

SYSTEMATIC TAXONOMY OF EARLY–MIDDLE MIOCENE PLANKTONIC FORAMINIFERA FROM THE EQUATORIAL PACIFIC OCEAN: INTEGRATED OCEAN DRILLING PROGRAM, SITE U1338

LYNDSEY R. FOX^{1,3} AND BRIDGET S. WADE^{1,2}

ABSTRACT

Integrated Ocean Drilling Program Expedition 320/321 at Site U1338 (equatorial Pacific Ocean) recovered lower–middle Miocene (17–13.5 Myr) sediments containing unusually well-preserved and diverse planktonic foraminifera. Previous taxonomic study of planktonic foraminifera from this interval in the eastern Pacific Ocean has been hindered by the absence of biogenic carbonate. Here we present a taxonomic analysis of these foraminifera, including wall textures and species variability, supported by scanning electron micrographs. Specimens exhibit open pore spaces, little evidence of calcitic overgrowth on the wall surface, and in many cases spines. Fifty-five species are recorded, including *Dentoglobigerina juxtabinaensis* n. sp. Dominant genera include *Paragloborotalia* and *Globigerinoides* with common *Dentoglobigerina*.

INTRODUCTION

The taxonomy of planktonic foraminifera is the foundation for understanding paleoclimate proxy measurements. To reconstruct Miocene paleoclimate records with any certainty, planktonic foraminifera must be studied at the species level. However, their morphology can be extremely variable, and large collections of specimens are needed to understand variation within a morphospecies. High-resolution scanning electron microscope (SEM) analyses of well-preserved planktonic tests can reveal previously unknown primary wall fabrics that are critical to understanding the taxonomy, phylogeny, and evolution of Miocene planktonic foraminifera.

Morphospecies diversity of planktonic foraminifera increased in the early Neogene (Aze and others, 2011), with the proliferation of spinose *Globigerinoides* and smooth-walled, nonspinose globorotaliform species in the middle Miocene (Wei and Kennet, 1986; Aze and others, 2011). After the evolution of major lineages in the middle Miocene (*Globigerinoides*, *Orbulina*, and *Globorotalia*), planktonic foraminiferal populations became structured like modern ones with all the extant species or their direct ancestors present.

Detailed SEM examination of well-preserved material collected from Integrated Ocean Drilling Program (IODP) Site U1338 (equatorial Pacific Ocean) permitted us to observe the wall textures and detailed morphology of extinct foraminifera. This information was then used: 1) to determine the taxonomy and variability of 55 early and

middle Miocene planktonic species; and 2) to document the state of preservation and degree of recrystallization in specimens prior to geochemical studies. Previous taxonomic studies of planktonic foraminifera from the lower–middle Miocene interval in the equatorial Pacific Ocean has been hindered by the absence of biogenic carbonate (e.g. ODP Leg 199) or by hiatuses in sedimentation (ODP Leg 144; Pearson, 1995). However, at Site U1338 assemblages are exceptionally diverse, and many of the taxa that were absent at other drilled Pacific Equatorial Age Transect (PEAT) sites are recorded here.

MATERIAL AND METHODS

LOCATION

Integrated Ocean Drilling Program Expedition 320/321 drilled eight sites (1331–1338) in the equatorial Pacific Ocean (Fig. 1). At Site U1338 four holes (A–D) were drilled on an ~18 Ma crust using the APC/XCB coring systems. An ~415-m thick succession of biogenic carbonate sediments of early Miocene–Recent age was recovered with high sedimentation rates averaging 30 m/Myr (Lyle and others, 2009).

Our study focuses on an 80-m section of lower–middle Miocene sediments from 350–430-m composite depth (mcd). This interval belongs to planktonic foraminiferal Zones N12–N5 of Kennett and Srinivasan (1983) and M9–M2 of Wade and others (2011). The sediments consist of white, pale yellow, and very pale brown nannofossil ooze, grading to nannofossil and calcareous chalk (Lyle and others, 2009). The transition from ooze to chalk occurs at ~378 mcd.

Core sample notation follows the standard IODP format, with designation for site, hole, core number, section number and centimeter interval.

SAMPLE PREPARATION

Sediment volumes of ~10 cm³ were collected at 10-cm intervals and washed with distilled/tap water over a 63- μ m sieve; the residues were dried in an oven at 40°C. All samples (Table 1) were examined under a binocular light microscope. Species identifications of the planktonic foraminifera were generally made on the 315–250- μ m and 250–150- μ m fractions, and the 150–63- μ m fraction was scanned for distinctive taxa. Selected specimens were mounted on SEM stubs, coated with gold, and inspected in a FEI Quanta 650 SEM at the University of Leeds, UK. After imaging their external surfaces at low and high resolution, four tests were broken using moderate pressure under a glass slide, and the fragments were used for the investigation of internal surfaces and test walls in cross-section.

¹School of Earth and Environment, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, UK

²Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT, UK

³Correspondence author. E-mail: eelf@leeds.ac.uk

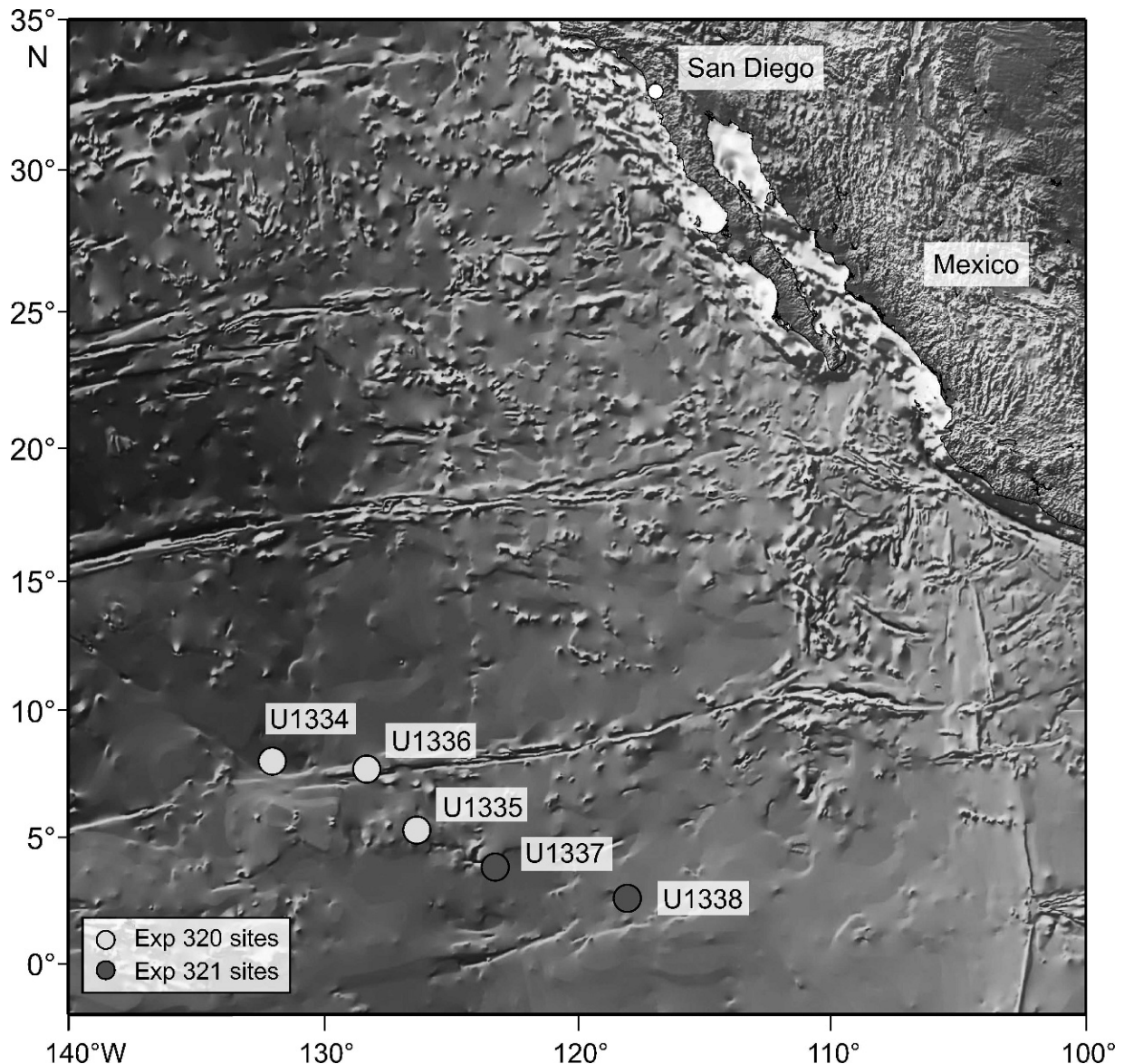


FIGURE 1. Topographic map showing the study area, Site U1338 (2°30.469'N, 117°58.178'W, 4200-m water depth), and some of the other sites drilled during Expedition 320/321 in the eastern equatorial Pacific Ocean (from Pälike and others, 2010).

RESULTS

FORAMINIFERA

All samples yielded abundant planktonic foraminifera; dominant genera included *Paragloborotalia* and *Globigerinoides*, with common *Dentoglobigerina*. Specimens of *Clavatorella bermudezi* were also unusually abundant. *Globorotaloides hexagonus* and *Globorotaloides* sp. are commonly found in many of the middle Miocene samples. However, further work is required to constrain their biostratigraphic range. Light microscope and SEM investigation also allowed us to distinguish *Dentoglobigerina juxtabinaiensis* n. sp. from its ancestor *D. binaiensis*.

Test preservation is excellent throughout the sampled interval, with open pore spaces, little calcitic overgrowth, and in many cases spines, though fragmentation occurs in

some samples. Specimens show little evidence of diagenetic alteration in transmitted light, and their test walls are optically translucent.

BIOSTRATIGRAPHY

Low-resolution biostratigraphic analysis was conducted onboard (Pälike and others, 2010) at Site U1338 (Hole A) using core catchers, and supplemented by additional samples (usually two/core; Fig. 2). Using insights gained through SEM studies, we have revised the shipboard range charts for extinct taxa, updated the biostratigraphy to include our observations from Holes B and C, and followed the planktonic foraminiferal zonal scheme presented in Wade and others (2011). The planktonic foraminiferal biostratigraphy for the upper 409 m is presented in Hayashi and others (2013).

TABLE 1. Stratigraphic distribution of planktonic foraminiferal samples composited from Site U1338 Holes A, B, and C (modified from Pälke and others, 2010). Preservation: VG = very good (no evidence of overgrowth, dissolution, or abrasion); G = good (little evidence of overgrowth, dissolution, or abrasion); M = moderate (calcite overgrowth, dissolution, or abrasion are common but minor); P = poor (substantial overgrowth, dissolution, or fragmentation). MCD = meter composite depth.

Sample	MCD	Preservation	% Planktonic foraminifera	Planktonic foraminiferal zone	<i>Clavatorella bermudezi</i>	<i>Dentoglobigerina altispina</i>	<i>Dentoglobigerina binaiensis</i>	<i>Dentoglobigerina globosa</i>	<i>Dentoglobigerina baroanensis</i>	<i>Dentoglobigerina juxtabaiensis</i>	<i>Dentoglobigerina tripartita</i>	<i>Dentoglobigerina</i> sp.	" <i>Dentoglobigerina</i> " <i>venezuelana</i>	<i>Globigerinella insueta</i>	<i>Globigerinella</i> sp.
321-U1338C-35H-5-W, 90–92cm	345.81	VG	-	M9		x							x		
321-U1338C-36H-2-W, 110–112cm	352.44	VG	-	M9											
321-U1338B-36H-2-W, 40–42cm	355.84	VG	-	M9				x	x						
321-U1338A-35X-2-W, 9–11cm	360.12	M	52	M9		x						x	x		
321-U1338A-35X-CC-PAL	361.42	M	57	M8		x		x	x				x		
321-U1338C-37H-1-W, 130–132cm	362.17	VG	-	M8		x									
321-U1338A-36X-1-W, 36–38cm	365.48	M	80	M8		x		x			x		x		
321-U1338A-36X-CC-PAL	366.30	M	86	M7		x		x	x		x		x		
321-U1338C-37H-4-W, 130–132cm	366.78	VG	-	M6											
321-U1338A-37X-1-W, 43–45cm	368.01	M	10	M6				x							
321-U1338A-37X-CC-PAL	368.78	G	89	M6	x	x		x	x		x		x		
321-U1338B-38H-2-W, 40–42cm	377.68	VG	-	M5b											
321-U1338A-38X-2-W, 35–37cm	378.38	P-M	88	M5b				x	x	x			x		x
321-U1338B-38H-4-W, 0–2cm	380.28	VG	-	M5b											
321-U1338B-38H-5-W, 20–22cm	381.98	VG	-	M5b											
321-U1338A-38X-5-W, 109–111cm	383.62	M-G	56	M5b				x					x		
321-U1338A-38X-CC-PAL	386.31	M	44	M5b		x					x		x	x	
321-U1338A-39X-2-W, 72–74cm	388.63	G	42	M5b					x		x	x	x	x	x
321-U1338C-39H-6-W, 140–142cm	389.9	VG	-	M5b	x										
321-U1338A-39X-5-W, 89–91cm	393.30	M	28	M5b				x			x	x	x		
321-U1338A-39X-CC-PAL	395.37	G	80	M5b				x	x		x		x	x	
321-U1338A-40X-1-W, 115–117cm	404.26	G	84	M5b		x		x	x	x	x	x	x	x	x
321-U1338A-40X-3-W, 27–29cm	405.87	G	94	M5b				x	x		x	x	x	x	
321-U1338A-40X-CC-PAL	406.45	G	88	M5b		x		x	x		x		x		
321-U1338C-41H-4-W, 30–32cm	406.69	VG	-	M5a										x	
321-U1338B-41H-3-W, 30–32cm	414.17	VG	-	M5a		x			x				x	x	
321-U1338B-42H-2-W, 40–42cm	423.04	VG	-	M5a											
321-U1338A-41X-2-W, 60–68cm	423.68	G	90	M5a				x	x		x		x		
321-U1338A-41X-4-W, 9–11cm	426.11	G	98	M5a		x		x	x	x	x		x		x
321-U1338A-41X-CC-PAL	430.24	M-G	76	M5a				x		x	x	x	x		
321-U1338A-42X-2-W, 31–33cm	432.53	G	92	M5a				x		x	x		x	x	
321-U1338A-42X-4, 114–116cm	436.36	G	42	M5a				x		x	x		x	x	x
321-U1338A-42X-CC-PAL	438.19	G	52	M3-M4				x	x	x	x		x	x	
321-U1338A-43X-2-W, 18–20cm	441.15	M	24	M3-M4		x	x	x	x	x	x		x	x	
321-U1338A-43X-CC-PAL	442.68	M	36	M3-M4				x		x	x		x	x	
321-U1338A-44X-2-W, 55–57cm	450.71	M-P	50	M2			x	x	x	x	x		x		
321-U1338A-44X-3-W, 102–104cm	452.68	M-P	40	M2			x	x	x	x	x		x		
321-U1338A-44X-CC-PAL	454.20	P	48	M2			x	x		x	x		x		

DISCUSSION

FORAMINIFERAL ASSEMBLAGES

Fifty-five planktonic foraminiferal species were identified in this study. We illustrate a range of specimens in Figures 3–21, and the stratigraphic ranges of the illustrated species are given in Figure 2. These Miocene planktonic foraminiferal assemblages are characterized by high occurrences of mixed-layer, warm-water taxa such as *Globigerinoides* and eutrophic, thermocline-dwelling taxa such as *Paragloborotalia* (Wade and others, 2007). In the modern ocean, upwelling of nutrient-rich subsurface water in the equatorial Pacific Ocean sustains a band of high primary

productivity, where distinctive planktonic foraminifera such as *Globigerinita glutinata* thrive (Cayre and others, 1999). The planktonic foraminiferal assemblages found in the Miocene sediments of Site U1338 can be compared with those that characterize present-day upwelling waters, due to the high abundance of *Globigerinoides ruber* (d'Orbigny, 1839) and presence of *G. glutinata* and *G. menardii* (d'Orbigny, 1826) (Watkins and others, 1996, 1998).

The range chart in Pälke and others (2010) identifies several taxa which were absent in our study, including *Catapsydrax unicavus* (Bolli, 1957) and *Mutabellia mirabilis* (Pearson and others, 2001). Our post-cruise SEM examination of wall textures revealed that specimens previously

TABLE 1. Extended.

[illegible]

identified shipboard as *M. miriabilis* are not microperforate, and many specimens of *Catapsydrax* may in fact be bullate *Dentoglobigerina tripartita*. The absence of primary marker species *Catapsydrax dissimilis* and *Globigerinatella* sp. prevented us from differentiating between Zones M3 and M4. Zones M6 and M7 appear reduced due to the proximity of the lowest occurrence of marker species *Orbulina suturalis* (Brönnimann, 1951) and *Fohsella peripheroacuta*.

PRESERVATION

After burial, the preservation of foraminiferal tests can be affected by a variety of diagenetic processes; these can be

loosely categorized as dissolution, overgrowth, and recrystallization, although the processes are interrelated. Foraminiferal tests are prone to diagenetic alteration by overgrowth, changes in the shell crystal structure at the micron scale, and/or infilling of the original shell, all of which can significantly affect their geochemical composition (Pearson and Burgess, 2008). Therefore, it is important to identify fossil material that is well-preserved.

Dissolution results from the action of migrating pore waters. The process begins by stripping the outer layers of calcite from the test, thus weakening and destroying the relatively thin, latest chambers first (Collen and Burgess, 1979). Partial dissolution or "etching" of test surfaces has

been observed on a number of specimens of thin-walled *Clavatorella*, causing test surfaces that were originally smooth to appear roughened and pores to be enlarged. We also observed species-specific fragmentation, resulting in chamber holes (e.g., Figs. 13, 16) and missing ultimate chambers (e.g., Figs. 3–6, 9, 10), which may explain the wide variation in test size of *Dentoglobigerina altispira*.

Overgrowth occurs when inorganic calcite crystals are precipitated from solution onto the outer or internal surface of the test, where they then progressively increase in size and merge (Pearson and Burgess, 2008). Overgrowths can obscure ornamentation and prevent identification; however, almost no overgrowth has been observed in our samples, with the exception of some rare individual specimens exhibiting minor to moderate overgrowth.

Recrystallization develops when the internal microgranular structure of the test is replaced by larger crystals (Pearson and Burgess, 2008). In contrast to glassy preservation in clay-rich facies, recrystallized specimens appear opaque in reflected light (Pearson and others, 2001, 2007; Bown and others, 2008). Tests also crumble much more easily under moderate compressive stress and they are less able to withstand ultrasonic cleaning (Pearson and Burgess, 2008).

Pearson and Burgess (2008) presented four criteria for distinguishing foraminiferal shells that are not significantly recrystallized: 1) shells should be glassy or translucent in reflected light; 2) ultrafine features such as spines should survive (e.g., Fig. 10.3c); 3) smooth parts of the shell such as the apertural lips, sutures, outer surface (in some species), and inner surface (in most species) should appear smooth at the submicron scale in high resolution SEM images (e.g., Figs. 18, 20, 21); and 4) in cross-section, the original submicron microgranular wall texture should be clear when the shell is broken (Figs. 18, 19). Our specimens from Hole A (Figs. 3–21) were recorded as having poor to moderate preservation during the expedition (Table 1); however, our post-cruise studies found that preservation of foraminiferal tests satisfied criteria 2–4 of Pearson and Burgess (2008). The excellent preservation of wall structures illustrated in four crushed specimens (Figs. 18–21) indicates that foraminifera from Site U1338 have not undergone substantial recrystallization. The lithological transition at ~378 mcd from ooze to chalk has no obvious effect on preservation.

Previous studies of well-preserved calcareous microfossils have attributed excellent preservation to shallow burial depth and impermeable clay-rich facies that restricted pore water movement and post-depositional recrystallization (Pearson and others, 2001; Bown and others, 2008). In contrast, our well-preserved specimens come from >400-m burial depth in low clay sediment, averaging ~90% combined CaCO₃ and SiO₂. Good preservation is rare in these conditions, and the preservation at Site U1338 is distinctly superior to nearby Site U1337. We attribute the enhanced preservation at Site U1338 to the relatively high sedimentation rates (30 m/Myr; Lyle and others, 2009) in comparison to a linear sedimentation rate of 17–21 m/Myr during the middle Miocene at Site U1337 (Pälike and others, 2010).

Our observations suggest that Site U1338 will be useful for the establishment of tropical sea-surface temperatures in the Miocene. Stable isotope studies are currently in progress which will provide an eastern equatorial Pacific Ocean climate record for the middle Miocene that will be higher in resolution than those currently in existence (Fox and others, unpublished data).

DIVERSITY

The diversity of foraminiferal assemblages at Site U1338 is relatively high compared to Miocene sections drilled at other sites. Site 806 on the northeastern margin of the Ontong Java Plateau identified <45 species for the same interval (Chaisson and Leckie, 1993). In middle Miocene sediments at Site 1126 (western Great Australian Bight), <30 species were found, and planktonic foraminifera were rare and poorly preserved in sediments from shallower locations, especially Sites 1127, 1129, and 1131 (Li and others, 2003). At Site U1337, a slightly higher diversity was recorded (58 species) over the same interval; however, assemblages are dominated by large dissolution-resistant forms such as “*Dentoglobigerina*” *venezuelana* (Pälike and others, 2010).

SYSTEMATIC PALEONTOLOGY

The systematic descriptions follow the existing understanding of early-middle Miocene planktonic foraminiferal taxonomy (Kennett and Srinivasan, 1983; Spezzaferri and Premoli Silva, 1990; Chaisson and Leckie, 1993; Spezzaferri, 1994; Pearson and Chaisson, 1997). The primary classification is based on the wall structure, and principally spinose or non-spinose ornamentation (Fleisher, 1974; Olsson and others, 1992).

In this study, we have documented all species to provide a database of planktonic foraminiferal ranges for the early–middle Miocene at Site U1338. The original reference for each species is given, as are subsequent references relevant to the progression toward the currently used species concept. Synonymies are limited to the original descriptions; additional references are included when needed to support our species concept. The “stratigraphic range” (Fig. 2) is the range of the species in Hole U1338A. Specific samples from the B and C Holes are listed that include irregular or otherwise noteworthy specimens. Taxa are listed alphabetically by genus and species name within individual families.

Our SEM images (Figs. 3–21) illustrate the morphologic criteria that we used to distinguish between ancestral and descendant forms in some important lineages. In many instances, the individual images have been arranged “stratigraphically” on the figures to help illustrate size and morphologic changes between phylogenetically related species. Short comments are included in order to clarify the taxonomic concepts followed in this study and to note significant morphological features. Integrated Ocean Drilling Program material is held at the University of Kiel, Germany, except for the type specimens of *D. juxtabi-naiensis* n. sp. held at the Natural History Museum, London.

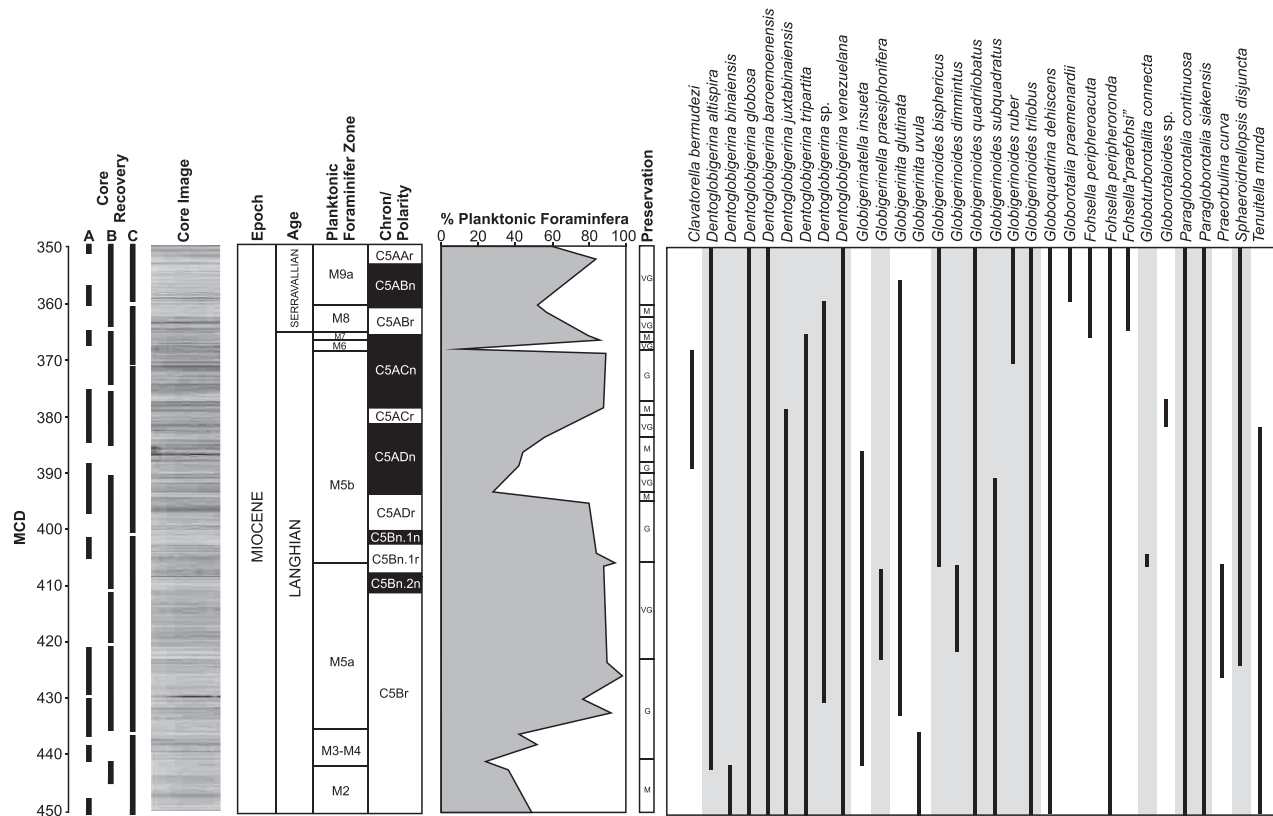


FIGURE 2. Compositing foraminiferal ranges from U1338 cores A, B, and C, with taxonomic and zonal revisions (Wade and others, 2011). This study covers foraminiferal Zones M2–M9. MCD = meter composite depth. See Table 1 caption for explanation of preservation abbreviations.

Order FORAMINIFERIDA d'Orbigny, 1826
 Superfamily GLOBIGERINACEAE Carpenter,
 Parker and Jones, 1862
 Family GLOBIGERINIDAE Carpenter,
 Parker and Jones, 1862
 Genus *Clavatorella* Blow, 1965
 Type species: *Hastigerinella bermudezi* Bolli, 1957

Clavatorella bermudezi (Bolli, 1957)
 Figs. 3.1–3.6

Hastigerinella bermudezi Bolli, 1957, p. 112, pl. 25, figs. 1a–c.
Clavatorella bermudezi (Bolli). Kennett and Srinivasan, 1983, p. 218,
 pl. 54, figs. 2, 6–8.

Stratigraphic range. U1338B-37H-6, 30–32 cm →
 U1338C-39H-6, 140–142 cm.

Remarks. This species was found in only one core-catcher
 sample during shipboard studies (Pälike and others, 2010);
 however, in our post-cruise examination of Holes B and C, it
 was present in most samples between U1338B-37H-6–U1338C-
 39H-4 (372–387 mcd). Specimens exhibit a broad spectrum of
 morphologic variation as demonstrated in Figure 3.

Genus *Dentoglobigerina* Blow, 1979
 Type species: *Globigerina galavisi* Bermudez, 1961

Dentoglobigerina altispira (Cushman and Jarvis, 1936)
 Figs. 4.1–4.6

Globigerina altispira Cushman and Jarvis, 1936, p. 5, pl. 1, figs. 13a–c.
Dentoglobigerina altispira altispira (Cushman and Jarvis). Kennett and
 Srinivasan, 1983, p. 188, pl. 46, figs. 4–6.

Dentoglobigerina altispira (Cushman and Jarvis). Chaisson and Leckie,
 1993, p. 177, pl. 9, fig. 8.

Stratigraphic range. U1338A-5H-CC → U1338A-43X-2,
 18–20 cm.

Remarks. This species is abundant in samples above
 U1338A-38X-CC. *Dentoglobigerina altispira* varies widely
 in test size, trochospire height, and chamber embracement.
 Spine holes were not evident on any specimens, suggesting
 this species is non-spinose or that a gametogenic crust
 prevents the identification of the spinose wall. All examined
 specimens exhibited fragmentation of the final chamber.

Dentoglobigerina baroemoensis (LeRoy, 1939)
 Figs. 5.1, 5.2

Globigerina baroemoensis LeRoy, 1939, p. 263, pl. 6, figs. 1, 2.
Dentoglobigerina baroemoensis (LeRoy). Kennett and Srinivasan,
 1983, p. 186, pl. 46, figs. 1–3.

Stratigraphic range. U1338A-8H-5, 106–108 cm →
 U1338A-44X-3, 102–104 cm.

Remarks. Typical specimens exhibit a wide umbilicus and
 slightly flattened chambers, which increase rapidly in size in
 the final whorl. These features distinguish it from “*D.*”
venezuelana, which has a more closed umbilicus and more
 embracing chambers.

Dentoglobigerina binaiensis (Koch, 1935)
 Figs. 5.3, 5.4

Globigerina binaiensis Koch, 1935, p. 558; Kennett and Srinivasan,
 1983, p. 183, pl. 45, figs. 1–3.
Globoquadrina binaiensis (Koch). Chaisson and Leckie, 1993, p. 159,
 pl. 9, fig. 13; Spezzaferri, 1994, p. 42, pl. 42, figs. 3a–c.

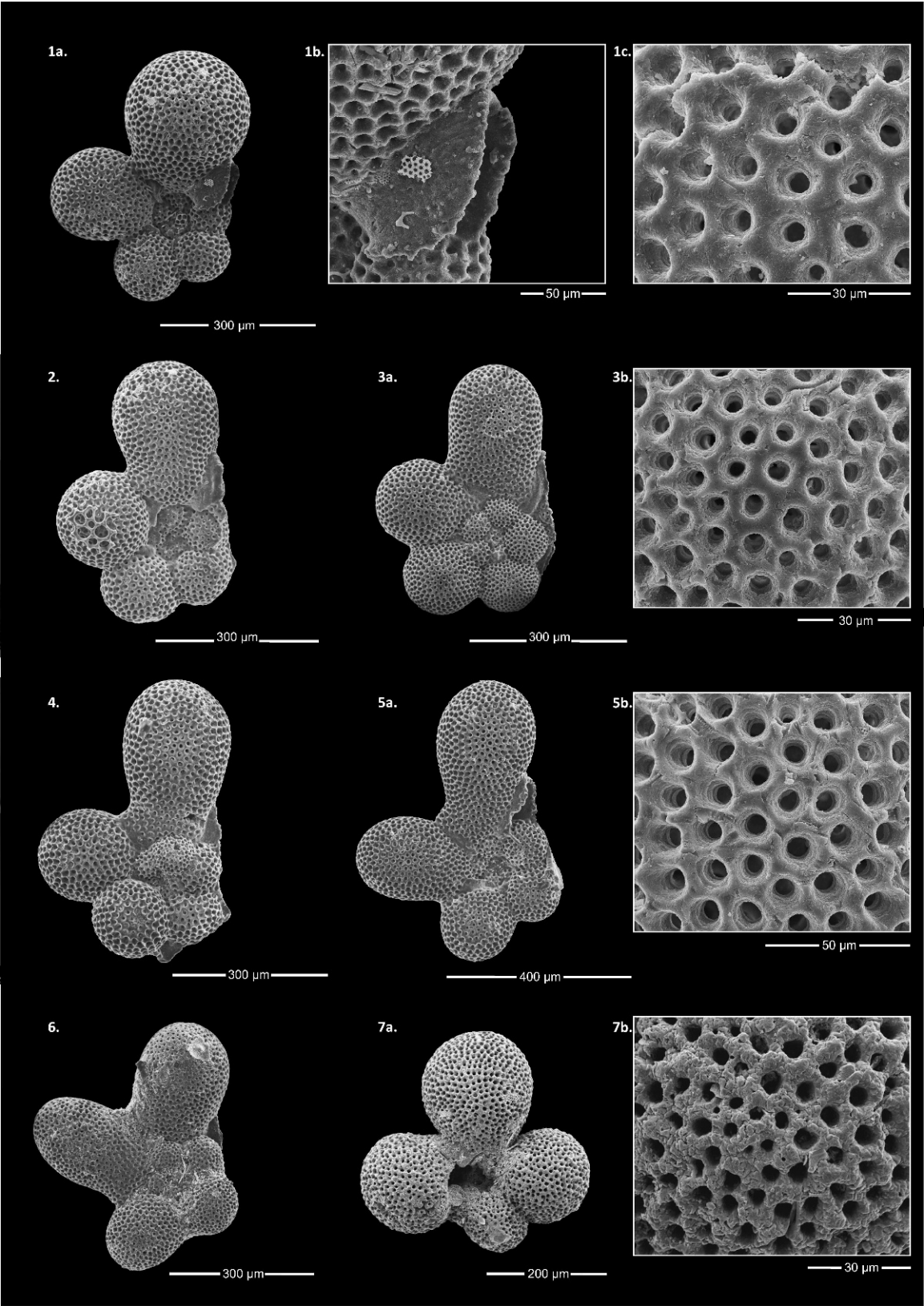


FIGURE 3. 1–6 *Clavatorella bermudezi*, U1338C-39H-6, 140–142 cm. 7 *Clavatorella* sp., U1338B-42H-2, 40–42 cm.

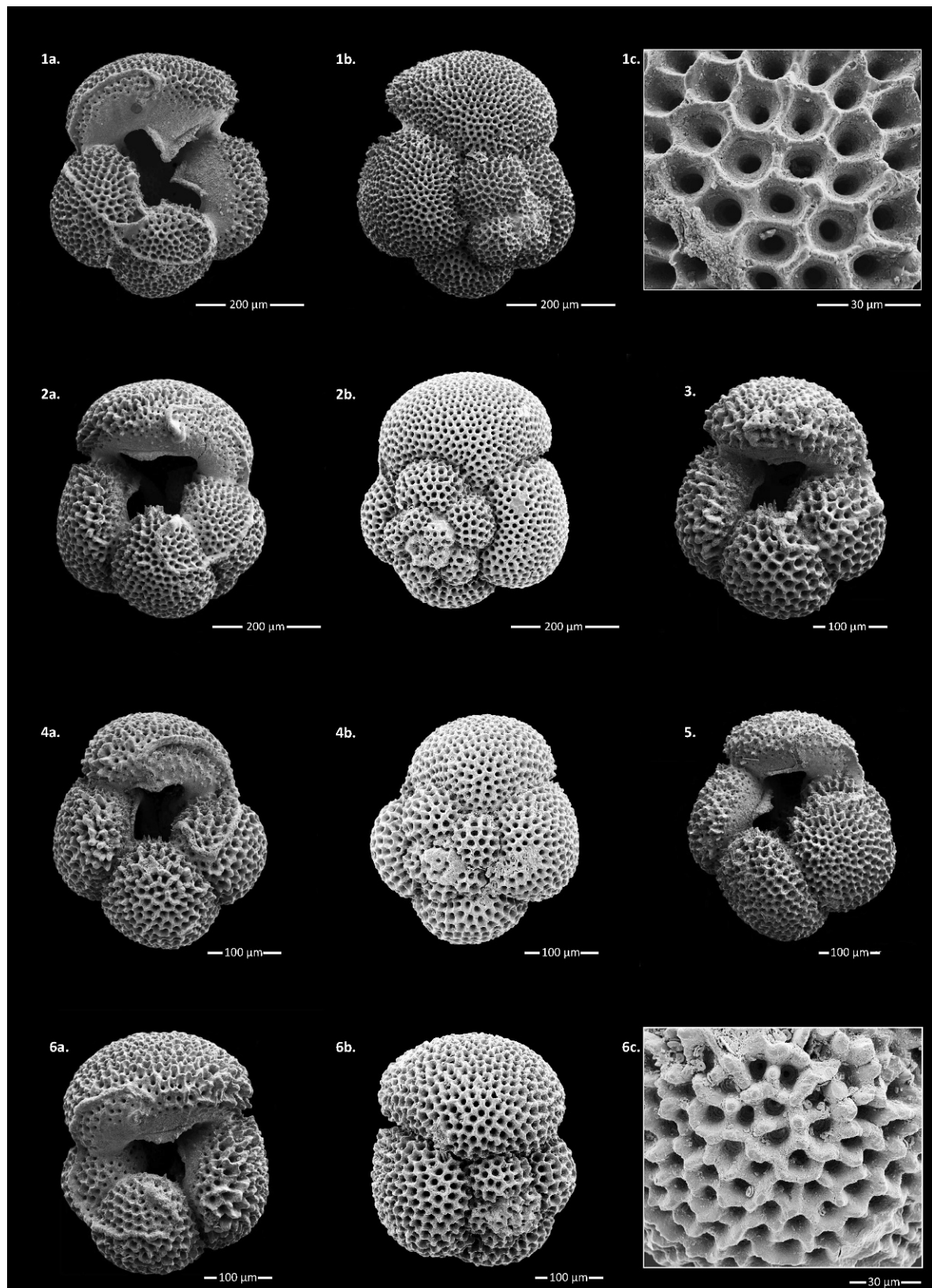


FIGURE 4. 1–6 *Dentoglobigerina altispira*, U1338C-37H-1, 130–132 cm.

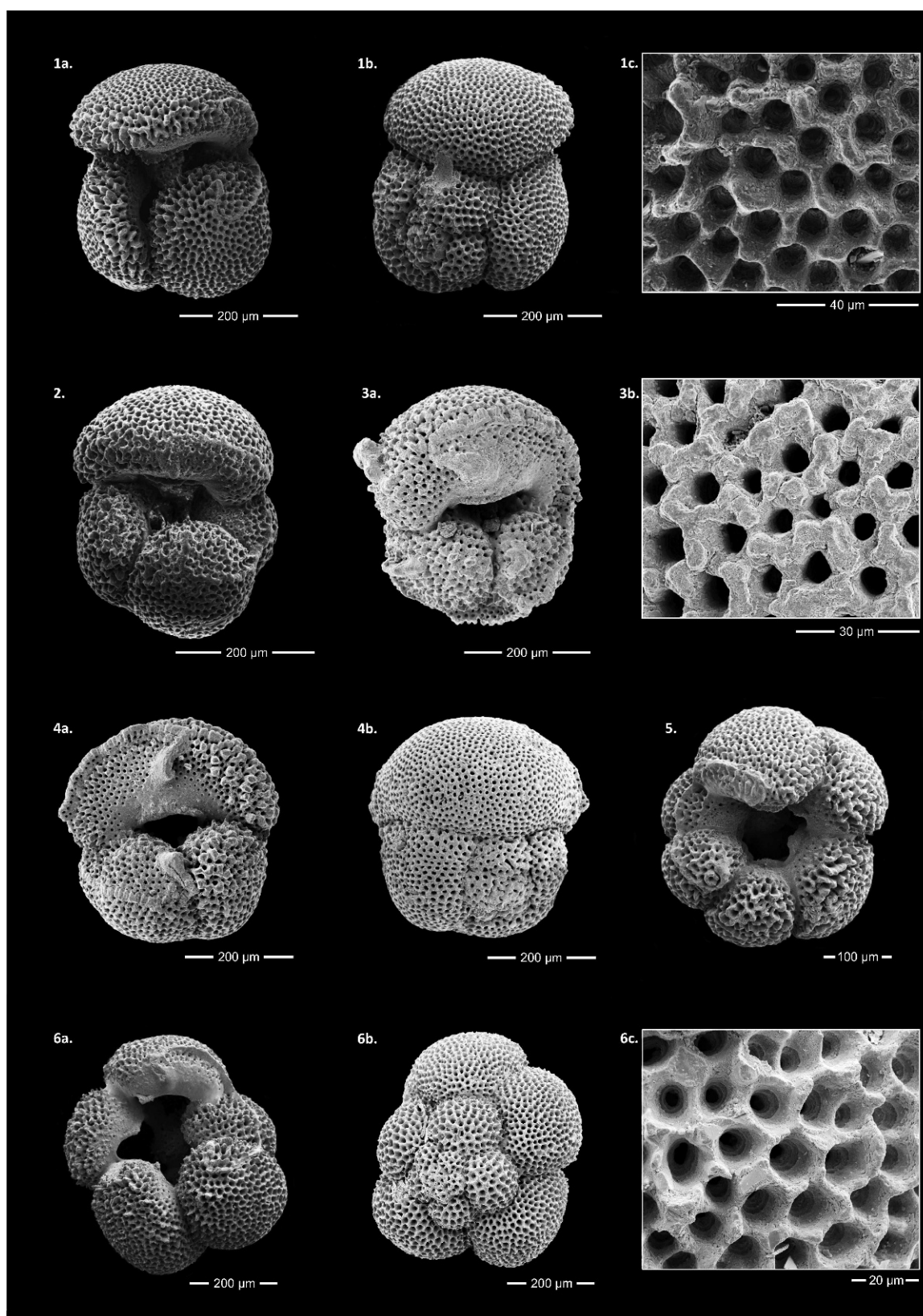


FIGURE 5. 1, 2 *Dentoglobigerina baroemoenensis*, U1338B-41H-3, 30–32 cm. 3, 4 *Dentoglobigerina binaiensis*, U1338B-41H-3, 30–32 cm. 5, 6 *Dentoglobigerina globosa*, U1338B-36H-2, 40–42 cm.

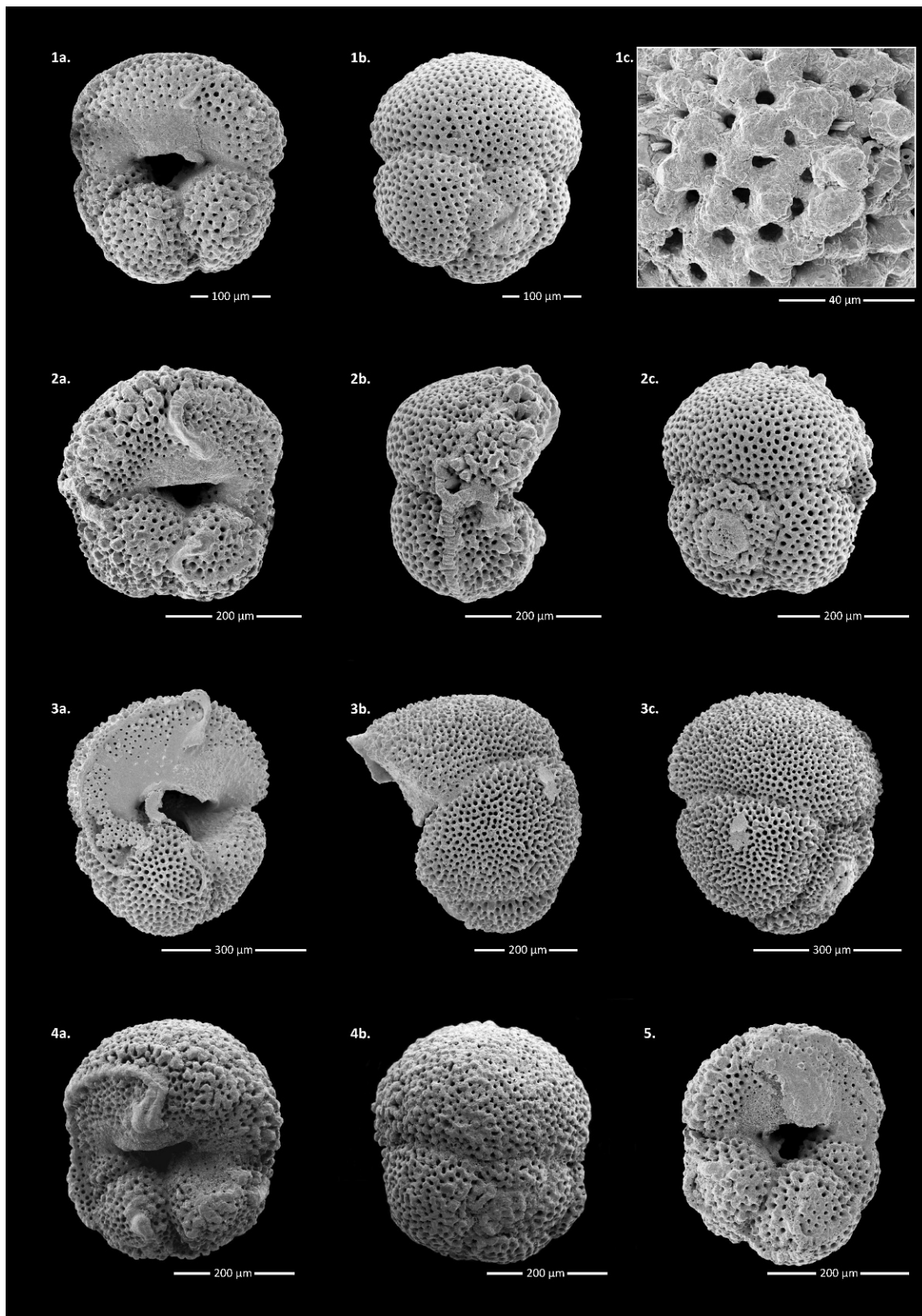


FIGURE 6. 1–5 *Dentoglobigerina juxtabinaiensis* n. sp.: 1–3, 5, paratypes (NHMUK PM PF 70875–70877, 70873), U1338A-42X-CC; 4, paratype (70871), U1338B-41H-3, 30–32 cm.

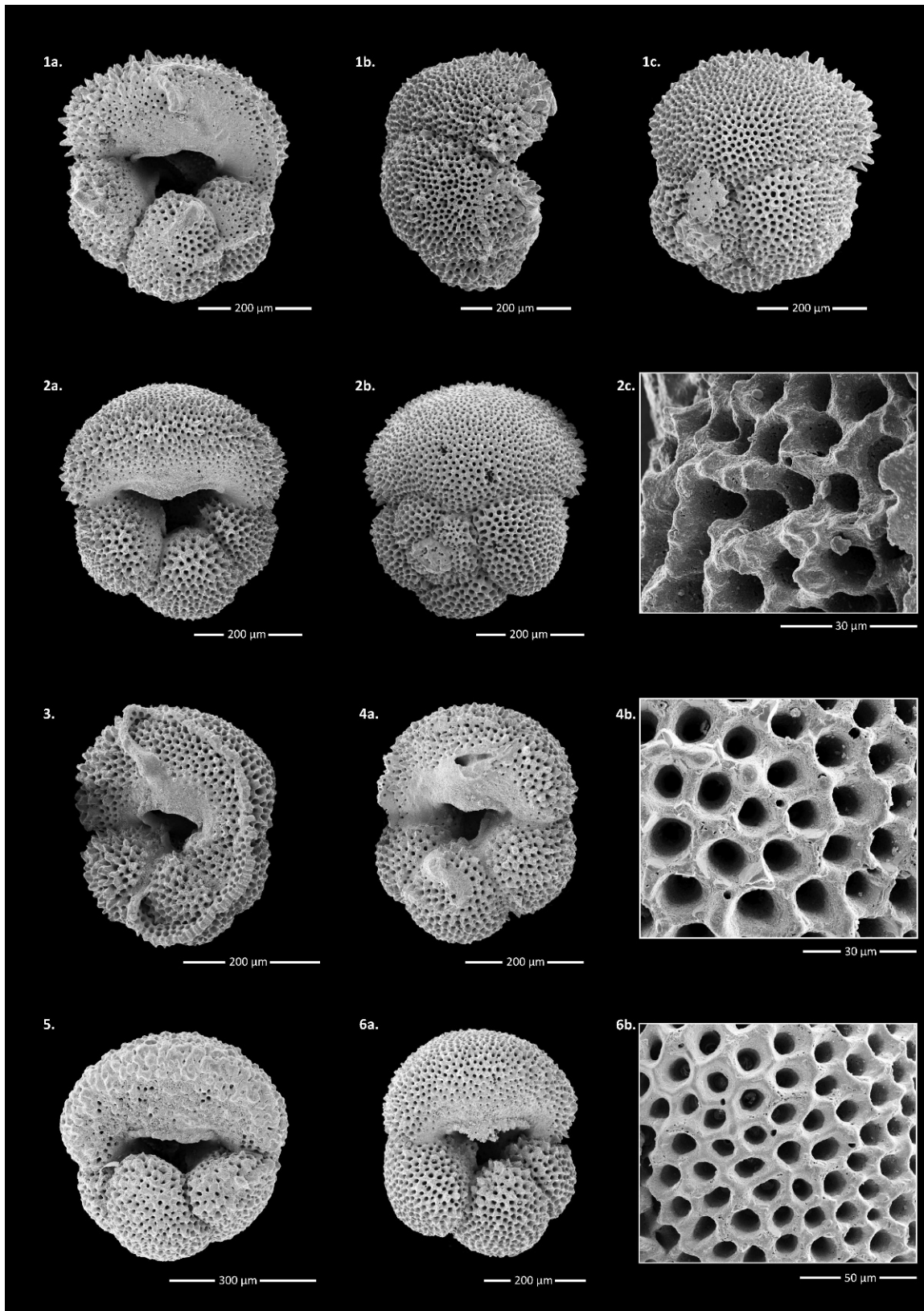


FIGURE 7. 1–6 *Dentoglobigerina juxtabinaiensis* n. sp.: 1, holotype (NHMUK PM PF 70870), U1337A-42X-CC; 2, 6, paratypes (70878, 70881), 871-12H-2, 59–61 cm; 3, paratype (70879), U1337A-38X-CC; 4, paratype (70874), 871-15H-1, 124–126 cm; 5, paratype (70880), U1337A-42X-CC.

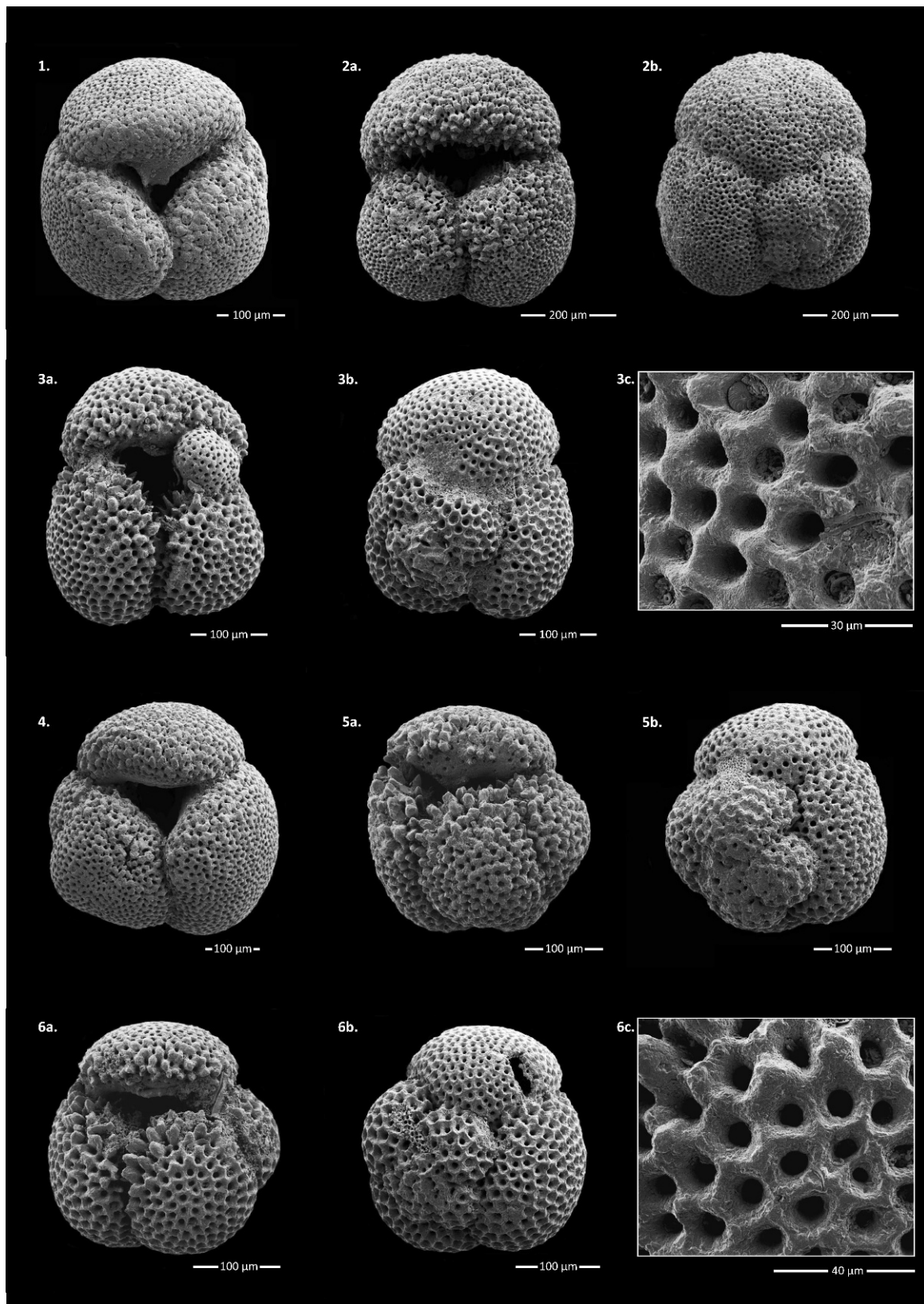


FIGURE 8. 1–3 *Dentoglobigerina tripartita*, U1338B-36H-2, 40–42 cm. 4–6 “*Dentoglobigerina*” *venezuelana*, U1338B-41H-3, 30–32 cm.

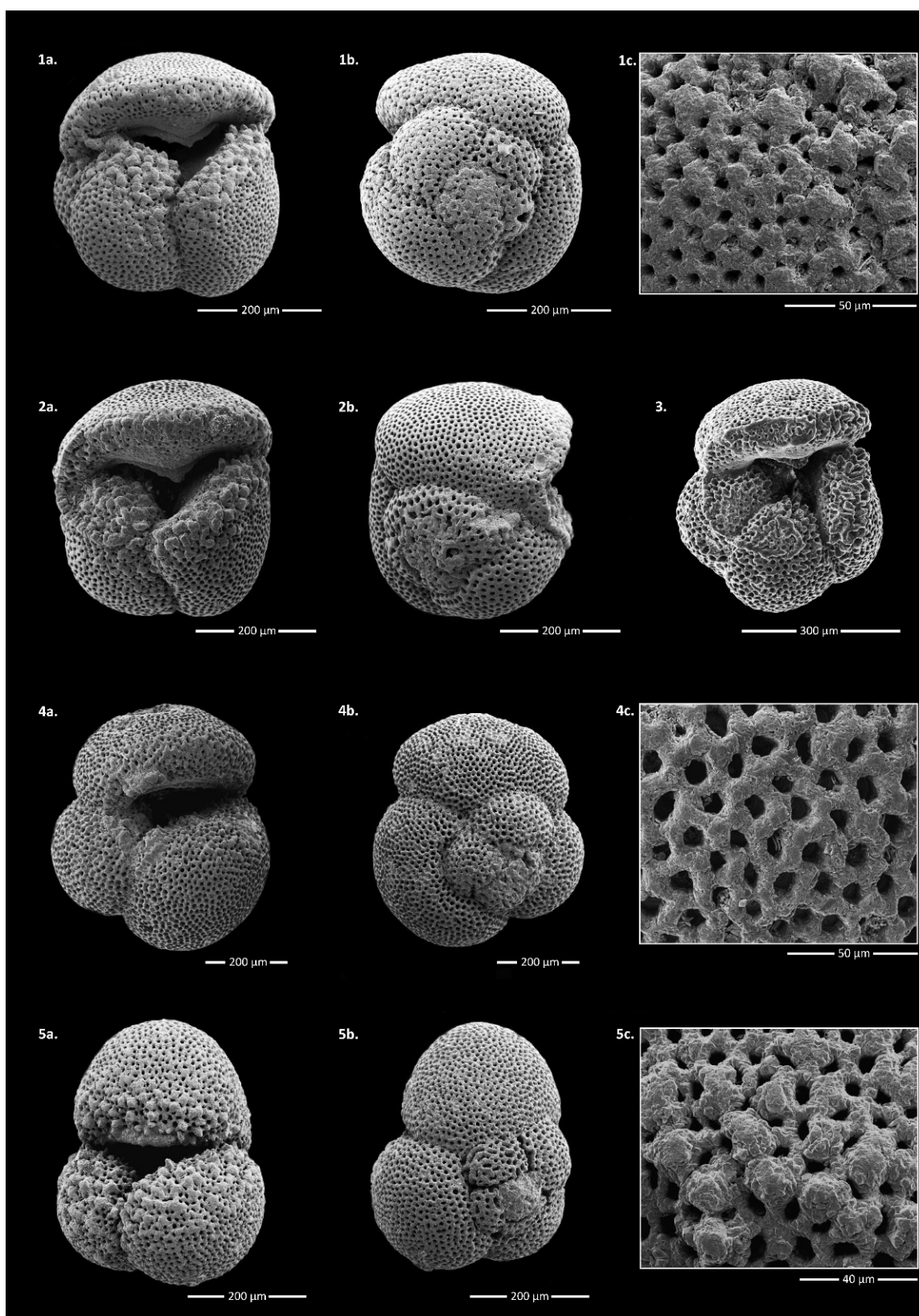


FIGURE 9. 1–3 *Globoquadrina dehiscens*, U1338B-41H-4, 30–32 cm. 4 *Dentoglobigerina* sp., U1338B-36H-2, 40–42 cm. 5 *Sphaeroidinellopsis* sp., U1338B-41H-4, 30–32 cm.

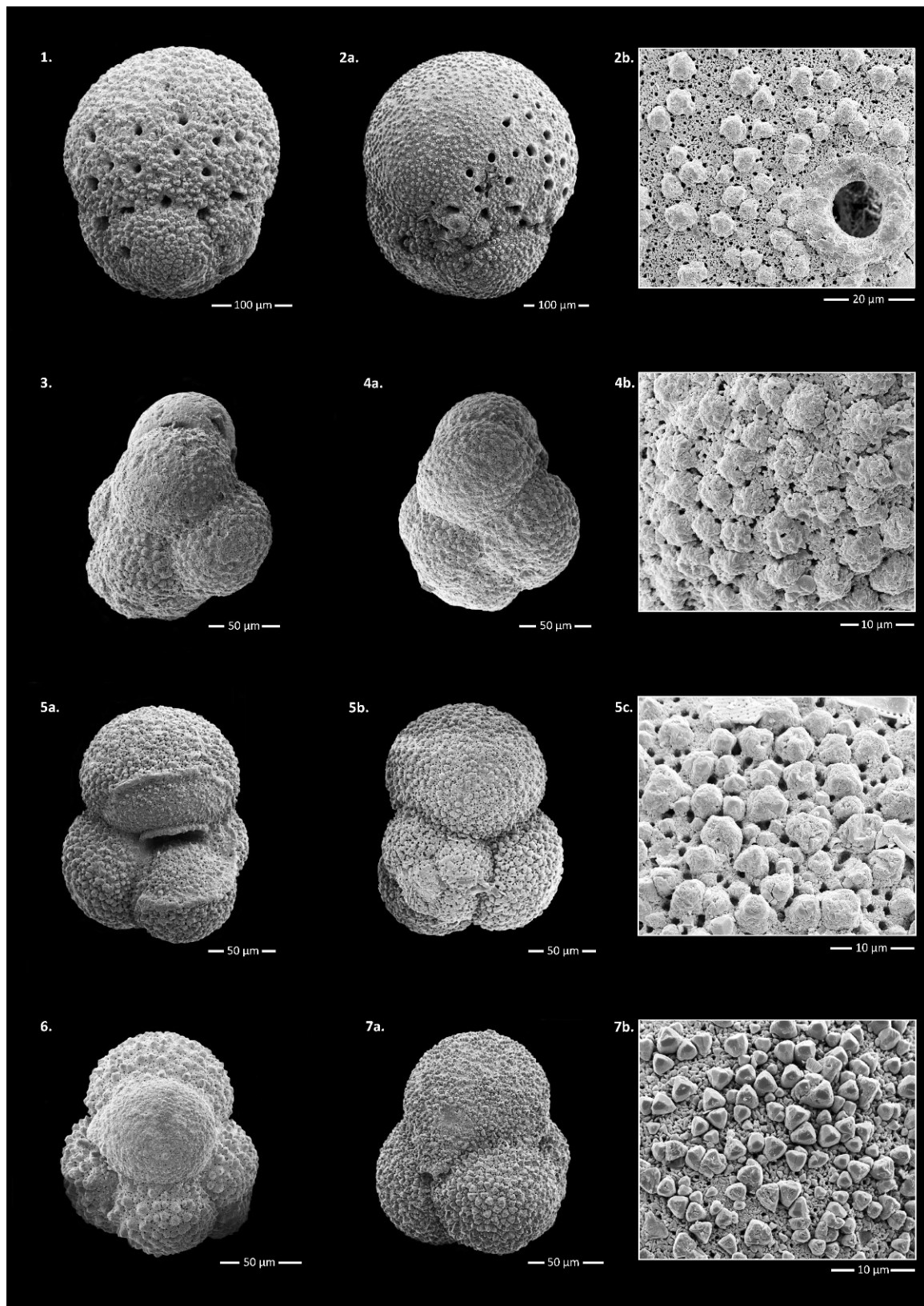


FIGURE 10. 1, 2 *Globigerinatella insueta*, U1338B-41H-3, 30–32 cm. 3, 4 *Globigerinita uvula*, U1338A-44X-3. 5–7 *Globigerinita glutinata* U1338B-36H-2, 40–42 cm.

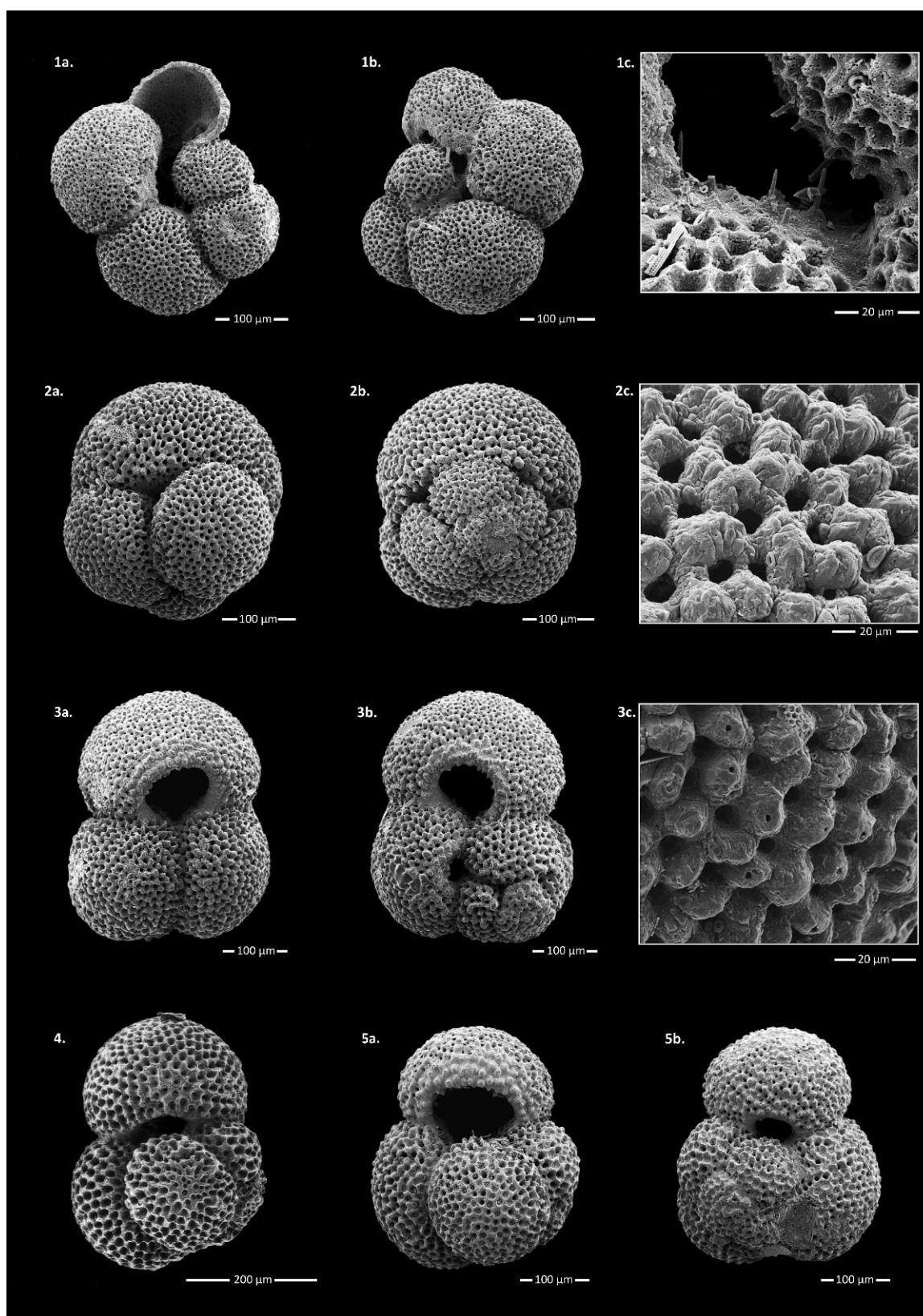


FIGURE 11. 1 *Globigerinella praesiphonifera*, U1338B-42H-2, 40–42 cm. 2 *Globigerinoides* sp., U1338C-41H-4, 30–32 cm. 3 *Globigerinoides subquadratus*, U1338B-42H-2, 40–42 cm. 4 *Globigerinoides quadrilobatus*, U1338A-38X-CC. 5 *Globigerinoides* cf. *G. obliquus*, U1338-41H-4, 30–32 cm.

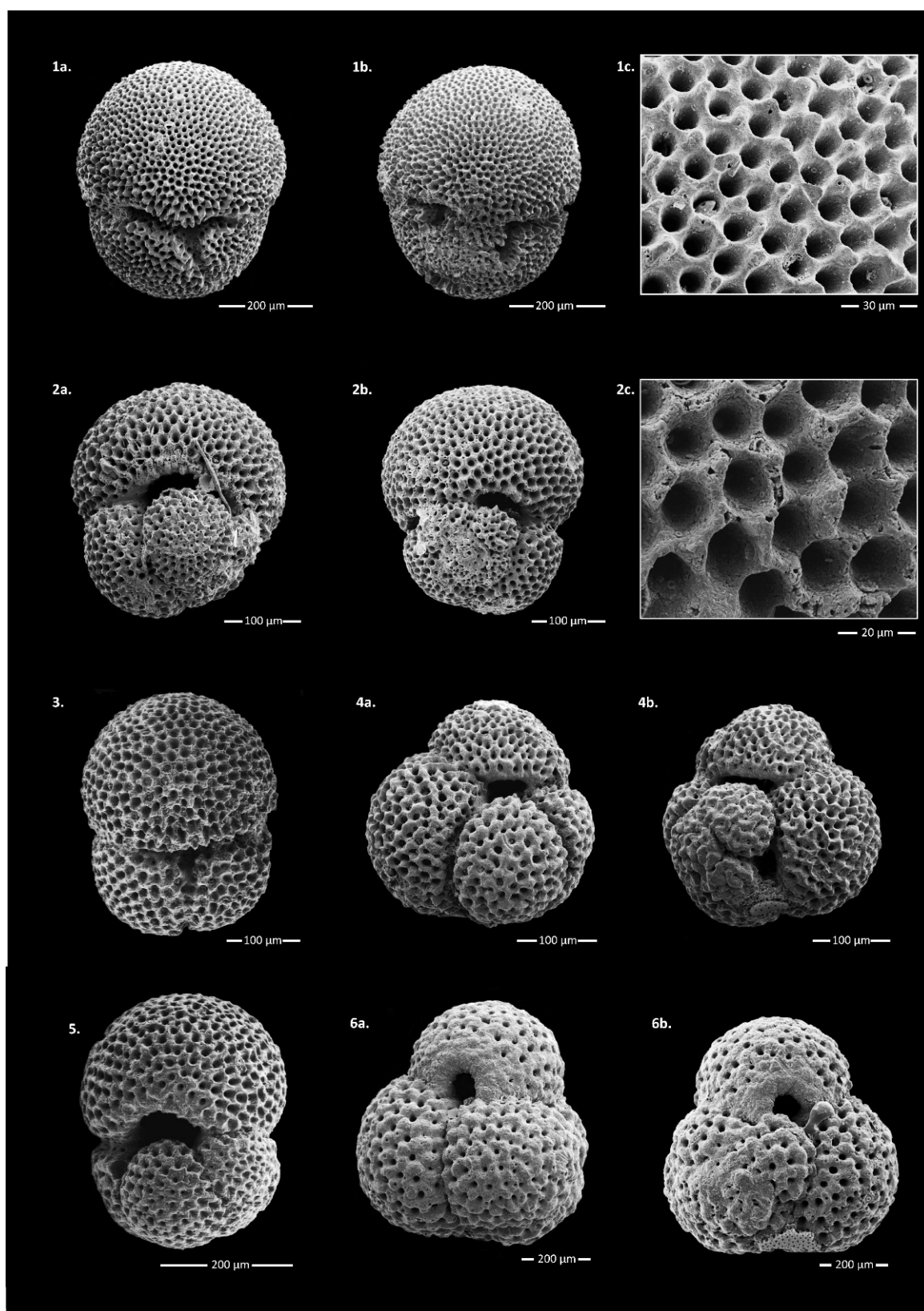


FIGURE 12. 1 *Globigerinoides bisphericus*, U1338C-41H-4, 30–32 cm. 2, 3 *Globigerinoides trilobus*, U1338C-41H-4, 30–32 cm. 4 *Globigerinoides* sp., U1338A-34X-2, 78–80 cm, 5 *Globigerinoides trilobus*, U1338A-42X-CC. 6 *Globigerinoides diminutus*, U1338B-41H-4, 30–32 cm.

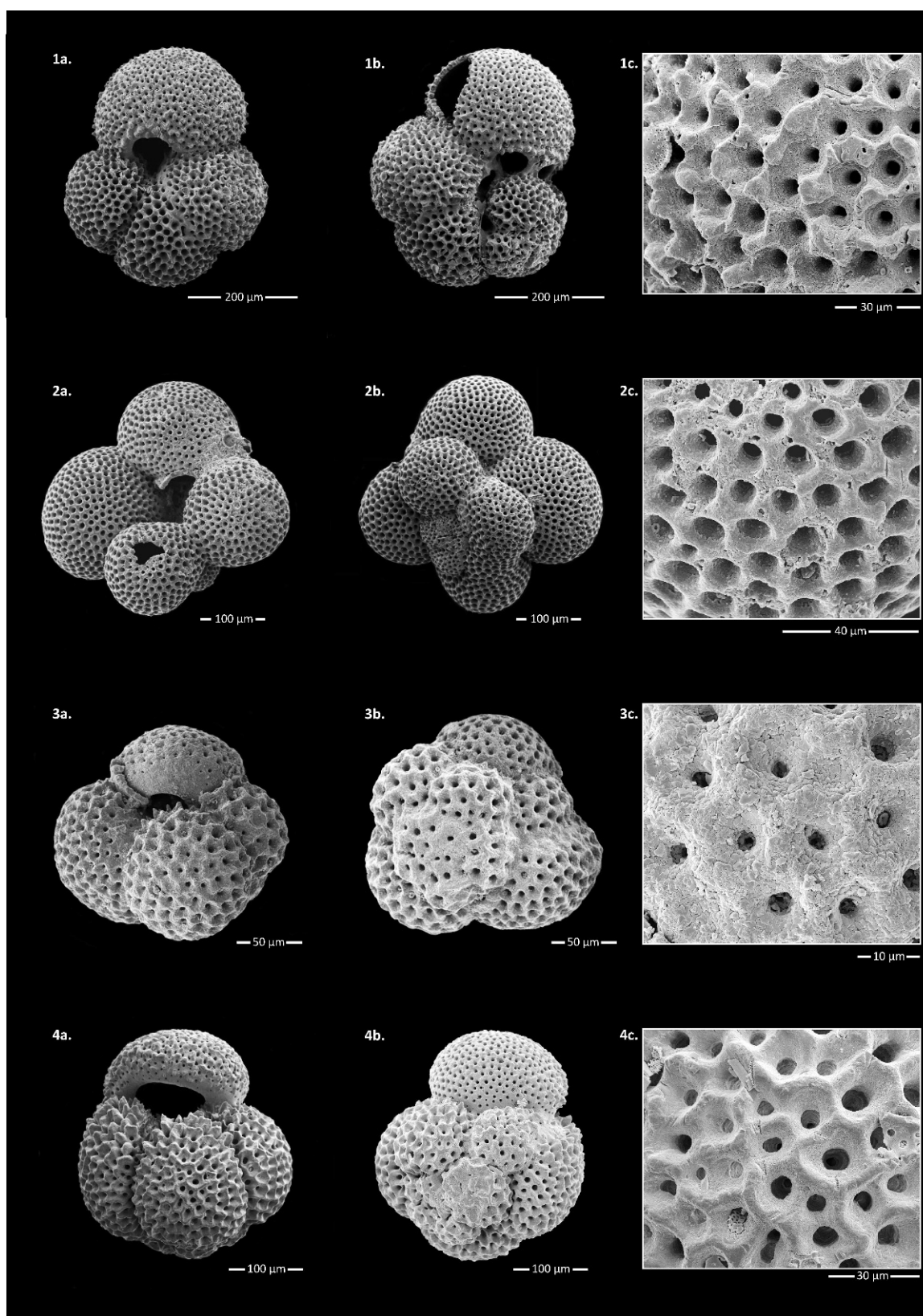


FIGURE 13. 1 *Globigerinoides* aff. *G. grilli*, U1338B-42H-2, 40–42 cm. 2 *Globorotaloides* cf. *G. hexagonus*, U1338B-41H-3, 30–32 cm. 3 *Globoturborotalita* sp., U1338A-40X-2, 78–80 cm. 4 “*Dentoglobigerina*” *venezuelana*, U1338B-41H-4, 30–32 cm.

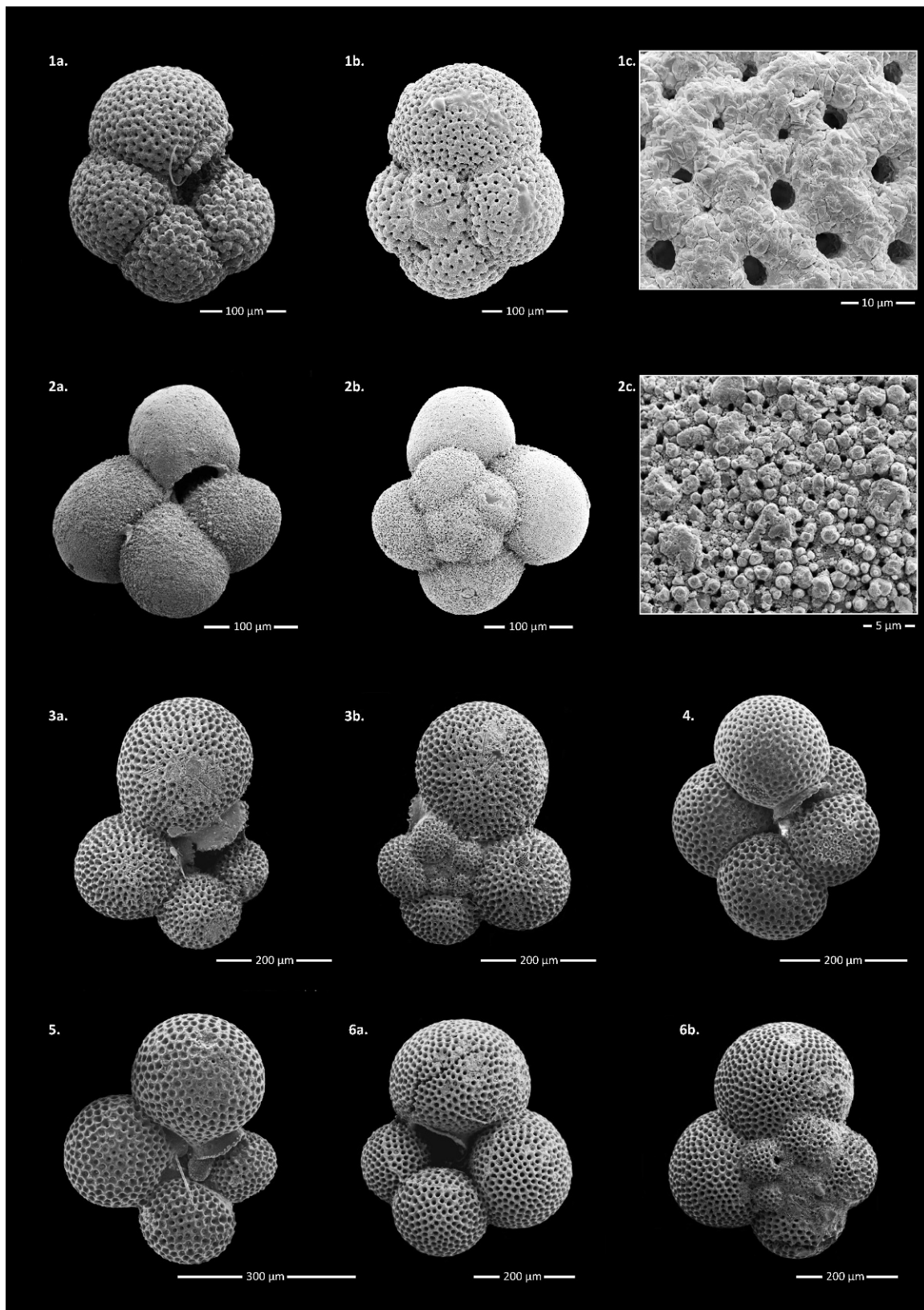


FIGURE 14. 1 *Paragoborotalia continuosa*, U1338B-41H-4, 30–32 cm. 2 *Tenuitella munda* U1338B-38H-5, 20–22 cm. 3–6 *Globorotaloides* sp., U1338B-38H-4, 0–2 cm.

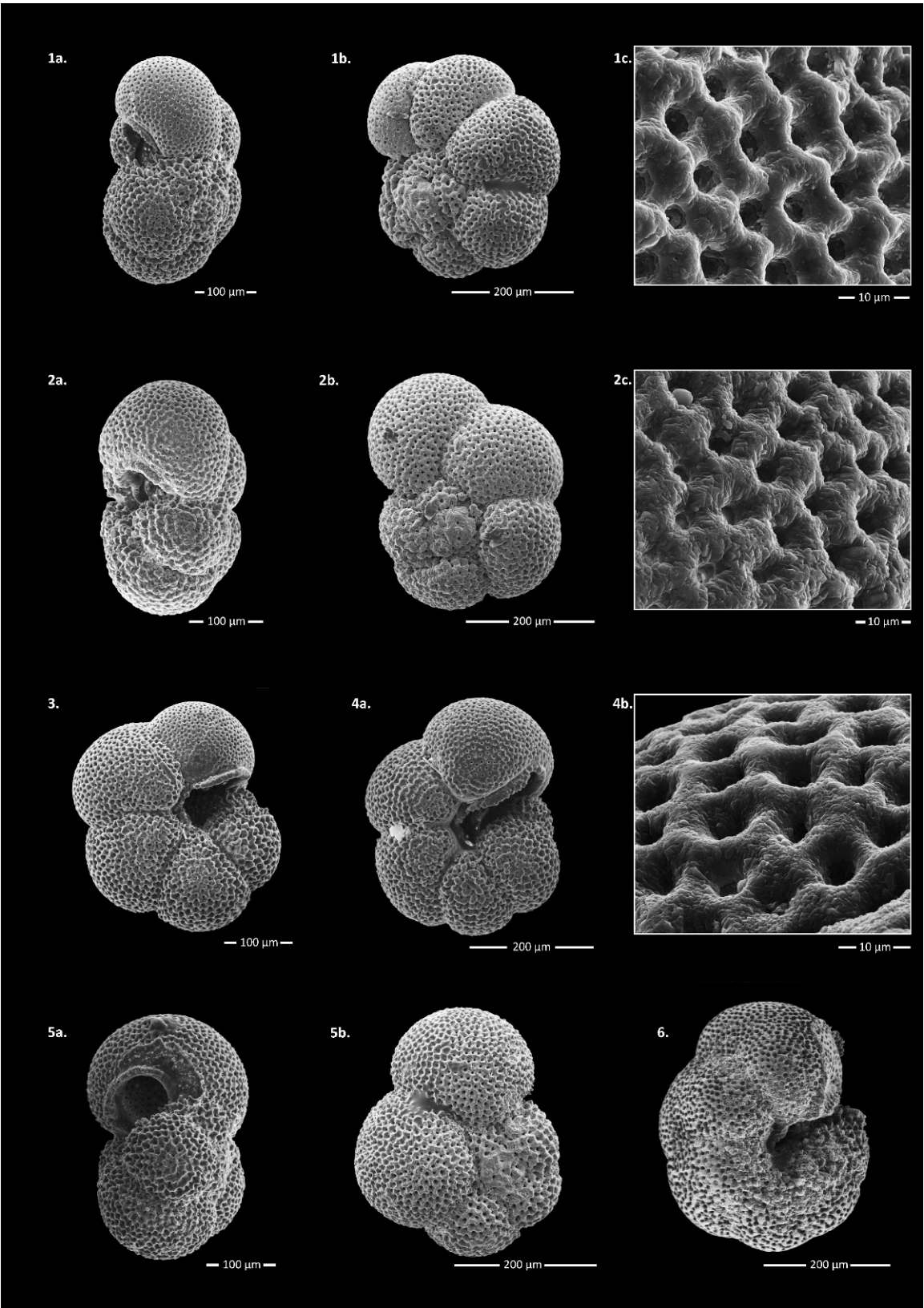


FIGURE 15. 1–5 *Paragloborotalia siakensis*, U1338C-37H-4, 130–132 cm. 6 *Fohsella peripheroronda*, U1338A-38X-CC.

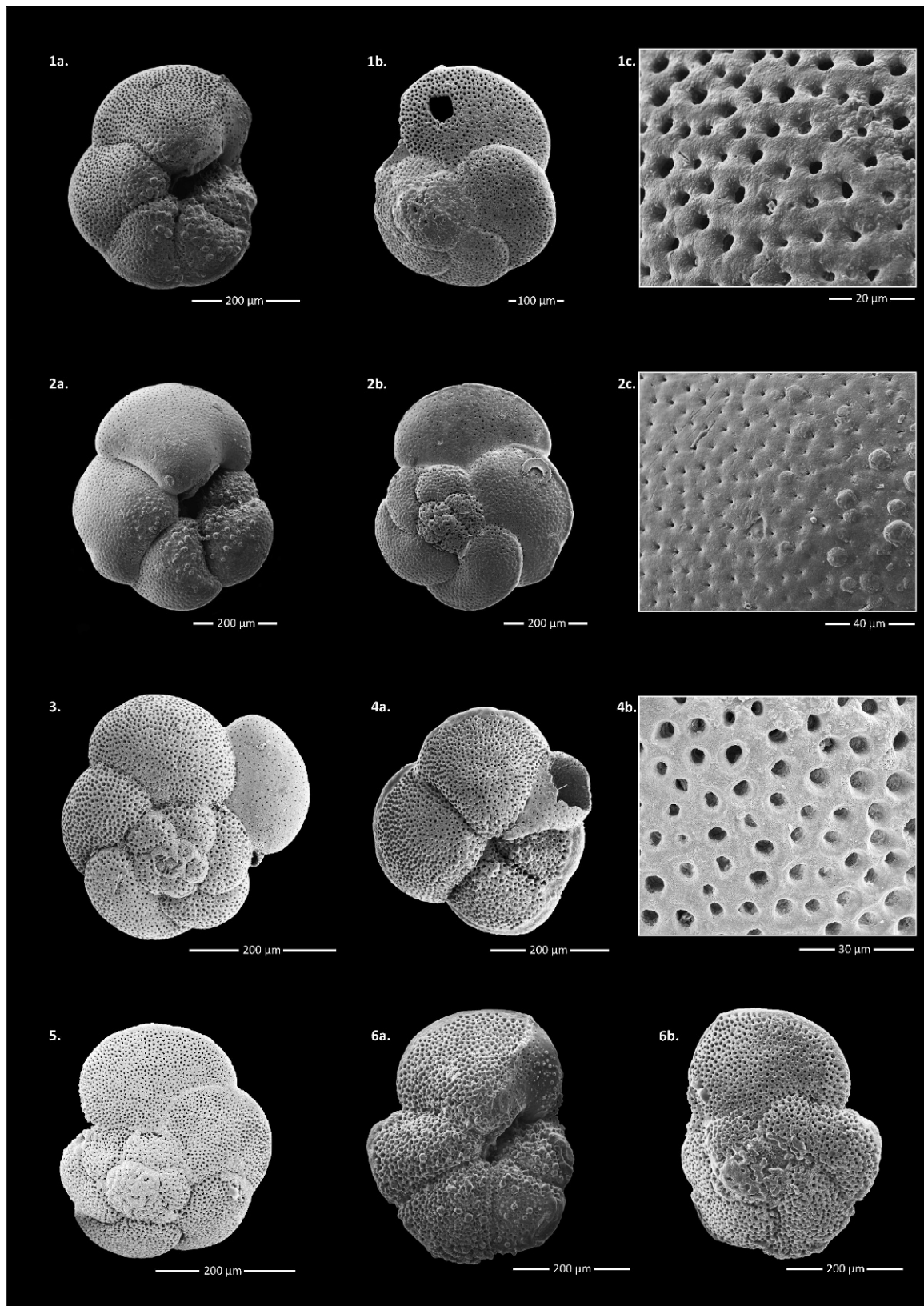


FIGURE 16. 1, 2, 4–6 *Globorotalia praemenardii*, U1338C-35H-5, 90–92 cm. 3 *Fohsella peripheroacuta* U1338B-36H-2, 30–32 cm.

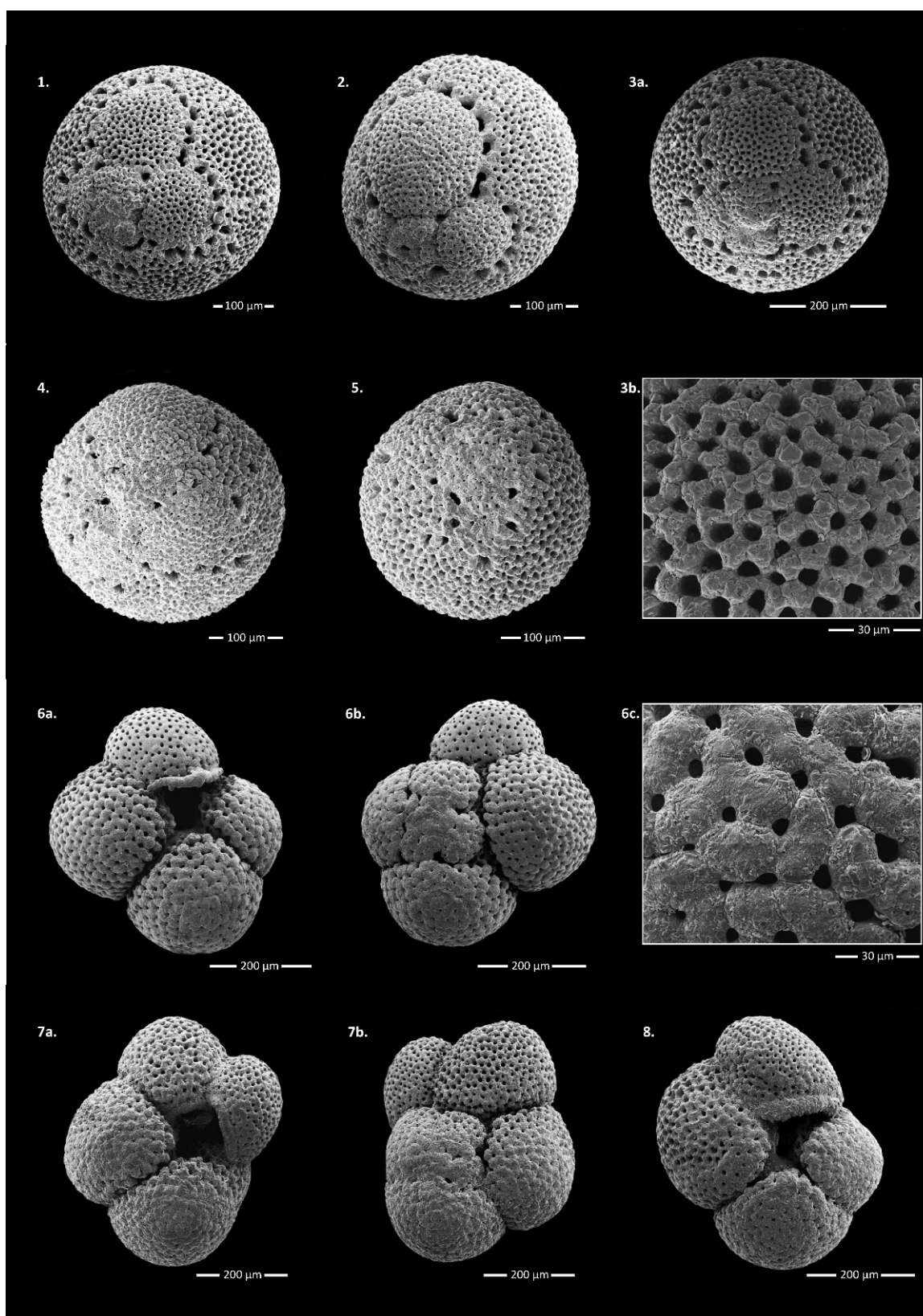


FIGURE 17. 1-5 *Praeorbulina circularis*, U1338B-42H-2, 40-42 cm. 6-8 *Sphaeroidinellopsis disjuncta*, U1338C-35H-5, 90-92 cm.

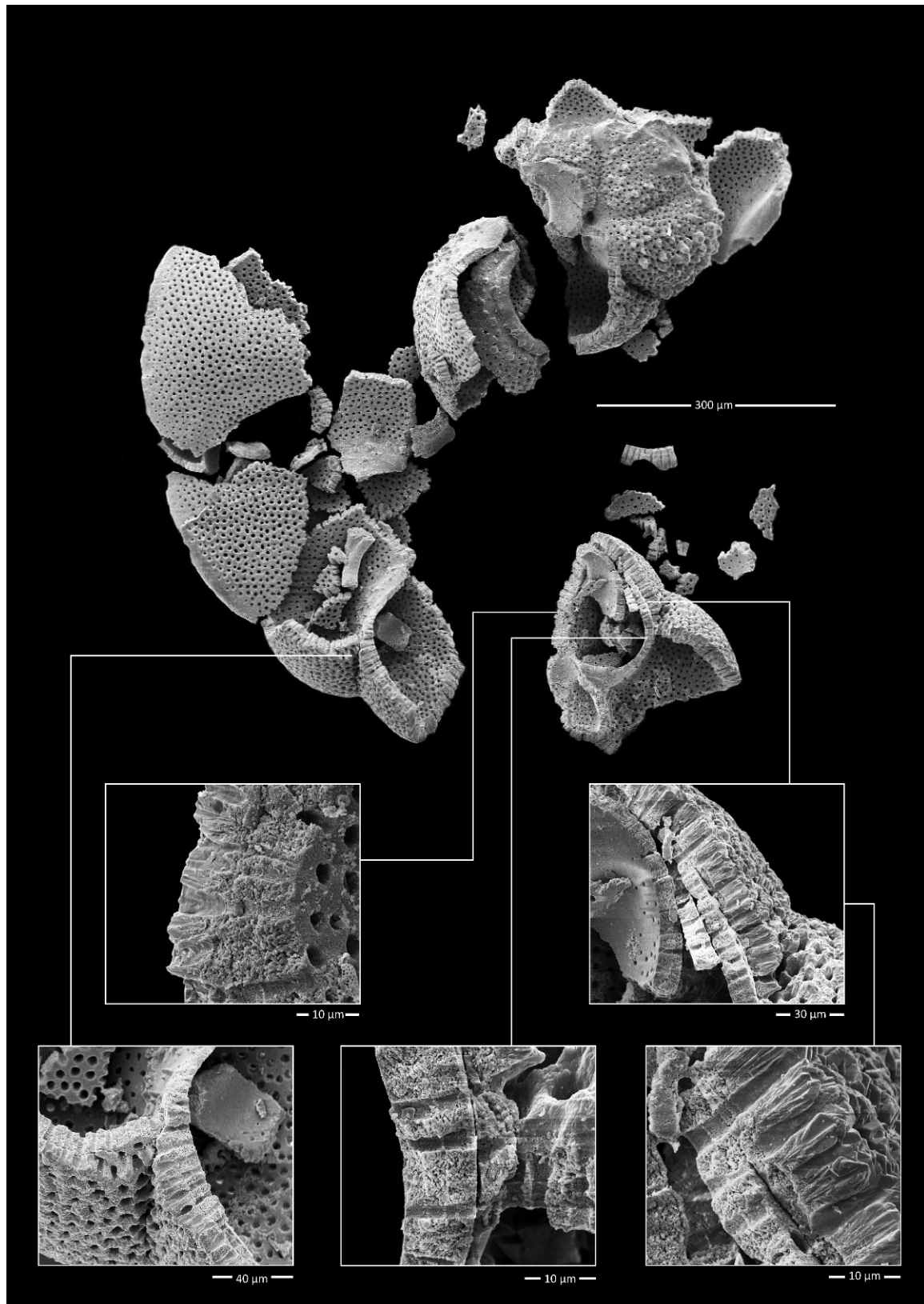


FIGURE 18. *Globorotalia praemenardii*, U1338B-36H-2, 30–32 cm; test broken to reveal wall structure.

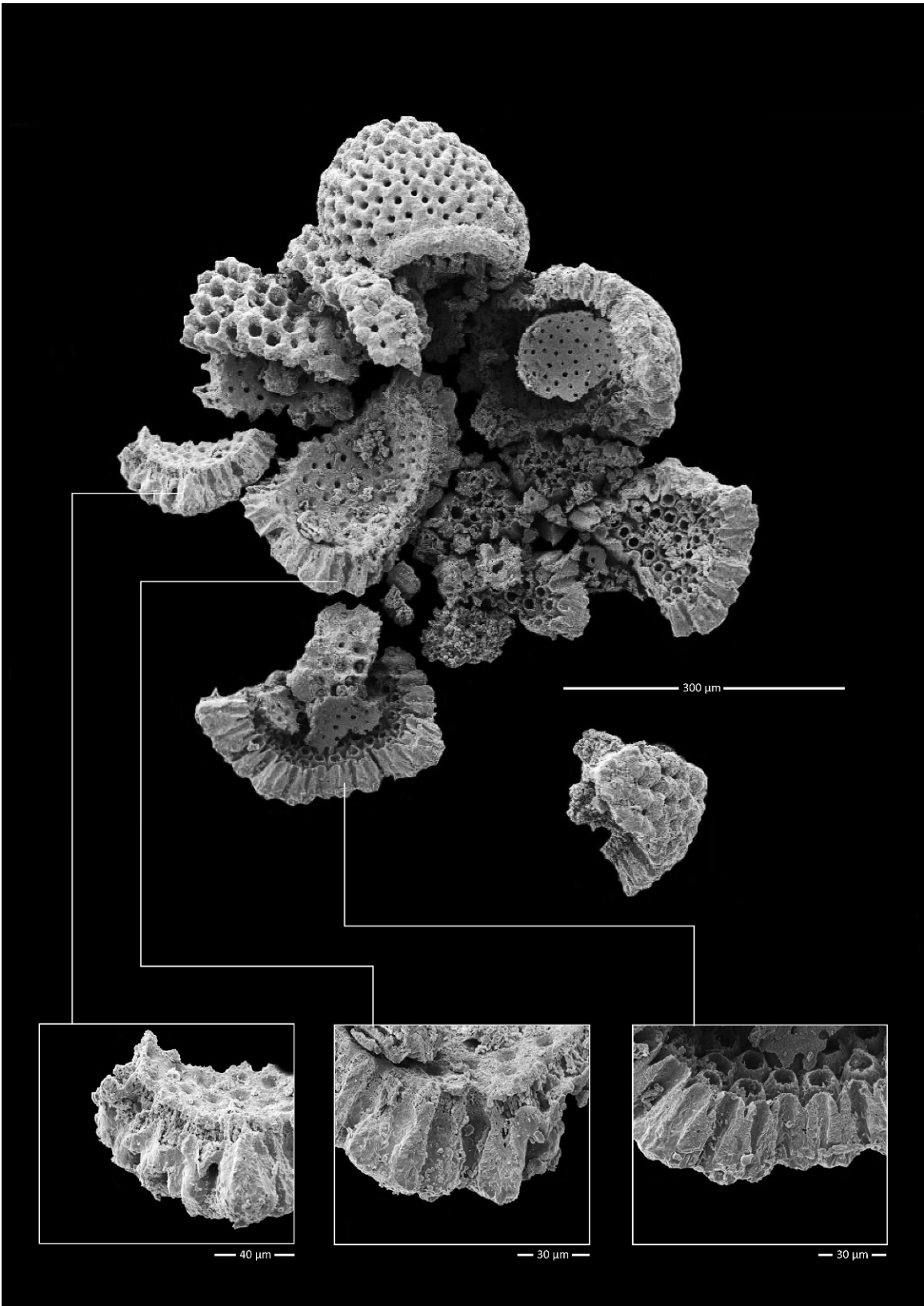


FIGURE 19. *Sphaeroidinellopsis disjuncta*, U1338C-35H-5, 90–92 cm; test broken to reveal internal wall structure.

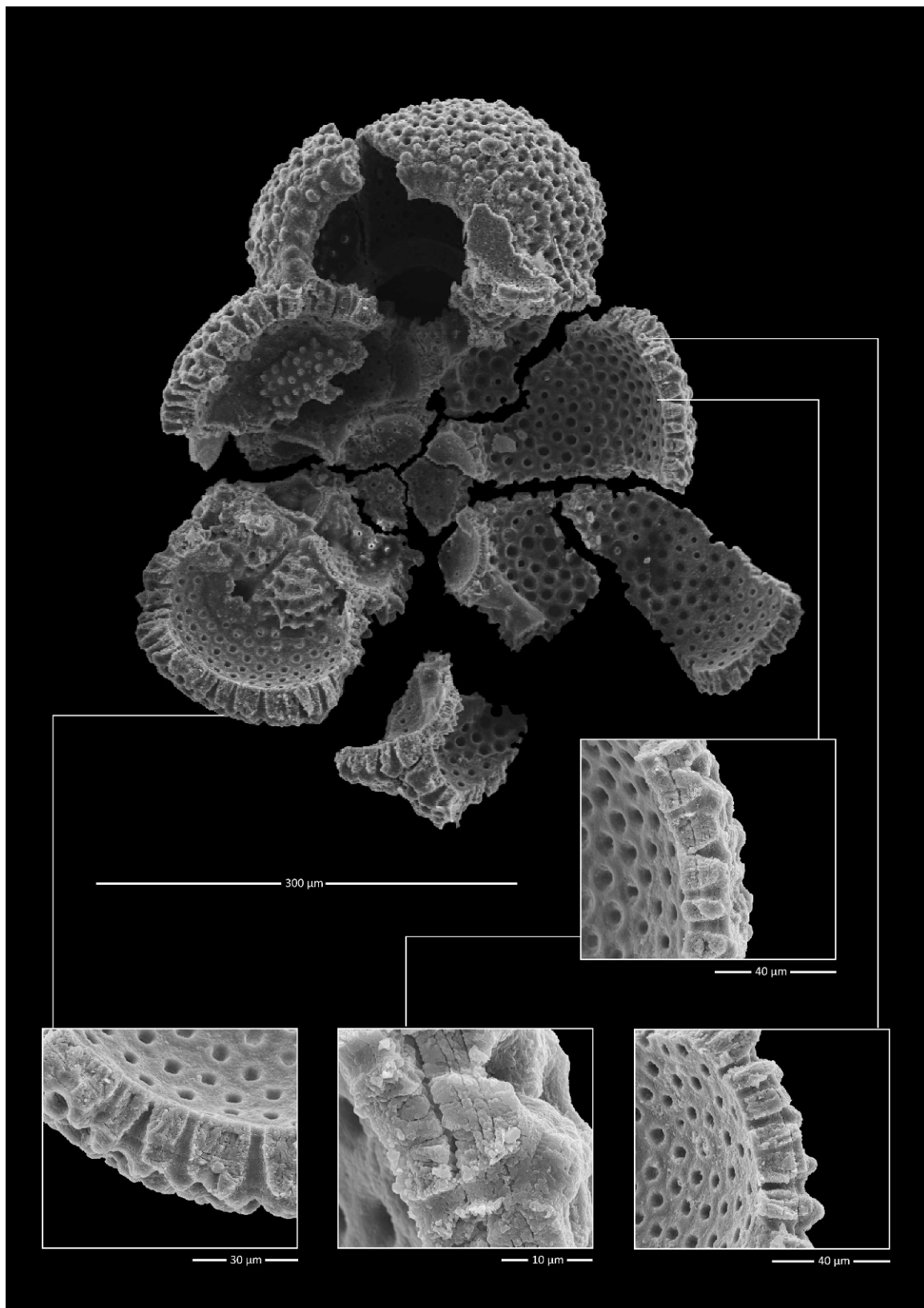


FIGURE 20. *Globigerinoides subquadratus*, U1338B-42H-2, 40–42 cm; test broken to reveal wall structure.

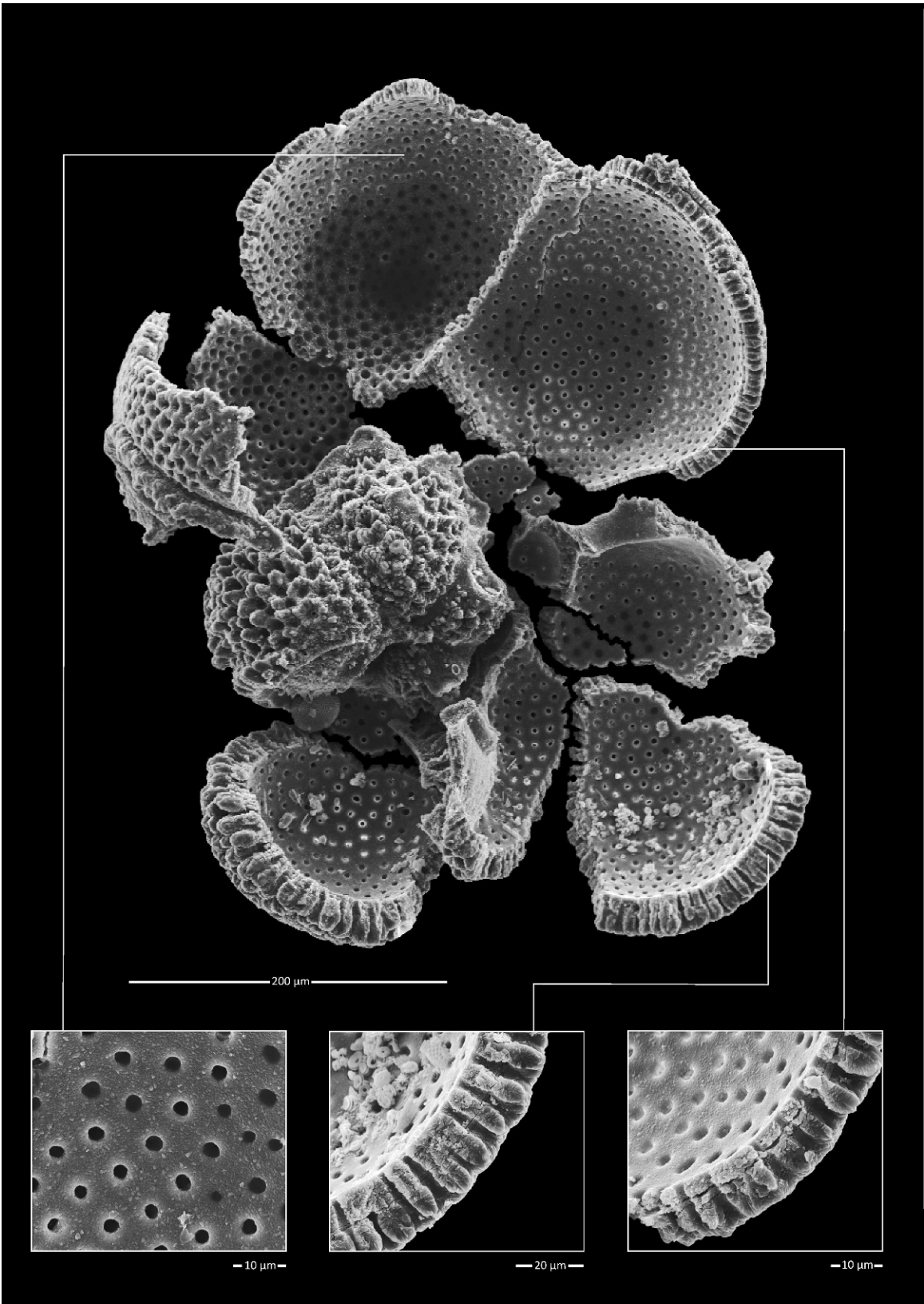


FIGURE 21. *Paragloborotalia siakensis*, U1338C-37H-4, 130–132 cm; test broken to reveal internal wall structure.

Stratigraphic range. U1338A-38X-2, 35–37 cm → U1338A-44X-CC.

Remarks. *Dentoglobigerina binaiensis* evolved from *D. sellii* in the latest Oligocene (Spezzaferri and Premoli Silva, 1990). It is distinguished by 3 chambers in the final whorl with a flattened, commonly pustulose apertural face. The final chamber is large and occupies about half of the test. It gave rise to *D. juxtabinaiensis* n. sp. in the early Miocene.

Dentoglobigerina globosa (Bolli, 1957)

Figs. 5.5, 5.6

Globoquadrina altispira subsp. *globosa* Bolli, 1957, p. 111, pl. 24, figs. 9a–c, 10a–c.

Dentoglobigerina altispira globosa (Bolli). Kennett and Srinivasan, 1983 p. 189, pl. 46, figs. 7–9.

Stratigraphic range. U1338A-7H-CC → U1338A-44X-CC.

Remarks. This species was present in most samples; we distinguish *D. altispira* from *D. globosa* by the higher number of chambers in the final whorl, with *D. altispira* possessing 4 and *D. globosa*, 5–6. The latter also differs in having more rounded chambers and a more circular outline compared to *D. altispira*, which is slightly lobate.

Dentoglobigerina juxtabinaiensis n. sp.

Figs. 6.1–6.5, 7.1–7.6

Globoquadrina dehiscens Chapman, Parr, and Collins. Chaisson and Leckie, 1993, pl. 9, fig. 14. Not *Globoquadrina dehiscens* Chapman, Parr, and Collins, 1934, p. 569, pl. 11, figs. 36a–c.

Globoquadrina binaiensis (Koch). Spezzaferri, 1994, p. 42, pl. 38, figs. 1a–d, pl. 42, figs. 4a–c.

Stratigraphic range. U1338A-38X-2, 35–37 cm → U1338A-44X-3, 102–104 cm. The highest occurrence is not currently well constrained. It is abundant up to Zone M5a at Site U1338, with intermittent occurrences to the top of Zone M5b (recorded as *Globoquadrina* cf. *binaiensis* in Pälike and others, 2010). The lowest occurrence is in Zone M2 at Site U1337.

Type specimens. Deposited in the Natural History Museum, London (NHMUK). Holotype: PM PF 70870 (Site U1337-42X-CC). Paratypes: PM PF 70871, 70872 (Site U1338B-41H-3, 30–32 cm); 70873, 70875–70877 (Site U1338A-42X-CC); 70874 (Site 871-15H-1, 124–126 cm); 70878, 70881 (Site 871-12H-2, 59–61 cm); 70879 (Site U1337A-38CX-CC); and 70880 (Site U1337-42X-CC).

Etymology. Derived from “juxta” referring to its close relationship to its ancestor *D. binaiensis*.

Description. Test wall macroperforate, spinose; chambers arranged in a moderate trochospiral; test tightly coiled with 3 whorls, 4 chambers in the final whorl, increasing slowly then rapidly in size with the arched final chamber accounting for half of the test; peripheral outline rounded in umbilical and spiral view, semi-circular to major circular sectoral in edge view; chambers on umbilical side, wedge shaped, with final chamber semi-circular and flattened; dense and fused pustules concentrated around the periphery; sutures distinct, incised, straight to slightly curved; deep umbilical aperture bordered by a thin to broad lip, sometimes pustulose, with an imperforate area on the umbilical face; on spiral side chambers ovoid; sutures weakly depressed, curved.

Remarks. *Dentoglobigerina binaiensis* is used as a secondary biostratigraphic marker within Zone M2 (Wade and others, 2011). However, four-chambered forms referred to as *Globoquadrina* cf. *binaiensis* were found at Sites U1337 and U1338 (Pälike and others, 2010). To retain the utility of *D. binaiensis* as a bioevent we have chosen to apply a strict species concept and confine *D. binaiensis* to the three-chambered forms, consistent with the original description (Fig. 5.3a). This, therefore, necessitates describing the common four-chambered forms that are found in the early Miocene and earliest middle Miocene as a new species.

D. juxtabinaiensis is distinguished from its ancestor *D. binaiensis* by its greater number of chambers (4 rather than 3) in the final whorl, which are also more wedge shaped. It differs from *G. dehiscens* by its more circular periphery and lack of umbilical shoulders. Specimens commonly show evidence of a broken ultimate chamber as seen in Figures 6.2 and 6.5. The lip is highly variable and can appear tooth-like in some specimens.

Spezzaferri (1994) recognized these forms as the more evolved *D. binaiensis* in the early Miocene from the eastern tropical Atlantic Ocean (Site 667) and equatorial Indian Ocean (Site 709). Chaisson and Leckie (1993) also distinguished between the three- and four-chambered specimens of *D. binaiensis* in their study from the western equatorial Pacific Ocean (Site 806).

Significantly many of our specimens show evidence of spine holes, indicative of a spinose wall texture. Previously, *Dentoglobigerina* and *Globoquadrina* have been considered non-spinose (e.g., Pearson and others, 2006).

Phylogeny. *Dentoglobigerina juxtabinaiensis* evolved from *D. binaiensis* in the early Miocene by developing four chambers in the final whorl and a more open aperture.

Distribution. Probably restricted to low latitudes; known from the equatorial regions of the Indian Ocean, Atlantic Ocean (Spezzaferri, 1994), and Pacific Ocean (Chaisson and Leckie, 1993; this study).

Dentoglobigerina tripartita (Koch, 1926)

Figs. 8.1–8.3

Globoquadrina bulloides d'Orbigny var. *tripartita* Koch, 1926, p. 742, text-figs. 21a, b.

Globoquadrina tripartita Koch. Blow and Banner, 1962, p. 96, pl. 10, figs. A–C (reillustrated holotype).

Dentoglobigerina tripartita (Koch). Pearson and others, 2006, p. 409, pl. 13.3, figs. 1–3 (reillustrated holotype), 4–8, 12, 13, 15, 16.

Stratigraphic range. U1338A-29X-2, 136–138 cm → U1338A-44X-CC.

Remarks. *Dentoglobigerina tripartita* is characterized by its large size, with three chambers in the final whorl. Specimens of *D. tripartita* commonly have pustules around the umbilicus and appear to intergrade with *Globoquadrina dehiscens*. Many specimens have a bulla of variable size. In Figure 9 we illustrate three specimens which appear very different morphologically but fit the taxonomic description of *D. tripartita* in Kennett and Srinivasan, (1983). The extensive morphological variability has also been noted by Leckie and others (1993). *Catapsydrax unicus* was recorded as abundant during shipboard studies at site 1338 (Pälike and others, 2010), but our post-cruise investigation suggests many of the forms are bullate *D. tripartita*.

Dentoglobigerina sp.

Fig. 9.4

Stratigraphic range. U1338B-41H-3, 30–32 cm.*Remarks.* Although referred to here as *Dentoglobigerina* sp., the specimen resembles *Dentoglobigerina* aff. *D. larmeu* in Spezzaferri and Premoli Silva (1991, pl. 17, fig. 3).*“Dentoglobigerina” venezuelana* (Hedberg, 1937)

Figs. 8.4–8.6, 13.4

Globigerina venezuelana Hedberg, 1937, p. 681, pl. 92, fig. 72b; Kennett and Srinivasan, 1983, p. 180, pl. 44, figs. 5–7.*Stratigraphic range.* U1338A-7H-CC → U1338A-44X-CC.*Remarks.* This species is abundant in most samples. The shape of the chambers in the final whorl can vary noticeably from specimen to specimen. Stewart and others (2012) separate “*D.*” *venezuelana* into three distinct morphotypes: 1) specimens with a kummerform, flattened, final chamber, and rectangular aperture; 2) individuals possessing kummerform, flattened, final chambers, and low arched (often asymmetrical) apertures; and 3) specimens with a large, embracing final chamber and rectangular aperture. Our illustrated specimens fall into the first and second categories. We refer to the specimen illustrated in Figure 13.4 as “*D.*” *venezuelana* but have placed it on Figure 13 with other unusual specimens found in our samples.Genus *Globigerinella* Cushman, 1927Type species: *Globigerina aequilateralis* Brady, 1879*Globigerinella praesiphonifera* (Blow, 1969)

Fig. 11.1

Hastigerina siphonifera praesiphonifera Blow, 1969, p. 408, pl. 54, figs. 7–9.*Globigerinella praesiphonifera* (Blow). Kennett and Srinivasan, 1983, p. 239, pl. 60, figs. 4–6.*Stratigraphic range.* U1338A-25H-CC → U1338A-40X-CC.*Remarks.* This species is very rare. We found only single specimens appearing intermittently in samples throughout its range, many of which have spines preserved around the aperture (Fig. 11.1c).Genus *Globigerinoides* Cushman, 1927Type species: *Globigerina rubra* d’Orbigny, 1839*Globigerinoides bisphericus* Todd, 1954

Fig. 12.1

Globigerinoides bisphericus Todd in Todd and others, 1954, p. 681, pl. 1, figs. 1a–c, 4; Jenkins and others, 1981, p. 265, pl. 1, figs. 1a–c.*Stratigraphic range.* U1338B-35H-5, 50–52 cm → U1338C-41H-4, 30–32 cm.*Remarks.* Specimens of *G. bisphericus* in many samples tend to grade toward *G. trilobus*. The former is distinguished by its more enveloping final chamber and more reduced umbilicus. Further work is required to constrain its stratigraphic range.*Globigerinoides diminutus* Bolli, 1957

Fig. 12.6

Globigerinoides diminutus Bolli, 1957, p. 114, pl. 25, figs. 11a–c; Kennett and Srinivasan, 1983, p. 74, pl. 16, figs. 4–6.*Stratigraphic range.* Presently unconstrained.*Remarks.* *Globigerinoides diminutus* is smaller than *G. subquadratus* and has a distinctly more compact test. This small and easily recognizable species is abundant in the <150-μm fraction of our samples.*Globigerinoides* aff. *G. grilli* Schmid, 1967

Fig. 13.1

Stratigraphic range. U1338B-42H-2, 40–42 cm.*Remarks.* This specimen has a cancellate and spinose wall texture and possesses sutural apertures on the spiral side comparable to the type examples of *G. grilli* illustrated by Schmid (1967). However, our specimen differs in having a high arched aperture and much lower trochospire.*Globigerinoides quadrilobatus* (d’Orbigny, 1846)

Fig. 11.4

Globigerina quadrilobatus d’Orbigny, 1846, p. 164, pl. 9, figs. 7–10.*Globigerinoides quadrilobatus* (d’Orbigny). Kennett and Srinivasan, 1983, p. 66, pl. 14, figs. 1–3.*Stratigraphic range.* U1338A-8H-2, 43–45 cm → U1338A-44X-3, 102–104 cm.*Remarks.* *Globigerinoides quadrilobatus* is very common throughout its range at Site U1338, and many specimens were found with spines preserved around the primary aperture. This species is closely related to *G. sacculifer* (Brady, 1877), which differs from *G. quadrilobatus* in its stronger cancellate wall texture and possession of an elongate sack-like terminal chamber. It is distinguished from *G. trilobus* by its greater number of chambers (4 rather than 3) in the final whorl.*Globigerinoides* sp.

Fig. 11.2

Stratigraphic range. U1338C-41H-4, 30–32 cm.*Remarks.* *Globigerinoides* sp. appears intermittently in our samples, and further work is required to constrain its stratigraphic range. The test is small and compact in size with 3 high trochospiral whorls.*Globigerinoides subquadratus* Brönnimann, 1954

Figs. 11.4, 20

Globigerinoides subquadrata Brönnimann, 1954, p. 680, pl. 1, figs. 8a–c.*Globigerinoides subquadratus* Brönnimann. Kennett and Srinivasan, 1983, p. 74, pl. 16, figs. 1–3.*Stratigraphic range.* U1338C-39H-7, 40–42 cm → U1338A-42X-CC.*Remarks.* *Globigerinoides subquadratus* is the most common species in the early Miocene samples. Our specimens display a distinct rim around the primary aperture, and possess two or more supplementary apertures. Many specimens also have spines. Wall cross sections are illustrated in Figure 20.The extinction of *G. subquadratus* has previously been located within the *Globorotalia mayeri* Zone (M11). However, at Site U1338 this event is recorded in the far older planktonic foraminiferal Zone M5b. We also measured a thickness of 18.95 m (~650 kyr) between the last occurrence of *G. subquadratus* and the first occurrence of its homeomorph *Globigerinoides ruber* (d’Orbigny, 1839). This non-overlapping interval has been mentioned by

various authors (Bolli, 1957; Blow, 1969; Stainforth and others, 1975; Liska, 1985; Martinotti, 1990), with the length of the interval varying between sites. Therefore, further high resolution biostratigraphic research is needed to determine the diachronism of this event.

Globigerinoides trilobus (Reuss, 1850)

Figs. 12.2, 12.3, 12.5

Globigerina triloba Reuss, 1850, p. 374, pl. 447, figs. 11a–c.

Globigerinoides triloba triloba (Reuss). Bolli, 1957, p. 112, pl. 25, figs. 2a–c; Blow, 1959, p. 187, pl. 11, figs. 60a, b.

Globigerinoides trilobus (Reuss). Bermudez, 1961, p. 1244, pl. 12, fig. 6; Kennett and Srinivasan, 1983, p. 62, pl. 13, figs. 1–3.

Globigerinoides trilobus trilobus (Reuss). Gibson, 1983, p. 371, pl. 4, fig. 12.

Stratigraphic range. U1338A-4H-5, 56–58 cm → U1338A-44X-3, 102–104 cm.

Remarks. *Globigerinoides trilobus* is common in most samples and abundant in samples U1338A-36X-1, 36–38 cm and U1338A-41X-4, 9–11 cm. The species is distinguished from all other *Globigerinoides* by its low arched slit-like primary and supplementary apertures. Typical specimens are coarsely cancellate and have a more compact test compared to *G. subquadratus* and *G. primordius*.

Genus *Globoquadrina* Finlay, 1947

Type species: *Globorotalia dehiscens* Chapman, Parr, and Collins, 1934

Globoquadrina dehiscens (Chapman, Parr, and Collins, 1934)
Figs. 9.1–9.3

Globorotalia dehiscens Chapman, Parr, and Collins, 1934, p. 569, pl. 11, figs. 36a–c.

Globoquadrina dehiscens (Chapman, Parr, and Collins). Kennett and Srinivasan, 1983, p. 184, pl. 44, fig. 2, pl. 45, figs. 7–9.

Stratigraphic range. U1338A-4H-5, 56–58 cm → U1338A-44X-CC.

Remarks. *Globoquadrina dehiscens* is characterized by its flattened umbilical face, pronounced umbilical shoulders, and “v”-shaped tooth. In spiral view, the early sutures are poorly incised. This species was common in most samples.

Genus *Globorotaloides* Bolli 1957

Type species: *Globorotaloides variabilis* Bolli, 1957

Globorotaloides cf. *G. hexagonus* (Natland, 1938)
Fig. 13.2

Globigerina hexagona Natland, 1938, p. 149, pl. 7, figs. 1a–c.

Globorotaloides hexagonus (Natland). Kennett and Srinivasan, 1983, p. 216, figs. 1, 3, 5.

Stratigraphic range. U1338B-37H-6, 30–32 cm → U1338B-41H-3, 30–32 cm.

Remarks. This specimen possesses inflated globular chambers, slightly curved to radial sutures, and cancellate wall texture typical of *G. hexagonus*; however, it exhibits an unusually high trochospire and apertural tooth.

Globorotaloides sp.

Figs. 14.3–14.6

Stratigraphic range. U1338B-37H-6, 30–32 cm → U1338C-39H-4, 140–142 cm.

Remarks. The genus *Globorotaloides* includes forms with a low trochospiral test, ovate to spherical chambers and cancellate wall texture. The spiral side of the specimen

illustrated in Figure 14.3b is flattened, with radial sutures and rapidly increasing chamber size in the final whorl. Similar to Figure 14.5, its final chamber is much larger than the penultimate chamber and the aperture is bordered by an unusually large lip. Figure 14.4 also exhibits a pronounced lip, but has slightly curved sutures. It is more compact than the other illustrated specimens. Figure 14.6 has a low trochospire and a more open aperture bordered by a thin lip.

Genus *Globoturborotalita* Hofker, 1976

Type species: *Globigerina rubescens* Hofker, 1956

Globoturborotalita sp.

Fig. 13.3

Stratigraphic range. U1338A-40X-1, 115–117 cm → U1338A-40X-3, 27–29 cm.

Remarks. This small form has a compact test, moderate trochospire, and subglobular chambers. In shape and size it is comparable to *Globoturborotalita rubescens* illustrated by Li and others (2003), but is distinguished by its lower arched aperture which does not possess a lip.

Genus *Paragloborotalia* Cifelli, 1982

Type species: *Globorotalia opima opima* Bolli, 1957

Paragloborotalia continuosa (Blow, 1959)

Fig. 14.1

Globorotalia opima continuosa Blow, 1959, p. 218, pl. 19, figs. 125a–c. *Globorotalia continuosa* Blow. Bolli and Saunders, 1985, p. 204, figs. 26.8–26.14.

Paragloborotalia continuosa Blow. Spezzaferri, 1994, p. 54, pl. 20, figs. 7a–c.

Stratigraphic range. U1338A-26H-CC → U1338A-44X-CC.

Remarks. *Paragloborotalia continuosa* differs from *P. siakensis* in having a more subquadrangular profile with fewer chambers in the final whorl. Wall texture is cancellate and no spines were found on the studied specimens. The species is very rare throughout its range.

Paragloborotalia siakensis (LeRoy, 1939)

Figs. 15.1–15.5, 21

Globorotalia siakensis LeRoy, 1939, p. 262, pl. 4, figs. 20–22.

Globorotalia (Jenkinsella) siakensis LeRoy. Kennett and Srinivasan, 1983, p. 172, pl. 42, figs. 1, 6–8.

Paragloborotalia siakensis (LeRoy). Zachariasse and Sudijono, 2012, figs. 5.1–5.3, 6.1–6.13.

Stratigraphic range. U1338A-25H-6, 5–7 cm → U1338A-44X-CC.

Remarks. In many samples, *P. siakensis* was the dominant species and represented a large proportion of the assemblage. Our specimens are consistent with new SEMs of the holotype in Zachariasse and Sudijono (2012, fig. 5). Figure 21 illustrates a well preserved specimen which has been broken to reveal the wall structure.

Genus *Praeorbulina* Olsson, 1964

Type species: *Globigerinoides glomerosa* subsp. *glomerosa* Blow, 1956

Praeorbulina circularis (Blow, 1956)

Figs. 17.1–17.5

Globigerinoides glomerosa circularis Blow, 1956, p. 64, figs. 2.3, 2.4; Kennett and Srinivasan, 1983, p. 85, pl. 19, figs. 1–5.

Stratigraphic range. U1338A-37X-CC → U1338A-39X-2, 72–74 cm.

Remarks. *Praeorbulina circularis* is distinguished from its ancestor *P. glomerosa* by having more numerous apertures along the basal sutures and a more circular outline. It differs from the closely related *Orbulina universa* (d'Orbigny, 1839) in having the earlier chambers of the test breaking the outline of the sphere. Maximum numbers of this species were found in Sample U1338C-36H-2, 110–112 cm, and it was very common in Sample U1338B-36H-2, 40–42 cm.

Genus *Sphaeroidinellopsis* Banner and Blow, 1959
Type species: *Globigerina seminulina* Schwager, 1866

Sphaeroidinellopsis disjuncta (Finlay, 1940)
Figs. 17.6–17.8, 19

Sphaeroidinella disjuncta Finlay, 1940, p. 467, pl. 67, figs. 224–228.
Sphaeroidinellopsis disjuncta (Finlay). Kennett and Srinivasan, 1983, p. 206, pl. 51, figs. 3–5.

Stratigraphic range. U1338A-25H-6, 5–7 cm → U1338A-42X-4, 114–116 cm.

Remarks. *Sphaeroidinellopsis disjuncta* is a fairly persistent taxon throughout the middle Miocene sediments of Holes 1338B and C, and has intermittent bursts of high abundance in the middle Miocene. This species has a coarsely cancellate and thickened test wall, which can be observed in detail in Figure 19.

Family GLOBOROTALIIDAE Cushman, 1927

Genus *Fohsella* Bandy, 1972

Type species: *Globorotalia (Fohsella) praefohsi* Blow and Banner, 1966

Fohsella peripheroacuta (Blow and Banner, 1966)
Fig. 16.3

Globorotalia (Turborotalia) peripheroacuta Blow and Banner, 1966, p. 294, pl. 1, figs. 2a–c.

Globorotalia (Fohsella) peripheroacuta Blow and Banner. Kennett and Srinivasan, 1983, p. 96, pl. 22, figs. 4–6.

Globorotalia fohsi peripheroacuta Blow and Banner. Bolli and Saunders, 1985, p. 213, figs. 29.5a–c, 29.13a–c.

Fohsella peripheroacuta (Blow and Banner). Pearson and Chaisson, 1997, p. 58.

Stratigraphic range. U1338C-35H-5, 90–92 cm → U1338B-36H-2, 40–42 cm.

Remarks. This species differs from *F. "praefohsi"* in being noncarinate, and from its ancestor *F. peripheroronda* by having a more angular peripheral margin.

Fohsella peripheroronda (Blow and Banner, 1966)
Fig. 15.6

Globorotalia (Turborotalia) peripheroronda Blow and Banner, 1966, p. 294, pl. 1, figs. 1a–c.

Globorotalia (Fohsella) peripheroronda Blow and Banner. Kennett and Srinivasan, 1983, p. 96, pl. 22, figs. 1–3.

Fohsella peripheroronda (Blow and Banner). Pearson and Chaisson, 1997, p. 58.

Stratigraphic range. U1338A-36X-1, 36–38 cm → U1338A-43X-CC.

Remarks. This species is found intermittently throughout its range and has low abundance in the few samples where it is observed. Specimens tend to have poorly incised sutures and 5–6 chambers in the final whorl. *Fohsella peripheror-*

onda has a round to subround peripheral margin compared with the keeled edge of *F. peripheroacuta*.

Genus *Globorotalia* Cushman and Stainforth, 1945
Type species *Pulvinulina menardii* var. *tumida* Brady, 1877

Globorotalia praemenardii Cushman and Stainforth, 1945
Figs. 16.1, 16.2, 16.4–16.6, 18.

Globorotalia praemenardii Cushman and Stainforth, 1945, p. 70, pl. 13, figs. 14a–c; Bolli and Saunders, 1985, p. 220, figs. 32.7a–c; Chaisson and Leckie, 1993, p. 162, pl. 5, figs. 12–14.

Globorotalia (Menardella) praemenardii Cushman and Stainforth. Kennett and Srinivasan, 1983, p. 122, pl. 28, figs. 6–8.

Stratigraphic range. U1336A-11H-5, 65–67 cm → U1338C-35H-5, 90–92 cm.

Remarks. *Globorotalia praemenardii* was common in the uppermost samples from our section. The species is distinguished from its ancestor, *G. archeomenardii*, by being larger and possessing a peripheral keel, and from its descendent, *G. menardii*, by being smaller, more lobate, having a thinner keel, and having only five chambers in the final whorl. The wall structure is illustrated in detail on Figure 18.

Superfamily CANDEINACEA Cushman, 1927
Family GLOBIGERINITIDAE Bermudez, 1961
Genus *Globigerinatella* Cushman and Stainforth, 1945
Type species: *Globigerinatella insueta* Cushman and Stainforth, 1945

Globigerinatella insueta Cushman and Stainforth, 1945
Figs. 10.1, 10.2

Globigerinatella insueta Cushman and Stainforth, 1945, p. 69, pl. 13, figs. 7–9; Kennett and Srinivasan, 1983, p. 228, pl. 56, fig. 2, pl. 57, figs. 4, 5.

Stratigraphic range. U1338A-38X-CC → U1338A-43X-CC.

Remarks. *Globigerinatella insueta* is found intermittently in samples from Site U1338. It differs from its ancestor *Globigerinatella* sp. in possessing numerous areal apertures bordered by a thick lip on one side of the large embracing final chamber (Pearson, 1995). This species is very similar in shape to *Praeorbulina* but is distinguished by its micro-perforate wall texture, largely covered by small crystallites.

Genus *Globigerinita* Brönnimann, 1951
Type species: *Globigerinita naparimaensis* Brönnimann, 1951

Globigerinita glutinata (Egger, 1893)
Figs. 10.5–10.7

Globigerina glutinata Egger, 1893, p. 371, pl. 13, figs. 19–21.

Globigerinita glutinata (Egger). Kennett and Srinivasan, 1983, p. 224, pl. 56, figs. 1, 3–5.

Stratigraphic range. U1338A-1H-CC → U1338A-42X-2, 31–33 cm.

Remarks. This species was rare in most samples and many specimens lack bullae.

Globigerinita uvula (Ehrenberg, 1861)
Figs. 10.3, 10.4

Pyrodexia uvula Ehrenberg, 1861, p. 276, pl. 2, figs. 24, 25.

Globigerinita uvula (Ehrenberg). Kennett and Srinivasan, 1983, p. 224, pl. 56, figs. 6–8.

Stratigraphic range. U1338A-24H-2, 50–52 cm → U1338A-44X-3, 102–104 cm.

Remarks. *Globigerinita uvula* is rarely seen in Holes U1338B and C; only two specimens were found in samples from Hole U1338A. This species is characterized by its microperforate wall texture and high trochospire; the primary aperture is bordered by a thin lip.

Genus *Tenuitella* Fleisher, 1974

Type species: *Globorotalia gemma* (Jenkins, 1966)

Tenuitella munda (Jenkins, 1966)

Fig. 14.2

Globorotalia munda Jenkins, 1966, p. 1121, fig. 14, nos. 126–133, pl. 13, nos. 152–156.

Globorotalia (*Tenuitella*) *munda* Jenkins. Kennett and Srinivasan, 1983, p. 162, pl. 39, figs. 5–7.

Tenuitella munda (Jenkins). Li, 1987, p. 310, pl. 2, fig. 13.

Stratigraphic range. U1338A-42X-4, 114–116 cm → U1338A-44X-CC.

Remarks. *Tenuitella munda* was very rare and present in only two samples. This microperforate species is described in Kennett and Srinivasan (1983) as having subspherical chambers, but the specimens observed in our samples have moderately lobate ones. The wall texture is typically smooth, although pustules (Fig. 14.2) surround the umbilical-extraumbilical aperture, which is bordered by a very thin lip.

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