

## **Pleistocene to Upper Miocene collodarians and spumellarians (polycystine radiolarians) from the western Indian Ocean, ODP Site 710**

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### **Abstract**

The purpose of this study is to present microphotographs of the encountered taxa of collodarians/spumellarians (polycystine radiolarians) from the Pleistocene to upper Miocene at ODP Site 710 in the western Indian Ocean to analyze the species diversity of radiolarians. Totally 96 species or species groups of collodarians/spumellarians were identified from Site 710 in the western Indian Ocean. These taxa include 13 unidentified forms, particularly within the families Collosphaeridae, Haliommidae, and Zonariidae. Some of these taxa might be new species. Micro-photographs have been illustrated in the 13 plates.

### **Introduction**

The Indian Ocean has a unique geometry, and some of the water masses and circulation patterns are distinctly different from those in the Atlantic and the Pacific (Backman et al., 1988). Cenozoic sediments were recovered at 12 sites from the tropical Indian Ocean during Ocean Drilling Program (ODP) Leg 115. A major goal of ODP Leg 115 was to develop paleoceanographic records which reflect temporal changes from the surface to deep-water environment. Site 710 was located in the western tropical Indian Ocean, and contained the first good magnetostratigraphic record to be obtained during Leg 115. This site contained common radiolarian assemblages, which is one of siliceous microfossils, within the Pleistocene to upper Miocene interval. Johnson (1990) studied biostratigraphic distribution of selected radiolarians at ODP Site 710 in the western Indian Ocean. However, species component of radiolarian assemblages since the upper Miocene are still unknown. The purpose of this study is to present microphotographs of the encountered taxa of collodarians and spumellarians (polycystine radiolarians) from the Pleistocene to upper Miocene at Site 710 in order to analyze the species diversity of radiolarians.

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## Materials and Methods

Site 710 lies on the central Madingley Rise, a regional topographic high between the Carlsberg Ridge and the northern Mascarene Plateau (4°18.7'S and 60°58.8'E, at a water depth of 3812 m) (Backman et al., 1988). The lithology from the Pleistocene to upper Miocene is characterized by nannofossil ooze with well-preserved radiolarians (Johnson, 1990). A total of 112 sediment samples from 710A-1H-1, 20-22 cm to 9H-3, 50-52 cm (0.20 to 80.10 meters below seafloor; 0.02 to 9.81 Ma) were examined in this study. Sample preparation for microscopic examination of radiolarian taxa were prepared following the methods described in Kamikuri and Motoyama (2020). Sediment samples were treated with H<sub>2</sub>O<sub>2</sub> and HCl solution. The residues were sieved with 45 µm. An optical microscope was used for observation and photomicrographic work. Genus identification followed the nomenclature of O'Dogherty et al. (2021) and Suzuki et al. (2021).

## Radiolarian fauna

A total 96 morphotypes of collodarians/spumellarians (polycystine radiolarians) including 27 collodarians and 70 spumellarians were encountered at Site 710 in the western Indian Ocean (plates 1 to 13). These taxa include 13 unidentified forms (5 collodarians and 8 spumellarians). Some of these forms will be described as new species in the near future.

## Explanation of plates

### Plate 1

**1a-3. *Collosphaera huxleyi* Müller:** 1a, 1b. 710A-7H-1, 20-22 cm, O34/0; 2a, 2b. 710A-7H-1, 20-22 cm, N33/4; 3. 710A-7H-1, 20-22 cm, V33/1. **4a-5b. *Collosphaera* aff. *huxleyi* Müller:** 4a, 4b. 710A-7H-1, 20-22 cm, N25/0; 5a, 5b. 710A-7H-1, 20-22 cm, O34/2. **6a, 6b. *Collosphaera macropora* Popofsky:** 710A-7H-1, 20-22 cm, P17/1. **7a-8b. *Collosphaera* cf. *macropora* Popofsky:** 7a, 7b. 710A-7H-1, 20-22 cm, E31/4; 8a, 8b. 710A-7H-1, 20-22 cm, E31/3. **9a, 9b. *Collosphaera* ? *reynoldsi* Kamikuri:** 710A-9H-1, 120-122 cm, X20/1. **10a-11b. *Collosphaera uniformis* Haswell and Hedlesy:** 10a, 10b. 710A-7H-1, 20-22 cm, R34/3; 11a, 11b. 710A-1H-5, 20-22 cm, T28/4. **12-20. *Collosphaera planca* Su group:** 12. 710A-9H-2, 70-72 cm, H29/0; 13. 710A-9H-2, 70-72 cm, S18/1; 14. 7H-1, 20-22 cm, E29/2; 15. 710A-7H-3, 20-22 cm, V23/3; 16. 710A-7H-3, 20-22 cm, T24/0; 17. 710A-7H-3, 20-22 cm, D17/3; 18. 710A-7H-3, 20-22 cm, H22/3; 19. 710A-9H-2, 70-72 cm, L23/0; 20. 710A-9H-1, 20-22 cm, Q30/0. **21a, 21b. *Collosphaera tuberosa* Haeckel:** 710A-1H-1, 100-102 cm, D30/0. **22-23b. *Choenicosphaera hirsuta* (Ehrenberg):** 22. 710A-1H-5, 20-22 cm, U31/0; 23a, 23b. 710A-1H-5, 20-22 cm, Q13/3.

### Plate 2

**1a-3b. *Disolenia micractis* (Ehrenberg):** 1a, 1b. 710A-1H-1, 100-102 cm, K12/3; 2a, 2b. 710A-1H-1, 20-22 cm, C23/0; 3a, 3b. 710A-1H-1, 20-22 cm, U27/2. **4a-6b. *Disolenia zanguibarica* (Ehrenberg) group:** 4a, 4b.

710A-1H-1, 20-22 cm, U28/1; 5a, 5b. 710A-1H-3, 20-22 cm, B23/0; 6a, 6b. 710A-1H-3, 20-22 cm, Q32/0. **7a-8b. *Odontosphaera monodon* Haeckel:** 7a, 7b. 710A-7H-1, 20-22 cm, O34/4; 8a, 8b. 710A-7H-1, 20-22 cm, S35/0. **9a, 9b. *Odontosphaera cyrtodon* Haeckel:** 710A-1H-4, 20-22 cm, U26/1. **10a-11b. *Otosphaera polymorpha* Haeckel:** 10a, 10b. 710A-9H-1, 120-122 cm, D24/0; 11a, 11b. 710A-9H-1, 120-122 cm, H28/4.

## Plate 3

**1a-2b. *Otosphaera* sp. A:** 1a, 1b. 710A-9H-1, 120-122 cm, J31/2; 2a, 2b. 710A-7H-1, 20-22 cm, J34/1. **3a, 3b. *Otosphaera* sp. B:** 710A-7H-1, 20-22 cm, F20/0. **4a-5b. *Otosphaera inflata* (Haeckel):** 4a, 4b. 710A-7H-1, 20-22 cm, E31/2; 5a, 5b. 710A-7H-1, 20-22 cm, F20/0. **6a-7b. *Polysolenia spinosa* (Haeckel):** 6a, 6b. 710A-1H-5, 20-22 cm, R27/4; 7a, 7b. 710A-1H-5, 20-22 cm, N28/4. **8a-9b. *Polysolenia pseudoarktioides* (Caulet):** 8a, 8b. 710A-1H-4, 20-22 cm, H14/0; 9a, 9b. 710A-1H-5, 20-22 cm, V27/0. **10a, 10b. *Siphonosphaera* sp. B:** 710A-9H-1, 120-122 cm, O20/1. **11a, 11b. *Collosphaera cf. tuberosa* Haeckel:** 710A-1H-1, 20-22 cm, U32/2. **12a, 12b. *Collosphaera armata* Brandt:** 710A-7H-1, 20-22 cm, F20/4. **13. *Collosphaera* sp.:** 710A-7H-1, 20-22 cm, G17/4.

## Plate 4

**1a-3b. *Siphonosphaera brachysiphonia* Dumitrica:** 1a, 1b. 710A-7H-1, 20-22 cm, F20/1; 2a, 2b. 710A-1H-1, 100-102 cm, J29/4; 3a, 3b. 710A-7H-1, 20-22 cm, Q26/1. **4a-8b. *Siphonosphaera abyssi* (Ehrenberg):** 4a, 4b. 710A-1H-4, 20-22 cm, N28/0; 5. 710A-1H-4, 20-22 cm, G28/0; 6a, 6b. 710A-1H-4, 20-22 cm, J27/4; 7a, 7b. 710A-1H-5, 20-22 cm, R24/2; 8a, 8b. 710A-1H-5, 20-22 cm, M27/0. **9a, 9b. *Siphonosphaera* sp. A:** 710A-7H-1, 20-22 cm, O23/1. **10a-11b. *Siphonosphaera omnitubus* (Riedel and Sanfilippo):** 10a, 10b. 710A-7H-1, 20-22 cm, O34/0; 11a, 11b. 710A-7H-1, 20-22 cm, S35/2. **12a, 12b. *Disolenia* sp. A:** 710A-1H-4, 20-22 cm, U17/1. **13a, 13b. *Tribonosphaera invaginata* (Haeckel):** 710A-1H-1, 20-22 cm, G34/4.

## Plate 5

**1a, 1b. *Rhizosphaera trigonacantha* (Haeckel):** 710A-1H-4, 20-22 cm, N11/1. **2a, 2b. *Hexacromyum arachnoidale* (Hollande and Enjumet):** 710A-1H-4, 20-22 cm, R21/0. **3a, 3b. *Hexacromyum hexacanthum* (Müller):** 710A-1H-4, 20-22 cm, J12/1. **4a, 4b. *Hexacromyum* sp. A:** 710A-1H-4, 20-22 cm, G11/4. **5a, 5b. *Hexacromyum anaximandri* (Haeckel):** 710A-1H-4, 20-22 cm, N11/2. **6a, 6b. *Cromyosphaera livae* (Goll and Bjørklund):** 710A-2H-4, 20-22 cm, V22/0. **7a, 7b. *Hexacromyum pachydermum* (Jørgensen):** 710A-1H-5, 20-22 cm, V24/0. **8a, 8b. *Actinomma langii* (Dreyer):** 710A-1H-4, 20-22 cm, S28/0. **9a, 9b. *Actinomma robusta* (Kling):** 710A-9H-1, 120-122 cm, F32/2. **10a, 10b. *Hexacromyum* sp. B:** 710A-7H-1, 20-22 cm, E19/0. **11a, 11b. *Haliometta* aff. *miocenica* (Campbell and Clark):** 710A-1H-4, 20-22 cm, R19/2.

## Plate 6

**1a-2b. *Axoprunum ? angelinum* (Campbell and Clark):** 1a, 1b. 710A-3H-1, 100-102 cm, W23/0; 2a, 2b. 710A-1H-5, 20-22 cm, Q26/1. **3a, 3b. *Stylatractona neptunus* (Haeckel):** 710A-1H-4, 20-22 cm, G29/2. **4a-6b. *Stylatractona santaennae* (Campbell and Clark):** 4a, 4b. 710A-7H-1, 20-22 cm, F19/3; 5a, 5b. 710A-

1H-4, 20-22 cm, O25/2; 6a, 6b. 710A-1H-4, 20-22 cm, J25/4. **7a, 7b. *Axoprunum bispiculum* (Popofsky):** 710A-1H-2, 20-22 cm, J13/2. **8a, 8b. *Axoprunum* sp. A:** 710A-1H-4, 20-22 cm, D13/2. **9a, 9b. *Stylosphaera timmsi* (Campbell and Clark):** 710A-9H-1, 120-122 cm, R24/0. **10. *Stylosphaera irregularis* (Popofsky):** 710A-1H-4, 20-22 cm, D24/1.

## Plate 7

**1a-2b. *Ethmosphaera setosa* (Ehrenberg):** 1a, 1b. 710A-1H-4, 20-22 cm, F24/2; 2a, 2b. 710A-1H-4, 20-22 cm, M25/2. **3a, 3b. *Haliomma* ? sp. A:** 710A-1H-5, 20-22 cm, T14/3. **4a-5b. *Ethmosphaera riedeli* (Blueford):** 4a, 4b. 710A-1H-5, 20-22 cm, U28/4; 5a, 5b. 710A-2H-4, 20-22 cm, F27/4. **6a-8b. *Haliomma* sp. B:** 6a, 6b. 710A-1H-5, 20-22 cm, T28/3; 7a, 7b. 710A-1H-5, 20-22 cm, R25/4; 8a, 8b. 710A-1H-4, 20-22 cm, Q27/0. **9. *Heliodiscus asteriscus* Haeckel:** 710A-2H-4, 20-22 cm, V15/0. **10. *Heliodiscus echiniscus* Haeckel:** 710A-1H-4, 20-22 cm, E26/2. **11. *Circodiscus microporus* (Stöhr):** 710A-1H-5, 20-22 cm, K29/4.

## Plate 8

**1-3. *Trigonastrum ypsilon* (Haeckel):** 1. 710A-2H-4, 20-22 cm, O30/3; 2. 710A-3H-2, 20-22 cm, Y26/3; 3. 710A-1H-4, 20-22 cm, O21/0. **4, 5. *Trigonastrum perforatum* (Popofsky):** 4. 710B-4H-1, 40-42 cm, Q12/4; 5. 710B-4H-4, 20-22 cm, N15/2. **6, 7. *Dictyocoryne muelleri* (Haeckel) group:** 6. 710A-1H-5, 20-22 cm, P28/0; 7. 710A-1H-5, 20-22 cm, G12/2. **8-10. *Dictyocoryne furcata* (Ehrenberg):** 8. 710A-9H-1, 120-122 cm, M30/0; 9. 710A-1H-5, 20-22 cm, Q10/2; 10. 710A-1H-5, 20-22 cm, K12/0. **11. *Dictyocoryne* sp. A:** 710A-7H-1, 20-22 cm, M21/0. **12. *Ommatogramma cylindrica* (Haeckel):** 710A-9H-1, 120-122 cm, V21/1.

## Plate 9

**1, 2. *Trigonastrum trispinosum* (Haeckel):** 1. 710A-1H-4, 20-22 cm, N19/2; 2. 710A-1H-4, 20-22 cm, J20/4. **3, 6, 8, 9. *Dictyocoryne muelleri* (Haeckel) group:** 3. 710A-2H-4, 20-22 cm, D20/4; 6. 710A-2H-4, 20-22 cm, D30/0; 8. 710A-7H-1, 20-22 cm, P36/3; 9. 710A-9H-1, 120-122 cm, U19/1. **4. *Trigonastrum cf. trispinosum* (Haeckel):** 710A-1H-5, 20-22 cm, P28/0. **5. *Dictyocoryne profunda* Ehrenberg:** 710A-2H-4, 20-22 cm, G26/2. **7. *Dictyocoryne strelkovi* Kruglikova:** 710A-7H-1, 20-22 cm, E18/0.

## Plate 10

**1, 2, 4. *Spiremaria* aff. *decens* Kozlova:** 1. 710A-7H-1, 20-22 cm, G15/0; 2. 710A-7H-1, 20-22 cm, U35/2; 4. 710A-9H-1, 120-122 cm, O22/4. **3. *Spiremaria* cf. *elliptica* (Ehrenberg):** 710A-9H-1, 120-122 cm, P30/0. **5, 6. *Middourium polyacantha* (Campbell and Clark):** 5. 710A-7H-1, 20-22 cm, N16/0; 6. 710A-7H-1, 20-22 cm, S34/3. **7-10. *Sphaerolarnacillium exactum* Zhang and Suzuki:** 7. 710A-1H-4, 20-22 cm, G12/3; 8. 710A-1H-4, 20-22 cm, C11/3; 9. 710A-1H-4, 20-22 cm, L15/0; 10. 710A-1H-5, 20-22 cm, O11/0. **11. *Spiremaria elliptica* (Ehrenberg):** 710A-1H-4, 20-22 cm, F25/2. **12, 13. *Lithelius haeckelispiralis* Matsuzaki and Suzuki:** 12. 710A-1H-4, 20-22 cm, N20/0; 13. 710A-1H-4, 20-22 cm, F26/1. **14, 15. *Middourium weddelium* (Lazarus, Faust and Popova-Goll):** 14. 710A-9H-1, 120-122 cm, S22/2; 15. 710A-1H-4, 20-22 cm, M17/4. **16, 17. *Tholospira buetschlii buetschlii* (Dreyer):** 16. 710A-1H-4, 20-22

cm, H21/3; 17. 710A-1H-4, 20-22 cm, N20/0. **18. *Lithelius klingi* Kamikuri:** 710A-3H-2, 20-22 cm, X30/1. **19. *Spongaster tetras tetras* Ehrenberg:** 710A-2H-4, 20-22 cm, G29/3. **20. *Spongaster tetras irregularis* Nigrini:** 710A-1H-5, 20-22 cm, N15/1. **21. *Spongasteriscus pentas* (Riedel and Sanfilippo):** 710B-4H-5, 90-92 cm, Q30/0. **22. *Spongasteriscus berminghami* Campbell and Clark:** 710B-5H-5, 20-22 cm, T28/1.

## Plate 11

**1-4. *Flustrella ornata* (Campbell and Clark):** 1. 710A-2H-4, 20-22 cm, R17/4; 2. 710A-2H-4, 20-22 cm, V15/2; 3. 710A-7H-1, 20-22 cm, Q36/1; 4. 710A-2H-4, 20-22 cm, S18/2. **5-8. *Flustrella orbiculatus* (Haeckel):** 5. 710A-1H-4, 20-22 cm, G18/4; 6. 710A-7H-1, 20-22 cm, P29/0; 7. 710A-7H-1, 20-22 cm, U29/3; 8. 710A-1H-5, 20-22 cm, G31/0. **9. *Stylodictya polygonia* Popofsky:** 710A-1H-4, 20-22 cm, G28/3. **10. *Flustrella* sp.A:** 710A-1H-4, 20-22 cm, O22/0. **11. *Flustrella praetexta* Ehrenberg:** 710A-1H-4, 20-22 cm, M17/0. **12. *Stylodictya stella* Bailey:** 710A-1H-4, 20-22 cm, J22/1. **13, 14. *Spongobrachiopyle* sp. A:** 13. 710A-1H-4, 20-22 cm, H21/1; 14. 710A-1H-4, 20-22 cm, H20/2. **15-17. *Spongodiscus resurgens* Ehrenberg:** 15. 710A-1H-4, 20-22 cm, K21/4; 16. 710A-1H-4, 20-22 cm, V17/0; 17. 710A-1H-4, 20-22 cm, L18/1. **18, 19. *Spongobrachiopyle osculosa* (Dreyer):** 18. 710A-2H-4, 20-22 cm, C27/4; 19. 710A-1H-4, 20-22 cm, N20/0. **20. *Spongobrachiopyle dreyerii* (Carnevale):** 710A-9H-1, 120-122 cm, M30/0. **21, 22. *Excentrococcus* aff. *annulatus* Dumitrica:** 21. 710A-9H-1, 120-122 cm, K32/4; 22. 710A-9H-1, 120-122 cm, H19/1.

## Plate 12

**1. *Circodiscus microporus* (Stöhr):** 710A-1H-5, 20-22 cm, V31/2. **2a, 2b. *Tetrapyle scutatatum* (Chen and Tan):** 710A-1H-5, 20-22 cm, T24/4. **3, 9-28. *Phorticium/Tetrapyle* group:** 3. 710A-1H-5, 20-22 cm, R17/3; 9. 710A-1H-5, 20-22 cm, U16/0; 10. 710A-1H-5, 20-22 cm, F18/1; 11. 710A-1H-5, 20-22 cm, N23/1; 12. 710A-1H-5, 20-22 cm, G22/2; 13. 710A-1H-5, 20-22 cm, U29/0; 14. 710A-1H-5, 20-22 cm, N28/4; 15. 710A-1H-4, 20-22 cm, L23/3; 16. 710A-1H-4, 20-22 cm, R15/1; 17. 710A-1H-5, 20-22 cm, S28/0; 18. 710A-1H-5, 20-22 cm, L32/0; 19. 710A-9H-1, 120-122 cm, T24/1; 20. 710A-9H-1, 120-122 cm, M53/0; 21. 710A-1H-5, 20-22 cm, J31/1; 22. 710A-1H-5, 20-22 cm, E32/3; 23. 710A-1H-5, 20-22 cm, M25/0; 24. 710A-1H-5, 20-22 cm, E32/0; 25. 710A-9H-1, 120-122 cm, D18/1; 26. 710A-9H-1, 120-122 cm, B18/4; 27. 710A-9H-1, 120-122 cm, Q22/2; 28. 710A-9H-1, 120-122 cm, P18/0. **4. *Larcospira quadrangula* Haeckel:** 710A-1H-5, 20-22 cm, T31/0. **5. *Larcospira moschkovskii* Kruglikova:** 710B-7H-4, 70-72 cm, O13/0. **6. *Tholomura hexonium* (Haeckel):** 710A-2H-4, 20-22 cm, Q32/0. **7a-8b. *Tholospira mole* (Zhang and Suzuki):** 7a, 7b. 710A-1H-5, 20-22 cm, P28/3; 8a, 8b. 710A-1H-5, 20-22 cm, F24/0.

## Plate 13

**1. *Didymocyrtis tetrathalamus* (Haeckel):** 710A-1H-5, 20-22 cm, O27/3. **2, 3. *Didymocyrtis avita* (Riedel):** 2. 710B-5H-1, 20-22 cm, O17/2; 3. 710B-6H-6, 100-102 cm, O12/2. **4. *Didymocyrtis penultima* (Riedel):** 710B-4H-7, 20-22 cm, K23/0. **5. *Didymocyrtis antepenultima* (Riedel and Sanfilippo):** 710A-7H-5, 70-72 cm, L29/0. **6. *Cannartus laticonus* Riedel:** 710A-9H-2, 20-22 cm, S31/0. **7, 8. *Diartus hughesi* (Campbell and Clark):** 7. 710A-7H-6, 20-22 cm, N21/3; 8. 710A-9H-2, 20-22 cm, O28/0. **9, 10. *Diartus petterssoni***

**(Riedel and Sanfilippo):** 9. 710A-9H-1, 120-122 cm, U18/0; 10. 710A-9H-1, 120-122 cm, V21/2. **11-14. *Cannartus noritoshii* (Matsuzaki):** 11. 710A-8H-CC, H16/4; 12. 710A-8H-CC, V27/2; 13. 710A-8H-CC, P25/2; 14. 710A-9H-1, 20-22 cm, O31/0.

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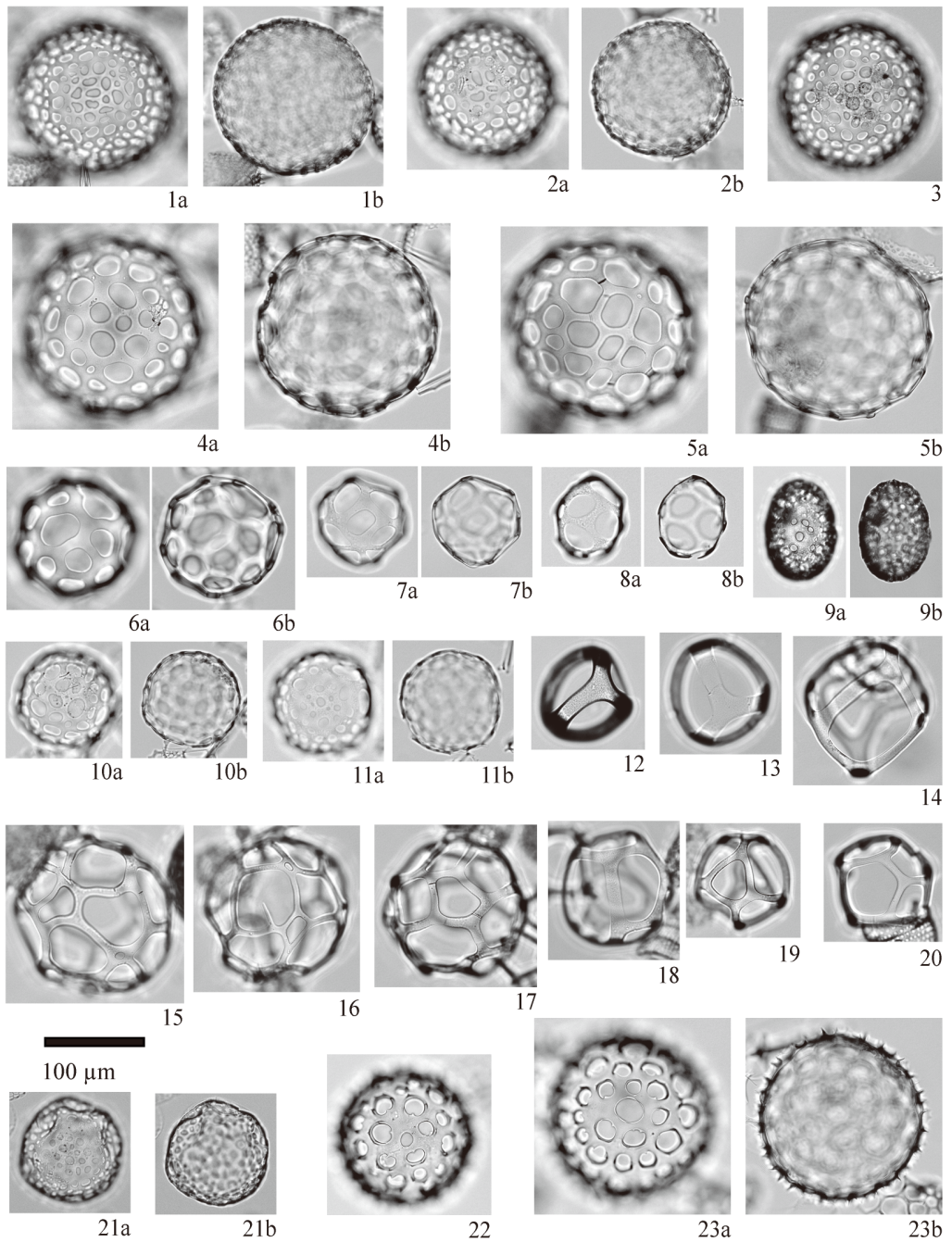


Plate 1. Illustrations of the encountered collodarians

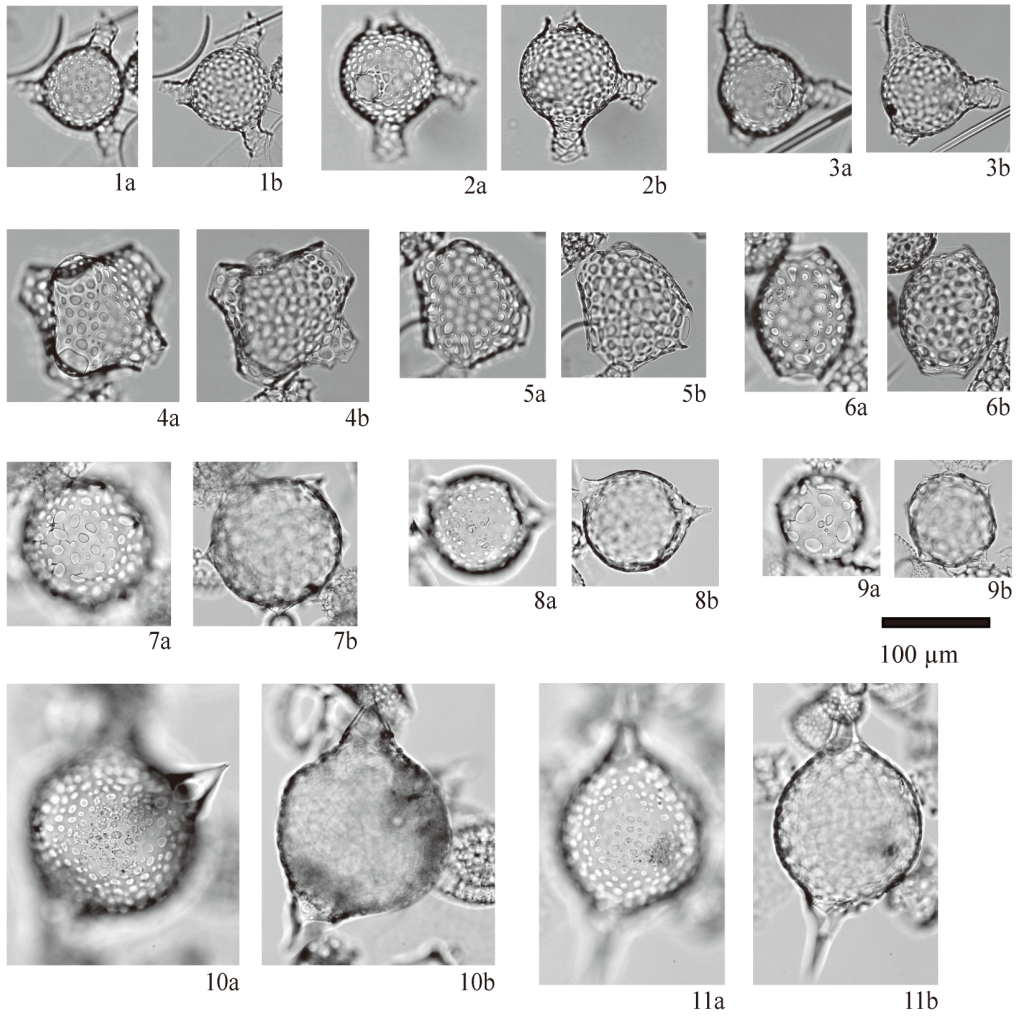


Plate 2. Illustrations of the encountered collodarians



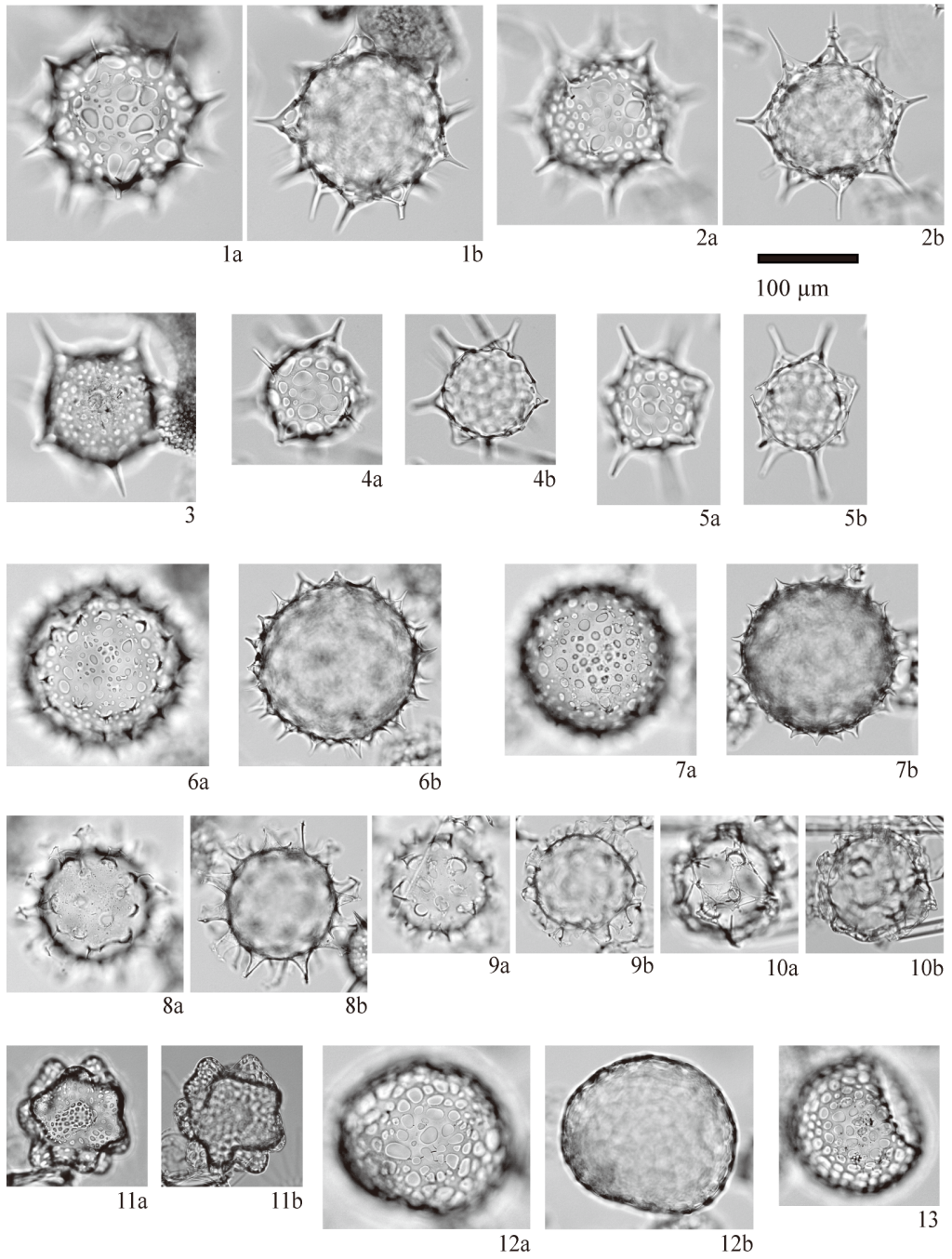


Plate 3. Illustrations of the encountered collodarians

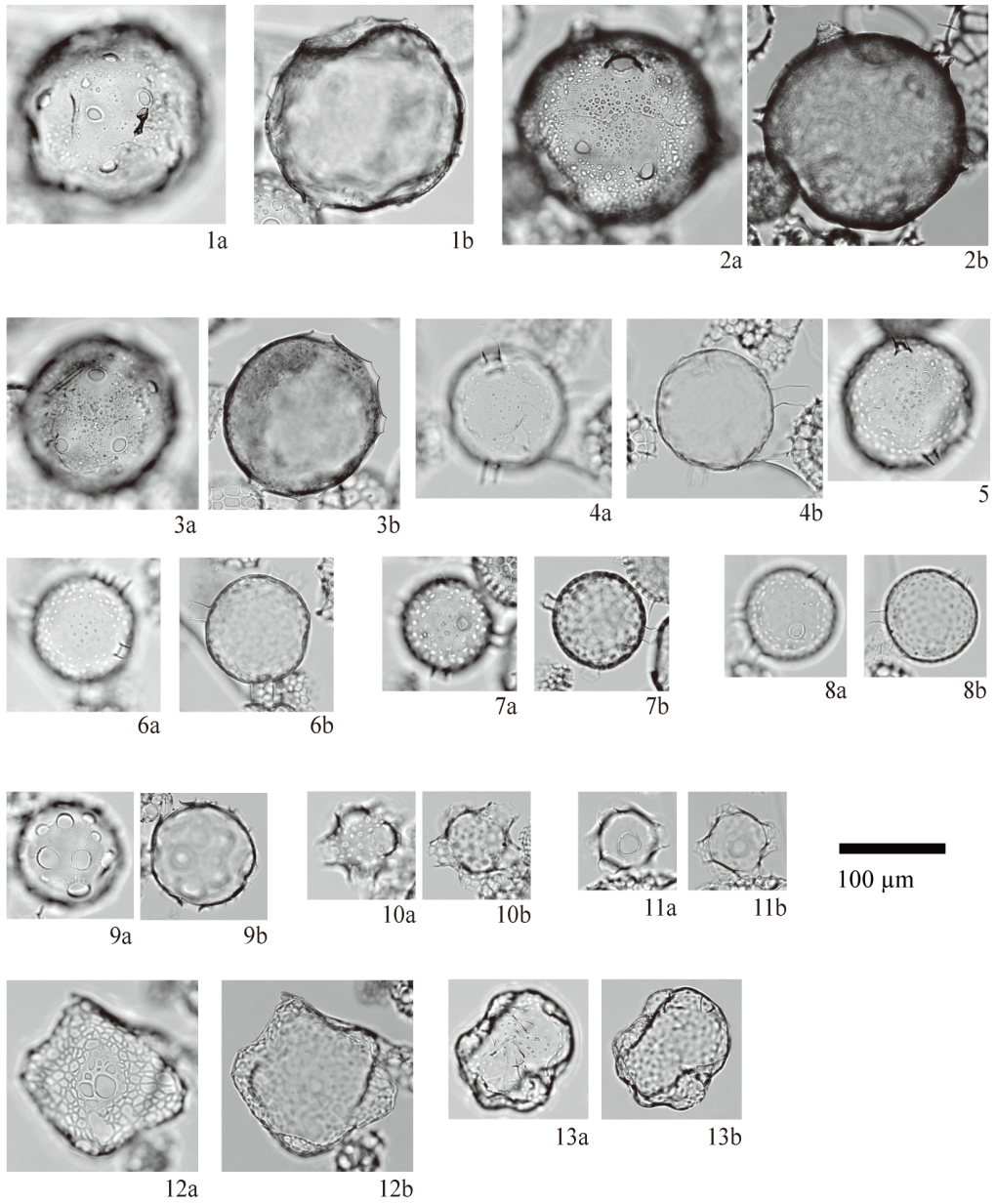


Plate 4. Illustrations of the encountered collodarians

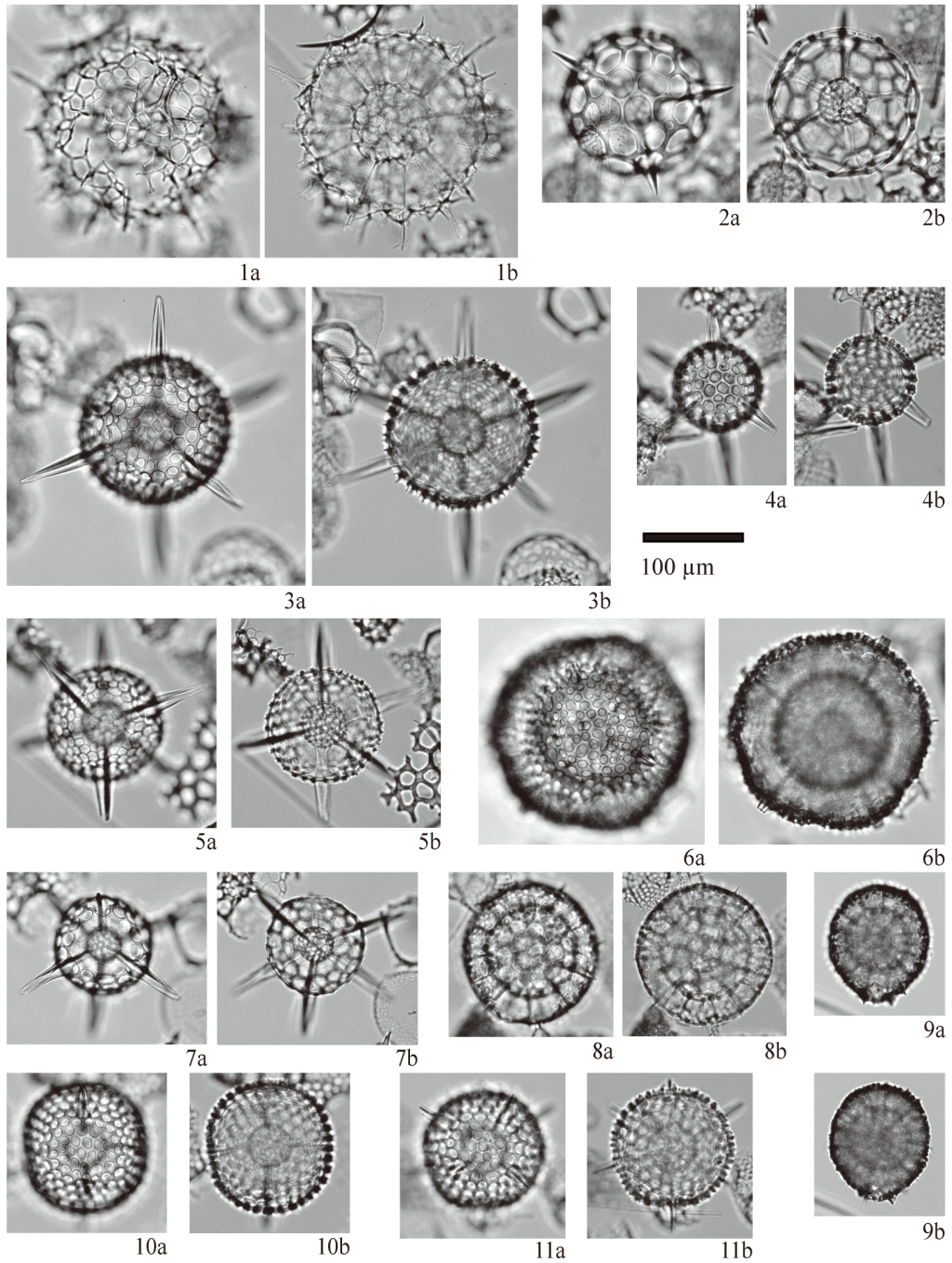


Plate 5. Illustrations of the encountered spumellarians

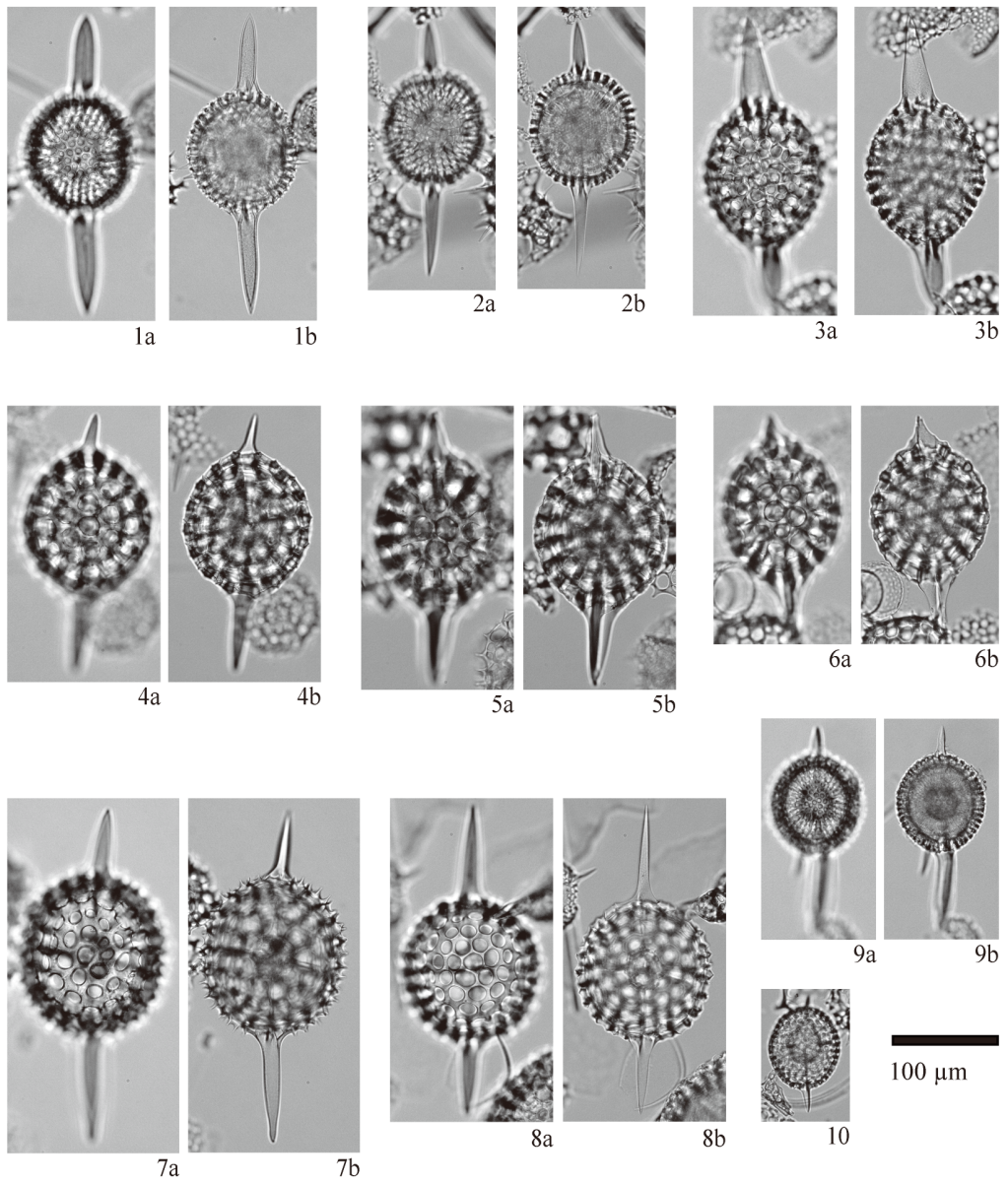


Plate 6. Illustrations of the encountered spumellarians

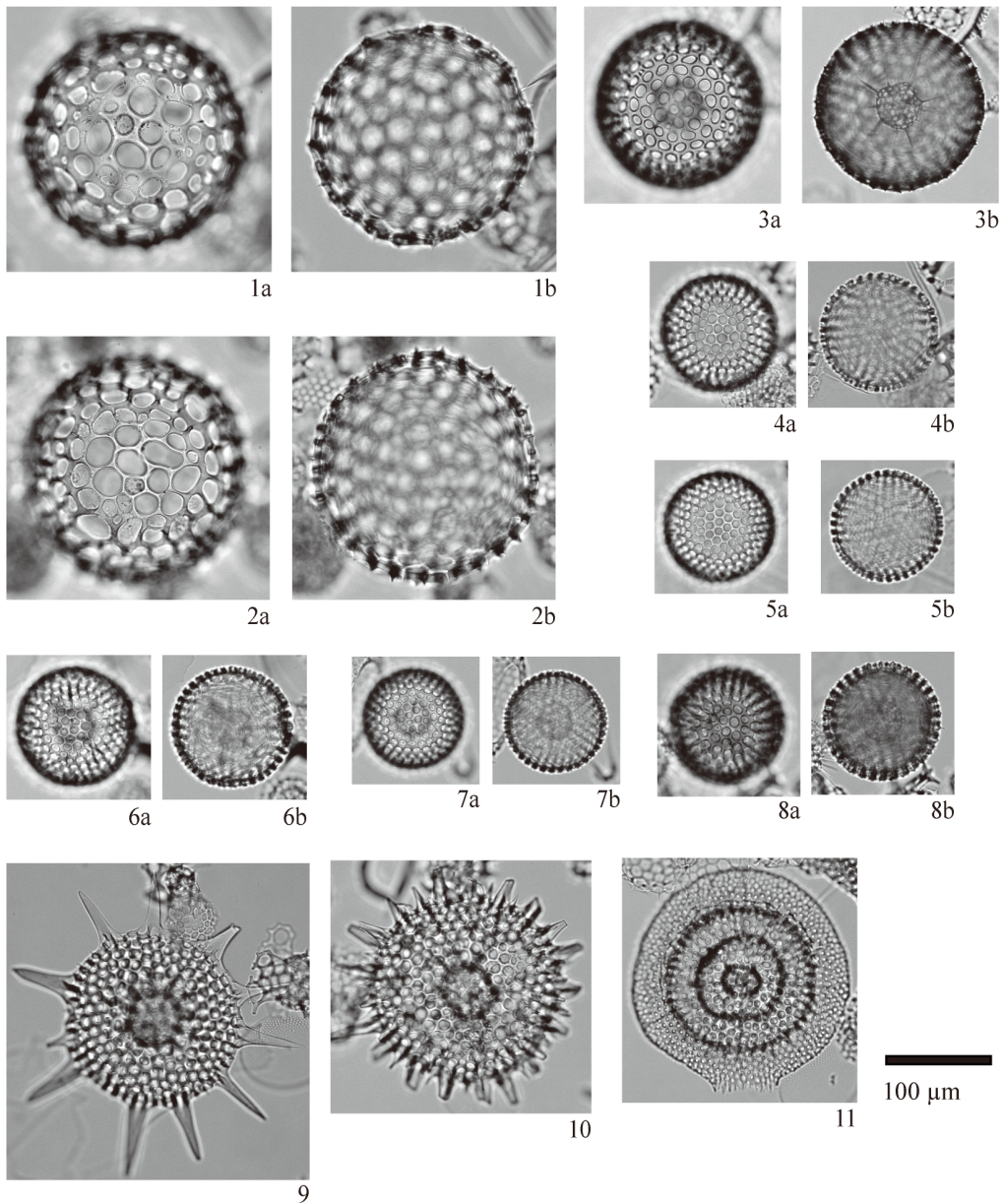


Plate 7. Illustrations of the encountered spumellarians

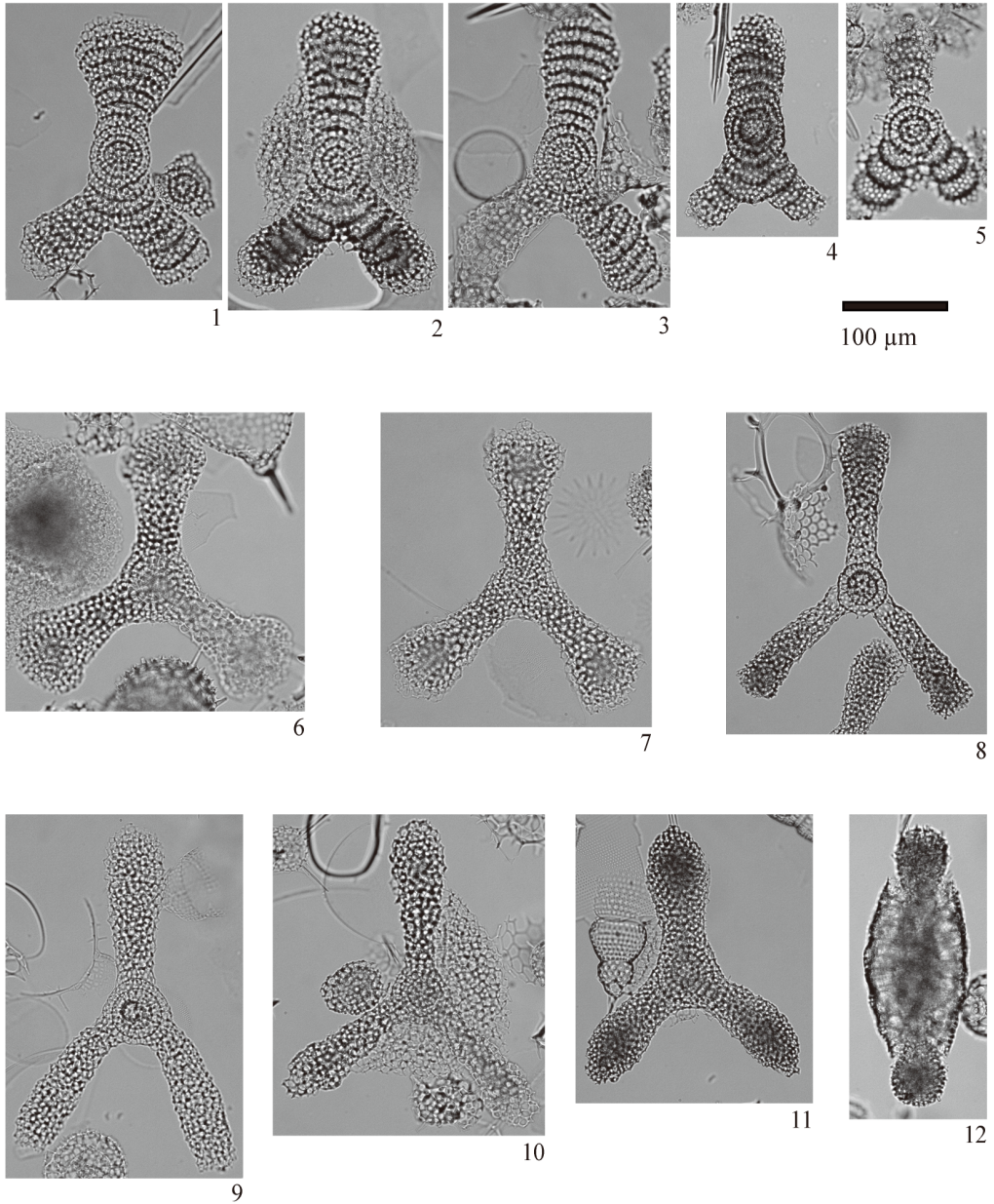


Plate 8. Illustrations of the encountered spumellarians

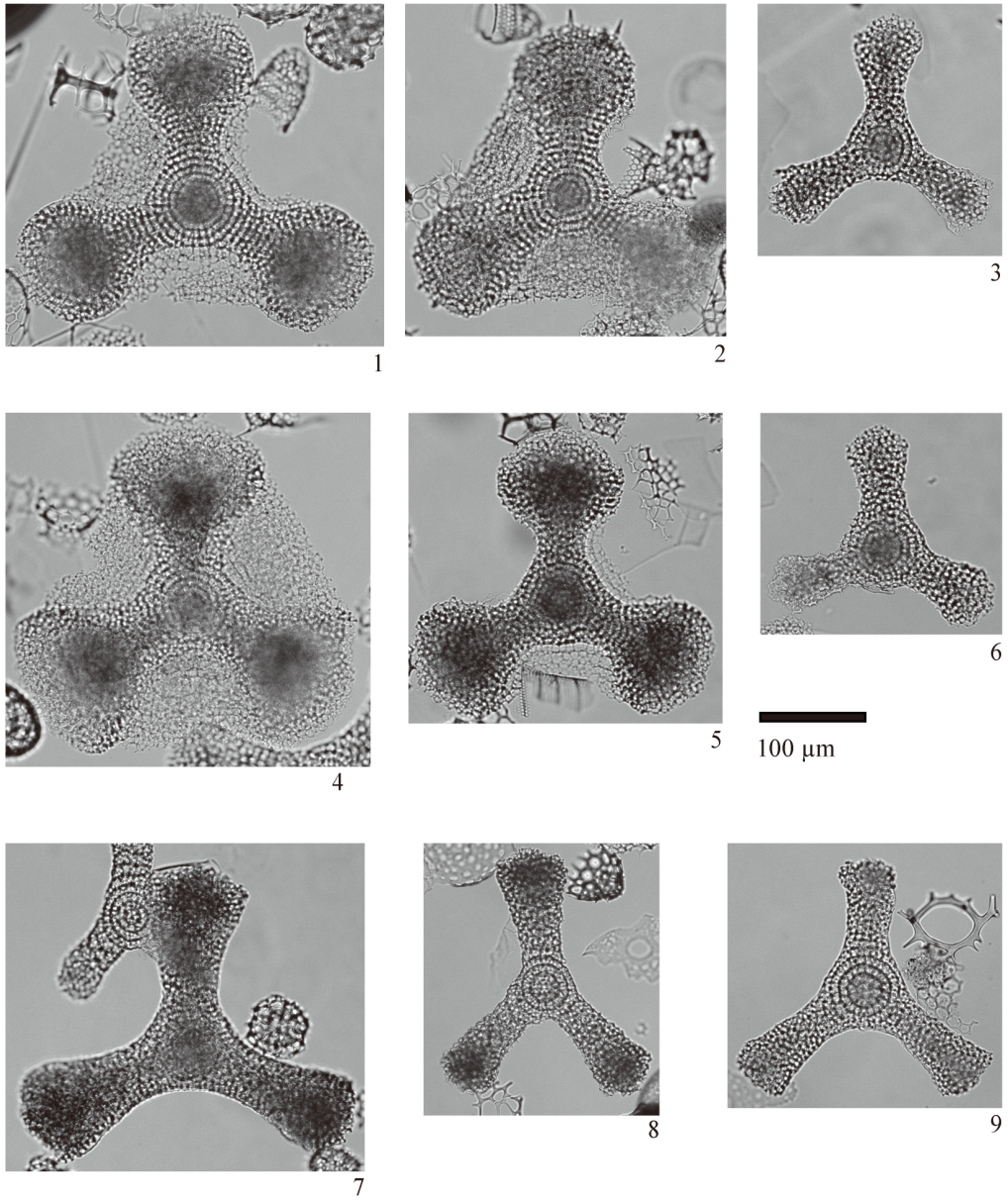


Plate 9. Illustrations of the encountered spumellarians

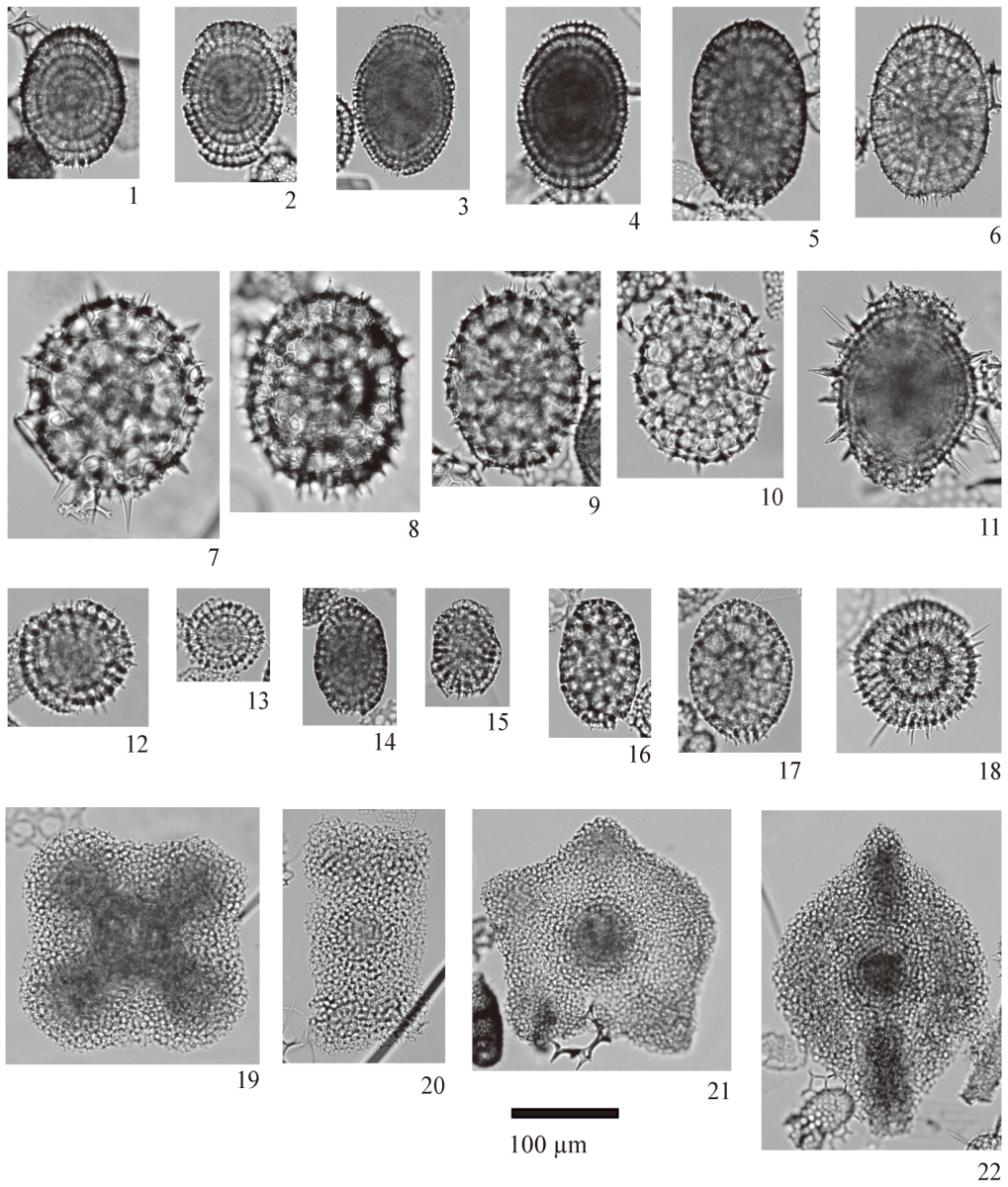


Plate 10. Illustrations of the encountered spumellarians



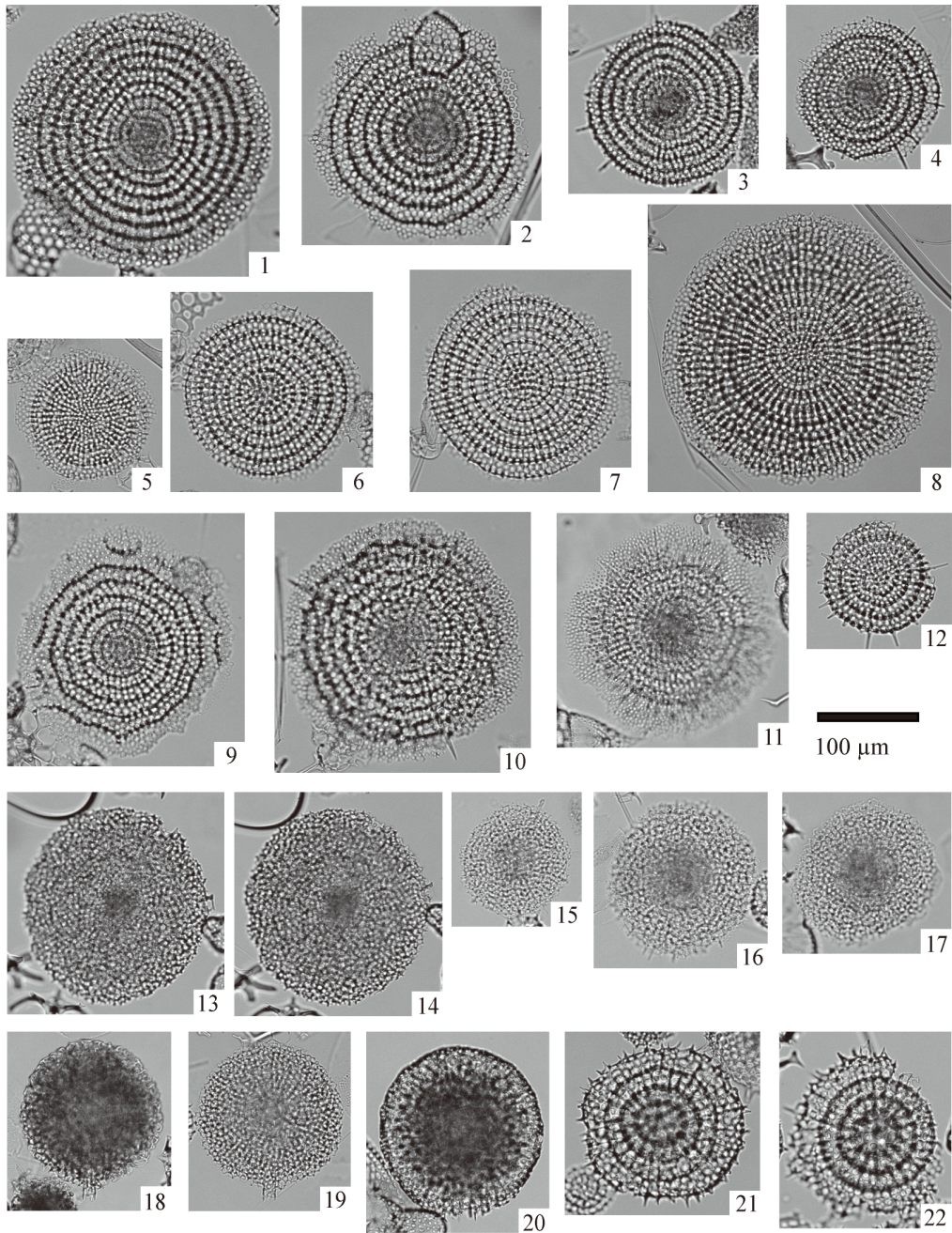


Plate 11. Illustrations of the encountered spumellarians

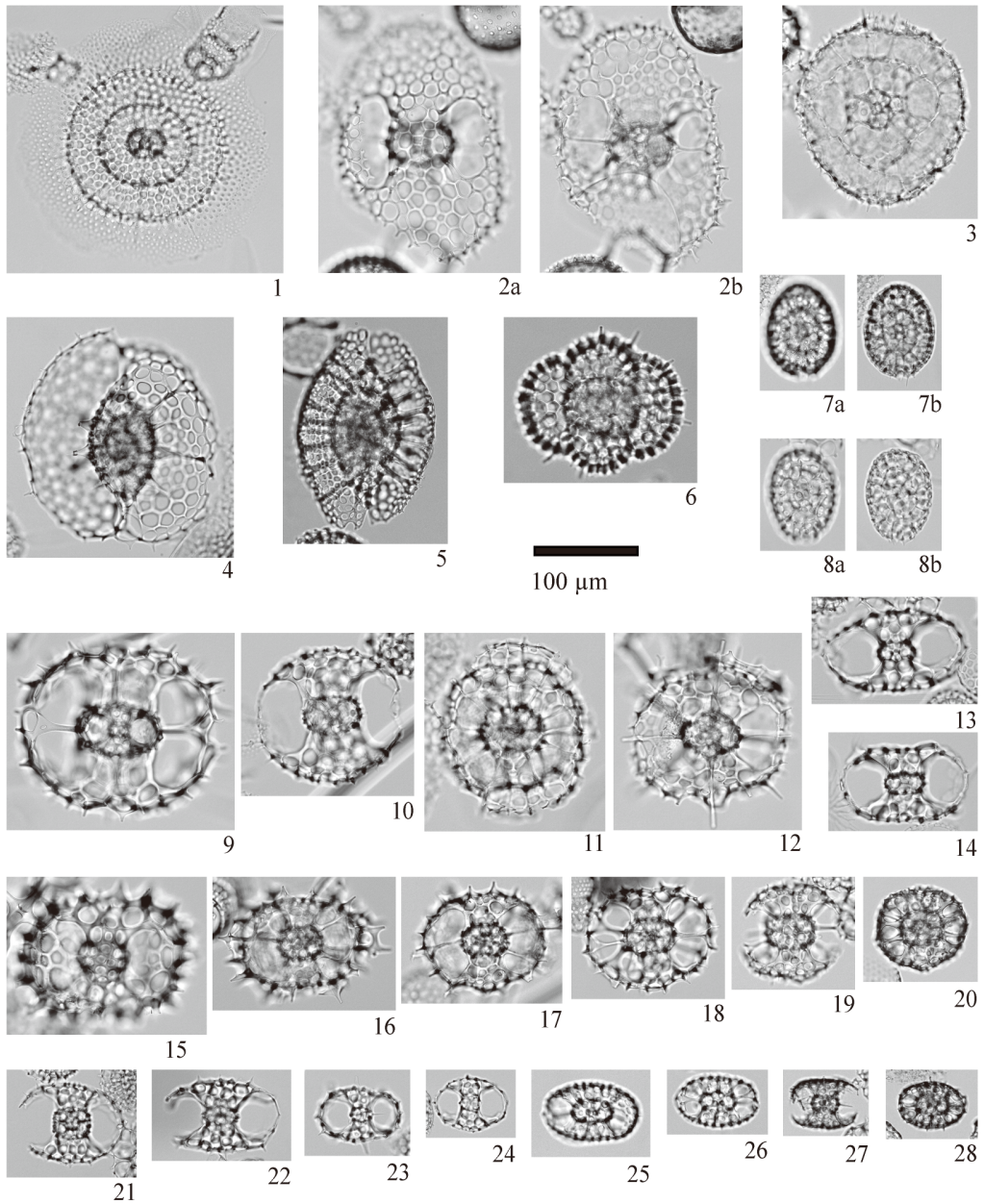


Plate 12. Illustrations of the encountered spumellarians

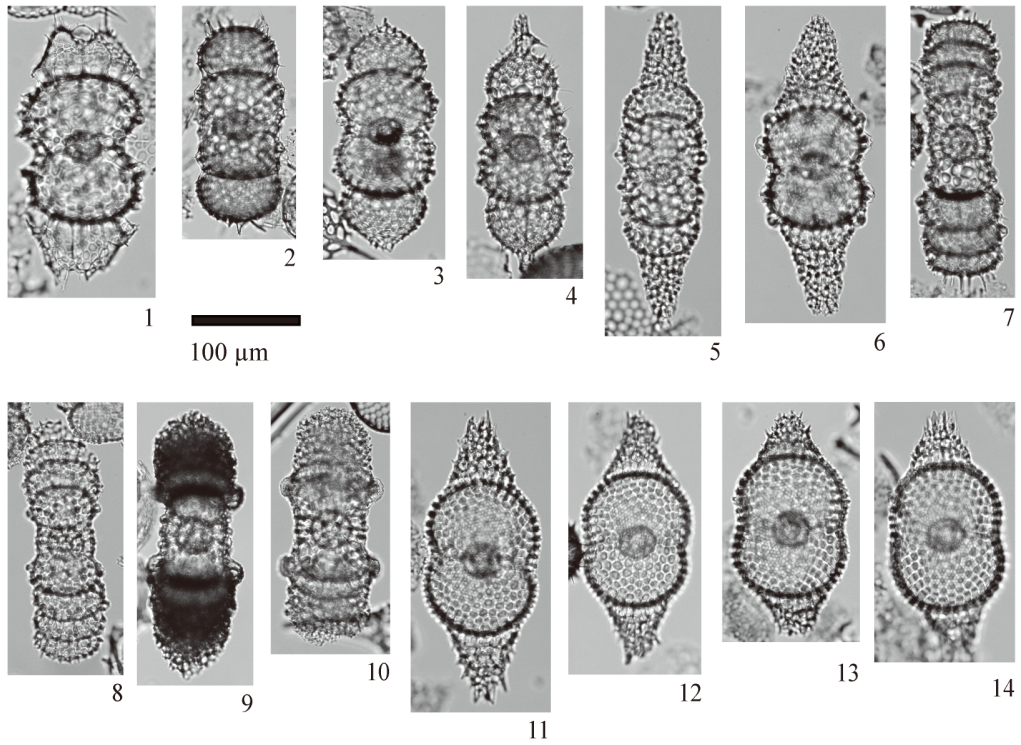


Plate 13. Illustrations of the encountered spumellarians

