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# Chapter 6

# TAXONOMY, BIOSTRATIGRAPHY, AND PHYLOGENY OF OLIGOCENE *GLOBIGERINA, GLOBIGERINELLA,* AND *QUILTYELLA* N. GEN.

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## ABSTRACT

**The taxonomy, phylogeny and biostratigraphy of Oligocene *Globigerina, Globigerinella* and the new genus *Quiltyella* is reviewed. *Globigerina* and *Globigerinella* are long-ranging genera that extend into the modern. *Globigerina* appeared in the middle Eocene and diversified in the early Oligocene to give rise to several geographically wide-ranging and cosmopolitan species. *Globigerinella* originated and diversified in the early Oligocene and includes both common cosmopolitan species together with rare clavate and digitate species that were previously referred to the genus *Protentella* Lipps. Based on new wall textural studies we describe a third related genus, *Quiltyella* Coxall and Spezzaferri n. gen., which is always rare and highly geographically restricted. This is distinguished from *Globigerina* and *Globigerinella* by the higher pore concentration and extreme digitate chamber morphology. The following species are considered as valid: *Globigerina archaeobulloides* Hemleben and Olsson n. sp., *Globigerina bulloides* d'Orbigny, *Globigerina officinalis* Subbotina, *Globigerinella clavaticamerata* (Jenkins), *Globigerinella megaperta* Rögl, *Globigerinella molinae* (Popescu and Brotea), *Globigerinella navazuelensis* (Molina), *Globigerinella obesa* (Bolli), *Globigerinella praesiphonifera* (Blow), *Globigerinella roeglina* Spezzaferri and Coxall n. sp., and *Globigerinella wagneri* (Rögl), *Quiltyella clavacella* (Rögl), and *Quiltyella nazcaensis* (Quilty).**

## INTRODUCTION

*Globigerina* and *Globigerinella* include long ranging cosmopolitan species that are sometimes persistent through the late Eocene to Neogene and remain important components of modern assemblages across a variety of oceanic environments (Kennett and Srinivasan, 1983; Hemleben and others, 1989; Olsson and others, 2006). Both genera are characterized by a *bulloides*-type wall texture consisting of spines supported by spine collars, which coalesce to form ridges (Hemleben and Olsson, 2006). Species of *Globigerinella,* including modern *G. siphonifera, G. adamsi* and fossil *G. obesa,* have relatively limited spatial distributions, whereas *Globigerina*, typified by the iconic species *Globigerina bulloides*, is ubiquitous, still occurring today from the equator to the poles. One challenge for our Oligocene taxonomy is to constrain the usage of *Globigerina*. Perhaps because it was the first planktonic foraminiferal genus described (d'Orbigny, 1826), and/or since the classical '*bulloides*' morphology (globular chambers, umbilical aperture) occurs multiple times in the different Cenozoic planktonic foraminifera radiations, there are many late Paleogene and Neogene planktonic foraminiferal morphologies that have been variably assigned to this genus, such that the full genus level synonymy list would be very long. Modern wall textures analysis, and molecular sequencing in the case of living forms, provide a framework for better defining the limits of *Globigerina*, although even these methods do not always agree (see below). Practically, recognizing *Globigerina* in the Oligocene is still not always easy because the representatives are often small (<250 μm), the gross test morphology and size is comparable to a number of other genera, especially *Globoturborotalita*, thus good preservation and careful comparative wall texture study are required to make the diagnosis. A number of Oligocene forms originally described as *Globigerina* are now placed in *Globoturborotalita* (Chapter 8, this volume), *Ciperoella* (Chapter 7, this volume) and *Subbotina* (Chapter 10, this volume).

The origin and phylogeny of *Globigerina* is uncertain. Fossil records show that the distinctive *bulloides*-type wall first appeared in *Globigerina officinalis* in middle Eocene Zone E10 (Hemleben and Olsson, 2006). Further back in time, *Subbotina crociapertura* Blow and its probable ancestor *Subbotina roesnaesensis* Olsson and Berggren, which have overlapping ranges in Zones E8 to E10, show tendencies towards a *Globigerina*-like wall (Olsson and others, 2006), suggesting that the *Globigerina* wall texture ancestry lay in this lineage in the lower middle Eocene. This idea is consistent with the molecular phylogeny of Darling and others (1997), based on analysis of the foraminiferal ribosomal rRNA gene. The evolutionary relationship between *Globigerinella* and *Globigerina* is also unclear. Similarity of wall textures in the two genera suggests that *Globigerinella* is closely related to, and likely evolved directly from, *Globigerina* (Aze and others, 2011). Molecular analysis in living representatives, however, consistently shows *Globigerinella* clustering more closely with members of *Globigerinoides* (Darling and others, 1997; de Vargas and others, 1999); which has an entirely different wall structure, typified by the spinose but variably cancellate *ruber*/*sacculifer*-type and *sacculifer*-type walls (Hemleben and Olsson, 2006). This raises questions about the limits of both the molecular and wall texture approaches for planktonic foraminiferal classification.

Our revised taxonomy combines new observations of foraminiferal wall textures with stratigraphical and geographical data of the *Globigerina*-*Globigerinella* group attempting to systematically restrict the usage of both. Under our classification 4 to 4½ chambered species with trochospiral coiling, an umbilical aperture and pore density between 70 and 130 pores/50 $\mu m^2$ test surface area are referred to *Globigerina*. Forms with 4 or more chambers in the final whorl, initial low trochospiral coiling, with tendency to a planispiral coiling mode and pore density between 75 and 100 pores/50 $\mu m^2$ test surface area are referred to *Globigerinella*. Species with several strongly digitate chambers in the last whorl with a strong tendency to irregular coiling and with 120-160 pores/50 $\mu m^2$ test surface area are referred to *Quiltyella* Coxall and Spezzaferri n. gen. These are extremely soft boundaries as there is much variability in general test and wall texture morphology as well as confusion over actual wall textures because of the limits of preservation quality in much of the figured material and/or lack of magnified wall texture views. For example, entirely planispiral specimens of *Globigerinella navazuelensis* (Plate 6.7, Figs. 16-18) and *G. clavaticamerata* (Plate 6.4, Figs. 1-2, 6-8) occur. Several of the *Globigerinella* species classified here were previously attributed to *Protentella* (e.g., Jenkins, 1965; Molina, 1979, Popescu and Brotea, 1989; Kennett and Srinivasan, 1983; Premoli Silva and Spezzaferri, 1990; Spezzaferri, 1994). Our recent investigation on the wall textures revealed that the type species of the genus *Protentella*, *P. prolixa* Lipps, has a *Clavigerinella*-type wall texture very different from the *bulloides*-type typical of *Globigerinella* (Plate 6.4, Figs. 6-8).

Clavate and digitate morphologies, as in other Cretaceous and Cenozoic epochs (see Coxall and others, 2007), are a rare but notable aspect of some Oligocene assemblages, especially in the Paratethys region. Most described forms show pseudo-planispiral

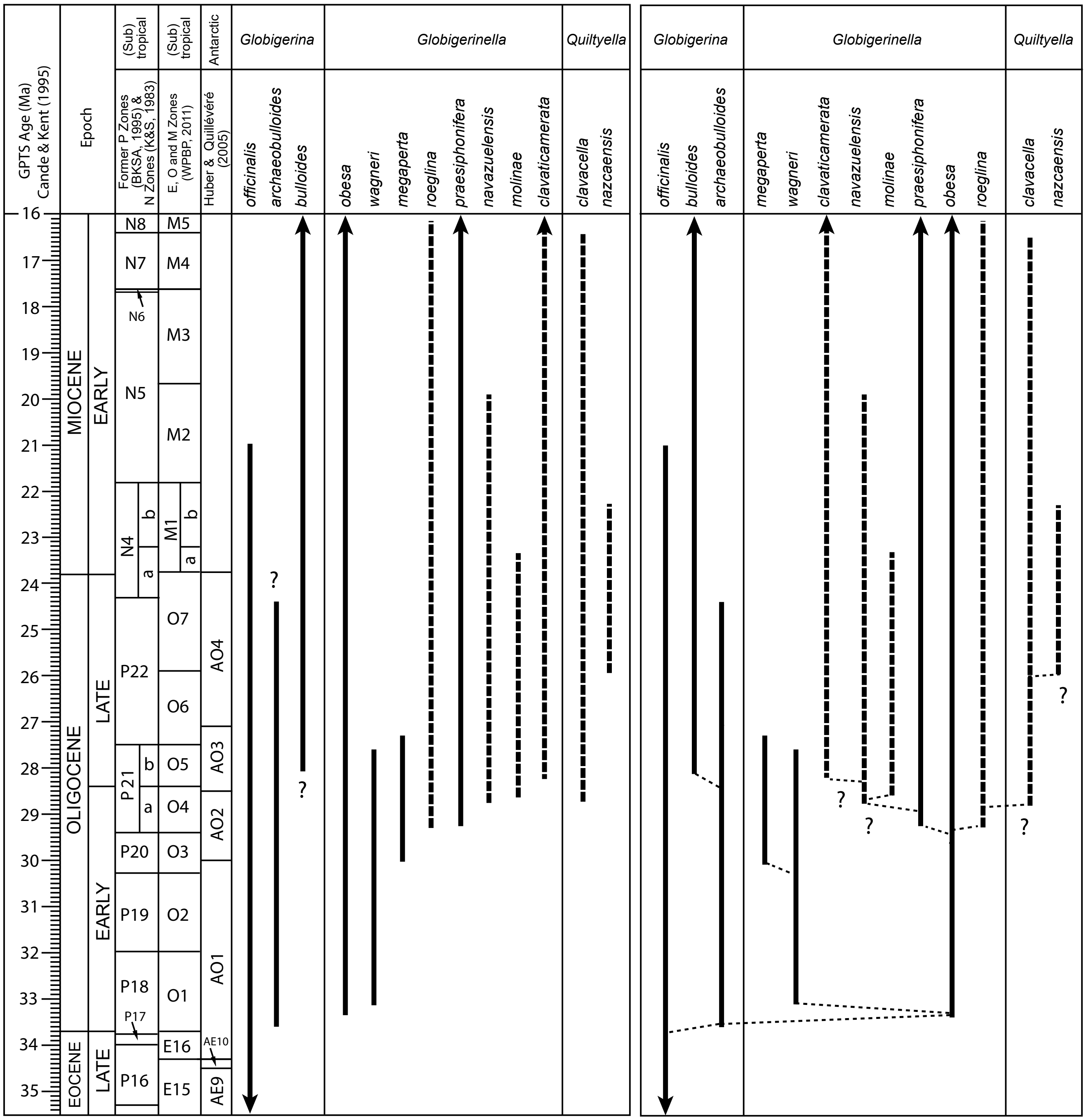


FIGURE 6.1. Stratigraphic ranges and inferred phylogenetic relationships of Oligocene *Globigerina, Globigerinella* and *Quiltyella* n. gen. BKSA, 1995 = Berggren and others, 1995; K&S, 1983 = Kennett and Srinivasan, 1983; WPBP, 2011 = Wade and others, 2011.

or streptospiral coiling, have the aperture tending to became extraumbilical and show variability in the degree of chamber elongation. They have highly restricted distributions and most are known only from the type locality. We have been unable to obtain material for first hand study in most cases, nonetheless, using original published images we have reviewed the six described clavate/digitate forms and tentatively classified them as far as possible using the wall texture. We conclude that most from the Atlantic Ocean and Paratethys can be assigned to *Globigerinella*: (*clavaticamerata* (Jenkins), *molinae* (Popescu and Brotea), *navazuelensis* (Molina), *roeglina* Spezzaferri and Coxall n. sp.). Quilty's (1976) extreme-digitate equatorial Pacific species *nazcaensis*, together with Rögl's (1969) species *clavacella* are placed in the new genus *Quiltyella* Coxall and Spezzaferri n. gen., which is distinguished from *Globigerinella* by the higher pore density.

The occurrence of these Oligocene clavate/digitate species may have environmental implications. Coxall and others (2007) showed that most clavate species were/are deep-dwelling and suggested that elongated chambers were advantageous for survival in a deep mesopelagic habitat where food is usually scarce, and that there is an additional link with episodes of enhanced ocean productivity associated with expansion of the oxygen minimum zone (OMZ). Non-clavate typically shallow-dwelling *Globigerinella* then, may have given rise to descendants that increasingly occupied deeper layers of the water column as such environments developed, within for example the increasingly restricted Paratethys Seaway. Species of *Globigerinella,* such as *G. megaperta* and *G. wagneri* that often occur together with the central European clavate forms, have been so far observed only in sediments from the restricted gateway between the Atlantic and Indian Oceans, i.e., the western Tethys which formed a proto-Mediterranean Sea and the Paratethys (Rögl, 1999; Harzhauser and Piller, 2007). Their absence from other ocean basins suggests these species were somehow endemic to the region.

Based on the framework presented here the following Oligocene species are recognized as valid: *Globigerina archaeobulloides, Globigerina bulloides, Globigerina officinalis, Globigerinella clavaticamerata, Globigerina megaperta, Globigerinella molinae, Globigerinella navazuelensis, Globigerinella obesa, Globigerinella praesiphonifera and Globigerinella wagneri.* We describe a new species of *Globigerinella, Globigerinella roeglina* Spezzaferri and Coxall, which has the base morphology from which evolved the strongly digitate forms belonging to the new genus *Quiltyella* Coxall and Spezzaferri with the species *Q. clavacella* and *Q. nazcaensis.* The species-level range-chart and phylogeny is presented in Figure 6.1. Wall textures are discussed and illustrated in Chapter 3 (this volume).

## SYSTEMATIC TAXONOMY

### Order FORAMINIFERIDA d'Orbigny, 1826
### Superfamily GLOBIGERINOIDEA Carpenter, Parker, and Jones, 1862
### Family GLOBIGERINIDAE Carpenter, Parker, and Jones, 1862

### Genus *Globigerina* d'Orbigny, 1826

TYPE SPECIES.— *Globigerina bulloides* d'Orbigny, 1826.

DESCRIPTION.

*Type of wall*: Wall spinose, '*bulloides*-type wall'; spines are supported by spine collars, which coalesce to form ridges. Pore concentrations range from 70-130 pores/50 μm$^2$ test surface area and pore diameters range from 0.7 μm to 0.9 μm.

*Test morphology*: Low trochospiral, globulose test. Three to five chambers in the last whorl rapidly increasing in size. Aperture is an umbilical high arch bordered sometimes by an imperforate rim. Umbilicus varies from small and restricted to large and open.

DISTINGUISHING FEATURES.— The main characteristic of the genus is the *bulloides*-type wall texture, which is characterized by a smooth surface with spine collars that may coalesce to form ridges.

DISCUSSION.— *Globigerina* is a common genus in the Oligocene to Recent. Its first appearance is documented in the middle Eocene Zone E10 (Olsson and others, 2006), where it is relatively uncommon. A main radiation of the genus occurred in the lower Oligocene.

PHYLOGENETIC RELATIONSHIPS.— As was pointed out by Olsson and others (2006) the origin of *Globigerina* is uncertain. Its wall texture seems to resemble that of *Subbotina roesnaesensis,* which possesses a *ruber*-type cancellate wall texture but with spine collars (first observed in its ancestral species *Subbotina triangularis* in Zone P4).

STRATIGRAPHIC RANGE.— Middle Eocene Zone E10 (Olsson and others, 2006) to Recent (e.g., Hemleben and others, 1989).

GEOGRAPHIC DISTRIBUTION.— It is a cosmopolitan genus present and abundant from low to high latitudes in northern and southern hemispheres.

### *Globigerina archaeobulloides* Hemleben and Olsson, new species

Plate 6.1, Figures 1-13

DESCRIPTION.

*Type of wall*: Normal perforate, spinose, *bulloides*-type wall structure. Pore concentrations range from 80 to 130 pores/50 μm$^2$ test surface area and pore diameters range from 0.7 μm to 0.9 μm.

*Test morphology*: Test low to moderately elevated trochospiral consisting of 2½ whorls, lobulate in outline, chambers globular; in spiral view 4-4½ globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, final chamber varies in size and degree of inflation, sutures moderately depressed and straight; in umbilical view 4-4½ globular, slightly embracing chambers, increasing rapidly in size, sutures moderately depressed, straight, umbilicus large, open, enclosed by surrounding chambers, aperture umbilical, a broad arch bordered by an imperforate rim; in edge view chambers globular in shape, slightly embracing.

*Size*: Maximum diameter of holotype 0.20 mm.

ETYMOLOGY.— Named *archaeobulloides* in recognition of ancestry to *Globigerina bulloides*.

DISTINGUISHING FEATURES.— *Globigerina archaeobulloides* n. sp. is distinguished by its small globular test, umbilical aperture and *bulloides*-type wall. No such form has to our knowledge been described or imaged previously. It differs from *G. bulloides* in its smaller size, by having up to 4½ chambers in the ultimate whorl and by having some morphotypes with a moderately elevated trochospire. It is distinguished from *G. officinalis* by lobed peripheral outline, and fully developed *bulloides*-type wall, especially on the final chamber. It is distinguished from *Globoturborotalita ouachitaensis* by the *bulloides*-type wall.

DISCUSSION.— *Globigerina archaeobulloides* n. sp. traces the development of the *bulloides*-type wall to the lowermost Oligocene Zone O1. *Globigerina officinalis* Subbotina has generally been regarded as ancestral to *G. bulloides* and can be regarded as a transitional species from a subbotinid ancestor (see discussion in Olsson and others, 2006). The wall texture of *G. officinalis* in the Eocene, however, is not a fully developed *bulloides*-type wall in that the pore concentration is lower (~50 pores/50 μm$^2$ area); but the species develops a higher pore concentration in the lower Oligocene (72-85 pores/50 μm$^2$ area). *Globigerina archaeobulloides* is morphologically similar to *G. bulloides* and has a fully developed *bulloides*-type wall.

PHYLOGENETIC RELATIONSHIPS.— *Globigerina archaeobulloides* probably evolved from *G. officinalis* in Zone O1. It gave rise to *Globigerinella obesa* in Zone O1 and is thus ancestral to genus *Globigerinella*. It is also the direct ancestor of *Globigerina bulloides*, which appeared in Zone O5.

TYPE LEVEL.— *Pseudohastigerina naguewichiensis* Zone (Zone O1), locality AGS 66, 9A-1A, Shubuta Fm., Alabama. So far not identified in other localities.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O1 probably to the upper Oligocene where it gives rise to *G. bulloides* in Zone O5 (this study).

GEOGRAPHIC DISTRIBUTION.— Probably had a distribution similar to *G. bulloides*. Modern *G. bulloides* is a cosmopolitan species but it also occurs in cool upwelling regions.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype USNM 598581 and paratypes USNM 598582, 598583 deposited at the Smithsonian Museum of Natural History, Washington, D.C.

### *Globigerina bulloides* d'Orbigny, 1826

Plate 6.2, Figures 1-16

*Globigerina bulloides* d'Orbigny, 1826 [Recent, Adriatic Sea, near Rimini, Italy].—Saito, Thompson, and Berger, 1981:40, pl. 7, figs. 1a-c [Recent, eastern North Atlantic Ocean].—Cifelli, 1982:7, pl. 8, figs. 2, 3, pl. 9, figs. 1-3 [Recent, western North Atlantic Ocean].—Kennett and Srinivasan, 1983:36, pl. 6, figs. 4-6 [upper Miocene, DSDP Site 284, New Zealand Plateau, southwest Pacific

Ocean].—Li and McGowran, 2000:42, fig. 23F [lower Miocene Zone M2, Lakes Entrance Oil Shaft, Gibbsland, southeastern Australia].

*Globigerina praebulloides* Blow.—Spezzaferri and Premoli Silva, 1991:244, pl. VI, figs. 4a-d [upper Oligocene Zone P22, DSDP Hole 538A, Gulf of Mexico].—Spezzaferri, 1994:27 pl. 2, figs. 3a-c [lower Miocene Subzone M1b, DSDP Hole 516F, South Atlantic Ocean].

*Globigerina ouachitaensis* Howe and Wallace.—Spezzaferri, 1994:27, pl. 2, figs. 1a-c [lower Miocene Subzone M1b, DSDP Hole 516F, South Atlantic Ocean].

*Globigerina* cf. *G. bulloides* d'Orbigny.— Pearson and Wade, 2009:203, pl. 4, figs. 1a-2d [uppermost Oligocene Zone O6 (now O7), Cipero Fm., near San Fernando, Trinidad].

DESCRIPTION.

*Type of wall*: Normal perforate, spinose, *bulloides*-type wall structure. Pore concentrations range from 70-100 pores/50 μm$^2$ test surface area and pore diameters range from 0.7 μm to 0.9 μm.

*Test morphology*: Test low trochospiral consisting of 2½ whorls, lobulate in outline, chambers globular; in spiral view 4 globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures straight and moderately depressed; in umbilical view 4 globular, slightly embracing chambers, increasing rapidly in size, sutures straight and moderately depressed, umbilicus large, open, enclosed by surrounding chambers, aperture umbilical, a broad arch bordered by an imperforate rim; in edge view chambers globular in shape, slightly embracing.

*Size*: Maximum diameter of lectotype 0.67 mm.

DISTINGUISHING FEATURES.— *Globigerina bulloides* is distinguished from outwardly similar forms of *Subbotina* and *Globoturborotalita* by its *bulloides*-type wall, large globular test, large umbilical aperture and absence of a thickened apertural rim. It is distinguished from *Globigerinella obesa* by the higher pore density, the less inflated final chamber and more umbilically positioned aperture. It differs from *Globigerinella praesiphonifera* by the smaller number of chambers in final whorl (4 compared to 4½-5 in *G. praesiphonifera*) and umbilically positioned aperture.

DISCUSSION.— *Globigerina bulloides* was described from Recent deposits, near Rimini, Adriatic Sea, Italy (d'Orbigny, 1826) and is a common species in the Neogene. A holotype was never selected. Banner and Blow (1960) designated a lectotype (Banner and Blow, 1960; pl. 1, figs. 1, 4; illustration reproduced here on Pl. 6.2, Figs. 1-3) from a set of syntypes that were "theoretically"…"included by d'Orbigny in his concept of the species at the time of the first publication". The syntype suite contained diverse morphologies and selection was aided by reference to two plaster models of *bulloides* made by d'Orbigny, which constrained d'Orbigny's core concept. Kennett and Srinivasan (1983) derived *G. bulloides* from *G. praebulloides* Blow in the upper part of the lower Miocene. SEM images of the holotype of *G. praebulloides* (Pl. 6.8, Figs. 4-6) and *Globigerinella obesa* (Bolli) indicate that *G. praebulloides* is a junior synonym of *G. obesa*, which is unclear from Blow's holotype drawing of *G. praebulloides*. *Globigerinella obesa* has a *bulloides*-type wall texture but it differs from *G. bulloides* in that the pore concentration is lower (~60 pores/50 μm$^2$ test surface area), the pore diameter is larger (~1.5-2 μm) and the trochospire is lower. It is similar to *Globigerinella praesiphonifera* in wall structure. These species appear to be a separate phylogenetic lineage from that of *G. bulloides*. The wall texture characteristic of *G. bulloides* first appears in Zone O1 in the new species *G. archaeobulloides*.

PHYLOGENETIC RELATIONSHIPS.— This species evolved from *G. archaeobulloides* n. sp. probably in Zone O5. See *G. archaeobulloides* and *G. officinalis* entries for previous views on *G. bulloides* ancestry.

TYPE LEVEL.— Recent, Adriatic Sea, near Rimini, Italy.

STRATIGRAPHIC RANGE.— Upper Oligocene (Zone O5) to Recent. In the Lakes Entrance Oil Shaft, southeastern Australia, Li and McGowran (2000) record *G. bulloides* as common to abundant throughout Zones P22 (O6-O7) to N17/N18 (M13b-PL1a). It is common in

Plate 6.1, 1-13 *Globigerina archaeobulloides* Hemleben and Olsson new species; 14-17 *Globigerinella obesa* (Bolli, 1957)

*Globigerina archaeobulloides* **1-4**, (holotype USNM 598581); **5-13**, paratypes USNM 598582, 598583), Zone O1 [= *Pseudohastigerina naguewichiensis* Zone], Shubuta Formation, Alabama, locality AGS 66, 9A-1A.
*Globigerinella obesa* **14-17**, Transitional *Globigerinella* morphology, Zone O1 [= *Pseudohastigerina naguewichiensis* Zone], Shubuta Formation, Alabama, locality AGS 66, 9A-1A. Scale bar: **1-3**, **5-7**, **10-12**, **14-16** = 50 μm; **8** = 10 μm; **9**, **13** = 25 μm$^2$ surface area; **4**, **17** = 50 μm$^2$ surface area.

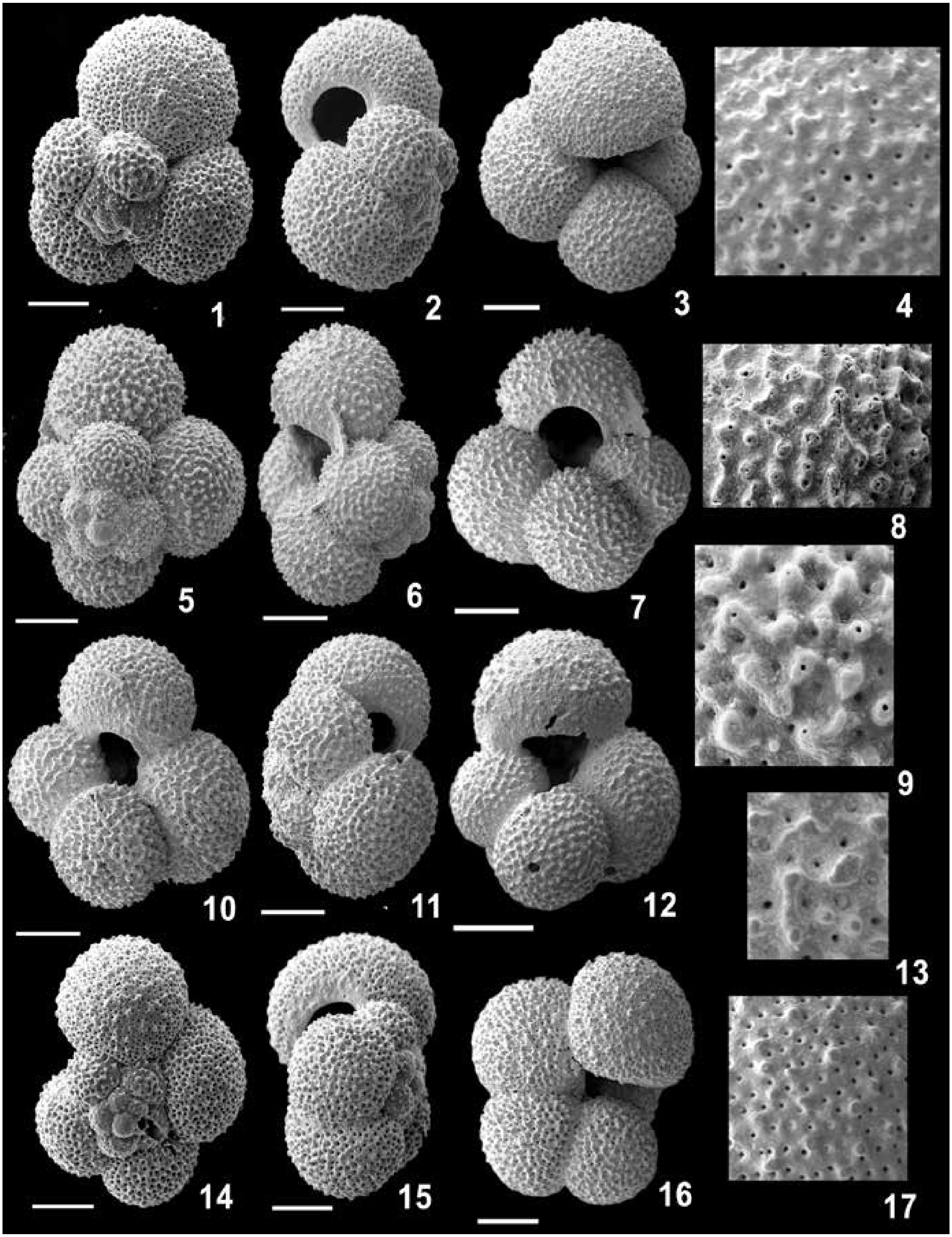


**Plate 6.1** *Globigerina archaeobulloides* Hemleben and Olsson, new species; *Globigerinella obesa* (Bolli, 1957)

Zone O7 in the Atlantic Slope Project corehole, western Atlantic Ocean (this study).

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan but more abundant in middle to high latitudes. Modern *G. bulloides* is a transitional to polar water species but it also occurs in cool upwelling regions (see Schiebel and Hemleben, 2017).

STABLE ISOTOPE PALEOBIOLOGY.— Observations from plankton tows indicate calcification depths within the upper 30 to 50 m of the water column (e.g. Spero and Lea, 1996; Niebler and others, 1999). Stable isotopes measured on living and fossil *G. bulloides* have shown that this species secretes its shell out of equilibrium with respect to both carbon and oxygen isotopes (Curry and Matthews, 1981; Kahn and Williams, 1981; Deuser and Ross, 1989; Sautter and Thunell, 1991; Spero and Lea, 1996). Adjustments may be applied to $\delta^{13}C$ and $\delta^{18}O$ data from well-constrained size ranges to yield either oxygen isotope equilibrium or ambient $\delta^{13}C$ of seawater $\Sigma CO_2$ (Spero and Lea, 1996).

REPOSITORY.— A type species was never selected. A lectotype was designated by Banner and Blow (1960). They did not state in their publication where it was deposited. However, Vénec-Peyré (2005) indicates that the specimen selected by Blow and Banner (1960) with the collection number MNHN FO305 is held in the Alcide d'Orbigny Collection, Muséum Nationale de l'Histoire Naturelle, Paris.

### *Globigerina officinalis* Subbotina, 1953

Plate 6.3, Figures 1-13

*Globigerina officinalis* Subbotina, 1953:105, pl. 11, figs. 1-7 [upper Eocene *Bolivina* Zone, Kheu River, Northern Caucasus], fig. 2, [lower Oligocene?, Kheu River, Nalchik, Northern Caucasus].—Blow and Banner 1962:93, pl. IX, figs. A-C [lower Oligocene *Globigerina oligocaenica* Zone, Lindi area, Tanzania].—Spezzaferri and Premoli Silva, 1991:244, pl. VI, figs. 1a-c, 2a-c [upper Oligocene Zone P22, DSDP Hole 538A, Gulf of Mexico].—Poag and Commeau, 1995:152, pl. 7, figs. 8, 9 [lower Oligocene Subzone P21a, Hammond Core, Maryland].—Olsson and others, 2006:114, pl. 6.1, figs. 1-12, 16 [various localities].—Pearson and Wade, 2015:9, fig. 5.1 [re-illustration of the holotype of *Globigerina praebulloides leroyi* Blow and Banner, 1962], 5.2 [lower Oligocene Zone O1, Sample TDP 11/19/1, 10-20 cm, Stakishari, Tanzania].

*Globigerina praebulloides leroyi* Blow and Banner, 1962:93, pl. 9, figs. R-T [lower Oligocene *Globigerina oligocaenica* Zone, Lindi area, Tanzania].— Olsson and others, 2006, pl. 6.1, figs. 13-15 [holotype re-illustrated].

*Globigerina praebulloides* Blow.—Székely and Filipescu, 2016:490, pl. 2, figs. 4a-c [upper Oligocene, Chattian, Transylvanian Basin, Romania], pl. 2 fig. 6, [lower Oligocene, Rupilean, Transylvanian Basin, Romania]. [Not Blow, 1959.]

DESCRIPTION.

*Type of wall*: Perforate and spinose, *bulloides*-type wall structure. Pore concentrations average 77 pores/50 μm² test surface area and pore diameters average 0.84 μm.

*Test morphology*: Test moderately high trochospiral consisting of 3 whorls, lobulate in outline, chambers globular; in spiral view 4 globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures moderately depressed, straight, the last 4 chambers make up about 3/5 of the test size; in umbilical view 4 globular, slightly embracing chambers, increasing rapidly in size, sutures moderately depressed, straight, umbilicus small, open, enclosed by surrounding chambers, aperture umbilical, a low to high arch bordered by an imperforate rim; in edge view chambers globular in shape, slightly embracing (Olsson and others, 2006).

*Size*: Maximum diameters of holotype 0.14-0.20 mm, thickness 0.11 mm.

DISTINGUISHING FEATURES.— The species is characterized by its globular, slightly embracing, chambers with a moderately high arched, umbilical aperture bordered by a thickened imperforate rim, and its *bulloides*-type wall texture (Olsson and others, 2006). It differs from *G. archaeobulloides* by the more compact test and less strongly developed *bulloides*-type wall. It differs from compact species of *Globoturborotalita* and

Plate 6.2 *Globigerina bulloides* d'Orbigny, 1826

**1-3** (lectotype drawing x100), Adriatic Sea, near Remini, Italy; **4-9**, **13-15**, Zone O5, Atlantic Slope Project corehole 5B/19D/29, 35", western Atlantic Ocean; **10-12**, Recent, Sample POS 334, MC 651, Azores; **16**, Recent, Meteor 11/1 Sta. 887, MSN 518, 60-30 m, Mediterrean Sea. Scale bar: **4-6**, **11**, **13-16** = 100 μm; **7-10**, **12** = 50 μm² surface area.

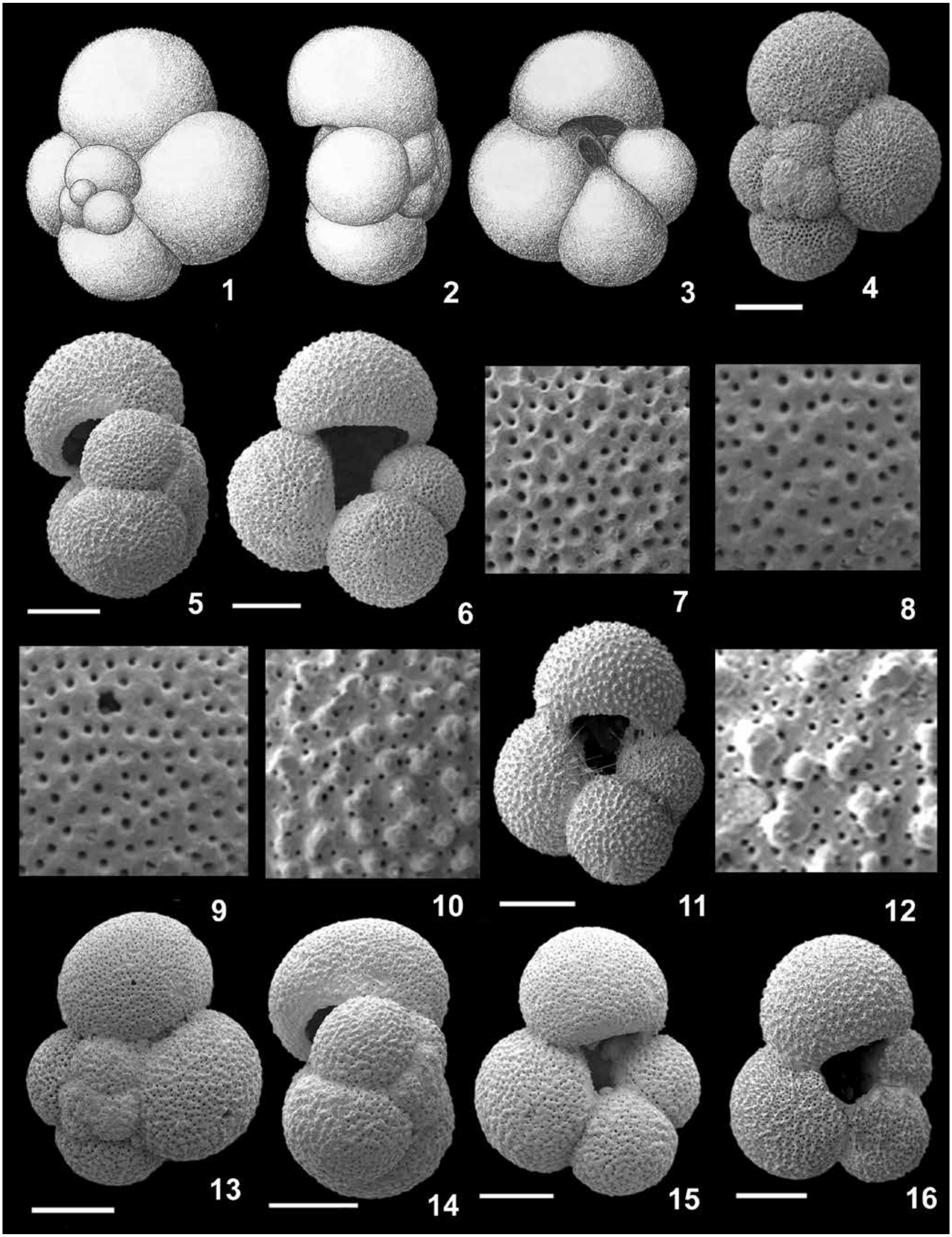

**Plate 6.2** *Globigerina bulloides* d'Orbigny, 1826

*Subbotina* due to the possession of the wall with discrete spine collars and lack of a cancellate wall.

DISCUSSION.— Described from the upper Eocene and lower Oligocene of the Northern Caucausus, *Globigerina officinalis* Subbotina has been little used by workers, which may be due to its small size and lack of biostratigraphic value. Subbotina (1953) stressed the variability in size of the ultimate chamber of *G. officinalis* and illustrated this range of variation in a suite of specimens. Thus, there is a moderate range of variability in the initial lineage of *Globigerina* and it is preferable to treat these morphotypes as a single species, *G. officinalis*. Under our taxonomy we recognize *Globigerina officinalis* as the first species in the evolution of the genus *Globigerina.* The earlier development of *Globigerina* (*bulloides*-type) wall texture is observed in *Subbotina crociapertura* Blow, which first appears in Zone E7. *Subbotina crociapertura*, however, retains the basic subbotinid test morphology and has a distinctive umbilical-extraumbilical hook-shaped aperture, which suggests a morphologic trend away from the *Globigerina* test morphology. Nevertheless, the origin of the genus may derive from closely related subbotinid morphotypes either related to this species or to its probable ancestor species, *Subbotina roesnaesensis* Olsson and Berggren.

Previously, *Globigerina praebulloides*, described from the upper lower Miocene (Zone M3/4) of Venezuela (Blow, 1959), has been regarded as the ancestor of *G. bulloides.* Our new SEM images of the holotype (USNM 625701) of *G. praebulloides* Blow confirms that it has a *Globigerina* (*bulloides*-type) wall texture, however, the morphology is the same as the *Globigerinella obesa* holotype (USNM P5673), which leads us to place *G. praebulloides* as a junior synonym of *G. obesa* (Pl. 6.8, Figs. 4-6). Blow and Banner (1962) erected a subspecies of *G. praebulloides*, *G. praebulloides leroyi* and they placed in synonymy with it one of Subbotina's illustrations of *G. officinalis* (pl. 11, figs. 4 a-c), which is where it stayed in Olsson and others' (2006) treatment of the group in the *Atlas of Eocene Planktonic Foraminifera* (p. 114, pl. 6.1, figs. 13-15). Blow and Banner (1962) subsequently described examples of *G. praebulloides* from the Oligocene (Zone O3) of Tanzania (their pl. IX, figs. O-Q), which we would now also place in *G. officinalis*. The outcome of this taxonomic tangle is that *G. praebulloides*, which turns out to be *Globigerinella obesa*, cannot be ancestral to *G. bulloides*, while *G. officinalis*, giving rise to *G. archaeobulloides* n. sp., provides a parsimonious ancestral pathway.

PHYLOGENETIC RELATIONSHIPS.— The origin of *Globigerina officinalis* is uncertain, but see discussion above. It appeared around middle Eocene Zone E10 and is transitional to *Globigerina archaeobulloides* n. sp., which appeared with a fully developed *bulloides*-type wall texture in early Oligocene Zone O1.

TYPE LEVEL.— Upper Eocene, Upper F3 Series, *Bolivina* Zone from Nalchik, along the Kheu River, Northern Caucasus (Subbotina, 1953).

STRATIGRAPHIC RANGE.— Zone E10? (Olsson and others, 2006) to lower Miocene, lower part of Zone M2 (Spezzaferri, 1994).

GEOGRAPHIC DISTRIBUTION.— Distributed in low to mid-latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— Pearson and others (2001) have recorded for *G. officinalis* relatively negative $\delta^{18}O$ and positive $\delta^{13}C$, which suggest a shallow water habitat.

REPOSITORY.— Holotype (No. 4038) deposited in the VNIGRI collections, St. Petersburg, Russia.

### Genus *Globigerinella* Cushman, 1927

TYPE SPECIES.— *Globigerina aequilateralis* Brady, 1879 = junior subjective synonym of *Globigerinella siphonifera* (d'Orbigny, 1839).

DESCRIPTION.

*Type of wall*: Spinose; spines are supported by spine collars which coalesce to form ridges. Pore concentrations range from around 75 to 100 pores/50 $\mu m^2$ test surface area and pore diameters range from

Plate 6.3 *Globigerina officinalis* Subbotina, 1953

**1-4** (paratype, VNIGRI 4040) upper Eocene, *Bolivina* Zone, Kheu River, North Caucasus; **5-7**, Zone NP23, Waschberg unit, Ottenthal, No. 138, Austria; **8-13**, Zone NP23 [= O2-O3 Zone], Rögl sample 4-91, Waschberg unit, lower Austria. Scale bar: **8**, **10-12** = 50 µm; **1-3**, **5**, **6** = 40 µm; **13** = 25 $\mu m^2$ surface area; **9** = 10 µm; **4**, **7** = 50 $\mu m^2$ surface area.

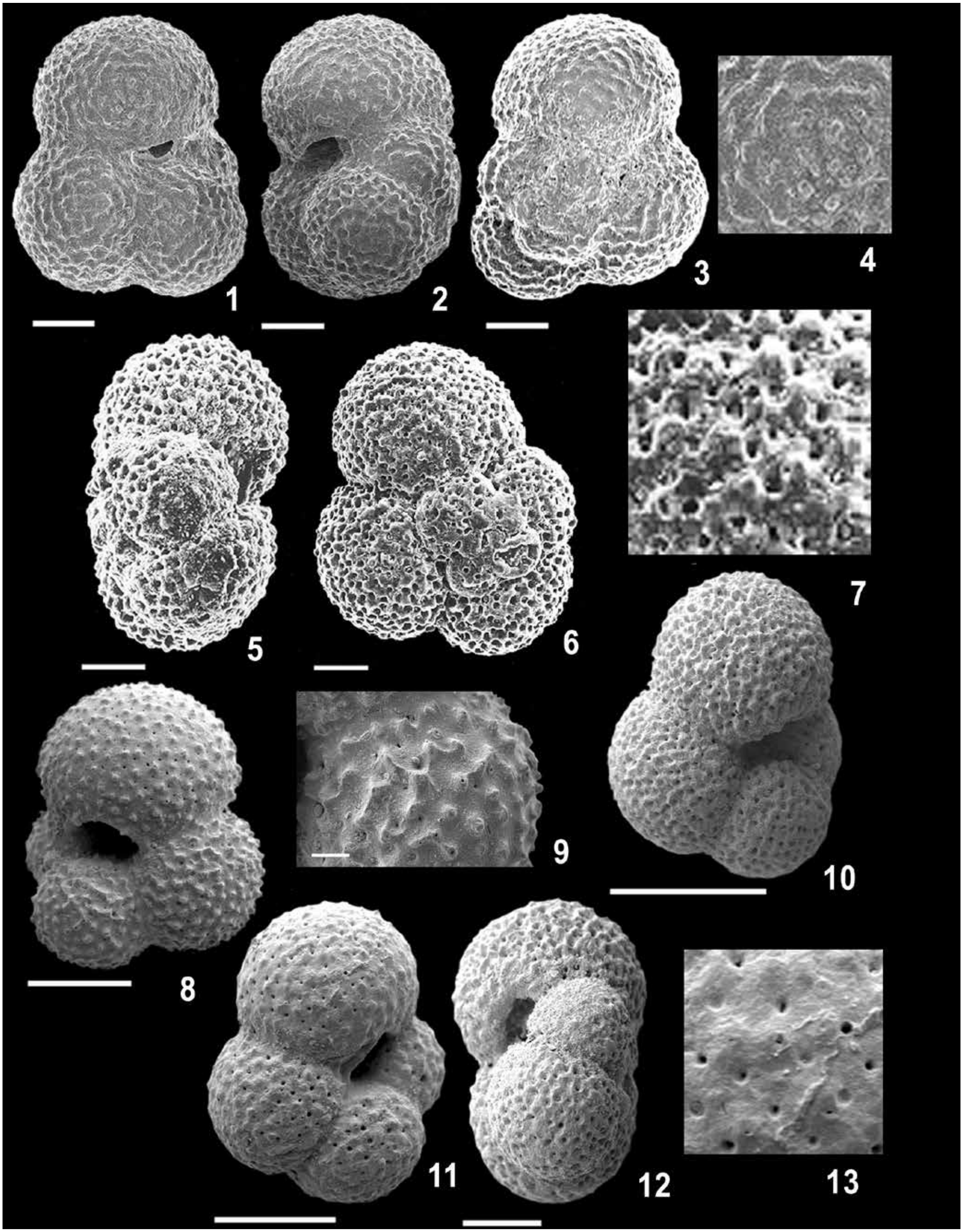


**Plate 6.3** *Globigerina officinalis* Subbotina, 1953

around 1.6 µm to 3.5 µm.

*Test morphology*: Test trochospiral in initial stages becoming planispiral in adult stage, with 4 to several globular to ovate chambers, moderately inflating in the ultimate whorl. Aperture umbilical-extraumbilical, interiomarginal, sometimes divided in two by a median septum. A spiral sutural opening of the ultimate chamber may be present.

DISTINGUISHING FEATURES.— *Globigerinella* differs from *Globigerina* by the coiling mode, which is initially trochospiral tending to planispiral, in most species, and by the umbilical-extraumbilical aperture. Early representatives of the genus may lack the planispiral stage (e.g., *G. obesa* and *G. roeglina*).

DISCUSSION.— *Globigerinella* is a common genus in the Neogene and is present in modern oceans. *Globigerinella* was considered by Bolli (1957) as a junior synonym of *Hastigerina* Thomson due to the common planispiral form. The advent of wall texture based classifications resulted in clear distinctions between these genera based on spine morphology and shell ultrastructure; see discussion in Kennett and Srinivasan (1983). DNA-based studies have revealed high genetic diversity in *G. siphonifera* with different genotypes having been detected with corresponding morphologies (Bijma and others, 1998; de Vargas and others, 2002). They show subtle differences in ecology and physiology, their empty shells are difficult to differentiate, although some small morphological differences are recognized, and should thus be best regarded as sister species (Huber and others, 1997; Bijma and others, 1998; de Vargas and others, 2002). We cannot exclude that also the fossil *Globigerinella* possessed multiple genotypes, but lacking DNA studies it cannot be demonstrated. The genus first appears in the lower Oligocene. A series of Oligocene globigerinellids described from the Paratethys region, Indian Ocean and Pacific, developed radially elongate chambers in the final whorl. Among these are several species previously attributed to the genus *Protentella*. We have reviewed the taxonomy of these digitate forms and explored possible evolutionary connections. We recognize however, that it is very possible that some or all of these forms represent independent derivations of similar clavate/digitate forms from a globigerinellid ancestor close to *G. obesa* or *G. praesiphonifera*.

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella* probably originated from *G. archaeobulloides* in the lower Oligocene.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O1 (Spezzaferri, 1994) to Recent (e.g., Hemleben and others, 1989).

STABLE ISOTOPE PALEOBIOLOGY.— Modern *Globigerinella siphonifera* are symbiont bearing, and inhabit the mixed-layer of oligotrophic, tropical to subtropical water masses. The isotopic composition of Type I and Type II of *G. siphonifera* are strongly influenced by feeding regime and light intensity rather than depth habitat (Bijma and others, 1998).

### *Globigerinella clavaticamerata* (Jenkins, 1977)

PLATE 6.4, FIGURES 1-16

*Protentella clavaticamerata* Jenkins 1977:308-312, pl. 4, figs. 12-14, pl. 5, figs. 1-8 [lower Miocene *Globigerinoides trilobus trilobus* Zone, Wimpey Sealab Trial Borehole, English Channel].—Premoli Silva and Spezzaferri 1990:314, pl. 4, figs. 5a-c [upper Oligocene Zone P22, ODP Site 709, Indian Ocean].

*Protentella rohiensis* Popescu and Brotea 1989:258, pl. 1 (partim), figs. 7-8, 11-12 [mid-Oligocene, *Paragloborotalia opima* Zone, Vima Fm., Transylvanian Basin, Romania]. [Not Popescu and Brotea.]

DESCRIPTION.

*Type of wall*: Spinose; spines are supported by spine collars, which coalesce to form ridges. Pore concentrations range from around 80 pores/50 µm$^2$ test surface area and pore diameters range from around 2 µm.

*Test morphology*: Test very low trochospiral,

Plate 6.4 *Globigerinella clavaticamerata* (Jenkins, 1977)

**1-2** (holotype, MPK 1357)*, Globigerinoides trilobus trilobus* Zone, English Channel, reproduced from Jenkins, 1977, pl. 5, figs. 1, 2); **3-5**, Subzone M1a, DSDP Hole 354, equatorial Atlantic Ocean; **6-8**, Zone M5, DSDP Sample 94/9/4, 7-9 cm, Caribbean (Spezzaferri, 1994); **9-12**, Zone O7, DSDP Sample 538A/2/CC, Gulf of Mexico; Zone O7, DSDP Sample 538A/2/CC, Gulf of Mexico; **13-16**, Zone O7, DSDP Sample 538A/2/CC, Gulf of Mexico, Gulf of Mexico. Scale bar: **1-11**, **13-15** = 100µm; **12**, **16** = 10 µm.

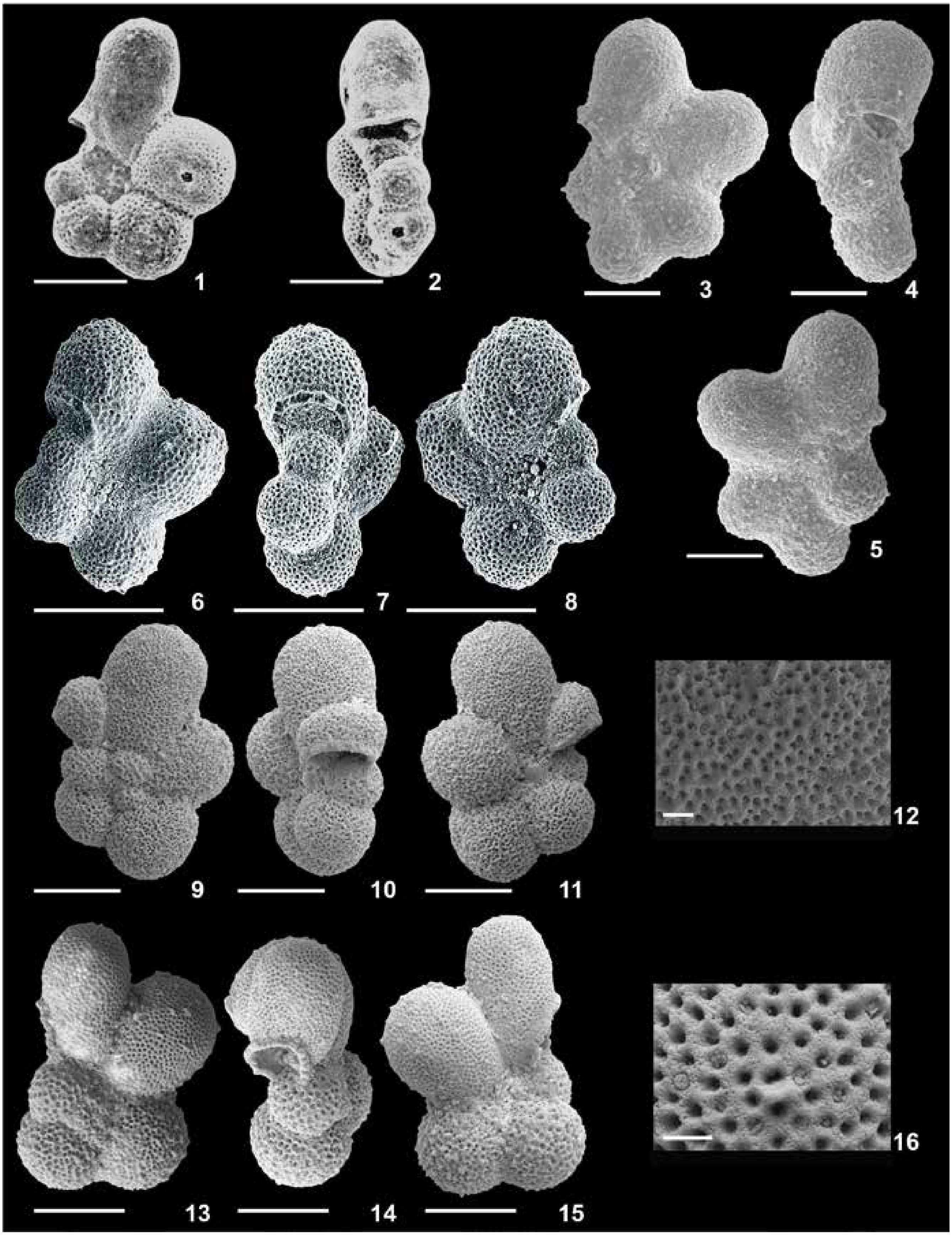


**Plate 6.4** *Globigerinella clavaticamerata* (Jenkins 1977)

consisting of 2 whorls, sometimes becoming almost planispiral in the last whorl, ovate and slightly lobulate in outline, 4-6 chambers in the last whorl, increasing moderately in size, the last chamber, sometimes the last two chambers of the last whorl may be strongly radially elongated, sutures depressed, straight to slightly curved on both sides; aperture at the base of the last chamber interiomarginal a low arch bordered by a distinct lip.

*Size*: Maximum diameter of the holotype 0.26 mm.

DISTINGUISHING FEATURES.— This species, described form the lower Miocene of a borehole in the English Channel, is distinguished from other *Globigerinella* species by having a radially elongated penultimate and/or last chambers. It differs from *G. molinae* by the more marked elongation of the last chamber. It differs from *Protentella prolixa* Lipps by the wall texture, which is finely cancellate in *P. prolixa* compared to *bulloides*-type in *G. clavaticamerata*.

DISCUSSION.— Jenkins (1977) described *G. clavaticamerata* as biumbilicate, thus, planispiral, however, the paratypes include also low trochospiral forms, i.e. with the spiral and umbilical sides distinguishable. Therefore, we include in this species also slightly trochospiral morphologies. The specimens identified as *Protentella rohiensis* and illustrated by Popescu and Brotea (1989, in pl. I, figs. 7-8 and 11-12) are referred to *G. clavaticamerata* because of a clear similarity in morphology.

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella clavaticamerata* possibly evolved from *Globigerinella navazuelensis* in the upper Oligocene Zone O5.

TYPE LEVEL.— Lower Miocene, Burdigalian *Globigerinoides trilobus* Zone, west of the isles of Scilly, Wimpey Sealab Trial Borehole, English Channel.

STRATIGRAPHIC RANGE.— Difficult to establish due to the sporadic occurrence. Existing constraints suggest it ranges from the upper Oligocene Zone O5 (Spezzaferri, 1994) to the Langhian in the middle Miocene (Jenkins, 1977).

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan, documented in the English Channel, Atlantic, Indian and Pacific Oceans. It is however, never abundant.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (MPK 1357) and paratypes (MPK 131, 1332, 1359) deposited in the collection of the Institute of Geological Sciences, Leeds, U.K., and now located at the British Geological Survey, Keyworth, U.K.

## *Globigerinella megaperta* Rögl, 1994

Plate 6.5, Figures 1-15

*Globigerinella megaperta* Rögl, 1994:142, pl. 3, figs. 7-13, pl. 4, fig. 6 [mid-Oligocene, lower Eggerian, Austrian Molasse Basin].—Cicha and others, 1998:101, pl. 37, figs. 10-13 [mid-Oligocene, lower Eggerian, Austrian Molasse Basin].—Székely and Filipescu, 2016:490, pl. 2, figs. 8a-c [upper Oligocene, Chattian, Transylvanian Basin, Romania].

'Giant *Globigerina ciperoensis*' Ujetz and Wernli 1994:200-201 (partim), pl. 1, figs. 2a-b [lower Oligocene Zone P20, Haute Savoie, France] (not figs. 1a-b = *Globigerinella wagneri*).

DESCRIPTION.

*Type of wall*: Spinose; spines are supported by spine collars, which coalesce to form ridges. Pore concentrations range from around 85-90 pores/50 μm$^2$ test surface area and pore diameters range from around 2-3.5 μm.

*Test morphology*: low trochospiral to pseudoplanispiral, inner coil depressed, lobulate in outline with depressed and straight sutures on both sides. Eleven chambers are arranged in 2½ whorls, the chambers of the inner whorls are very small, the 5-6 globular chambers of the last whorl increase rapidly in size, the last 4 chambers open into the large and

Plate 6.5 *Globigerinella megaperta* Rögl, 1994

**1-4** (holotype, Natural History Museum in Vienna, 1994/26), lower Eggerian, Zone NP24-NP25, Puchkirchen Fm., drill site Schallerback-2, 350 m, Austrian Molasse Basin (Rögl, 1994, pl. 3, figs. 11-13); **5-7**, (paratype, Natural History Museum, Vienna, Rö-12/92), Zone NP24- NP25, Puchkirchen Fm., Sample drill site Schallerback-2, 320 m, Austrian Molasse Basin (Rögl, 1994, pl. 3, figs. 8-10); **8-12**, upper Oligocene, Puchkirchen Fm., drill site Liniet-1, Austrian Molasse Basin; **13-15**, upper Oligocene, Puchkirchen Fm., drill site Liniet-1, Sample 622-624, Austrian Molasse Basin. Scale bar: **1-3**, **5-7**, **8-10**, **13-15** = 100 μm; **4**, **11**, **12** = 10 μm.

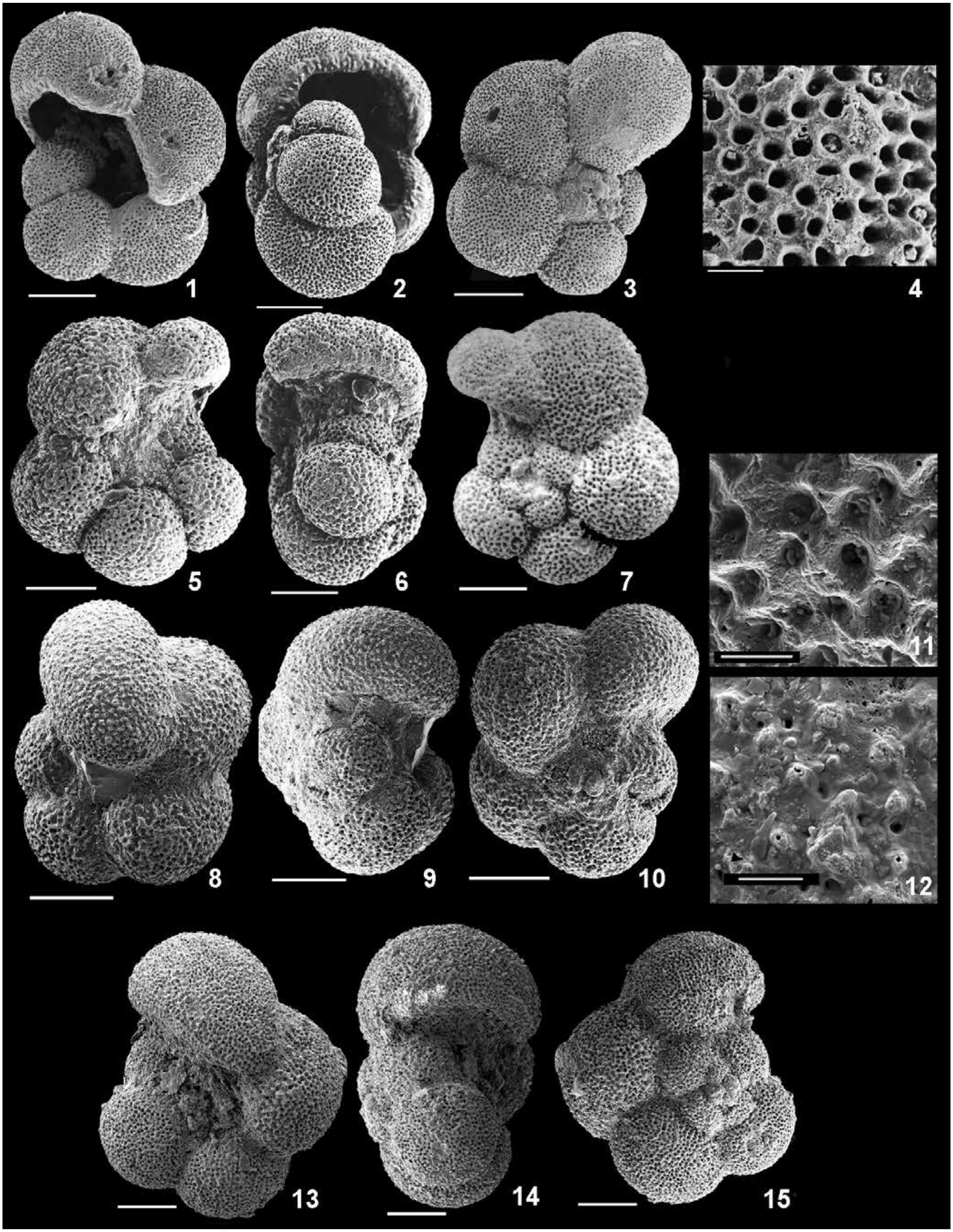


**Plate 6.5** *Globigerinella megaperta* Rögl, 1994

deep umbilicus. The aperture is a very large and high asymmetrical arch interiomarginal becoming marginal, and bordered by a thick rim.

*Size*: Diameter of the holotype from 0.45 mm.

DISTINGUISHING FEATURES.— This species is characterized by the unusually open and highly arched interiormarginal aperture and streptospiral initial coiling mode, producing a form reminiscent of *Globigerinella siphonifera*, to which it is not closely related. It differs from *G. wagneri* by the more developed and more open high arched aperture and tendency towards planispiral coiling. *Globigerinella megaperta* can be distinguished from *G. obesa* and *G. praesiphonifera* by the gaping aperture that reveals the final four chambers compared to the latter species in which the apertural opening is restricted to the last chamber. It differs from these species by its greater pore density and pore size.

DISCUSSION.— *Globigerinella megaperta* and closely related *G. wagneri* are unique to the Paratethys and possess a globigerinid wall of high pore porosity and wall structure of coalescing ridges with evidence of spine collars, as is diagnostic of the *bulloides*-type wall. Based on these features, together with the extraumbilical-to equatorial position of the aperture, they are placed in *Globigerinella*, although it is important to point out that they do not have the typical *bulloides*-type wall of pore diameters less than 1µm. Some specimens may display a sac-like last chamber and/or aberrant chambers. This also co-occurs in *G. wagneri* (Rögl, 1994).

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella megaperta* evolved from *G. wagneri* in lower Oligocene Zone O3 and can be considered as an end member of a unique Paratethys globigerinellid lineage.

TYPE LEVEL.— 'Middle' Oligocene (lower Eggerian), of the Austrian Molasse Basin, Puchkirchen Formation from the water drill site Schallerbach 2.

STRATIGRAPHIC RANGE.— This species was described from the late Rupelian and Chattian of the Austrian Molasse Basin (Rögl, 1994; Cicha and others, 1998) corresponding to the interval spanning Zone O4 to O5. The specimens documented by Ujetz and Wernli (1994) from Zone P20 in Haute Savoie (French Alps) allow the extension of its range down to Zone O3.

GEOGRAPHIC DISTRIBUTION.— This species has been found only in Haute Savoie and Central Paratethys.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype deposited in the collection of the Natural History Museum in Vienna (n. 1994/34).

### *Globigerinella molinae* (Popescu and Brotea, 1989)

Plate 6.6, Figures 1-17

*Protentella molinae* Popescu and Brotea 1989:258, pl. 1, figs. 9, 10 [mid-Oligocene *Paragloborotalia opima* Zone, Vima Fm., Transylvania, Romania].

*Clavatorella* aff. *C. nicobarensis* Srinivasan and Kennett, 1974.—van Eijden and Smit, 1991:112, pl. 4, figs. 9, 10 [upper Oligocene Zone P22, ODP Site 758, eastern Indian Ocean]. [Not Srinivasan and Kennett, 1974.]

DESCRIPTION.

*Type of wall*: Normal perforate, spinose, probably with spines supported by spine collars, which coalesce to form ridges. It is impossible to evaluate pore concentration and pore diameter from the existing documentation.

*Test morphology*: Test composed of 2 whorls, initially trochospiral becoming almost planispiral in the last whorl, ovate and slightly lobulate in outline, 5-6 chambers in ultimate whorl, increasing moderately in size, the last chamber, sometimes the last two chambers of the last whorl may be slightly radially elongated, sutures depressed, straight on both sides; aperture equatorial, position at the base of the last chamber, a low arch bordered by a distinct lip.

*Size*: Maximum diameter of holotype approximately 0.3 mm.

Plate 6.6 *Globigerinella molinae* (Popescu and Brotea, 1989)

**1-2** (holotype, Institut de Geologie si Geofizica, Bucharest, P.105.562), *Paragloborotalia opima* Zone, Transylvania, reproduced from Popescu and Brotea (1989), pl. 1, figs. 9, 10; **3-6**, Subzone M1a, ODP Hole 709B/22/1, 87-89 cm, Indian Ocean; **7-9**, Subzone M1a, ODP Hole 709B/22/1, 87-89 cm, Indian Ocean; **10-13**, Subzone M1a, ODP Hole 709B/22/1, 82-83 cm, Indian Ocean; **14-17**, Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico. Scale bar: **1-2**, **14-16** = 100 µm; **3-4**, **6**, **7-12** = 50 µm; **5**, **13** = 10 µm; **17** = 20 µm.

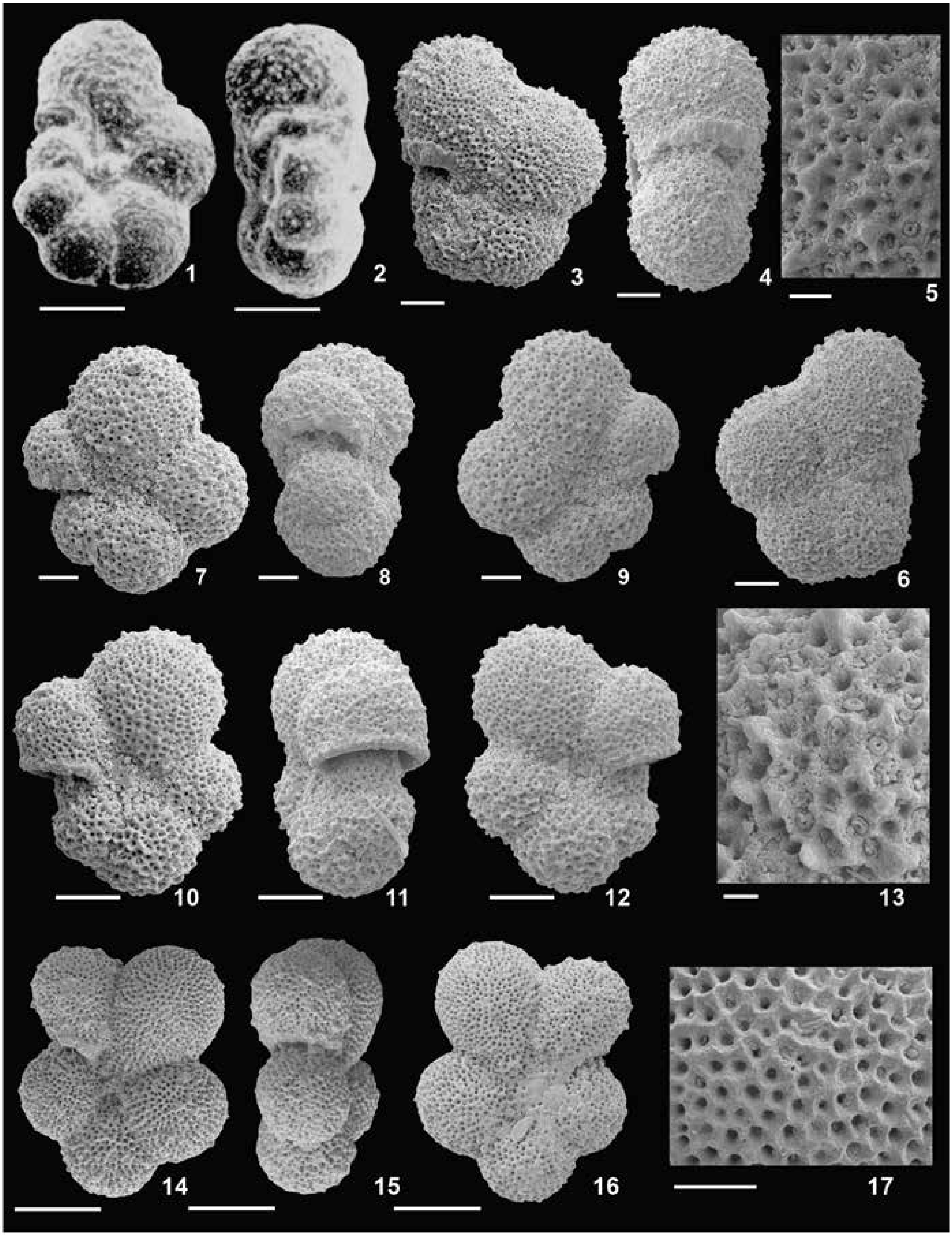


**Plate 6.6** *Globigerinella molinae* (Popescu and Brotea, 1989)

DISTINGUISHING FEATURES.— This species is distinguished from *G. navazuelensis* by its slightly more radially elongated last and/or penultimate chambers and single equatorial aperture. It differs from *G. clavaticamerata* by having clearly less radially elongated last chambers and more planispiral coiling. It differs from *G. obesa* and *G. praesiphonifera* by the marked tendency to become planispiral in the last whorl and for the position of the aperture tending to move across the peripheral margin.

DISCUSSION.— The images of the holotype and paratypes of *molinae* reported in Popescu and Brotea (1989) show only one side and an edge view. Although described as biumbilicate, thus planispiral, they clearly show that the two sides are not identical and therefore are not completely planispiral. They are characterized by a single, small aperture and a tendency for slightly radially elongated chambers. In the Transylvanian Basin, *G. molinae* is a potential alternative marker for the base of the *C. angulisuturalis* Zone (Popescu and Brotea, 1989).

PHYLOGENETIC RELATIONSHIPS.— It probably evolved from *G. navazuelensis* in the lower Oligocene Zone O4.

TYPE LEVEL.— Mid-Oligocene, upper Rupelian-lower Chattian, lower Vima Formation, above the highest occurrence of *Turborotalia ampliapertura*, in a thin band (5-10 cm thick) containing the uppermost occurrence of Mediterranean and Paratethyan fauna.

STRATIGRAPHIC RANGE.— Upper part of Zone O4 (Popescu and Brotea, 1989) to Subzone M1a.

GEOGRAPHIC DISTRIBUTION.— Paratethys, South Atlantic and Indian Ocean (Popescu and Brotea, 1989, Spezzaferri, 1994).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype deposited in the collection of the Institute of Geology and Geophysics, Bucharest, Romania (no. P 105.562).

### *Globigerinella navazuelensis* (Molina, 1979)

Plate 6.7, Figures 1-21

*Protentella navazuelensis* Molina, 1979:265, pl. 33, figs. 1a-d [upper Oligocene *G. primordius* Zone, Canad de Jaén, Spain].—Popescu and Brotea, 1989:258, pl. 1, figs. 13, 14, pl. 2, figs. 5, 6, 8-13, [lower Oligocene Subzone P21a, Transylvania, Romania].—Premoli Silva and Spezzaferri, 1990, pl. 4, figs. 6a-d, [upper Oligocene Zone O7, ODP Hole 709B, Indian Ocean].—Spezzaferri, 1994:51-52, pl. 17, figs. 3a-c [lower Miocene Zone M1, ODP Hole 709B, Indian Ocean], pl. 18, figs. 4a-c [lower Miocene Zone M1, ODP Hole 709A, Indian Ocean].

*Protentella* aff. *P. prolixa* Lipps, 1964.—van Eijden and Smit, 1991:114, pl. 5, figs. 11-12 [upper Oligocene Zone P22, ODP Site 758, eastern Indian Ocean].

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars which coalesce to form ridges. Pore concentrations average 100 pores/50 μm$^2$ test surface area and pore diameters average 2 μm.

*Test morphology*: Test planispiral, lobulate in outline, 5-6 globular, chambers in ultimate whorl, increasing moderately in size, ultimate chamber may reduced in size, sutures depressed, straight on both sides; biumbilicate, with narrow umbilici, aperture symmetrical, bordered by a distinct rim, variable; a single or double low equatorial arch at the base of the final chamber, or double umbilical-extraumbilical apertures, opening symmetrically into the umbilici.

*Size*: Maximum diameter of holotype 0.25 mm.

DISTINGUISHING FEATURES.— Characterized by a symmetrical sometimes double arch aperture bordered by a thick rim. It differs from *G. clavaticamerata* by lacking the elongated last or penultimate chamber and by the planispiral coiling also in the last whorl. It differs from *G. molinae* by having globular chambers and lacking the slight elongation of the last chambers.

Plate 6.7 *Globigerinella navazuelensis* (Molina, 1979)

**1-3** (holotype, reproduced from Molina, 1979, pl. 33, figs. 1a-d), *Globigerinoides primordius* Zone, Canad de Jaén; **5-7**, Subzone M1a, ODP Hole 709B/22X/1, 81-83 cm, Indian Ocean; **4**, **8**, **12**, Subzone M1a, ODP Hole 709B/22X/1, 81-83 cm, Indian Ocean; **9-11,** Subzone M1a, ODP Hole 709B/22X/1, 77-79 cm, Indian Ocean; **13-15**, Zone O7, DSDP 538A/2H/CC, Gulf of Mexico; **16-19**, Subzone M1b, ODP Hole 588C/9R/3, 134-136 cm, Tasman Sea; **20**, **21**, Subzone M1b, ODP Hole 526A/27/3, 30-32 cm, South Atlantic Ocean; Scale bar: **1-3**, **9-11**, **20**, **21** = 100μm; **4-8**, **12**, **13-18** = 50 μm; **19** = 10 μm.

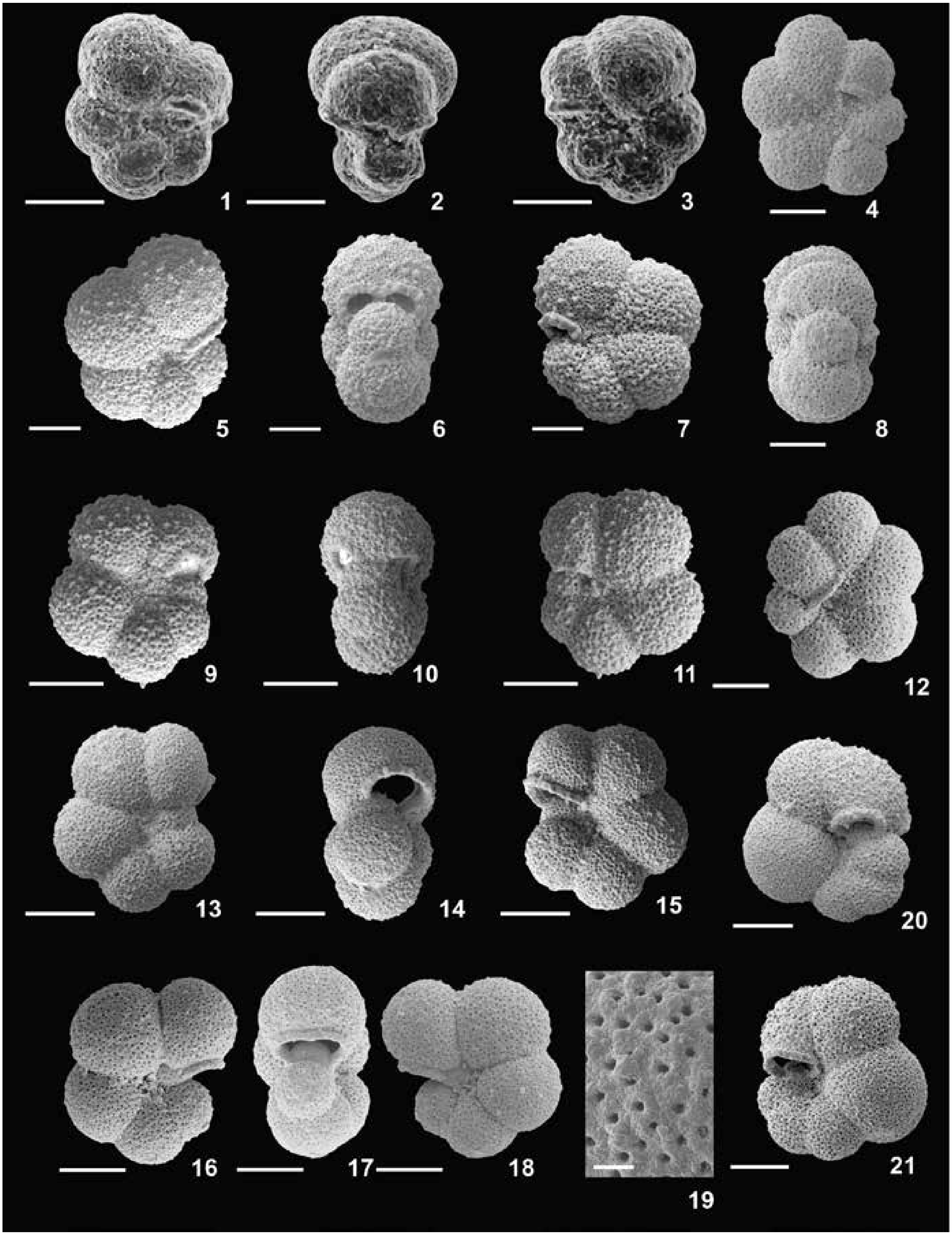


**Plate 6.7** *Globigerinella navazuelensis* (Molina, 1979)

DISCUSSION.— This species is almost completely planispiral during ontogeny, although some specimens may still show the initial trochospiral coiling (Plate 6.7, Figs. 13-15). The small specimens described as *Protentella* affinis *navazuelensis* by Spezzaferri (1994) and displaying a quadrangular profile and a single aperture are probably juvenile forms of *G. navazuelensis.*

PHYLOGENETIC RELATIONSHIPS.— We suggest that *Globigerinella navazuelensis* evolved from *Globigerinella praesiphonifera* (Blow) in the mid-Oligocene Zone O4 by developing a more marked planispiral coiling mode and from which it differs also by more numerous chambers in the last whorl.

TYPE LEVEL.— Lower Miocene *Globigerinoides primordius* Zone, Aquitanian, Canada de Jaen Section, Spain.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O4 to lower Miocene Zone M2 (Spezzaferri, 1994).

GEOGRAPHIC DISTRIBUTION.— Common at low latitudes especially in the Atlantic and Indian Ocean but present also in the Mediterranean.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype deposited in the collection of the Department of Paleontology of the University of Granada. No reference number is given.

### *Globigerinella obesa* (Bolli, 1957)

Plate 6.1, Figures 14-17
Plate 6.8, Figures 1-23
(Pl. 6.8, Figs. 1-3: new SEMs of holotype of *Globorotalia obesa* Bolli)

*Globorotalia obesa* Bolli, 1957:119, pl. 29, figs. 2a-3 [middle Miocene *Globorotalia fohsi robusta* Zone, Cipero Fm., Trinidad].—Stainforth and others, 1975:297, fig. 130 [middle Miocene, Cipero Fm., Trinidad and Pozón Fm., Venezuela].—Molina, 1979:231, pl. 32, figs. 1A-C [lower Miocene, Cordilleras Beticas, Spain].—Kennett and Srinivasan, 1983:234, pl. 59, figs. 2–5 [lower Pliocene *Globorotalia puncticulata* Zone, DSDP Site 281, South Tasman Rise].

*Globorotalia* (*Turborotalia*) *obesa* Bolli.—Jenkins, 1971:127, pl. 13, figs. 348-350 [lower Miocene, Parengarenga Harbour section, New Zealand].

*Globigerinella obesa* (Bolli).—Kennett and Srinivasan, 1983:234, pl. 59, figs. 2-5 [early Pliocene *Globorotalia puncticulata* Zone, DSDP Site 281, South Tasman Rise, Tasman Sea].—Spezzaferri and Premoli Silva, 1991:251, pl. XI, figs. 3a-c [upper Oligocene Zone P22 (= O7), DSDP Hole 538A, Gulf of Mexico].—Spezzaferri, 1994:50, pl.17, figs. 5a-c [upper Oligocene Zone P22 (= O7), ODP Hole 709B, Indian Ocean].—Pearson and Wade, 2009:206, pl. 4, figs. 5a-d [upper Oligocene Zone O6 (= Zone O7), Cipero Fm., Trinidad].—Beldean and others, 2012:178, pl. 1, fig. 10 [lower Miocene Zones NN1 and NN2, Hida Fm., northwest Transylvanian Basin].

*Globigerina praebulloides* Blow, 1959: pl. 8, figs. 47a-c, holotype [lower Miocene *Globigerinatella insueta/ Globigerinoides bisphericus* Zone, Pozón Fm., Venezuela].

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars which coalesce to form ridges. Pore concentrations average 62 pores/50 μm$^2$ test surface area and pore diameters average 2.5 μm.

*Test morphology*: Test very low trochospiral, consisting of 2-2½ whorls, lobulate in outline, chambers globular; in spiral view 4 globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures moderately depressed, straight; in umbilical view 4 globular, slightly embracing chambers, increasing rapidly in size, sutures moderately depressed, straight, umbilicus small, open, enclosed by surrounding chambers, aperture umbilical-extraumbilical, a low arch sometimes bordered by an imperforate rim; in edge view chambers globular in shape, slightly embracing.

*Size*: Maximum diameter of holotype 0.5 mm.

DISTINGUISHING FEATURES.— *Globigerinella obesa* is characterized by low trochospiral lobulate

Plate 6.8 *Globigerinella obesa* (Bolli, 1957)

**1-3** (holotype, USNM P5674), middle Miocene, *Globorotalia fohsi robusta* Zone, Cipero Fm., Trinidad; **4-6**, (holotype of *Globigerina praebulloides* Blow, USNM 625701), *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Pozon Fm. Venezuela; **7-9**, Subzone M1b, DSDP Hole 526A/27/3, 30-32 cm, South Atlantic Ocean; **10-12**, Zone O6, ODP Hole 709B/23X/3, 73-75 cm, Indian Ocean; **13-15**, Subzone M1a, DSDP Hole 516F/9/1, 140-142 cm, South Atlantic Ocean; **16-19**, Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico; **20-23**, Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico. Scale bar: **1-18**, **20-22** =100 μm; **19**, **23** = 20 μm.

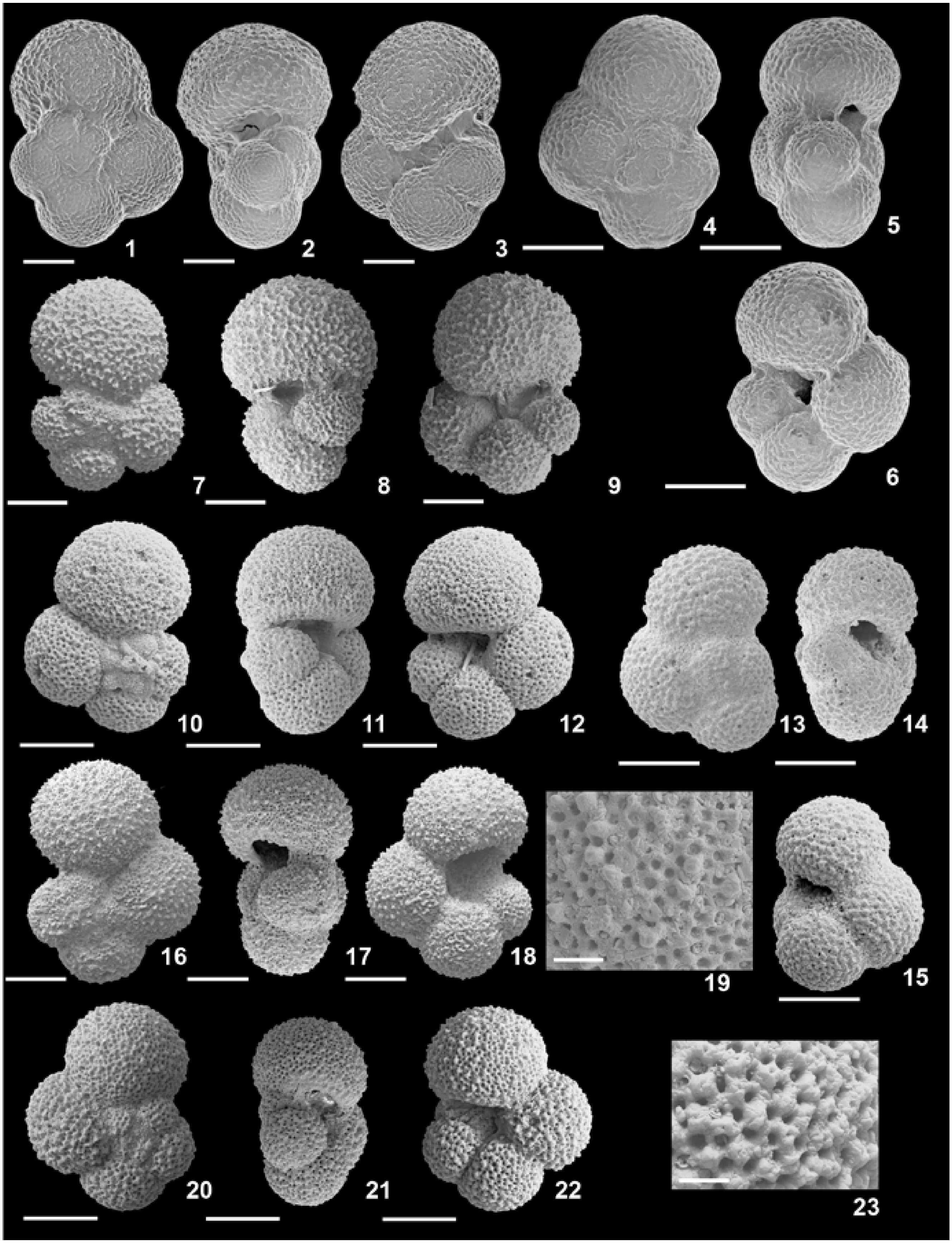


**Plate 6.8** *Globigerinella obesa* (Bolli, 1957)

test, 4 chambers in the last whorl, extraumbilical to equatorial aperture and a *bulloides*-type wall texture. It differs from *G. archaeobulloides*, from which it evolved, and *G. bulloides* by having an umbilical-extraumbilical aperture tending toward the peripheral margin and a somewhat inflated final chamber. It differs from *G. praesiphonifera* by the more enrolled coiling, having 4 chambers in the last whorl instead of 5 in *G. praesiphonifera*, lesser tendency towards planispirality and a less lobulate outline.

DISCUSSION.— *Globigerinella obesa* was initially included in the genus *Globorotalia*. It is now recognized as the first species of *Globigerinella.* SEMs of the holotype of Blow's *Globigerina praebulloides* and the paratype USNM 625702A show that they have a *bulloides*-type wall texture, but chamber architecture very similar to *G. obesa*, e.g., umbilical-extraumbilical primary aperture therefore, *praebulloides* is here considered a junior synonym of *Globigerinella obesa* Bolli (Pl. 6.8, Figs. 4-6).

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella obesa* evolved from *Globigerina archaeobulloides* n. sp. in the lower Oligocene Zone O1 and gave rise to *G. praesiphonifera* in the mid-Oligocene Zone O4.

TYPE LEVEL.— Miocene, uppermost part of the Cipero Formation, *Globorotalia fohsi robusta* Zone, light bluish gray marls with black streaks.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O1 (Plate 6.1, Figs. 14-17) to the lower Pliocene (Kennett and Srinivasan, 1983).

GEOGRAPHIC DISTRIBUTION.— Identified in low to middle latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (P5674) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

## ***Globigerinella praesiphonifera*** **(Blow, 1969)**

Plate 6.9, Figures 1-20
(Pl. 6.9, Figs. 1-3: new SEMs of holotype of *Hastigerina siphonifera praesiphonifera* Blow)

*Hastigerina siphonifera praesiphonifera* Blow, 1969:408, pl. 54, figs. 7-9 [middle Miocene Zone N8, Aguide, Falcón, Venezuela].

*Hastigerina praesiphonifera* Blow.—Bolli and Saunders, 1985:251, fig.42 (5a-c) [holotype re-illustrated].

"*Globorotalia*" *obesa* Bolli/*Globigerinella praesiphonifera* (Blow).—Spezzaferri and Premoli Silva, 1990:303, pl. 4, fig. la-c [upper Oligocene/lower Miocene Zone N4, ODP Hole 709B, equatorial Indian Ocean].

*Globigerinella praesiphonifera* (Blow, 1969).—Spezzaferri, 1994:50, pl. 17, figs. 2a-c; 4a-d [lower Miocene Subzone N4a, ODP Hole 709B, equatorial Indian Ocean].

Not *Globigerinella praesiphonifera* (Blow, 1969).—Kennett and Srinivasan, 1983:238, pl. 60, figs. 1-3 [lower Miocene Zone N5, DSDP Site 289, western equatorial Pacific Ocean] (= *G. obesa*).

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars which coalesce to form ridges. Pore concentrations average 90-100 pores/50 $\mu m^2$ test surface area and pore diameters average 1.7 µm.

*Test morphology*: Test low trochospiral consisting of 3 whorls, lobulate in outline, chambers globular; in spiral view 5 globular, slightly embracing chambers in ultimate whorl, increasing moderately in size, ultimate chamber may be reduced in size, sutures moderately depressed, straight, occasionally a small to very large secondary opening occurs at the spiral suture of the ultimate chamber; in umbilical view 5 globular, slightly embracing chambers, increasing moderately in size, ultimate chamber may be reduced in size, sutures moderately depressed, straight, umbilicus small, open, enclosed by surrounding chambers, aperture a low arch, umbilical-extraumbilical extending onto the peripheral edge, bordered by an imperforate rim; in edge view chambers globular in shape, slightly embracing.

*Size*: Maximum diameter of holotype given as 0.62 mm.

Plate 6.9 *Globigerinella praesiphonifera* Blow, 1969

**1-3** (holotype NHM P49766), Zone M5 [=Zone N8], Aguide, Falcón, Venezuela; **4**, **5**, **10**, **15**, Zone O5, Atlantic Slope Project corehole 5B/19D/29-35", western Atlantic Ocean; **6-9**, Zone O6, Atlantic Slope Project corehole 5B 5A/0-6", western Atlantic Ocean; **11-14**, Zone O4, Alazan Fm., type locality, Tuxpan, Tampico, Mexico; **16-20**, Zone O6, Atlantic Slope Project corehole 5B 5A/0-6", western Atlantic Ocean. Scale bar: **1-3**, **5-8**, **10**, **11**, **13-16**, **18-20** = 100 µm; **4**, **9**, **12**, **17** = 50 $\mu m^2$ surface area.

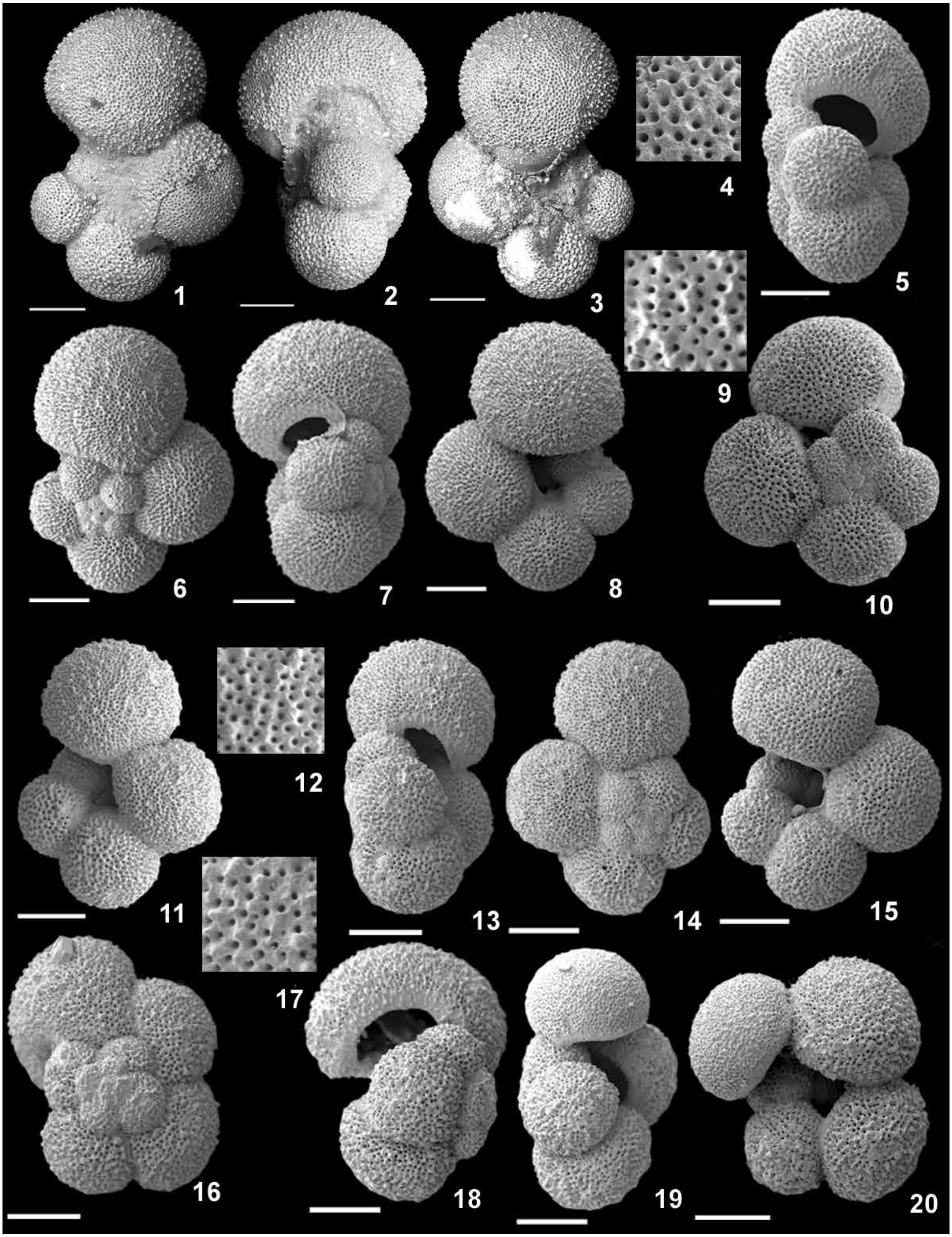


**Plate 6.9** *Globigerinella praesiphonifera* (Blow 1969)

DISTINGUISHING FEATURES.— Characterized by low trochospiral lobulate test, 5 chambers in the last whorl, possible presence of secondary opening occurs at the spiral suture of the ultimate chamber, extraumbilical to equatorial aperture and *Globigerina* wall texture.

DISCUSSION.— As mentioned above with respect to *Globigerinella obesa*, it is now clear that *praesiphonifera* has a *bulloides*-type wall and is not related to *Hastigerina,* as was originally suggested by Blow (1969) based on the *Hastigerina*-like near-planispiral coiling in *obesa*. Blow (1969) described *Globigerinella praesiphonifera* as having an initial trochospiral whorl of chambers with the last three chambers having a planispiral position and equatorial aperture. Oligocene populations of *Globigerinella praesiphonifera* are morphologically very similar to Blow's species from the lower middle Miocene, except that the final chambers do not become fully planispiral. As noted by Spezzaferri (1994), the specimens reported by Kennett and Srinivasan (1983) (pl. 60, figs. 1-3) are considered transitional to *G. obesa* because the test is trochospirally coiled throughout.

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella praesiphonifera* evolved from *Globigerinella obesa* (Bolli) in early Oligocene Zone O4 and gave rise to *G. siphonifera* in the early middle Miocene.

TYPE LEVEL.— Middle Miocene Zone N8, Aguide, Falcón, Venezuela.

STRATIGRAPHIC RANGE.— Forms transitional from *G. obesa* have been reported from Zone O4 with more typical morphologies from Zone O6/O7 (P22 in Spezzaferri, 1994).

GEOGRAPHIC DISTRIBUTION.— Identified in low to middle latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— Pearson and others (1997) found that the $\delta^{18}O$ of *G. praesiphonifera* generally records values intermediate between shallow- and deep-water taxa. However its $\delta^{13}C$ is considerably more negative than that of *Dentoglobigerina venezuelana* (see Chapter 11, this volume). They interpret the carbon isotope offset as a probable vital effect.

REPOSITORY.— Holotype (no. 209), deposited in the Natural History Museum, London.

## *Globigerinella roeglina* Spezzaferri and Coxall, new species

Plate 6.10, Figures 1-21

*Protentella* sp. Spezzaferri 1994, pl. 18, figs. 5a-c [upper Oligocene lower part of Zone P22, DSDP Hole 538A, Gulf of Mexico]; figs. 6a-c [upper Oligocene lower part of Zone P22, ODP Hole 709C, Indian Ocean].

*Clavatorella* aff. *C. nicobarensis* Srinivasan and Kennett, 1974.—van Eijden and Smit, 1991:112, pl. 4, fig. 11 [upper Oligocene Zone P22, ODP Site 758, eastern Indian Ocean]. [Not Srinivasan and Kennett, 1974.]

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars, which coalesce to form ridges. Pore concentrations average 80 pores/50 $\mu m^2$ test surface area and pore diameters average 1.5 µm.

*Test morphology*: Test low trochospiral consisting of 2 whorls, slightly tending to planispiral, lobulate in outline, chambers globular 4-5 in the last whorl, increasing rapidly in size, if present the last chamber may be either slightly radially elongated or smaller that the last chamber. Sutures are depressed, straight on both sides; the umbilicus is moderately small, open, enclosed by surrounding chambers, aperture an umbilical-extraumbilical high arch sometimes tending to move to completely extraumbilical, bordered by an imperforate and very thick rim.

*Size*: Maximum diameter of holotype around 0.35 mm.

ETYMOLOGY.— Named after Fred Rögl for his outstanding contribution to micropaleontology.

Plate 6.10 *Globigerinella roeglina* Spezzaferri and Coxall, new species

**1-4** (holotype, 32501, Natural History Museum, Fribourg), Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico; **5-8** (paratype 32502, Natural History Museum, Fribourg), Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico; **9-12** (paratype 32503, Natural History Museum, Fribourg), Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico; **13-15**, Zone O7, upper Oligocene, Sample 38, Vima Fm., Transylvania; **18-20**, Zone O7?, upper Oligocene, Sample 38, Vima Fm., Transylvania; **16-17**, **21**, Zone O7, DSDP Hole 538A/2/CC, Gulf of Mexico. Scale bar: **13-15**, **16-21** = 100 µm; **1-3**, **5-7**, **9-11** = 50 µm; **4**, **8**, **12** = 10 µm.

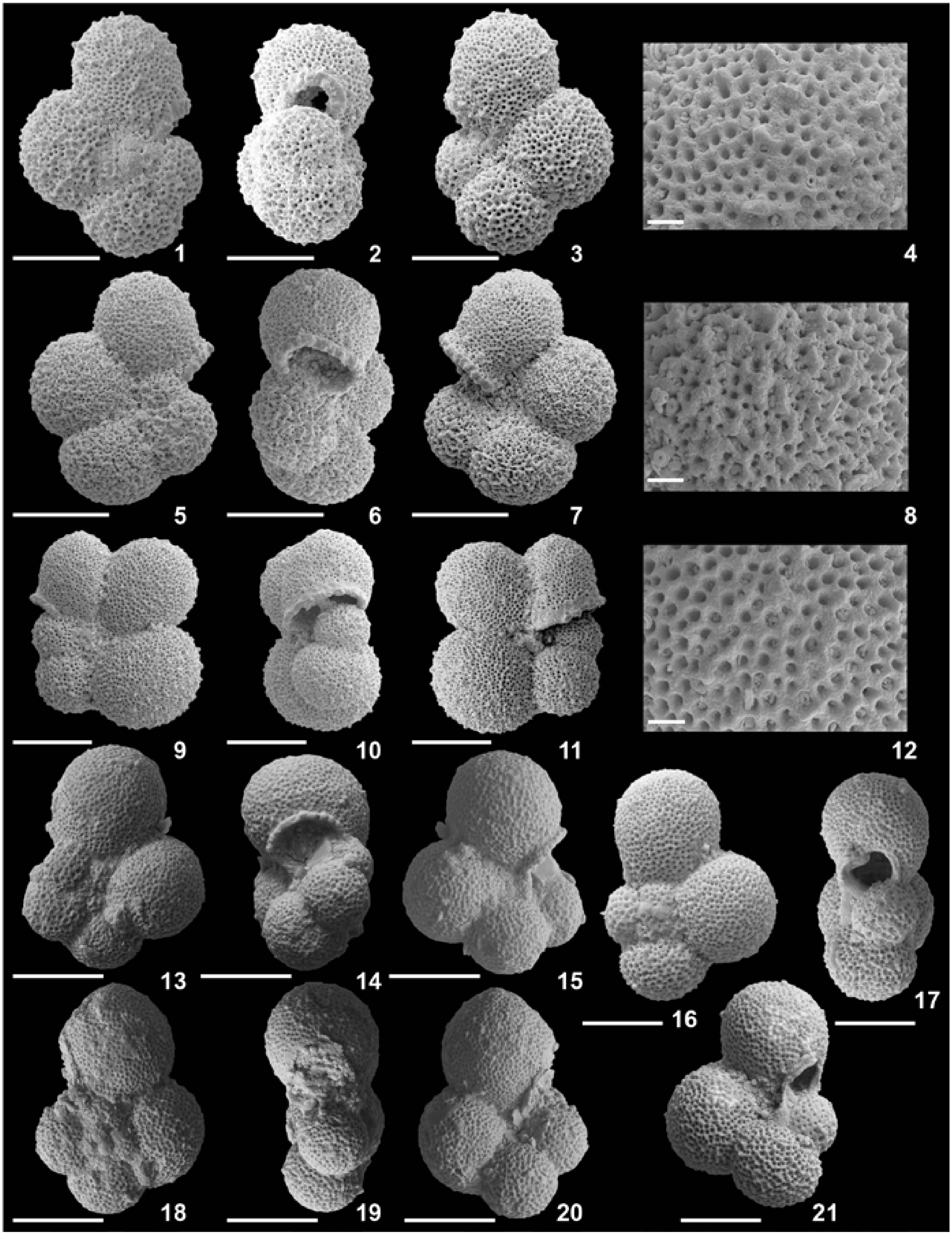


**Plate 6.10** *Globigerinella roeglina* Spezzaferri and Coxall, new species

DISTINGUISHING FEATURES.— The distinctive characters of *G. roeglina* are the thick rim bordering the aperture and the presence of a last slightly radially elongated chamber. It differs from *G. obesa* by the higher arched aperture bordered by the thick rim and from *G. clavaticamerata* by its less developed elongated last chamber and by the thick rim bordering the aperture instead of a small lip typical of *G. clavaticamerata.*

DISCUSSION.— *Globigerinella roeglina* is here established as a new species because its typical morphology is recurrent in the investigated samples and, although generally small, it does not seem to be a juvenile form. Rather it looks like the "base" morphology from which the extreme clavate species of *Quiltyella* (*Q. nazcaensis*, and *Q. clavacella*) evolve. This species shows a moderate intraspecific variability, with specimens characterized by a slightly radially elongated or smaller last chamber. The species was previously identified by Spezzaferri (1994) and informally called "*Protentella* sp.". It is here attributed to the genus *Globigerinella* because of the typical wall texture and because of its tendency to a planispiral coiling mode, even if rarely reached.

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *Globigerinella obesa* in the upper lower Oligocene Zone O4.

TYPE LEVEL.— DSDP Hole 538A-2CC, upper Oligocene Zone O7 from the Gulf of Mexico, northeast of the Campeche Escarpment. Foraminiferal nannofossil ooze.

STRATIGRAPHIC RANGE.— Sporadic occurrence from lower Oligocene Zone O4 to possibly lower/mid -Miocene Zone M5 (Spezzaferri, 1994).

GEOGRAPHIC DISTRIBUTION.— Found at low latitudes in the Gulf of Mexico, tropical Indian Ocean and Paratethys sequences of Transylvania.

STABLE ISOTOPE PALEOBIOLOGY.— Unpublished data of S. Spezzaferri indicate a deep water habitat for this species.

REPOSITORY.— Holotype (32501), and paratypes (32502, 32503 and 32504) deposited at the Museum of Natural History of Fribourg, Switzerland.

### ***Globigerinella wagneri* (Rögl, 1994)**

PLATE 6.11, FIGURES 1-17

*Globigerina wagneri* Rögl, 1994:142, pl. 2, figs. 7-12, pl. 3, figs. 1-6; pl. 4, figs. 4, 5 ['middle' Oligocene, lower Eggerian, Austrian Molasse Basin].—Cicha and others, 1998:101, pl. 31, figs. 29-34 ['middle' Oligocene, lower Eggerian, Austrian Molasse Basin].

'Giant *Globigerina ciperoensis*'.—Ujetz and Wernli 1994:200-201 (partim), pl. 1, fig. 1a-b [lower Oligocene Zone P20, Haute Savoie, France] (not figs. 2a-b = *G. megaperta*).—Ujetz and others, 1994:pl. 2, figs. 16, 17 [lower Oligocene Zone P20, Haute Savoie, France].

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars which coalesce to form ridges. Pore concentrations average 75-85 pores/50 µm$^2$ test surface area and pore diameters average 2 µm.

*Test morphology*: Low trochospiral, evolute, lobulate in outline with depressed, straight and deeply incised sutures on both sides. Fourteen chambers are arranged in 2 whorls, the 4-5 globular chambers of the last whorl increase gradually in size, the penultimate chambers opens into the umbilicus. Aperture slightly extraumbilical, a very large low umbilical arch, open, quadrangular elongated.

*Size*: Maximum diameter of the holotype 0.35 mm.

DISTINGUISHING FEATURES.— *Globigerinella wagneri* differs from *G. megaperta* by having 4-5 chambers in the last whorl instead of 5-6, by the low

Plate 6.11 *Globigerinella wagneri* (Rögl, 1994)

**1-5** (holotype, lower Eggerian, Natural History Museum in Vienna, 1994/34), Oligocene Zone NP24-NP25, Puchkirchen Fm., Sample drill site Schallerback-2, 460 m, Austrian Molasse Basin (Rögl, 1994, pl. 2, figs. 7-9); **6**, **7** (paratype), locality and level as holotype (Rögl, 1994, pl. 3, figs. 10, 11); **8-10** (paratypes of *Globigerina wagneri*) lower Oligocene, Kiscellian, Zone NP23, Ottenthal, Waschberg unit, no. 138, farmyard L. Hauer, sample Rö 4-91, lower Austria, 8-9 same specimen (Rögl, 1994, pl. 3, figs. 1-3); **11-13** (paratypes of *Globigerina wagneri* Oligocene Zone NP24-NP25, Puchkirchen Fm., drill site Schallerback-2, Austrian Molasse Basin, 11, sample from 320 m, 12-13 sample from 370 m, same specimen) (Rögl, 1994, pl. 3, figs. 4-6); **14**, **15** (topotype), locality and level as holotype; **16-17** Oligocene Zone NP24, Ottenthal, Waschberg unit, Waldweg, 49.7-49.8 m. Scale bar: **1-3**, **6-13**, **14**, **16**, **17** = 100 µm; **4**, **5**, **15** = 10 µm.

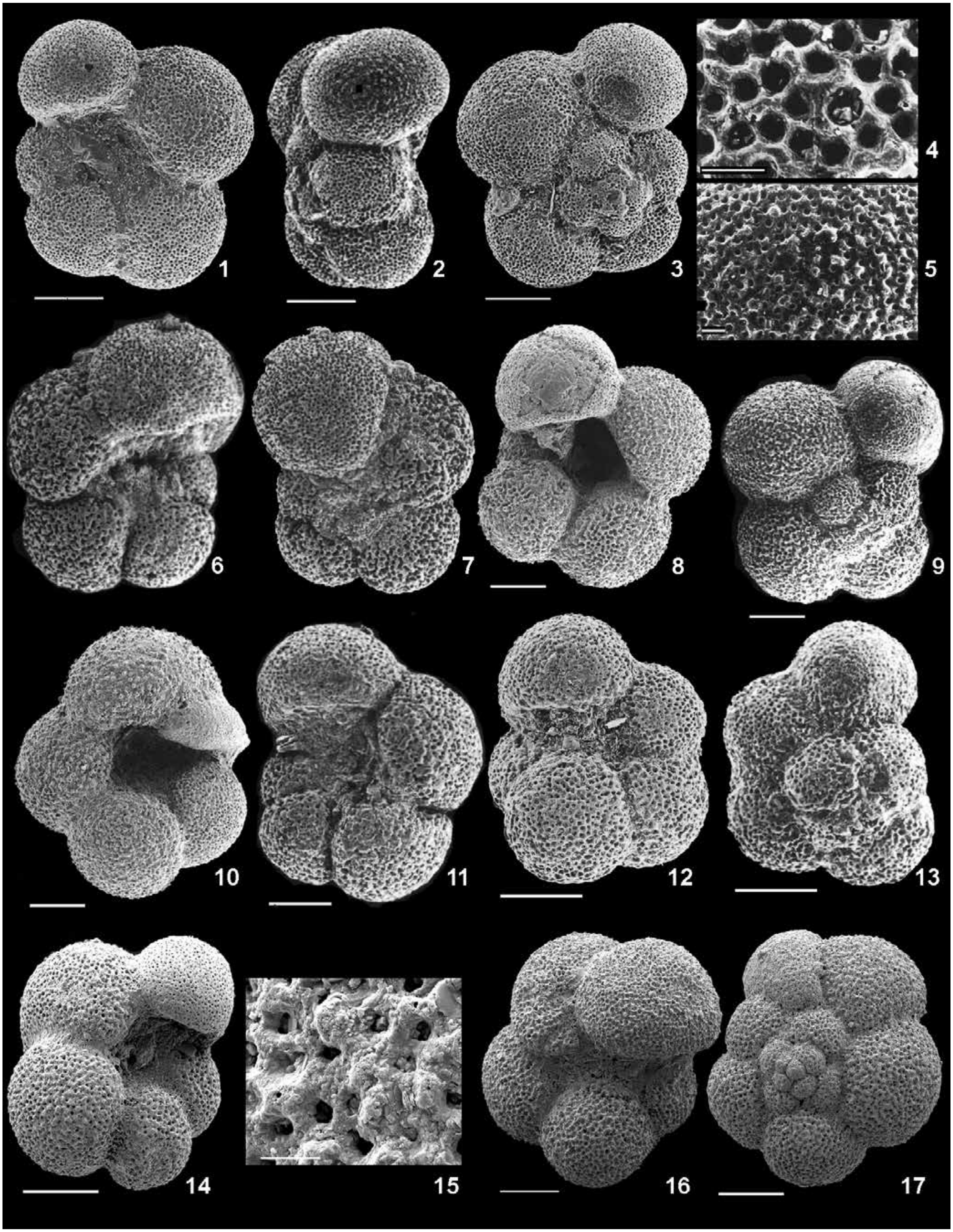


**Plate 6.11** *Globigerinella wagneri* (Rögl, 1994)

arched umbilical to extraumbilical aperture lacking a thick rim and less extreme uncoiling. It differs from 5 chambered species of *Ciperoella*, especially *C. fariasi*, by the lower spire and the wall texture, which is characterized by spine collars coalescing to form ridges and the lower spire.

DISCUSSION.— This species is here placed in *Globigerinella* rather than *Globigerina* due to its slight tendency towards planispiral coiling and close link with *Globigerinella megaperta*. It bears an outward similarity to the *Ciperoella ciperoensis* and *C. fariasi* forms, and has been recorded as 'giant *Globigerina ciperoensis* (Ujetz and Wernli, 1994), and thus is somewhat less planispirally coiled than the proposed ancestor *Globigerinella obesa*. This species has thus far not been found outside of the Paratethys region, although it is commonly recognized within it (Rögl, 1994; Cicha and others, 1998; Švábenická and others, 2007). Some specimens of *G. wagneri* may display a sac-like last chamber and/or aberrant chambers. In Austria this species occurs together with *G. megaperta* and other large planktonic species such as *Dentoglobigerina globularis* in a horizon characterized by typically large planktonic foraminiferal specimens that Rögl (1994) proposed can be traced from the Paratethys to the Caribbean. This horizon is interpreted as signaling cold waters and upwelling possibly due to a connection between the Paratethys and the northern seas in the Kiscellian (Baldi, 1984; Rögl, 1994).

PHYLOGENETIC RELATIONSHIPS.— *Globigerinella wagneri* is ancestral to *G. megaperta*. These species represent an early radiation of large, unrolled planispiral morphologies in the genus *Globigerinella* in the lower Oligocene. This branch probably evolved from *G. obesa* in Zone O1 and gave rise to the *siphonifera*-homologue *G. megaperta* in Zone O3.

TYPE LEVEL.— Oligocene (lower Eggerian), of the Austrian Molasse Basin, Puchkirchen Formation from the water drill site Schallerbach 2.

STRATIGRAPHIC RANGE.— This species has been described from the early Oligocene (Cicha and others, 1998) of the Austrian Molasse Basin (Rögl, 1994; Cicha and others, 1998) and spans the interval from Zone O1 to O5 (Rögl, 1994).

GEOGRAPHIC DISTRIBUTION.— This species has been found in Haute Savoie, the Central Paratethys (Rögl, 1994; Ujetz and Wernli, 1994) and in Transylvania (Švábenická and others, 2007; Spezzaferri, personal observation).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype deposited in the collection of the Natural History Museum in Vienna (n. 1994/34).

### Genus *Quiltyella* Coxall and Spezzaferri n. gen.

TYPE SPECIES.— *Clavigerinella nazcaensis* Quilty 1976.

ETYMOLOGY.— This genus is named *Quiltyella* after Patrick Quilty who first described the species *Clavigerinella nazcaensis* from DSDP Sites drilled on the Nazca Plate, southeastern Pacific Ocean.

TYPE LEVEL.— DSDP Hole 320B/2/CC, Zone N2/N3 transition. Oligocene, nannofossil foraminiferal ooze.

DESCRIPTION.

*Type of wall*: Spinose, spines are supported by spine collars which coalesce to form ridges. Pore concentrations ranging from 120-160 pores/50 $\mu m^2$ test surface area and pore diameters range from around 1.2-2 µm.

*Test morphology*: Test trochospiral generally consisting of 3 whorls, it may became slightly planispiral in the last whorl, 5-6 chambers in the last whorl often strongly radially elongated and developing a knob-like distal termination, the size and development of this feature varies significantly among species, sutures straight and depressed to slightly arched on both sides. Aperture at the base of the last chamber interiomarginal but strongly tending to encompass the peripheral margin, a symmetrical arch, sometimes bordered by a distinct rim.

DISTINGUISHING FEATURES.— This genus differs from *Globigerinella* by the presence of markedly elongate and digitate chambers in the final whorl and by the higher pore concentrations ranging from 120-160 pores/50 $\mu m^2$.

DISCUSSION.— The new genus *Quiltyella* Coxall and Spezzaferri has been erected to distinguish globigerinellids with distinctly elongate, sometimes extreme, chambers in the final whorl. Based on their typical wall texture and morphology, the species *Q. nazcaensis* and *Q. clavacella* cannot be attributed to existing digitate genera showing comparable morphologies such as *Clavigerinella, Hastigerina/Hastigerinella* and *Beella*. In particular, *Quiltyella* differs from *Hastigerina/Hastigerinella* by its higher pore concentration wall texture, and no evidence of triradiate spines typical of the latter (e.g., Hemleben and others, 1989). It differs from *Clavigerinella* by having a spinose wall texture with spines supported by spine collars which coalesce to form ridges typical of the *bulloides*-type wall texture (e.g., Hemleben and others, 1989; Hemleben and Olsson, 2006) and not weakly cancellate as in *Clavigerinella* (Coxall and Pearson, 2006). In the genus *Beella* the degree of elongation varies significantly between specimens (Coxall and others, 2007) whereas in adult specimens of *Quiltyella* all chambers of the last whorl are strongly elongated.

PHYLOGENETIC RELATIONSHIPS.— We tentatively propose that the genus evolved from *Globigerinella roeglina* n. sp. in mid-Oligocene Zone O4. However, it is possible that species of *Quiltyella*, like many other clavate/digitate forms discussed here, represent independent derivations from a globigerinellid form close to *G. obesa*.

GEOGRAPHIC DISTRIBUTION.— Highly restricted in some levels from the Paratethys and the Pacific Ocean.

STRATIGRAPHIC RANGE.— The stratigraphic range of *Quiltyella* is uncertain because its occurrence is extremely sporadic. Based on the limited data we suggest it ranges from the lower Oligocene Zone O4 to somewhere in the lower or middle Miocene (Quilty, 1976).

STABLE ISOTOPE PALEOBIOLOGY.— Although no data are available on the species belonging to this genus, Coxall and others (2007) based on isotopic evidence, suggested that digitate morphologies are typical of deep, subthermocline (>150 m) habitat, characterized by lower temperatures, reduced oxygen content, and enrichment of dissolved inorganic carbon.

## ***Quiltyella clavacella* (Rögl, 1969)**

Plate 6.12, Figures 1-17

*Hastigerinella clavacella* Rögl, 1969:95, pl. 9, figs. 1-5 [lower Miocene upper *Globigerinoides trilobus* Zone, Laa and der Thaya, Molasse Basin, Austria].—Rögl, 1985:324, figs. 5.27-5.28 [lower Miocene upper *Globigerinoides trilobus* Zone, Laa and der Thaya, Molasse Basin, Austria].

*Protentella rohiensis* Popescu and Brotea, 1989:258, pl. 1 (partim), figs. 1, 2 (holotype), figs. 4, 5 (paratype) [upper Oligocene *Paragloborotalia opima* Zone, Vima Fm., Transylvanian Basin, Romania].

*Beella clavacella* (Rögl).—Cicha and others, 1998:82, pl. 38, figs. 13-15 [lower Miocene upper *Globigerinoides trilobus* Zone, Laa and der Thaya, Molasse Basin, Austria].

DESCRIPTION.

*Type of wall*: Spinose; spines are supported by spine collars which coalesce to form ridges. Pore concentrations range from around 120 pores/50 $\mu m^2$ test surface area and pore diameters range from around 1.5-2 µm.

*Test morphology*: Test consisting of 3 whorls, initially trochospiral, tending to became irregularly coiled in the last whorl of adult specimens, 5-6 chambers strongly radially elongated, digitate and ending with a spherical termination, final chamber may be smaller than the penultimate, bulla like; sutures straight and depressed in juvenile specimens, not clearly visible in adult specimens; aperture variable in shape and position: at the base of the last chamber interiomarginal, extending around the peripheral margin, or a symmetrical arch, bordered by a distinct rim; in edge view chambers strongly elongated in shape.

*Size*: Diameter of the holotype around 0.7-0.8 mm.

DISTINGUISHING FEATURES.— This species differs from *Quiltyella nazcaensis* by having less elongated, typical club-shaped chambers that gradually develop into an inflated knob-like distal extremity. It is distinguished from *Globigerinella roeglina* and *G. molinae* by the more irregular coiling and low trochospiral form and from *G. navazuelensis* also by the greater degree of chamber elongation.

DISCUSSION.— This species has been described for the Karpatian regional stage of the Paratethys, corresponding to Zone M4. Two of the specimens illustrated by Popescu and Brotea (1989) as *Protentella rohiensis* (holotype nr 105.560, pl. I. figs. 1, 2 and paratype P.105.561, pl. I. figs. 4, 5) are here placed in synonymy with *Q. clavacella* because they show the typical radially elongated and digitate chambers in the last whorl, ending with a spherical termination. Like the globigerinellid digitate forms *Q. clavacella* occurs only sporadically and its range is difficult to determine. Based on the range of *P. rohiensis* in Popescu and Brotea (1989) and the specimens from the Nazca Plate region of the Pacific we extend the range of *Q. clavacella* to Zone O4.

PHYLOGENETIC RELATIONSHIPS.— The phylogenetic relationship is uncertain because of limited stratigraphic information and sporadic occurrences of the morphotypes. *Quiltyella clavacella* may have evolved from *G. roeglina* n. sp. in mid-Oligocene Zone O4 (transitional forms of *G. roeglina/Q. clavacella* are in Plate 6.12, Figs. 10-11). Alternatively, the irregular coiling is suggestive of a connection with *G. navazuelensis*. We suggest *Q. clavacella* gave rise to *Q. nazcaensis* at the Zone O6/O7 boundary.

TYPE LEVEL.— Ziegelei Brandhuber, Laa and der Thaya, Karpatian (lower Miocene, *Globigerinatella insueta/Globigerinoides bisphericus* Zone)

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O4 to the top of the lower Miocene Zone M4 (Rögl, 1969).

GEOGRAPHIC DISTRIBUTION.— This species has been found in the Molasse Basin of the Austrian Paratethys and in the east Pacific Ocean (DSDP Hole 320B).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— The holotype is deposited in the collection of the Institute of Paleontology of the University of Vienna (No. 3997/D734).

### *Quiltyella nazcaensis* (Quilty, 1976)

Plate 6.13, Figures 1-18

*Clavigerinella nazcaensis* Quilty, 1976:650, pl.18, figs.1-12 [Oligocene Zone N2-N3 transition, DSDP Hole 320B, Nazca Plate, southeastern Pacific Ocean].

*Hastigerinoides* (?) sp. Jenkins and Orr, 1972:1106, pl. 37, fig. 7 [lower Oligocene *Chiloguembelina cubensis* Zone, Nazca Plate, southeastern Pacific Ocean].

DESCRIPTION.

*Type of wall*: Normal perforate, spinose, *bulloides*-type wall structure. Pore concentrations average 160 pores/50 μm$^2$ test surface area and pore diameters average 1.5-2 μm.

*Test morphology*: Test composed of 3 whorls, initially trochospiral, globigeriniform planispiral in the last whorl, 5-6 chambers are delicate, tube-like and strongly radially elongated and sharply developing a knob-like distal extremity, sutures straight and depressed in juvenile specimens, none clearly visible in adult specimens; aperture at the base of the last chamber interiomarginal but strongly tending to encompass the peripheral margin, a symmetrical arch, bordered by a distinct rim; in edge view chambers strongly elongated in shape.

*Size*: Estimated maximum diameter of holotype 0.9 mm. Longest individual broken chamber 0.5 mm.

DISTINGUISHING FEATURES.— *Quiltyella nazcaensis* is characterized by strongly elongated

Plate 6.12 *Quiltyella clavacella* (Rögl, 1969)

**1-3** (holotype, Institute of Paleontology of the University of Vienna, 3997/D734), *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Laa and der Thaya, Austrian Molasse Basin, reproduced from Rögl (1969); **4**, **5** *Protentella rohiensis* Popescu and Brotea (holotype reproduced from Popescu and Brotea, 1989, pl. 1, figs. 1, 2, Institut de Geologie si Geofizica, Bucharest, 105.560), mid-Oligocene, *Paragloborotalia opima* Zone, Vima Formation, Sample not specified, Transylvanian Basin, Romania: **6**, *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Sample Waschberg Unit 49.7-49.8 m, Otthenthal, Austria; **7**, **8**, *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Sample Waschberg Unit 49.7-49.8 m, Otthenthal, Austria; **9**, **12**, **13**, Zone M1, DSDP Hole 320B/1/6, 147-149 cm, Nazca Plate, southeastern Pacific Ocean; **10**, *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Sample Waschberg Unit 49.7-49.8 m, Otthenthal, Austria, *G. roeglina/Q. clavacella* transition; **11**, *Globigerinatella insueta/Globigerinoides bisphericus* Zone, Sample Waschberg Unit 49.7-49.8 m, Otthenthal, Austria, *G. roeglina/Q. clavacella* transition. **14-17**, Zone M1, DSDP Hole 320B/1/6, 147-149 cm, Nazca Plate, southeastern Pacific Ocean. Scale bar: **1-7**, **9-16** = 100 μm; **17** = 20 μm; **8** = 10 μm.

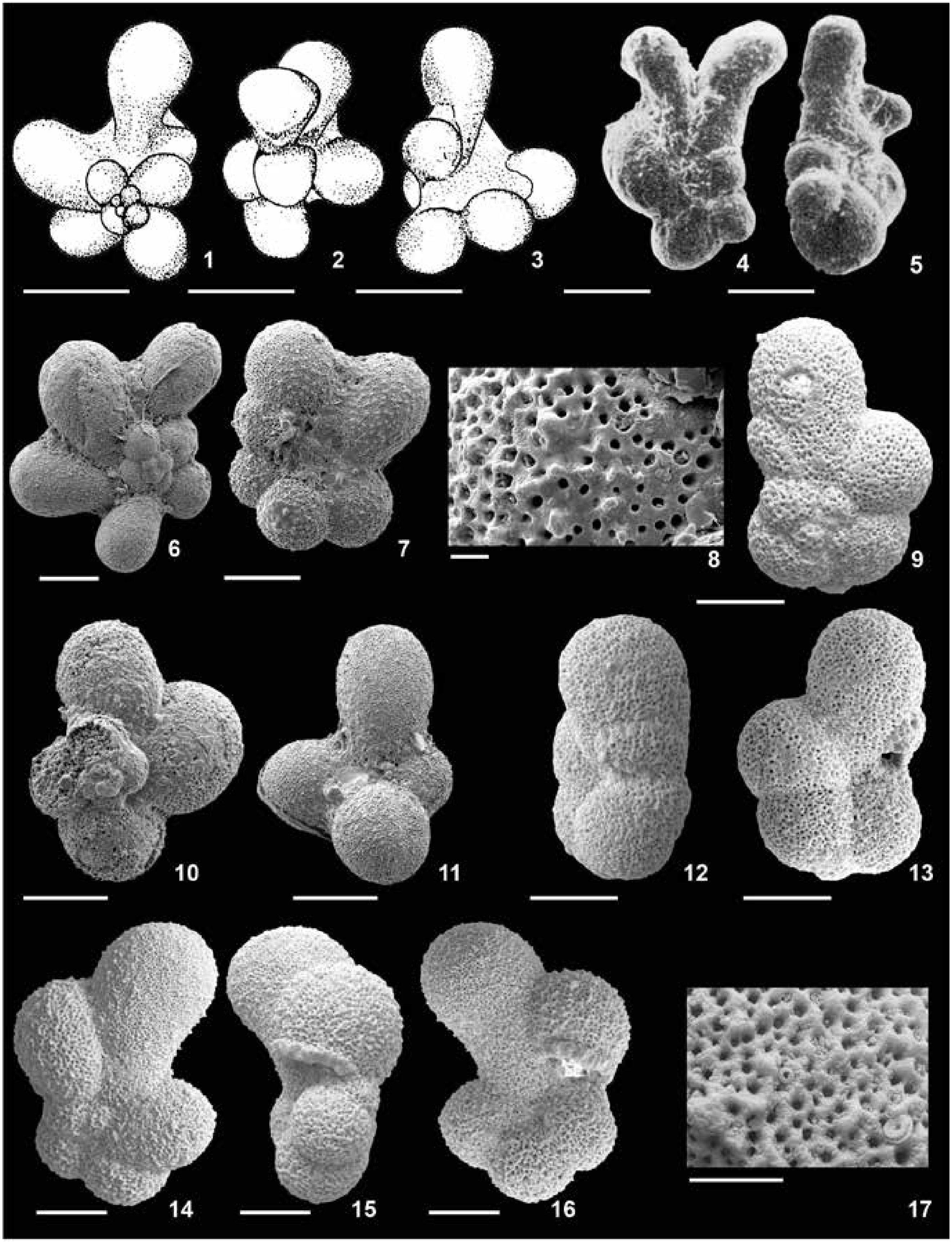


**Plate 6.12** *Quiltyella clavacella* (Rögl, 1969)

chambers, sharply ending with spherical knob-like termination. It is very fragile and easily broken, discrete digitate chambers are often the only part preserved of the entire specimens.

DISCUSSION.— The type material from DSDP Site 320 is somewhat recrystallized, however areas of wall texture are exposed that indicate the presence of a *bulloides*-type wall and thus support an affiliation with *Globigerinella*. Quilty (1976) identified *Clavigerinella akersi* from the Eocene as the possible ancestor of *Globigerinella nazcaensis*. However, *Clavigerinella* has a weakly developed cancellate wall texture (Coxall and Pearson, 2006). Derivation of *Clavatorella bermudezi* from *Q. nazcaensis*, as suggested by Quilty (1976) is also unlikely on the grounds of wall texture differences. *Clavatorella bermudezi* possess a strongly cancellate, nonspinose wall texture whereas *Q. nazcaensis* appears to be related to *Globigerinella*. Although Quilty (1976) described the aperture of this species as lacking any rim or lip, reinvestigations of samples from Site 320 provided well-preserved specimens clearly showing a thick rim bordering the aperture.

Popescu and Brotea (1989) also recognized similarities between *P. rohiensis* and *Q. nazcaensis*, and identified potential differences only in the less incised sutures in the young stage, and relatively shorter radially elongated chambers. However, they included in the species *Protentella rohiensis* a large variability of morphologies, including specimens with radially elongated chambers, very similar to *Quiltyella clavacella* (see Popescu and Brotea, 1989, pl. I, figs. 4, 5), and specimens with only one or two radially elongated chamber more resembling *G. clavaticamerata* or *G. molinae* (see Popescu and Brotea, 1989, pl. I, figs. 11, 12 and 9, 10, respectively). While there may be a case to place at least some of Popescu and Brotea's examples of *P. rohiensis* in *Q. nazcaensis*, we suggest this as an unnecessary complication, and currently untestable due to the lack of material. We thus regard all of the extreme elongated forms of *P. rohiensis* (Popescu and Brotea, 1989, pl. I, figs. 1, 2 and 4, 5) as *Q. clavacella*, while other less clavate forms (Popescu and Brotea, 1989, pl. I, figs. 7, 8 and 11, 12) are referred to *G. clavaticamerata*.

PHYLOGENETIC RELATIONSHIPS.— We suggest this species evolved from *Q. clavacella* at the Zone O6/O7 transition in the upper Oligocene.

TYPE LEVEL.— DSDP Hole 320B/2/CC, Zone N2/N3 transition in the upper Oligocene, nannofossils foraminiferal ooze.

STRATIGRAPHIC RANGE.— Upper Oligocene Zone O6-O7 to Zone M1 in the lower Miocene.

GEOGRAPHIC DISTRIBUTION.— Described from the southeastern Pacific Ocean. Inclusion of *rohiensis* as a junior synonym of *Q. nazcaensis* would extend the spatial range to the Paratethys region.

STABLE ISOTOPE PALEOBIOLOGY.— No data available. The occurrence of *Q. nazcaensis* close to the eastern equatorial upwelling belt is consistent with observations on other Cenozoic digitate species, which show links with upwelling conditions (Coxall and others, 2007).

REPOSITORY.— Holotype deposited in the collection of the Geology Department, University of Western Australia, Nedlands (no. 74429), paratypes (74422-74426, 74428 and 74430-74433).

Plate 6.13 *Quiltyella nazcaensis* (Quilty, 1976)

**1** (holotype, reproduced from Quilty, 1976, pl. 18, fig. 8), Zone N2, DSDP 320B/2/CC, southeastern Pacific Ocean; **2-4**, (paratypes, reproduced from Quilty, 1976, pl. 18, figs. 11, 5 and 3), 2, Zone N2/N3, DSDP Hole 320B/2/2, 137-139 cm, Nazca Plate, southeastern Pacific Ocean, 3, 4, Zone N2, DSDP Hole 320B/2/CC, Nazca Plate, southeastern Pacific Ocean, **5-8**, Zone N2/N3, DSDP Hole 320B/2/2, 137-139 cm, Nazca Plate, southeastern Pacific Ocean; **9**, **10**, Zone N4, DSDP Hole 320B/1/5, 8-10 cm, Nazca Plate, southeastern Pacific Ocean; **11**, Zone N2/N3, DSDP Hole 320B/2/2, 137-139 cm, Nazca Plate, southeastern Pacific Ocean; **12**, 'reworked' *Hastigerinoides* (?) sp., (reproduced from Jenkins and Orr, 1972, pl. 37, fig. 7) *C. cubensis* Zone, DSDP Hole 77B/42/CC, east equatorial Pacific Ocean; **13**, Zone N2/N3 DSDP Hole 320B/2/3, 50-52 cm, Nazca Plate, southeastern Pacific Ocean; **14**, Zone N2/N3 DSDP Hole 320B/2/3, 50-52 cm, Nazca Plate, Pacific Ocean; **15**, Zone N2/N3 DSDP Hole 320B/2/3, 50-52 cm, Nazca Plate, Pacific Ocean; **16**, **17**, (detached chambers) Zone N2/N3 Zone, DSDP Hole 320B/2/3, 50-52 cm, Nazca Plate, southeastern Pacific Ocean; **18**, (detached chamber) Zone N2/N3, DSDP Hole 320B/2/2, 137-139 cm, Pacific Ocean. Scale bar: **1-7**, **9**, **11**, **16-18** = 100 µm, **12-15** = 50 µm, **8**, **10** = 20 µm.

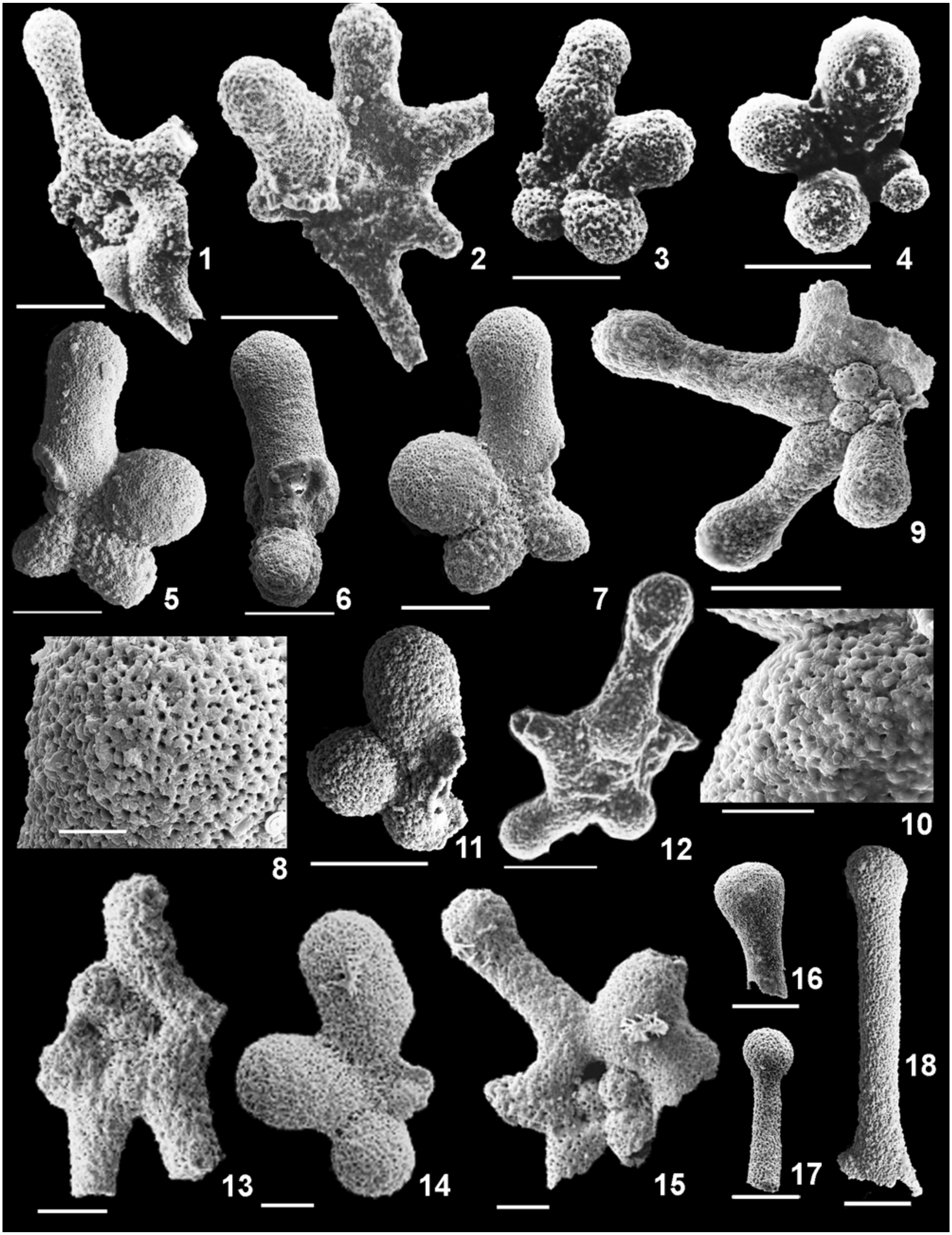


**Plate 6.13** *Quiltyella nazcaensis* (Quilty, 1976)

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