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Taxonomy, biostratigraphy, and phylogeny of Oligocene Streptochilus

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Chapter 19

TAXONOMY, BIOSTRATIGRAPHY AND PHYLOGENY OF OLIGOCENE *STREPTOCHILUS*

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ABSTRACT

Our investigation of the taxonomy, biostratigraphy, and phylogeny of the microperforate Oligocene species generally included in the planktonic genus *Streptochilus* documents that biserial planktonic foraminifera occur in the upper Oligocene, despite previous descriptions of a global gap in occurrence of such taxa over that time interval. We describe a total of four distinct morphological species, namely *Streptochilus martini* (Pijpers), *Streptochilus pristinum* Brönnimann and Resig, *Streptochilus rockallkiddensis* Smart and Thomas, and *Streptochilus tasmanensis* Smart and Thomas n. sp. Some Recent biserial foraminifera (*Streptochilus globigerus*) live tychopelagically, i.e., the species lives in the plankton but is genetically identical to the neritic benthic species *Bolivina variabilis*. Fossil species could have had a similar lifestyle, from which they could have evolved into true planktonic species, implying polyphyletic, multiple evolution of planktonic from benthic biserial groups. It is likely, therefore, that the stratigraphic distribution of the genus *Streptochilus* represents one or more expatriation events from the coastal benthos to the pelagic zone, and that not all or no species traditionally placed in the genus *Streptochilus* are descended from the genus *Chiloguembelina*. The name *Streptochilus* has been used for species which morphologically cannot be distinguished from species in the benthic genus *Bolivina* but live planktonically, and the genus thus is polyphyletic. We do not have sufficient

information on evolutionary patterns to define clades of biserial planktonic species, and here propose to keep the name *Streptochilus* provisionally for biserial planktonic species until evolutionary relations have been clarified. We assign the genus to the Superfamily Bolivinoidea.

INTRODUCTION

The biserial genus *Streptochilus* belongs to the microperforate planktonic foraminifera, characterized by a non-spinose, smooth to pustulose wall with pores less than 1 μm in diameter (e.g., Huber and others, 2006). These planktonic species are generally small (~ 100-150 μm), and they have been commonly overlooked in taxonomic and biostratigraphic studies. Traditionally, the Eocene-Recent biserial planktonic genus *Streptochilus* (with a toothplate) has been thought to have evolved from the biserial planktonic genus *Chiloguembelina* (without toothplate) in the middle Eocene (e.g. Huber and others, 2006). Genetic evidence, however, shows that the Recent biserial planktonic foraminiferal species *Streptochilus globigerus* belongs to the same biological species as the shelf-dwelling benthic foraminifera *Bolivina variabilis* (Darling and others, 2009). Geochemical evidence suggests that this species can survive, calcify and reproduce in both planktonic and benthic domains (the tychopelagic life habit) (Darling and others, 2009). Such tychopelagic taxa could have evolved into true planktonic species multiple times in the past (Leckie, 2009; Georgescu and others, 2011). Similarly, genetic evidence suggests that the living triserial planktonic foraminiferal species *Gallitellia vivans* did not evolve from older triserial planktonic species, but descended from triserial benthics in the Miocene (Ujiié and others, 2008). A recent supraordinal classification of the Phylum Foraminifera does not consider planktonic foraminifera a separate order (Pawlowski and others, 2013).

Originally, all *Streptochilus* species, including the extant *S. globulosus*, the type species of the genus *Streptochilus* (Brönnimann and Resig, 1971; Resig and Kroopnick, 1983; Resig, 1989, 1993) had been placed in the genus *Bolivina* (Order Buliminida) because of their strong morphological similarities, including biserial test formation and presence of a ‘collar’ around the aperture, extending into a toothplate (Smart and Thomas, 2006, 2007). The chambers of most biserial planktonics tend to be more inflated than those of benthics, although there is considerable intraspecific and interspecific variability (e.g., Darling and others, 2009).

The biserial genus *Laterostomella* was originally also placed in the Buliminida by de Klasz and Rérat (1962). Loeblich and Tappan (1987) placed *Laterostomella* in the Chiloguembelinidae because they considered it to be a planktonic taxon, and they designated *Streptochilus* its junior synonym. However, de Klasz and others (1989) demonstrated that *Laterostomella* is in fact a benthic taxon, based on oxygen stable isotopic data, and therefore considered *Laterostomella* and *Streptochilus* as separate genera. Various authors (e.g. Brönnimann and Resig, 1971; Kennett and Srinivasan, 1983; Resig and Kroopnick, 1983; Poore and Gosnell, 1985; de Klasz and others, 1989; Huber and others, 2006) suggest that the planktonic genus *Streptochilus* evolved from *Chiloguembelina*, thus should be assigned to the Chiloguembelinidae. However, in view of the evidence that at least some species of *Streptochilus*, e.g., the living *S. globigerus*, are not descended from *Chiloguembelina*, the Family Chiloguembelinidae (Reiss, 1963) is revised to exclude them (see Chapter 17, this volume).

A planktonic mode of life of the two living species of *Streptochilus* (*S. globigerus* Schwager and *S. globulosus* Cushman) is documented by its occurrence in plankton tows (Hemleben and others, 1998; Schmuker and Schiebel, 2002), by stable isotope analyses (Resig and Kroopnick, 1983) and Mg/Ca ratios (Darling and others, 2009). Similarly, late Eocene (Sexton and others, 2006) and early Miocene (Smart and Thomas, 2006) *Streptochilus* have stable isotopic signatures indicative of a planktonic mode of life. The oxygen isotope values are more negative, indicating high (surface) water temperatures similar to those in other mixed-layer dwelling planktonic foraminifera, whereas the carbon isotope values are also light, in some cases lighter than those of benthics in the same samples (Smart and Thomas, 2006). Resig and Kroopnick (1983) suggested that these carbon isotope values reflect a 'deep planktonic habitat within the oxygen minimum layer', but in such a habitat, the $\delta^{18}O$ values would be much more positive than observed. Smart and Thomas (2006) explained the light carbon isotope signature in early Miocene *Streptochilus* as resulting from rapid calcification in a region with variable upwelling conditions, as such isotope signatures are seen in Recent surface dwellers in regions with intermittent upwelling, e.g. monsoonal areas in the Arabian Sea (e.g., Kroon and Ganssen, 1989; Naidu and Niitsuma, 2004). Such a habitat would be in agreement with inferences that Paleogene biserial forms generally indicate eutrophic conditions (e.g., Hallock and others, 1991; Smart and Thomas, 2006). However, the extant triserial form *Gallitellia vivans*, living in eutrophic coastal regions, also has a very light carbon isotopic signature (Kimoto and others, 2009). Kimoto and others

(2009) attributed the negative $\delta^{13}C$ values to isotopic disequilibrium, and it is likely that the negative $\delta^{13}C$ values in *Streptochilus* are due to metabolic disequilibrium effects in small foraminiferal tests (see, for example, Birch and others, 2013, for a discussion of this effect).

Streptochilus has been differentiated from *Chiloguembelina* by the presence of an internal plate connecting successive foramina which is a prominent extension of an apertural collar, and a smooth to granular rather than a pustulose to costate surface texture (Poore and Gosnell, 1985; Huber and others, 2006). Poore and Gosnell (1985) suggested that some species usually assigned to *Chiloguembelina* (e.g. *Textularia martini* Pijpers) should be included in *Streptochilus* because of the presence of a toothplate, as agreed by Huber and others (2006) and Sexton and others (2006), and here. Poore and Gosnell (1985) included *Guembelina cubensis* Palmer in *Streptochilus*, based on the presence of an internal plate connecting the foramina of all but the final one or two chambers, although they noted that the development of the internal plate is very variable within individual specimens and with the form of the aperture. Resig (1993) suggested *cubensis* should be included in *Chiloguembelina* due to the typically lower arched aperture and off-centred position of the internal plate. Huber and others (2006) also placed *cubensis* in *Chiloguembelina*, which is followed here (see Chapter 17, this volume). Not all *Streptochilus* species have a smooth surface texture, with living *S. globigerus* (= *B. variabilis*) showing a distinctive cancellate wall, and *S. rockallkiddensis* having a granular wall (see below).

Streptochilus is described as having an aperture bordered by a collar. "Near the base of the inside margin, the collar and apertural edge are turned inward, producing a plate-like connection with the proximal margin of the collar of the previous aperture'' (Brönnimann and Resig, 1971:1288; Smart and Thomas, 2007:84). Within the Superfamily Buliminacea, most genera (e.g. *Bolivina*) possess a toothplate, a contorted plate running from an intercameral foramen to an aperture, and attached to both. It has been suggested that *Streptochilus* evolved from *Chiloguembelina* (probably *C. ototara*), which does not have a toothplate, during the late Eocene through infolding of the inner margin of the aperture (e.g. Huber and others, 2006). The plate-like structure in *Streptochilus* has been described as not a true toothplate, missing its internal monolamellar part (Smart and Thomas, 2006), although it is often difficult to assess the exact nature of the toothplate, particularly in small species (Darling and others, 2009). In fact, Darling and others (2009) argue that there does not appear to be any real structural difference in the toothplates of *Streptochilus* and *Bolivina*, because

there is significantly more intrageneric, and even intraspecific variability, than intergeneric variability.

Chiloguembelina fusiformis Kim is a biserial species described from the upper Oligocene San Gregorio Formation of Baja California, Mexico. This species is tentatively placed in *Streptochilus*, however, we have not been able to study the type material and its placement relative to the species described herein is uncertain.

The stratigraphic range of *Streptochilus* has been recorded as middle Eocene (Zone E10) to Recent (Huber and others, 2006), but it was suggested (Kennett and Srinivasan, 1983; de Klasz and others, 1989) that there is a global stratigraphic gap in the upper Oligocene, from which no biserial planktonic foraminifera have been described. This gap is most likely due to lack of observations of the small species in this time period, and we have observed *Streptochilus* species occurring during this interval. *Streptochilus rockallkiddensis* was reported from the lower Miocene of the northeastern Atlantic Ocean, and we have now identified this species in the lower to upper Oligocene of the southwestern Atlantic Ocean. *Streptochilus pristinum* has been reported from the lower through middle Miocene (Resig, 1989, 1993), and the upper Oligocene of New Zealand (Hornibrook, 1990), and we have observed rare occurrences of this species in the upper Oligocene of Syria (Jihar and Jazal boreholes, Hernitz Kučenjak and others, 2006). We report *S. tasmanensis* n. sp. from the upper Oligocene of the South Pacific Ocean. In total, we thus recognize four distinct species of *Streptochilus* in the Oligocene (*S. martini, S. pristinum, S. rockallkiddensis* and *S. tasmanensis* n. sp.) which apparently occur intermittently, with the intermittent ranges probably in part due to lack of observations of small planktonic taxa. The stratigraphic ranges and phylogeny of Oligocene *Streptochilus* are shown in text-figure 19.1.

SYSTEMATIC TAXONOMY

Order FORAMINIFERIDA Eichwald, 1830

Superfamily BOLIVINOIDEA Glaessner, 1937

Family BOLIVINIDAE Glaessner, 1937

Genus *Streptochilus* Brönnimann and Resig, 1971, emended Smart and Thomas, 2007

TYPE SPECIES.— *Bolivina tokelauae* Boersma, 1969 (in Kierstead and others, 1969; = *Bolivina globulosa* Cushman, 1933, according to Resig and Kroopnick, 1983).

DISTINGUISHING FEATURES.— "Test biserial, may become staggered uniserial, sometimes twisted; wall calcareous, perforate; aperture a high arch, eccentric in position, extending from the base of the last chamber onto the apertural face. On the outside margin, a collar borders the aperture. Near the base of the inside margin, the collar and apertural edge are turned inward, producing a plate-like connection with the proximal margin of the collar of the previous aperture. Aperture may be obscured by a thickening of the wall including the rim of the aperture. The length of the test varies between 75 and 300 μm" (Smart and Thomas, 2007:84). Smart and Thomas (2007) emended the description of *Streptochilus* to include the morphological features of the early Miocene species, *S. rockallkiddensis*, which has a test that may become staggered uniserial, and the aperture may be obscured by a thickening of the wall including the rim of the aperture.

DISCUSSION.— See Huber and others (2006), Smart and Thomas (2007) and Darling and others (2009).

PHYLOGENETIC RELATIONSHIPS.— It is possible that the distribution of *Streptochilus* spp. represents one or more expatriation events from the coastal benthos to the pelagic zone (Darling and others, 2009), in addition to lack of observation of these small taxa, explaining its intermittent temporal distribution in the fossil record. Furthermore, it is likely that either no or not all species traditionally placed in the genus *Streptochilus* are descended from the genus *Chiloguembelina*. The name *Streptochilus* is used for planktonic species which morphologically cannot be distinguished from species in the benthic genus *Bolivina*. The genus, therefore, is polyphyletic, including potentially different clades. At present, however, we do not have enough information on evolutionary patterns to identify clades of biserial planktonic species, and it is proposed, therefore, that the name *Streptochilus* be retained provisionally until evolutionary relations are understood.

STRATIGRAPHIC RANGE.— Middle Eocene (Zone E10) to Recent; intermittent. *Streptochilus martini* has been suggested as the earliest species (Huber and others, 2006), and Recent species include *S. globigerus* and *S. globulosus*.

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

***Streptochilus martini* (Pijpers, 1933)**

PLATE 19.1, FIGURES 1-17

Textularia martini Pijpers, 1933:57, figs. 6-10 [upper Eocene, Bonaire, Dutch West Indies].
Guembelina mauriciana Howe and Roberts *in* Howe, 1939:62, pl. 8: figs. 9-11 [Eocene Cook Mountain Fm., Louisiana].
Guembelina martini (Pijpers).—Drooger, 1953:100, pl. 1: figs. 2, text-fig. 4 [upper Eocene, Curacao and Bonaire].
Guembelina tenuis Todd, 1957:303, pl. 65: fig. 31a,b [upper Eocene, Saipan, Mariana Islands].
Chiloguembelina martini (Pijpers).—Beckmann, 1957:89, pl. 21: text-fig. 14 (9-11, 14-18, 20-23) [Eocene, upper Lizard Springs, Navet, and San Fernando Fms., Trinidad].—Hartono, 1969:157, pl. 20: fig. 1 [upper Eocene, Nanggulan, central Java].—Warraich and Ogasawara, 2001:13, figs. 3(1-2) [middle Eocene, Zones P12-P14, Sulaiman Range, Pakistan].
Guembelina goodwini Cushman and Jarvis, *in* Cushman, 1933:69, pl. 7: figs. 15-16 [upper Eocene, Trinidad].
Chiloguembelina goodwini (Cushman and Jarvis).—Warraich and Ogasawara, 2001:11-13, figs. 3 (9-10) [middle-upper Eocene, Sulaiman Range, Pakistan].
Guembelina venezuelana Nuttall, 1935:126, pl. 15: figs. 2-4 [upper Eocene, Bolivar District, Venezuela].
Chiloguembelina victoriana Beckman, 1957, pl. 21: figs. 19, 20, text-fig. 15 (46-48) [upper Eocene, San Fernando, Trinidad].—Warraich and Ogasawara, 2001:13-15, figs. 3 (3-4) [middle Eocene, Zone P12, Sulaiman Range, Pakistan].
Chiloguembelina woodi Samanta, 1973:432, pl. 15: figs. 15-16 [middle Eocene, Zone P12, Sulaiman Range, Pakistan].—Warraich and Ogasawara, 2001:15, figs. 3 (11-12) [middle Eocene, Zones P12-P14, Sulaiman Range, Pakistan].
Streptochilus martini (Pijpers).—Poore and Gosnell, 1985, pl. 1: figs. 1-7 [upper Eocene, DSDP 522-37-CC, South Atlantic].—Resig, 1993, pl. 1: figs. 11-12, 14-16, 18 [upper Eocene, Zone P17, ODP Hole 807C, Ontong-Java Plateau].—Huber and others, 2006, pl.

16.3, figs. 1-2 (holotype of *Chiloguembelina victoriana* Beckman, 1957), pl. 16.3, figs. 3, 6 [upper Eocene, Atlantic City Borehole, New Jersey, ODP Hole 150X], pl. 16.3, figs. 4, 5 [middle Eocene Zone P9, Aragon Fm., Tampico, Mexico], pl. 16.3, figs. 7, 8 [upper Eocene Zone P15, lower Kitunda slopes, Lindi, Tanzania].—Pearson and Wade, 2015, fig. 30 (4-6) [upper Eocene Zone E15/16, Tanzania].

DESCRIPTION

Type of wall: Microperforate, although low latitude forms may have macroperforations (e.g. Pearson and Wade, 2015), smooth to finely pustulose.

Test morphology: "Test elongate, somewhat compressed, sometimes slightly twisted, gradually to moderately tapering, peripheral margin subrounded; chambers biserial, increasing gradually in size, sutures flush to slightly depressed and oblique in first two to three pairs of chambers, later more strongly depressed and nearly horizontal; aperture a semicircular arch with a thin lip that projects on one side more than the other and an internal toothplate that connects foramina of successive chambers" (Huber and others, 2006:477).

Size: Syntype length 0.246 mm, width 0.185 mm, thickness 0.110 mm (Plate 19.1, Figs. 1-2; Pijpers, 1933, fig. 6).

DISTINGUISHING FEATURES.— Distinguished from *Chiloguembelina ototara* and *C. crinita* by the more compressed and tapering test, smoother test surface, and presence of a toothplate. *Streptochilus martini* differs from *S. pristinum* and *S. rockallkiddensis* by its more gradual to moderate tapering of the test. It differs from *S. rockallkiddensis* by the lack of granular surface ornamentation, and differs from *S. tasmanensis* n. sp. by the lack of surface circular pore mounds.

DISCUSSION.— Apparently, Pijpers (1933) did not designate a holotype of *Textularia martini* (= *S. martini*). SEM images of one of the type specimens (syntypes) of *S. martini* taken from Pijpers' collection (Pijpers, 1933, fig. 6) are shown in Plate 19.1 (Figs. 1-2), but unfortunately the specimen has a broken-off final chamber and the aperture cannot be seen clearly. Pijpers (1933) describes the aperture as: "elongate, occasionally slightly curved, at the inner margin of the last formed chamber and perpendicular to that margin". Huber and others (2006) argued that the Eocene species *C. victoriana* Beckmann and *S. martini* should be included within the same species because of the considerable overlap in test elongation and degree of chamber appression. Due to priority, *C. victoriana* was considered a junior

synonym of *S. martini* (Huber and others, 2006). Eocene *Chiloguembelina woodi* Samanta was distinguished from *S. martini* by having more globular chambers and a broader, sub-circular, symmetrical aperture (Samanta, 1973). Without detailed information on how these features vary in populations of *S. martini*, Huber and others (2006) united these taxa.

PHYLOGENETIC RELATIONSHIPS.— Huber and others (2006) suggested that *S. martini* was probably derived from *Chiloguembelina crinita* during the middle Eocene, but evolution of *Streptochilus* spp. may have been polyphyletic, from multiple benthic biserial groups. It is likely that the distribution of *Streptochilus* spp., including *S. martini*, represents a series of excursions of expatriated tychopelagic individuals into the planktic domain (Darling and others, 2009), explaining the intermittent temporal distribution of *Streptochilus* in the fossil record.

TYPE LEVEL.— Upper Eocene, Bonaire, Caribbean Netherlands (formerly Dutch West Indies).

STRATIGRAPHIC RANGE.— Middle Eocene Zone E10 (Huber and others, 2006) to lower Oligocene Zone O2 (Adriatic Sea). Resig (1993) reported the HO of *S. martini* at the Eocene/Oligocene boundary at ODP Site 807 (Ontong Java Plateau), although the LO was not recovered.

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan.

STABLE ISOTOPE PALEOBIOLOGY.— Late middle Eocene $\delta^{18}O$ and $\delta^{13}C$ values of *S. martini* from the NW Atlantic Ocean (ODP Site 1052) suggest it was a thermocline dweller (Sexton and others, 2006).

REPOSITORY.— Department of Earth Sciences, University of Utrecht, The Netherlands.

Streptochilus pristinum **Brönnimann and Resig, 1971**

PLATE 19.1, FIGURES 18-32

Streptochilus pristinum Brönnimann and Resig, 1971:1289, pl. 51: fig. 4 [middle Miocene Zone N13, DSDP Hole 62.1, Eauripik Rise, western equatorial Pacific Ocean].—Jenkins and Srinivasan, 1986, pl. 5: fig. 10 [upper Oligocene, DSDP Hole 593A, Challenger Plateau, southwest Pacific Ocean].—Spezzaferri, 1994, pl. 29: fig. 6 [lower Miocene Zone M1a, DSDP Hole 354, Ceara Rise, equatorial Atlantic Ocean].—Spezzaferri, 1994, pl. 29: figs. 7a,b [lower Miocene Zone M1a, DSDP Hole 593, Challenger Plateau, southwest Pacific Ocean].—Hernitz Kučenjak and others, 2006, pl. 5: fig. 10 [upper Oligocene, Zone O6, Sample Jihar-5 well, Syria].—Beldean and others, 2010: fig. 2 [lower Miocene, Transylvanian Basin].—Beldean and others, 2013, pl. 1: figs. 1-6 [lower Miocene, Transylvanian Basin].

DESCRIPTION

Type of wall: Microperforate, smooth.

Test morphology: Test biserial, early portion of test with straight lateral profile and no chamber inflation, followed by slight inflation of the later chambers, becoming gradually tapered, usually 5-8 pairs of chambers; sutures straight to slightly curved and depressed; aperture a narrow high arch with a rim/collar at the outer margin and the opposite margin turned in to form a ramp to the collar of the previous aperture.

Size: Holotype length 0.180 mm, width 0.076 mm; length range 0.125-0.250 mm, maximum width 0.100 mm.

DISTINGUISHING FEATURES.— Distinguished from other species of the genus by the "straight lateral profile of the early portion of the test followed by the tendency toward inflation of the later chambers" (Brönnimann and Resig, 1971:1289). *Streptochilus pristinum* is distinguished from *Chiloguembelina ototara* by the more compressed test, smoother test surface, and presence of a toothplate. *Streptochilus pristinum* differs from *S. martini* and *S. tasmanensis* n. sp. by its straight lateral profile of the initial part of the test, followed by inflation of later chambers. It differs from *S. rockallkiddensis* by the lack of granular surface ornamentation, and differs from *S. tasmanensis* n. sp. by the lack of surface circular pore mounds.

DISCUSSION.— de Klasz and others (1989) called it, incorrectly, *S. pristinus*. The name *Streptochilus* is derived from streptos, Greek (στρεπτοσ) for 'twisted' and cheilos (χειλοσ), Greek for 'lip' (Brönnimann and Resig, 1971), with the latter word neuter, thus requiring *pristinum* as specific name.

PHYLOGENETIC RELATIONSHIPS.— Resig (1993) suggested that the evolution of *S. pristinum* occurred before the mid late Oligocene, either from *C. cubensis* or from an undiscovered ancestral Eocene *Streptochilus*. Resig (1993) commented that the appearance of *S. pristinum* in the late Oligocene of New Zealand (Hornibrook, 1990), as compared with the low-latitude occurrence at ODP Site 807 (Ontong Java Plateau), implies that the evolution of *S. pristinum* may have occurred in mid-latitudes rather than the tropics. However, some Recent biserial foraminifera are able to live tychopelagically, suggesting a similar lifestyle for species in the past, and suggesting potential polyphyletic evolution of planktonic from benthic biserial groups (Darling and others, 2009). The distribution of *S. pristinum* might, therefore, signify multiple excursions of tychopelegic individuals from the coastal benthos to the pelagic zone (Darling and others, 2009), and its ancestor is unknown.

TYPE LEVEL.— Middle Miocene (Zone N13), DSDP Hole 62.1/34/2, 109-111 cm, Eauripik Ridge, western equatorial Pacific Ocean.

STRATIGRAPHIC RANGE.— Upper Oligocene (Zone O6) (Syria) to Upper Miocene (Zone M13a) (Ontong Java Plateau, Resig, 1993), intermittent.

GEOGRAPHIC DISTRIBUTION.— The distribution during the Oligocene is unknown as it is very rare; known from Syria and New Zealand.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM 688752) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Streptochilus rockallkiddensis **Smart and Thomas, 2007**

PLATE 19.2, FIGURES 1-15

Bolivina sp. Smart and Murray, 1994:141, fig. 2: no. 1 [lower Miocene Zone ~M3, DSDP Hole 563/11/5, 19-21 cm, west flank of Mid Atlantic Ridge, North Atlantic Ocean].— Smart and Ramsay, 1995:736, fig. 2 [lower Miocene Zone ~M3, DSDP Hole 563, west flank of Mid Atlantic Ridge, North Atlantic Ocean].

Bolivina sp. 9. Poag and Low, 1985:502, pl. 1: figs. 16-18 [upper Oligocene Zone O5 to late Pliocene Zone PL6, DSDP Holes 548 and 548A, Goban Spur, northeastern Atlantic Ocean].

Streptochilus rockallkiddensis Smart and Thomas, 2007:84-86, pl. 1: figs. 1a,b (holotype), pl. 1, figs. 2-13; pl. 2-5 (paratypes) [lower Miocene Zones ~M3 to M4a, northeastern Atlantic Ocean, DSDP Hole 608].

DESCRIPTION

Type of wall: Microperforate, surface ornamentation varies from smooth to finely granular to coarsely granular.

Test morphology: Test biserial, shape variable, commonly elongate, parallel-sided and rectilinear, occasionally flared, in some elongate specimens the later formed part of the test may narrow towards the apertural end, rarely twisted; laterally slightly compressed, periphery rounded and non-lobulate to lobulate; chambers increase regularly in size as added, slightly wider than high, initial chambers small and commonly obscured by granular surface ornamentation, number of pairs of chambers varies from 5-8 or more; sutures slightly curved and depressed; aperture low-arch shaped, offset to one side of test, with an internal plate formed by the infolding and downward extension of one margin of the rimmed aperture; no obvious differences between micro- and megalospheric specimens. In early Miocene specimens, the test is biserial and may become staggered uniserial in some elongate specimens, with final chamber often having a thickened rim (Smart and Thomas, 2007:84).

Size: Holotype length 0.225 mm, width 0.075 µm; length range 0.130-0.260 mm, width range 0.070-0.100 mm, thickness range 0.060-0.070 mm.

DISTINGUISHING FEATURES.— Distinguished by commonly elongate rectilinear shape, occasionally flared, laterally slightly compressed, surface ornamentation varying from smooth to granular. *Streptochilus rockallkiddensis* is distinguished from *Chiloguembelina ototara* by the more compressed, commonly elongate rectilinear test, tendency to become

uniserial in some elongate specimens, common granular surface ornamentation, and presence of a toothplate. *Streptochilus rockallkiddensis* differs from *S. martini*, *S. pristinum* and *S. tasmanensis* n. sp. by its more elongate rectilinear shape which becomes occasionally staggered uniserial, and by its surface ornamentation which is often granular.

DISCUSSION.— *Streptochilus rockallkiddensis* was called *Bolivina spathulata* (Williamson) by Thomas (1986, 1987), but it was not illustrated. Smart and Thomas (2007:84) noted that early Miocene forms were typically small, elongate, laterally slightly compressed, biserial becoming staggered uniserial, commonly rectilinear and often narrower towards apertural end, aperture with thickened rim and often obscured, surface ornamentation varying from smooth to granular.

PHYLOGENETIC RELATIONSHIPS.— It has been shown that some Recent biserial foraminifera are able to live tychopelagically implying a similar lifestyle for fossil species, suggesting polyphyletic evolution of planktonic from benthic biserial groups (Darling and others, 2009). The stratigraphic distribution of *S. rockallkiddensis* may represent numerous excursions of expatriated tychopelgic individuals from the coastal benthos to the pelagic zone (Darling and others, 2009), and its ancestor is unknown.

TYPE LEVEL.— Lower Miocene (Zones ~M4a/M4b), DSDP Hole 608/37X/4, 38-40 cm, King's Trough, northeastern Atlantic Ocean.

STRATIGRAPHIC RANGE.— Lower Oligocene Zone O2/O3 (DSDP Site 516, South Atlantic) to upper Pliocene Zone PL6 (DSDP Site 610, North Atlantic, Thomas, 1987), intermittent.

GEOGRAPHIC DISTRIBUTION.— Known from the North and South Atlantic Ocean (Goban Spur, DSDP Site 548 and Rio Grande Rise, DSDP Hole 516F).

STABLE ISOTOPE PALEOBIOLOGY.— The $\delta^{18}O$ values of lower Miocene *S. rockallkiddensis* from Site 608 overlap with those of surface dwelling planktonic foraminifera in the same samples, indicating a mixed-layer habitat, and $\delta^{13}C$ values are lighter than the values for other planktonics, and overlap with, or are lighter than, those of

benthics in the same samples (Smart and Thomas, 2006). The light carbon isotope values were explained as resulting from rapid calcification in a region with variable upwelling conditions (Smart and Thomas, 2006).

REPOSITORY.— Holotype (BM(NH) PF 67972) deposited at the Natural History Museum, London.

Streptochilus tasmanensis Smart and Thomas new species

PLATE 19.2, FIGURES 16-31
PLATE 19.3, FIGURES 1-26

DESCRIPTION

Type of wall: Microperforate, surface scattered with circular pore mounds.

Test morphology: Test small, biserial, elongate, increasing regularly in size, often narrowing towards apertural end, occasionally flared, rarely twisted, occasionally slightly curved; laterally compressed, periphery broadly rounded and lobulate; usually 5-8 pairs of chambers, rarely more, slightly inflated, wider than high, increasing gradually in size as added; sutures slightly curved and depressed; aperture high-arch shaped, offset slightly to one side of test, extending from the base of the last chamber onto apertural face, bordered by a thickened rim/collar along the top and outer side of the arch, the opposite side is turned inward to a plate connecting with the top of the collar and the in-turned portion of the preceding foramen; no obvious differences between micro- and megalospheric specimens.

Size: Holotype length 0.195 mm, width 0.104 mm; length range 0.100-0.318 mm (mean 0.156 mm, St. Dev. 0.033, n = 207), width range 0.072-0.135 mm (mean 0.090 µm, St. Dev. 0.011, n = 207), thickness range 0.041-0.067 mm (mean 0.054 mm, St. Dev. 0.007, n = 42).

ETYMOLOGY.— Named after the area where it has been found, i.e. South Tasman Rise, off Tasmania (ODP Site 1170).

DISTINGUISHING FEATURES.— Distinguished by often becoming narrower towards apertural end, occasionally flared, laterally compressed, surface ornamentation with scattered

circular pore mounds. According to the terminology of Georgescu and others (2011), *S. tasmanensis* n. sp. displays scattered incipient to well-developed pore mounds (2.8-3.7 µm) with circular pores (0.8-1.8 µm). *Streptochilus tasmanensis* n. sp. is distinguished from *Chiloguembelina ototara* by the more compressed test, surface ornamentation of scattered pore mounds, and presence of a toothplate. *Streptochilus tasmanensis* n. sp. differs from *S. martini*, *S. pristinum* and *S. rockallkiddensis* by surface ornamentation of scattered pore mounds. It differs from *S. martini* and *S. pristinum* by the narrowing of the test towards the apertural end.

DISCUSSION.— Similar to the Miocene *S. mascarenensis* Smart and Thomas, but *S. tasmanensis* n. sp. does not become parallel-sided, has less curved sutures and has pore mounds.

PHYLOGENETIC RELATIONSHIPS.— It has been shown that some Recent biserial foraminifera are able to live tychopelagically implying a similar lifestyle for fossil species and polyphyletic evolution of planktonic from benthic biserial groups (Darling and others, 2009). It is likely that the distribution of *S. tasmanensis* n. sp. represents a separate expatriation event from the coastal benthos to the pelagic zone (Darling and others, 2009).

STRATIGRAPHIC RANGE.— Upper Oligocene Zone O7 to lower Miocene (Zone M1) (ODP Hole 1170A), pending further investigations.

TYPE LEVEL.— Upper Oligocene Zone O7, ODP Hole 1170A/43X/3, 56-57 cm, South Tasman Rise, off Tasmania.

GEOGRAPHIC DISTRIBUTION.— Currently only known from South Tasman Rise, off Tasmania (ODP Site 1170).

STABLE ISOTOPE PALEOBIOLOGY.— Late Oligocene $\delta^{18}O$ values of *S. tasmanensis* n. sp. from Site 1170 (samples ODP 1170A/43X/3, 56-57 cm and ODP 1170A/43X/5, 57-58 cm) overlap with those of surface dwelling planktonic foraminifera ("*Globigerina*" cf. *bulloides*) indicating high (surface) water temperatures (text-figure 19.2), and are lighter than those of benthic foraminifera (*Cibicidoides kullenbergi*, *Oridorsalis umbonatus* and *Bolivina*

huneri). $\delta^{13}C$ values of *S. tasmanensis* n. sp. are lighter than the values for other planktonics, and overlap with, or are heavier than, those of benthics in the same samples.

REPOSITORY.— Holotype (NHMUK PM PF 71098) deposited at the Natural History Museum, London.

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FIGURE CAPTIONS

FIGURE 19.1 (a) Stratigraphic ranges, and (b) phylogeny of Oligocene species of *Streptochilus* discussed in this chapter. Shaded vertical lines in (b) represent multiple expatriation events from the coastal benthos to the pelagic zone. Horizontal dashed lines in (b) represent first expatriation events from the coastal benthos to the pelagic zone. BKSA, 1995 = Berggren and others, 1995; K&S, 1983 = Kennett and Srinivasan, 1983; WPBP, 2011 = Wade and others, 2011.

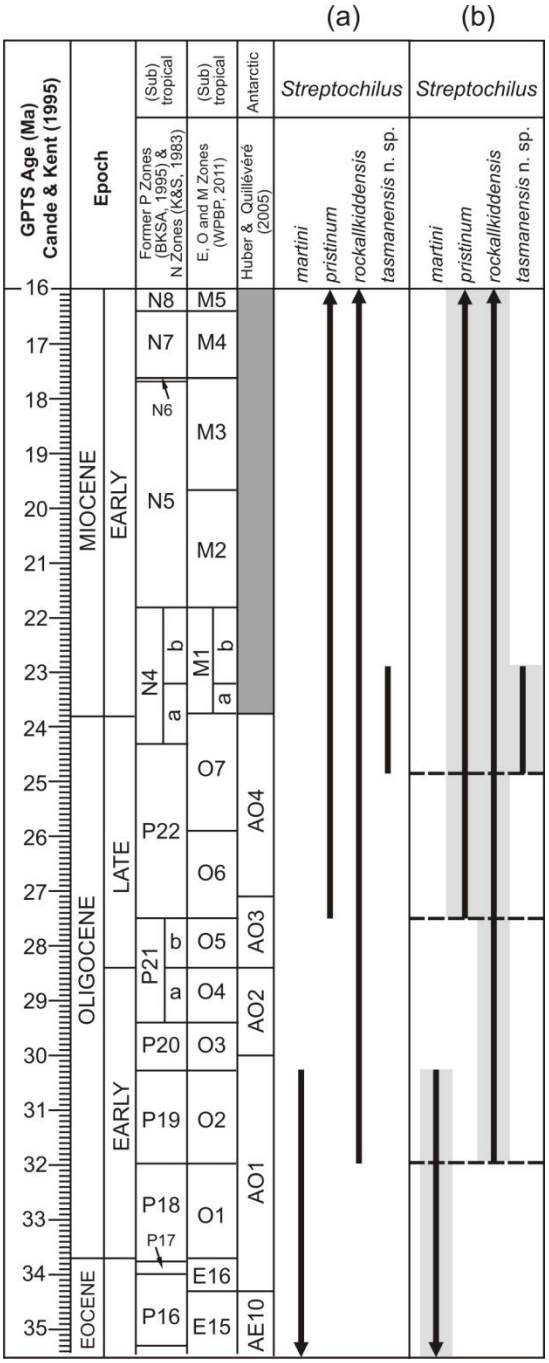

FIGURE 19. 2 Oxygen and carbon isotope values (‰) of late Oligocene *Streptochilus tasmanensis* n. sp., *Dentoglobigerina venezuelana*, "*Globigerina*" cf. *bulloides*, *Cibicidoides kullenbergi*, *Oridorsalis umbonatus* and *Bolivina huneri* for samples ODP Hole 1170A/43X/3, 56-57 cm (solid black circles) and ODP Hole 1170A/43X/5, 57-58 cm (open black circles).

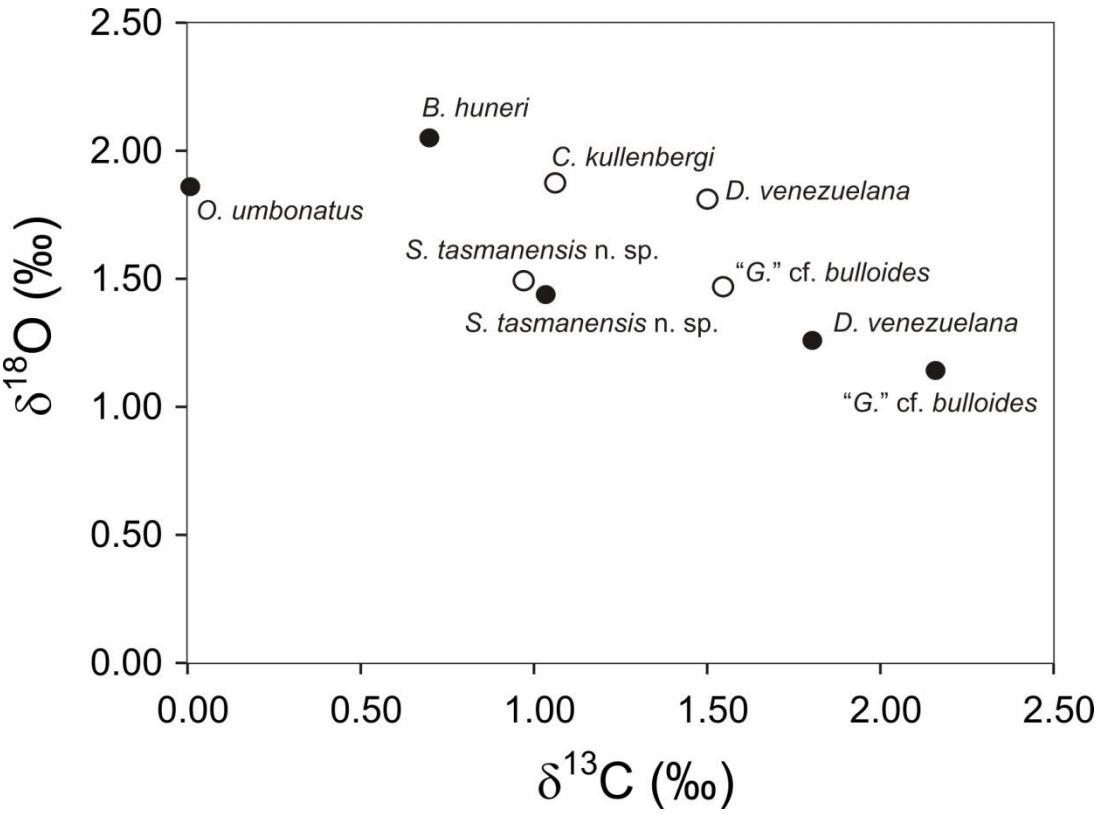

TABLE CAPTIONS

Table 19.1 Oxygen and carbon isotope values (‰) of Oligocene *Streptochilus tasmanensis* n. sp., "*Globigerina*" cf. *bulloides*, *Dentoglobigerina venezuelana*, *Cibicidoides kullenbergi*, *Oridorsalis umbonatus* and *Bolivina huneri* for samples ODP Hole 1170A/43X/3, 56-57 cm and ODP Hole 1170A/43X/5, 57-58 cm. Isotope data are reported with reference to the international standard vPDB and the precision is better than ±0.06 ‰ for $\delta^{13}C$ and ±0.08 ‰ for $\delta^{18}O$. The isotope data are not corrected for disequilibrium.

Species	**Sample**	**Zone**	**Size fraction**	**Number of specimens analyzed**	**$\delta^{18}O$**	**$\delta^{13}C$**
Bolivina huneri	ODP Hole 1170A/43X/3, 56-57 cm	O7	>63 µm	22	2.06	0.70
Cibicidoides kullenbergi	ODP Hole 1170A/43X/5, 57-58 cm	O7	>150 µm	14	1.88	1.06
Dentoglobigerina venezuelana	ODP Hole 1170A/43X/3, 56-57 cm	O7	250-355 µm	12	1.27	1.81
Dentoglobigerina venezuelana	ODP Hole 1170A/43X/5, 57-58 cm	O7	250-355 µm	14	1.82	1.50
"*Globigerina*" cf. *bulloides*	ODP Hole 1170A/43X/3, 56-57 cm	O7	250-355 µm	20	1.16	2.16
"*Globigerina*" cf. *bulloides*	ODP Hole 1170A/43X/5, 57-58 cm	O7	250-355 µm	9	1.48	1.55
Oridorsalis umbonatus	ODP Hole 1170A/43X/3, 56-57 cm	O7	>63 µm	7	1.87	0.01
Streptochilus tasmanensis n. sp.	ODP Hole 1170A/43X/3, 56-57 cm	O7	>63 µm	150	1.45	1.03
Streptochilus tasmanensis n. sp.	ODP Hole 1170A/43X/5, 57-58 cm	O7	>63 µm	150	1.50	0.97

PLATE DESCRIPTIONS

Plate 19.1, 1-17, *Streptochilus martini* (Pijpers, 1933); 18-32, *Streptochilus pristinum* Brönnimann and Resig, 1971.

1-17, *Streptochilus martini*; **1-3**, (same specimen, *Textularia martini* Pijpers, 1933, syntype, SEM image of Pijpers, 1933, fig. 6 (final chamber broken), upper Eocene, Sample well near Porta Spaño, ~15 m deep, northwestern part of the Columbia Plantation, Bonaire, Caribbean Netherlands (formerly Dutch West Indies)); **4-5**, (same specimen), (*Chiloguembelina victoriana* Beckmann, 1957, holotype, USNM P5789), Zone E15/16, Sample San Fernando Fm, Trinidad (Huber and others, 2006, pl. 16.3, figs. 1-2); **6-7**, (same specimen), Zone O2, Sample Istra more-3 well, 1200 m, Adriatic Sea; **8-9**, (same specimen), Eocene/Oligocene boundary, Sample Istra more-3 well, 1295 m, Adriatic Sea; **10**, Eocene/Oligocene boundary, Sample Istra more-3 well, 1295 m, Adriatic Sea; **11**, Eocene/Oligocene boundary, Sample Istra more-4 well, 1385 m, Adriatic Sea; **12**, Zone O1, Sample Jazal-3 borehole, 600-610 m, Syria; **13**; **14-15**, (same specimen); **16-17**, (same specimen, broken), Eocene/Oligocene boundary, Sample Jazal-3 borehole, 630-640 m, Syria.

18-32, *Streptochilus pristinum*; **18-19**, (holotype, USNM 688752), Zones ~M9b-M10, Sample DSDP Hole 62.1/34/2, 109-111 cm, Eauripik Ridge, southwestern Pacific Ocean; **20-23**, (topotype, USNM 688753B), Zones ~M9b-M10, Sample DSDP Hole 62.1/34/2, 109-111 cm, Eauripik Ridge, southwestern Pacific Ocean; **24**; **25-26**, (same specimen, broken), Zones ~M9b-M10, Sample DSDP Hole 62.1/34/2, 109-111 cm, Eauripik Ridge, southwestern Pacific Ocean; **27-28**, (same specimen), Zone O6, Sample Jihar-5 well, 160-170 m, Syria (Hernitz Kučenjak and others, 2006, pl. 5, fig. 10); **29-30**, (same specimen), Zone O6, Sample Jazal-2 well, Syria; **31-32**, (same specimen), Zone O6, Sample Jihar-9 well, 310-320m, Syria. Scale bars: **1-2, 4-6, 9, 10-12, 17, 18-21, 24-25, 28-29**, **32** = 50 µm, **3, 7-8, 15-16, 22-23, 26-27**, **30-31** = 10 µm.

Plate 19.2, 1-15, *Streptochilus rockallkiddensis* Smart and Thomas, 2007; 16-31, *Streptochilus tasmanensis* Smart and Thomas n. sp.

1-15, *Streptochilus rockallkiddensis*; **1-2**, (holotype, BM(NH) PF 67972), Zones ~M4a/M4b, Sample DSDP Hole 608/37X/4, 38-40 cm, King's Trough, northeastern Atlantic Ocean (Smart and Thomas, 2007, pl. 1, figs. 1a-b); **3-4**, (same specimen); **5-6**, (same specimen); **7-8**, (same specimen); **9**; **10-11**, (same specimen), Zone O6/O7, Sample DSDP Hole 516F/7/2, 50-52 cm, Rio Grande Rise, southwestern Atlantic Ocean; **12-13**, (same specimen, broken); **14-15**, (same specimen, broken), Zone O6/O7, Sample DSDP Hole 516F/8/1, 100-101 cm, Rio Grande Rise, southwestern Atlantic Ocean.

16-31, *Streptochilus tasmanensis* Smart and Thomas n. sp., Zone O7, Sample ODP Hole 1170A/43X/3, 56-57 cm, South Tasman Rise, off Tasmania, **16-18**, (holotype, NHMUK PM PF 71098); **19-21**, (paratype, NHMUK PM PF 71099); **22-23** (paratype, NHMUK PM PF 71100); **24-25**, (paratype, NHMUK PM PF 71101), **26-27**, (paratype, NHMUK PM PF 71102); **28-29**, (paratype, NHMUK PM PF 71103); **30-31**, (paratype, NHMUK PM PF 71104). Scale bars: **1, 4-5, 8-10, 13-14, 16, 19, 22, 24, 27-28, 31** = 50 µm, **2-3, 6-7, 11-12, 15, 17-18, 20, 23, 25-26, 29-30** = 10 µm, **21** = 5 µm.

Plate 19.3 *Streptochilus tasmanensis* Smart and Thomas n. sp.

1-24 (paratypes), Zone O7, Sample ODP Hole 1170A/43X/3, 56-57 cm, South Tasman Rise, off Tasmania; **1**, (paratype, NHMUK PM PF 71105); **2**, (paratype, NHMUK PM PF 71106); **3**, (paratype, NHMUK PM PF 71107); **4**, (paratype, NHMUK PM PF 71108); **5**, (paratype, NHMUK PM PF 71109); **6**, (paratype, NHMUK PM PF 71110); **7**, (paratype, NHMUK PM PF 71111); **8**, (paratype, NHMUK PM PF 71112); **9**, (paratype, NHMUK PM PF 71113); **10**, (paratype, NHMUK PM PF 71114); **11**, (paratype, NHMUK PM PF 71115); **12**, (paratype, NHMUK PM PF 71116); **13**, (paratype, NHMUK PM PF 71117); **14-16**, (paratype, NHMUK PM PF 71118); **17-18**, (paratype, NHMUK PM PF 71119); **19-20**, (paratype, NHMUK PM PF 71120); **21-22**, (paratype, NHMUK PM PF 71121, broken); **23-24** (paratype, NHMUK PM PF 71122, broken); **25**, (broken), Zone O7, Sample ODP Hole 1170A/43X/5, 57-58 cm, South Tasman Rise, off Tasmania; **26** (polished), Zone O7, Sample ODP Hole 1170A/43X/3, 56-57 cm, South Tasman Rise, off Tasmania. Scale bars: **1-14, 17, 20-21, 24-26** = 50 µm, **15-16, 18-19, 22-23** = 10 µm.

PLATE 19.1

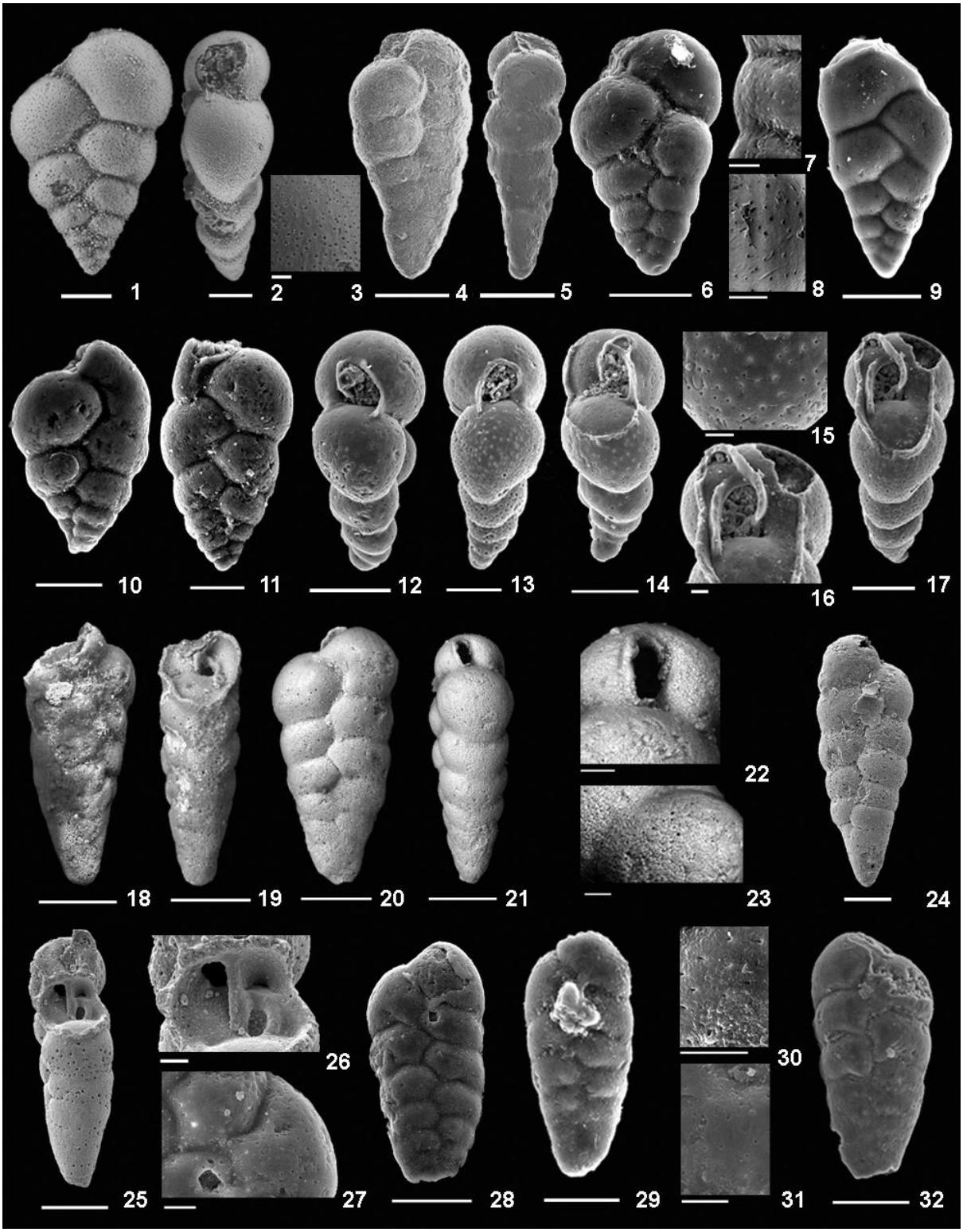
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PLATE 19.2

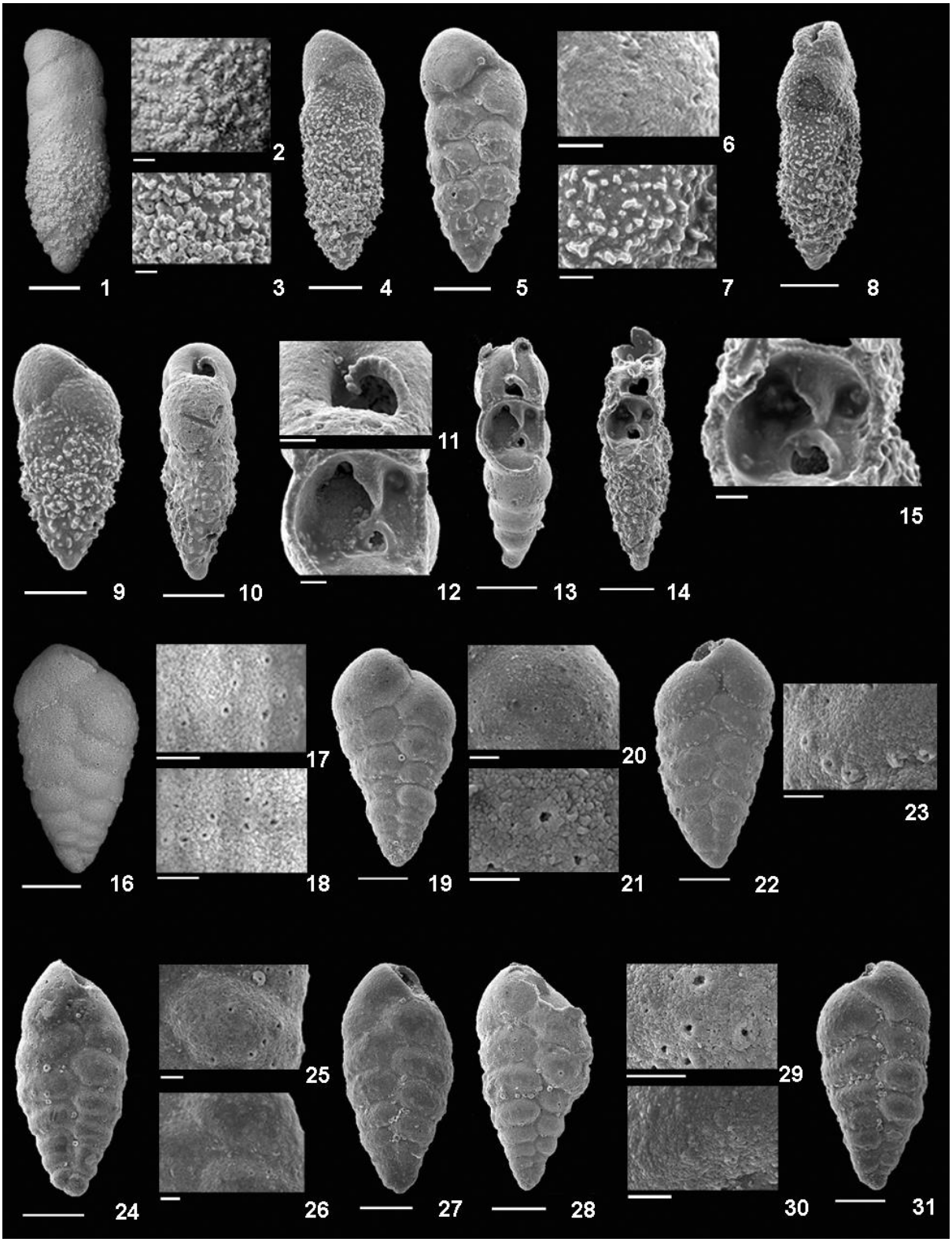
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PLATE 19.3