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Chapter 10

TAXONOMY, BIOSTRATIGRAPHY, AND PHYLOGENY OF OLIGOCENE *SUBBOTINA*

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ABSTRACT

The taxonomy, biostratigraphy, and phylogeny of Oligocene *Subbotina* is discussed and reviewed. We include forms that have teeth extending into the umbilicus. A total of nine species are accepted as distinct, namely *Subbotina angiporoides* (Hornibrook), *Subbotina corpulenta* (Subbotina), *Subbotina eocaena* (Gümbel), *Subbotina gortanii* (Borsetti), *Subbotina linaperta* (Finlay), *Subbotina minima* (Jenkins), *Subbotina projecta* Olsson, Pearson, and Wade n. sp., *Subbotina tecta* Pearson and Wade, and *Subbotina utilisindex* (Jenkins and Orr).

INTRODUCTION

Subbotina is characterized by a cancellate spinose wall texture, globular chambers, an intra-extraumbilical aperture, which commonly has a distinct lip. The genus contains most globigeriniform planktonic foraminifera from the Paleogene. In the original description, Brotzen and Pozaryska (1961) distinguished the genus from *Globigerina* by its reticulate / cancellate wall. The diagnosis was emended by Olsson and others (1999) to include the spinose wall texture and was subsequently reviewed by Olsson and others (2006). In our review of Oligocene taxa, we incorporate some cancellate spinose forms that have a tooth and/or teeth extending into the umbilicus. Previously these forms have frequently been included in *Dentoglobigerina*, however, their rounded, globular chambers (particularly in spiral view), lobate periphery and more distinctly cancellate spinose wall texture places them in *Subbotina*. The tooth in such forms also tends to be more symmetrical than in *Dentoglobigerina.*

Subbotina evolved in the early Danian and was a significant element of Paleocene and Eocene assemblages (see, for example, Olsson and others, 1999, 2006; Koutsoukos, 2014). Geochemical studies show that most species lived in subsurface thermocline

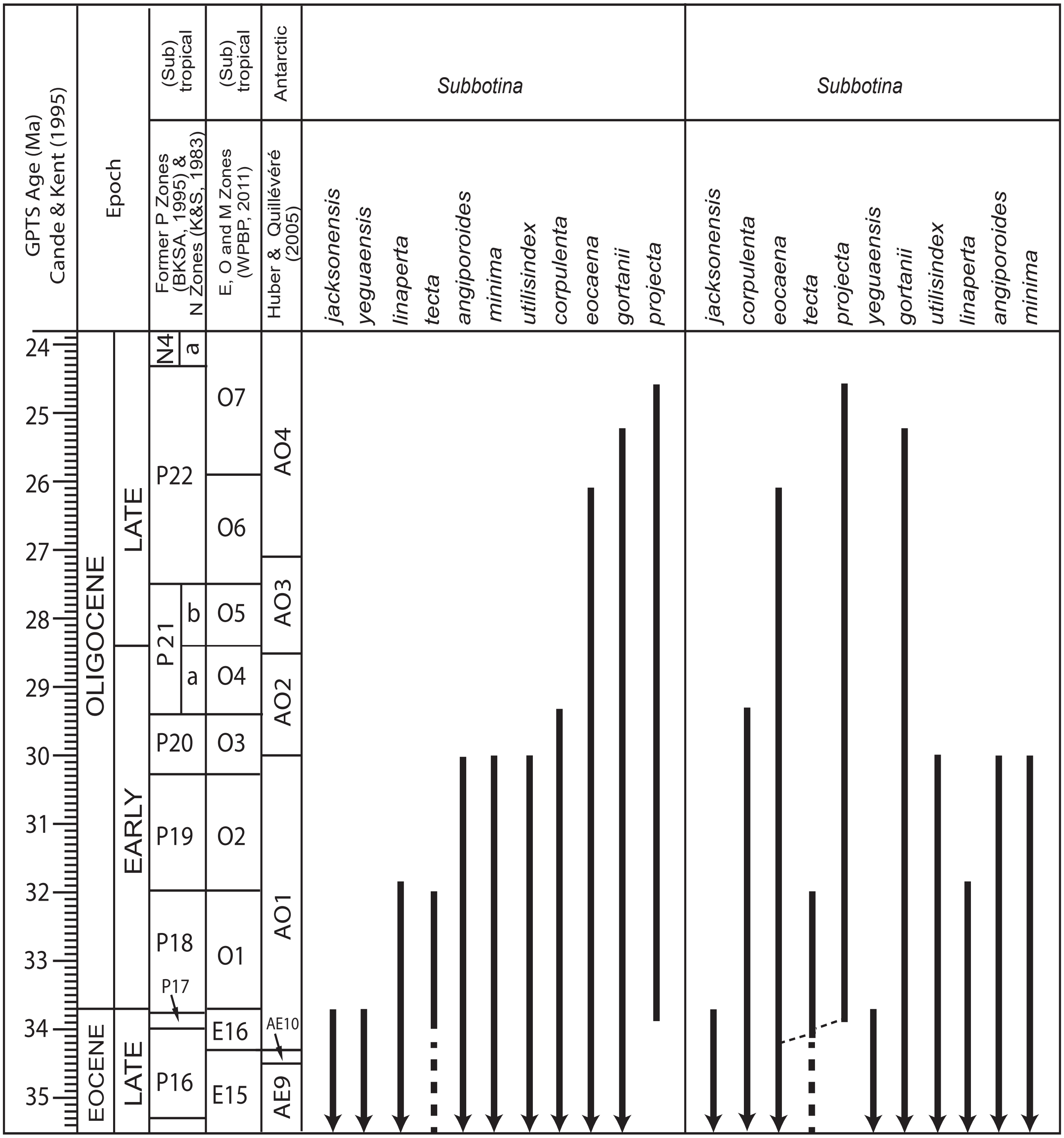

FIGURE 10.1. Stratigraphic ranges and inferred phylogenetic relationships of Oligocene species of *Subbotina* discussed in this chapter. BKSA, 1995 = Berggren and others, 1995; K&S, 1983 = Kennett and Srinivasan, 1983; WPBP, 2011 = Wade and others, 2011.

environments (Douglas and Savin, 1978; Boersma and others, 1987; and many more recent studies). Several distinct taxa survived into the Oligocene and can be abundant, particularly in the lower Oligocene. The species level range-chart and phylogenetic relationships of Oligocene *Subbotina* are shown in Figure 10.1.

The species *Globigerina senilis* Bandy has been commonly reported from Oligocene sites (e.g., Quilty, 1976; Krasheninnikov and Basov, 1983). This species was considered a junior synonym of *Subbotina jacksonensis* Bandy by Olsson and others (2006). However, the high-spired *S. jacksonensis* seems to be restricted to the Eocene and has not been found in Oligocene sediments, and most illustrated specimens of '*G. senilis*' from the Oligocene are now considered as species of *Globoturborotalita* (see Chapter 8, this volume).

SYSTEMATIC TAXONOMY

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

Genus *Subbotina* Brotzen and Pozaryska, 1961; emended Olsson, Hemleben, Berggren and Huber, 1999; herein emended

TYPE SPECIES.— *Globigerina triloculinoides* Plummer, 1926.

DISTINGUISHING FEATURES.— Low trochospiral, tripartite test consisting of 10-12 chambers, with 3-4 rapidly inflating, globular chambers in the ultimate whorl. Aperture interiomarginal, umbilical to slightly extraumbilical in most species, commonly with a low arch. Apertural lip varies from narrow to fairly broad with a distinct apparatus extending over the umbilicus, may have a projecting umbilical tooth in some species. Umbilicus small and nearly closed by tight coiling. Wall cancellate and spinose; spines set at juncture of the cancellate ridges with or without spine collars. Cancellate texture varies from weak to very strong and from moderate to very coarse or distinctly honeycombed (modified from Olsson and others, 2006).

Subbotina is distinguished from *Dentoglobigerina* by its globular chambers, lobate outline and spinose wall texture. In spiral view, *Subbotina* chambers always appear more rounded, whereas *Dentoglobigerina* chambers appear subrectangular. *Subbotina* is distinguished from *Globoturborotalita* by its generally larger size, less compact test, and more globular chambers.

DISCUSSION.— See Olsson and others (2006:125) for a discussion of the genus. The genus is emended here to include some forms with an apertural tooth.

PHYLOGENETIC RELATIONSHIPS.— "*Subbotina* evolved from *Eoglobigerina eobulloides* in the lower part of Zone Pα. *Globoturborotalita* and *Globigerina* have their origin in the genus *Subbotina*" (Olsson and others, 2006:125).

STRATIGRAPHIC RANGE.— The earliest subbotinid *S. trivialis* appears in the middle of lower Paleocene Zone Pα (Olsson and others, 2006) or P1a (Koutsoukos, 2014). Our youngest recorded specimens are from the upper Oligocene Zone O7.

GEOGRAPHIC DISTRIBUTION.— Global in low to high latitudes in northern and southern hemispheres.

Subbotina angiporoides (Hornibrook, 1965)

Plate 10.1, Figures 1-8

Globigerina angipora Stache.—Finlay, 1939:125 [not illustrated]. [Not Stache, 1865 = *nomen dubium*.]

Globigerina angiporoides Hornibrook, 1965:835-838, text-figs. 1a-i, 2 [uppermost Eocene, Campbells Beach, South Island, New Zealand].—Quilty, 1976:637, pl. 1, figs. 5, 6 [lower Oligocene Zone P19, DSDP Site 321, Nazca Plate, southeast Pacific Ocean].—Loubere, 1985, pl. 4, fig. 4 [lower Oligocene Zone P20, DSDP Hole 549A, northeast Atlantic Ocean].—Poore, 1984, pl. 2, figs. 5, 6 [lower Oligocene Zone OL2, DSDP Site 522, Angola Basin, South Atlantic Ocean].—van Eijden and Smit, 1991:109-110, pl. 2, fig. 8 [lower Oligocene Zone P20, ODP Hole 756C, eastern Indian Ocean].

Globigerina (*Subbotina*) *angiporoides angiporoides* Hornibrook.—Jenkins, 1971:160-161, pl. 20, figs. 588-594 [upper Eocene-lower Oligocene, Earthquakes Marl, South Island, New Zealand].

Globigerina angiporoides angiporoides Hornibrook.—Poore and Brabb, 1977:255, pl. 1, figs. 1-4 [lower Oligocene, San Lorenzo Fm., Santa Cruz Mountains, California].

Subbotina angiporoides angiporoides (Hornibrook).—Blow, 1979:1250-1252, pl. 12, fig. 3 [metatype; uppermost Eocene, Campbells Beach, South Island, New Zealand], fig. 4 [lower Oligocene Zone P19, Lindi, Tanzania].

Subbotina angiporoides (Hornibrook).—Huber, 1991:440, pl. 5, fig. 5 [lower Oligocene Zone AP13, ODP Hole 738B, Kerguelen Plateau, South Indian Ocean].—Spezzaferri and Premoli Silva, 1991:257, pl. XV, fig. 3 [Subzone P21a = Zone O3-O5, DSDP Hole 538A, Gulf of Mexico], fig. 4 [lower Oligocene Zone P20 = Zone O1, DSDP Hole 538A, Gulf of Mexico].—Gallagher and Holdgate, 2000, fig.14 [lower Oligocene Zone P18-P21a = Zone O1-O4, Otway Basin, Australia].—Li and others, 2003, pl. 2, fig. 15 [lower Oligocene, ODP Hole 1134A, Great Australian Bight].—Olsson and others, 2006:126-129, pl. 6.6 (partim), figs. 1-3 [SEMs of holotype of *Globigerina angiporoides*, upper Eocene, Campbells Beach, South Island, New Zealand], fig. 4 [upper Eocene, Atlantic City Borehole, ODP Hole 150X, New Jersey], figs. 6, 7, 13 [upper Eocene, ODP Hole 690B, Maud Rise, Weddell Sea], figs. 8, 12, SEMs of paratype of *Globigerina angiporoides minima* Jenkins [middle Eocene *Globigerinatheka* (*Globigerapsis*) *index index* Zone (not upper Eocene as stated by Olsson and others, 2006), Hampden Beach, South Island, New Zealand].

Subbotina angiporoides minima (Jenkins).—Nocchi and others, 1991:270, pl. 6, figs. 13-15 [lower Oligocene Zone P18-P20 = Zone O1-O2, ODP Hole 703A, Subantarctic South Atlantic Ocean]. [Not Jenkins, 1965.]

Globigerina linaperta Finlay subsp. *transdanubica* Samuel, 1972:181-182, pl. 37, fig. 4a-c, pl. 38, figs. 1, 2 [upper Eocene, Nagyveleg-1 borehole, Bakony Mountains, Hungary].

Globorotalia sp. 2. Loubere, 1985:559, pl. 4, fig. 1 [lower Oligocene Zone P18, DSDP Hole 549A, northeastern Atlantic Ocean], figs. 2, 3 [upper Eocene Zone P17, DSDP Hole 549A, northeastern Atlantic Ocean].

Not *Subbotina angiporoides* (Hornibrook).—Leckie and others, 1993:125, pl. 1, fig. 18 [lower Oligocene Zone P18, ODP Hole 628A, western North Atlantic Ocean], fig. 19 [lower Oligocene Zone P19, ODP Hole 803D, Ontong Java Plateau, western equatorial Pacific Ocean], fig. 20 [lower Oligocene Zone P19, ODP Hole 628A, western North Atlantic Ocean] (= *Subbotina utilisindex*).—Olsson and others, 2006:126-129, pl. 6.6 (partim), fig. 5, SEM of paratype of *Globigerina angiporoides* [middle (not upper, as stated) Eocene, Campbells Beach, South Island, New Zealand], figs. 9-11, SEMs of holotype of *Globigerina angiporoides minima* Jenkins [middle (not upper, as stated) Eocene, Hampden Beach, South Island, New Zealand] (= *Subbotina minima*).

DESCRIPTION.

Type of wall: Spinose, normal perforate, moderately cancellate, often thickened by addition of gametogenetic calcite, *ruber/sacculifer*-type wall.

Test morphology: "Test small to moderate size, non-umbilicate, spherical, quadrilobate, axial periphery rounded; chambers inflated, increasing moderately in size, 11-13 coiled in 3 whorls, usually 4 chambers in the final whorl that are often elongated along the radial axis; final chamber usually strongly embracing, kummerform, and extended over the umbilical sutures; sutures weakly depressed, radial to slightly curved; aperture a low, indistinct, interiomarginal slit bordered by a thick lip that extends the full width of the chamber face, opening in and sometimes beyond the umbilical area" (Olsson and others, 2006:126).

Size: Holotype maximum diameter 0.45 mm; hypotype size range 0.45 to 0.55 mm.

DISTINGUISHING FEATURES.— Distinguished by often having a kummerform final chamber that resembles a bulla and extends over the umbilicus, and "a low slit-like aperture that is bordered by a thick lip and is centered over the antepenultimate chamber" (Olsson and others, 2006:126). In *S. angiporoides* the penultimate and ultimate chambers are about the same size giving rise to a test that appears compact. Furthermore, the lip on *S. angiporoides* appears continuous from one adjacent chamber to the other. It is distinguished from *S. utilisindex* by its more compact test, kummerform final chamber with slit-like aperture and 3½-4 (rather than 3) chambers in the final whorl. *Subbotina minima* has a less compact test, more open umbilicus, shorter more

Plate 10.1, 1-8 *Subbotina angiporoides* (Hornibrook, 1965); 9-16 *Subbotina minima* (Jenkins, 1965)

Subbotina angiporoides **1-3** (holotype of *Globigerina angiporoides* Hornibrook), uppermost Eocene or lowermost Oligocene, Campbells Beach, South Island, New Zealand; **4**, Zone O1, ODP Site 647, 30R/5, 10-12 cm Labrador Sea, North Atlantic Ocean; **5**, **8**, Zone AO1, ODP Hole 1137A/19R/CC, Elan Bank, Kerguelen Plateau, southern Indian Ocean; **6**, Zone AO1, ODP Hole 1137A/18R/CC, Elan Bank, Kerguelen Plateau, southern Indian Ocean; **7**, Zone E15, Nanggulan Formation, Central Java.

Subbotina minima **9** (paratype of *Globigerina angiporoides* Hornibrook), uppermost Eocene or lowermost Oligocene, Campbells Beach, South Island, New Zealand; **10-12** (holotype of *Globigerina angiporoides minima* Jenkins), upper Eocene, Hampden Beach, South Island, New Zealand; **13-14**, Zone O1, IODP Hole U1334B/26X/4, 108-110 cm, equatorial Pacific Ocean; **15-16**, Zone O1, IODP Hole U1334B/26X/5, 22-24 cm, equatorial Pacific Ocean. Scale bar: **1-16** = 100 μm.

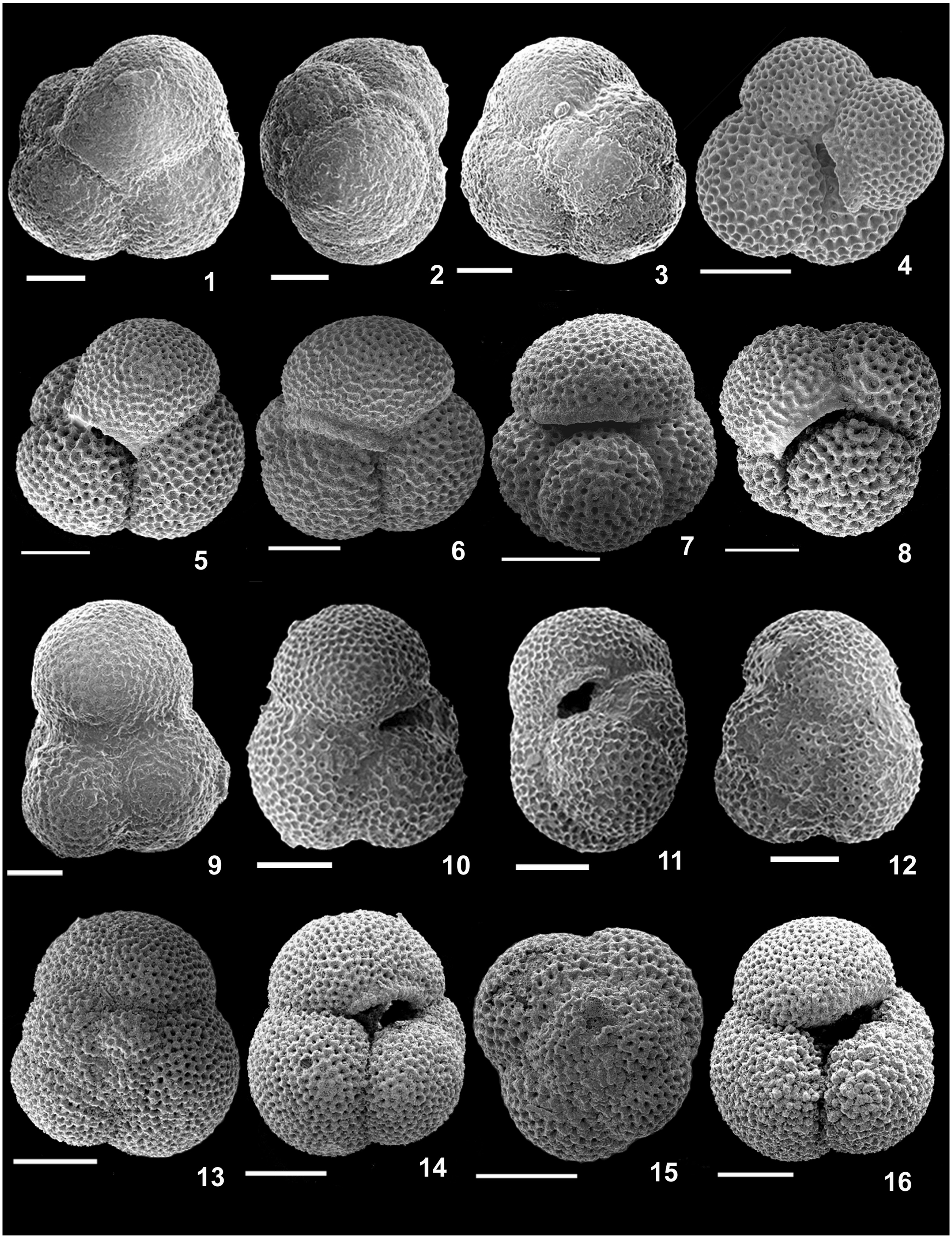

Plate 10.1 *Subbotina angiporoides* (Hornibrook, 1965), *Subbotina minima* (Jenkins, 1965)

arched aperture and often a less defined lip. It differs from *Catapsydrax unicavus* by its more compact test, well-defined lip and no bulla.

DISCUSSION.— *Globigerina angipora* Stache was described from sediments collected from the lower Oligocene (according to Hornibrook, 1965) Whaingaroa siltstone of New Zealand (Stache, 1865:287, pl. 24, fig. 36a-b). Unfortunately the description and illustrations are poor by modern standards and according to Hornibrook (1965), subsequent New Zealand taxonomists (following Finlay, 1939) identified a different form under the same name. Hornibrook (1965) declared *angipora* a *nomen dubium* and erected *angiporoides* to incorporate those forms previously described as *angipora*. A full discussion of this species was provided by Olsson and others (2006). The species is a common component of early Oligocene high latitude assemblages. Olsson and others (2006) considered *Subbotina angiporoides minima* (Jenkins) to be a junior synonym of *Subbotina angiporoides* (Hornibrook), however here we recognize *Subbotina minima* as a distinct species.

PHYLOGENETIC RELATIONSHIPS.— Descended from *S. minima* during the middle Eocene, perhaps close to the Zone P13/14 (now Zone E12/E13) boundary (Blow, 1979).

STRATIGRAPHIC RANGE.— The first appearance datum of *S. angiporoides* marks the base of middle Eocene Zone AE7 (Huber and Quillévéré, 2005). The extinction of *S. angiporoides* has been used as a primary biostratigraphic marker in the high latitude zonations of Jenkins (1965) and Stott and Kennett (1990) and is used to define the base of Zone OL4 in Poore (1984) and the base of Zone AO2 in Huber and Quillévéré (2005). *Subbotina angiporoides* is a secondary marker in the tropical zonations of Berggren and others (1995) and Wade and others (2011). The last appearance datum is within lower Oligocene Zone O3 and calibrated to Chron C11n in multiple sites (Berggren and others, 1995).

TYPE LEVEL.— Uppermost Eocene or lower Oligocene, upper *Globigerina ampliapertura* Zone, upper MacDonald Limestone, Campbells Beach, South Island, New Zealand.

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan, generally considered a high latitude form, but also recorded from low latitudes, e.g., Gulf of Mexico (Spezzaferri and Premoli Silva, 1991) and Tanzania (Blow, 1979).

STABLE ISOTOPIC PALEOBIOLOGY.— "Poore and Matthews (1984) recorded lower Oligocene samples with $\delta^{18}O$ values intermediate between other species from DSDP Site 522" (Olsson and others, 2006:129). It is generally considered to be a cool water taxon due to its prevalence in high latitudes (Spezzaferri and Premoli Silva, 1991).

REPOSITORY.— Holotype TF 1491/1 and paratypes (TF 1491/2-5) deposited at the Geological and Nuclear Science Institute, Lower Hutt, New Zealand.

Subbotina corpulenta **(Subbotina, 1953)**

Plate 10.2, Figures 1-8

?*Globigerina bulloides* d'Orbigny var. *cryptomphala* Glaessner 1937:29, pl. 1, fig. 1a,b [upper Eocene, northern Caucasus].

Globigerina cryptomphala Glaessner.— Toumarkine and Luterbacher, 1985:149, fig. 42, 5a-b [reillustration of holotype], 42.6 [reillustration of *Catapsydrax pera* (Todd) from Charollais and others, 1980, pl. 5, fig. 14, lower Oligocene, Marnes à Foraminifères, Haute-Savoie, France].

Globigerina corpulenta Subbotina, 1953:101, pl. 9, figs. 5a-7c (5a-c = holotype) [upper Eocene zone of *Globigerinoides conglobatus* and large *Globigerina*, northern Caucasus], pl. 10, fig. 1a-c [upper Eocene, subzone with large *Globigerina*, White Series, Kuban River, northern Caucasus], pl. 10, fig. 2a-c [upper Eocene *Globigerinoides conglobatus* Zone, Upper White Series, Mangyshlak Dzhaman-Kyzylyt, western Kazakhstan], pl. 10, fig. 3a-c [upper Eocene zone of *Globigerinoides conglobatus* and large *Globigerina*, Kheu River, northern Caucasus], pl. 10, fig. 4a,b [upper Eocene Lagenid zone, Kiev Stage (kw), Krasnoarmeisk, Stalingrad (Volgograd) region, Russia].

Subbotina corpulenta (Subbotina).—Olsson and others, 2006:129-134, pl. 6.7, figs. 1-3 [SEMs of holotype of *Globigerina corpulenta* Subbotina, VNIGRI No. 4033, upper Eocene, Foraminiferal layer Series F3, Kheu River, northern Caucasus], fig. 4 [middle Eocene Zone P12, Istra More-3 well, north Adriatic Sea], fig. 5 [middle Eocene Zone P14, Istra More-3 well, north Adriatic Sea], figs. 6-8 [lower-middle Eocene Zone P9, Aragon Fm, Mexico], figs. 9, 10 [upper Eocene Zone E14, *Globigerina corpulenta* Zone, Belaglin Clay Fm., Kuban River, North Caucasus], figs. 11-14 [upper Eocene Zone E14, ODP Hole 1053A, Blake Nose, western North Atlantic Ocean].—Pearson and Wade, 2015:13, fig. 10.3 [upper Eocene Zone E15/16, TDP Site 12, Stakishari, Tanzania], fig. 10.4 [lower Oligocene Zone O1, TDP Site 17, Stakishari, Tanzania].

Globigerina pseudoeocaena Subbotina var. *pseudoeocaena* Subbotina, 1953:81 (partim, not holotype), pl. 5, fig. 6a-c [lower-middle Eocene Zone of conical *Globorotalia*, Kuban River, northern Caucasus]. [Not Subbotina, 1953.]

Globigerina pera Todd, 1957:301, pl. 70, figs. 10, 11 [upper Eocene, Saipan, northern Mariana Islands].

Globigerinita pera (Todd).—Blow and Banner, 1962:112, pl.14, figs. E-H [lower Oligocene *Globigerina oligocaenica* Zone, Lindi area, Tanzania].

Catapsydrax pera (Todd).—Charollais and others, 1980, pl. 5, fig. 14 [lower Oligocene, Marnes à Foraminifères, Haute-Savoie, France].

Globigerina (*Subbotina*) *eocaena* Gümbel.—Hagn and Lindenberg, 1969:236 (partim; not pl. 1, figs. 2a-4). [Not Gümbel, 1868.]

Globorotaloides suteri Bolli.—Blow, 1979, pl. 247, fig. 10 [lower Oligocene Zone P19/P20, Cipero Fm., Trinidad]. [Not Bolli, 1957.]

Globigerina gortanii (Borsetti).—Leckie and others, 1993:123, pl. 3 (partim), fig. 7 [upper Oligocene Subzone P21b, ODP Hole 803D, Ontong Java Plateau, Pacific Ocean], fig. 11 [upper Oligocene Zone P22, ODP Hole 803D, Ontong Java Plateau, Pacific Ocean], fig. 13 [lower Oligocene Zone P19, ODP Hole 803D, Ontong Java Plateau, Pacific Ocean], figs. 8, 10 [lower Oligocene Zone P18, ODP Hole 628A, Bahama Bank, Atlantic Ocean], figs. 12, 14 [upper Oligocene Zone P22, ODP Hole 628A, Bahama Bank, Atlantic Ocean]. [Not Borsetti, 1959.]

?*Globigerina* cf. *G. gortanii* (Borsetti).—Cifelli, 1982, pl. 1, fig. 4 [upper Oligocene, *Globorotalia opima* Zone, Trinidad].

?*Subbotina senilis* (Bandy).—Rincón and others, 2007, pl. 6, fig. 6 [upper Oligocene, *Paragloborotalia opima* Zone, Carmen Fm., Bolívar, Colombia]. [Not Bandy, 1949 = junior synonym of *S. jacksonensis.*]

Not *Catapsydrax perus* (Todd).—Fleisher, 1974, pl. 4, fig. 7 (= *Catapsydrax unicavus*).

DESCRIPTION.

Type of wall: Cancellate, normal perforate, spinose.

Test morphology: Test moderately high trochospiral, lobulate in outline, chambers globular, arranged in three whorls; in spiral view 4-4½ globular chambers in ultimate whorl, increasing moderately in size, sutures moderately depressed, straight to slightly curved; in umbilical view 4-4½ globular chambers, increasing moderately in size, often with a reduced ultimate chamber cantilevered over the umbilicus, sometimes centered and resembling a bulla, sutures moderately depressed, straight to slightly curved, umbilicus moderate in size, enclosed by surrounding chambers and often partly to entirely covered by the ultimate chamber, aperture umbilical, deep, with or without a lip; in edge view test with a moderately elevated initial whorl, chambers globular in shape, aperture generally not visible (modified from Olsson and others, 2006).

Size: Maximum diameter of holotype 0.57 mm, thickness 0.38 mm.

DISTINGUISHING FEATURES.— “The species is characterized by its generally large adult size, moderately elevated initial spire, lobulate test, globular chambers and the cantilevered ultimate chamber directed over the umbilicus” (Olsson and others, 2006:130). It is distinguished from *Subbotina eocaena* by its less developed lip and common bulla-like ultimate chamber. The frequency of a bulla-like chamber on *S. corpulenta* could lead to confusion with the genus *Catapsydrax* (e.g., Blow, 1979, pl. 247, fig. 10) and *Subbotina gortanii* (Leckie and others, 1993, pl. 3). However, *S. corpulenta* is distinguished from *C. unicavus* by its more lobate periphery, less compact coiling and generally more incised sutures, and from *S. gortanii* by its lower trochospire and more lobate periphery.

DISCUSSION.— *Subbotina corpulenta* can be common in Oligocene low latitude assemblages. The specimen selected for a holotype by Subbotina (1953) lacks a cantilevered ultimate chamber, but she discusses the common presence of a ‘bulla’ in the specimens she studied from Northern Caucasus. The ultimate chamber can be highly variable in *S. corpulenta* in terms of size, position and development; in some of our specimens it is well developed, appearing more as a cantilevered ultimate chamber with a lip or tooth. The name *corpulenta* indicating fat or stout is somewhat misleading. Our specimens are not particularly high-spired or portly, especially in comparison to large forms such as *gortanii*.

As in Olsson and others (2006) we consider *Globigerina pera* Todd from the upper Eocene to be a junior synonym of *Subbotina corpulenta*, however, many specimens have been confused with *Catapsydrax unicavus* (see Chapter 4, this volume). *Globigerinita*

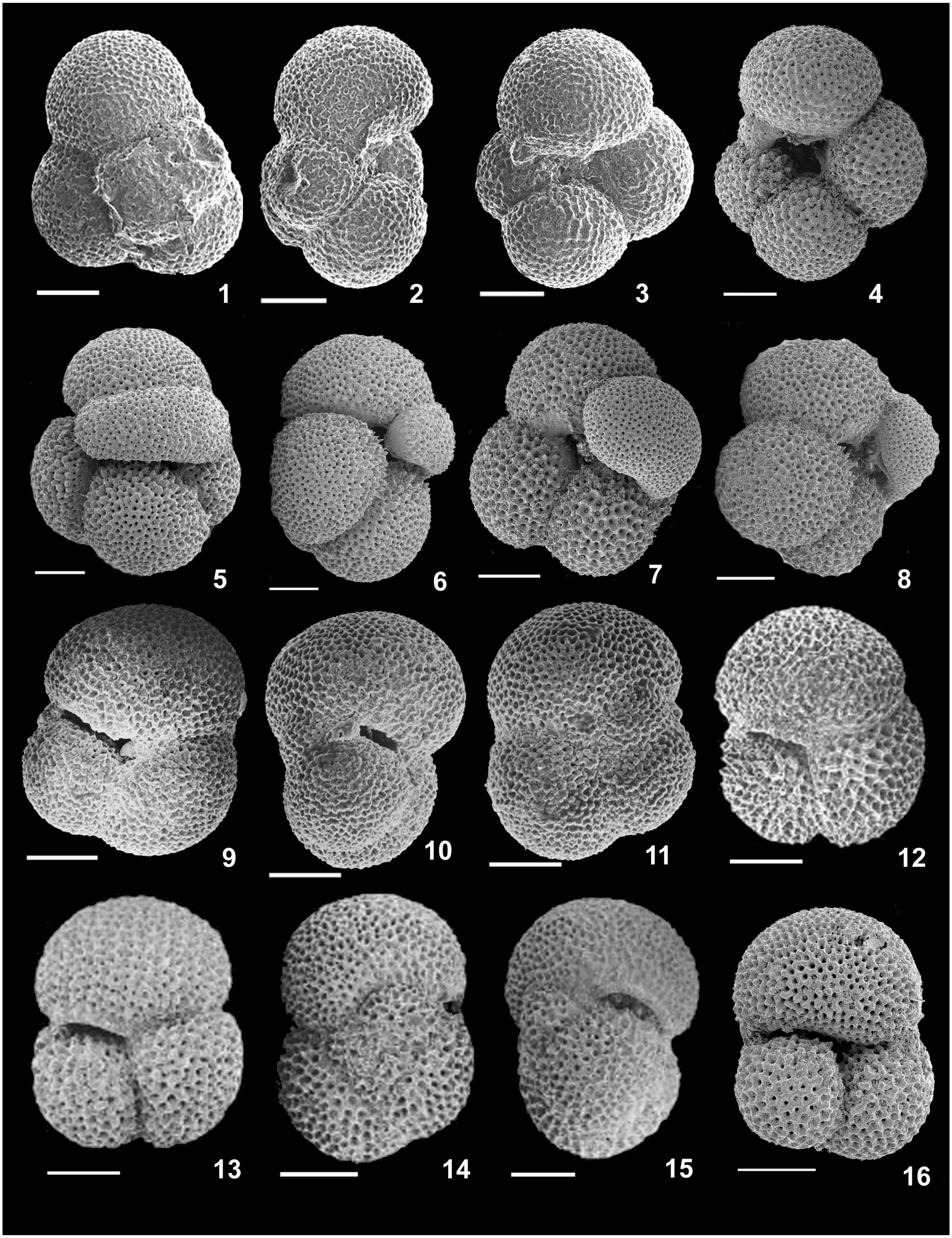

Plate 10.2 *Subbotina corpulenta* (Subbotina, 1953), *Subbotina utilisindex* (Jenkins and Orr, 1973)

riveroae Bermúdez is considered to be a junior synonym of *Catapsydrax dissimilis* (see Chapter 4, this volume).

Globigerina hagni Gohrbandt (1967) was previously assigned to *Subbotina* by various authors including Poore and Brabb (1977) and Olsson and others (2006). Rögl and Egger (2012) re-examined and illustrated the type specimens described by Gohrbandt and concluded that *S. hagni* belonged in the genus *Parasubbotina*. We support their conclusions here. The specimens (not illustrated) assigned to *S. hagni* in Wade and Pearson (2008) with a stratigraphic range that extended into lower Oligocene Zone O1 are now considered to be *S. corpulenta* (see Pearson and Wade, 2015, for discussion).

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *Subbotina eocaena* in Zone E7.

STRATIGRAPHIC RANGE.— *Subbotina corpulenta* is first reported in Zone E7 but its extinction is not well constrained. We find specimens as young as Zone O3-O4 at ODP Site 1237 (see Pl. 10.2). Leckie and others (1993, pl. 3) illustrated specimens which they referred to as *Globigerina gortanii*, but we think are consistent with *Subbotina corpulenta*, ranging to the uppermost Oligocene.

TYPE LEVEL.— Upper Eocene, Kheu River, Nalchik, North Caucasus, Russia.

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

STABLE ISOTOPE PALEOBIOLOGY.— Wade and Pearson (2008) record relatively negative $\delta^{18}O$ for *S. corpulenta* in the upper Eocene, but more positive $\delta^{18}O$ relative to other species in the lower Oligocene. At IODP Site U1334 (equatorial Pacific Ocean), multispecies stable isotope investigations show that *S. corpulenta* has very similar $\delta^{18}O$ and $\delta^{13}C$ values to co-occurring *S. minima* and *S. utilisindex* (Moore and others, 2014). Poore and Matthews (1984) and Boersma and others (1987) record *Globigerina perus* and *Catapsydrax perus*, respectively (now considered junior synonyms of *Subbotina corpulenta*) as having the most positive $\delta^{18}O$ of any planktonic foraminiferal species in the lower Oligocene. However, the specimens were not illustrated and we suspect that the analyzed specimens were of *Catapsydrax*, consistent with the stable isotope data and that *S. corpulenta* is rather rare in the assemblages.

REPOSITORY.— Holotype (No. 4033) deposited in the VNIGRI collections, St. Petersburg, Russia.

Subbotina eocaena (Gümbel, 1868)

Plate 10.3, Figures 1-16

Globigerina eocaena Gümbel, 1868:662, pl. 2, fig. 109a, b [upper Eocene, precise locality unknown, Bavarian Alps, Austria].

Globigerina (*Subbotina*) *eocaena* Gümbel.—Hagn and Lindenberg, 1966:349-350, pl. 1, fig. 1a-c [neotype, upper Eocene, Gerhartsreiter Graben, Siegsdorf, Bavarian Alps, Austria].—Hagn and Lindenberg, 1969:236 (partim), pl. 1, fig. 1a-c [reproduction of neotype illustration, upper Eocene, Gerhartsreiter Graben, Siegsdorf, Bavarian Alps, Austria], pl. 1, fig. 5a-c [lower Oligocene, Reit im Winkl, Bavarian Alps, Austria] (not pl. 1, figs. 2a-4 = *Subbotina corpulenta* Subbotina).

Subbotina eocaena (Gümbel).—Olsson and others, 2006:134-138, pl. 6.9, figs. 1, 2, 4-6, 9, 10 [lower-middle Eocene Zone P9, Aragon Fm, Mexico], figs. 3, 7, 8 [middle Eocene Zone P12, Guayabal Fm. type locality, Tampico, Mexico], figs. 11-13 [SEMs of holotype of *Globigerina pseudoeocaena compacta* Subbotina, 1953, VNIGRI No. 4012], figs. 14-16 [SEMs of holotype of *Globigerina pseudoeocaena trilobata* Subbotina, 1953, VNIGRI No. 4014, middle-upper Eocene, Zone of *Acarinina*, Kuban River, North Caucasus].—Pearson and Wade, 2015:14, figs. 10.5, 10.7 [upper Eocene Zone E15/16, TDP Site 12, Stakishari, Tanzania], fig. 10.6 [lower Oligocene Zone

Plate 10.2, 1-8, *Subbotina corpulenta* (Subbotina, 1953), 9-16, *Subbotina utilisindex* (Jenkins and Orr, 1973)

Subbotina corpulenta **1-3**, (holotype of *Globigerina corpulenta*, VNIGRI No. 4033), upper Eocene, Foraminiferal layer Series F3, Kheu River, North Caucasus; **4**, **7**, **8**, Zone O3/4, ODP Hole 1237B/32/3, 85-87 cm, Nazca Plate, southeastern Pacific Ocean; **5**, **6**, Zone E16, ODP Site 647/36/4, 113-115 cm, Labrador Sea.
Subbotina utilisindex **9-11**, (holotype, reproduced from Jenkins and Orr, 1973, pl. 1, figs. 1-3), lower Oligocene, DSDP Hole 77B, eastern equatorial Pacific Ocean; **12**, (Huber, 1991, pl. 5, fig. 6), ODP Site 738, Kerguelen Plateau, southern Indian Ocean; **13-15**, (Nocchi and others, 1991, pl. 6, figs. 10-12), lower Oligocene, Site 703A, Subantarctic South Atlantic Ocean; **16**, Zone O1, IODP Hole 1334A/25X/7, 43-45 cm, equatorial Pacific Ocean. Scale bar: **1-16** = 100 µm.

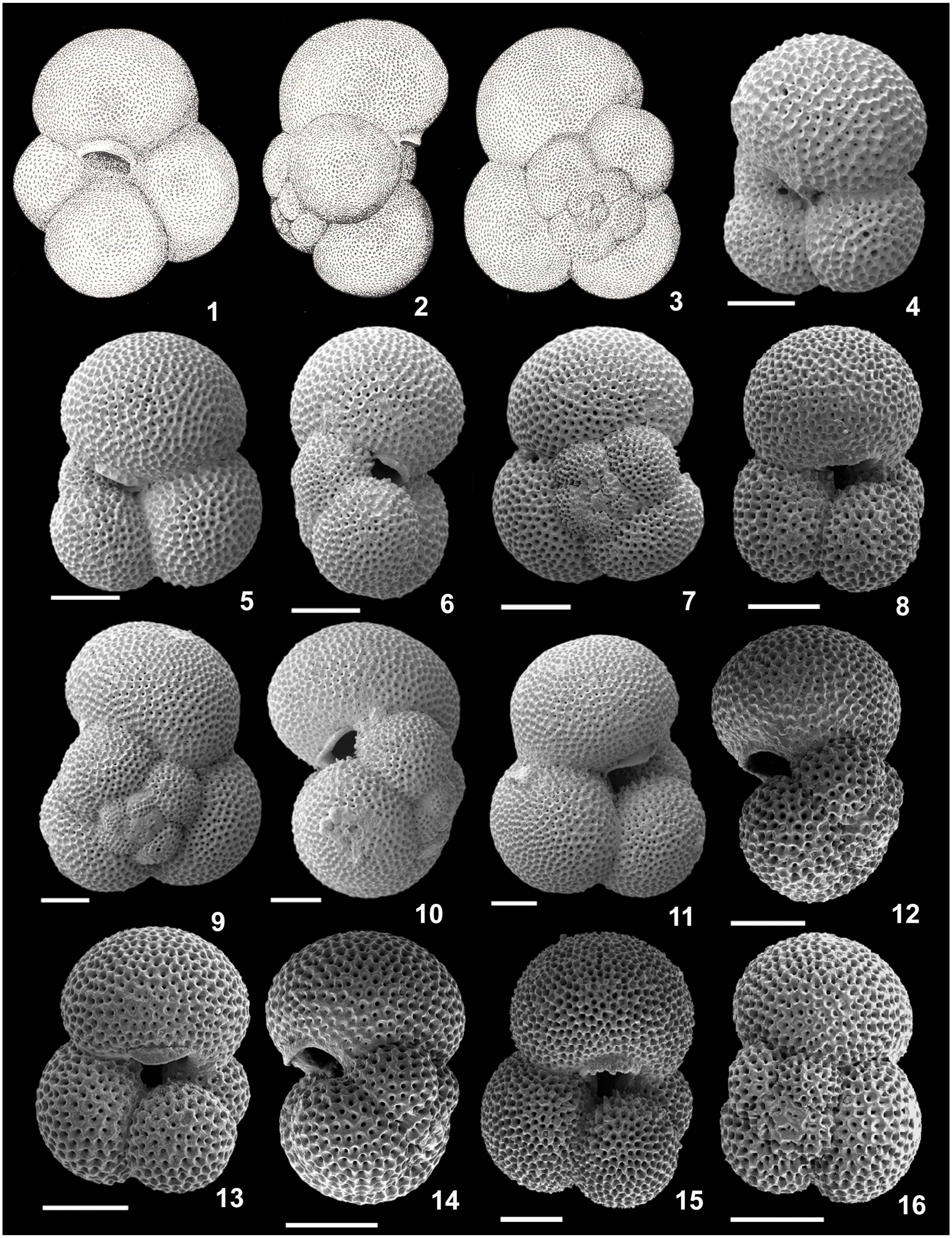

Plate 10.3 *Subbotina eocaena* (Gümbel, 1868)

O1, TDP Site 12, Stakishari, Tanzania], fig. 10.8 [lower Oligocene Zone O1, TDP Site 17, Stakishari, Tanzania].

Globigerina eocaenica Terquem, 1882:86, pl. 9, fig. 4 [middle Eocene, Vaudancourt, near Paris, France].

Globigerina eocaenica Terquem var. *irregularis* Subbotina, 1953:110, pl. 11, figs. 12a-14c [upper Eocene Lagenid Zone, Crimea].

Globigerina pseudoeocaena Subbotina var. *pseudoeocaena* Subbotina, 1953:81 (partim; not pl. 4, fig. 9a-c, holotype = *Subbotina yeguaensis* [Weinzierl and Applin]; not pl. 5, fig. 6a-c = *Subbotina corpulenta* [Subbotina]), pl. 5, figs. 1a-2c [lower-middle Eocene *Acarinina* Zone, Kuban River, northern Caucasus]. [Not Subbotina, 1953.]

Globigerina pseudoeocaena Subbotina var. *compacta* Subbotina 1953:81, pl. 5, fig. 3a-c [holotype, lower-middle Eocene *Acarinina* Zone, Kuban River, northern Caucasus], pl. 5, fig. 4a-c [upper Eocene, white marls, Bakhchisaria, Crimea].

Globigerina bulloides Subbotina var. *compacta* Subbotina, 1953:100, pl. 9, fig. 4a-c [upper Eocene subzone of large *Globigerina*, Kheu River, northern Caucasus]. Secondary homonym of *Globigerina pseudoeocaena* var. *compacta* Subbotina, 1953:81.

Globigerina subtriloculinoides Khalilov, 1956:240, pl. 1, figs. 6, 7 ["upper Eocene" (= probably middle Eocene), Abrakumis, Nakhichevan Autnomous Republic].

Globigerina (?) *winkleri* Bermúdez.—Quilty, 1976, pl. 4, figs. 17, 18 [lower Oligocene Zone P18, DSDP Site 321, Nazca Plate, southeastern Pacific Ocean]. [Not Bermúdez, 1961.]

Not *Globigerina eocaena* Gümbel.—Subbotina, 1953:85, pl. 6, fig. 5a-c; pl. 7, fig. 1a-c [= *Parasubbotina hagni* (Gohrbandt, 1967)].

Not *Subbotina*? *eocaena* (Gümbel).—Leckie and others, 1993, pl. 2, figs. 7-11 [= various species].

DESCRIPTION.

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

Test morphology: Test low trochospiral, globular, oval in outline, chambers globular arranged in three whorls; in spiral view 3½-4 globular, embracing chambers in ultimate whorl, increasing moderately rapidly in size, sutures moderately depressed, straight to slightly curved; in umbilical view 3½-4 globular, embracing chambers, increasing moderately in size, sutures moderately depressed, straight, umbilicus small, enclosed by surrounding chambers, aperture umbilical to slightly extraumbilical, directed somewhat anteriorly over the umbilicus, bordered by a thin, irregular lip; in edge view chambers globular in shape, embracing, aperture visible as a circular arch, bordered by a thin, irregular lip (modified from Olsson and others, 2006).

Size: Maximum diameter of neotype 0.69 mm, maximum thickness 0.45 mm.

DISTINGUISHING FEATURES.— *Subbotina eocaena* is typified by its low rate of chamber size increase, globular chambers, open umbilicus, with a low arched aperture bordered by a thin irregular lip. It is distinguished from *S. corpulenta* by its well-developed lip and large, globular final chamber. It is distinguished from *Subbotina tecta* by its more radially compressed chambers and lack of a prominent polygonal tooth.

DISCUSSION.— This species was discussed by Olsson and others (2006).

PHYLOGENETIC RELATIONSHIPS.— *Subbotina eocaena* probably evolved from *S. roesnaesensis* by an increase in test size and the development of globular, more embracing chambers (Olsson and others, 2006). It most likely gave rise to *Subbotina tecta* in the upper Eocene.

STRATIGRAPHIC RANGE.— *Subbotina eocaena* ranges from the early Eocene Zone E6 (Olsson and others, 2006). The extinction is currently poorly defined. Olsson and others (2006) suggested a range to lower Oligocene Zone O1, however, we have identified specimens as high as upper Oligocene Zone O6 (see Plate 10.3).

TYPE LEVEL.— This was one of the first Paleogene planktonic foraminifera to be described. Gümbel (1858) illustrated a single specimen from what he described as upper Eocene nummulitic chalk, and although he listed a number of localities, where he had found his species, he did not indicate where exactly the figured specimen came from. No repository was designated and the type series was subsequently lost, but a neotype was illustrated by

Plate 10.3 *Subbotina eocaena* (Gümbel, 1868)

1-3, (neotype, reproduced from Hagn and Lindenberg, 1969), upper Eocene, Gerhartsreiter Graben, Siegsdorf, Bavarian Alps, Austria; **4-7**, **9-11** (same specimen), Zone O6, Atlantic Slope Project corehole 5B/5A/1, 6", western North Atlantic Slope; **8**, **12**,**16** (same specimen), (Pearson and Wade, 2015, fig. 10.5a-c), **13**, **14** (same specimen), (Pearson and Wade, 2015, fig. 10.7a-b), Zone E15/16, TDP Site 12/36/1, 0-10 cm, Stakishari, Tanzania; **15**, Zone O1, TDP 12/9/2, 23-36 cm, Stakishari, Tanzania. Scale bar: **4-16** = 100 µm.

Hagn and Lindenberg (1966, 1969) from upper Eocene strata in the Gerhartsreiter Graben, Siegsdorf, Bavarian Alps, Austria.

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

STABLE ISOTOPE PALEOBIOLOGY.— "Recorded by Boersma and others (1987) and Stott and Kennett (1990) (as *S. eocaenica*) with relatively positive $\delta^{18}O$ indicating a deep planktonic habitat. Pearson and others (2001) also recorded it as a deep-dwelling form. A lowermost Oligocene sample analyzed by van Eijden and Ganssen (1995) recorded a more intermediate $\delta^{18}O$ value" (Olsson and others, 2006:138). Wade and Pearson (2008) recorded relatively negative $\delta^{18}O$ for upper Eocene specimens, but more positive values for the lowermost Oligocene.

REPOSITORY.— Neotype deposited at the Bayerischen Staatssammlung für Paläontologie u. Historische Geologie in München, Germany.

Subbotina gortanii (Borsetti, 1959)

PLATE 10.4, FIGURES 1-16
(Pl. 10.4, Figs. 1-3: new SEMs of holotype of *Catapsydrax gortanii* Borsetti)
(Pl. 10.4, Figs. 5-7, new SEMs of holotype of *Catapsydrax venzoi* Borsetti)
(Pl. 10.4, Figs. 13-15, new SEMs of holotype of *Globigerina winkleri* Bermúdez)

?*Globigerina pseudocorpulenta* Khalilov, 1956:246, pl. 4, fig. 3a-c [upper Eocene, Maly Caucasus].

Catapsydrax gortanii Borsetti, 1959:205, pl. 1, figs. 1a-d (1a-c = holotype) [lower Oligocene, 1.5 km west of Vigoleno, Piacenza Province, northern Italy].

Globigerina gortanii gortanii (Borsetti).—Blow, 1969:320, pl. 17, fig. 1 [lower Oligocene Zone P19, Lindi area, Tanzania].—Blow, 1979:851, pl. 17, fig. 1 [reillustration of Blow, 1969, pl. 17, fig. 1]; pl. 247, fig. 4 [lower Oligocene Zone P19/P20, DSDP Site 14, central South Atlantic Ocean], pl. 251, fig. 9 [upper Oligocene Zone O6, DSDP Site 14, central South Atlantic Ocean].—Charollais, and others, 1980:62, pl. 5, figs. 1, 2 [lower Oligocene, France].

Globigerina gortanii (Borsetti).—Stainforth and others, 1975:281-283, fig. 122-1-4 [Oligocene, Tinguaro Fm., Cuba].—Pujol, 1983:651, pl. 11, fig. 4 [lower Oligocene Zone O3, DSDP Hole 516F, Rio Grande Rise, southwestern South Atlantic Ocean]; pl. 15, fig. 4 [lower Miocene Zone N5/6, DSDP Site 516, Rio Grande Rise, southwestern South Atlantic Ocean].—Snyder and Waters, 1985:459, pl. 1, figs. 16-18 [upper Oligocene Zone O5, DSDP Hole 549A, Goban Spur, eastern North Atlantic Ocean].—Leckie and others, 1993:123, pl. 3 (partim), fig. 9 [lower Oligocene Zone P18, ODP Hole 628A, Bahama Bank, Atlantic Ocean].

Subbotina gortanii (Borsetti).—Spezzaferri and Premoli Silva, 1991:257, pl. XVI, fig. 3a-d [lower Oligocene Zone P18, DSDP Hole 538A, Gulf of Mexico].—Olsson and others, 2006 (partim):138-142, pl. 6.10, figs. 1-3 [SEMs of holotype of *Globigerina turritilina* Blow and Banner, 1962, BMNH P44537, lower Oligocene Zone P19, Sample FCRM 1964, Kitunda Cliff, Lindi area, Tanzania], figs. 4-8 [upper Eocene, Lindi area, Tanzania], figs. 9-12 [SEMs of holotype of *Globigerina turritilina praeturritilina* Blow and Banner, 1962, BMNH P44535, north of Kitunda Cliff, Lindi area, Tanzania].—Rincón and others, 2007:296, pl. 6, figs. 1, 2 [upper Oligocene *Paragloborotalia opima* zone, Carmen Fm., Bolívar, Colombia].—Pearson and Wade, 2015:14, figs. 11.1a-d [SEMs of holotype of *Globigerina turritilina praeturritilina* Blow and Banner, re-illustrated from Olsson and others, 2006, pl. 6.10, fig. 11], figs. 11.2a-d [SEMs of holotype of *Globigerina turritilina turritilina* Blow and Banner, re-illustrated from Olsson and others, 2006, pl. 6.10, fig. 1a-c, 2], fig. 11.3 [upper Eocene Zone E15/16, TDP Site 17, Stakishari, Tanzania], fig. 11.4 [lower Oligocene Zone O1, TDP Site 12, Stakishari, Tanzania], fig. 11.5 [lower Oligocene Zone O1, TDP Site 11, Stakishari, Tanzania], fig. 11.6 [upper Eocene Zone E15/16, TDP Site 12, Stakishari, Tanzania], figs. 11.7-11.8 [lower Oligocene Zone O1, TDP Site 17, Stakishari, Tanzania].

Catapsydrax venzoi Borsetti, 1959:207, pl. 1, figs. 2a-c ["lower Oligocene", Marne Variagate, Piacenza province, northern Italy].

Globigerina winkleri Bermúdez, 1961:1208, pl. 6, figs. 4a-c

Plate 10.4 *Subbotina gortanii* (Borsetti, 1959)

1-3, (holotype), lower Oligocene, Piacenza Province, northern Italy; **4**, **8** (same specimen) Zone O1, IODP Hole U1334A/25X/7, 43-45 cm, equatorial Pacific Ocean; **5-7**, (*Catapsydrax venzoi* Borsetti, 1959 holotype) lower Oligocene, Piacenza Province, northern Italy; **9**, Zone O1, IODP Hole U1334A/25X/1, 43-45 cm, equatorial Pacific Ocean; **10**, **11** (same specimen) Zone O1, IODP Hole U1334A/25X/2, 43-45 cm, equatorial Pacific Ocean; **12**, **16**, Zone O6, IODP Hole U1367B/2/3, 30-32 cm, South Pacific Ocean; **13-15** (*Globigerina winkleri* Bermúdez, 1961 holotype USNM 638964), 'mid' Oligocene *G. dissimilis* Zone, Trinidad. Scale bar: **1-16** = 100 µm.

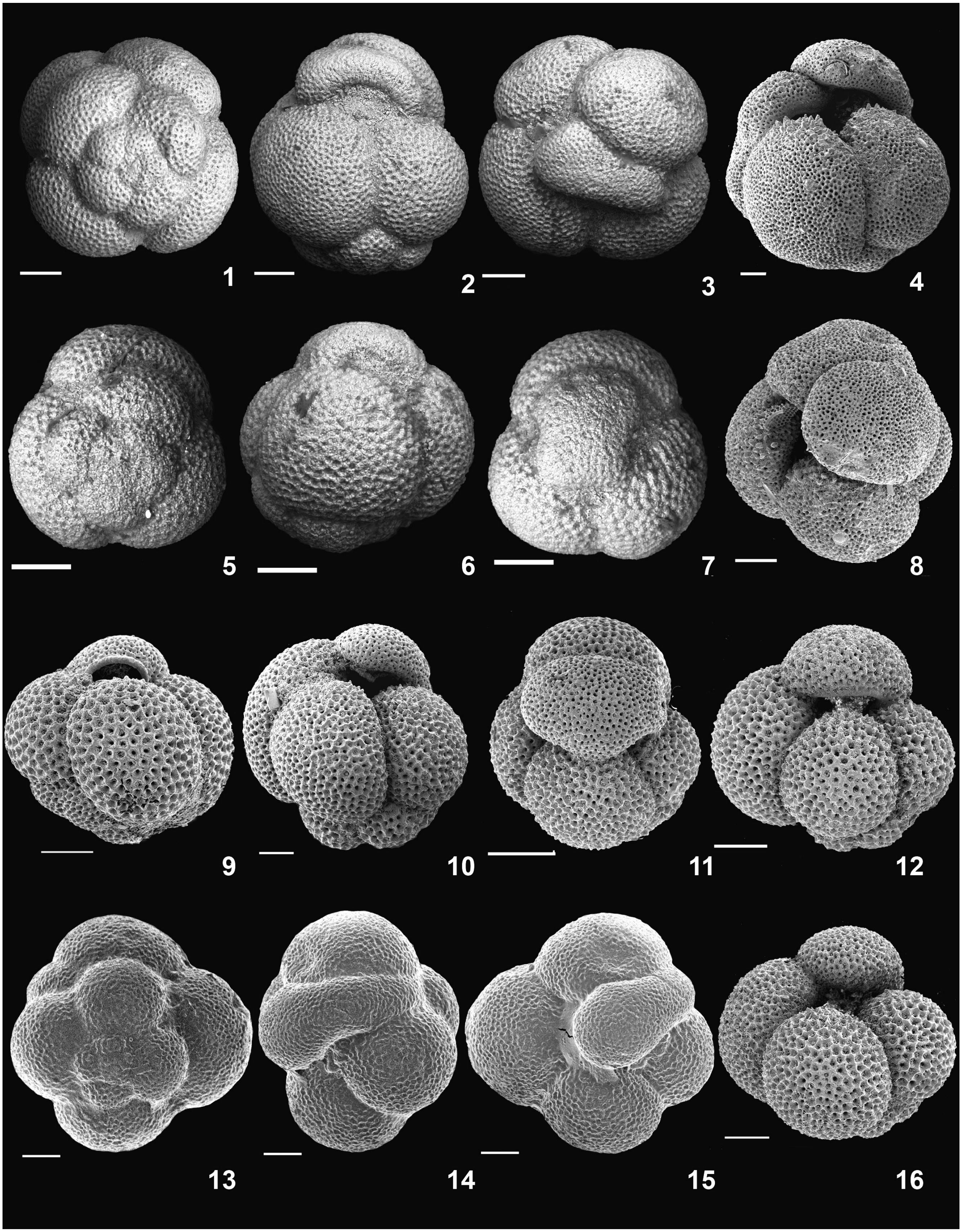

Plate 10.4 *Subbotina gortanii* (Borsetti, 1959)

['mid-' Oligocene *G. dissimilis* Zone, Trinidad].

Subbotina winkleri (Bermúdez).—Fleisher, 1974:1033, pl. 17, fig. 1 [upper Eocene Zone P15, DSDP Site 219, Arabian Sea].

Globigerina turritilina turritilina Blow and Banner, 1962:98, pl. 13, figs. D-G [lower Oligocene *Globigerina oligocaenica* Zone, Lindi area, Tanzania].

Globigerina turritilina praeturritilina Blow and Banner, 1962:99, pl. 13, figs. A-C [upper Eocene *Globigerapsis semiinvoluta* Zone, Lindi area, Tanzania].

Subbotina praeturritilina (Blow and Banner).—Spezzaferri and Premoli Silva, 1991:257, pl. XVI, fig. 1a-c [lower Oligocene Zone O1, DSDP Hole 538A, Gulf of Mexico].

Dentoglobigerina aff. *D. larmeui* (Akers).—Spezzaferri and Premoli Silva, 1991:243, pl. 7, fig. 3a-b [Oligocene Subzone P21a, DSDP Hole 538A, Gulf of Mexico]. [Not Akers, 1955.]

Not *Globigerina gortanii* (Borsetti).—Leckie and others, 1993:123, pl. 3 (partim), figs. 7, 8, 10-14 = *S. corpulenta*.

Not *Subbotina gortanii* (Borsetti).—Olsson and others, 2006: pl. 6.10, figs. 13-17 = ? *Globoturborotalita ouachitaensis.*

DESCRIPTION.

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

Test morphology: High trochospiral, globular in outline, chambers globular; in spiral view 4 globular, loosely embracing chambers arranged in 3 whorls, increasing moderately in size, sutures deeply depressed, straight; in umbilical view 4 globular, loosely embracing chambers, increasing moderately in size, sutures deeply depressed, straight, umbilicus large, enclosed by surrounding chambers, aperture umbilical, bordered by a thickened, narrow rim; in edge view chambers arranged in a high, loosely coiled spire (modified from Olsson and others, 2006).

Size: Maximum diameter of holotype 0.62 mm, thickness 0.54 mm.

DISTINGUISHING FEATURES.— "The species is characterized by its trochospiral loosely coiled test, globular chambers, and umbilical aperture" (Olsson and others, 2006:141). *Subbotina gortanii* is distinguished from other Oligocene subbotinids and from species of *Catapsydrax* by its very high trochospire. Specimens are commonly large in size and may have a large inflated bulla-like chamber and may possess a tooth.

DISCUSSION.— Borsetti (1959) described *Catapsydrax venzoi* from the same locality and level as *gortanii*, and we illustrate here new SEMs of the holotype. The specimen has a higher spire than typical *Catapsydrax* and in our view is synonymous with *Subbotina gortanii*.

Globigerina winkleri Bermúdez is commonly referred to in the literature from the 1960s and 70s. Stainforth (1974) considered this form to be related to *Subbotina corpulenta* group. Blow (1979) placed the taxon within his new genus *Dentoglobigerina* and considered it to be a stratigraphically useful form that evolved from *D. galavisi*. We have obtained new SEM images of the holotype and find this to be a large form, with a wrap-around bulla and we consider this species to be a junior synonym of *Subbotina gortanii*. See Olsson and others (2006) for a full discussion *S. gortanii*.

PHYLOGENETIC RELATIONSHIPS.— Olsson and others (2006) suggested that *Subbotina gortanii* evolved from *Subbotina yeguaensis* by an increase in the height of the spire.

STRATIGRAPHIC RANGE.— The range of *Subbotina gortanii* is poorly defined. It ranges from the middle Eocene Zone E13 (Olsson and others, 2006) through the Oligocene to at least upper Oligocene Zone O6/O7 (=P22) (Spezzaferri and Premoli Silva, 1991). Pujol (1983) recorded a range to the early Miocene Zone N5/6 = Zone M2/3. Leckie and others (1993) find the highest occurrence close to the Oligocene/Miocene boundary at Sites 803 and 628A, however many of these bullate forms may be *Subbotina corpulenta*.

TYPE LEVEL.— Lower Oligocene, "variegated marls", 1.5 km west of Vigoleno, Piacenza Province, northern Italy.

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

STABLE ISOTOPE PALEOBIOLOGY.— "Pearson and others (2001) recorded this species (as *S.* cf. *praeturritilina*) as a deep-dwelling form in the upper Eocene. However Douglas and Savin (1978) and Boersma and others (1987) recorded relatively negative $\delta^{18}O$ for this species from the Oligocene, suggesting that it might have migrated into shallower water habitats" (Olsson and others, 2006:142).

REPOSITORY.— Holotype (No. IF-376) deposited at the Institute of Geology and Paleontology, University of Bologna, Italy.

Subbotina linaperta **(Finlay, 1939)**

Globigerina linaperta Finlay, 1939:125, pl. 23, figs. 54-57 [middle Eocene, Bortonian Stage, Hampden section, South Island, New Zealand].

Subbotina oregonensis McKeel and Lipps, 1975:262, pl. 4, figs. 3a-c [middle Eocene, Coaledo Fm., Oregon].

DISCUSSION.— Several authors (e.g., Jenkins, 1971; Olsson and others, 2006) have limited *Subbotina linaperta* to the Eocene. However, our own observations, in agreement with Nocchi and others (1991) reveal that this taxon ranges into the lowermost Oligocene (Figure 10.1). The most common species with which it is likely to be confused in the lower Oligocene is *S. utilisindex*. It is distinguished mainly by its less compact coiling and more rapid rate of chamber enlargement. See also comments under *S. minima*. Images and a full discussion of *S. linaperta* are in Olsson and others (2006).We agree with Olsson and others (2006) that *S. oregonensis* is a junior synonym of *S. linaperta.*

Subbotina minima **(Jenkins, 1965)**

Plate 10.1, Figures 9-16

Globigerina angiporoides minima Jenkins, 1965:1096, fig. 7, nos. 52-57 [middle Eocene, Hampden Beach, South Island, New Zealand].

Globigerina (*Subbotina*) *angiporoides minima* Jenkins.—Jenkins, 1971:162, pl.17, figs. 510-515 [middle Eocene, Hampden Beach, South Island, New Zealand].

Subbotina angiporoides minima (Jenkins).—Blow, 1979:1255, pl. 12, fig. 7 [upper Eocene Zone P16, Lindi, Tanzania].

Subbotina angiporoides minima (Jenkins).—Spezzaferri and Premoli Silva, 1991:257, pl. XV, fig. 1 [lower Oligocene Zone P19 = Zone O1, DSDP Hole 538A, Gulf of Mexico], fig. 2 [lower Oligocene Zone P20 = Zone O1, DSDP Hole 538A, Gulf of Mexico].

Subbotina minima (Jenkins).—Li and others, 2003, pl. 1, fig. 30 [upper Eocene, Zone P15/P16, ODP Hole 1134A, Great Australian Bight].

Subbotina angiporoides (Hornibrook).—Olsson and others, 2006:126-129, pl. 6.6 (partim), fig. 5, SEM of paratype of *Globigerina angiporoides* [upper Eocene/lower Oligocene, Campbells Beach, South Island, New Zealand], figs. 9-11, SEMs of holotype of *Globigerina angiporoides minima* Jenkins [middle Eocene *Globigerinatheka* (*Globigerapsis*) *index index* Zone (not upper Eocene as stated by Olsson and others, 2006), Hampden Beach, South Island, New Zealand]. [Not Hornibrook, 1965.]

Not *Subbotina angiporoides minima* (Jenkins).—Nocchi and others, 1991:270, pl. 6, figs. 13-15 [lower Oligocene Zone P18-P20 = Zone O1-O2, ODP Hole 703A, Subantarctic South Atlantic Ocean] [=*Subbotina angiporoides* (Hornibrook)].

DESCRIPTION.

Type of wall: Spinose, normal perforate, moderately cancellate, often thickened by addition of gametogenetic calcite, *ruber/sacculifer*-type wall.

Test morphology: Test small to moderate size, umbilicus small, open, low trochospiral, “reuleaux” triangular in shape, axial periphery rounded; chambers globular, embracing, increasing slowly in size, 10-12 chambers coiled in 2 whorls, 3½-4 chambers in the final whorl; sutures weakly depressed, radial to slightly curved; aperture a low arch, umbilical to extraumbilical, bordered by a lip.

Size: Maximum diameter of holotype 0.37 mm.

DISTINGUISHING FEATURES.— *Subbotina minima* has a “reuleaux” (inflated) triangular outline, particularly evident in spiral view. It is distinguished from *Subbotina angiporoides* by its less compact test, more open, not slit-like aperture, common absence of the kummerform final chamber and less distinct lip. It is distinguished from *S. linaperta* by lacking compressed chambers that increase rapidly in size and from *S. utilisindex* by its less compact triangular test and 3½-4 chambers in the final whorl.

DISCUSSION.— *Subbotina minima* (Jenkins) was considered a junior synonym of *Subbotina angiporoides* (Hornibrook) by Olsson and others (2006). However, in our investigations of new material from the equatorial Pacific Ocean IODP Site U1334, we frequently find forms with a more open umbilicus and less compact test, which are much more typical of *S. minima* than with *S. angiporoides*. We therefore recognize *S. minima* as a distinct morphospecies.

Jenkins (1965) suggested that *S. minima* is smaller than *S. angiporoides* and that this is a helpful characteristic for distinguishing between the two species. However, given the variability of illustrated specimens, we have not found this to be a particularly useful diagnostic feature and any size difference between the two species is subtle.

In our opinion, one of the paratype specimens (Olsson and others, 2006, pl. 6.6, fig. 5) of *S. angiporoides* has a more lobate periphery and open umbilicus consistent with *S. minima*. Also, two of the paratype specimens illustrated by Jenkins as *Globigerina angiporoides minima* (1965, pl. 7, figs. 55, 56) share morphological characteristics, specifically a much tighter coiling mode and embracing final chamber, more similar to *S. angiporoides*.

PHYLOGENETIC RELATIONSHIPS.— *Subbotina minima* descended from *S. linaperta* in the middle Eocene and subsequently gave rise to *S. angiporoides* (Jenkins, 1965).

STRATIGRAPHIC RANGE.— The range of *S. minima* is poorly constrained. It is described from the upper part of the middle Eocene. In the Gulf of Mexico, Spezzaferri and Premoli Silva (1991) found its extinction lower within Zone O3 than its descendant *S. angiporoides*.

TYPE LEVEL.— Middle Eocene, upper blue micaceous clays, Arnold Series, Bortonian Stage, Hampden Beach, South Island, New Zealand. The type level was placed in the *Globigerinatheka* (*Globigerapsis*) *index index* Zone by Jenkins (1971:40), which is equivalent to the upper part of the middle Eocene. Also occurring in the same sample are large acarininids such as *primitiva, topilensis* and others. Note that the type level was wrongly stated as upper Eocene by Olsson and others (2006).

GEOGRAPHIC DISTRIBUTION.— Common in high southern latitudes; probably cosmopolitan, although, so far no records in high northern latitudes.

STABLE ISOTOPIC PALEOBIOLOGY.— Multispecies stable isotope investigations from Site U1334 indicate that *Subbotina minima* calcifies in the thermocline. This species records more negative $\delta^{18}O$ values in comparison to co-occurring *S. utilisindex* (Moore and others, 2014).

REPOSITORY.— Holotype TF 1496/1 and paratypes (1496/2-4) deposited at the Geological and Nuclear Science Institute, Lower Hutt, New Zealand.

Subbotina projecta **Olsson, Pearson, and Wade, new species**

Plate 10.5, Figures 1-17

Globigerina sp. aff. *yeguaensis* Weinzierl and Applin.—Blow and Banner, 1962, pl. XI, figs. P, Q [lower Oligocene *G. oligocaenica* Zone, Lindi area, Tanzania]. [Not Weinzierl and Applin, 1929.]

Globigerina eocaena Gümbel.—Stainforth and others, 1975 (partim):268-270, fig. 115, no. 5-7 [upper Eocene Pachuta member, Yazoo Fm., Alabama]. [Not Gümbel, 1868.]

Subbotina ? *yeguaensis* (Weinzierl and Applin).—Leckie and others, 1993:125, pl. 3 (partim), fig. 2 [upper Oligocene Zone O7, ODP Hole 628A, Little Bahama Bank, western North Atlantic Ocean], fig. 6 [upper Eocene Zone E16, ODP Hole 628A, Little Bahama Bank, western North Atlantic Ocean]. [Not Weinzierl and Applin, 1929.]

Dentoglobigerina cf. *globularis* (Bermúdez).—Wade and others, 2007:172, pl. II, figs. a-d [upper Oligocene Zone O5, ODP Hole 1218B, equatorial Pacific Ocean]. [Not Bermúdez, 1961.]

Subbotina sp. Pearson and Wade, 2015:16, figs. 14.1-14.3, 14.5, 14.9 [lower Oligocene Zone O1, TDP 17, Stakishari, Tanzania], figs. 14.4, 14.6 [lower Oligocene Zone O1, TDP 12, Stakishari, Tanzania], fig. 14.7 [upper Eocene Zone E15/16, TDP 12, Stakishari, Tanzania], fig. 14.8 [lower Oligocene Zone O1, TDP 11, Stakishari, Tanzania].

DESCRIPTION.

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

Test morphology: "Test large, globular, 10 to 13 chambers arranged in three whorls, in a moderately high trochospiral, lobate, oval in outline, chambers spherical to subspherical; in spiral view 3½- 4 globular, embracing chambers in final whorl, increasing gradually in size, sutures straight or gently curved, moderately incised; in umbilical view 3½ globular chambers, increasing moderately rapidly in size, sutures depressed to incised, straight, umbilicus wide, square, deep, aperture umbilical, usually with teeth projecting into umbilicus from one or more chambers. Teeth vary from small and triangular to narrow elongate projections, often with a distinct rim or lip around the edges of the tooth that

Plate 10.5 *Subbotina projecta* Olsson, Pearson, and Wade, new species

1-8, **12-15**, (1-4 holotype, USNM 598588, 5 paratype, USNM 598589, 6 paratype, USNM 5985890, 7 paratype, USNM 5985891), Zone E16, Shubuta Clay Member, Yazoo Formation, Chickasawhay River, Wayne County, Mississippi; **9**, **10**, (Pearson and Wade, 2015, fig. 14.4a-4b), Zone O1, TDP 12/9/2, 23-36 cm, Stakishari, Tanzania; **11**, (Pearson and Wade, 2015, fig. 14.1), Zone O1, TDP 17/11/1, 0-10 cm, Stakishari, Tanzania; **16**, **17**, Zone O1, TDP 17/25/3, 44-58 cm, Stakishari, Tanzania. Scale bars: **1-3**, **5-9**, **11-13**, **16** = 100 µm, **17** = 50 µm, **10** = 20 µm, **15** = 5 µm, **4**, **14** = 4 µm.

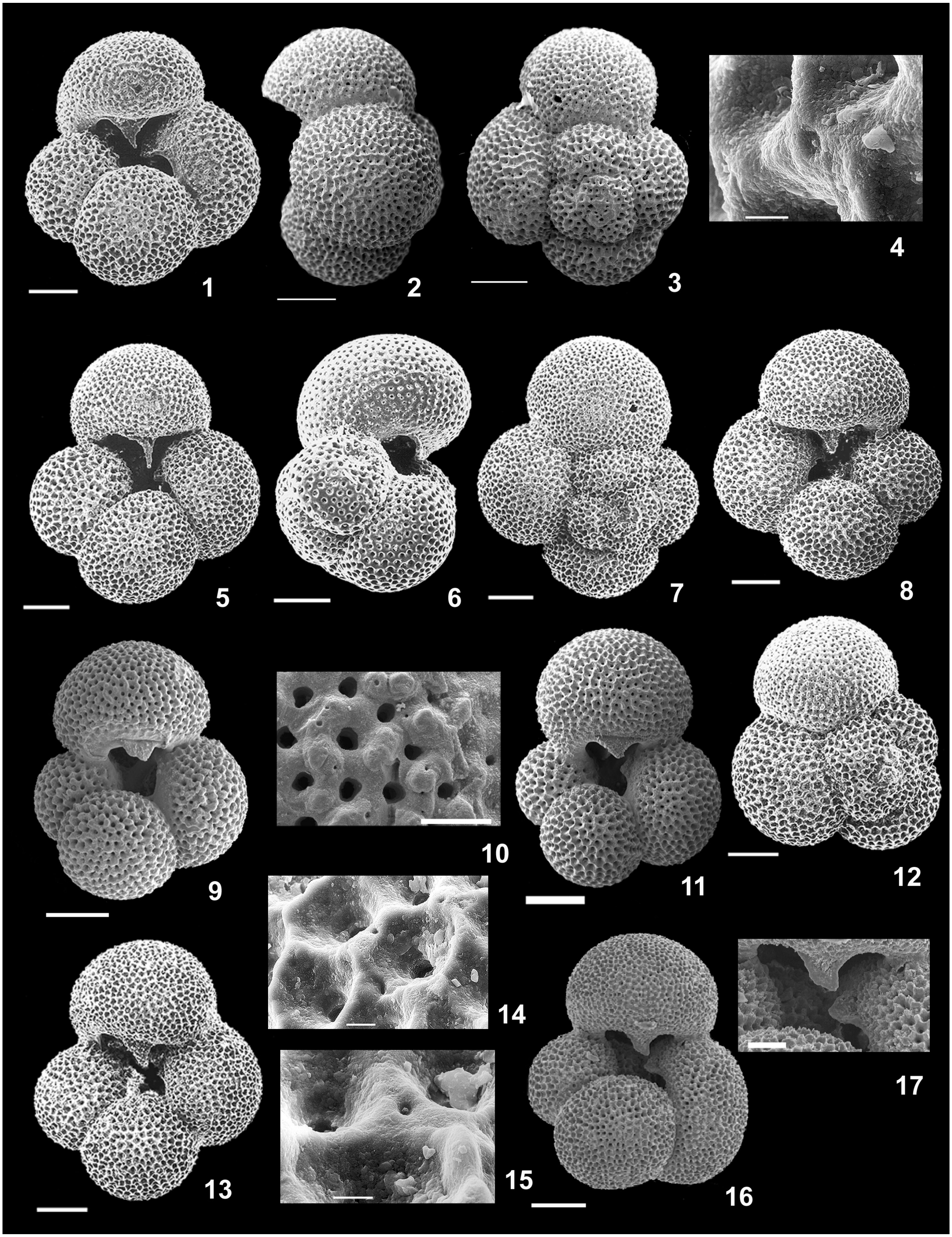

Plate 10.5 *Subbotina projecta* Olsson, Pearson, and Wade, new species

connect with the apertural lip; in edge view chambers globular in shape, embracing, teeth leaning into the umbilicus" (Pearson and Wade, 2015:18).

Size: Maximum diameter of holotype 0.50 mm.

ETYMOLOGY.— Named from Latin *projecta*, jutting or projecting, referring to the common prominent teeth.

DISTINGUISHING FEATURES.— The equatorial outline is in general diamond-shaped with chambers arranged in a cross. *Subbotina projecta* n. sp. is closely related to *S. tecta* "but is distinguished by its higher trochospiral coiling, wider, deeper, and generally more square umbilicus and detailed morphology of the teeth, which, although highly variable, can be quite elongate and are generally rimmed by a thin lip of constant thickness. It is distinguished from *S. yeguaensis* by its smaller size, more globular chambers, more incised umbilical sutures and by possessing true teeth rather than a broad, tapering lip" (Pearson and Wade, 2015:15). As seen in the synonymy list above, this morphotype has previously been attributed to *Dentoglobigerina globularis* (Bermúdez). However the SEMs of the holotype of *globularis* reveal a quite different general morphology, with more radially compressed and appressed chambers (see Chapter 11, this volume).

DISCUSSION.— This species was referred to as "*Subbotina* sp. 2" in Wade and Pearson (2008). "Our specimens show clear spine holes indicating a spinose condition in life. The relatively free, loosely attached spherical chambers establish the relationship with other *Subbotina* species" rather than *Dentoglobigerina* (Pearson and Wade, 2015:16).

PHYLOGENETIC RELATIONSHIPS.— *Subbotina projecta* n. sp. probably developed from *S. tecta* in the uppermost Eocene.

STRATIGRAPHIC RANGE.— *Subbotina projecta* n. sp. appears in the upper Eocene Zone E16 (Wade and Pearson, 2008 referred to as *Subbotina* sp. 2) and ranges through the Oligocene. Wade and others (2007) found specimens in upper Oligocene Zone O5, and Leckie and others (1993) have recorded specimens of *Subbotina* ? *yeguaensis* that are consistent with *Subbotina projecta* n. sp. in the uppermost Oligocene Zone O7 at ODP Sites 628 and 803.

TYPE LEVEL.— Upper Eocene Zone E16, Shubuta Clay Member, Yazoo Formation, Chickasawhay River, Wayne County, Mississippi.

GEOGRAPHIC DISTRIBUTION.— Probably restricted to low latitudes; currently known from the Gulf of Mexico, Indian Ocean (Tanzania), equatorial Pacific Ocean (ODP Sites 1218 and 803) and equatorial Atlantic Ocean (ODP Site 628).

STABLE ISOTOPE PALEOBIOLOGY.— Multispecies stable isotope analysis from the lower Oligocene Zone O1 at Tanzania Drilling Project Site 12 indicates a positive $\delta^{18}O$ signal consistent with a thermocline dwelling habitat (Wade and Pearson, 2008).

REPOSITORY.— Holotype (USNM 598588) and paratypes (USNM 598589 to USNM 598591) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Subbotina tecta Pearson and Wade, 2015

Plate 10.6, Figures 1-17

?*Globigerina yeguaensis* (Weinzierl and Applin).—Postuma, 1971:162, pl. on p. 163 [Sample E 227, Alabama]. [Not Weinzierl and Applin, 1929.]

?*Globigerina galavisi* Bermúdez.—Raju, 1971:24, pl. 5, figs. 2a-3 [*G. mexicana* zone, borehole NGT-1, Cauvery Basin, south-east India]. [Not Bermúdez, 1961.]

Subbotina yeguaensis (Weinzierl and Applin).—Olsson and others, 2006:162-163 (partim), pl. 6.18, figs. 12, 16 [upper Eocene Zone E15/16, Shubuta Clay, Wayne County, Mississippi]. [Not Weinzierl and Applin, 1929.]

Subbotina tecta Pearson and Wade, 2015:15, figs. 12.1a-f (holotype), 12.2, 12.3, 13.3, 13.4, 13.6 (paratypes) [upper Eocene Zone E15/16, TDP Site 12, Stakishari,

Plate 10.6 *Subbotina tecta* Pearson and Wade, 2015

1-3 (holotype, NHMUK PM PF 71158, Pearson and Wade, 2015, fig. 12.1a-c), upper Eocene Zone E15/16, Stakishari, Tanzania; **4** (paratype, NHMUK PM PF 71161, Pearson and Wade, 2015, fig. 13.1a), upper Eocene Zone E15/16, Stakishari, Tanzania; **5-7** (paratype, Pearson and Wade, 2015, fig. 13.4a-c), upper Eocene Zone E15/16, Stakishari, Tanzania; **9-11** (same specimen), Zone O1, DSDP Site 242/13R/5, 38-40 cm, western Indian Ocean; **8**, **12-17**, Zone O1, AGS 66, 9A-1A, Shubuta Formation, Alabama. Scale bar: **1-9**, **11-15** = 100 µm, **10**, **16**, **17** = 10 µm.

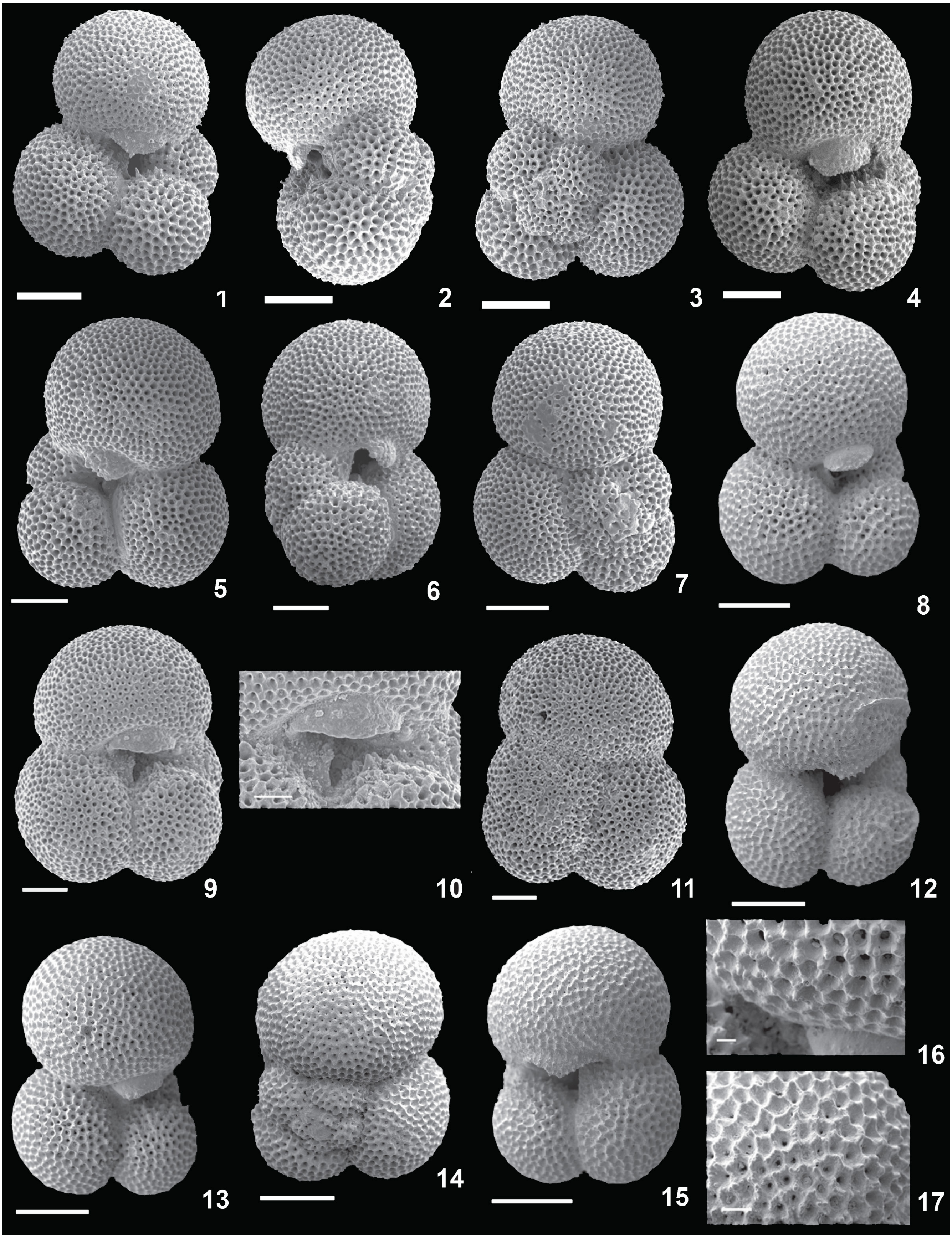

Plate 10.6 *Subbotina tecta* Pearson and Wade, 2015

Tanzania], figs. 13.1, 13.2, 13.5, 13.7 (paratypes) [upper Eocene Zone E15/16, TDP Site 17, Stakishari, Tanzania].

DESCRIPTION.

Type of wall: Symmetrically cancellate, *ruber*/*sacculifer*-type wall texture, spinose.

Test morphology: 10-13 near spherical chambers arranged in three whorls in "a low trochospiral, oval and strongly lobate in outline; in spiral view 3½ to occasionally 4 globular, embracing chambers in final whorl, increasing rapidly in size, sutures straight and depressed, becoming moderately incised between later chambers; in umbilical view 3½ globular chambers, increasing rapidly in size, sutures depressed to incised, straight, umbilicus small, aperture umbilical to slightly extraumbilical in position, obscured by a distinctive trapezoidal to triangular, non-porous, often pustulose tooth, with relict teeth of earlier chambers sometimes visible, the adjacent chamber shoulders sometimes distinctly pustulose; in edge view chambers globular in shape, embracing, tooth convex and arching over the umbilicus. Coiling direction is approximately random" (Pearson and Wade, 2015:15).

Size: Maximum diameter of holotype 0.61 mm.

DISTINGUISHING FEATURES.— "*Subbotina tecta* is closely related to *S. eocaena* (Gümbel) from which it probably evolved in the uppermost Eocene. It is distinguished from *S. eocaena* ... by its more spherical chambers (although note that the neotype drawing of *S. eocaena* has very spherical chambers) and by possessing a large and prominent tooth, which is evidently a modification of the slightly pustulose lip of *S. eocaena*. When well developed, the tooth is positioned high over the umbilicus and forms a distinct platform above the primary aperture... . The two species are linked by intermediate forms ... and their distinction may be subjective; however, a distinct tooth rather than an irregular lip is critical for our diagnosis of *S. tecta* and ... the chambers are almost always more spherical. The distinctive apertural system and tooth in *S. tecta* may have been related to feeding, for example for securing prey in the umbilical region, and if this is correct it could indicate that *S. tecta* was a separate biospecies with a particular dietary specialization. It is distinguished from *S. yeguaensis* by having a lower trochospire and less embracing, more spherical chambers. It is distinguished from *Subbotina* sp. 1 [= *S. projecta* n. sp. in this study] by having a lower trochospiral and narrower umbilicus, and generally, a less slender, blunter tooth" (Pearson and Wade, 2015:14-15). It is highly homeomorphic with *Globigerina pseudoeocaena* Subbotina (now considered a junior synonym of *Subbotina yeguaensis*, see Olsson and others, 2006) described from the lower middle Eocene. However *S. tecta* is differentiated from *G. pseudoeocaena* by its very spherical chambers and projecting lip. It is distinguished from *Dentoglobigerina galavisi* (Bermúdez) by its more globular chambers, lobate periphery and protrusive tooth.

DISCUSSION.— "A specimen of *S. tecta* was illustrated by Olsson and others (2006, plate 6.18, fig. 12) as *S. yeguaensis*. In the past, other specimens may have been assigned to either *D. galavisi* or *S. yeguaensis* (possibly including the specimen illustrated as *Globigerina yeguaensis* by Postuma, 1971); however, *S. tecta* is a very distinctive morphotype which may be confined to the uppermost Eocene and lowermost Oligocene" (Pearson and Wade, 2015:15). In addition to the holotypes and paratypes illustrated from Tanzania (Pearson and Wade, 2015, figs. 12.1-12.3, 13.1-13.7), we have found comparable specimens from DSDP Site 242 (Indian Ocean), ODP Site 647 (North Atlantic Ocean), IODP Site U1334 (equatorial Pacific Ocean) and the US Gulf Coast. Referred to as *Subbotina* sp. 1 in Wade and Pearson (2008).

PHYLOGENETIC RELATIONSHIPS.— *Subbotina tecta* descended from *S. eocaena* in the uppermost Eocene and forms a phylogenetic link to *S. projecta* n. sp.

STRATIGRAPHIC RANGE.— *Subbotina tecta* has a restricted range, confined to upper Eocene Zone E16 to lower Oligocene Zone O1, pending further investigations. "Questionable specimens illustrated by Raju (1971) are from the *G. mexicana* zone of India, here equivalent to Zone E14, hence likely from a lower stratigraphic level than we have been able to confirm, and he records the highest occurrence in *G. sastrii* zone, equivalent to Zone O1. We did not find this species in any middle Eocene cores from Tanzania. Blow (1979) illustrated a specimen from the middle Eocene of Tanzania (Zone P11 = Zone E9) that is quite convincingly *S. tecta*, but we have studied the type locality in many outcrop and borehole samples and never found this morphology, so we suspect contamination with an upper Eocene sample" (Pearson and Wade, 2015:15).

TYPE LEVEL.— Upper Eocene Zone E15/E16, TDP 12/42/1, 36-46 cm, Stakishari, Tanzania.

GEOGRAPHIC DISTRIBUTION.— Global, but most common in low and mid-latitudes, so far known to occur in the western Indian Ocean, equatorial Pacific Ocean, Caribbean Sea, Gulf of Mexico and Labrador Sea.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (NHMUK PM PF 71158) and paratypes (NHMUK PM PF 71159-71164) deposited at the Natural History Museum, London.

Subbotina utilisindex (Jenkins and Orr, 1973)

Plate 10.2, Figures 9-16

"*Globigerina* sp. A" Beckmann, 1971:719, pl. 1, figs. 1-4 [lower Oligocene, DSDP Sites 69, 70, 72, eastern equatorial Pacific Ocean].

Globigerina utilisindex Jenkins and Orr, 1973:133-135, pl. 1, figs. 1-3 (partim; not paratype, pl. 1, figs. 4-6) [lower Oligocene, DSDP Hole 77B, eastern equatorial Pacific Ocean].

Subbotina utilisindex Jenkins and Orr.—Huber, 1991:441, pl. 5, fig. 6 [lower Oligocene Zone AP13, ODP Site 738, Kerguelen Plateau, southern Indian Ocean].—Nocchi and others, 1991:271, pl. 6, figs. 10-12 [lower Oligocene Zone P18-P20 (= Zone O1-O2), ODP Hole 703A, Subantarctic South Atlantic Ocean], figs. 16, 17 [lower Oligocene Subzone P21a (= Zone O3-O4), ODP Hole 703A, Subantarctic South Atlantic Ocean].—Spezzaferri and Premoli Silva, 1991:257, pl. XVI, figs. 4a-d [lower Oligocene Zone P19, DSDP Hole 538A, Gulf of Mexico].—Olsson and others, 2006:161-162, pl. 6.6, figs. 14, 15 [upper Eocene, Atlantic City Borehole, New Jersey, DSDP 150X], figs. 16-19 [lower Oligocene Zone AP13, ODP Hole 738B, Kerguelen Plateau, southern Indian Ocean], fig. 20 [middle Eocene Zone AP10, ODP Hole 748B, Kerguelen Plateau, southern Indian Ocean].

Subbotina angiporoides (Hornibrook).—Leckie and others, 1993:125, pl. 1, fig. 18 [lower Oligocene Zone P18, ODP Hole 628A, Little Bahama Bank, western North Atlantic Ocean], fig. 19 [lower Oligocene Zone P19, ODP Hole 803D, Ontong Java Plateau, western equatorial Pacific Ocean], fig. 20 [lower Oligocene Zone P19, ODP Hole 628A, Little Bahama Bank, western North Atlantic Ocean]. [Not Hornibrook, 1965.]

Not *Globigerina utilisindex* Jenkins and Orr, 1973, pl. 1, figs. 4-6 = *Subbotina linaperta* (Finlay) [lower Oligocene, DSDP Hole 77B, eastern equatorial Pacific Ocean]. [Not Finlay, 1939.]

DESCRIPTION.

Type of wall: Spinose, cancellate, normal perforate, *ruber/sacculifer*-type wall.

Test morphology: Test trilobate, equatorial margin rounded; chambers coiled in compact, low trochospire, arranged in two whorls, chambers globular, final chamber comprising less than half of test; sutures radial to slightly curved, moderately depressed; umbilicus narrow, shallow; aperture a very low interiomarginal, umbilical-extraumbilical slit bordered by a narrow lip (modified after Olsson and others, 2006).

Size: Holotype maximum diameter 0.37 mm.

DISTINGUISHING FEATURES.— *Subbotina utilisindex* is characterized by its low rate of chamber expansion resulting in a compact test consisting of three evenly sized chambers in the final whorl. It is distinguished from *S. minima* by the more closed umbilicus and compressed chambers. It "differs from *Subbotina linaperta* by (1) the more compact coiling, (2) more equidimensional size of final whorl chambers, (3) lower apertural arch and more umbilical position of the aperture, (4) less developed apertural lip, and (5) less coarsely cancellate wall texture. Differs from *S. angiporoides* by not possessing an enveloping final chamber" (Olsson and others, 2006:161).

DISCUSSION.— This species is common in lower Oligocene assemblages. Jenkins and Orr (1973) regarded *S. utilisindex* to be intermediate between *S. linaperta* and *S. angiporoides*. We consider the paratype specimens of Jenkins and Orr (1973) illustrated on pl. 1, figs. 4-6, to be more consistent with *S. linaperta*. Furthermore, some specimens illustrated by Leckie and others (1993) appear to morphologically converge with the *S. angiporoides/minima* group (see Plate 10.1).

PHYLOGENETIC RELATIONSHIPS.— Probably descended from *S. linaperta* during the late Eocene (Olsson and others, 2006).

STRATIGRAPHIC RANGE.— "Originally recorded in the eastern equatorial Pacific (Jenkins and Orr, 1973). At southern, high latitudes Huber (1991) recorded *S. utilisindex* from the middle upper Eocene through lower Oligocene (Zones AE9-AO1)" (Olsson and others, 2006:161-162). The extinction of *S. utilisindex* is at the same level as the extinction of *S. angiporoides* in high latitudes (Nocchi and others, 1991), but precedes *S. angiporoides* in the Gulf of Mexico (Spezzaferri and Premoli Silva, 1991).

TYPE LEVEL.— Lower Oligocene, DSDP Hole 77B, 51-CC, eastern equatorial Pacific Ocean.

GEOGRAPHIC DISTRIBUTION.— "Cosmopolitan; particularly common in early Oligocene assemblages at southern, high latitudes. It may have been adapted to cold, nutrient rich waters" (Olsson and others, 2006:162).

STABLE ISOTOPE PALEOBIOLOGY.— "Poore and Matthews (1984) and Wade and Kroon (2002) recorded this species as having $\delta^{18}O$ values intermediate between surface dwelling and benthic species, indicating a deep planktonic habitat" (Olsson and others, 2006:162). This interpretation is supported by multispecies stable isotope analyses from equatorial Pacific Ocean Site U1334 (Moore and others, 2014).

REPOSITORY.— As discussed in Olsson and others (2006), Jenkins and Orr (1973) state that the holotype was deposited at the USNM, however, this taxon was never accessioned and, therefore, was probably never sent. We reillustrate SEMs of the holotype from Jenkins and Orr (1973) on Plate 10.2.

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