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Chapter 8

TAXONOMY, BIOSTRATIGRAPHY, AND PHYLOGENY OF OLIGOCENE AND LOWER MIOCENE *GLOBOTURBOROTALITA*

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ABSTRACT

The taxonomy, phylogeny and biostratigraphy of Oligocene and lower Miocene *Globoturborotalita* is reviewed. *Globoturborotalita* is a long-ranging genus appearing in the basal Eocene and still present in modern oceans with one living representative *G. rubescens*. Species attributed to this genus are generally common and cosmopolitan. The following species are recognized as valid: *Globoturborotalita barbula* Pearson and Wade, *Globoturborotalita bassriverensis* Olsson and Hemleben, *Globoturborotalita brazieri* (Jenkins), *Globoturborotalita cancellata* (Pessagno), *Globoturborotalita connecta* (Jenkins), *Globoturborotalita eolabiacrassata* Spezzaferri and Coxall n. sp., *Globoturborotalita euapertura* (Jenkins), *Globoturborotalita gnaucki* (Blow and Banner), *Globoturborotalita labiacrassata* (Jenkins), *Globoturborotalita martini* (Blow and Banner), *Globoturborotalita occlusa* (Blow and Banner), *Globoturborotalita ouachitaensis* (Howe and Wallace), *Globoturborotalita paracancellata* Olsson and Hemleben n. sp., *Globoturborotalita pseudopraebulloides* Olsson and Hemleben n. sp., and *Globoturborotalita woodi* (Jenkins).

INTRODUCTION

The genus *Globoturborotalita* was established by Hofker (1976) to include globular forms, with a coarse macroperforate and honeycomb wall texture. He included in the genus trochospiral forms composed of three whorls, with a lobulate periphery, four chambers in the last whorl, sutures depressed on both sides and an umbilical and arched aperture. Oligocene species of *Globoturborotalita* are typically small (<250 μm) and their reporting and identification in the literature has been inconsistent, with morphotypes being variably assigned to *Globigerina*, *Catapsydrax,* and *Globigerinita* as well as *Globoturborotalita*. The genus has been recently amended by Spezzaferri and others (2015) to include 3-3½ chambered species such as *Globoturborotalita connecta*. The genus appears at the base of the Eocene Zone E1-E2 with the species *G. bassriverensis* (Olsson and others, 2006). It ranges into the Oligocene and persists as an important element of Neogene as-

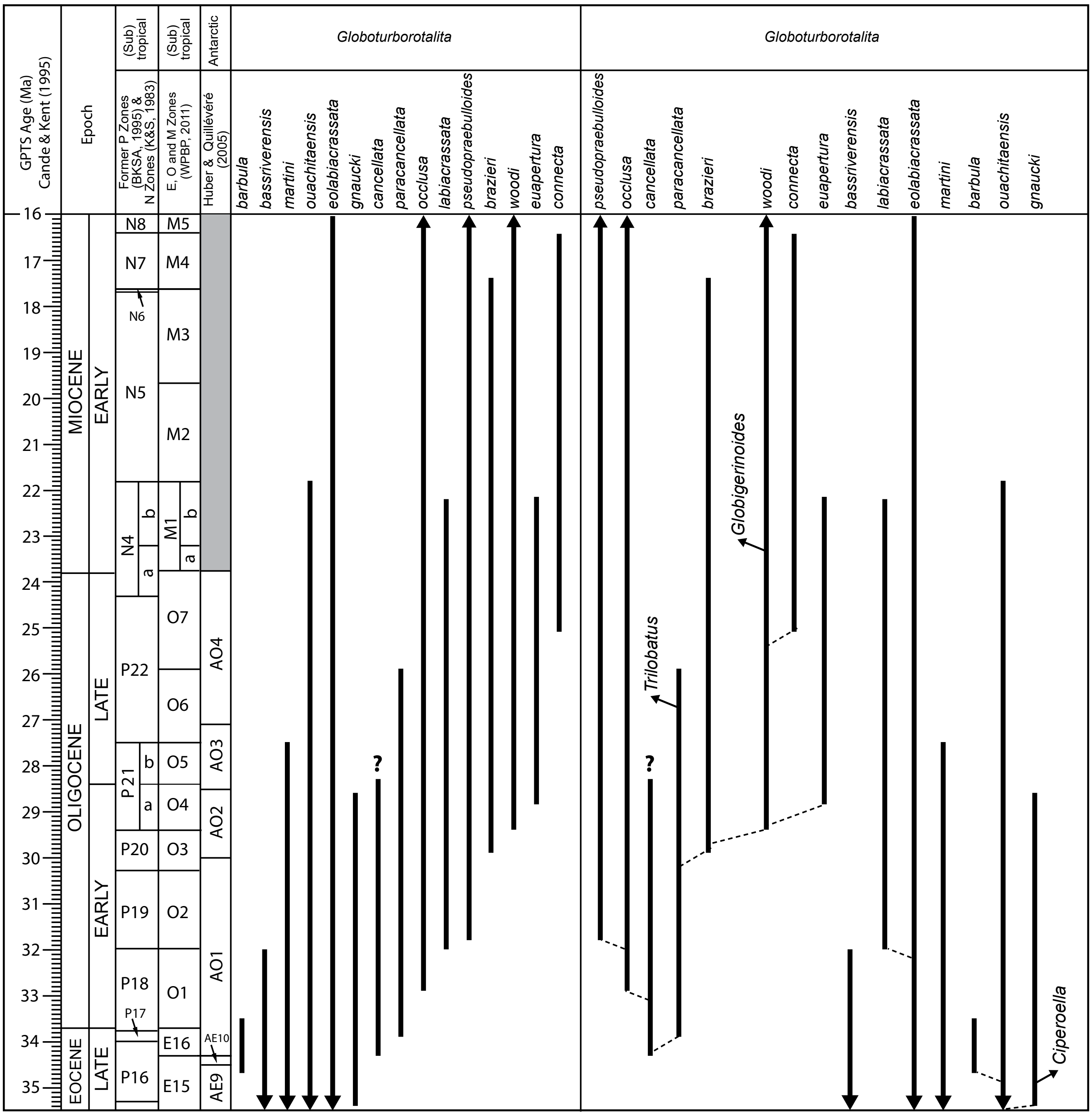

FIGURE 8.1. Stratigraphic ranges and inferred phylogenetic relationships of Oligocene and lower Miocene *Globoturborotalita*. BKSA, 1995 = Berggren and others, 1995; K&S, 1983 = Kennett and Srinivasan, 1983; WPBP, 2011 = Wade and others, 2011.

semblages. The lineage survived to the Recent as one, possibly two species, the best known being *Globoturborotalita rubescens,* which is a small and sometimes common warm water species (Bé, 1977; Hemleben and others, 1989). Hemleben and others (1989) include *Globoturborotalita tenella* (Parker) as a second living representative of the genus. This species has a supplementary aperture and was originally described as *Globigerinoides*, although the wall texture (Chapter 3, this volume) resembles *G. rubescens*. We are reluctant to assign *tenella* to *Globoturborotalita* because it would be the only species consistently having supplementary apertures in the genus. A final generic assignment requires revision of modern material that is outside the scope of this study. *Globoturborotalita* gave rise to the genus *Trilobatus* Spezzaferri and others (2015) in the upper Oligocene and to *Globigerinoides* in the basal Miocene (Spezzaferri and others, 2015).

Here we present a refined morphological framework to aid the diagnosis of Oligocene and lower Miocene *Globoturborotalita*. Under our classification we place in *Globoturborotalita* species with a spinose *ruber/sacculifer*-type or *sacculifer*-type wall texture; low to relatively high trochospiral coiling; globular tests, an umbilical primary aperture bordered by a distinct lip, and 3 or more chambers in the final whorl. As discussed in Chapter 3, this volume, the cancellate *ruber/sacculifer*-type wall texture of *Globoturborotalita* may be symmetrical on some parts of the test wall and somewhat asymmetrical on other parts producing changes in the symmetry of pore pits in the phylogeny of this group. For this reason the wall texture may vary from *ruber/sacculifer*- to *sacculifer*-type within the same specimen and the same species but also from species to species within the same lineage. For example, *G. cancellata* with a *sacculifer*-type wall texture is a stem species which gives rise to two species with a *sacculifer*-type wall texture (*G. euapertura* and *G. connecta*) and five species with a *ruber/sacculifer*-type wall texture (*G. brazieri, G. occlusa, G. paracancellata, G. pseudopraebulloides* and *G. woodi*).

A significant aspect of our taxonomy is the distinction but close phylogenetic relationship of *Globoturborotalita* to the genus *Ciperoella* Olsson and Hemleben n. gen. (Chapter 7, this volume). Typified by *C. ciperoensis* (Bolli), *Ciperoella* contains morphotypes with a wall texture similar to the *Globoturborotalita* wall, but with some slight modifications and a more evolute coiling than the globoturborotaliid ancestors. Blow's (1969) species '*anguliofficinalis'* was previously assigned to *Globoturborotalita* (e.g., Olsson and others, 2006) but is here considered to belong to *Ciperoella* (Chapter 7, this volume).

Olsson and others (2006) presented a detailed discussion of the origin of *Globoturborotalita* and linked its first occurrence to the Paleocene-Eocene Thermal Maximum and the carbon isotope excursion that signals major disruption to ocean carbon cycling at the time. In our new treatment of *Globoturborotalita* we include some overlooked species such as *G. cancellata* (Pessagno) and describe three new species: *G. paracancellata, G. pseudopraebulloides* and *G. eolabiacrassata. Globoturborotalita pseudopraebulloides* n. sp. includes Oligocene forms previously identified by many workers as *Globigerina praebulloides.* Importantly, we demonstrate that this taxon has the *ruber/sacculifer*-type wall of *Globoturborotalita,* not a *bulloides*-type wall as the name suggests (see discussion below). The new species *Globoturborotalita eolabiacrassata,* which is characterized by a thickened apertural rim, evolved in the middle Eocene. It provides a link to the later heavily-rimmed *G. labiacrassata* beginning in the Oligocene.

A growing body of stable isotopic evidence indicates that at least some Oligocene members of *Globoturborotalita* had an asymbiotic mixed-layer habitat (Sexton and others, 2006; Wade and Pearson, 2008; Pearson and Wade, 2009), which is consistent with the preferred depth habitat of extant species *G. rubescens* as determined from plankton tows, sediment traps and stable isotopes (Bé, 1977; Storz and others, 2009; Birch and others, 2013). Previous authors have attributed fossil globoturborotalitids to deeper levels in the water column (Keller, 1985). The species-level range chart and phylogeny are presented in Figure 8.1.

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

Genus *Globoturborotalita* Hofker, 1976, emended by Spezzaferri and others (2015)

Zeaglobigerina Kennett and Srinivasan, 1983:42.

TYPE SPECIES.— *Globigerina rubescens* Hofker, 1956.

DESCRIPTION.

Type of wall: Cancellate, normal perforate, spinose, *ruber/sacculifer*-type and *sacculifer*-type wall texture.

Test morphology: Test moderately low to medium trochospiral, globular, lobulate in outline, chambers globular; in spiral view 3-5 slightly embracing globular chambers increasing moderately in size in the last whorl, in umbilical view 3-5 globular, slightly embracing chambers, increasing moderately in size, sutures depressed and straight on both sides, the umbilicus is generally small, open, enclosed by surrounding chambers, in some species it can be larger, the aperture is umbilical, low to a very high rounded arch, bordered by a thin lip, rarely by a thickened rim; in edge view chambers are globular in shape, slightly embracing, and the umbilical aperture may be partly visible.

DISTINGUISHING FEATURES.— A globular test, slightly embracing chambers, umbilical aperture, and coarse cancellate wall texture characterize the genus. See Olsson and others (2006) for discussion of Eocene species of *Globoturborotalita*. See Spezzaferri and others (2015) for discussion and emendation of the genus. *Globoturborotalita* is distinguished from *Ciperoella* because the latter has a spinose *Neogloboquadrina*-type wall (Chapters 3 and 7, this volume) in contrast to the *ruber/sacculifer*- and *sacculifer*-type wall in *Globoturborotalita*. *Globoturborotalita* is distinguished from *Subbotina* first by the wall texture, which is described as cancellate with both symmetrical and slightly asymmetrical patterning of pores and interpore ridges, compared to the more strongly cancellate and symmetrically oriented (honeycomb structure) of *Subbotina.* Species of *Globoturborotalita* are also generally smaller, have fewer less embracing chambers and a more symmetrical aperture than subbotinids (Olsson and others, 2006; Chapter 10, this volume). The only exception is *G. connecta*, which displays compact coiling and a slightly asymmetrical, umbilical-extraumbilical aperture. *Globigerina* differs from *Globoturborotalita* by the wall texture, which in *Globigerina* is characterized by spines supported by distinctive spine collars coalescing to form ridges (Olsson and others, 2006; Chapters 3 and 6, this volume).

DISCUSSION.— In the description of this genus, Hofker (1976) and Olsson and others (2006) included only forms with 4-5 chambers in the last whorl. Spezzaferri and others (2015) amended the genus to include also 3-3½ chambered forms such as *G. connecta*. Olsson and others (2006) discussed the taxonomic connection and synonymy between Kennett and Srinivasan's (1983) genus *Zeaglobigerina* and *Globoturborotalita*. Olsson and others (2006) also included in the genus *Globoturborotalita anguliofficinalis,* which is now placed in the new genus *Ciperoella* based on the wall texture and possession of 4½-5 chambers in the final whorl (Chapter 7, this volume).

PHYLOGENETIC RELATIONSHIPS.— The genus evolved in Zone E1 from *Subbotina hornibrooki* (Olsson and others, 2006) and gave rise to the genera *Trilobatus* in upper Oligocene Zone O7 and to *Globigerinoides* in basal Miocene Zone M1 (Spezzaferri and others, 2015).

STRATIGRAPHIC RANGE.— It ranges from Zone E1 (Olsson and others, 2006) to the Recent (e.g., Kennett and Srinivasan, 1983).

GEOGRAPHIC DISTRIBUTION.— Species of *Globoturborotalita* are cosmopolitan in the Oligocene including at both high southern (Southern Ocean/New Zealand) and high northern (Labrador Sea, and the North Sea region) latitudes. They can be common especially in the <250 μm fraction. Some species appear to be more abundant at high southern latitudes and the Austral realm.

Globoturborotalita barbula Pearson and Wade, 2015

Plate 8.1, Figures 1-7

Globoturborotalita barbula Pearson and Wade 2015:10-11, figs. 6, 1a-5b; 7,1a-5; 8, 1a-8 [upper Eocene Zone E15/E16, TDP Site 17, Tanzania].

DESCRIPTION.

Type of wall: Normal perforate, cancellate, spinose, *ruber/sacculifer*-type wall texture with an average of 18 pores/50 μm^2 test surface area. Minute spikes "barbules" concentrated in sutural areas.

Test morphology: Test moderately to very high trochospiral, petaloid in outline, chambers globular and inflated; in spiral view usually 3½ (occasionally 4), slightly embracing in the final whorl, increasing moderately in size; in umbilical view 3½ (occasionally 4) globular, slightly embracing chambers, increasing moderately in size, the last chamber is usually kummerform, sutures depressed, straight or slightly arched on both sides, umbilicus large and open, aperture umbilical, a rounded arch, bordered by an imperforate, thickened rim; in edge view chambers globular in shape, slightly embracing. A detailed description is given in Pearson and Wade (2015).

Size: Maximum diameter of holotype 0.23 mm.

DISTINGUISHING FEATURES.— The peculiar distinguishing feature of this species is the high density of minute, highly conical, spikes that are concentrated in the sutural regions of the test on both the umbilical and spiral sides (Pl. 8.1, Figs. 4 and 7).

DISCUSSION.— This species is a common component in assemblages at the Eocene/Oligocene transition in Tanzania and Java (Pearson and Wade, 2015). Due to its small size it has probably been overlooked in previous studies. Some specimens illustrated in Olsson and others (2006, pl. 6.10, figs. 13, 15) as *Subbotina gortanii* are very similar in morphology to *G. barbula,* but the presence of barbules is not proven. Wade and Pearson (2008) assigned these specimens to *G. ouachitaensis*. However, comparison with the holotype of *G. ouachitaensis* illustrated in Pl. 8.11, Figs. 1-3, disproves this hypothesis. We retain here *G. ouachitaensis* as the most probable ancestor of *G. barbula.*

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita barbula* probably evolved from *G. ouachitaensis*.

STRATIGRAPHIC RANGE.— This species has a short stratigraphic range from the uppermost Eocene (Zone E15/E16) to the lowermost Oligocene (Zone O1).

TYPE LEVEL.— Eocene-Oligocene transition from Tanzania Drilling Project Site 17.

GEOGRAPHIC DISTRIBUTION.— Very common in Tanzania, its presence has been documented also in Java.

STABLE ISOTOPE PALEOBIOLOGY.— The data from Pearson and Wade (2015) indicate that this species calcified in warm surface water habitat.

REPOSITORY.— Holotype (NHMUK PM PF 71143) and paratypes (NHMUK PM PF 71144 – 71157) deposited at the Natural History Museum, London.

Globoturborotalita bassriverensis Olsson and Hemleben, 2006

Plate 8.1, Figures 8-14

Globoturborotalita bassriverensis Olsson and Hemleben, 2006:117, pl. 6.3, figs. 1-14 [lower Eocene Zone E1, ODP 174AX, 1150.0-1169.2 feet, Bass River, New Jersey].—Pearson and Wade, 2015, fig. 9.6a-b [upper Eocene Zone E15/16, Sample TDP12/40/3, 88-96 cm, Tanzania].

DISCUSSION.— This species was described from lower Eocene Zone E1 and is more typical of the Eocene than the Oligocene (see Olsson and others, 2006 for the complete description, synonymy and discussion). Initially reported as ranging to Zone E10 (Olsson and others, 2006), it is here included for completeness because new observations have extended its range to the lower Oligocene Zone AO1 (Pl. 8.1, Figs. 11-14). Four specimens that were originally figured as *G. bassriverensis* by Olsson and others (2006) in plate 6.3, figs. 16-19, are here assigned to *Globoturborotalita eolabiacrassata* Spezzaferri and Coxall n. sp. (Pl. 8.5) based on their more compact profile and possession of a thickened rim bordering the aperture. The *Globoturborotalita bassriverensis* diagnosis, therefore, is restricted to forms with a more enclosing globular final chamber and a thin apertural lip.

Globoturborotalita brazieri (Jenkins, 1965)

Plate 8.2, Figures 1-19
(Pl. 8.2, Figs. 1-3: new SEMs of holotype of *Globigerina brazieri* Jenkins)

Globigerina brazieri Jenkins, 1965:1098, figs. 6, 43-51 [lower Miocene, Blue Cliffs Section, New Zealand].—Jenkins, 1971:140, pl. 15, figs. 433-441 [lower Miocene, Blue Cliffs Section, New Zealand].

Globigerina (*Zeaglobigerina*) *brazieri* Jenkins.—Kennett and Srinivasan, 1983:43, pl. 7, figs. 7, 8 [lower Miocene

Globoquadrina dehiscens Zone, DSDP Site 208, Lord Howe Rise, southwestern Pacific Ocean].

Globigerina (*Globoturborotalita*) *woodi brazieri* Jenkins.—Chaproniere, 1988:128, pl. 1, figs. 17-19 [lower Miocene, Lakes Entrance Oil Shaft, Gippsland, Victoria, southeastern Australia], pl. 2, figs. 1-4, 10 [lower Miocene, Fishing Point Marl, Castle Cove, southeastern Australia].

Subbotina brazieri (Jenkins).—Premoli Silva and Spezzaferri, 1990:296, pl. 3, figs. 6a-c [lower Oligocene Subzone P21a, ODP Hole 709B, Indian Ocean].

Zeaglobigerina brazieri (Jenkins).—Spezzaferri, 1994:32, pl. 6, figs. 3a-c [upper Oligocene Zone P22, ODP Hole 709B, Indian Ocean], figs. 4a-c [lower Miocene Zone Subzone N4b, DSDP Site 94, Gulf of Mexico].

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber/sacculifer*-type wall texture with an average of 18 pores/50 µm^2 test surface area.

Test morphology: Low trochospiral, consisting of 3 whorls, subquadrate and poorly to moderately lobulate in profile, chambers subglobular; in spiral view 3½-4 subglobular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, the last chamber may vary from slightly to strongly subquadrate, sutures depressed, straight to slightly curved; in umbilical view 3-3½ subglobular, slightly embracing chambers, increasing rapidly in size, sutures depressed, straight to slightly curved, umbilicus relatively wide, deep and open, enclosed by surrounding chambers, aperture umbilical, a symmetrical, rounded high arch, reverse drop-like with lower terminations joining at their base, it may be bordered by a thick rim.

Size: Maximum diameter of holotype 0.45 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita brazieri* is distinguished from all 4 chambered *Globoturborotalita,* including *G. woodi,* by its high, symmetrical umbilical aperture, often circular or higher than wide, tending towards a reverse droplet shape. It differs from *G. woodi* also by its less lobulate and more compact subquadrate profile, but, as pointed out by Jenkins (1971), with a more rapid rate of chamber size increase in the final whorl. It also differs from *G. cancellata* by its less lobulate profile and the *ruber/sacculifer*-type wall texture instead of *sacculifer*-type, and from *G. paracancellata* n. sp. and *G. occlusa* by its subquadrate profile and the higher arched aperture.

DISCUSSION.— Jenkins (1965) and Chaproniere (1988) distinguished *G. brazieri* from *G. woodi* on the basis of the aperture, which in *G. brazieri* is higher arched, more rounded and resembles a reverse droplet, commonly higher than it is wide, and on the chambers in the last whorl that increase more rapidly in size in *G. brazieri*. Kennett and Srinivasan (1983) describe the aperture of *G. brazieri* as symmetrically placed over the sutures of the penultimate and antepenultimate chambers. Retained here in the species *G. brazieri* are specimens possessing an aperture tending towards a reverse droplet shape together, as documented in the paratypes of Jenkins (1965), with those with a more rounded aperture typical of the holotype. Although paratype 5 of Jenkins (1965) shows a bulla covering the aperture, this structure has not been observed in our material.

Jenkins (1965) suggested that *G. brazieri* evolved from *G. woodi* in the lower Miocene and identified the range of *G. brazieri* as restricted to the lower Miocene (from the *Globoquadrina dehiscens* Zone to the lower part of the *Globigerina woodi connecta* Zone = interval spanning Zones O7 to M1). However, Premoli Silva and Spezzaferri (1990) found this species occurring in Zone P20 in the Indian Ocean, and Spezzaferri (1994) recorded it in Subzone P21a in DSDP Holes 354 and 667A (equatorial Atlantic Ocean), 526A, 363 360, 516F (South Atlantic Ocean) and ODP Hole 709C (Indian Ocean). Thus, within our taxonomic and stratigraphic framework we suggest that *G. brazieri* was the ancestor of *G. woodi* and that *G. brazieri* evolved from *G. paracancellata* n. sp.

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita brazieri* probably evolved from *G. paracancellata* by developing a more subquadrate profile and a higher but less wide, arched, and typically inverse drop-like, umbilical aperture.

Plate 8.1, 1-7 *Globoturborotalita barbula* Pearson and Wade, 2015; 8-14 *Globoturborotalita bassriverensis* Olsson and Hemleben, 2006.

1-4, *Globoturborotalita barbula* (holotype NHMUK PM PF 71143), Zone E15/16, Sample TDP 17/40/2, 0–12 cm, Tanzania; **5-7**, paratype (Pearson and Wade, fig. 8.4) upper Eocene Zone E15/16, Sample TDP17/40/2, 0–12 cm, Tanzania.
8-10*, Globoturborotalita bassriverensis* (holotype USNM 521867); **11**, **12-14** (same specimen) Zone AO1, ODP Hole 647A/30R/3, 67-69 cm, Southern Labrador Sea. Scale bar: **1-3**, **5, 6**, **8-13** = 100 µm; **4**, **14** = 20 µm; **7** = 5 µm.

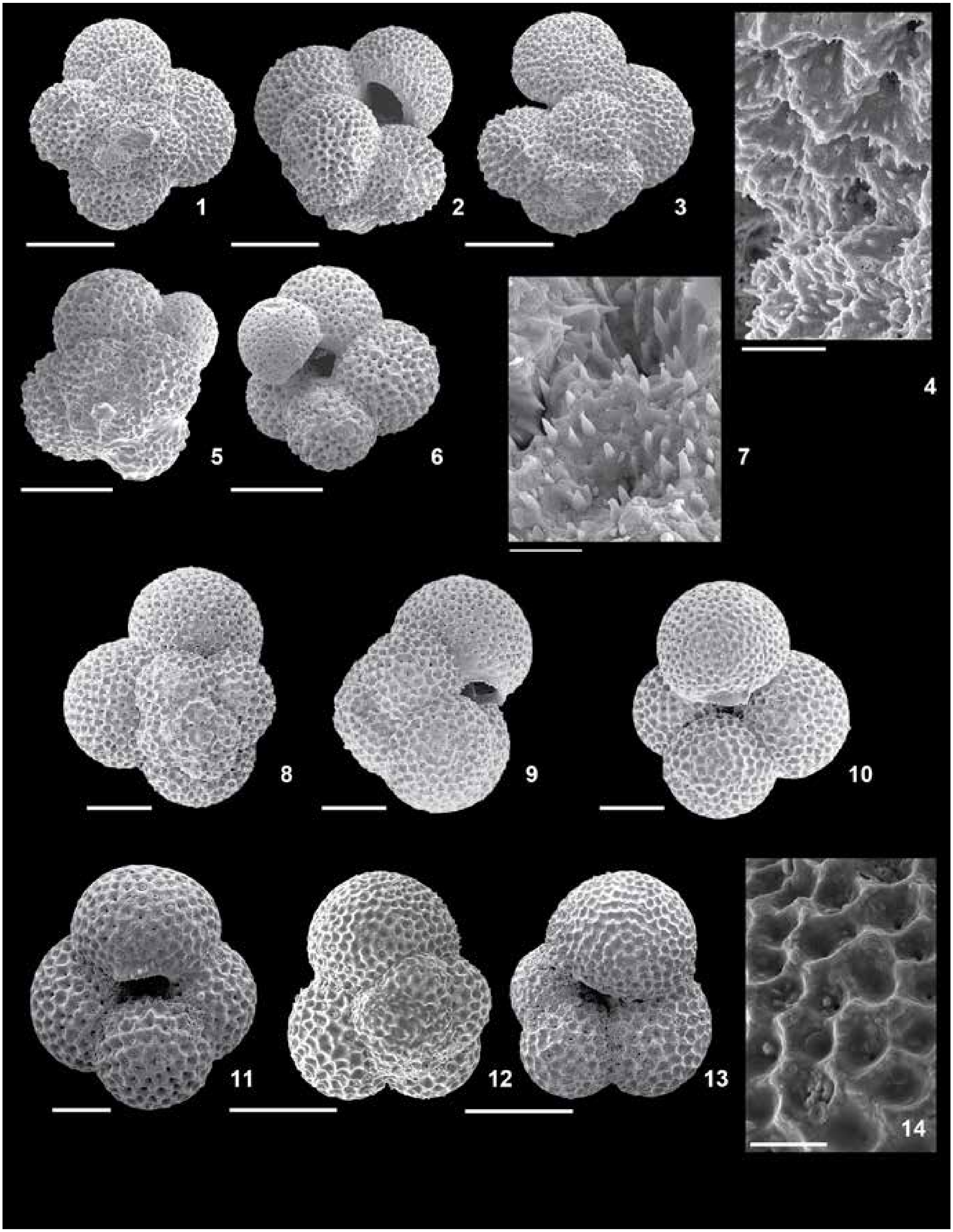

Plate 8.1 *Globoturborotalita barbula* Pearson and Wade, 2015; *Globoturborotalita bassriverensis* Olsson and Hemleben, 2006

STRATIGRAPHIC RANGE.— This species has been observed from Zone O3 (Subzone P21a of Premoli Silva and Spezzaferri, 1990) in the Indian Ocean ODP Hole 709B to Zone M4? (Kennett and Srinivasan, 1983). According to Huber (1991) it disappears within Chron C6N at the Kerguelen Plateau.

TYPE LEVEL.— Lower Miocene from the Blue Cliffs section, Landon Series, Waitakian Stage, New Zealand.

GEOGRAPHIC DISTRIBUTION.— Very common in Australia, New Zealand and Tasman Sea, it is also present and sometimes very abundant in the Gulf of Mexico, South Atlantic, Pacific and Indian Oceans.

STABLE ISOTOPE PALEOBIOLOGY.— Recent isotope data (Spezzaferri, unpublished) suggest a mixed-layer and shallow-water habitat for this species.

REPOSITORY.— Holotype (TF 1497) deposited at the Geological and Nuclear Research Institute, Lower Hutt, New Zealand.

Globoturborotalita cancellata **(Pessagno, 1963)**

Plate 8.3, Figures 1-18
(Pl. 8.3, Figs. 1-3: new SEMs of holotype of *Globigerina ampliapertura cancellata* Pessagno)

Globigerina ampliapertura cancellata Pessagno, 1963:58, pl. 1, figs. 7-9, paratype; pl. 2, figs. 15-17 holotype [upper Oligocene *Globorotalia opima opima* Zone, Juana Díaz Fm., Puerto Rico].

DESCRIPTION.

Type of wall: Normal perforate, spinose, *sacculifer*-type wall, pore concentrations average 22 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, globular, consisting of 3 whorls. The profile is lobulate, with globular chambers; in spiral view 3½-4 globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size. The last chamber generally consists of a third of the test. The sutures are depressed, slightly curved; in umbilical view 3½-4 globular, slightly embracing chambers, increasing rapidly in size, sutures depressed, slightly curved, umbilicus large, open, enclosed by surrounding chambers, aperture umbilical, a low rounded arch, bordered by a thin thickened rim; in edge view chambers globular, slightly embracing, initial whorl slightly elevated.

Size: Maximum diameter of holotype 0.28 mm, minimum diameter 0.26 mm, maximum width 0.2 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita cancellata* differs from *G. paracancellata* by the more lobulate profile, by the more gradual increase in chamber size in the ultimate whorl; in *G. paracancellata* the final chamber represents approximately half the size of the test, compared with a third in *G. cancellata*. *Globoturborotalita pseudopraebulloides* is more loosely coiled, has a more rapid rate of final whorl chamber size increase and is generally larger than *G. cancellata* (see discussion below). It is distinguished from *Subbotina cancellata* Blow from the lower Paleocene by the less strongly cancellate less asymmetrical cancellate wall and more highly arched and umbilical centered aperture. *Globoturborotalita cancellata* is distinguished from *Subbotina eocaena* and *Dentoglobigerina taci*, with which it shares similar gross test morphology, by the coarser cancellate wall texture (see Chapter 11, this volume, for discussion and SEM images of *D. taci*), more open, rounded and umbilical position of the aperture (compared to *S. eocaena*), more rounded form of the final chamber.

DISCUSSION.— *Globoturborotalita cancellata* apparently is a little known or overlooked species among Oligocene workers probably due to its low numbers in samples. Pessagno (1963) considered this species as a subspecies of *Turborotalia ampliapertura*, however, in agreement with Blow (1969) and Jenkins (1971) we consider these forms to be unrelated. Blow (1979) suggested this species was referrable to *Dentoglobigerina*, however, our studies of the wall texture and aperture morphology indicate it belongs in *Globoturborotalita.*

Plate 8.2 *Globoturborotalita brazieri* (Jenkins, 1965)

1-3, (holotype, TF 1497) Waitakian Stage, Auckland, New Zealand; **4-7**, Subzone M1b, Sample Bolli 407, Cipero Fm., Trinidad; **8-11**, Subzone M1b, Sample Bolli 407, Cipero Fm., Trinidad; **12-15**, Zone M1, DSDP Hole 588C/9R/3,134-136 cm; Tasman Sea; **16-19**, Subzone M1b, DSDP Hole 588C/9R/3, 130-132 cm Tasman Sea. Scale bar: **1-6**, **8-10**, **12-14**, **16-18** = 100 μm; **15**, **19** = 20 μm; **7**, **11** = 10 μm.

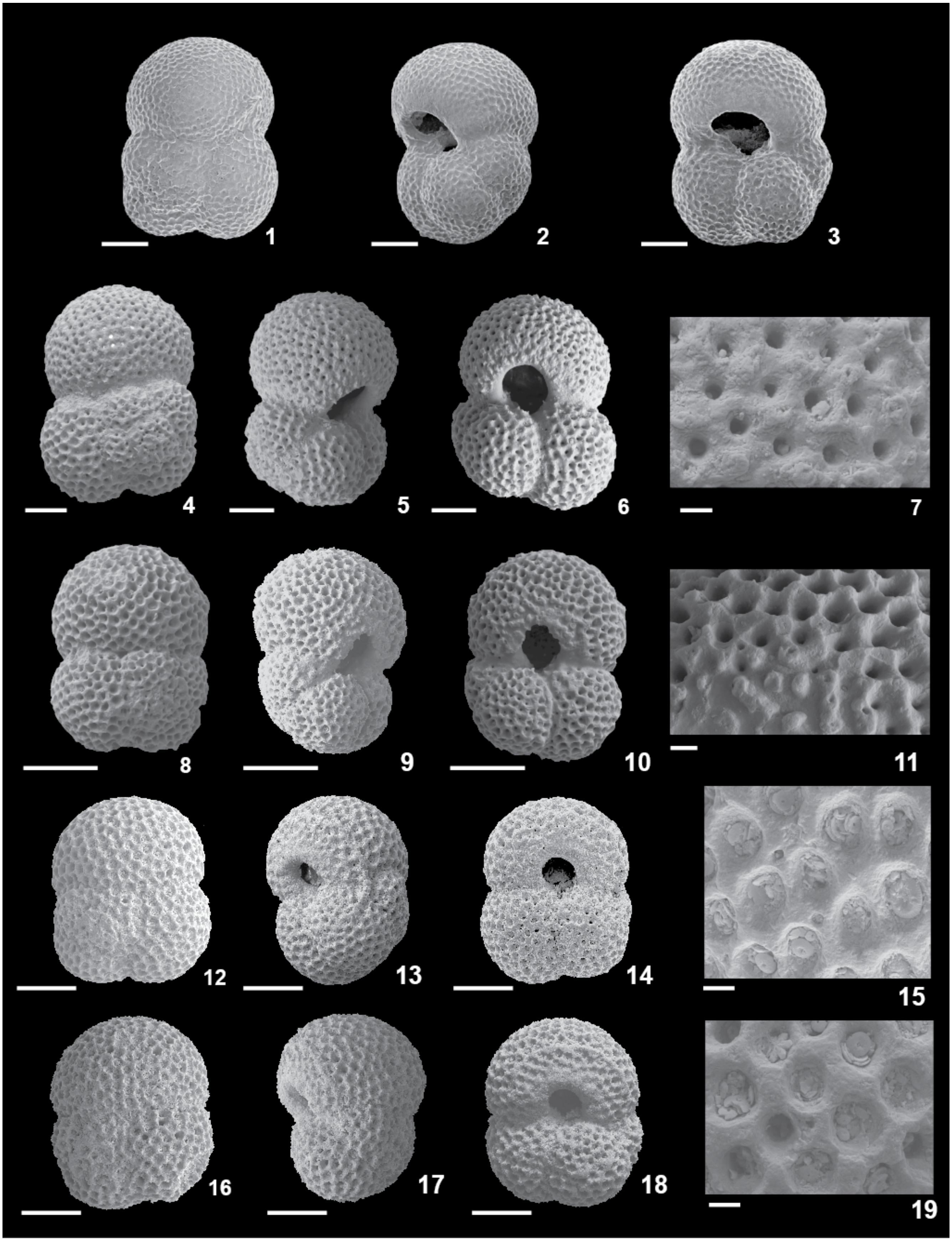

Plate 8.2 *Globoturborotalita brazieri* (Jenkins, 1965)

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita cancellata* probably evolved from *Globoturborotalita bassriverensis*.

STRATIGRAPHIC RANGE.— Zone E16 to O5?

TYPE LEVEL.— Upper shale member of the Juana Diaz Formation, *Globorotalia opima opima* Zone.

GEOGRAPHIC DISTRIBUTION.— We have identified specimens from low to middle latitude localities.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM 640996) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Globoturborotalita connecta (Jenkins, 1964)

Plate 8.4, Figures 1-19
(Pl. 8.4, Figs. 1-3: new SEMs of holotype of *Globigerina woodi connecta* Jenkins)

Globigerina woodi connecta Jenkins, 1964:72, figs. 1a-c [lower Miocene, North Island, New Zealand].—Jenkins, 1971:157, pl. 18, figs. 545-547 [lower Miocene, North Island, New Zealand].—Jenkins, 1978:726, pl. 1, figs. 1-5 [lower Miocene, *Globigerina woodi connecta* Zone, DSDP Site 360, Walvis Ridge, southeastern Atlantic Ocean].—Basov and others, 1983:839, pl. 11, figs. 5-7 [lower Miocene, DSDP Site 513A, Falkland Plateau, South Atlantic Ocean].

Globigerina (*Zeaglobigerina*) *connecta* Jenkins.—Kennett and Srinivasan, 1983:44, pl. 8, figs. 1-3 [lower Miocene, *Catapsydrax dissimilis* Zone, DSDP Site 208, Lord Howe Rise, southwestern Pacific Ocean].

Globigerina (*Globoturborotalita*) *woodi connecta* Jenkins.—Chaproniere, 1988:129, pl. 2, figs. 6-9, 11-14 [lower Miocene, southeastern Australia].

Zeaglobigerina connecta (Jenkins).—Spezzaferri, 1994:32-33, pl. 4, figs. 4a-c [lower Miocene, Subzone N4b, ODP Hole 709C, Indian Ocean].

Globoturborotalita connecta (Jenkins).—Li and McGowran, 2000:44, fig. 20H [lower Miocene, Zone SN2, southeastern Australia].

Globigerina woodi Jenkins.—Chaisson and Leckie, 1993:156, pl. 1, fig. 15 [lower Miocene, Subzone N4b, ODP Site 806, western equatorial Pacific Ocean]. [Not Jenkins, 1960.]

DESCRIPTION.

Type of wall: Coarsely perforate, spinose, *sacculifer*-type wall texture, pore concentration between 12.5-14 pores/50 µm^2 test surface area.

Test morphology: Very low trochospiral, consisting of 2-2½ whorls, trilobate to quadrangular, compact in profile, chambers subglobular to trapezoidal; in spiral view 3-3½ subglobular strongly embracing chambers in ultimate whorl, increasing slowly in size, sutures depressed, straight; in umbilical view 3 subglobular, embracing chambers, increasing slowly in size, sutures depressed, straight, umbilicus small, aperture umbilical to extraumbilical, a very low arch, bordered by a thin rim; in edge view chambers globular.

Size: Maximum diameter of holotype 0.34 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita connecta* is distinguished from all other species of *Globoturborotalita* by its very coarsely cancellate, low porosity test, 3-3½ chambers symmetrically arranged around the umbilicus, and very low umbilical-extraumbilical aperture.

DISCUSSION.— The first appearance of this species marks the base of the lower Miocene *G. woodi* Zone in Australia and New Zealand, although Spezzaferri (1994) documented a few specimens of *G. connecta* in DSDP Holes 588C and 593 (Tasman Sea) from the upper Zone P22 (= Zone O7). Spezzaferri (1994) also recorded some specimens of *G. connecta* from Zone P22 at high latitudes in the North Atlantic Ocean. Jenkins (1964) identified *Globoturborotalita woodi* as the ancestor of *G. connecta* and the evolution to be synchronous in New Zealand and southeast Australia.

Plate 8.3 *Globoturborotalita cancellata* (Pessagno, 1963)

1-3 (holotype, USNM 640996), *Globorotalia opima opima* Zone, Puerto Rico; **4**, **17**, **18**, Zone O1, Sample, AGS 66, 9A-1A, Shubuta Fm., Alabama; **5-9**, **12**, **13**, Zone O2, Sample Bolli *G. ampliapertura* Zone (Fribourg collection), Cipero Fm., Trinidad; **10**, **11**, Zone O2, Palma Real Fm., type locality, Tampico, Mexico; **14-16**, Zone O1, Atlantic Slope Project corehole 5B 30A/0-6", western Atlantic Ocean. Scale bar: **1-7**, **9**, **10**, **13-15**, **18** = 100 µm; **8**, **11**, **12**, **16**, **17** = 50 µm^2 surface area.

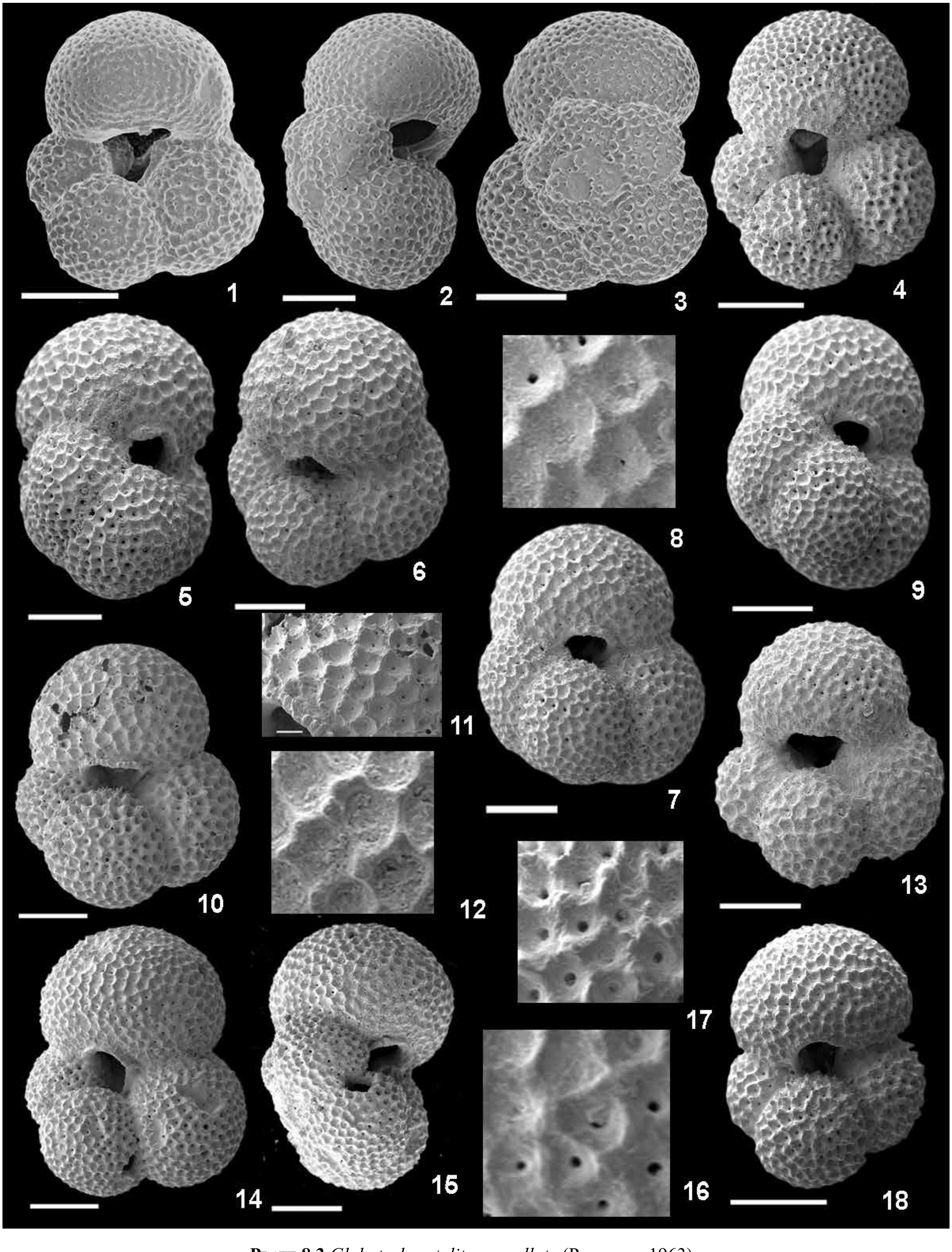

Plate 8.3 *Globoturborotalita cancellata* (Pessagno, 1963)

PHYLOGENETIC RELATIONSHIPS.— It probably evolved from *G. woodi* in the late Oligocene Zone O7.

STRATIGRAPHIC RANGE.— Zone O7 (Spezzaferri, 1994) to Zone M4, i.e., lower Miocene *Globigerinoides trilobus* Zone of Jenkins (1985).

TYPE LEVEL.— Lower Miocene, Otainan Stage from the Parengarenga section in North Island, New Zealand.

GEOGRAPHIC DISTRIBUTION.— Although it was described from New Zealand, *G. connecta* is cosmopolitan and also occurs at low latitudes in the Atlantic Ocean. It is generally rare.

STABLE ISOTOPE PALEOBIOLOGY.— Stable isotope data (Spezzaferri, unpublished) suggests this species had a shallow mixed-layer habitat.

REPOSITORY.— Holotype (TP 1483) deposited at the Geological and Nuclear Research Institute, Lower Hutt, New Zealand.

Globoturborotalita eolabiacrassata Spezzaferri and Coxall, new species

Plate 8.5, Figures 1-20

Globigerina officinalis Subbotina.—Hooyberghs and De Meuter, 1972:21, pl. 5, fig. 4a ['upper Oligocene', Houthalan Sands, Belgium]. [Not Subbotina, 1953.]

Globigerina senilis Bandy.—Quilty, 1976:639, pl. 4, figs. 7, 8 [lower Oligocene Zone P18, DSDP Site 321, Nazca Plate, southeast Pacific Ocean]. [Not Bandy, 1949.]

Globoturborotalita labiacrassata (Jenkins).—Huber, 1991:pl. 5, fig. 16 [lower Oligocene, Zone AP14, ODP Site 744A, Kerguelen Plateau, southern Indian Ocean]. [Not Jenkins, 1965.]

Zeaglobigerina labiacrassata (Jenkins).—Spezzaferri, 1994:33, pl. 4, figs.1a-c [lower Miocene, Subzone N4b, ODP Site 667A, equatorial Atlantic Ocean]. [Not Jenkins, 1965.]

Globoturborotalita bassriverensis Olsson and Hemleben, 2006:117, pl. 6.3, fig. 16 [middle Eocene Zone E8, TDP Site 2, Kilwa, Tanzania], fig. 17 [middle Eocene Zone E9, TDP Site 2, Kilwa, Tanzania], fig. 18 [middle Eocene, ODP 150X, Island Beach Borehole, New Jersey], fig. 19 [lower-middle Eocene Zone E7, Tercis, Lesperon, France]. [Not Olsson and Hemleben, 2006.]

'*Globoturborotalita* sp.—Sexton and others, 2006:6, pl. 1, fig. 6 [middle Eocene Zone E13, ODP Site 1052 Blake Nose, western North Atlantic Ocean].

Globigerina lentiana Rögl.—Székely and Filipescu, 2016:490, pl. 2, figs. 3a-b [lower Oligocene, Rupelian, Transylvanian Basin, Romania]. [Not Rögl, 1969.]

DESCRIPTION.

Type of wall: Normal perforate, cancellate, spinose, *ruber/sacculifer*-type wall texture. Pore concentration between 12-14 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, compact, consisting of 2½-3 whorls, slightly lobulate in profile outline. Both in spiral and umbilical views 4 subglobular chambers in the last whorl, increasing gradually in size. The last chamber is generally smaller than the previous ones, or it is equidimensional with the penultimate. The early whorl may not be visible because of calcite overgrowth in the figured specimens. The sutures are depressed and straight on both sides; umbilicus open but small, the single aperture is an umbilical, symmetrical or slightly asymmetrical, low rounded arch, bordered by a very thick rim.

Size: Maximum diameter of the holotype is 0.15 mm.

ETYMOLOGY.— Named *eolabiacrassata* ("dawn" *labiacrassata*) because ancestral to *G. labiacrassata.*

DISTINGUISHING FEATURES.— *Globoturborotalita eolabiacrassata* n. sp. differs from *G. labiacrassata* by its more compact profile, the less open and lower arched aperture and by the final chamber being smaller than the previous ones. It differs from *G. bassriverensis* in the more compact form and possession of a thickened apertural rim, and from *G. martini* in lacking a bulla on the primary aperture together with the more compact profile. It differs from *G. woodi* and *G. brazieri* by the lower arched aperture and by the thick lip. *Globoturborotalita eolabiacrassata* n. sp. is distinguished from *G. cancellata, G. paracancellata*, *G.*

Plate 8.4 *Globoturborotalita connecta* (Jenkins, 1964)

1-3 (holotype TF1483), Otaian Stage, Auckland, New Zealand; **4-7**, Zone O6, Sample Bolli 407, Cipero Fm., Trinidad; **8-11**, Zone O6, Sample Bolli 407, Cipero Fm., Trinidad; **12-15**, Zone O6, Sample Bolli 409, Cipero Fm., Trinidad; **16-19**, Zone M1, DSDP Hole 526A/27/3, 30-32 cm, South Atlantic Ocean. Scale bar: **1-3** = 100 μm; **5-7**, **9-11**, **13-15**, **16-18** = 50 μm; **4**, **8**, **12**, **19** = 20 μm.

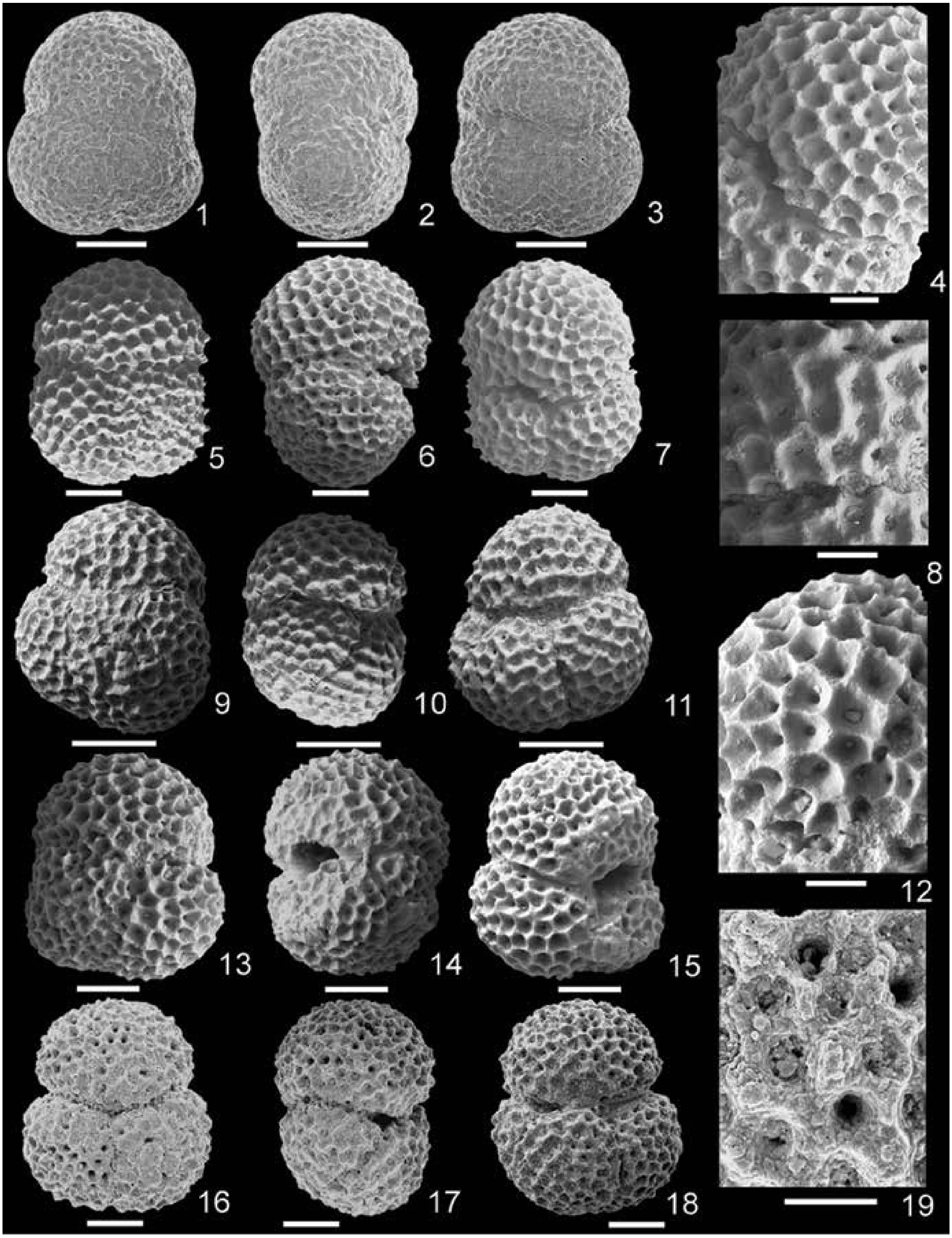

Plate 8.4 *Globoturborotalita connecta* (Jenkins, 1964)

occlusa and *G. pseudopraebulloides* by its smaller size, the compact profile, the aperture bordered by the thick rim. It is distinguished from *G. connecta* by having 4 chambers in the last whorl, the more lobulate profile, the thick apertural rim and the *ruber/sacculifer*-type wall texture. Compared to *G. ouachitaensis, G. eolabiacrassata* has a less lobate outline and smaller/lower aperture, which in the latter is markedly rimmed.

DISCUSSION.— A similar form identified as *Globigerina* cf. *G. labiacrassata* was identified at ODP Hole 1137A up to the upper Oligocene (Shipboard Scientific Party, 2000). This form probably corresponds to *G. eolabiacrassata* n. sp. The specimens identified as '*Z. labiacrassata'* by Spezzaferri (1994) at DSDP Holes 667A (Subzone M1b) and 588C (Zone M5) can be attributed to *G. eolabiacrassata* n. sp.

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita eolabiacrassata* evolved from *G. bassriverensis* (Olsson and others, 2006). It gave rise to *G. labiacrassata* in the lower Oligocene close to the boundary between Zones O1/O2.

STRATIGRAPHIC RANGE.— It appears in Eocene Zone E7 (Olsson and others 2006, pl. 6.3, fig. 19). We have observed it ranging up to Miocene Zone M5 in Hole 588C, Pacific Ocean (Spezzaferri, 1994).

TYPE LEVEL.— Lower Miocene, Subzone M1a, ODP Hole 1137A/12R/1, 65-69 cm, Kerguelen Plateau.

GEOGRAPHIC DISTRIBUTION.— This species is very frequent in the South Indian Ocean, Kerguelen Plateau, but it has been observed also in the tropical Indian Ocean and the equatorial Atlantic Ocean.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (32613) and paratypes (32614 and 32615) are deposited at the Museum of Natural History of Fribourg, Switzerland.

***Globoturborotalita euapertura* (Jenkins, 1960)**

Plate 8.6, Figures 1-16
(Pl. 8.6, Figs. 1-3: new SEMs of holotype of *Globigerina euapertura* Jenkins)

Globigerina euapertura Jenkins, 1960:351, pl. 1, figs. 8a-c [lower Miocene pre-*Globoquadrina dehiscens dehiscens* Zone, Lakes Entrance Oil Shaft, Victoria, southeastern Australia].—Jenkins and Orr, 1972:1088, pl. 9, figs. 1-6 [lower Oligocene *C. cubensis* Zone, DSDP Hole 77B, equatorial Pacific Ocean].—Stott and Kennett, 1990:559, pl. 7, fig. 7 [upper Oligocene Zone AP14a (= AO2, Huber and Quillévéré, 2005), DSDP Hole 690B, Maud Rise, South Atlantic Ocean].—Berggren, 1992a:563, pl. 4, fig. 16 [upper Oligocene Zone *G. euapertura* Zone (= AO2 of Huber and Quillévéré, 2005), ODP Hole 748B, Kerguelen Plateau, southern Indian Ocean].

Globigerina cf. *euapertura* Jenkins.—Jenkins and Orr, 1972:1088, pl. 9, figs. 7-9 [lower Miocene *G. kugleri* Zone, DSDP Hole 77B, equatorial Pacific Ocean].

"*Globigerina*" *euapertura* Jenkins.—Spezzaferri, 1994:30, pl. 39, fig. 1 [lower Miocene Subzone N4b, ODP Hole 709C, Indian Ocean], fig. 2 [upper Oligocene Zone P22, ODP Hole 538A, Gulf of Mexico].

Turborotalia euapertura (Jenkins).—Li and others, 2003:16, pl. P2, fig. 20 [lower Miocene, ODP Hole 1134A, Great Australian Bight].—Li and others, 2005:19, pl. 2 (partim), fig. 2 [Miocene, ODP Hole 1148A, South China Sea].

Globigerina woodi Jenkins.—Hooyberghs and De Meuter, 1972:27, pl. 8, fig. 4a ['upper Oligocene', Houthalan Sands, Belgium]. [Not Jenkins, 1960.]

Globigerina cf. *G. woodi* Jenkins.—Chaisson and Leckie, 1993:pl. 1, fig. 16 [lower Miocene, Subzone N4b, Hole 806B, western equatorial Pacific Ocean].

Not "*Turborotalia*" *euapertura* Jenkins.—Fleisher, 1975:pl. 3, figs. 8, 9 [lower Oligocene, "*Turborotalia*" *ampliapertura* Zone, DSDP Site 305, North Pacific Ocean] (= *Dentoglobigerina prasaepis*).

Not *Globigerina euapertura* Jenkins.—Poore, 1984:pl. 2, fig. 7 [lower Oligocene Zone OL2, DSDP Site 522, South Atlantic Ocean].—Leckie and others, 1993:123, pl. 4, fig. 10 [lower Oligocene Zone P18, ODP Hole 803D, Ontong Java Plateau, western equatorial Pacific Ocean], fig. 11 [upper Oligocene Subzone P21b, ODP

Plate 8.5 *Globoturborotalita eolabiacrassata* Spezzaferri and Coxall, new species

1-4 (holotype 32613 Natural History Museum, Fribourg), Subzone M1a, ODP Hole 1137A/12R/1, 65-69 cm, Kerguelen Plateau; **5-7** (paratype 32614), Subzone M1a, ODP Hole 1137A/12R/1, 65-69 cm, Kerguelen Plateau; **8-10**, Zone O6, DSDP Site 593/50X/5, 148-149 cm, Tasman Sea; **11-13**, Zone O7, ODP Hole 1137A/13R/1, 45-49 cm, Kerguelen Plateau; **14-16**, Zone O5, DSDP Hole 744A/13H/5, 95-100 cm, Kerguelen Plateau; **17-19** (paratype 32615), Subzone M1a, ODP Hole 1137A/12R/1, 65-69 cm, Kerguelen Plateau; **20**, Zone E9, TDP Site 2/13/CC, Tanzania (Olsson and others, 2006, pl. 6.3, fig. 17). Scale bar: **1-3**, **5-20** = 100 µm; **4** = 10 µm.

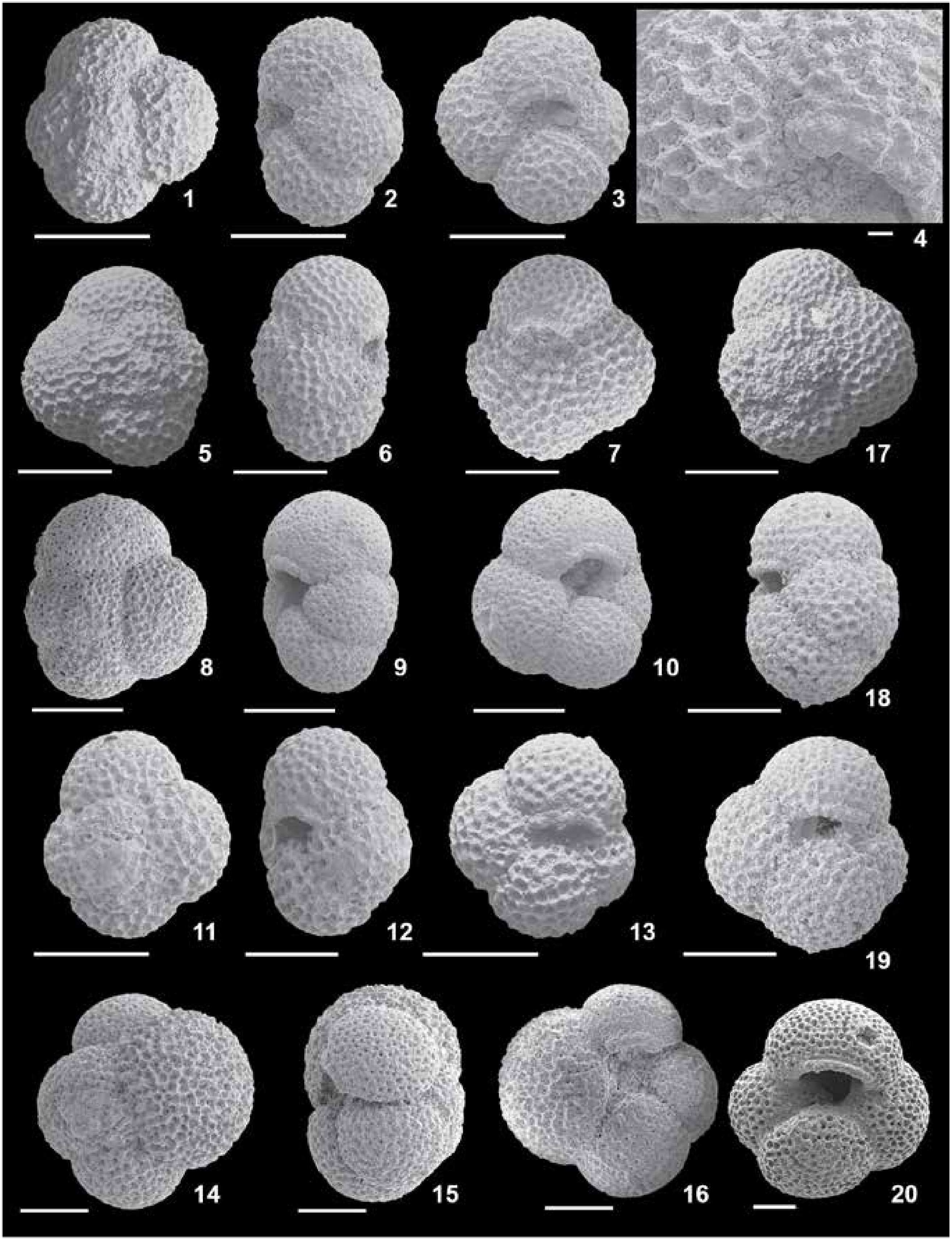

Plate 8.5 *Globoturborotalita eolabiacrassata* Spezzaferri and Coxall, new species

Hole 803D, Ontong Java Plateau, western equatorial Pacific Ocean], figs. 12, 13 [lower Oligocene Subzone P21a, ODP Hole 628A, western North Atlantic Ocean] (= *Dentoglobigerina prasaepis*).

Not *Globigerina euaperta* Jenkins.—Loubere, 1985:pl. 4, fig. 12 (= microperforate).

Not *Turborotalia euapertura* Jenkins.—Li and others, 2005:pl. 2, fig. 1 [lower Oligocene, ODP Hole 1148A, South China Sea] (= *Dentoglobigerina prasaepis*).

DESCRIPTION.

Type of wall: Normal perforate, spinose, *sacculifer*-type wall texture, an average of about 20 pores/50 μm² test surface area.

Test morphology: Low trochospiral, medium sized test, consisting of 3 whorls, weakly lobulate in outline, 4 subglobular, slightly embracing chambers in the last whorl, increasing slowly in size, sutures incised, straight to slightly curved on both sides; low arched umbilical aperture, bordered by a thin, indistinct rim; final chamber reniform in shape, directly over the umbilicus; in edge view chambers ovoid in shape, ultimate chamber extends over the umbilicus, oval to subcircular in outline.

Size: Holotype maximum diameter 0.30 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita euapertura* has four chambers in the final whorl with the aperture confined to the umbilicus and located over the second chamber. It is distinguished by its deeply incised sutures, broad, low arched aperture and wedge like chambers. The final chamber has a distinctive reniform shape. It differs from *Dentoglobigerina prasaepis* by its wall texture and chamber shape and from *D. venezuelana* by its generally smaller size, more lobulate outline, lack of a tooth/lip and looser coiling mode. It is distinguished from *Turborotalia ampliapertura* by its umbilical, low arched aperture, rather than extraumbilical, high arched aperture and *sacculifer*-type wall texture.

DISCUSSION.— The taxonomic affinity of *Globoturborotalita euapertura* has long been debated. Many authors have considered this form to be homeomorphic with *Dentoglobigerina prasaepis* (Blow) or related to *Turborotalia ampliapertura* (Bolli), while others have referred it to the original genus designation *Globigerina* (Stott and Kennett, 1990; Huber, 1991; Huber and Quillévéré, 2005). Jenkins (1960) considered his new species to be intermediate between *Globigerina venezuelana* and *Globigerina ampliapertura. Dentoglobigerina prasaepis* was considered to be a junior synonym of *G. euapertura* by Jenkins and Orr (1972) and Fleisher (1975). However, inspection of SEM images of the holotype and our new material, indicates the taxon has a cancellate test that differs from the wall structure of *Dentoglobigerina* or *Turborotalia*. We therefore conclude that *euapertura* belongs to *Globoturborotalita*, and is unrelated to *Turborotalia ampliapertura* and species of *Dentoglobigerina* as previously suggested. This refined diagnosis is consistent with Huber and Quillévéré's (2005) concept of this species as used to define the upper Oligocene "*Globigerina euapertura* Highest-occurrence Zone" (Zone AO4). Jenkins (1960) reports an increase in the size of *G. euapertura* specimens in the younger part of the range but this has not been verified by morphometric studies elsewhere.

PHYLOGENETIC RELATIONSHIPS.— It probably evolved from *G. woodi* by developing a more rounded periphery, a lower, wider arched aperture and more wedge like chambers.

STRATIGRAPHIC RANGE.— Not currently well constrained. This species has been recorded from the upper Eocene through lower Miocene (e.g., Leckie and others, 1993), though it has frequently been confused with *D. venezuelana* and *D. prasaepis*. It is considered valuable in mid- to high southern latitudes. Jenkins (1965) erected the *G. euapertura* Zone from the 'mid' Oligocene to lower Miocene, a concept that has been carried over in recent high southern latitude biozonation schemes (Stott and Kennett, 1990; Berggren, 1992a,b; Huber and Quillévéré, 2005). Spezzaferri and Premoli Silva (1991) record a lowest occurrence in mid- Subzone P21a, Huber and Quillévéré (2005) record this species from lower to middle Zone AO1.

Berggren (1992b) constrain the LAD at the Kerguelen Plateau to Chron C6Cn.2n (23.8 Ma), close to the Oligocene/Miocene boundary. However, *Glo-*

Plate 8.6 *Globoturborotalita euapertura* (Jenkins, 1960)

1-3 (holotype USNM CPC4163), Miocene, Victoria, southeastern Australia; **4-6** (hypotypes, reillustration of Jenkins, 1971, pl. 15, figs. 457-459), Whaingaroan, Raglan Harbor Section, New Zealand; **7-9** (same specimen), Zone P22, ODP Hole 588C/12/3, 130-132 cm, Tasman Sea; **10-12** (same specimen), **13-16** (same specimen), Subzone M1b, ODP Hole 588C/9/3, 134-136 cm, Tasman Sea. Scale bar: **1-15** = 100 μm; **16** = 10 μm.

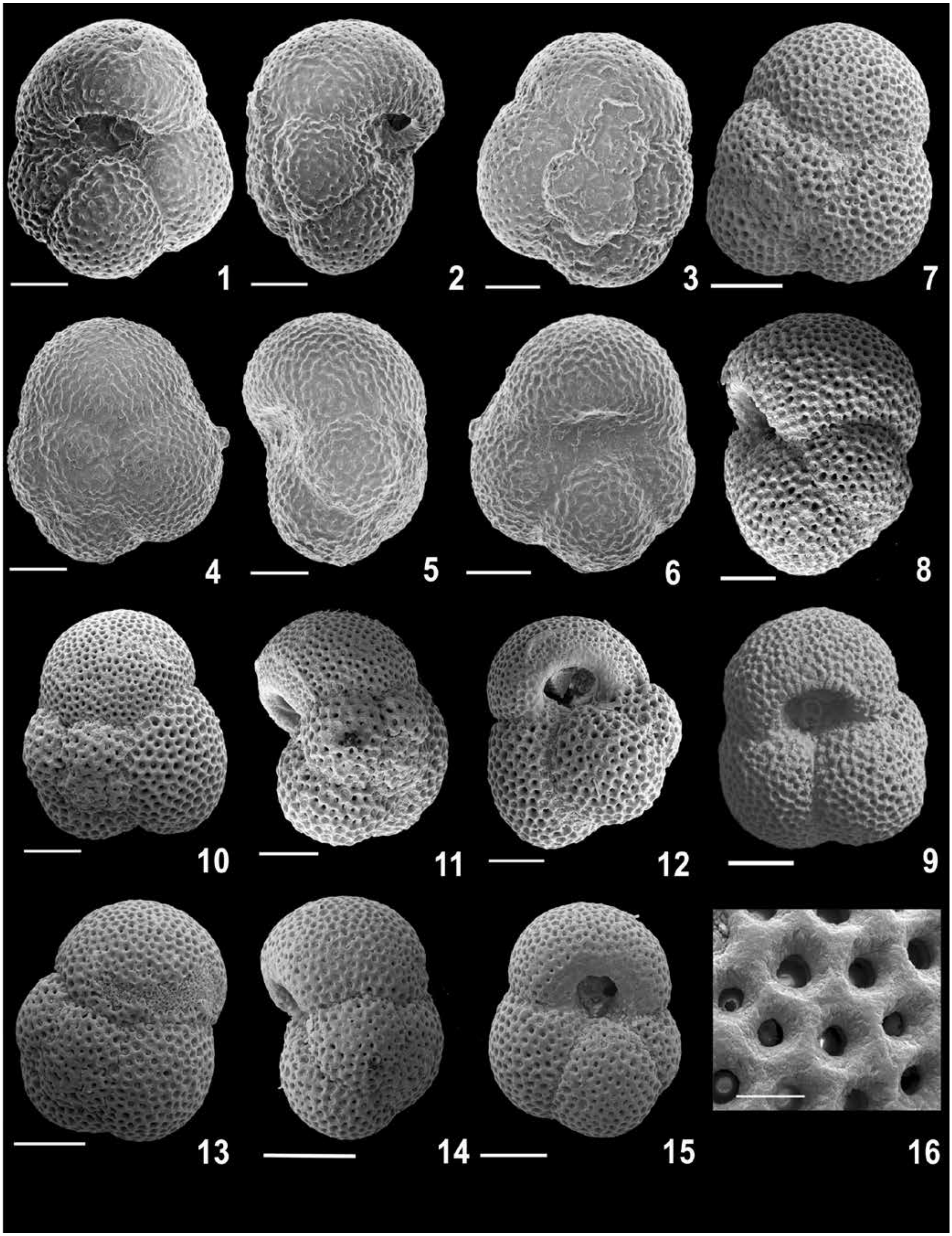

Plate 8.6 *Globoturborotalita euapertura* (Jenkins, 1960)

boturborotalita euapertura has frequently been recorded from lower Miocene sediments and was indeed described from the lower Miocene.

TYPE LEVEL.— From 1188 feet, upper Oligocene, pre-*Globoquadrina dehiscens dehiscens* Zone, Lakes Entrance Oil Shaft, Victoria, southeastern Australia.

GEOGRAPHIC DISTRIBUTION.— More common in colder water high southern latitude environments, though it has been recorded in subtropical sites (Premoli Silva and Boersma, 1988).

STABLE ISOTOPE PALEOBIOLOGY.— Poore and Matthews (1984) suggest an intermediate (thermocline) dwelling habitat for *G. euapertura*, however they find inconsistent results and acknowledge that more than one morphospecies may have been analyzed. The specimens analyzed by Wade and Pearson (2008) are now considered to be *Dentoglobigerina prasaepis.*

REPOSITORY.— Holotype (CPC 4163) deposited at the Bureau of Mineral Resources, Canberra, Australia.

Globoturborotalita gnaucki (Blow and Banner, 1962)

Plate 8.7, Figures 1-13

Globigerina ouachitaensis Howe and Wallace, 1932, (partim. paratype, not holotype) [Zone E15/16, Danville Landing, Louisiana]. [Not Howe and Wallace, 1932.]

Globigerina ouachitaensis Howe and Wallace.—Charollais and others, 1980:64, pl. 6, figs. 14-17 [lower Oligocene, France]. [Not Howe and Wallace, 1932.]

Globigerina ouachitaensis gnaucki Blow and Banner, 1962:91, pl. IX, figs. l-n, holotype [lower Oligocene *Globigerina oligocaenica* Zone, Sample FCRM 1965, Lindi area, Tanzania].—Blow, 1969:320, pl. 2, figs. 1-3 (holotype re-illustrated).—Bolli and Saunders, 1985:182, fig. 13.16a-c (holotype re-illustrated).

Globoturborotalita gnaucki (Blow and Banner, 1962).—Olsson and others, 2006:118, pl. 6.4, figs. 5-14 [upper Eocene, Zone E15/E16, Shubuta Clay, Yazoo Fm., Wayne Country, Mississippi].

DESCRIPTION.

Type of wall: Cancellate, normal perforate, spinose, *ruber/sacculifer*-type wall texture, an average of 30 pores/50 µm^2 test surface area.

Test morphology: Test moderately low trochospiral, globular, lobulate in outline, chambers globular; in spiral view 4½ globular, slightly embracing chambers in ultimate whorl, increasing moderately in size, sutures depressed, straight; in umbilical view 4½ globular, slightly embracing chambers, increasing moderately in size, sutures depressed, straight, umbilicus large, open, enclosed by surrounding chambers, aperture umbilical, a rounded arch, bordered by a thin thickened rim; in edge view chambers globular in shape, slightly embracing, initial spire of chambers slightly elevated.

Size: Maximum diameter 0.25-0.36 mm, minimum diameter 0.23-30 mm, maximum width 0.19 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita gnaucki* differs from the other species belonging to the genus *Globoturborotalita* by the more evolute coiling and lobulate profile, the presence of 4½ globular, slightly embracing chambers in the ultimate whorl compared with 3½-4 in the other species, and in having a more open and higher aperture. It further differs from *G. ouachitaensis*, to which it is most closely related, by the size of the final chamber, which is larger than the penultimate in *G. gnaucki* but of similar size or smaller than the ultimate chamber in *G. ouachitaensis,* and the absence of a thickened lip.

DISCUSSION.— See Olsson and others (2006) for discussion of this species.

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita gnaucki* derived from *Globoturborotalita ouachitaensis* by an increase in the number of chambers in the ultimate whorl to 4½ and by losing the thickened lip. It gave rise to *Ciperoella anguliofficinalis* in upper Eocene Zone E16 and it is therefore ancestral to the genus *Ciperoella* n. gen. (Chapter 7, this volume).

STRATIGRAPHIC RANGE.— This species appears

Plate 8.7 *Globoturborotalita gnaucki* (Blow and Banner, 1962)

1-3 (holotype BMNH P44509), Zone O2, Sample FCRM1965, Lindi area, Tanzania; **4-6**, *Globigerina ouachitaensis* Howe and Wallace, 1932 (paratype), upper Eocene, Louisiana State University Museum, Collection Baton Rouge); **7-10**, Zone O4, Sample Bolli 381, Cipero Fm., Trinidad; **11-13**, Zone O1, ODP Site 647/30R/3, 67-69 cm, Labrador Sea. Scale bar: **1-9**, **11-12** = 100 µm; **10**, **13** = 10 µm.

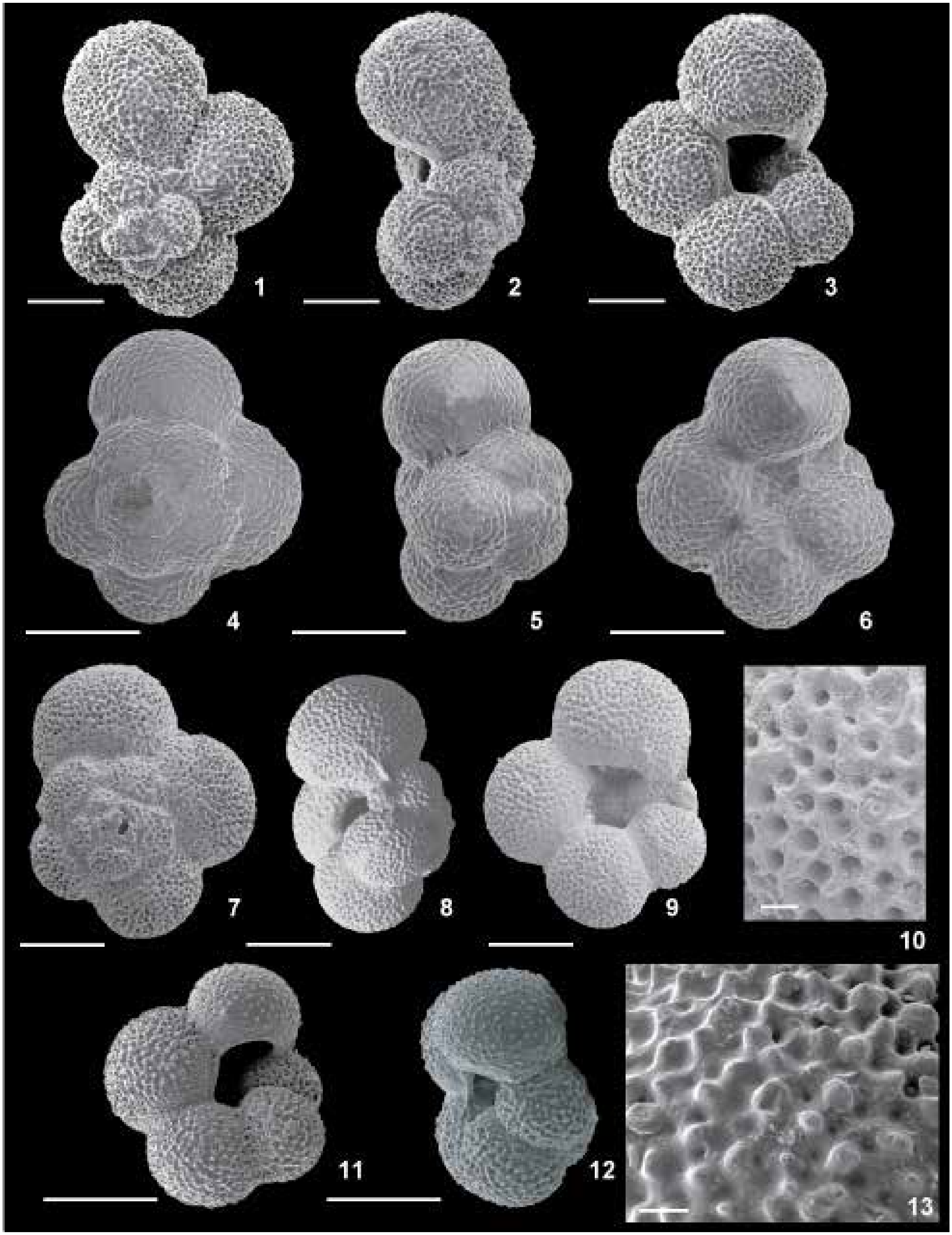

Plate 8.7 *Globoturborotalita gnaucki* (Blow and Banner, 1962)

in the upper Eocene Zone E15. We have observed it in ranging up to the lower Oligocene Zone O4 in Trinidad (Plate 8.7).

TYPE LEVEL.— Lower Oligocene *Globigerina oligocaenica* Zone (equivalent to Zone upper O1/ lower O2 of Wade and others, 2011) at Kitunda Cliff about 200 m east of Lindi Creek near its entry into Lindi Bay, Tanzania, Sample FCRM 1965.

GEOGRAPHIC DISTRIBUTION.— This species is distributed in mid to low latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (P44509) deposited at the Natural History Museum, London.

Globoturborotalita labiacrassata **(Jenkins, 1965)**

Plate 8.8, Figures 1-16
(Pl. 8.8, Figs. 1-3: new SEMs of holotype of *Globigerina labiacrassata* Jenkins)

Globigerina labiacrassata Jenkins, 1965:1102, fig. 8, no. 64-71 [lower Oligocene, Earthquake Section, Waitaki Valley, New Zealand].—Stott and Kennett, 1990:559, pl.7, fig. 1 [upper Oligocene Zone AP14a (= AO2, Huber and Quillévéré, 2005), DSDP Hole 690B, Maud Rise, South Atlantic Ocean].—Nocchi and others, 1991:pl. 5, figs. 11, 12 [Zone P22, upper Oligocene, ODP Site 703A, Kerguelen Plateau, southern Indian Ocean].—Berggren, 1992a:563, pl. 4, figs. 13, 14 [upper Oligocene '*G. suteri* Zone' (= AO2 of Huber and Quillévéré, 2005), ODP Hole 749B, Kerguelen Plateau, southern Indian Ocean].

Globigerina (*Globigerina*) *labiacrassata* Jenkins.—Jenkins, 1971:151, pl. 16, figs. 474-484 [lower Oligocene, Earthquake Section, Waitaki Valley, New Zealand].

Zeaglobigerina labiacrassata (Jenkins).—Spezzaferri, 1994:33, pl. 6, figs. 2a-c [lower Oligocene Subzone P21a, DSDP Site 526A, South Atlantic Ocean].

Not *Globoturborotalita labiacrassata* (Jenkins).—Huber, 1991:pl. 5, fig. 16 [lower Oligocene, Zone AP14, ODP Site 744A, Kerguelen Plateau, southern Indian Ocean] (= *G. eolabiacrassata* n. sp.).

Not *Zeaglobigerina labiacrassata* (Jenkins).—Spezzaferri, 1994:33, pl. 4, fig.1a-c [lower Miocene, Subzone N4b, ODP Site 667A, equatorial Atlantic Ocean] (= *G. eolabiacrassata* n. sp.).

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber/sacculifer*-type wall texture, the strong cancellation is often not visible because of calcitic overgrowth, an average of 22 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, consisting of 2½ whorls, strongly lobulate in outline, 4 subglobular chambers visible in the last whorl on both sides, increasing slowly in size, sutures depressed, straight to slightly curved on both sides; umbilicus large and open, primary aperture umbilical, a symmetrical, rounded very high arch, bordered by a very thick rim.

Size: Maximum diameter of holotype 0.50 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita labiacrassata* is distinguished from the other 4 chambered *Globoturborotalita* including *G. woodi, G. brazieri, G. cancellata, G. paracancellata* and *G. occlusa* by its higher arched, symmetrical umbilical aperture, which is always bordered by a very thick rim. It differs from *G. eolabiacrassata* n. sp. (Plate 8.5) by its more lobulate profile and higher arched aperture. It differs from *G. gnaucki* by having only 4 chambers in the last whorl instead of 4½ and by the much thicker and more prominent rim bordering the aperture.

DISCUSSION.— Jenkins (1965) described this species as possessing a finely pitted wall texture possibly merging into *G. bulloides* population at the end of its range. However, based on its *ruber/sacculifer*-type wall texture, it is clear that *G. labiacrassata* is not related to the *G. bulloides* group. Jenkins (1965) documented specimens within the population of *labiacrassata* with a 'low arched aperture' resembling *G. connecta* and displaying strong variation in the thickness of the rim bordering the aperture. Here we restrict the concept of *G. labiacrassata* to specimens that closely resemble the holotype; i.e. showing the lobulate profile, and a

Plate 8.8 *Globoturborotalita labiacrassata* (Jenkins, 1965)

1-3 (holotype TF1499), lower Oligocene, New Zealand; **4-6** (paratype TF1499-2); **7-9**, Zone O2, Sample Bolli "*G. ampliapertura*" (Fribourg collection), Trinidad; **10-12**, upper part of Zone O7, Sample Bolli 407, Trinidad; **13-15**, **16**, *G.* cf. *labiacrassata*, Subzone M1b, DSDP Site 593/50X/2,140-142 cm, South Pacific Ocean. Scale bar: **1-15** = 100 μm; **16** = 10 μm.

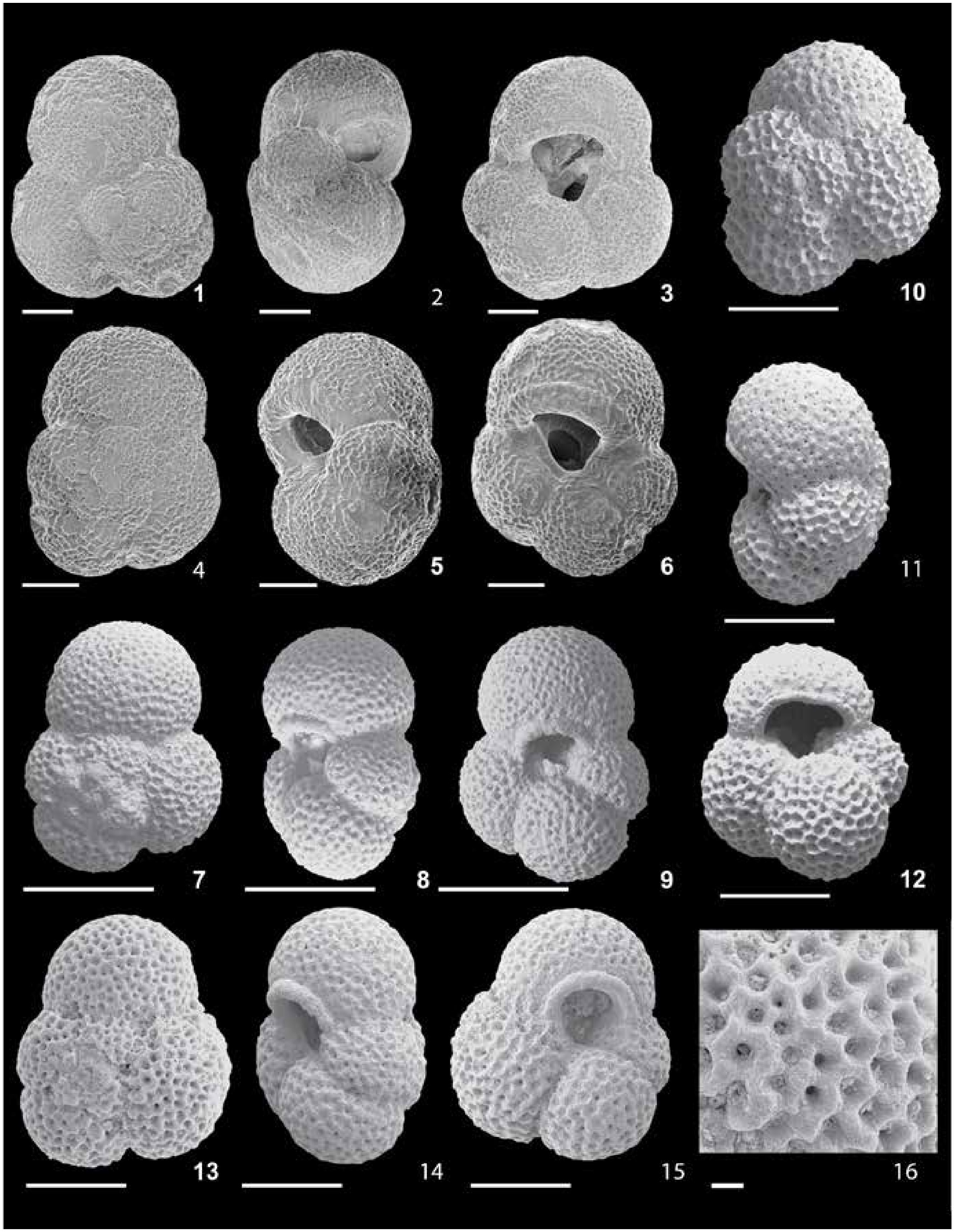

Plate 8.8 *Globoturborotalita labiacrassata* (Jenkins, 1965)

high arched open aperture bordered by a highly thickened rim. Little information was previously available on the ancestry of *G. labiacrassata*, which appears to be distinct from the *G. woodi* clade that lacks a thickened apertural rim. Identification of *G. eolabiacrassata* Spezzaferri and Coxall, n. sp., which also possesses a thickened apertural rim, provides an ancestral link to Eocene species of *Globoturborotalita.*

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita labiacrassata* probably evolved from *G. eolabiacrassata* in the lower Oligocene through modifications to the final chamber that produced a more lobulate periphery, a more highly arched aperture and a thicker apertural rim.

STRATIGRAPHIC RANGE.— Jenkins (1965) identified the range of *G. labiacrassata* from the *S. angiporoides angiporoides* Zone (lower Oligocene, Zone O2) to the lower part of the *G. dehiscens* Zone (lower Miocene, upper part of Zone M1). Huber and Quillévéré (2005) record this species from the lower to middle Zone AO1 (around Zone O1/O2 boundary). Berggren and others (1995) and Huber (1991) have constrained from multiple sites the LAD of this species to the upper Oligocene (Chron C8n-C9n) and this biohorizon is used to define the AO3/AO4 biozone boundary in the most recent Antarctic Oligocene zonation scheme (Huber and Quillévéré, 2005). However, we note specimens resembling *G. labiacrassata* that can be traced up to Subzone M1b (Pl. 8.8, Figs. 10-15).

TYPE LEVEL.— Oligocene, Kokoamus greensand, Landon Series, Whaingaroan Stage (Jenkins, 1965).

GEOGRAPHIC DISTRIBUTION.— Dominant in the high southern hemisphere. It is recorded as being common in the South Atlantic and South Pacific Oceans (Spezzaferri, 1994), and very common in Australia and New Zealand (Jenkins, 1965).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (TF1499) deposited at the Geological and Nuclear Research Institute, Lower Hutt, New Zealand.

Globoturborotalita martini (Blow and Banner, 1962)

Plate 8.9, Figures 1-15

Globigerinita martini martini Blow and Banner, 1962:110, pl. 14, fig. O [upper Eocene *Cribrohantkenina danvillensis* Zone, Sample FCRM 1932, Lindi area, Tanzania].—Blow, 1979:1340, pl. 24, fig. 5; pl. 245, figs. 5, 6 [upper Eocene Zone E15/16, Red Bluff Clay, type locality, Alabama].

Catapsydrax martini (Blow and Banner).—Warraich and Ogasawara, 2001:45, figs. 12, 15, 16 [Zone E10/11, Kirthar Fm., Sulaiman Range, Pakistan].—Spezzaferri and Premoli Silva, 1991, pl. 1, figs. 5a-c [upper Oligocene Subzone P21b, DSDP Hole 538A, Gulf of Mexico].

Globoturborotalita martini (Blow and Banner).—Olsson and others, 2006:121, pl. 6.2, figs. 14-18 [upper Eocene, Zone E15/E16, Shubuta Clay, Yazoo Fm. Wayne County, Mississippi].—Sexton and others, 2006:6, pl. 1, fig. 3 [middle Eocene Zone E13, ODP Site 1052, Blake Nose, western North Atlantic Ocean].—Miller and others, 2008:fig. 6a [lower Oligocene Zone O1, St Stephens Quarry, Alabama].

Globigerinita martini scandretti Blow and Banner, 1962:111, pl. 14, figs. V-X [lower Oligocene *Globigerina oligocaenica* Zone, Sample FCRM 1922, Lindi area, Tanzania].—Blow, 1979:1342, pl. 24, figs. 6, 7 [lower Oligocene Zone O2, Sample FCRM 1922, Lindi area, Tanzania]; pl. 245, fig. 7 [lower Oligocene Zone O1, DSDP Site 14, central South Atlantic Ocean].

Globigerinita hardingae Blow, 1979:1338, pl. 178, figs. 1-5 (4 = holotype) [middle Eocene Zone E9, Sample RS. 24, Kilwa area, Tanzania].

DESCRIPTION.

Type of wall: Normal perforate, cancellate, spinose, *ruber/sacculifer*-type wall texture, an average of around 20 pores/50 μm^2 test surface area.

Test morphology: Test small, moderately low trochospiral, consisting of 3 whorls, globular, lobulate

Plate 8.9 *Globoturborotalita martini* (Blow and Banner, 1962)

1-4 (holotype BMNH P44549), Zone E15/16, Madingura River, Lindi area, Tanzania; **5-8**, *Globigerinita martini scandretti* Blow and Banner 1962 (holotype BMNH P44552), *Globigerina oligocenica* Zone, Madingura River, Lindi area, Tanzania (figs. 5-6, 8, Pearson and Wade, 2015, figs. 9.5a-b, 5d); **9-11**, *Globigerina ciperoensis* Zone, Sample Bolli 408, Cipero Fm., Trinidad; **12-13**, Zone O1, Sample NKK1-33b, 45-105 cm, Kali Kunir, Nanggulan Fm., central Java; **14**, Zone O1, Sample TDP Site 12/14/1, 81–83 cm, Tanzania (Pearson and Wade, 2015, fig. 9.8); **15**, Zone O1, Sample TDP12/14/1, 81–83 cm, Tanzania. Scale bar: **1-3, 9-15** = 100 μm; **5-7** = 60 μm; **8** = 12 μm; **4** = 10 μm.

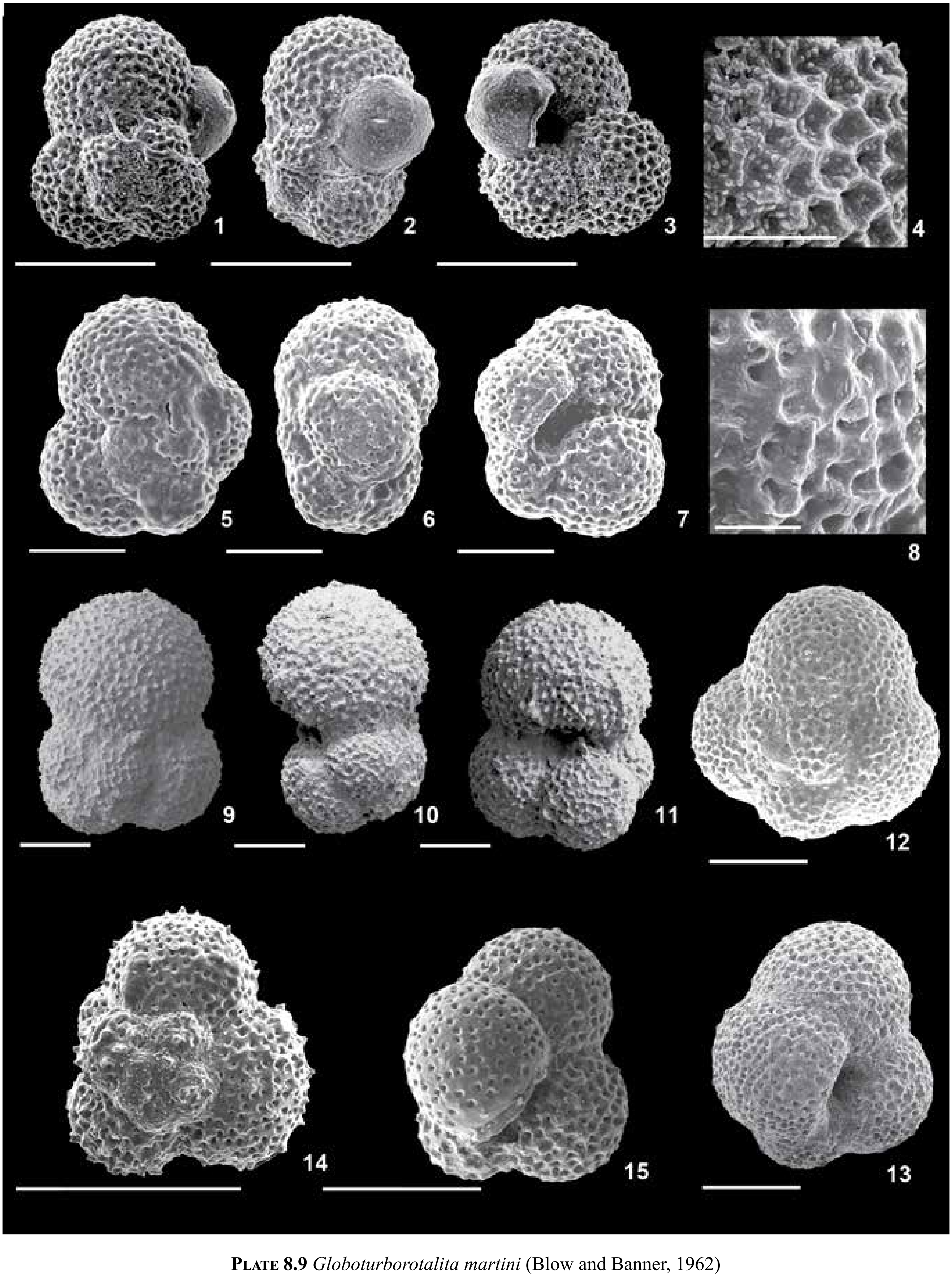

Plate 8.9 *Globoturborotalita martini* (Blow and Banner, 1962)

in outline, chambers globular; in spiral view 4 globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures depressed, straight; in umbilical view 4 globular, slightly embracing chambers, increasing rapidly in size, final chamber reduced in size extending over and partially covering the umbilicus, sutures depressed, straight, umbilicus small, partially covered by the ultimate chamber, aperture umbilical, a rounded arch, bordered by thickened rim; in edge view chambers globular in shape, slightly embracing.

Size: Holotype maximum diameter 0.22 mm.

DISTINGUISHING FEATURES.— This species is distinguished from the other species belonging to *Globoturborotalita* by its small size, 4 globular slightly embracing chambers in the last whorl and by the reduced last chamber that extends over and partially covers the umbilicus.

DISCUSSION.— See Olsson and others (2006) for discussion of this species.

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita martini* is believed to have evolved from *Globoturborotalita bassriverensis* in Zone E9 (Olsson and others, 2006) and may represent an intermediate morphology between four and five chambered species in the radiation of *Globoturborotalita* in the Eocene.

STRATIGRAPHIC RANGE.— The distribution of this species ranges from Zone E9 (Olsson and others, 2006) to Zone O5 (Spezzaferri and Premoli Silva, 1991).

TYPE LEVEL.— Upper Eocene, *Cribrohantkenina danvillensis* Zone, south side of Madingura River, about 10 km north and slightly west of Lindi, southern Tanzania, Sample FCRM 1932.

GEOGRAPHIC DISTRIBUTION.— Distributed in mid to low latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— Recorded (as *Globoturborotalita* sp.) with the most negative $\delta^{18}O$ of an upper Eocene assemblage from Tanzania by Pearson and others (2001), indicating a shallow, warm water habitat. Sexton and others (2006) suggest that *G. martini,* inhabited the mixed-layer during winter months.

REPOSITORY.— Holotype (P44549) deposited at the Natural History Museum, London.

Globoturborotalita occlusa (Blow and Banner, 1962)

Plate 8.10, Figures 1-17
(Pl. 8.10, Figs. 1-4: new SEMs of holotype of *Globigerina praebulloides occlusa* Blow and Banner)

Globigerina praebulloides occlusa Blow and Banner 1962:93, pl. IX, figs. U-W [lower Oligocene, *Globigerina oligocaenica* Zone, Cipero Fm, Trinidad].—Bolli and Saunders, 1985:181, figs. 13.12-14 [holotype, lower Oligocene, *Globigerina oligocaenica* Zone, Cipero Fm, Trinidad].—Spezzaferri and Premoli Silva, 1991:247, pl. 8, fig. 1a-d [upper Oligocene, Zone P22, DSDP Hole 538A, Gulf of Mexico].

Globigerina occlusa Blow and Banner.—Stainforth and Lamb, 1981:pl. 6, figs. 4a-c [upper Oligocene, *Globorotalia opima opima* Zone, Sample Corehole 29-42, 4,925 to 4,940 feet, Gulf of Mexico].

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber/sacculifer*-type wall texture, and an average of 46 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, consisting of 3 whorls, the profile is lobulate; in both spiral and umbilical view 3½-4 globular chambers in the last whorl, increasing moderately to rapidly in size, the last chamber is about ⅓ of the test, the sutures are depressed and straight on both sides. In edge view chambers globular in shape and slightly embracing. The umbilicus is small but distinct, it is narrow and enclosed by surrounding chambers, the aperture is an umbilical very low arch without lip.

Size: Holotype maximum diameter 0.37 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita occlusa* differs from *G. pseudopraebulloides* and *G.*

Plate 8.10 *Globoturborotalita occlusa* (Blow and Banner 1962)

1-4 (holotype P44512 BMNH); **5-8**, Zone O6, Sample PJ-271/K3-F10-76, Cipero Fm., Trinidad; **9-11**, Zone O7, DSDP Hole 538A/2H/CC, Gulf of Mexico; **12-14**, Subzone M1b, DSDP Hole 526A/28/2, 120-123 cm, South Atlantic Ocean; **15-17**, Subzone M1b, DSDP Hole 526A/27/1, 30-32 cm, South Atlantic Ocean. Scale bar: **1-3**, **5-7**, **9-17** = 100 µm; **4**, **8** = 20 µm.

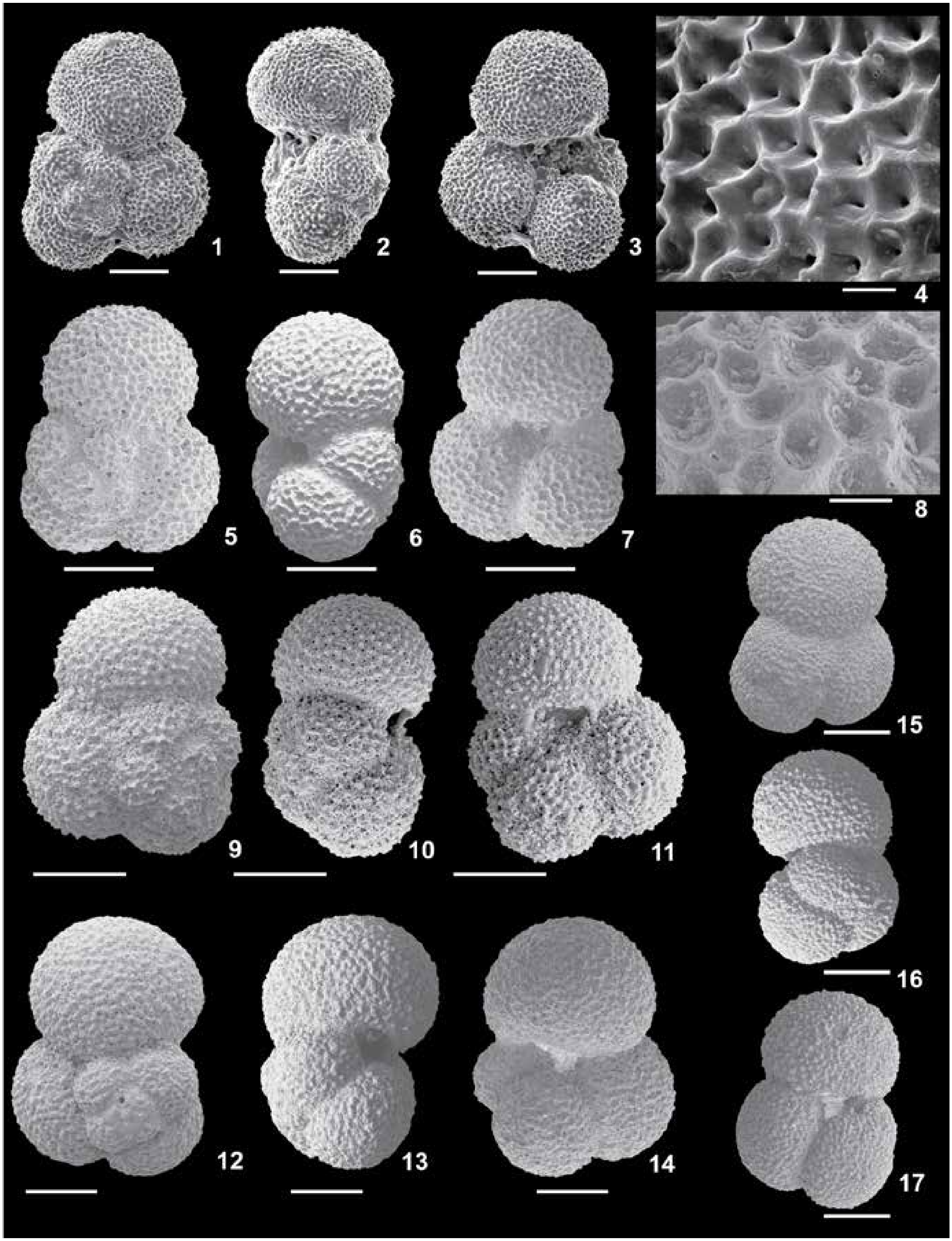

Plate 8.10 *Globoturborotalita occlusa* (Blow and Banner, 1962)

paracancellata by its low arched aperture and slightly more embracing chambers and from *G. cancellata* also by its more lobulate profile. It differs from *G. woodi* and *G. brazieri* by the low arched aperture, the more lobulate profile and the larger final chamber. It differs from *G. connecta* by the lobulate periphery, having 3½-4 well-developed chambers in the last whorl and the *ruber/sacculifer* instead of the *sacculifer*-type wall texture in *G. connecta*. It lacks the bulla-like final chamber typical of *G. martini* and has a maximum of 4 chambers in the last compared to the 4½ displayed by *G. gnaucki.*

DISCUSSION.— Banner and Blow (1962) described this species from the middle Eocene to the Aquitanian based on its similarity with specimens previously described in Bolli (1957) as *Globigerina* cf. *trilocularis* d'Orbigny 1832 (reported in Deshayes, 1832) from the middle Eocene Zone *Globorotalia cocoaensis* and from the *Globigerina ciperoensis ciperoensis*, respectively. However, the d'Orbigny species has 3 chambers in the last whorl, whereas *G. occlusa* has 4 chambers, and therefore does not show affinities with *G. trilocularis.*

Globoturborotalita occlusa has been considered by Blow and Banner (1962) as the oldest representative of the most primitive species of the *G. praebulloides* lineage, and the ancestor of *Trilobatus quadrilobatus*. This lineage is not retained here (see *G. paracancellata,* this chapter and *Trilobatus quadrilobatus* in Chapter 9, this volume).

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita occlusa* probably evolved from *G. cancellata* by developing a lower arched aperture and a more lobulate profile.

STRATIGRAPHIC RANGE.— Rare specimens attributed to this species are documented in ODP Leg 115 sites in the Indian Ocean in Zone O1 (Premoli Silva and Spezzaferri, 1990), however it commonly occurs from the lower Zone O4 (Spezzaferri, 1994). Ćorić and others (2012) report this species from the Serravallian (middle Miocene) of the Karaman high plain (Turkey, Konya Province). Like *G. ouachitaensis,* forms adhering strictly to the holotype are rare.

TYPE LEVEL.— Lower Oligocene *Globigerina oligocaenica* Zone, from the south side of Madingura River, north and slightly west of Lindi, southern Tanzania, Sample FCRM 1922.

GEOGRAPHIC DISTRIBUTION.— Global in low to mid-latitudes, including Tethys region. Most commonly described from the Atlantic Ocean. Ćorić and others (2012) report this species from the Serravallian of the Karaman high plain (Turkey, Konya Province).

STABLE ISOTOPE PALEOBIOLOGY.— Stewart and others (2004) measured relatively negative $\delta^{18}O$ for this species indicating a mixed-layer habitat.

REPOSITORY.— Holotype (P44512) deposited at the Natural History Museum, London.

***Globoturborotalita ouachitaensis* (Howe and Wallace, 1932)**

Plate 8.11, Figures 1-21
(Pl. 8.11, Figs. 1-3: new SEMs of the holotype of *Globigerina ouachitaensis* Howe and Wallace)

Globigerina ouachitaensis Howe and Wallace, 1932:74 (partim), pl. 10, fig. 5a-b [upper Eocene, Jackson Fm., Danville Landing, Louisiana].—Leckie and others, 1993:124, pl. 9, figs. 11, 12 [upper Eocene, ODP Hole 628A, Little Bahama Bank, western Atlantic Ocean].—Cicha and others, 1998:100, pl. 31, figs. 14-17 [Central Paratethys, lower Oligocene (locality unspecified)], fig. 21 [lower Oligocene, Pouzdrany unit, Pouzdrany, Moravia].

Globigerina ouachitaensis ouachitaensis Howe and Wallace.—Blow and Banner, 1962:90, pl. 9, figs. D, H, K [lower Oligocene *Globigerina oligocaenica* Zone, Sample FCRM 1627, Lindi area, Tanzania].

Globoturborotalita ouachitaensis (Howe and Wallace).—Olsson and others, 2006:122, 125, pl. 6.5, fig. 7 [mid-

Plate 8.11 *Globoturborotalita ouachitaensis* (Howe and Wallace, 1932)

1-3 (holotype, no. 716, Louisiana State University Museum, Collection Baton Rouge); **4-7**, Zone O2, Sample Bolli *G. ampliapertura* (Fribourg collection), Cipero Fm., Trinidad; **8-10**, Zone O2, Sample Bolli *G. ampliapertura* (Fribourg collection), Cipero Fm., Trinidad; **11-13**, Subzone M1b, DSDP Hole 526A/28/2, 120-122 cm, South Atlantic Ocean; **14-16**, Subzone M1b, DSDP Hole 151/5/2, 52-53 cm, Caribbean; **17**, **18**, Zone O1, Sample NKK1/33b, 45-105 cm, Kali Kunir, Nanggulan Fm., Central Java; **19-21**, *Globorotalia opima* Zone, Sample Bolli 381, Cipero Fm., Trinidad. Scale bar: **1-6**, **8-16**, **19-21** = 100 µm; **17** = 50 µm; **18** = 20 µm; **7** = 10 µm.

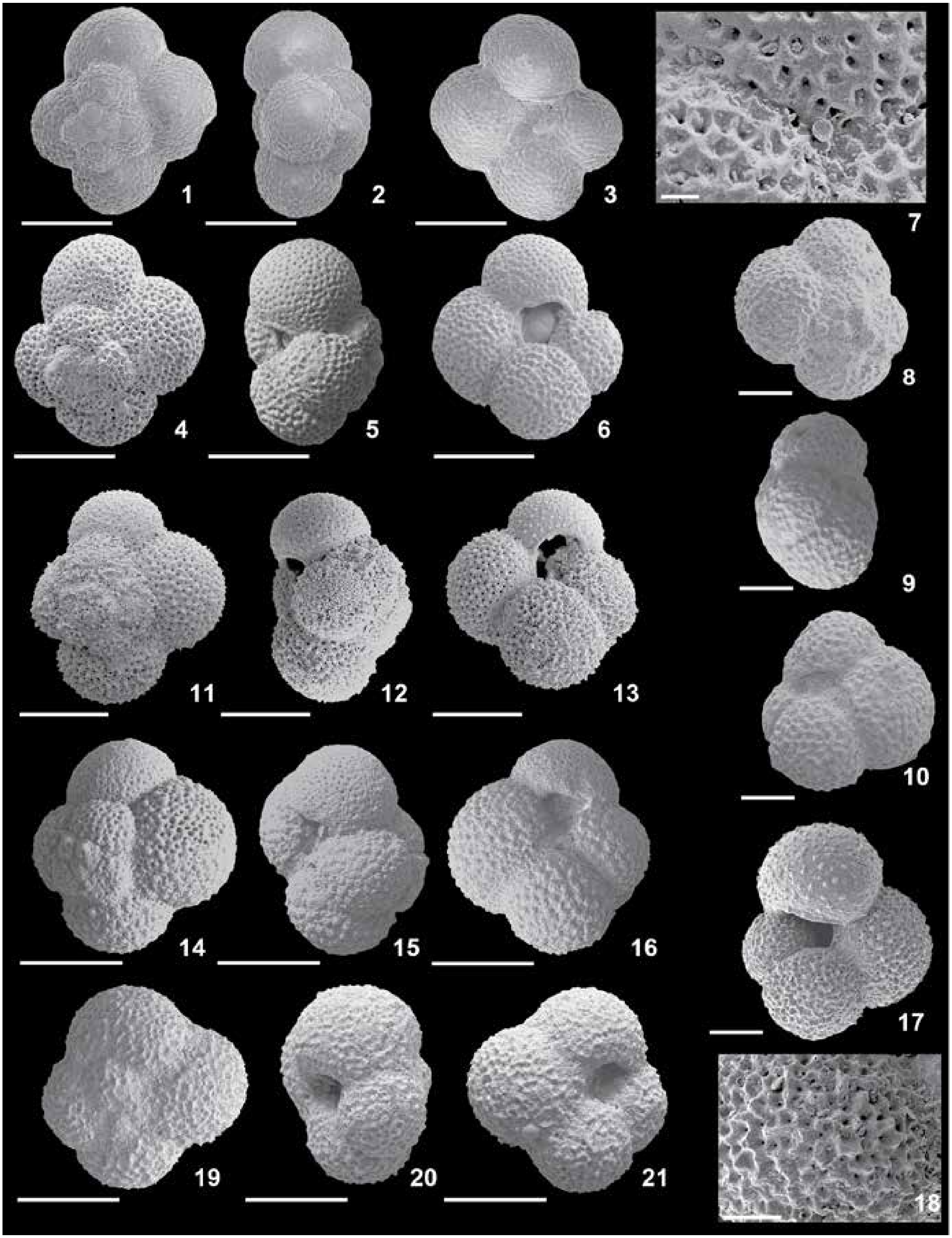

Plate 8.11 *Globoturborotalita ouachitaensis* (Howe and Wallace, 1932)

dle Eocene Zone E15/16, Shubuta Clay, Wayne County, Mississippi], figs. 15, 16, [middle Eocene Zone E10/11, Guayabal Fm, type locality, Tampico, Mexico].—Sexton and others, 2006:6, pl. 1, figs. 4, 5 [middle Eocene Zone E13, ODP Site 1052, Blake Nose, western North Atlantic Ocean].

?*Globigerina bollii lentiana* Rögl, 1969:220, pl. 3, fig. 1 [lower Miocene Nannoplankton Zone NN2, Ottnangian, Phosphoritsande, Plesching near Linz, Austria].

Globigerina officinalis Subbotina.—Samanta, 1970:191, pl. 1, figs. 2, 3 [middle Eocene Zone E12, Lakhpat, Cutch, western India].—Charollais and others, 1980:64, pl. 6, figs. 5-7 [lower Oligocene, Vernay, France].

Globigerina praebulloides occlusa Blow and Banner.—Samanta, 1970:191, pl. 1, figs. 5, 6 [middle Eocene Zone E12, Lakhpat, Cutch, western India].

Not *Globigerina ouachitaensis* Howe and Wallace.—Samanta, 1970:191, pl. 1, figs. 10-12 [middle Eocene Zone E12, Lakhpat, Cutch, western India].—Spezzaferri and Premoli Silva, 1991:237, pl. 6, fig. 5a-c [upper Oligocene Zone O6, DSDP Hole 538A, Gulf of Mexico] = *Globoturborotalita pseudopraebulloides* Olsson and Hemleben n. sp.

Not *Globoturborotalita ouachitaensis* (Howe and Wallace).—Olsson and others, 2006:122, 125, pl. 6.5, figs. 1-6 [middle Eocene Zone E15/16, Shubuta Clay, Wayne County, Mississippi] = *Globoturborotalita pseudopraebulloides* Olsson and Hemleben n. sp.

DESCRIPTION.

Type of wall: Cancellate, normal perforate, spinose, *ruber/sacculifer*-type wall structure, an average of 27 pores/50 μm^2 test surface area.

Test morphology; Test small, moderately low trochospiral consisting of 4 whorls. The profile is diamond-shape and lobulate, chambers globular; in spiral view 4 globular, slightly embracing chambers in ultimate whorl, increasing slowly in size, sutures depressed, straight; in umbilical view 4 globular, slightly embracing chambers, increasing slowly in size, sutures depressed, straight. The last chamber is smaller than the previous ones. The umbilicus is small but open, enclosed by surrounding chambers, aperture umbilical tending towards the peripheral margin, a low arch, bordered by a lip; in edge view chambers globular in shape, slightly embracing, initial spire of chambers slightly elevated.

Size: Holotype maximum diameter 0.19 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita ouachitaensis* can be distinguished from the other species of *Globoturborotalita* by its overall smaller size, the rather gradual rate of chamber size increase in the final whorl, the reduced size of the final chamber compared to the penultimate, and the low arched aperture tending to the peripheral margin. These features give a distinctive diamond-shape to the peripheral outline. *Globoturborotalita ouachitaensis* differs from *G. eolabiacrassata* Spezzaferri and Coxall n. sp. by its higher arched aperture, the absence of the very thick rim bordering the aperture and for the distinctive diamond-shape outline missing in *G. eolabiacrassata.*

DISCUSSION.— When the *Atlas of Eocene Planktonic Foraminifera* was published the holotype of *G. ouachitaensis* was not available (Olsson and others, 2006). Its wall texture was described as *sacculifer*-type. Now that we have SEM images for comparison it is apparent that some specimens attributed to *G. ouachitaensis* by Olsson and others (2006) do not strictly adhere to the holotype morphology and that the wall texture of the holotype is *ruber/sacculifer*-type. These have been variably assigned to *G. pseudopraebulloides* Olsson and Hemleben n. sp. and *G. bassriverensis* Olsson and Hemleben. Forms adhering strictly to the holotype are rare. For additional discussion of this species see Olsson and others (2006).

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita ouachitaensis* probably originated from *Globoturborotalita bassriverensis* Olsson and Hemleben, by modification of the chamber arrangement and opening of the aperture to give the diamond-shaped outline of the peripheral margin.

STRATIGRAPHIC RANGE.— Zone E10 (Olsson and others, 2006) to Subzone M1b (this study).

TYPE LEVEL.— Upper Eocene, Jackson upper horizon (bed 2) from Danville Landing on the Ouachita River, Catahoula Parish, Louisiana.

GEOGRAPHIC DISTRIBUTION.— Distributed in mid- to low latitudes, the Tethys region and North Atlantic Ocean.

STABLE ISOTOPE PALEOBIOLOGY.— *Globoturborotalita ouachitaensis* records the most negative $\delta^{18}O$ of an upper Eocene assemblage from Tanzania

(Wade and Pearson, 2008), indicating a shallow, warm water habitat. Sexton and others (2006) similarly suggest that *G. ouachitaensis* from the western North Atlantic Ocean, together with other co-occurring species of *Globoturborotalita*, inhabited the mixed-layer during winter months.

REPOSITORY.— Holotype deposited in the micropaleontological collections, Louisiana State University (No. 716). Paratype (USNM CC18946) at the Smithsonian Museum of Natural History, Washington, D.C.

Globoturborotalita paracancellata **Olsson and Hemleben, new species**

Plate 8.12, Figures 1-17

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber/sacculifer*-type wall texture, an average of 17 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, consisting of 3 whorls, globular, moderately lobulate profile, chambers globular; in spiral view 3½ globular, slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures depressed, straight; in umbilical view 3½ globular, slightly embracing chambers, increasing rapidly in size, sutures depressed, straight, umbilicus small, open, enclosed by surrounding chambers, aperture umbilical, a rounded arch, bordered by a thin thickened rim; in edge view chambers globular, slightly embracing, initial whorl of chambers flat.

Size: Maximum diameter of holotype 0.43 mm, minimum diameter 0.32 mm, thickness 0.30 mm.

ETYMOLOGY.—Named *paracancellata* because it evolves from *G. cancellata.*

DISTINGUISHING FEATURES.— *Globoturborotalita paracancellata* has a subbotinid-type morphology but differs in possessing a reticulate globoturborotalitid *ruber/sacculifer*-type wall and a thickened rim bordering the circular to moderately high arched aperture instead of a lip, as is typical of *Subbotina*. *Globoturborotalita cancellata* can be distinguished from *G. paracancellata* by having only 3½ chambers in the final whorl and a lower pore density than *G. paracancellata*. *Globoturborotalita cancellata* also has a generally smaller test. It differs from *G. occlusa* by the more open umbilical and higher arched aperture, bordered by a narrow rim that is absent in *G. occlusa*. It differs from *G. woodi* and *G. brazieri* by the lower arched aperture and by its 3½ chambers in the last whorl. *G. connecta* has a remarkably lower arched aperture. It differs from *G. ouachitaensis* also by its larger size and *G. pseudopraebulloides* Olsson and Hemleben n. sp. by having an apertural rim.

DISCUSSION.— Blow and Banner (1962) derived "*Globigerinoides*" from their subspecies *Globigerina praebulloides occlusa*. However, we do not retain here this lineage (see Chapter 9, this volume). According to our observations, the origin of the genus *Trilobatus* is preceded by morphotypes typified by *Globoturborotalita paracancellata* n. sp., which is hypothesized as the ancestral species.

PHYLOGENETIC RELATIONSHIPS.— The species name *paracancellata* is chosen because it is believed that this species evolved from *Globoturborotalita cancellata* by a more rapid increase in chamber size and having 3½ chambers in the ultimate whorl and developing a *ruber/sacculifer*-type wall texture.

STRATIGRAPHIC RANGE.— The illustrated specimens on Plate 8.12 range from Zone O1 to Zone O6. We have identified the species in samples from the uppermost Eocene Zone E16.

TYPE LEVEL.— Zone O6, Atlantic Slope Project corehole 5B 10F/6-12", western Atlantic Ocean.

GEOGRAPHIC DISTRIBUTION.— Known so far in the western Atlantic Ocean and the U.S. Gulf Coast. Probably widespread in low to middle latitudes due to its ancestry to *Trilobatus primordius*.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM 598584) and paratype (USNM 598585) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Globoturborotalita pseudopraebulloides Olsson and Hemleben, new species

Plate 8.13, Figures 1-17

Globigerina praebulloides praebulloides Blow, ideotype, 1962:92, pl. IX, figs. O-Q [lower Oligocene Zone P19, Tanzania]. [Not Blow, 1959.]

Globigerina praebulloides Blow.—Chaproniere, 1980:109, figs. 4 Ea-d, Ja,b [upper Oligocene/lower Miocene Zone O7/M1, northwest Australia].—Kennett and Srinivasan, 1983:36, pl. 36, figs. 1-3 [upper Oligocene Subzone N4a, DSDP Site 289, western equatorial Pacific Ocean].—Spezzaferri and Premoli Silva, 1991:246, pl. VI, figs. 3a-c, 4a-d, 6a-c, [upper Oligocene Zone P22, DSDP Hole 538A, Gulf of Mexico].—Spezzaferri, 1994:27, pl. 2, figs. 3a-c [lower Miocene Subzone N4b, DSDP Hole 516F, Rio Grande Rise, South Atlantic Ocean].—Li and McGowran, 2000:42, fig. 23E [lower Miocene Zone SN 2, southeastern Australia].

?*Globigerina bollii lentiana* Rögl, 1969:220, pl. 3, fig. 1 [lower Miocene, Nannoplankton Zone NN2, Phosphoritsande, Plesching near Linz, Austria].

Globigerina cf. *bulloides* d'Orbigny.—Pearson and Wade, 2009:203, pl. 4, figs. 1a-d [upper Oligocene Zone O7, Trinidad].

Globoturborotalita sp. C Li and McGowran, 2000:45, figs. 20C, D [lower Miocene, Zones SN2, southeastern Australia].

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber/sacculifer*-type wall texture, an average of 30 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, consisting of 3 whorls, lobulate in outline, chambers globular; in spiral view 4 slightly embracing chambers in ultimate whorl, increasing rapidly in size, sutures depressed, straight; in umbilical view 4 slightly embracing chambers, increasing rapidly in size, sutures depressed, straight, umbilicus large, open, enclosed by surrounding chambers, aperture umbilical, a rounded arch, a very thin rim may be present; in edge view slightly embracing, initial whorl of chambers slightly elevated.

Size: Maximum diameter of holotype 0.28 mm, minimum diameter 0.26 mm, maximum width 0.20 mm.

ETYMOLOGY.—Named *pseudopraebulloides* because the name *praebulloides* was previously used by workers for these forms in the lower Miocene and Oligocene.

DISTINGUISHING FEATURES.— Identified by its lobulate test with 4 rapidly enlarging chambers in ultimate whorl, large open umbilicus, and umbilical aperture. *Globoturborotalita pseudopraebulloides* is distinguished from *G. paracancellata* by having 4 complete chambers in the ultimate whorl, more evolute coiling, and a more open umbilicus. *Globigerina leroyi* Blow and Banner differs by having a *bulloides*-type wall texture, 3½ chambers in the ultimate whorl, a slower rate of chamber size increase, and smaller pore diameters. The low porosity *ruber/sacculifer*-type wall distinguishes *G. pseudopraebulloides* from other morphologically similar species with *bulloides*-type wall texture, such as *Globigerina archaeobulloides* n. sp., and *G. bulloides.*

DISCUSSION.— Blow's species *Globigerina praebulloides* has been used by many workers to represent forms resembling *Globigerina bulloides* and considered to be early representatives of the *bulloides* lineage. SEM images of the holotype of *praebulloides* reveal a *bulloides*-type wall texture (Plate 6.8, Figs. 4-6, Chapter 6, this volume), however, the morphology is of a globigerinellid, i.e. evolute coiling and an extraumbilical aperture, and it is regarded as a junior synonym of *Globigerinella obesa* Bolli, therefore invalidating the name. In contrast, the majority of forms identified as *G. praebulloides* have a lobulate *bulloides* test morphology but lack the *bulloides*-type wall texture, having instead a much lower pore density and a significantly larger pore diameter than in *G. bulloides*. These wall textures can be attributed to the *ruber/sacculifer*-type. *Globoturborotalita pseudopraebulloides* n. sp., described herein is designed to carry this *praebulloides* 'ideotype'. *Globigerina bulloides* s.s. appears in the upper Oligocene (Chapter 6, this volume) and overlaps in range with *G. pseudopraebulloides*. The *bulloides*-type wall texture can be traced to the lower Oligocene Zone O1 showing that the two species have separate unrelated lineages (see Chapter

Plate 8.12 *Globoturborotalita paracancellata* Olsson and Hemleben, new species

1-4 (holotype USNM 598584), Zone O6, Atlantic Slope Project corehole 5B 10F/6-12, western Atlantic Ocean; **5-8**, Zone O4, Sample Bolli 381, *Globorotalia opima* Zone, Cipero Fm., Trinidad; **9-17**, Zone O1, Sample AGS 66, 9A-1A, Shubuta Fm., Alabama. Scale bar: **1-3**, **5-7**, **9**, **11**, **13-15** = 100 µm; **4**, **8**, **10**, **12**, **16**, **17** = 50 μm^2 surface area.

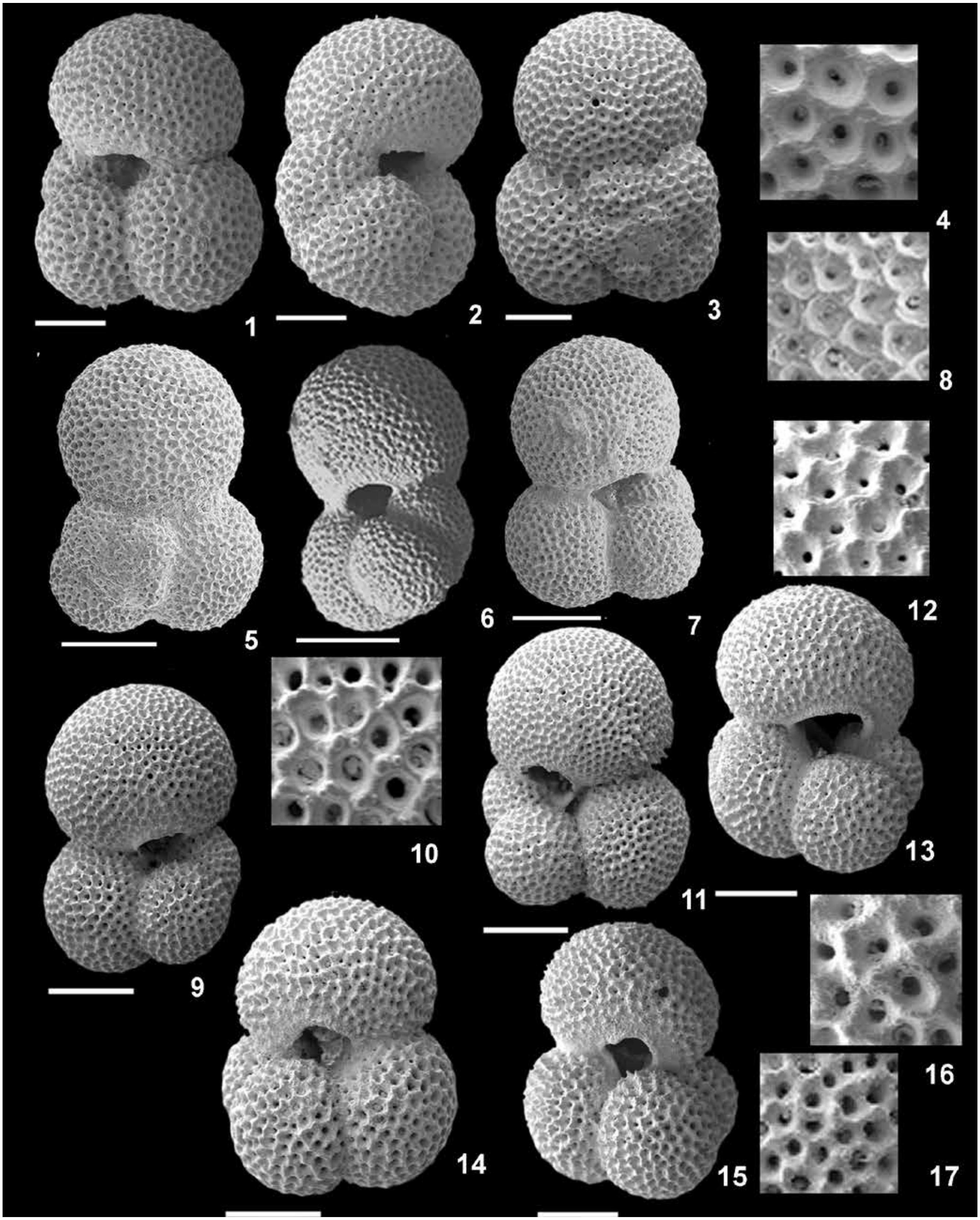

Plate 8.12 *Globoturborotalita paracancellata* Olsson and Hemleben, new species

6, this volume for further discussion).

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *Globoturborotalita occulusa* in the early Oligocene.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O2 to middle Miocene Zone M6 (Kennett and Srinivasan, 1983, Spezzaferri, 1994).

TYPE LEVEL.— Zone M1, ODP Site 904A-35-5, 101-106 cm, New Jersey continental slope, western Atlantic Ocean.

GEOGRAPHIC DISTRIBUTION.— Widespread in low and middle latitudes. Also occurs in the high latitude North Atlantic Ocean (ODP Site 647) during the lower Oligocene (this study).

STABLE ISOTOPE PALEOBIOLOGY.— Specimens identified as *Globigerina* cf. *bulloides* (here placed in *Globoturborotalita pseudopraebulloides* n. sp., Pl. 8.13, Figs. 9-11) from the Cipero Formation, Trinidad gave $\delta^{18}O$ and $\delta^{13}C$ values indicative of a mixed-layer habitat (Pearson and Wade, 2009).

REPOSITORY.— Holotype (USNM 598586) and paratype (USNM 598587) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Globoturborotalita woodi (Jenkins, 1960)

Plate 8.14, Figures 1-17
(Pl. 8.14, Figs. 1-3: new SEMs of the holotype of *Globigerina woodi* Jenkins)

Globigerina woodi Jenkins, 1960:352, pl. 2, fig. 2a-c [lower Miocene, southeastern Australia].—Jenkins, 1978:726, pl. 1, figs. 6, 7, [lower Miocene, *Globigerinoides trilobus trilobus* Zone, DSDP Site 362, Walvis Ridge, southeastern Atlantic Ocean].—Keller, 1981:200, pl. 3, figs. o-n [upper Oligocene/lower Miocene Zone N4, DSDP Site 292, northwestern Pacific Ocean].—Chaisson and Leckie, 1993:156, pl. 1, figs. 17, 18 [lower Miocene Subzone N4b, ODP Hole 806B, western equatorial Pacific Ocean].

Globigerina (*Zeaglobigerina*) *woodi* Jenkins.—Kennett and Srinivasan, 1983:43, pl. 7, figs. 4-6 [upper Miocene *Globigerina nepenthes* Zone, DSDP Site 207A, Lord Howe Rise, southwestern Pacific Ocean].

Globigerina woodi woodi Jenkins.—Basov and others, 1983:839, pl. 11, figs. 1-4 [lower Miocene, DSDP Hole 513A, Falkland Plateau, South Atlantic Ocean].

Globigerina (*Globoturborotalita*) *woodi woodi* Jenkins.—Chaproniere, 1988:129, pl. 1, figs. 1-15, 20-26; pl. 2, figs. 15-26 [lower Miocene Subzone M1b, southeastern Australia].

Zeaglobigerina woodi (Jenkins).—Spezzaferri, 1994:31-32, pl. 5, figs. 3a-c [lower Miocene Subzone N4b, ODP Hole 709B, Indian Ocean].

Globoturborotalita woodi (Jenkins).—Li and McGowran, 2000:45, fig. 20G [lower Miocene, Zone SN2, southeastern Australia].—Stewart and others, 2004: pl. A.2, figs. 12-14 [upper Miocene Zone M11-M12, Samples RAS99-38, Lindi, Tanzania].

Globigerina druryi Akers.—Hooyberghs and De Meuter, 1972:19, pl. 4, figs. 3a-c ['middle Miocene' Zone N11-N14 Antwerpen Sands, Belgium]. [Not Akers, 1955.]

DESCRIPTION.

Type of wall: Normal perforate, spinose, *ruber*/*sacculifer*-type wall texture, an average of 11 pores/50 μm^2 test surface area.

Test morphology: Low trochospiral, consisting of 3 whorls, globular, moderately lobulate in outline, chambers subglobular; in spiral view 3½-4 subglobular chambers in ultimate whorl, increasing rapidly in size, sutures depressed, straight; in umbilical view 3½-4 subglobular, slightly embracing chambers, increasing rapidly in size, sutures depressed, straight, umbilicus small, open, enclosed by surrounding chambers, aperture umbilical, a large, symmetrical, rounded arch, embracing the previous chambers; in edge view chambers globular, slightly embracing, initial whorl of chambers flat.

Size: Maximum diameter of holotype 0.45 mm.

DISTINGUISHING FEATURES.— *Globoturborotalita woodi* is distinguished by its coarsely cancellate, low porosity test, chambers symmetrically arranged around the umbilicus, and its large, symmetrical, rounded um-

Plate 8.13 *Globoturborotalita pseudopraebulloides* Olsson and Hemleben, new species

1-4 (holotype USNM 598586); **5-8** (paratype USNM 598587), Zone M1, ODP Hole 904A/35/5, 101-106 cm, New Jersey continental slope, western Atlantic Ocean; **9-11**, Zone O6 (=O7 this study), Cipero Fm., Trinidad (Pearson and Wade, 2009, pl. 4, figs. 1a-c); **12-14**, (holotype *Globigerina praebulloides* Blow, USNM 625701); **15-17**, Blow's ideotype (Blow and Banner, 1962, pl. IX, figs. O-Q [lower Oligocene Zone P19, Tanzania]). Scale bar: **1-3**, **5-7**, **9-14** = 100 µm; **4**, **8** = 50 μm^2 surface area.

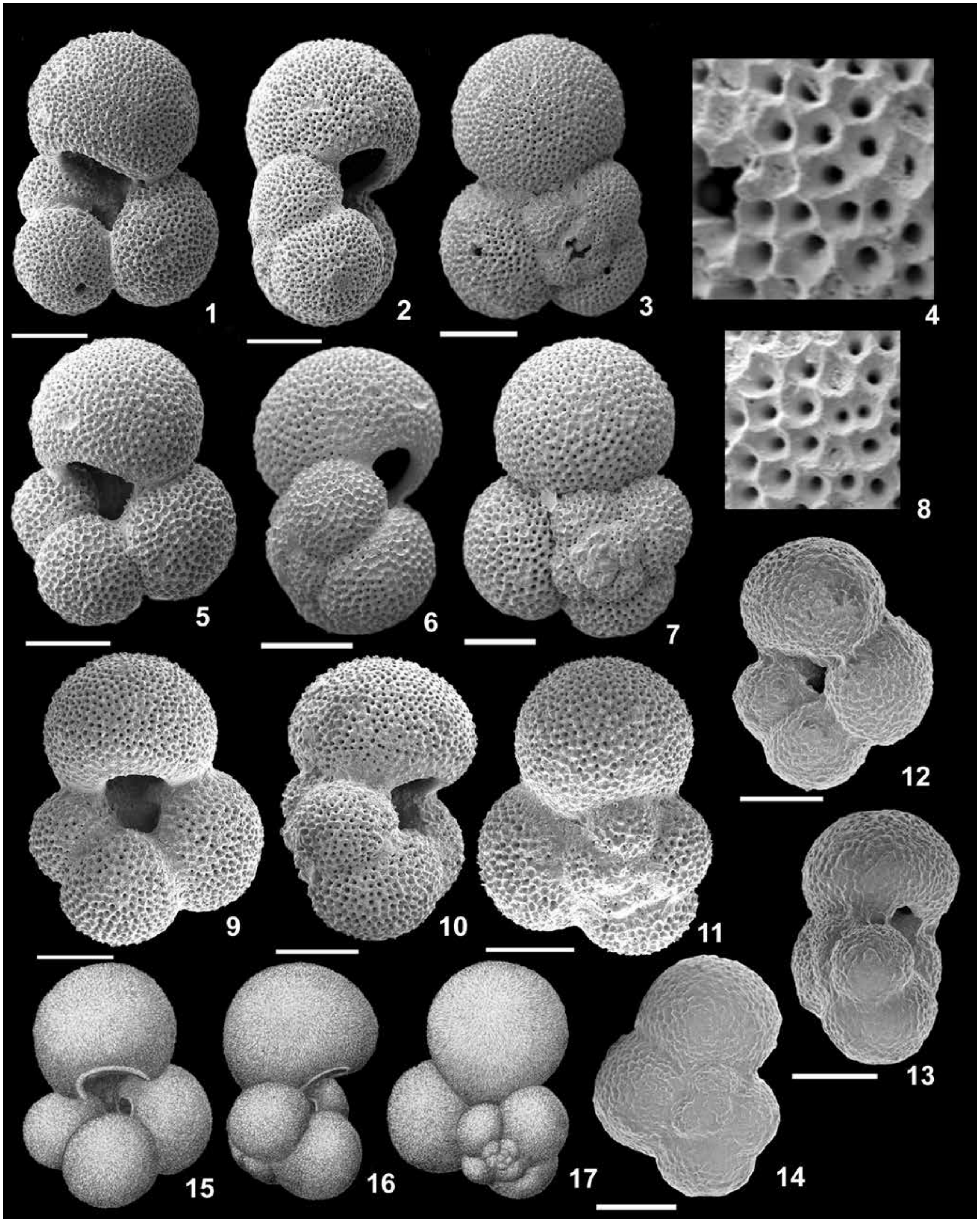

Plate 8.13 *Globoturborotalita pseudopraebulloides* Olsson and Hemleben, new species

bilical aperture. It differs from *G. brazieri* by its lower arched but wide aperture, and from *G. labiacrassata* by lacking the thick rim bordering the aperture. It is distinguished from *G. connecta* by the higher arched and umbilical aperture. It differs from *G. cancellata* and *G. paracancellata* by its more compact coiling, less lobulate profile and more symmetrical aperture.

DISCUSSION.— The species is a diagnostic form in the lower Miocene of Australia and New Zealand. Jenkins (1960, 1978) used the first appearance of this species to mark the base of the lower Miocene *G. woodi* Zone in Australia and New Zealand. However, Spezzaferri (1994) reported *G. woodi* in Subzone P21a (Zone O3/4) in DSDP Hole 588C (Tasman Sea), in DSDP Holes 526A and 360, 363 (South Atlantic Ocean), and ODP Hole 709C and 714A (Indian Ocean).

Jenkins (1960) proposed *G. praebulloides* as possible ancestor of *G. woodi*. Chaproniere (1992) proposed that *G. woodi* evolved from the warmer water species *Trilobatus quadrilobatus* through the loss of spiral apertures because of its possible appearance above a warming trend in the Australian region. However, since it has been recorded well below the first appearance of *Globigerinoides*, *G. woodi* appearance may be a migration event from higher latitudes where it evolved from a *Globoturborotalita* ancestor.

PHYLOGENETIC RELATIONSHIPS.— *Globoturborotalita woodi* probably evolved from *G. brazieri* in the late early Oligocene by developing a higher arched aperture and a more lobulate profile.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O4 (Spezzaferri, 1994) to Plio-Pleistocene Zone PL6. The extinction of *G. woodi* is astronomically calibrated to 2.30 Ma (Wade and others, 2011).

TYPE LEVEL.— Miocene from northeast of Lakes Entrance township, Victoria, southeastern Australia, ranges from *G. woodi* (lower Miocene Zones M2-M3) to *G. menardii miotumida* Zones (upper Miocene Zones M11-M12).

GEOGRAPHIC DISTRIBUTION.— It is very common in Australia and New Zealand, it is also present in the Gulf of Mexico, Atlantic, including the North Sea region (Hooyberghs and De Mueter, 1972), Pacific and Indian Oceans from temperate to mid-latitudes (Spezzaferri, 1994, 1995).

STABLE ISOTOPE PALEOBIOLOGY.— Stable isotope data indicate a surface mixed-layer habitat for this species (Pearson and others, 1997). New data of Spezzaferri (unpublished) confirm the observation of Pearson and others (1997). However, Keller (1985) suggests a deeper habitat for this species.

REPOSITORY.— Bureau of Mineral Resources, Canberra, Australia (CP 4169).

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Plate 8.14 *Globoturborotalita woodi* (Jenkins, 1960)

1–3 (holotype CP 4169 repository Bureau of Mineral Resources, Canberra, Australia), Otaian Stage; **4–6**, Zone O7, DSDP 538A/2/CC, Gulf of Mexico; **7–9**, Zone O7, DSDP Hole 538A/2/CC, Gulf of Mexico; **10-13**, Subzone M1b, Sample Bolli, 407, Trinidad, **14-17**, Subzone M1b, DSDP Hole 94/10/2, 22-24 cm. Scale bar: **1-12**, **14-16** = 100 µm; **13**, **17** = 10 µm.

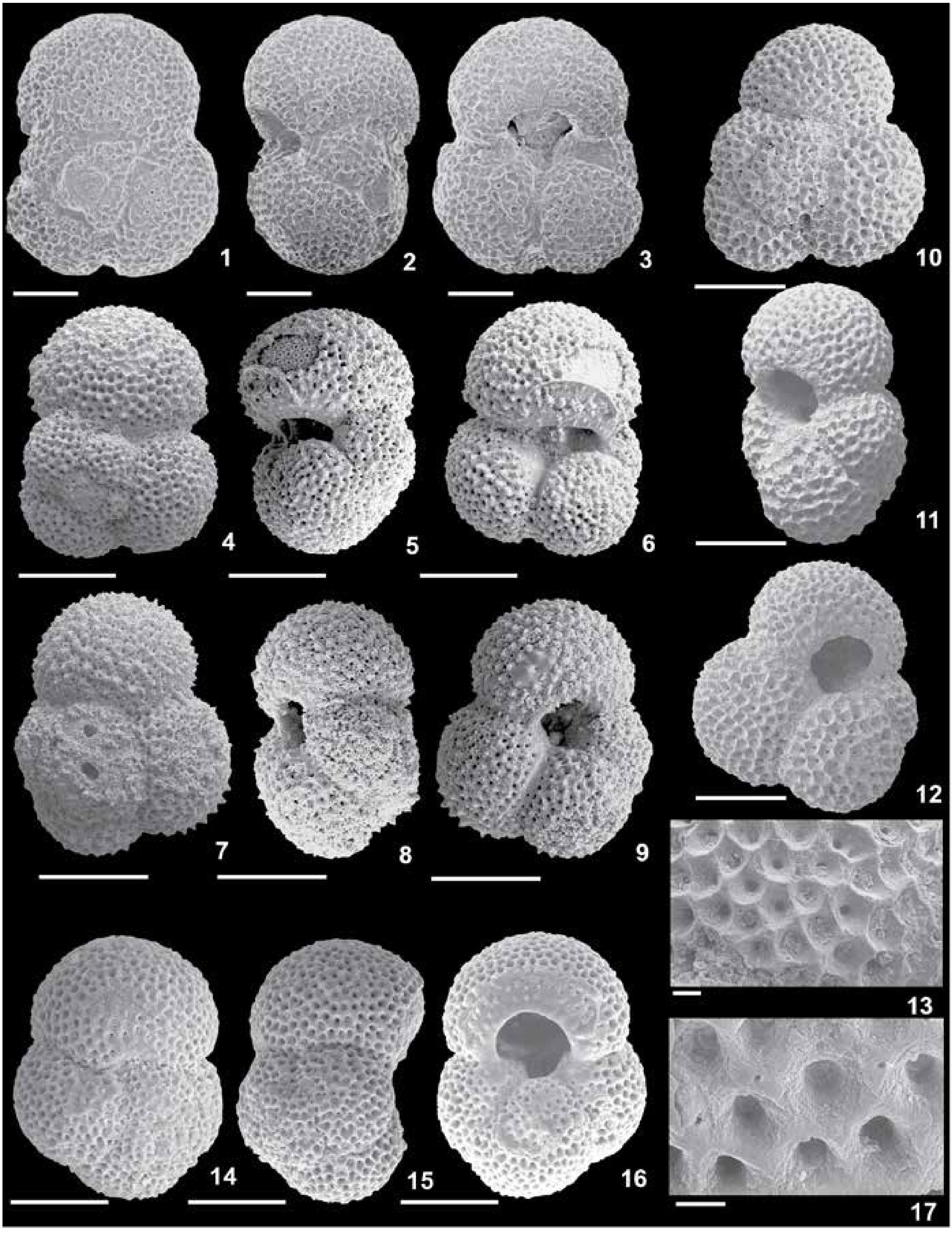

Plate 8.14 *Globoturborotalita woodi* (Jenkins, 1960)

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