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# Identification guide to extant planktonic foraminifera.

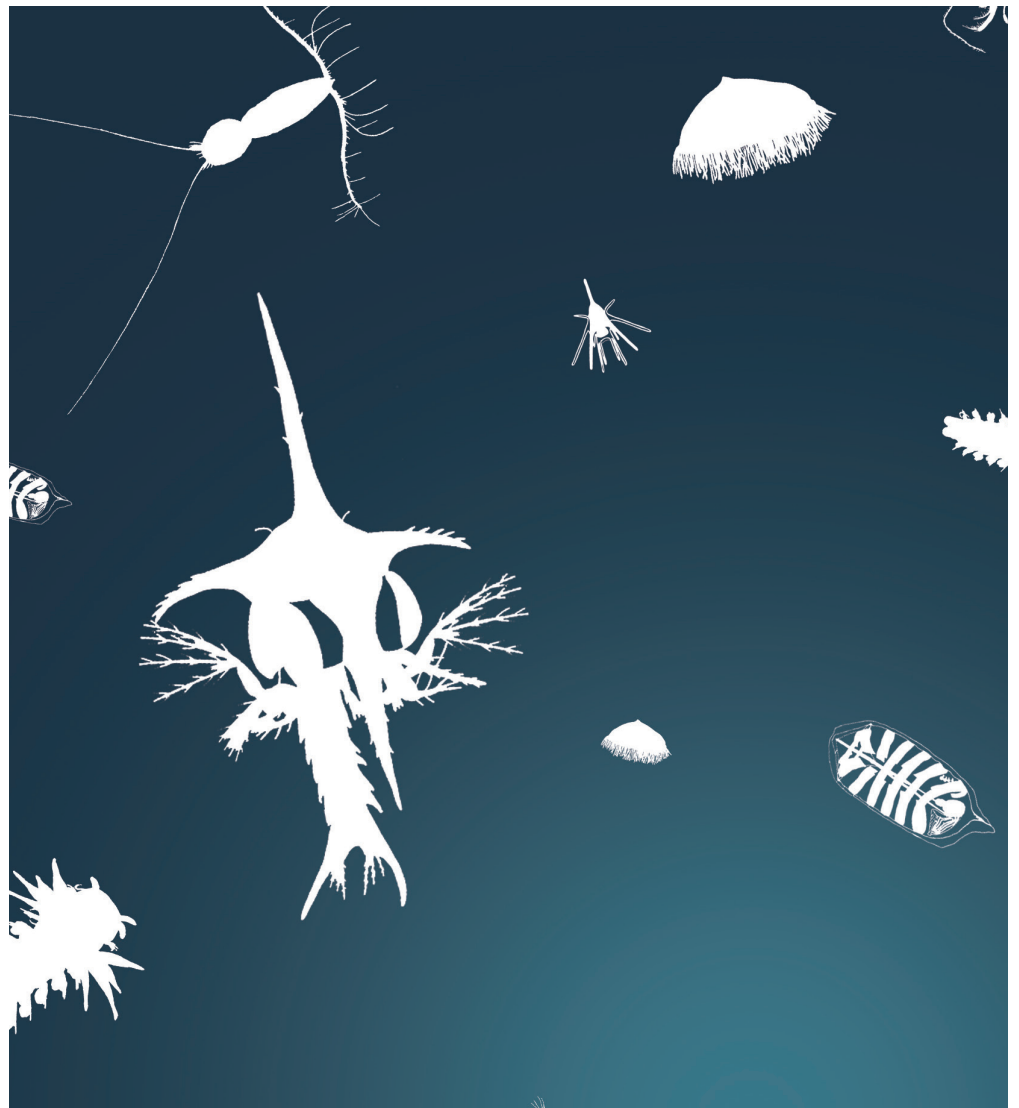
## Part 1: Family Candeinidae and genera *Berggrenia*, *Bolivina*, *Dentigloborotalia*, and *Neogallitellia*

Julie Meilland, Pauline Cornuault, Raphaël Morard, Geert-Jan A. Brummer, and Michal Kucera

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# Identification guide to extant planktonic foraminifera

## Part 1: Family Candeinidae and genera *Berggrenia*, *Bolivina*, *Dentigloborotalia*, and *Neogallitellia*

### 1 Summary

Planktonic foraminifera are a prolific and diverse group of Rhizaria, inhabiting the upper water column in all marine habitats. In the course of their evolution, different clades of the foraminifera colonized the plankton, making the fossil and extant planktonic foraminifera an ecological group rather than a clade with a single monophyletic origin. Fossil planktonic foraminifera have been extensively used to date marine sediments, to reconstruct past ocean circulation and climate, and to understand plankton evolution and macroecology. As a result, the taxonomy of planktonic foraminifera, including the extant taxa, is based on characters of their calcite shells (tests), which are preserved in sediments. This morphological classification has been largely vindicated by recent molecular phylogenies; the taxonomic descriptions and guides involved, however, are based on shells as found in sediments and are not ideal for the identification of living specimens. This is because when caught alive in the plankton the majority of individuals are from maturing populations that lack terminal ontogenetic features on their shells, upon which the classification of fossil foraminifera is mainly based. To aid researchers working with extant planktonic foraminifera, we present here a taxonomic guide specifically tailored towards the identification of living specimens. We begin with the microperforate Candeinidae and four lineages which appear to be represented in the plankton by a single species. The taxonomic concepts are supported by hand-drawn illustrations and light microscopic images; the key characteristics are listed in an overview table (Table 1) to aid rapid identification. Like most planktonic foraminifera, the 11 species described in this leaflet are cosmopolitan, occurring throughout the world oceans in broad latitudinal bands corresponding to their thermal requirements. Although the ecology of extant planktonic foraminifera has been studied extensively, most of the taxa described here are small and have long been considered obscure, with comprehensive distribution data existing only for three species of the microperforate Candeinidae.

### 2 Introduction

Most of our knowledge of the ecology and biogeography of planktonic foraminifera, and most of their applications in the fossil record, are based on the spinose Globigerinidae and the non-spinose macroperforate Globorotalidae. These clades contain species that are abundant and build large (up to 1 mm) shells, which are easy to handle and provide sufficient quantities of calcite as a substrate for geochemical analyses. In contrast, the distribution and ecology of the remaining clades of foraminifera that are represented in the plankton is documented for only a handful of species. Because of their small size that often excludes them from plankton and sediment studies, focusing on size-fractions larger than 150  $\mu\text{m}$ , and because of convergent shell morphology, these taxa have been often neglected or left taxonomically unresolved (Brummer *et al.*, 1986). This is unfortunate because metabarcoding studies indicate that representatives of

these small and obscure lineages are widespread and are likely to represent a considerable part of the planktonic foraminifera biomass (Morard *et al.*, 2018).

Here we provide illustrations and diagnoses of 11 species, representing what are likely to be five independent transitions from benthic ancestors towards a holoplanktonic or tychopelagic lifestyle. These include four lineages, each represented in the plankton by a single species: the tychopelagic biserial *Bolivina variabilis*, the triserial *Neogallitellia vivans*, and the ‘small taxa’ *Berggrenia pumilio* and *Dentigloborotalia anfracta*. Next, we provide a guide to the classification of the microperforate Candeinidae, represented in the modern plankton by three genera with seven species, including the monotypic *Candeina* (*C. nitida*), the abundant *Globigerinita* (*G. glutinata*, *G. minuta* and *G. uvula*), and the obscure *Tenuitellita* (*T. iota*, *T. fleisheri* and *T. parkerae*). The classification follows the scheme of Brummer and Kucera (submitted and in review in the Journal of Micropaleontology at time of writing) and largely reflects the classical taxonomy as presented in Schiebel and Hemleben (2017), upgraded from Hemleben *et al.* (1989). Unless stated otherwise, all illustrated specimens are from the North Atlantic Ocean. The drawings are based on SEM images derived from plankton or from Quaternary sediments, and include pictures published by Brummer and Kroon (1988). The images were selected to represent typical features of each species. Compared to the images, the drawings were slightly modified to remove potential shell damage or contamination on the surface. The key overall morphological features like chamber shape or number were systematically preserved.

### 3 Distribution

The taxa described in this leaflet appear to be cosmopolitan and inhabit the upper water layer of all oceans. Most of these species have been reported from warm to temperate waters, with the exception of *Globigerinita uvula* which is also abundant in subpolar to polar waters (Figure 1). Although the abundance and distribution of many of the species is poorly constrained, metabarcoding data (Morard *et al.*, 2019) revealed that the microperforate and small taxa are opportunistic and widespread; this indicates a greater ecological significance than previously assumed. All of the described taxa have been reported in metabarcoding data (Morard *et al.*, 2019) from plankton samples within the International Council for the Exploration of the Sea (ICES) area, that comprises the North Atlantic from 36°N to 85°N. Most of the described species are epipelagic, with *Candeina nitida*, *Globigerinita glutinata*, and *G. uvula* associated with photosymbiotic algae (Takagi *et al.*, 2019); the species of *Tenuitellita* and *Berggrenia* appear, however, to extend their habitat into the subsurface well below 100 m which implies that they may lack photosynthetically active symbionts (Rebotim *et al.*, 2017; Lessa *et al.*, 2020).

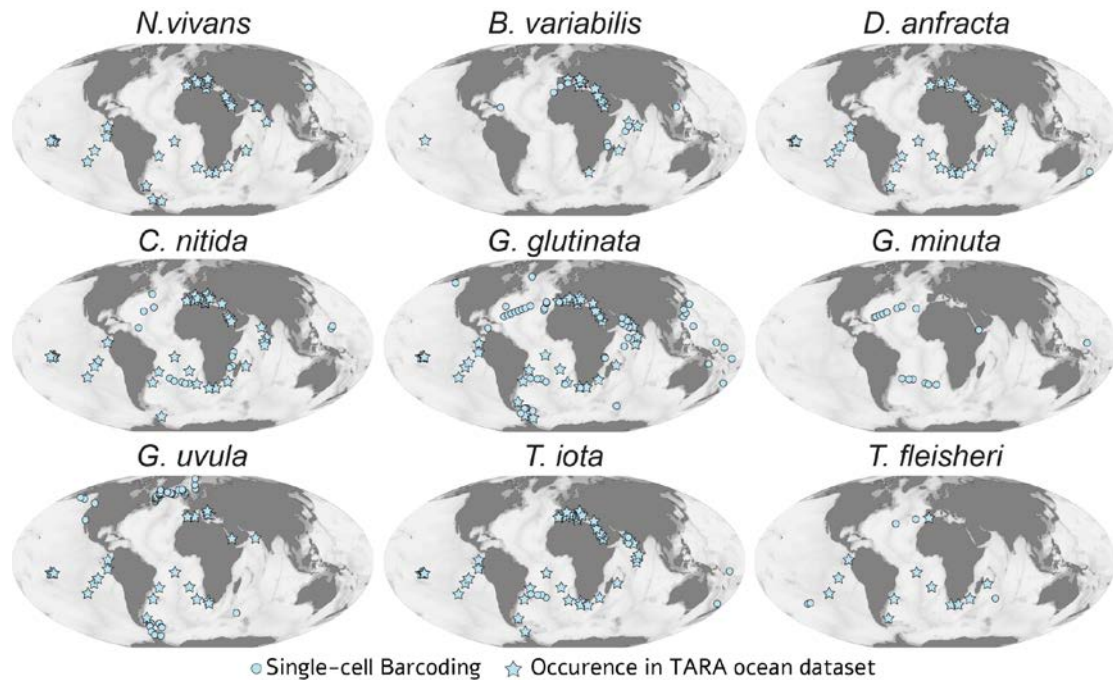


Figure 1. Distribution of nine of the species described in this leaflet based on genetic data and redrawn from (Kucera *et al.*, 2017; Morard *et al.*, 2019). Circles represent occurrences of individually barcoded specimens (see Morard [2019] for details), stars represent occurrences in the metabarcodes generated within the TARA ocean project (de Vargas *et al.*, 2015). All species are cosmopolitan within their preferred thermal range, with *G. uvula* showing an affinity towards colder waters of both hemispheres.

## 4 Taxonomic Guide

### 4.1 *Berggrenia pumilio* (Parker 1962)

**Morphology:** Shell wall thin, medioperforate (1–2  $\mu\text{m}$ ; Pearson *et al.*, 2018 chapter 16) pores sparsely distributed, mainly on the spiral side of the shell along the sutures, non-spinose, smooth except around the aperture and in the umbilicus where small pustules can be observed, umbilical side ornamented with faint striation, radiating from the umbilicus (Plate 1, A). **Shell** low trochospiral, compact, typically 5 to 6 chambers in the final whorl, slowly increasing in size. **Maximum diameter:** approximately 0.150 mm. Terminal chamber often kummerform, adumbilically displaced and slightly ampullate, sutures depressed and curved. Umbilicus distinct and open (Plate 1, A). **Aperture** umbilical-extraumbilical, medium arch. **Cytoplasm:** often in tones of brown.

**Diagnosis:** Under the light microscope, the species can be recognized by the smooth and shiny surface of the shell, compact shell outline, and the larger number of chambers in the final whorl (Plate 1, 7–8). In terminal stage, it is distinguished by the distinctly ampullate final chamber. When the non-spinose nature of the shell wall cannot be clearly established, specimens of this species can be easily confused with a range of spinose taxa, such as *Turborotalita* spp. or immature *Globigerinoides* and *Trilobatus sacculifer*.

**Ecology:** *B. pumilio* is a rare species found in warm to temperate waters of all oceans. The depth habitat and the presence of symbionts have not been constrained in this species.

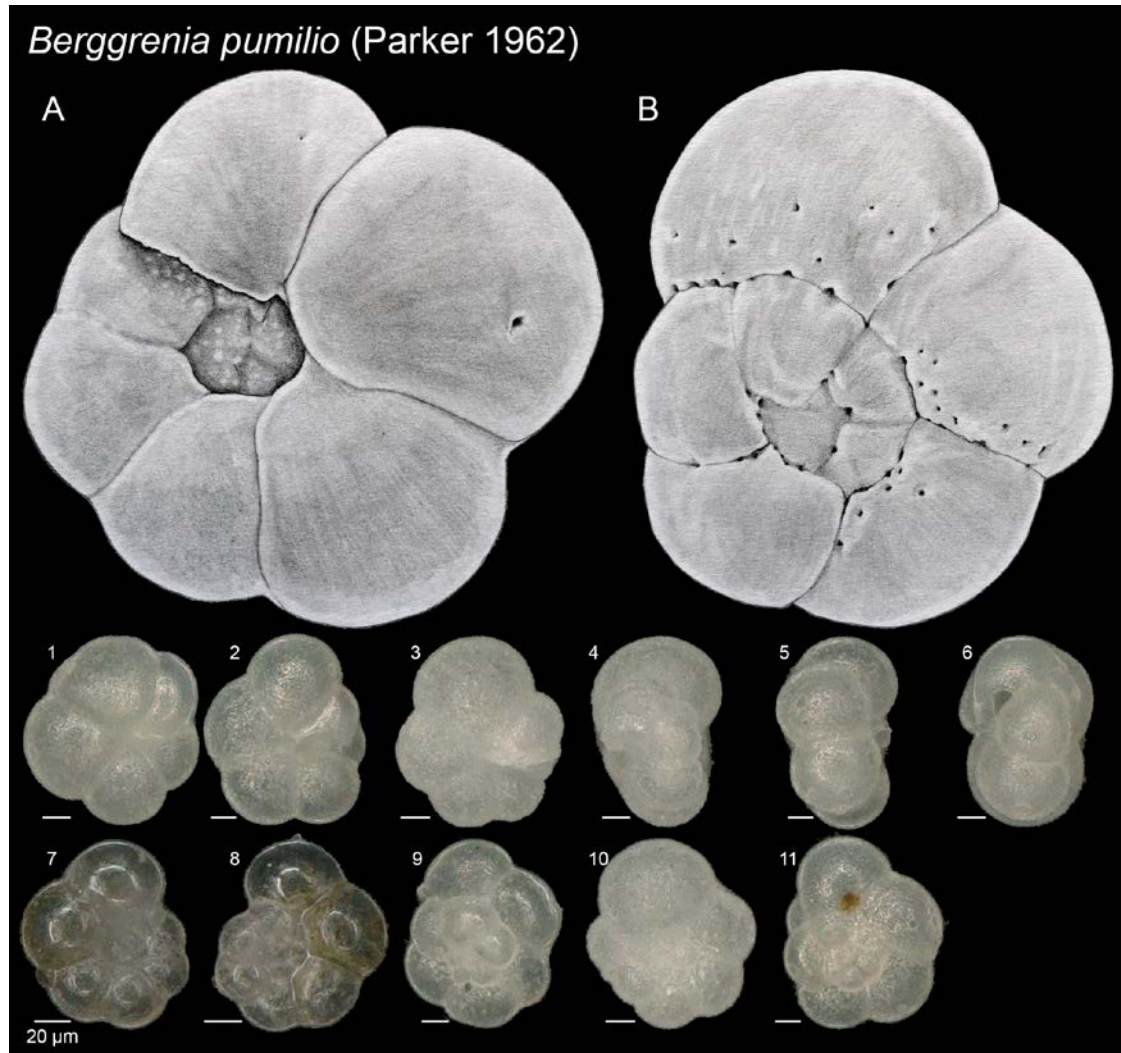


Plate 1. Drawing of A) umbilical and B) spiral view of a representative mature specimen of *B. pumilio* modelled on SEM images of a specimen 0.09 mm in diameter. Note the smooth shell wall texture, the medioperforation of the shell mostly on the spiral side and the ampullate final chamber. 1–11) Light microscope images of specimens from plankton tows. 1–3) umbilical views (note the characteristic shape of the last chamber); 4–6) lateral views showing the aperture extending outside the umbilicus (6); 7–11) spiral views including particularly smooth specimens with cytoplasm in 7 and 8. 1 and 6 and 2 and 11 are different views of the same specimen. Scale bars are all 20 µm.

#### 4.2 *Neogallitellia vivans* (Cushman 1934)

**Morphology:** Shell wall thin, microperforate, pores evenly distributed on the entire surface of the shell, non-spinose, smooth (Plate 2). **Shell** triserial, tapering, shell outline lobate, chambers globular, inflated, slowly increasing in size. **Maximum diameter:** approximately 0.120 mm. Sutures depressed. **Aperture** umbilical, semi-circular to loop-shaped, positioned in a depression of the chamber face, often possessing a small but distinct chamber wall protrusion, resembling a tooth (Plate 2). **Cytoplasm:** often translucent, difficult to observe.

**Diagnosis:** Easily distinguishable from all other extant species by the triserial shell architecture.

**Ecology:** *N. vivans* has been shown genetically to be related to the otherwise benthic *Stainforthia* (Ujiié *et al.*, 2008), and although stable isotopic data indicate that it calcifies in the plankton (Kroon and Nederbragt, 1990), it remains unclear whether the species is holoplanktonic throughout its life history. The species appears to be rare but cosmopolitan (Figure 1). Its depth habitat is not constrained. There is no evidence of the presence of symbionts in this species.



4.3 *Bolivina variabilis* (Williamson 1858)

**Morphology:** **Shell wall** thin, medioperforate (1–2  $\mu\text{m}$ ), pores evenly distributed on the surface of the shell, surface non-spinose, smooth to rough, ornamented with ridges (Plate 2). **Shell** biserial, shell outline compact, triangular. **Maximum diameter:** up to 0.5 mm, but is often smaller. Chambers elongated, initially rapidly then slowly increasing in size, inflated, becoming progressively more globular. Sutures depressed. **Aperture**, high arch to loop-shaped, extending from the basal suture of the final chamber, with a distinct lip. **Cytoplasm:** often in various hues of orange to dark red (Plate 2).

**Diagnosis:** Easily distinguishable from all other extant species by the biserial shell architecture. Previously classified as *Streptochilus* (Smart and Thomas, 2007; and references therein), with two extant species, but genetic data revealed the planktonic specimens to be conspecific with *B. variabilis*, known to occur in the benthos (Darling *et al.*, 2009). There appears to be a high degree of genetic variability among the studied specimens and it is possible that the plankton is (intermittently) inhabited by more than one species of *Bolivina* (Kucera *et al.*, 2017).

**Ecology:** Typically rare, but occasionally more abundant, cosmopolitan. Depth habitat not constrained, although calcification appears to occur in the surface layer (Darling *et al.*, 2009). There is no evidence of the presence of symbionts in this species.

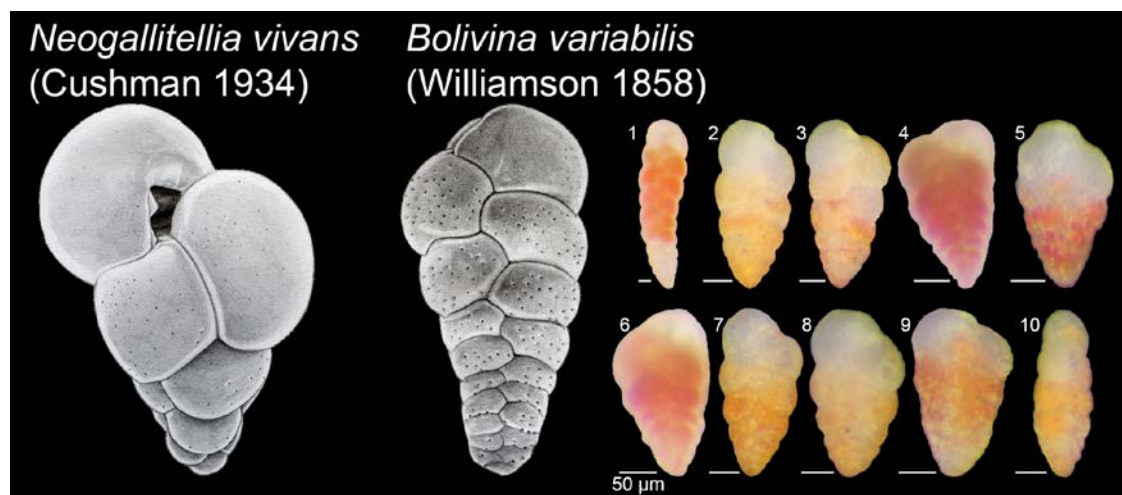


Plate 2. Left: Drawing of a representative mature specimen of the triserial *N. vivans* modelled on an SEM image of a specimen 0.13 mm in diameter. Note the smooth texture, the loop-shaped aperture and globular inflated chambers. Right: Drawing of a representative mature specimen of the biserial *B. variabilis* modelled on an SEM image of a specimen 0.15 mm in diameter and showing elongated chambers progressively becoming more globular and the aperture with a lip. 1–10) Light microscope images of specimens of *B. variabilis* from plankton tows showing large morphological variability. Scale bars are all 50  $\mu\text{m}$ .

4.4 *Dentigloborotalia anfracta* (Parker 1967)

**Morphology:** **Shell wall** thin, medioperforate (1–2  $\mu\text{m}$ ), pores denser on distal parts of the chambers, non-spinose, smooth except around the aperture where characteristic hook-shaped pustules can be observed. **Shell** low trochospiral, kidney-shaped chambers flattened on the spiral side, typically 4 to 5 in the final whorl, slowly increasing in size (Plate 3). **Maximum diameter:** approximately 0.2 mm. Sutures depressed and curved. **Aperture** umbilical-extraumbilical, low arched, with prominent flap on the ultimate chamber. **Cytoplasm:** often in tones of orange, light, sometimes difficult to observe.

**Diagnosis:** easily distinguished by the compressed, kidney-shaped chambers and smooth, clear and shiny surface of the shell under light microscope (Plate 3, specimens 1–12). Differs from

*Globorotalia scitula* by chamber compression mainly on the spiral side and by the ‘twisted’ kidney-shaped chambers.

**Ecology:** *D. anfracta* is a common species in warm to temperate waters of all oceans (Figure 1). Its depth habitat is not constrained. There is no evidence of the presence of symbionts.

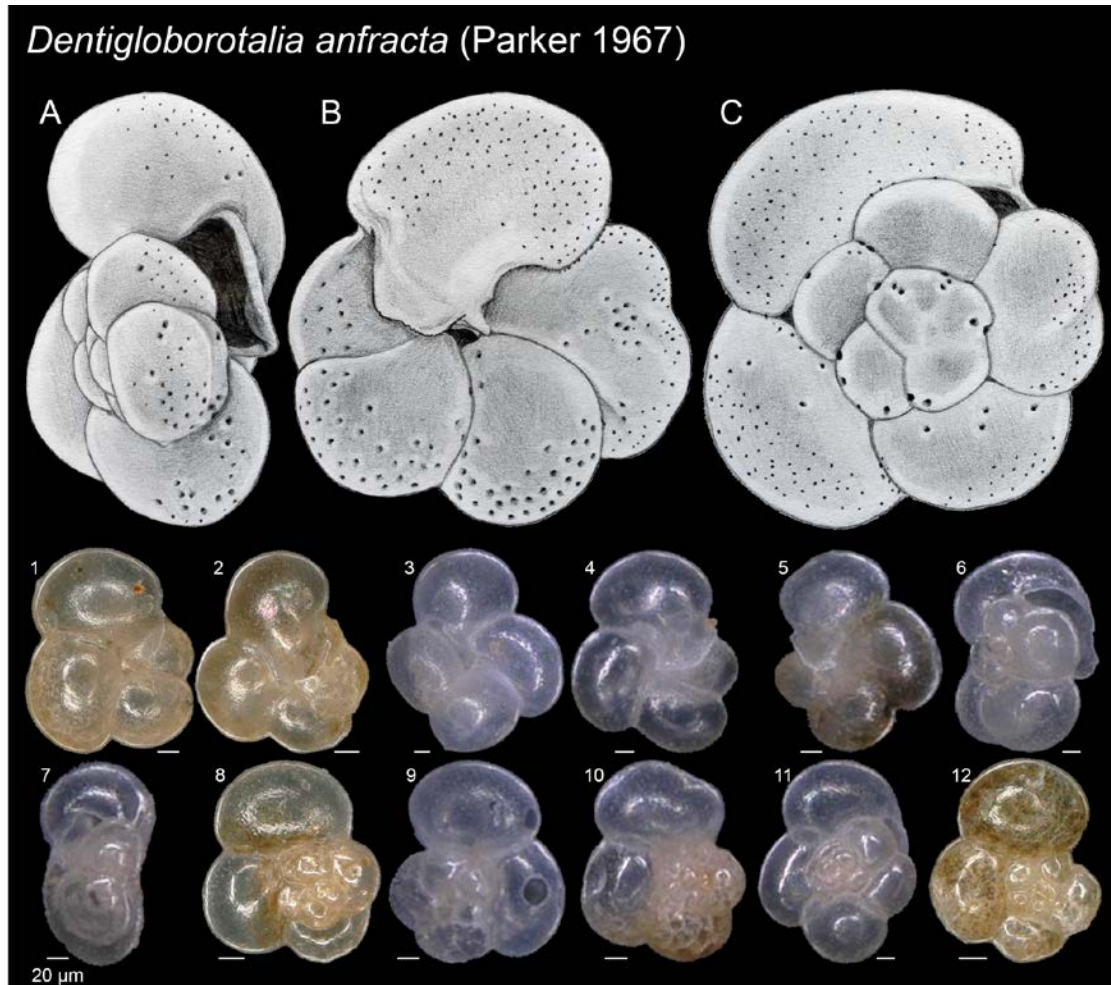


Plate 3. Drawing of A) lateral, B) umbilical, and C) spiral view of a representative mature specimen of *D. anfracta* modelled on SEM images of a specimen 0.12 mm in diameter. Note the smooth texture, medioperforation (denser on the distal part of the chambers), apertural flap, and kidney-shaped chambers. 1–12) Light microscope images of specimens from plankton tows. 1–5) umbilical views of cytoplasm bearing (1–2) and empty shells (3–5); 6–7) lateral view flattened on the spiral side showing the umbilical-extraumbilical aperture and the opening of the apertural flap of the specimen (6); 8–12) spiral views including cytoplasm bearing (8 and 12) and empty shells (9–11). Scale bars are all 20 µm.

#### 4.5 Family Candeinidae

The extant Candeinidae comprise three genera and seven species. The family is characterized by possessing low to high trochospiral shells with inflated chambers and microperforate shell wall. Genera are distinguished by apertural position, which is umbilical in *Globigerinita* (Brönnimann 1951) and umbilical-extraumbilical in *Tenuitellita* (Li, 1987). The latter species also shows a tendency for modifications of last chamber shape. The monotypic genus *Candeina* (d’Orbigny 1839) is distinguished by the presence of multiple sutural apertures.

4.5.1 *Candeina nitida* (d'Orbigny 1839)

**Morphology:** **Shell wall** microperforate, non-spinose, early chambers sparsely pustulate with pustules concentrated around the aperture, later chambers smooth. **Shell** medium to high trochospiral, chambers globular, embracing; typically 3 to 4 in the final whorl, increasing slowly in size. **Maximum diameter** of mature specimens: 0.5 mm. The sutures between chambers are depressed. **Primary aperture** present in pre-adult stages, umbilical, arched, with a thin rim, later during the ontogeny replaced by a series of small multiple sutural apertures with thick rims located along all sutures of the successively added chambers (Plate 4). **Cytoplasm:** typically green to brown, reflecting the presence of algal symbionts (Plate 4, specimens 2–5).

**Diagnosis:** easily recognized when mature by the presence of multiple sutural apertures and smooth shell surface. Pre-adult individuals resemble *G. glutinata* but have smoother surface and incipient sutural apertures appearing next to the large primary aperture.

**Ecology:** *C. nitida* is a rare to common species inhabiting surface to subsurface waters of tropical to subtropical oceans (Figure 1). It is known to carry photosynthesizing algal symbionts (Takagi *et al.*, 2019).

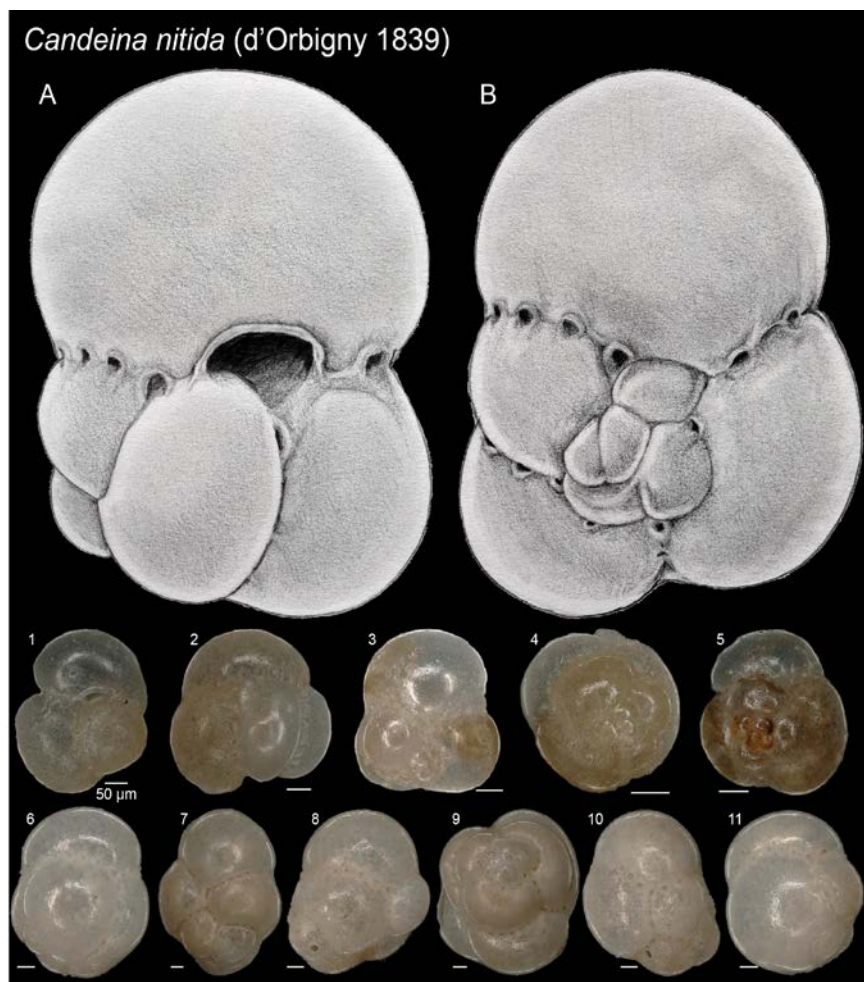


Plate 4. Drawing of A) umbilical and B) spiral view of a representative mature specimen of *C. nitida* modelled on SEM images of a specimen 0.35 mm in diameter. Note the smooth texture, the microperforation of the shell and the multiple sutural apertures. 1–11) Light microscope images of specimens collected with plankton tows (1–8) and from sediments (8–10). 1) umbilical view with main aperture visible; 4, 5, and 9) spiral views; 6–11) mature specimens with clearly visible sutural apertures. 2–5) cytoplasm bearing shells. 2 and 4, 8 and 10 and 6 and 11 are different views of same specimens. Scale bars are all 50 µm.

#### 4.5.2 *Globigerinita glutinata* (Egger 1893)

**Morphology:** **Shell wall** microperforate, non-spinose, covered with small pustules initially denser around the aperture, in mature specimens covering the chambers evenly. **Shell** medium to low trochospiral, chambers globular, embracing; 3 to 4 in the final whorl, slowly increasing in size. **Maximum diameter:** approximately 0.3 mm. Last chamber often smoother, with a mat sheen in light microscopy (Plate 5). Sutures between the chambers are curved, mostly radial and depressed; umbilicus shallow, in the terminal stage often (but not always) covered by a bulla with multiple infralaminal apertures (Plate 5, D). **Primary aperture** umbilical with a low arch in adult specimens and shorter and slightly higher arch in younger specimens, bordered with a fine lip. **Cytoplasm:** ranging in colour from light green and orange to red and dark brown.

**Diagnosis:** distinguished from *G. uvula* and *G. minuta* by a lower trochospire and from *G. minuta* by wider, lower arched aperture. Homeomorphic shell architecture appears in several spinose taxa, such as *Globigerina bulloides*, so that its identification requires confirmation of the microperforate wall structure.

**Ecology:** *G. glutinata* is one of the most abundant planktonic foraminifera species, inhabiting tropical to temperate waters of all oceans and in smaller numbers also extending into subpolar waters (Figure 1). It occurs mainly in surface waters and is known to carry photosynthesizing algal symbionts (Takagi *et al.*, 2019).

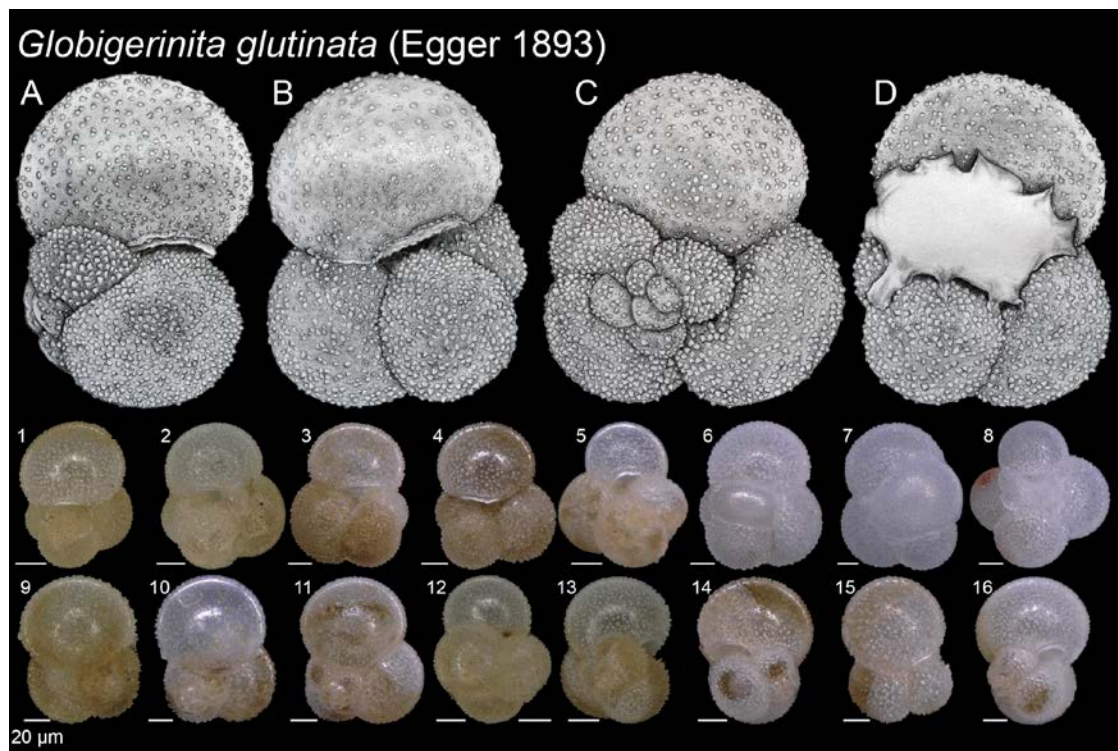


Plate 5. Drawing of A) lateral, B) and D) umbilical, C) spiral view of representative mature *G. glutinata* modelled on SEM images of specimens 0.17 mm in diameter. Note the thin apertural lip, the microperforation of the shell and pustules on the entire shell and in D) the presence of a bulla. 1–16) Light microscope images of specimens from plankton tows. 1–5) umbilical view of cytoplasm bearing specimens with umbilical aperture visible; 6–8) umbilical view of empty shells with the umbilical aperture covered by a bulla; 9–12) spiral view of cytoplasm bearing (9, 11, 12) and empty shells (10–11); 13–16) lateral view of cytoplasm bearing (13–15) and empty (16) specimens highlighting the low trochospiral arrangement of the chambers and the low-arched aperture (14). Scale bars are all 20 μm.

4.5.3 *Globigerinita uvula* (Ehrenberg 1861)

**Morphology:** **Shell wall** microperforate, non-spinose, smooth or covered with small pustules that are commonly concentrated around the aperture and chamber sutures (Plate 6). **Shell** highly trochospiral, elongated, chambers globular, typically 3.5 to 4 in the final whorl, slowly increasing in size. **Maximum diameter:** approximately 0.2 mm. The sutures between chambers are mostly radial and depressed. Ultimate chamber often kummerform, directed towards the umbilicus; umbilicus shallow. **Aperture** umbilical, low arched, bordered by a thin lip (Plate 6, A and 1). **Cytoplasm:** often in light tones of green and brown (Plate 6–1 and 3).

**Diagnosis:** characterized by the highly trochospiral coiling of the shell with chambers slowly increasing in size, creating an appearance akin to a bunch of grapes (Plate 6). Distinguished from *G. minuta* by higher trochospire and from the triserial *N. vivans* by the clearly trochospiral coiling of the early part of the shell.

**Ecology:** *G. uvula* is an abundant species inhabiting temperate and cold waters of all oceans, ranging into the polar waters of both hemispheres (Figure 1). The species is epipelagic and known to carry photosynthesizing algal symbionts (Takagi *et al.*, 2019).

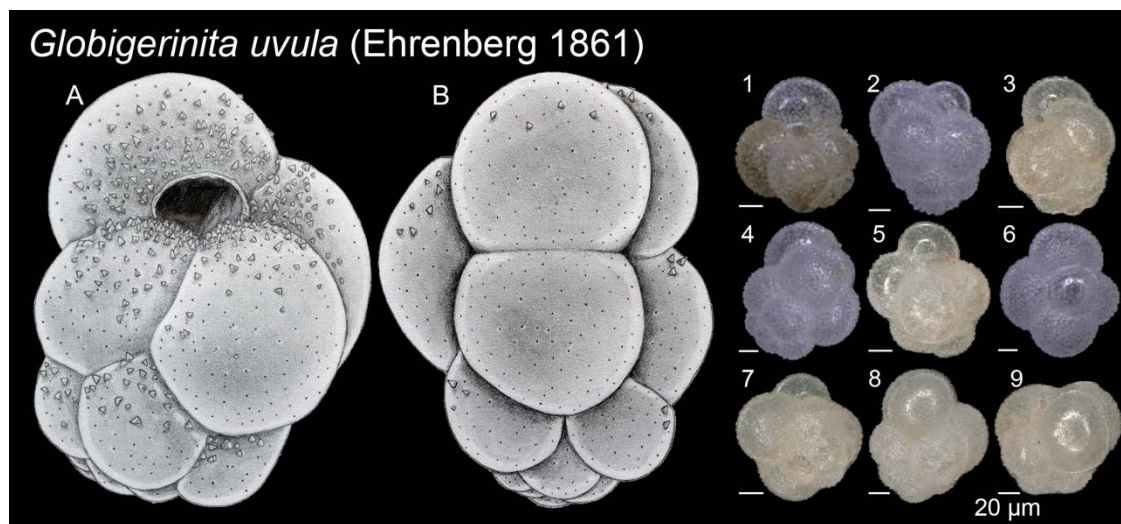


Plate 6. Drawing of A) umbilical / lateral-umbilical and B) lateral view of a representative mature specimen of *G. uvula* modelled on SEM images of a specimen 0.12 mm in diameter. Note the presence of a thin lip, the microperforation of the shell, the highly trochospiral arrangement of the chambers and the presence of pustules, unevenly distributed on the surface of the shell. 1–10) Light microscope images of specimens from plankton tows. 1–3) umbilico-lateral view of cytoplasm bearing (1) and empty (2–3) specimens with the umbilical aperture visible; 7–8) spiral view; 2, 3, 4, and 8) show a high trochospiral arrangement of their chambers. 2 and 4 and 5 and 7 are different views of same specimens. Scale bars are all 20 µm.

4.5.4 *Globigerinita minuta* (Natland 1938)

**Morphology:** **Shell wall** microperforate, non-spinose, densely covered by pustules in terminal stages. **Shell** medium to high trochospiral, chambers globular; typically 3.5 to 4 chambers in the final whorl, slowly increasing in size, highly embracing, giving the shell a compact appearance. **Maximum diameter:** approximately 0.2 mm. The sutures between chambers are mostly radial and depressed. Umbilicus shallow, its terminal stage may be covered by a bulla with multiple infralaminar apertures. **Primary aperture** umbilical, narrow, high arched, almost loop-shaped, bordered by a thin lip (Plate 7). **Cytoplasm:** brown.

**Diagnosis:** Characterized by slightly more trochospiral, more 'involute' shell architecture, an almost globorotaliid initial whorl (visible in transmitted light) and a higher arched aperture than *G. glutinata*. Distinguished, often with difficulty, from *G. uvula* by lower trochospire and

more compact shell, and from immature specimens of *T. iota* by more globular chambers and denser, more evenly distributed pustules.

**Ecology:** *G. minuta* appears to be epipelagic and common in temperate waters of all oceans. Its distribution remains largely elusive due to the difficulty to identify it, but it is most likely cosmopolitan (Figure 1; Morard *et al.*, 2018). The presence of symbionts in this species has not been constrained.

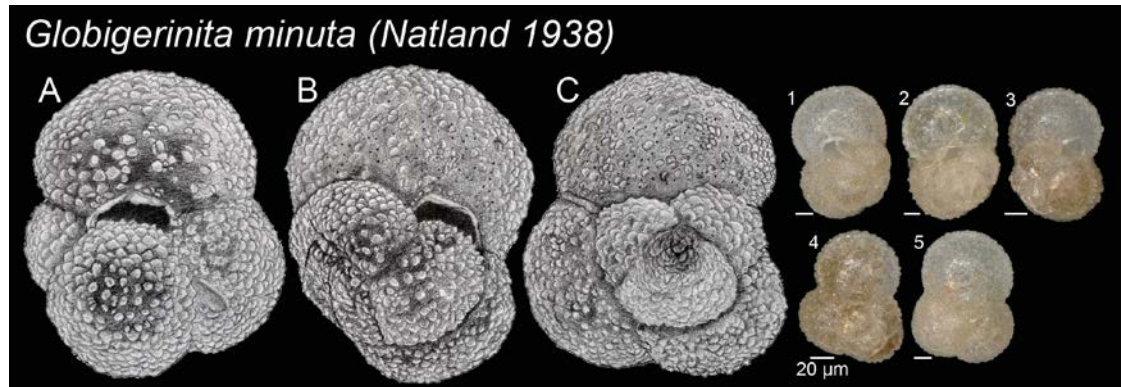


Plate 7. Drawing of A) umbilical, B) lateral and C) spiral view of a representative specimen of *G. minuta* modelled on SEM images of a specimen 0.09 mm in diameter. Note the high-arched aperture, a thin lip, the microperforation of the shell and the shell wall densely covered with pustules. 1–6) Light microscope images of specimens from plankton tows in the South and North Atlantic Ocean. 1–2) umbilical view of cytoplasm bearing specimens with the umbilical aperture and its thin lip visible; 3) lateral view of a cytoplasm bearing shells with the high-arched / loop-shaped umbilical aperture and the medium trochospiral arrangement of the chambers visible; 5–6) spiral view of cytoplasm bearing shells. 1 and 5 and 3 and 4 are different views of same specimens. Scale bars are all 20 µm.

#### 4.5.5 *Tenuitellita iota* (Parker 1962)

**Morphology:** **Shell wall** microperforate, non-spinose, covered densely by pustules when mature while immature individuals distinctly sparsely pustulate, with higher density of pustules around the aperture. **Shell** low trochospiral, chambers globular in immature specimens, appearing slightly compressed when mature; typically 4 to 4.5 in the final whorl, very slowly increasing in size, such that the sutures of the final whorl chambers form a cross, centered on the umbilicus. **Maximum diameter:** approximately 0.2 mm. The sutures between chambers are radial and depressed; umbilicus shallow. **Aperture** umbilical-extraumbilical, medium wide, low arched, bordered by a thin lip (Plate 8, B). In the terminal stage, umbilicus frequently covered by a distinctly shaped bulla bearing pustules and infralaminar apertures (Plate 8, A). **Cytoplasm:** yellow/brown to bright green.

**Diagnosis:** Mature specimens characterized by the dense cover of sharp pustules. Immature specimens distinguished from *G. glutinata* and *G. minuta* by a lower trochospiral shell, with distinct sparse pustules on the chambers surface and more pustules concentrated around the aperture.

**Ecology:** *T. iota* is a common species found in warm to temperate waters (Figure 1). No symbionts have been found in this species.

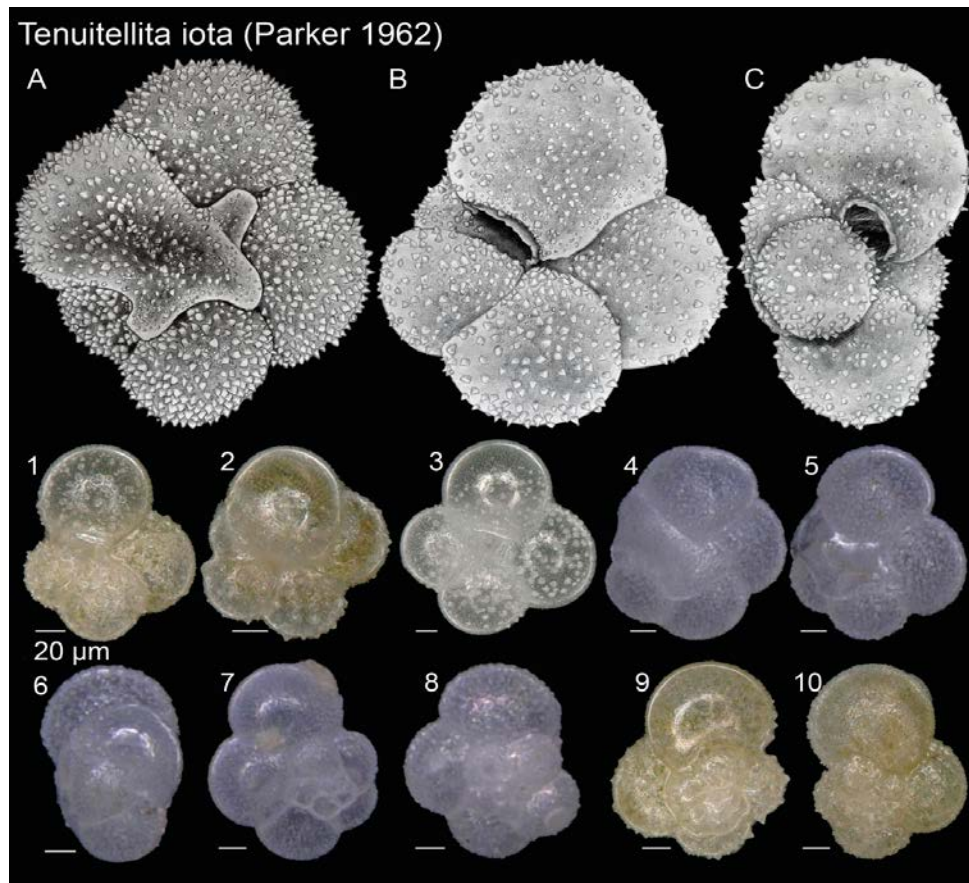


Plate 8. Drawing of the umbilical view with (A) and without (B) a bulla, and of the lateral view (C) of a representative specimen of *T. iota* modelled on SEM images of a specimen 0.12 mm in diameter. Note the thin lip, the microperforation of the shell and the distinct pustules. 1–9) Light microscope images of specimens from plankton tows. 1–3) umbilical view of cytoplasm-bearing specimens with the umbilical-extraumbilical aperture uncovered; 4–5) umbilical view of terminal stage specimens without cytoplasm and with a bulla covering the aperture; 6) lateral view of an empty shell; 7–8) spiral view of empty shells; 9–10) spiral view of cytoplasm bearing shells with the sharp pustules specifically visible on (9). 1 and 9 and 5, 6 and 8 are different views of same specimens. Scale bars are all 20  $\mu\text{m}$ .

#### 4.5.6 *Tenuitellita fleisheri* (Li 1987)

**Morphology:** **Shell wall** microperforate, non-spinose, with small pustules scattered on the entire surface. **Shell** very low trochospiral with a lobate outline, chambers inflated, curved and progressively slightly compressed, typically 4 to 5.5 in the final whorl, increasing slowly in size. **Maximum diameter:** approximately 0.2 mm. The sutures are radial, curved and incised. Ultimate chamber can be ampullate or bullate; umbilicus deep. **Aperture** umbilical-extraumbilical, medium arched, with a lip (Plate 9). **Cytoplasm:** light to dark brown (Plate 9). **Diagnosis:** Characterized by compressed chambers and curved sutures resulting in a unique shell appearance. Distinguished from *T. parkerae* and *T. iota* by the compressed chambers, which are more numerous in the final whorl, and the lightly pustulose surface.

**Ecology:** *T. fleisheri* is common in warm to temperate waters (Figure 1), where it inhabits the subsurface water, down to 100 m depth (Rebotim *et al.*, 2017). It is a non-symbiotic species (Takagi *et al.*, 2019).

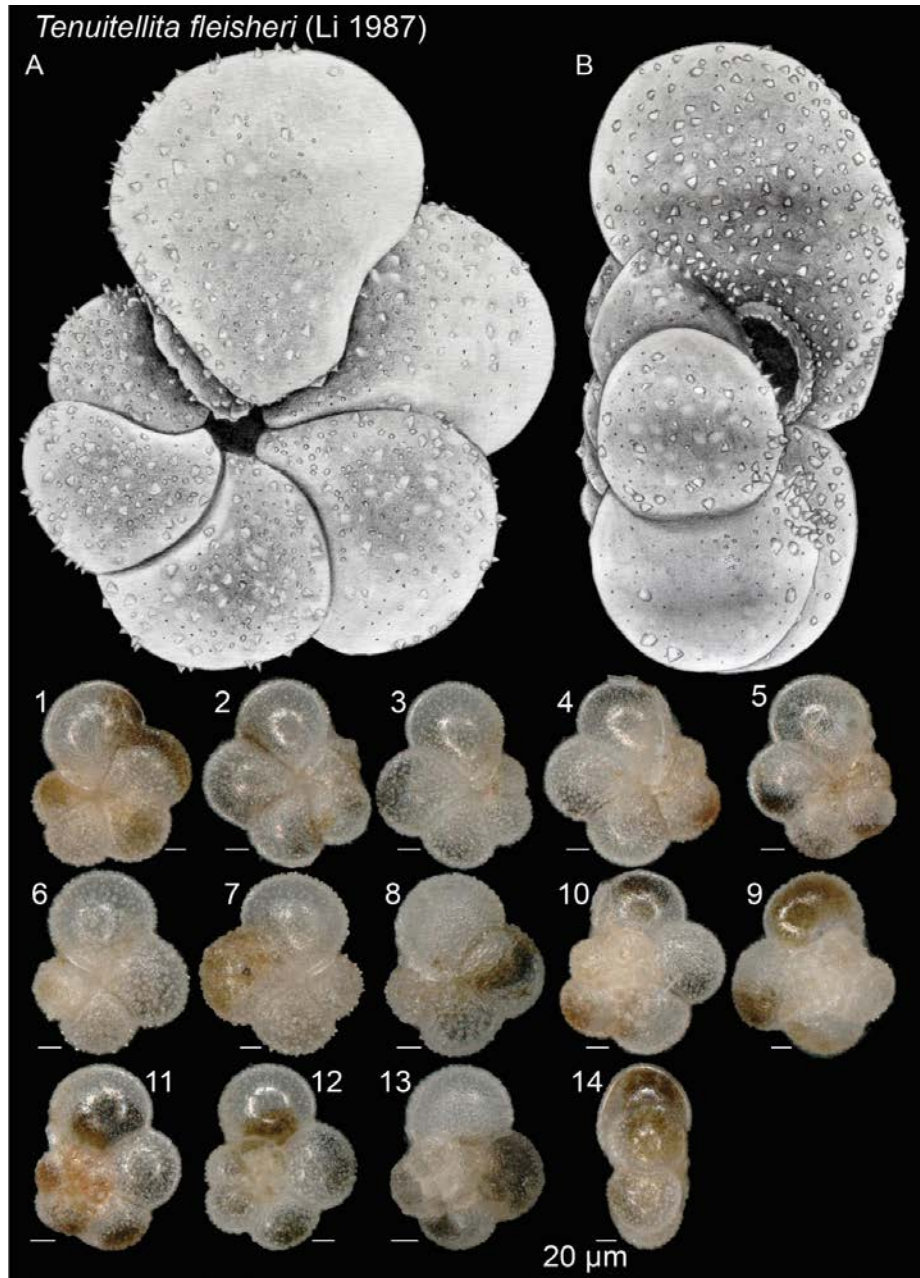


Plate 9. Drawing of A) umbilical and B) lateral view of a representative mature specimen of *T. fleisheri* modelled on SEM images of a specimen 0.14 mm in diameter. Note the curved sutures, the microperforation and the small pustules evenly distributed on the shell. 1–14) Light microscope images of cytoplasm-bearing specimens from plankton tows. 1–8) umbilical view of specimens with visible umbilical-extraumbilical aperture and 4 (6–7) to 5 (1) chambers in the last whorl; 9–13) spiral view; 14) lateral view showing the compressed chambers. 5 and 11, 6 and 9 and 8 and 13 are different views of same specimens. Scale bars are all 20  $\mu\text{m}$ .

#### 4.5.7 *Tenuitellita parkerae* (Brönnimann and Resig 1971)

**Morphology:** Shell wall microperforate, non-spinose, smooth, with small and sparse pustules distributed around the aperture and around the sutures, in later chambers also on the distal faces of the chambers (Plate 10). **Shell** low trochospiral with a lobate outline, chambers inflated, initially globular, later increasingly radially elongated, typically 4.5 to 5.5 in the final whorl, slowly increasing in size. **Maximum diameter:** approximately 0.2 mm. The sutures are radial,



slightly curved and depressed. Ultimate chamber often distinctly larger and more elongated; umbilicus shallow. **Aperture** umbilical-extraumbilical, low arched, with a lip (Plate 10).

**Cytoplasm:** light green to light brown (Plate 10).

**Diagnosis:** Characterised by smooth shell surface, with inflated chambers, which become distinctly radially elongated in mature individuals (Plate 10). Small specimens still without elongated chambers can be confused with other microperforate taxa.

**Ecology:** *T. parkerae* is rare to common in warm to temperate waters. Its depth habitat has not been sufficiently constrained, but it appears to range into the subsurface ocean, around 100 m depth (Rebotim *et al.*, 2017). The presence of symbionts in this species has not been constrained.

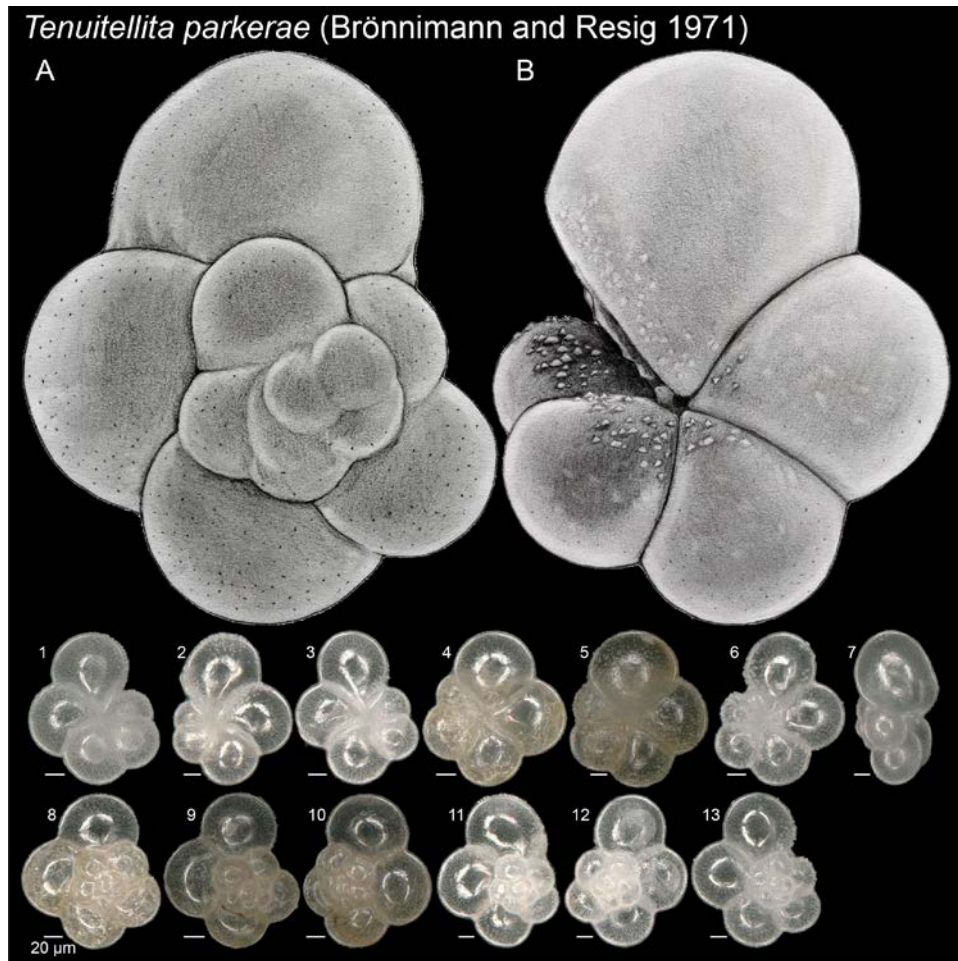


Plate 10. Drawing of A) spiral and B) umbilical view of a representative mature specimen of *T. parkerae* modelled on an SEM image of a specimen 0.11 mm in diameter. Note the presence of a thin lip, the microperforation of the shell and the presence of pustules specifically around the aperture. 1–13) Light microscope images of *T. parkerae* collected with plankton tows. 1–6) umbilical view of mature (1–3, 6) and immature (4–5) specimens with visible umbilical-extraumbilical aperture and pustules more densely distributed around the aperture and along the sutures (2,6); 7) lateral view showing; 8–13) spiral view of immature (8–10) and mature (11–13) specimens. 2, 11), 3, 12), 4, 8) and 6, 13) are different views of same specimens. Scale bars are all 20 µm.

## 5 Tables

**Table 1. Identification criteria for adult specimens of the eleven described species, Y/N referring to “Yes” or “No” for the potential presence of a bulla and “-” referring to the absence of apertural modifications.**

Species	Last chamber shape	Chambers in last whorl	Primary aperture	Apertural modifications	Bulla (Y/N)	Shell surface
<i>Berggrenia pumilio</i>	ampullate	5 to 6	umbilical-extraumbilical	-	N	smooth, striation by the umbilicus
<i>Neogallitellia vivans</i>	globular and inflated	3	umbilical	-	N	smooth
<i>Bolivina variabilis</i>	globular and inflated	2	basal to final chamber	lip	N	rough
<i>Dentigloborotalia anfracta</i>	kidney shaped	4 to 5	umbilical-extraumbilical	flap	N	smooth
<i>Candeina nitida</i>	globular and inflated	4	umbilical	rimmed sutural apertures	N	smooth
<i>Globigerinita glutinata</i>	globular	3 to 4	umbilical	thin lip	Y	covered with pustules
<i>Globigerinita uvula</i>	globular	4	umbilical	thin lip	-	smooth to covered with pustules
<i>Globigerinita minuta</i>	globular	4	umbilical	thin lip	Y	covered with pustules
<i>Tenuitellita iota</i>	globular and compressed	4 to 4.5	umbilical-extraumbilical	thin lip	Y	heavily pustuled
<i>Tenuitellita fleisheri</i>	ampullate	4 to 5.5	umbilical-extraumbilical	lip	N	covered with pustules
<i>Tenuitellita parkerae</i>	elongated	4 to 5	umbilical-extraumbilical	thin lip	N	smooth

## 6 Links to further information

### WoRMS link per species

*Berggrenia pumilio*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=526508>

*Neogallitellia vivans*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=526506>

*Bolivina variabilis* (under *Streptochilus* in WoRMS):

<http://www.marinespecies.org/aphia.php?p=taxdetails&id=558998>

*Dentigloborotalia anfracta*:

<http://www.marinespecies.org/aphia.php?p=taxdetails&id=1026357>

*Candeina nitida*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=418110>

*Globigerinita glutinata*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=113464>

*Globigerinita uvula*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=113465>

*Globigerinita minuta*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=558956>

*Tenuitellita iota*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=418112>

*Tenuitellita fleisheri*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=558957>

*Tenuitellita parkerae*: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=558958>

### Mikrotax link per species

*Berggrenia pumilio*:

[https://www.mikrotax.org/system/index.php?taxon=Berggrenia%20pumilio&module=pf\\_cenozoic](https://www.mikrotax.org/system/index.php?taxon=Berggrenia%20pumilio&module=pf_cenozoic)

*Neogallitellia vivans*:

[https://www.mikrotax.org/system/index.php?taxon=Gallitellia%20vivans&module=pf\\_cenozoic](https://www.mikrotax.org/system/index.php?taxon=Gallitellia%20vivans&module=pf_cenozoic)

*Bolivina variabilis* (under *Streptochilus* in Microtax):

[https://www.mikrotax.org/system/index.php?taxon=Streptochilus&module=pf\\_cenozoic](https://www.mikrotax.org/system/index.php?taxon=Streptochilus&module=pf_cenozoic)

*Dentigloborotalia anfracta*:

[https://www.mikrotax.org/system/index.php?taxon=Globorotalia%20anfracta&module=pf\\_cat](https://www.mikrotax.org/system/index.php?taxon=Globorotalia%20anfracta&module=pf_cat)

*Candeina nitida*:

[https://www.mikrotax.org/system/index.php?taxon=Candeina%20nitida&module=pf\\_cenozoic](https://www.mikrotax.org/system/index.php?taxon=Candeina%20nitida&module=pf_cenozoic)

*Globigerinita glutinata*:

[https://www.mikrotax.org/system/index.php?dir=pf\\_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20glutinata](https://www.mikrotax.org/system/index.php?dir=pf_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20glutinata)

*Globigerinita uvula*:

[https://www.mikrotax.org/system/index.php?dir=pf\\_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20uvula](https://www.mikrotax.org/system/index.php?dir=pf_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20uvula)

*Globigerinita minuta*:

[https://www.mikrotax.org/system/index.php?dir=pf\\_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20minuta](https://www.mikrotax.org/system/index.php?dir=pf_cenozoic/Globigerinitidae/Globigerinita/Globigerinita%20minuta)

*Tenuitellita iota*:

[https://www.mikrotax.org/system/index.php?taxon=Tenuitella%20iota&module=pf\\_cenozoic](https://www.mikrotax.org/system/index.php?taxon=Tenuitella%20iota&module=pf_cenozoic)

*Tenuitellita fleisheri*:

[https://www.mikrotax.org/system/index.php?dir=pf\\_cenozoic/Globigerinitidae/Tenuitella/Tenuitella%20fleisheri](https://www.mikrotax.org/system/index.php?dir=pf_cenozoic/Globigerinitidae/Tenuitella/Tenuitella%20fleisheri)

*Tenuitellita parkerae*:

[https://www.mikrotax.org/system/index.php?dir=pf\\_cenozoic/Globigerinitidae/Tenuitella/Tenuitella%20parkerae](https://www.mikrotax.org/system/index.php?dir=pf_cenozoic/Globigerinitidae/Tenuitella/Tenuitella%20parkerae)

## Molecular information

The majority of the species presented in this leaflet have been barcoded and their sequences can be found on NCBI (<https://www.ncbi.nlm.nih.gov/>) or in the PFR<sup>2</sup> database (<http://pfr2.sb-roscoff.fr/>; Morard *et al.*, 2015) although the genus name under which they have been deposited may sometimes differ. For detailed explanation of methodologies and accession numbers for *N. vivans* (herein referred as *Gallitellia vivans*) see Ujjié *et al.* (2008), for *B. variabilis* see Darling *et al.* (2009) and Kucera *et al.* (2017), and for *C. nitida*, *G. glutinata*, *G. minuta*, *G. uoula*, *T. iota*, and *T. fleisheri* see Morard *et al.* (2019). No molecular data are available to date for the species *B. pumilio* and *T. parkerae*, although the latter is likely represented by short environmental metabarcodes (de Vargas *et al.*, 2015) phylogenetically close to the other *Tenuitellita* species.

## Other useful links

For complementary information about the geographical distribution of the species presented here in surface sediments and in tow material, one should consult the following databases:

ForCenS (<https://doi.pangaea.de/10.1594/PANGAEA.873570>); and

FORCIS (<https://forcis.cerege.fr>).

## 7 Terminology

All the key terminology used in this document is presented here, in alphabetical order and with definitions.

Term	Definition
accessory aperture	Aperture that does not lead directly into the chamber lumen, but extends beneath accessory structures, such as a bulla (e.g. in <i>T. iota</i> ).
adumbilically	Generally said of a chamber displaced towards the umbilicus.
ampullate	Refers to ampoule-shaped final chamber, typically displaced away from the coiling axis towards the umbilicus.
apertural flap	A structural element of the last chamber observed where the chamber wall extends into the umbilicus and/or over the preceding chambers, covering the aperture (e.g. in <i>D. anfracta</i> ).
apertural lip	Small imperforate extension or thickening of the outer apertural margin over the umbilicus.
biserial	Refers to the disposition of chambers in two alternating series radiating from the proloculus.
bulla	A blister-like shell element extending over the umbilicus of the last whorl and covering the main or supplementary apertures; usually with marginal accessory apertures (e.g. in <i>G. glutinata</i> ).
chamber	An extension of the shell formed during a growth event, including the inner space that it encloses (=chamber lumen).
coiling axis	The axis of the spiral along which chambers are organized.
compact spiral outline	A condition where shell outline viewed perpendicular to the coiling axis shows indistinctly defined chambers.
compressed	Refers to chambers flattened laterally.
hook	short and sharp (hook-like) type of pustules found e.g. in <i>D. anfracta</i> .
inflated	Refers to chambers resembling the shape of an inflated balloon.
kidney-shaped	Refers to chambers shaped like a kidney (e.g. in <i>D. anfracta</i> ).
kummerform	Chamber that is equal or smaller in size than the penultimate chamber.
last whorl	Sequence of consecutive chambers including all chambers that form the outline of the shell.
lobate spiral outline	A condition where shell outline viewed perpendicular to the coiling axis shows distinctly defined chambers.
macroperforate	Possessing pores usually > 1 µm in diameter.
main aperture	The largest aperture on the umbilical side of the last chamber.
medioperforate	Possessing pores of 1-2 µm in diameter.
microperforate	Possessing numerous minute pores (usually < 1 µm in diameter).

<b>Term</b>	<b>Definition</b>
planispiral	Refers to the disposition of chambers such that successive chambers follow a two-dimensional spiral. A planispiral shell is bilaterally symmetrical.
pore	Small (< 10 µm) perforation traversing the entire chamber wall. Unlike apertures, pores do not serve for the passage of cytoplasm but are open for metabolic exchange of fluids and gases.
proloculus	The initial chamber of a foraminiferal shell.
pustules	Small subconical protuberances of the outer layer of the chamber wall.
radial	Perpendicular to the coiling axis.
radially elongated chambers	Refers to chambers that are elongated in the direction perpendicular to the coiling axis.
serial	Refers to the disposition of chambers in one or more alternating series radiating from the proloculus.
shell	Also named "test" from <i>testa</i> in Latin, the shell refers to the calcium carbonate skeleton secreted by the foraminifera during its life.
spiral	Refers to the disposition of chambers such that successive chamber centers follow a spiral.
spiral side	The side of a trochospiral shell where all chambers are visible; also named dorsal.
supplementary aperture	Any one of the primary openings in the last chamber existing in addition to the main aperture.
sutural apertures	Multiple apertures distributed along the sutures (e.g. in <i>C. nitida</i> ).
suture	The line on the shell surface defined by the position where a new chamber connects to the existing shell.
terminal stage	The final stage of shell growth, often marked by the appearance of an emergent chamber morphology and/or position, and/or calcification mode, which are irreversibly retained until the end of the growth (e.g. kummerform chambers are never followed by regular chambers)
tooth	Inward projection of the inner chamber wall into the aperture.
triserial	Refers to the disposition of chambers in three alternating series radiating from the proloculus.
trochospiral	Refers to the disposition of chambers such that successive chambers follow a three-dimensional spiral.
umbilical aperture	Aperture opening into the umbilicus.
umbilical side	The side of a trochospiral shell opposite the spiral side, usually exposing the umbilicus and the main aperture.
umbilical-extraumbilical aperture	Aperture extending from the umbilicus to the outer margin of the shell.
umbilicus	The space between the inner margins of chambers of the last whorl.
whorl	Sequence of consecutive chambers whose centres define one full revolution of a spiral.

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