 5, 6, Recent, North Atlantic Ocean, 7-10, Zone M1, ODP Site 904/34/5 - 144", New Jersey slope; **11-15**, *Globigerinella obesa*, Zone O7, sample PP07/T5, Trinidad, (11-13 from Pearson and Wade, 2009, pl. 4, figs. 4a-c), 14 wall of 13, 15 wall of 11; **16-19**, *Globigerinella praesiphonifera*, 16, 17, 19, Zone O6, ASP 5B/5A/0-6", Western North Atlantic slope, 18, Zone O6, ASP 5B/16B/29-35", western North Atlantic slope. Scale bar: **5, 7-9, 16-18** = 100 μm , **1, 4, 11-13** = 50 μm , **2** = 10 μm , **3**, 25 μm x 50 μm surface area, **6, 10, 14, 15, 19**, 50 μm^2 surface area showing high pore concentration typical of *bulloides*-type wall and spine collars with short connecting ridges.

Plate 3.10 *Quiltyella/Beella*-type wall texture

1-4, *Paragloborotalia* sp., Zone O2, Palma Real Fm., type locality, Tampico, Mexico; **5-8**, *Paragloborotalia nana*, Zone O4, Alazan Fm., type locality, Tuxpam, Tampico, Mexico; **9-12**, *Globigerinella* sp., Zone N4, DSDP Site 320B, Nazca Plate, southeastern Pacific Ocean; **13-15**, *Beella digitata*, Meteor" Cruise 31, Leg 3, sta. 116, northern Indian Ocean (or Arabian Sea), **16**, *Quiltyella nazcaensis*, Zone N4, DSDP Site 320B, Nazca Plate, southeastern Pacific Ocean. Scale bar: **1-3, 5-7, 9-11, 13-16** = 100 μm , **12** = 50 μm^2 , **4, 8** = 20 μm .

Plate 3.11 *Globoquadrina*-type wall texture

1, 2, *Dentoglobigerina galavisi*, Zone O1, Tanzania; **3, 4**, *Dentoglobigerina pseudovenezuelana*, Zone O1, Tanzania, 3, Pearson and Wade, 2015, fig. 17.3; **5-8**, *Dentoglobigerina eotripartita* n. sp.; 6, shows a spine hole, Zone O1, Tanzania; **9-12**, *Dentoglobigerina tripartita*, Zone O6, ASP 5B/16B/29-35", western North Atlantic slope; **13-15**, *Dentoglobigerina tapuriensis*, Zone O1, Tanzania; **17, 18**, *Dentoglobigerina venezuelana*, Zone O5, ASP 5B/19D/29-35", western North Atlantic slope; **16, 19, 20**, *Dentoglobigerina sellii*, Zone O4, Alazan Fm., type locality, Tuxpam, Tampico, Mexico. Scale bar: **1, 3, 5, 7, 9, 11-14, 17-20** = 100 μm , **2, 4, 6, 8, 10, 15, 16** = 20 μm .

Plate 3.12 *Globoquadrina*-type wall texture

1, 2, *Dentoglobigerina globosa*, Zone O6, ASP 5B 5A/0-6", western North Atlantic Slope; **3, 4**, *Dentoglobigerina* cf. *globosa*, Zone O6, ASP 5B 5A/0-6", western North Atlantic Slope; **5-7**, *Dentoglobigerina galavisi*, holotype, Upper Jackson Fm., Frost Ridge, Sample PJB-6, Mississippi, Zone E15/16; **8**, *Dentoglobigerina larmeu* transitional to *Globoquadrina dehiscens* showing the development of compressed ultimate chamber and apertural face, Zone M1, ODP Site 904/33/1 - 44", New Jersey slope; **9-11**, *Dentoglobigerina larmeu*, holotype, Shell Godchaux Sugars no. 1 well, St John the Baptist Parish, Louisiana, 9110-12 ft, middle Miocene; **12**, *Globoquadrina dehiscens*, showing the imperforate apertural face and triangular lip, ODP Site 904/33/1 - 44", New Jersey slope, Zone M1; **13-16**, *Globoquadrina dehiscens*, Subzone M1b, Trinidad, RDL sample 814, 14, 15, showing the imperforate apertural face and triangular lip. Scale bar: **1-3, 5-16** = 100 μm , **4** = 20 μm .

Plate 3.13 Microperforate wall texture (see Chapter 15 for discussion of wall texture types)

1-4, 7, *Chiloguembelina cubensis*, 1, 2, Zone O1, Jazal-2 well, 530-540 m, Chilou Fm., Syria, 3, 4, Zone O1, Istra More-3 well, 1200 m, north Adriatic Sea, Croatia, 7, Zone O2, Istra More-3 well, 1185.5-1195.5 m, North Adriatic Sea, Croatia; **5, 6, 8-10**, *Chiloguembelina ototara*, 5, 8, Zone O1, ODP Site 647A/30/2, 25-29 cm, Baffin Bay, North Atlantic Ocean, 6, Zone O2, Istra More-3 well, 1185.5-1195.5 m, North Adriatic Sea, Croatia, 9, Zone O1, Jazal-2 well, 500-510 m, Chilou Fm., Syria, 10, Zone O5?, Jazal-2 well, 400-410 m, Chilou Fm., Syria; **11, 13, 14**, *Tenuitella gemma*, Zone O2, Istra More-3 well, 1185.5-1195.5 m, north Adriatic Sea, Croatia; **12, 15**, *Tenuitella munda*, Zone O2, Istra More-3 well, 1185.5-1195.5 m, north Adriatic Sea, Croatia. Scale bar: **1, 3, 5, 6, 11-13** = 50 μm , **2, 4, 7, 8, 14, 15** = 10 μm , **9, 10** = 5 μm .

Plate 3.14 diagenesis

1-3, *Subbotina triangularis*, Zone P4, Whitesville Well, New Jersey coastal plain; **4-6**, *Subbotina* cf. *projecta*, Zone O2, *Globigerina ampliapertura* Zone, Trinidad; **7-8**, *Trilobatus primordius*, Zone O2, 7, 8, *ciperoensis* Zone, Trinidad; **9-11**, Zone O6, ASP 5B 10F/6-12", western North Atlantic slope; **12-15**, *Globoturborotalita anguliofficialis*, Zone O6, ASP 5B 10F/6-12", western Atlantic slope; **16, 17**, *Paragloborotalia siakensis*, Zone O6, ASP 5B 10F/6-12", western North Atlantic slope. Scale bar: **1, 4, 7, 9, 12, 14, 16** = 100 μm , **2, 3, 5, 6, 8, 10, 11, 13, 15, 17** = 10 μm .

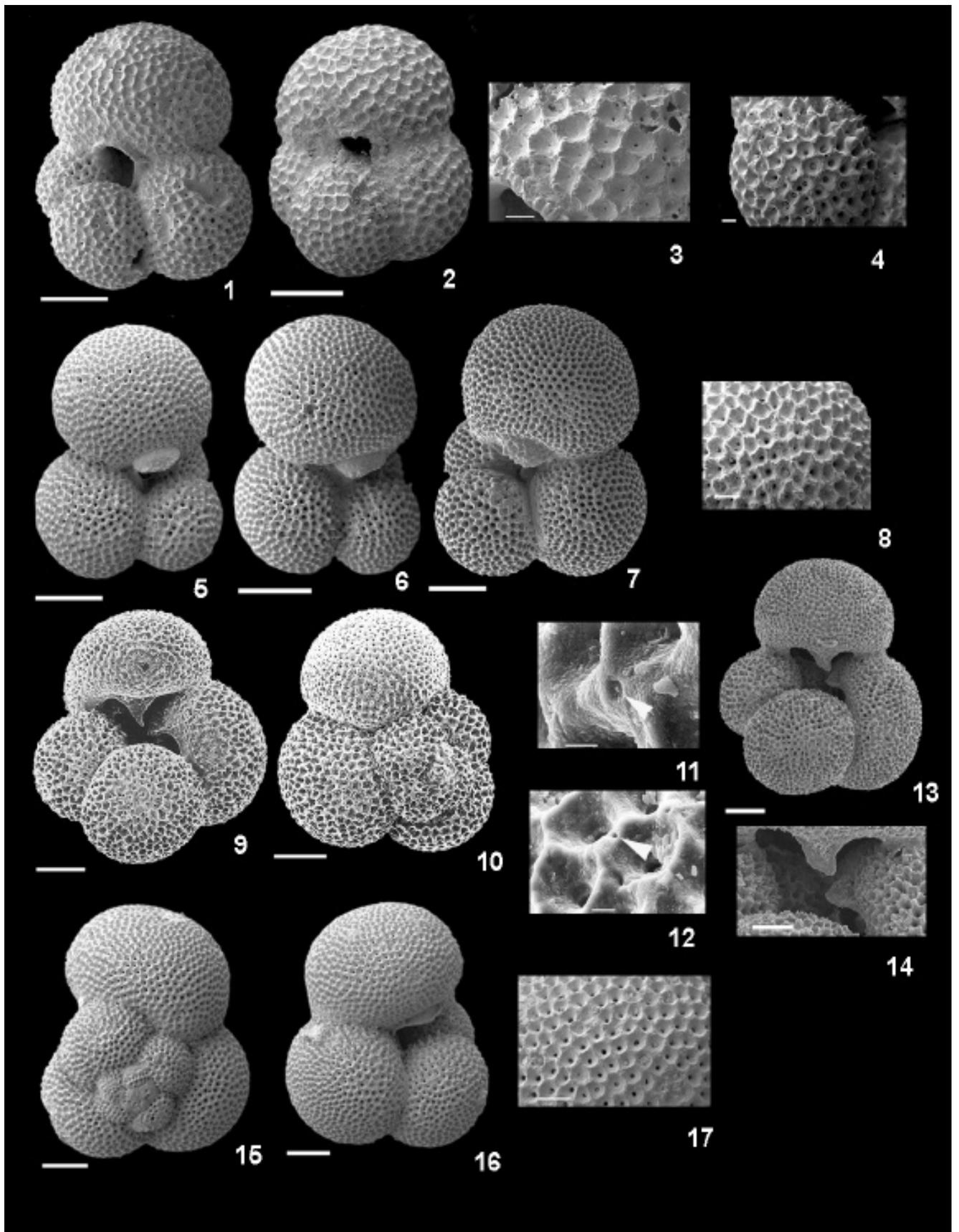
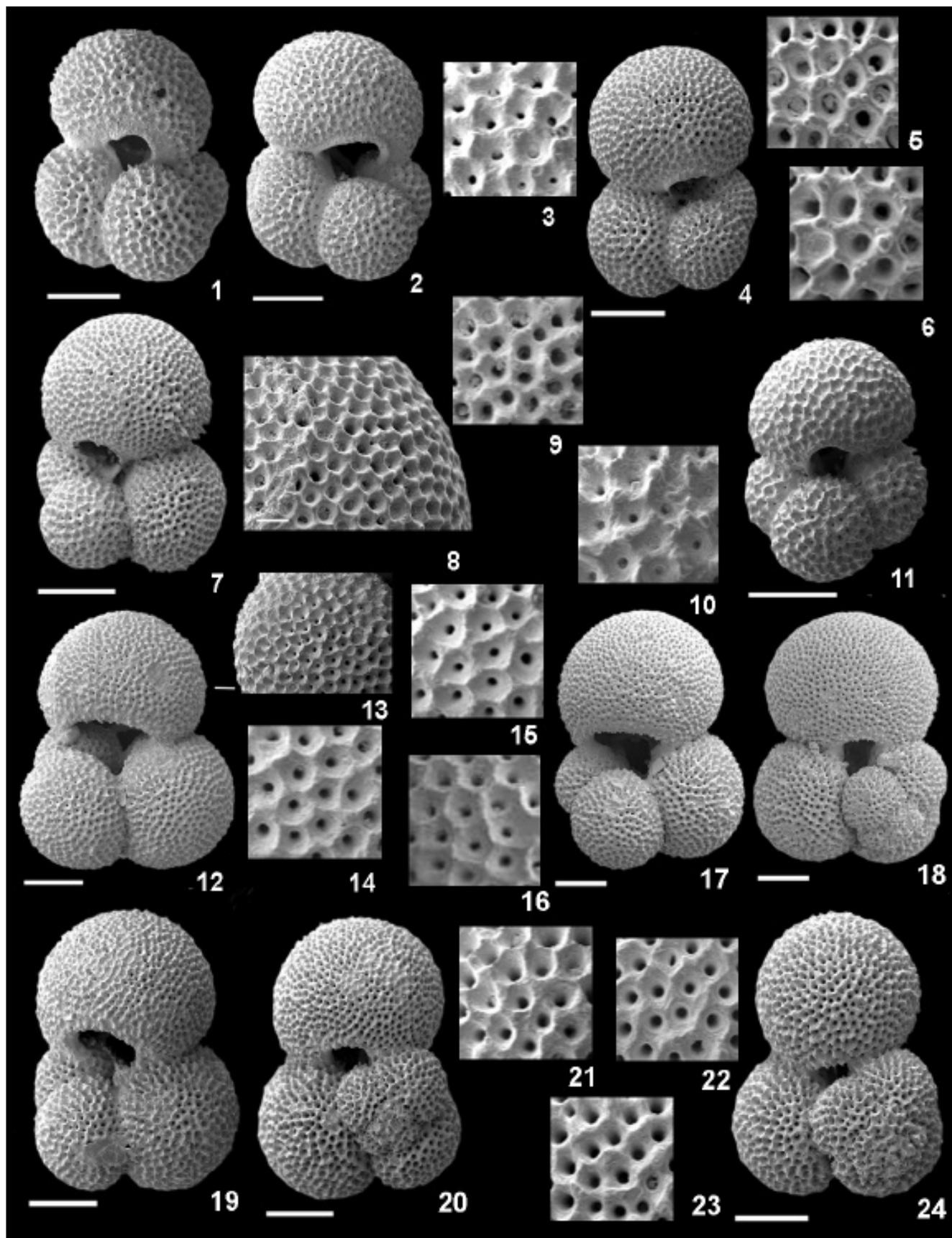


PLATE 3.1 *sacculifer* and *ruber/sacculifer*-type wall texture



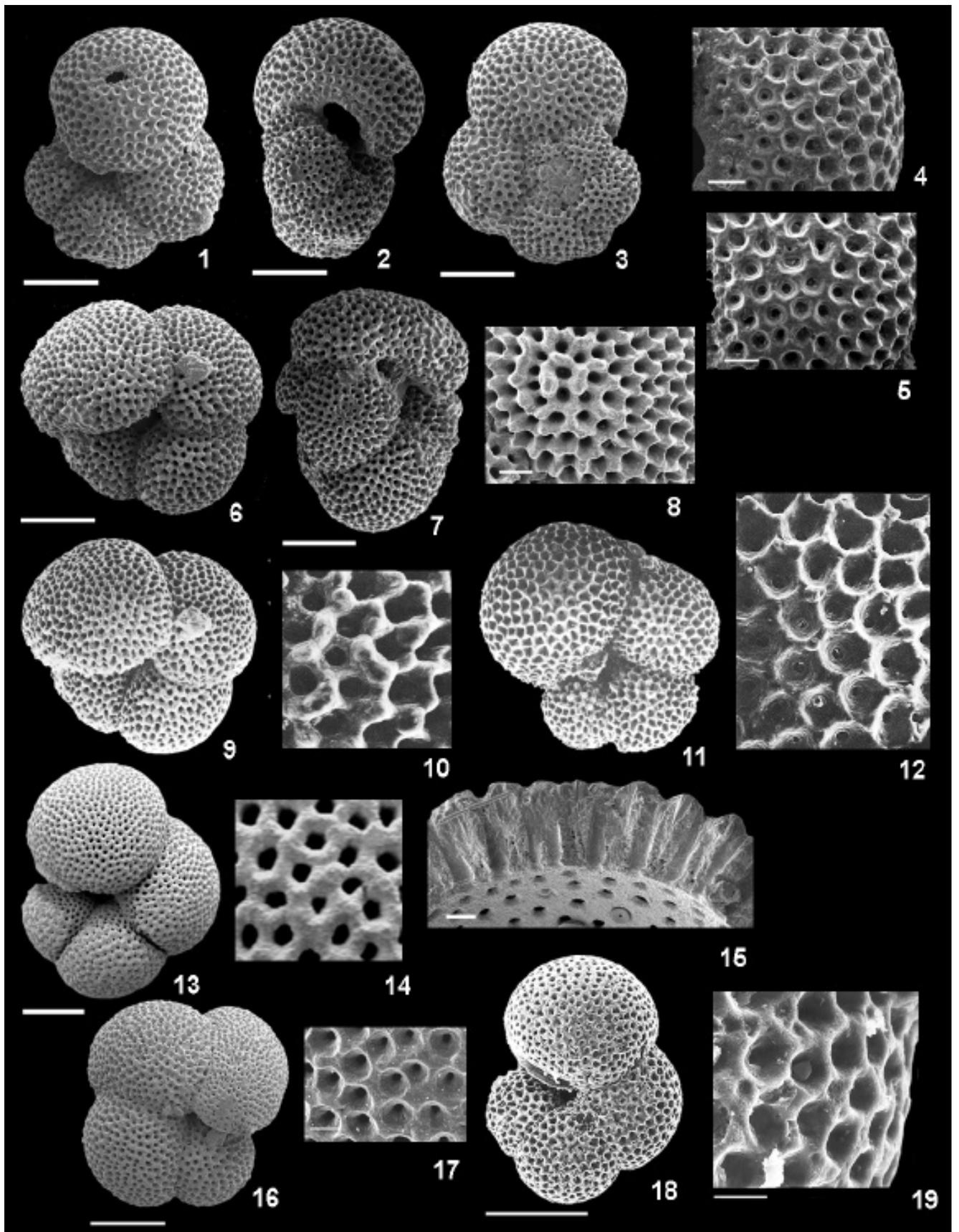


PLATE 3.3 *Paragloborotalia* wall texture

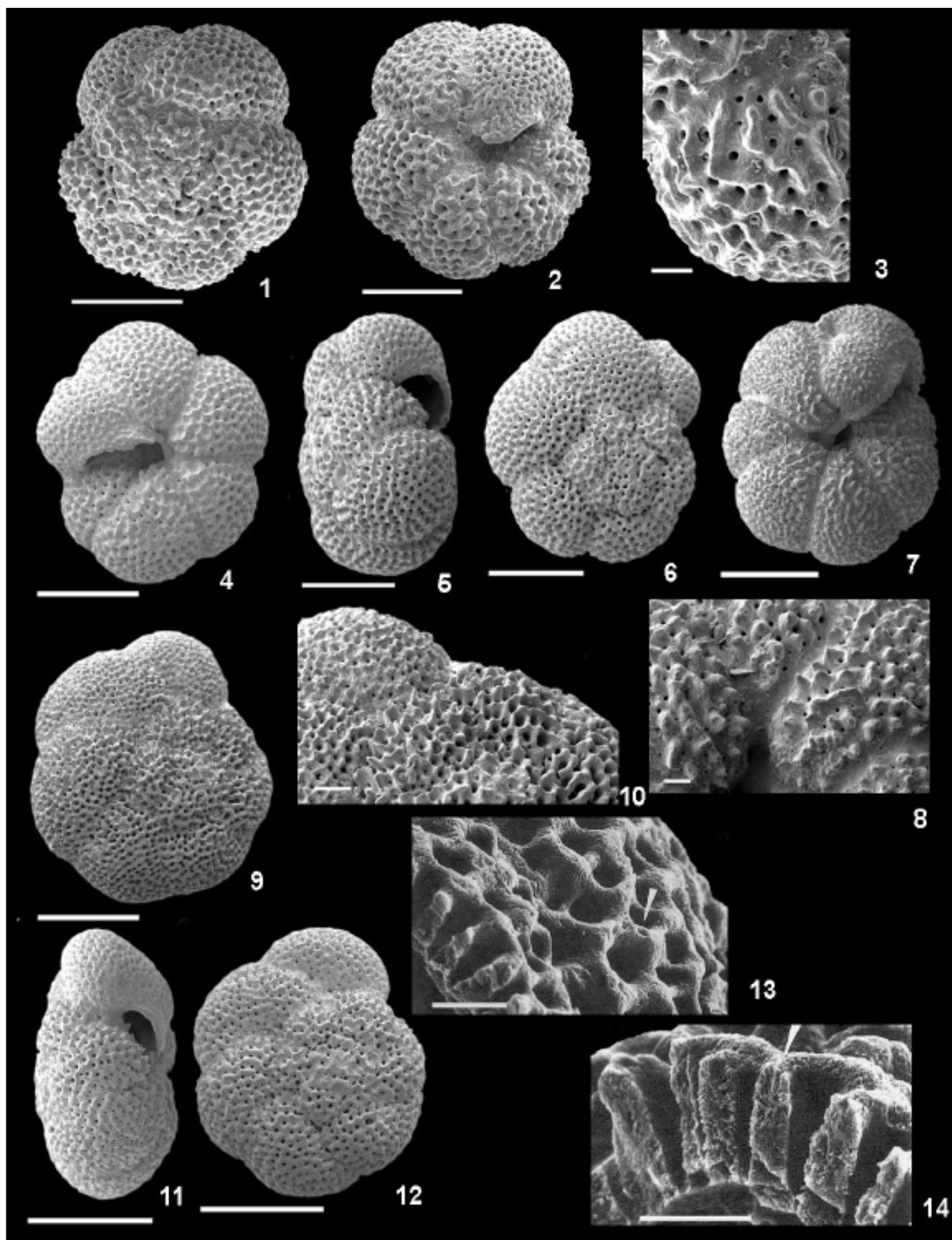


PLATE 3.4 *Neogloboquadrina*-type wall texture

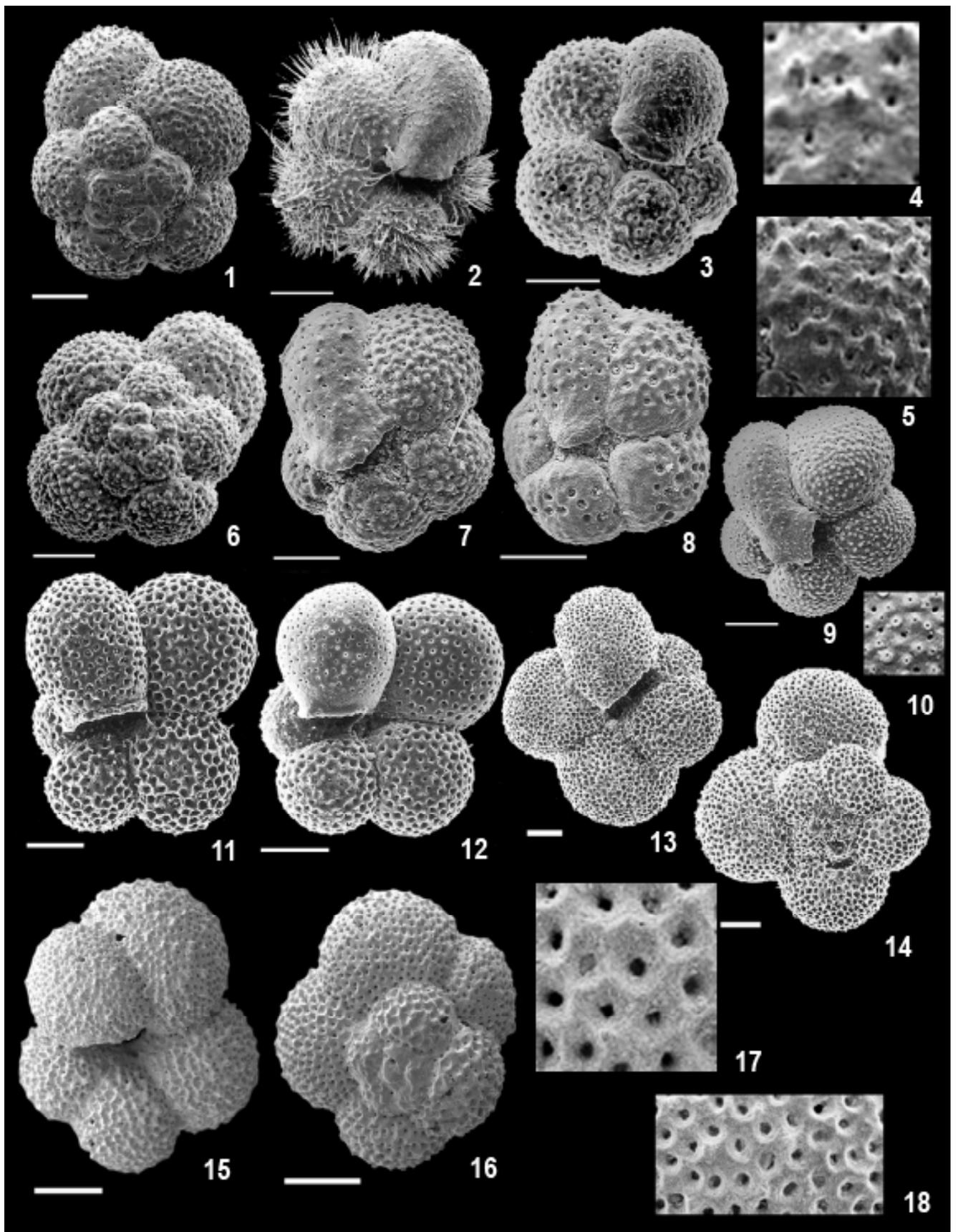
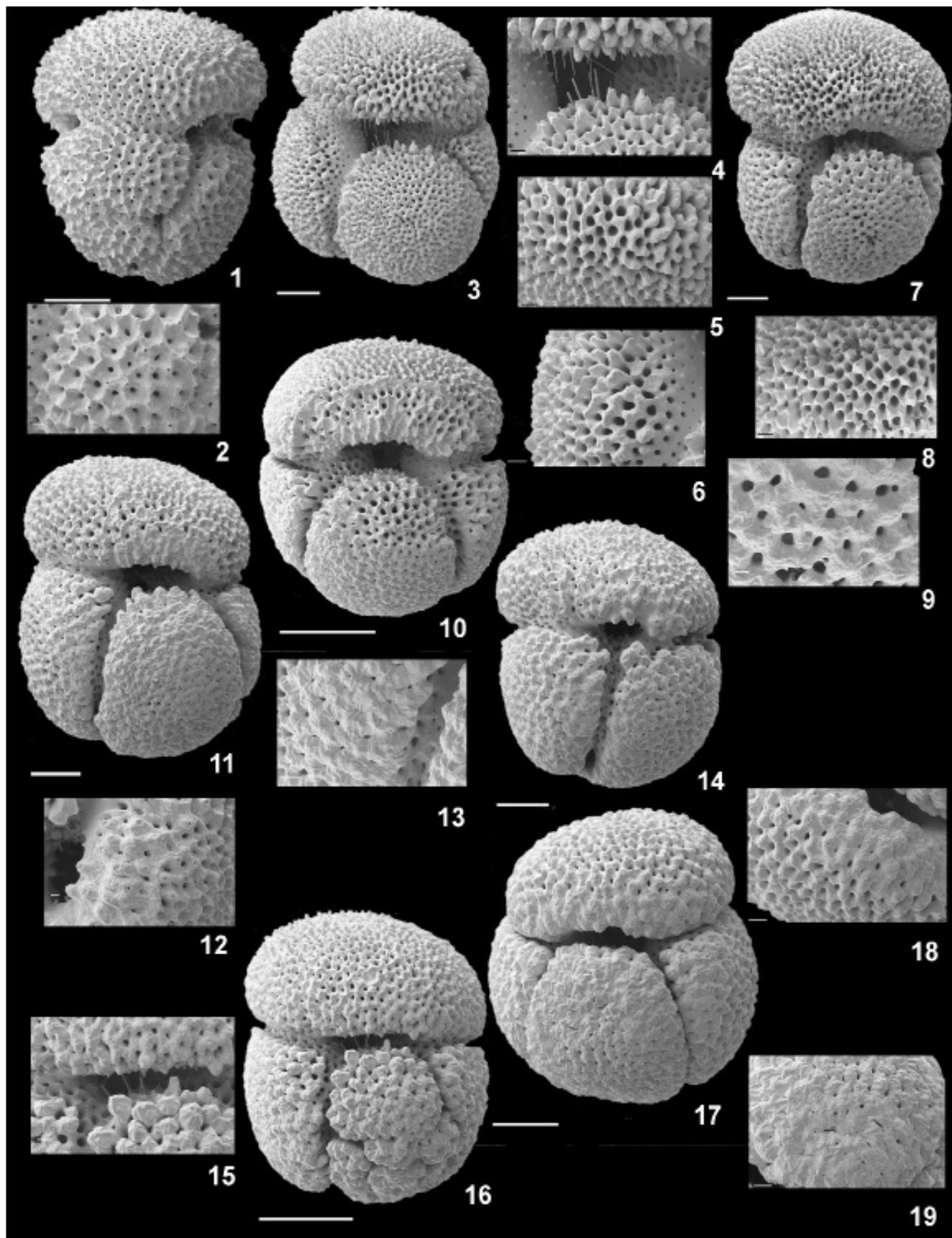


PLATE 3.5 *Turborotalita* wall texture



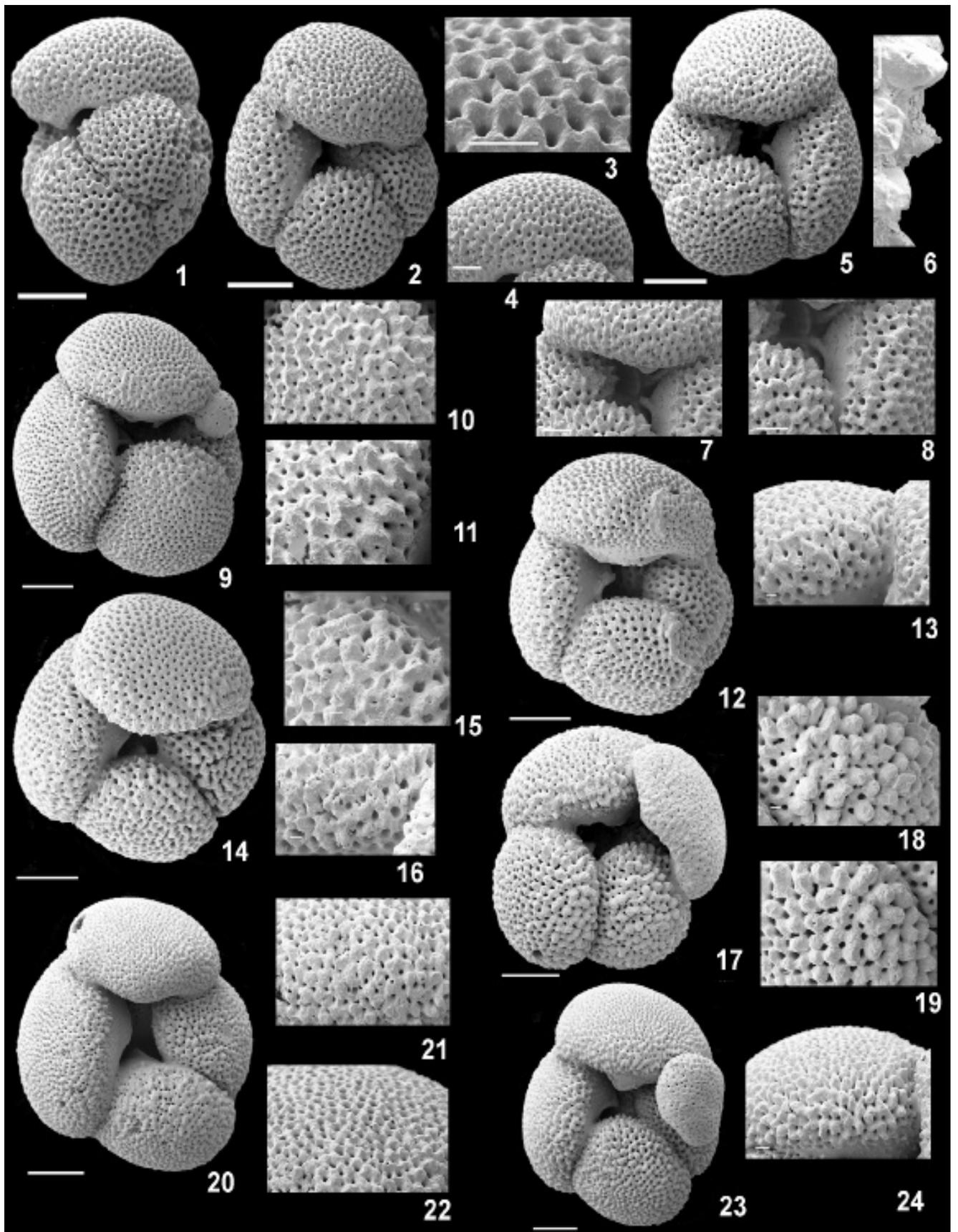
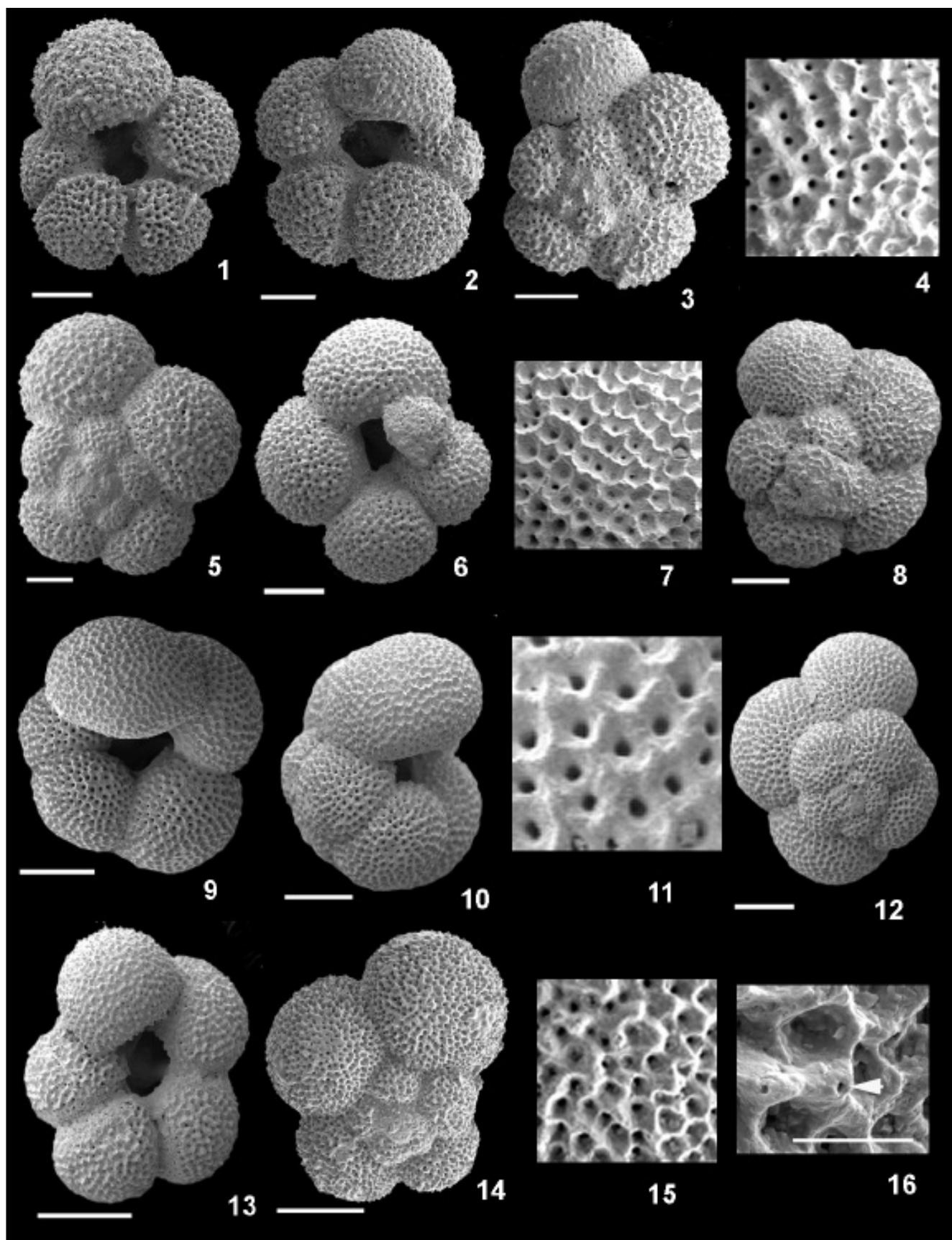


PLATE 3.7 *conglobatus*-type wall texture



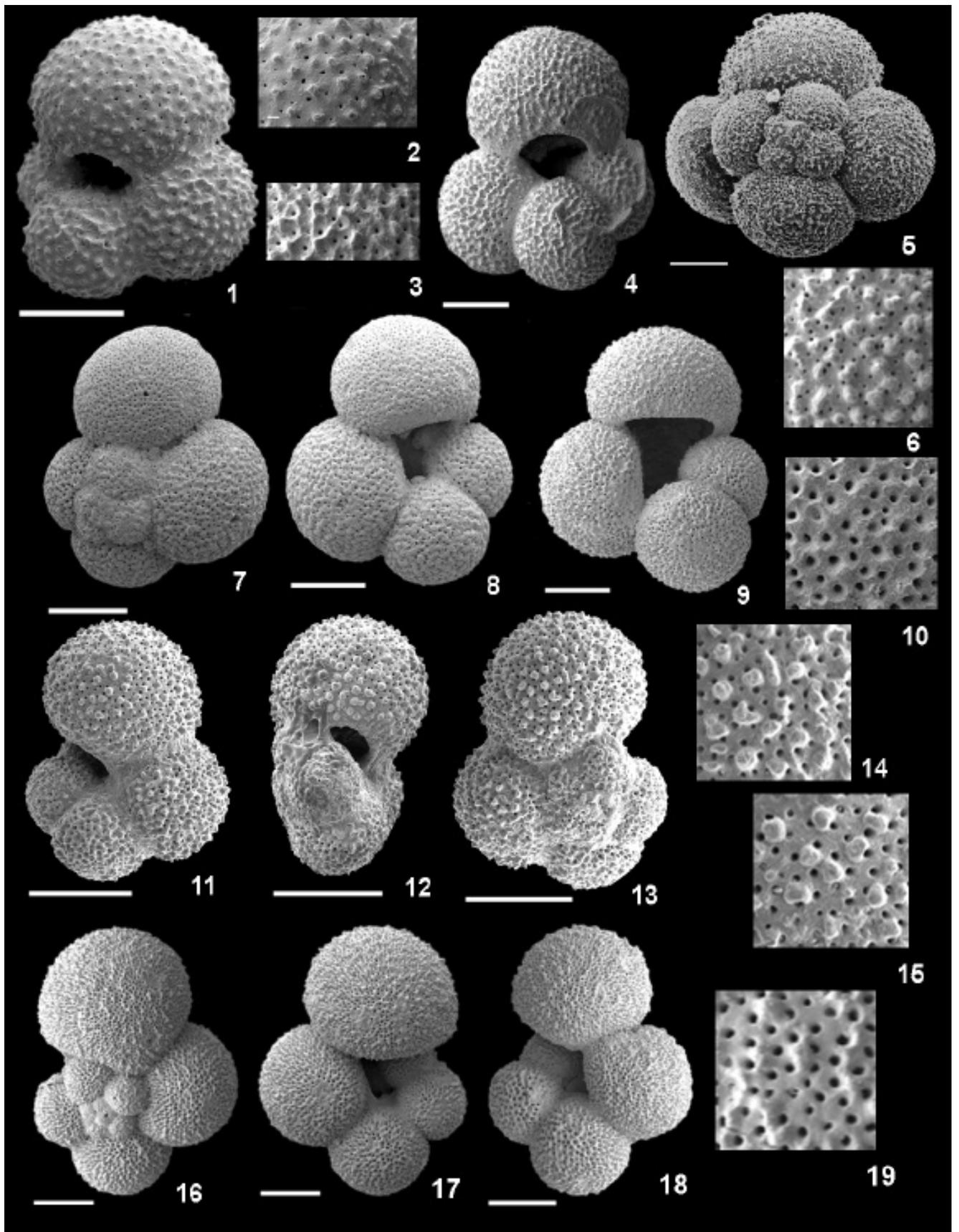
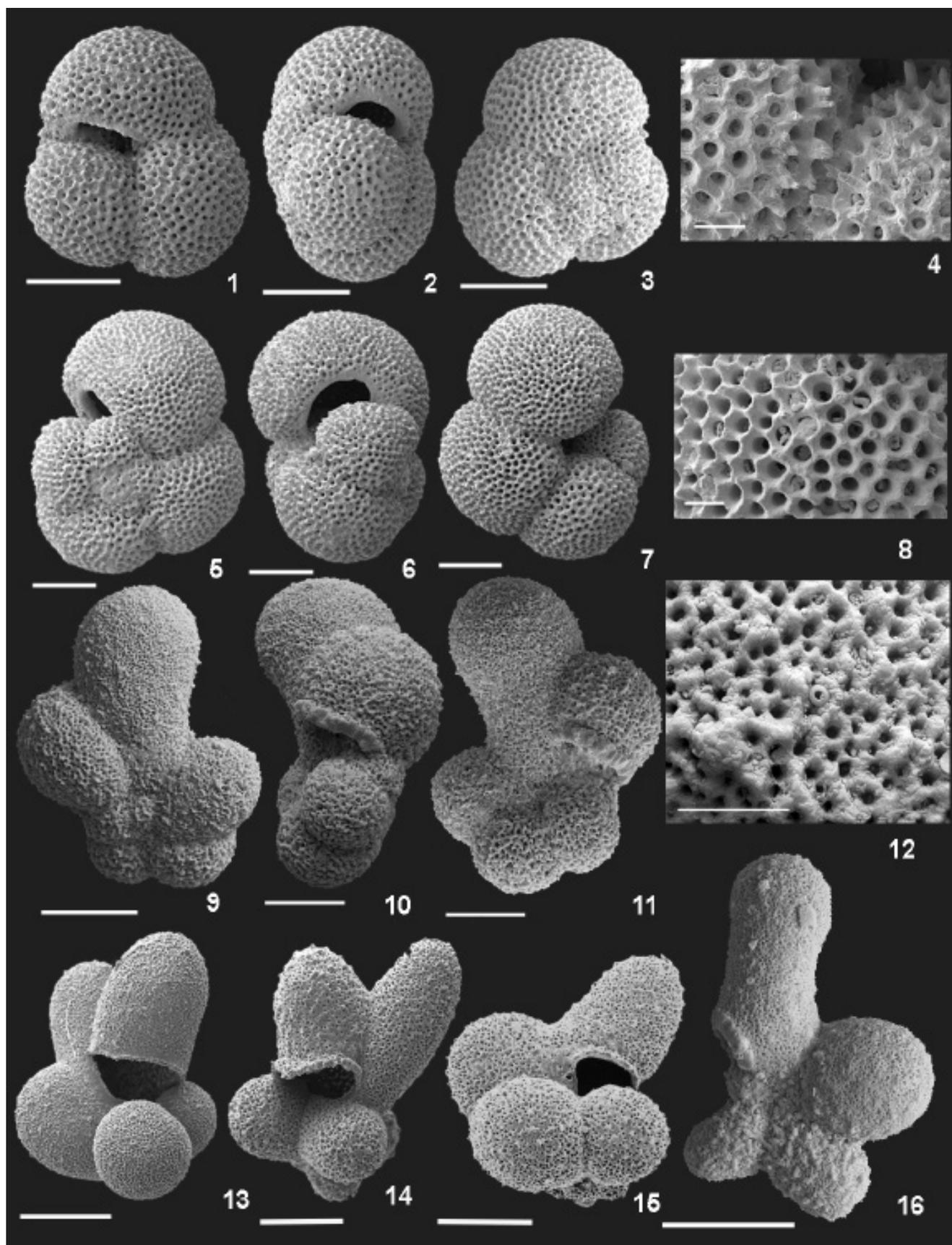


PLATE 3.9 *bulloides*-type wall texture



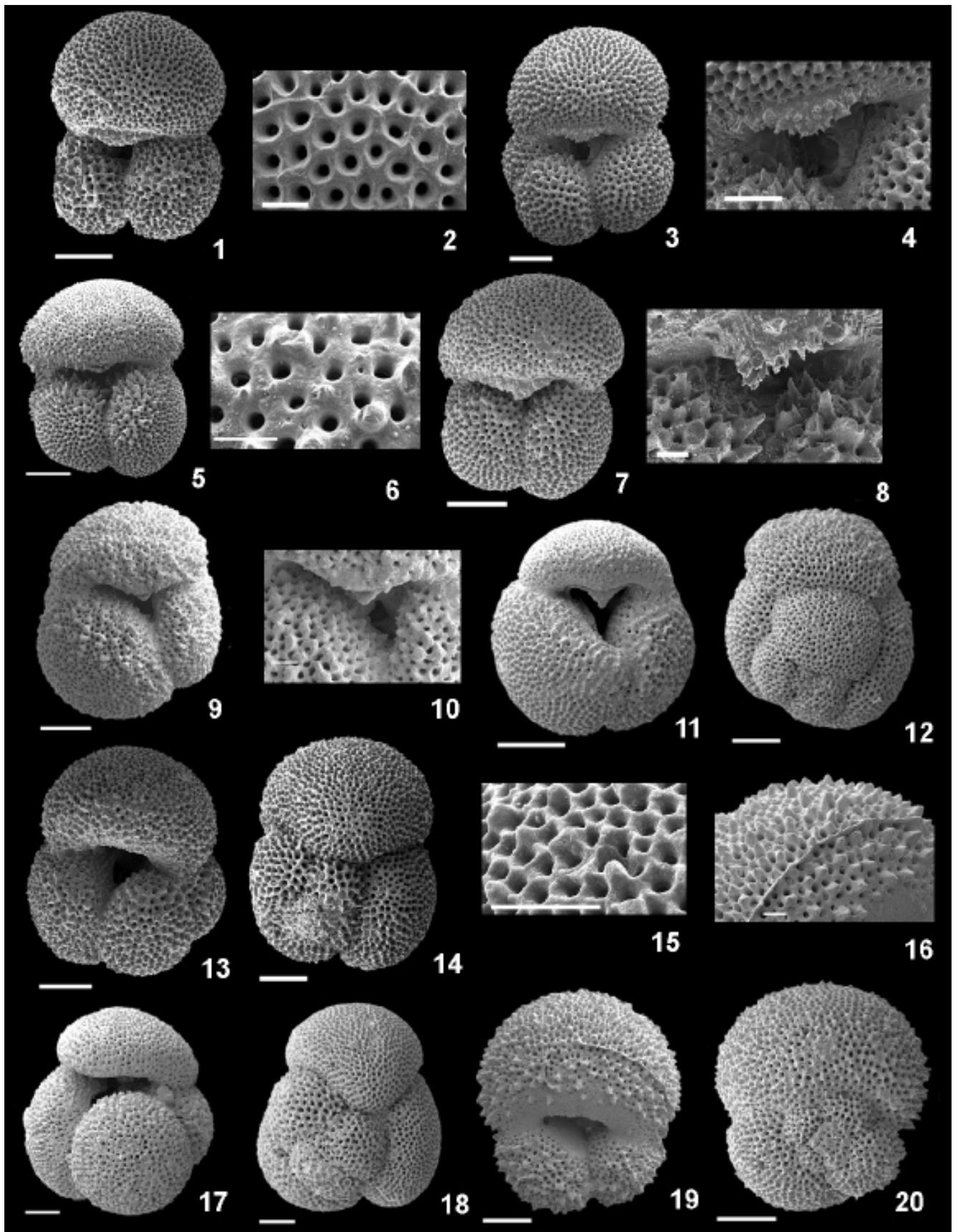
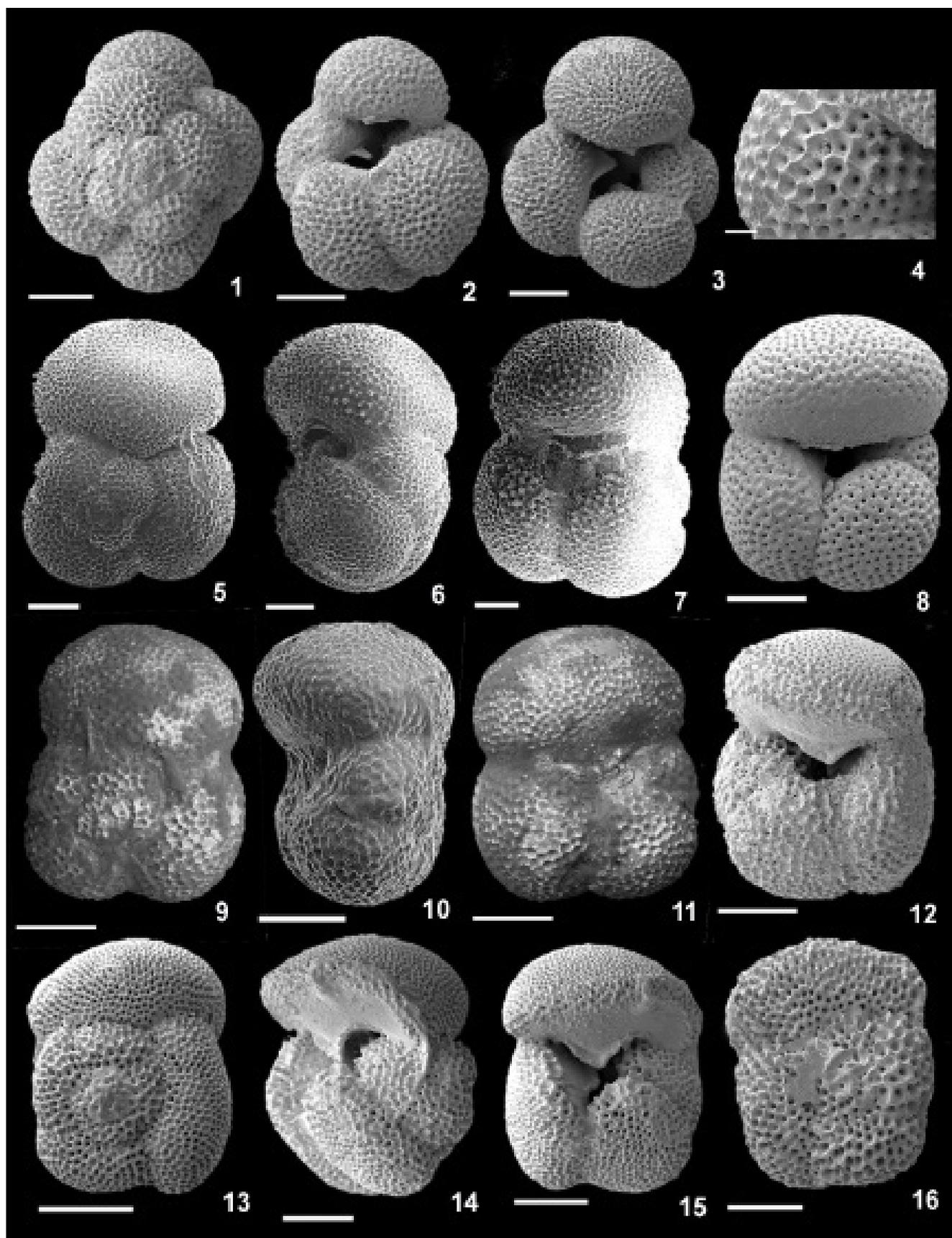


PLATE 3.11 *Globoquadrina*-type wall texture



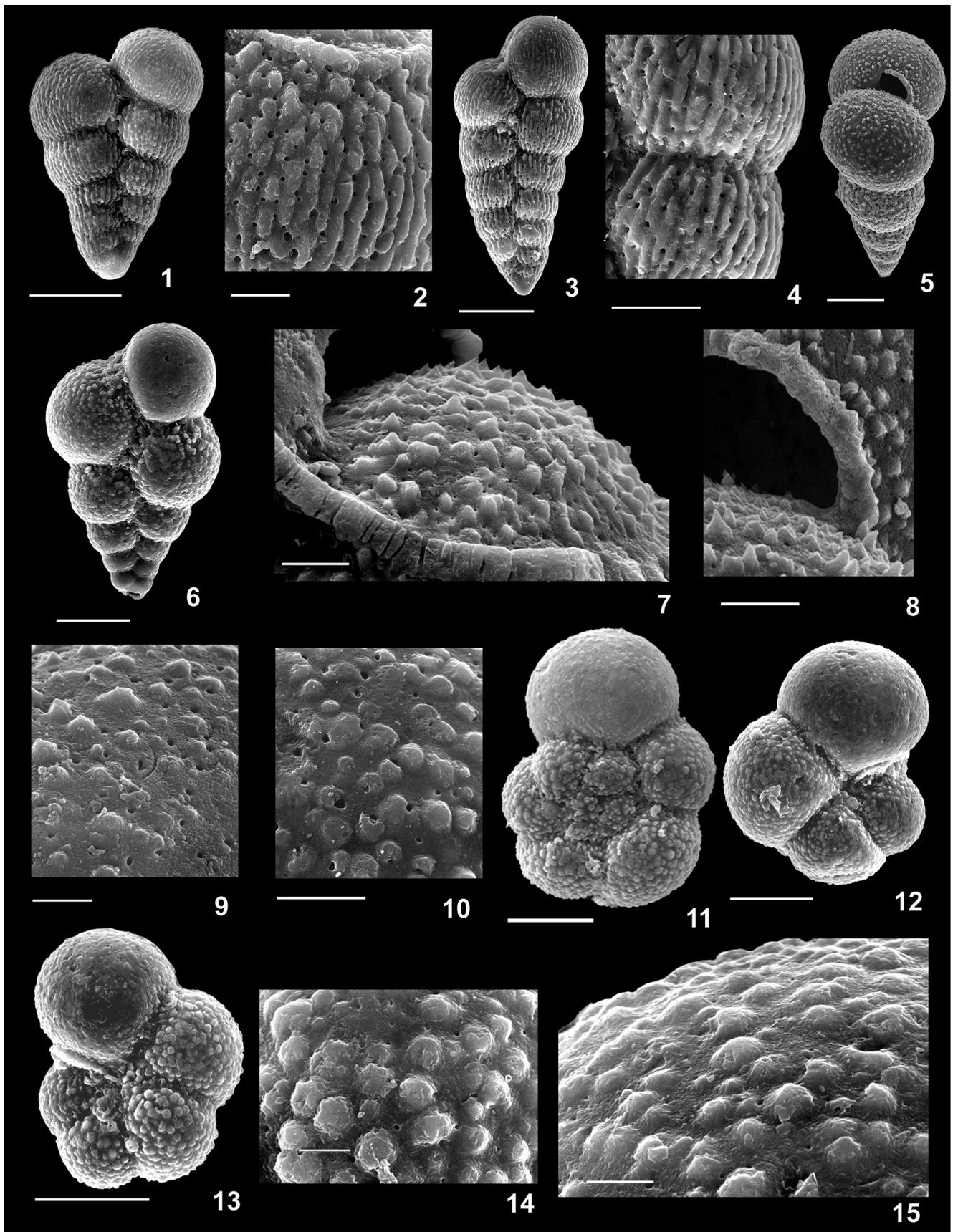


PLATE 3.13 microperforate wall texture

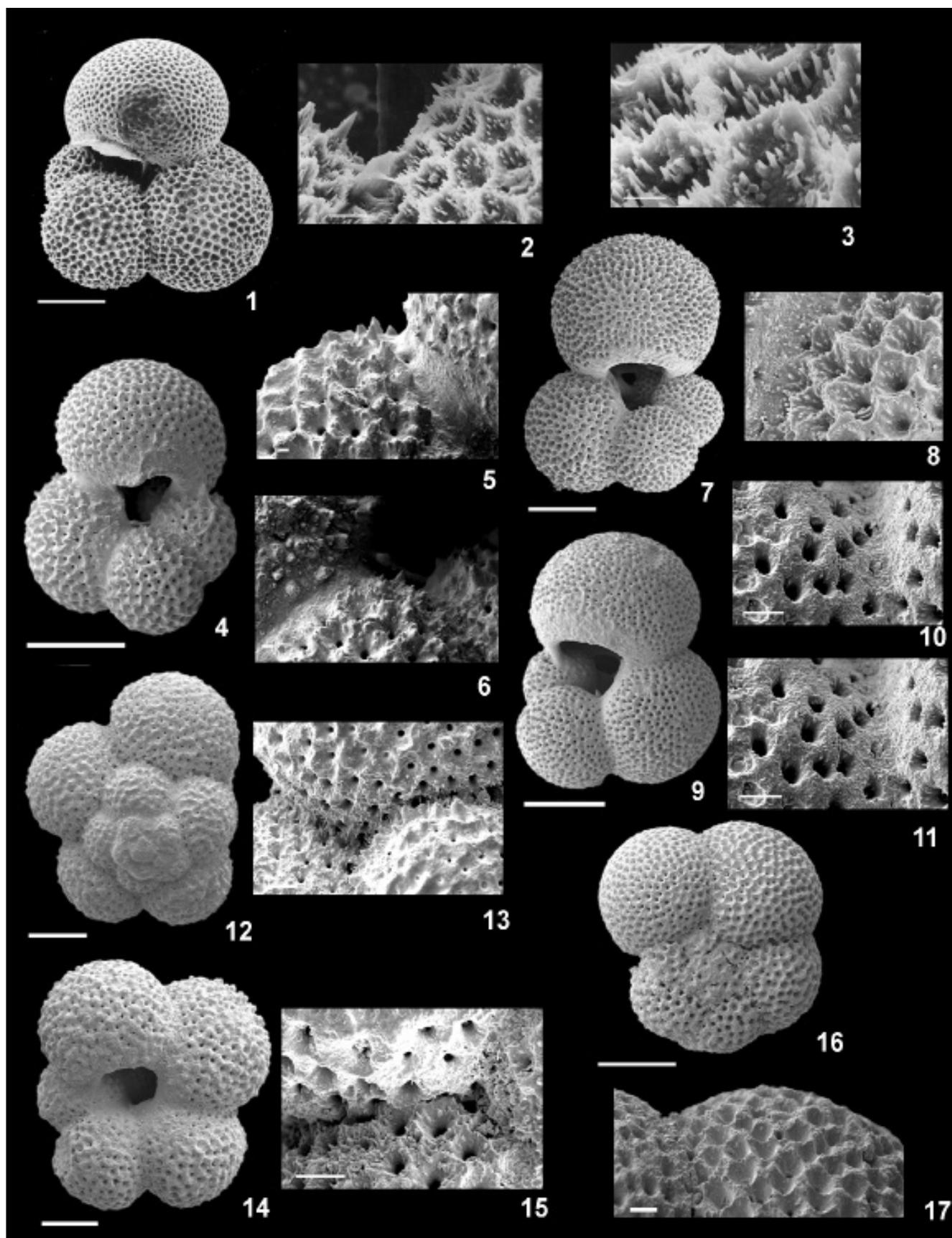


PLATE 3.14 diagenesis