

# New Palaeogene calcareous nannofossil taxa from coastal Tanzania: Tanzania Drilling Project Sites 11 to 14

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**Abstract** New calcareous nannofossil taxa are described from well-preserved and diverse Late Paleocene-Early Oligocene nannofossil assemblages from new onshore drilling sites in southern Tanzania. One new genus, *Leesella*, 30 new species, *Blackites flammeus*, *B. furvus*, *B. gracilentus*, *B. ornatus*, *B. singulus*, *B. spiculiformis*, *B. tortilis*, *Bomolithus supremus*, *Calcidiscus? gerrardii*, *Calciosolenia alternans*, *Daktylethra probertii*, *D. unitatis*, *Discoaster spinescens*, *Hayella simplex*, *Holodiscolithus catellus*, *H. fabaceus*, *Leesella procera*, *Micrantholithus minimus*, *Neochiastozygus pusillus*, *Orthozygus sudis*, *O. suggrandis*, *Pemma? triquetra*, *P.? uncinata*, *Sphenolithus runus*, *S. strigosus*, *Varolia boomeri*, *V. macleodii*, *V. sicca*, *Youngilithus pyxis* and *Zygodiscus multiforus*, one new combination, *Zygodiscus cearae*, and two indeterminate nannoliths are described and illustrated.

**Keywords** Paleocene, Eocene, Oligocene, calcareous nannofossils, taxonomy

## 1. Introduction

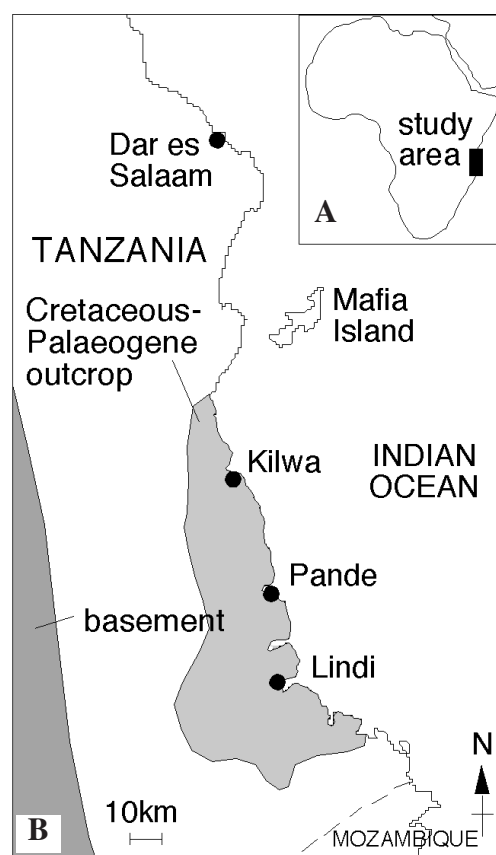
This paper documents and describes new Palaeogene calcareous nannofossil taxa from cores recovered during the 2004 drilling season of the Tanzania Drilling Project (TDP Sites 11-14). The hemipelagic mudstones of the coastal Tanzania sections yield exceptionally diverse and well-preserved microfossils, and nannofossil assemblages recovered during the previous drilling season included 56 new species, documented in Bown (2005). The geological setting and preliminary documentation of the geochemistry and other microfossil groups is provided in Pearson *et al.* (2004, subm., in prep.) and Bown (2005). Here, we illustrate, describe and discuss one new genus, 30 new species and one new combination of calcareous nannofossil, and two indeterminate nannoliths.

## 2. Material

Four new Tanzania Drilling Project sites were drilled in 2004 (TDP Sites 11-14), all in the vicinity of Pande in southern Tanzania (Figure 1). Sites were selected in order to target the Paleocene/Eocene and Eocene/Oligocene boundary intervals in sediments that yield the best-preserved microfossil material possible. The drilling techniques, sampling strategy, geological setting and lithostratigraphy are described in Pearson *et al.* (2004), Bown (2005) and Nicholas *et al.* (subm.). All cores are archived at the Tanzania Petroleum Development Corporation in Dar-es-Salaam, Tanzania.

## 3. Methods

Samples were prepared as smear-slides (Bown & Young, 1998) and analysed using a Zeiss Axiophot microscope at x1000 magnification in cross-polarised and phase-contrast light. Assemblages were logged semi-quantitatively, and slides were observed for at least 45 minutes, in most cases much longer. Images were captured using Scion Image software and macros written by Dr. Jeremy Young



**Figure 1:** Location of the Pande study area, A) in eastern Africa, and B) in southern Tanzania

(Bown & Young, 1998). For the Palaeogene, the NP biozones of Martini (1971) were used, along with the additional Middle Eocene subzones of Aubry (1991). The alternative bioevents used in the Okada & Bukry (1980) CP biozonation were also considered, where appropriate. NB The abbreviations FO and LO are used to denote first occurrence, *i.e.* oldest/lowest occurrence in the sections,

and last occurrence, youngest/highest occurrence in the sections, respectively.

#### 4. Stratigraphic age

Sites TDP 11 to 14 have been dated primarily using calcareous nannofossils and planktonic foraminifera. Sites TDP 11 and 12 recovered short intervals spanning the Eocene/Oligocene boundary (Zones NP19/20-21), and record the LOs of *Discoaster barbadensis* and *D. saipanensis*, and the LO of the planktonic foraminifer genus *Hantkenina*. TDP 13 is Middle Eocene in age (Subzone NP15b-Zone NP16), based on the LO of *Chiasmolithus gigas* and the presence of *Discoaster bifax*. TDP 14 is Late Paleocene in age (upper Zone NP9), based on the presence of *Discoaster multiradiatus* and *Campylosphaera dela*, and the absence of *Rhomboaster*. The base of Zone NP20 was not distinguished due to problems related to the unreliability of the marker-species, *Sphenolithus pseudoradians* (see Perch-Nielsen, 1985), hence the NP19/20 notation. Similarly, the base of Zone NP15 could not be unequivocally differentiated due to the rarity of *Nannotetrina* in these sections, and uncertainty concerning the reliability of the secondary marker, *Blackites inflatus* (see Perch-Nielsen, 1985), hence the NP14b/15a notation.

#### 5. Systematic palaeontology

Descriptive terminology follows the guidelines of Young *et al.* (1997). All new taxonomic names are based on Latin and the meaning is given in each case, except where epithets are in recognition of people. All images were captured at the same magnification and 2µm scale-bars are shown on each plate (magnification ~x2180). The layout of the taxonomy (and plates), and the higher taxonomic rationale follows the recently published *Guide to Extant Coccolithophore Taxonomy* (Young *et al.*, 2003), together with the reviews of Cenozoic taxonomy by Young & Bown (1997) and Bown (2005). Range information is given for stratigraphic distributions in the Tanzanian sites. Morphometric data are given for all new taxa. Only bibliographic references not included in Perch-Nielsen (1985) and Bown (1998) are included in the reference list. The following abbreviations are used: LM - light microscope, XPL - cross-polarised light, PC - phase-contrast illumination, L - length, H - height, W - width, D - diameter. Type material and images are stored in the Department of Earth Sciences, University College London.

##### 5.1 Placolith coccoliths

**Order COCCOSPHERALES Haeckel, 1894 emend.  
Young & Bown, 1997**

Family CALCIDISCACEAE Young & Bown, 1997

*Calcidiscus? gerrardii* sp. nov.

Pl.1, figs 1-7. **Derivation of name:** After Stephen Gerrard (Liverpool Football Club), captain. **Diagnosis:** Medium-

sized, broadly elliptical coccoliths with wide, low-birefringence shields and a very narrow central-area spanned by a small, disjunct, birefringent bar. The bar appears as two birefringent dots. A bright, narrow inner cycle may be visible. **Differentiation:** Distinguished from other Eocene *Calcidiscus?* species (see, e.g., Bown, 2005) by its narrow central area and transverse bar. **Dimensions:** L = 6.0-7.0µm. **Holotype:** Pl.1, fig.6 (fig.7 same specimen). **Paratype:** Pl.1, fig.2 (fig.3 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/12-2, 94cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

*Hayella simplex* sp. nov.

Pl.1, figs 11-15 (see also Bown, 2005, pl.10, figs 1-5). **Derivation of name:** From *simplex*, meaning 'simple', referring to the unadorned morphology of this coccolith. **Diagnosis:** Medium-sized, circular placolith coccoliths with an open, vacant central-area. The shield elements are distinct and show obliquity. The shield image is brighter towards the inner edge. **Differentiation:** This species lacks the elevated cycle that characterises *Hayella situliformis* Gartner, 1969. **Dimensions:** L = 5.0-7.0µm. **Holotype:** Pl.1, fig.13 (fig.14 same specimen). **Paratype:** Pl.1, fig.15. **Type locality:** TDP Site 2, Kilwa Masoko, Tanzania (see Bown, 2005). **Type level:** Middle Eocene, Sample TDP2/28-1, 50cm (Subzones NP14b/15a). **Occurrence:** NP14b-16; TDP Sites 2, 13.

##### 5.2 Murolith coccoliths

**Order ZYGODISCALES Young & Bown, 1997**  
Family ZYGODISCACEAE Hay & Mohler, 1967

*Zygodiscus multiforus* sp. nov.

Pl.1, figs 16-20. **Derivation of name:** From *multiforus*, meaning 'pierced with many holes', referring to the perforate nature of the coccolith rim. **Diagnosis:** Medium- to large-sized, elliptical murolith coccolith with a relatively broad, birefringent rim that has a perforate appearance on one side. The central-area is spanned by a transverse bar. **Remarks:** The perforate rim is a character also shared by certain species of *Helicosphaera* Kamptner, 1954, supporting the evolutionary relationship that has been suggested for these genera. *Z. multiforus* also exhibits asymmetric elevation of the rim, a feature characteristic of the genus *Lophodolichus* Deflandre, 1954, and this species may be transitional between these two genera. **Dimensions:** L = 8.6-9.3µm. **Holotype:** Pl.1, fig.18 (figs 19, 20 same specimen). **Paratype:** Pl.1, fig.17. **Type locality:** TDP Site 14, Pande, Tanzania. **Type level:** Upper Paleocene, Sample TDP14/11-1, 44cm (upper Zone NP9). **Occurrence:** Upper NP9; TDP Site 14.

*Zygodiscus cearae* (Perch-Nielsen, 1977) comb. nov.

Pl.1, figs 28-35. **Basionym:** *Neochiastozygus cearae* Perch-Nielsen, 1977, p.749, pl.40, fig.6. *Initial Reports of*

the DSDP, 39: 699-824. **Remarks:** A large (11.0-13.5 $\mu$ m) murolith coccolith with a broad central-area spanned by a transverse bar made up of crystallographically-distinct units that appear as low-angled, diagonal cross-bars at certain orientations in XPL. The bar morphology is quite unlike the four separated diagonal bars that are seen in the genus *Neochiastozygus*, but similar bars are seen in other species of *Zygodiscus*, hence the generic reassignment here. The bar is distinct from the 'lozenge-shaped' bar of *Zygodiscus adamas* Bramlette & Sullivan, 1961. These coccoliths also have high, narrow rims that are similar to those of early *Lophodolitus* specimens, indicating a possible evolutionary link. A selection of coeval *Zygodiscus* and *Lophodolitus* specimens is illustrated on Plate 1 (figs 16-35), in order to demonstrate the transitional nature of some of these morphologies. **Occurrence:** NP9; TDP Site 14. NP7-8 (Perch-Nielsen, 1985).

*Neochiastozygus pusillus* sp. nov.

Pl.2, figs 1-5. **Derivation of name:** From *pusillus*, meaning 'tiny', and referring to the relatively small size of this *Neochiastozygus* species. **Diagnosis:** Small, narrowly-elliptical *Neochiastozygus* with a bicyclic XPL image and curving, high-angled cross-bars that are slightly asymmetrical and offset where they meet. **Differentiation:** Smaller than most other species of *Neochiastozygus* ( $\sim$ 5 $\mu$ m), and with lower-angled bars than *Neochiastozygus imbrii* Haq & Lohmann, 1975. **Dimensions:** L = 4.5-5.0 $\mu$ m. **Holotype:** Pl.2, fig.1 (figs 2, 3 same specimen). **Paratype:** Pl.2, fig.4 (fig.5 same specimen). **Type locality:** TDP Site 14, Pande, Tanzania. **Type level:** Upper Paleocene, Sample TDP14/9-1, 20cm (upper Zone NP9). **Occurrence:** NP9; TDP Site 14.

**Order SYRACOSPHAERALES Hay, 1977 emend.  
Young et al., 2003**

**Family CALCIOSOLENIACEAE Kamptner, 1927**

*Calciosolenia alternans* sp. nov.

Pl.2, figs 6-10. **Derivation of name:** From *alternans*, meaning 'alternating', and referring to the distinctive appearance of the central-area structure. **Diagnosis:** Small *Calciosolenia* with a relatively broad central-area filled by a plate-like structure that displays a four-fold, alternating light-dark birefringence image. **Dimensions:** L = 4.4-5.1 $\mu$ m. **Holotype:** Pl.2, fig.9 (fig.8 same specimen). **Paratype:** Pl.2, fig.7 (fig.6 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/1-1, 42cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

**Family RHABDOSPHAERACEAE Haeckel, 1894**

*Blackites furvus* sp. nov.

Pl.2, figs 11-14, 16-19. **Derivation of name:** From *furvus*, meaning 'dark', referring to the LM appearance of this coccolith. **Diagnosis:** Medium-sized, subcircular to

circular coccoliths with broad, low-birefringence shields crossed by strongly-curving extinction lines. The central-area is narrow or closed and is typically marked by a dark, subcircular process. **Remarks:** Shafik (1989) described a number of Late Eocene low-spined Rhabdosphaeraceae from SE Australia as three new genera, *Amitha*, *Ommatolithus* and *Notiocyrtolithus*. *B. furvus* may be comparable to these taxa, but electron microscopy is required to determine its ultrastructure. *Blackites amplus* Roth & Hay, 1967, is another example of a Palaeogene 'spineless' rhabdolith coccolith that was initially described using electron microscopy, but there have been subsequent LM identifications, which, however, all show a bright central cycle/process (see, e.g., Aubry, 1999, p.132). **Dimensions:** L = 5.0-6.0 $\mu$ m. **Holotype:** Pl.2, fig.13 (fig.14 same specimen). **Paratype:** Pl.2, fig.18 (fig.19 same specimen). **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Lower Oligocene, Sample TDP12/10-1, 55cm (Zone NP21). **Occurrence:** NP21; TDP Sites 11, 12.

*Blackites* cf. *B. furvus*

Pl.2, figs 15, 20. **Remarks:** Like *Blackites furvus*, but distinctly narrowly-elliptical in outline. **Occurrence:** NP16-17; TDP Sites 4, 13.

*Blackites singulus* sp. nov.

Pl.2, figs 21-24. **Derivation of name:** From *singulus*, meaning 'separate', referring to the fact that these spines are typically found without a coccolith base. **Diagnosis:** Long, slender spine that tapers gradually and has a characteristic thickening at the broader end. The spine is birefringent when parallel with the polarising directions, has a narrow, axial canal and is typically seen with no basal coccolith. **Differentiation:** Most likely a spine of the genus *Blackites*, but distinguished from other gracile species, such as *B. tenuis* (Bramlette & Sullivan, 1961) (Pl.2, fig.25), by the distinctive thickening at one end, and the fact that it is typically found as isolated spines. **Dimensions:** L = 11.0-19.5 $\mu$ m. **Holotype:** Pl.2, fig.21. **Paratype:** Pl.2, fig.22. **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Upper Eocene, Sample TDP12/47-4, 35cm (Zone NP19/20). **Occurrence:** NP19/20; TDP Site 12.

*Blackites tortilis* sp. nov.

Pl.2, figs 26-30. **Derivation of name:** From *tortilis*, meaning 'twisted', referring to the spiralling pattern characteristic of this spine. **Diagnosis:** Long spine that tapers at both ends and displays a characteristic spiralling pattern in XPL. The spine has a narrow axial canal and is typically seen with no basal coccolith. **Remarks:** Most likely a spine of the genus *Blackites*, but reminiscent of Cretaceous rod-shaped nannoliths, such as *Microrhabdulus* Deflandre, 1959. **Dimensions:** L = 9.0-16.0 $\mu$ m. **Holotype:** Pl.2, fig.28 (figs 29, 30 same specimen). **Paratype:** Pl.2, fig.26 (fig.27 same specimen).



**Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/8-2, 23cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

*Blackites ornatus* sp. nov.

Pl.2, figs 31-34 (see also Bown, 2005, pl.26, figs 13-15). **Derivation of name:** From *ornatus*, meaning 'ornament', referring to the spine of this coccolith. **Diagnosis:** Large, table-tennis-bat-shaped spine covered in fine, cross-hatched ornamentation when viewed in XPL. The spines have not been found attached to a coccolith base, and they appear to be rather flat. **Remarks:** Cross-hatched ornamentation is a common feature found towards the spine-ends of many *Blackites* species, but *B. ornatus* spines are more completely ornamented. *Bramletteius* Gartner, 1969 spines are similarly flat, but have no ornamentation (Pl.2, fig.35). **Dimensions:** H = 10.4-11.0 $\mu$ m; W = 5.9-7.8 $\mu$ m. **Holotype:** Pl.2, fig.32. **Paratype:** Pl.2, fig.33. **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/16-1, 75cm (Zone NP16). **Occurrence:** NP15c-16; TDP Sites 2, 13.

*Blackites spiculiformis* sp. nov.

Pl.3, figs 1-5. **Derivation of name:** From *spica*, meaning 'spike', referring to the spine of this coccolith. **Diagnosis:** Rhabdolith coccolith with a *Blackites gladius*-like rim (see Bown, 2005, p.34) and a relatively short, narrow, tapering, hollow spine that may incorporate a basal collar. **Differentiation:** Similar to *Blackites creber* (Deflandre, 1954), but with a shorter, broader spine. Differentiated from *B. vitreus* (Deflandre, 1954) by its narrower spine and lack of prominent, basal spine buttresses. **Dimensions:** H = 6.3-7.8 $\mu$ m; W = 4.2-4.7 $\mu$ m. **Holotype:** Pl.3, fig.2 (figs 1, 3 same specimen). **Paratype:** Pl.3, fig.4 (fig.5 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/18-1, 30cm (Subzone NP15b). **Occurrence:** NP15; TDP Site 13.

*Blackites* cf. *B. spiculiformis* sp. nov.

Pl.3, figs 6-8. **Remarks:** Like *Blackites spiculiformis*, but the rim is more like that of the *B. morionum* group (see Bown, 2005, pp.34-35). **Occurrence:** NP16; TDP Site 13.

*Blackites flammeus* sp. nov.

Pl.3, figs 11-17. **Derivation of name:** From *flammeus*, meaning 'flame', referring to the shape of the spine of this coccolith. **Diagnosis:** Rhabdolith coccolith with a relatively narrow coccolith base and a flame-shaped, slightly asymmetric, hollow spine. **Dimensions:** H = 6.8-7.2 $\mu$ m; W = 2.4-2.9 $\mu$ m. **Holotype:** Pl.3, fig.16 (fig.17 same specimen). **Paratype:** Pl.3, fig.14 (fig.15 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/8-2, 23cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

*Blackites* cf. *B. virgatus* Bown, 2005

Pl.3, fig.18. **Remarks:** Similar to *Blackites virgatus*, but the spine is more robust and less tapered (see Bown, 2005, pl.25, figs 6-15). **Occurrence:** NP16; TDP Site 13.

*Blackites* cf. *B. dupuisii* (Steurbaut, 1990) Bown, 2005 Pl.3, fig.19. **Remarks:** Like *Blackites dupuisii*, but the spines are narrower than the type specimens of Steurbaut (1990) (see also Bown, 2005, pl.25, figs 16-20). **Occurrence:** NP16; TDP Site 13.

*Blackites gracilentus* sp. nov.

Pl.3, figs 20-25. **Derivation of name:** From *gracilentus*, meaning 'slender', referring to the spine of this coccolith. **Diagnosis:** Rhabdolith coccolith with a thin, narrow coccolith base and a narrow spine with an axial canal. **Remarks:** The coccoliths are similar to extant morphologies classified as *Rhabdosphaera clavigera* Murray & Blackman, 1898, but have more gracile, narrow spines. Also reminiscent of the original illustration of *Blackites rectus* (Deflandre, 1954; the name has since been used for distinctly different morphologies, e.g. Stradner & Edwards (1968)), but with a proportionally narrower base. **Dimensions:** H = 6.4-10.1 $\mu$ m; W = 2.0-2.3 $\mu$ m. **Holotype:** Pl.3, fig.21 (fig.22 same specimen). **Paratype:** Pl.3, fig.23. **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/1-1, 42cm (Zone NP16). **Occurrence:** NP16-19/20; TDP Sites 12, 13.

### 5.3 Holococcoliths

Family CALYPTROSPHAERACEAE Boudreaux & Hay, 1967

Plates 3-6. **Remarks:** The coccoliths described below have not yet had their ultrastructure determined by scanning electron microscopy, however, their distinctive appearance in XPL suggests that they are most likely holococcoliths.

*Holodiscolithus catellus* sp. nov.

Pl.3, figs 26-30. **Derivation of name:** From *catellus*, meaning 'little chain', referring to the beaded morphology of the rim of this coccolith. **Diagnosis:** A small, elliptical coccolith comprising a single, narrow cycle of moderately birefringent, bead-like elements (as viewed in LM), and a relatively broad, vacant central-area. **Dimensions:** L = 3.6-4.8 $\mu$ m. **Holotype:** Pl.3, fig.26 (fig.27 same specimen). **Paratype:** Pl.3, fig.28 (fig.29 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/8-2, 23cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

*Holodiscolithus fabaceus* sp. nov.

Pl.3, figs 31-35. **Derivation of name:** From *fabaceus*, meaning 'like a bean', referring to the general appearance of this holococcolith. **Diagnosis:** A small, elliptical,

closed holococcolith with a longitudinal suture and low birefringence in XPL. **Dimensions:**  $L = 3.6\text{--}4.5\mu\text{m}$ . **Holotype:** Pl.3, fig.31. **Paratype:** Pl.3, fig.32 (figs 33, 34 same specimen). **Type locality:** TDP Site 11, Pande, Tanzania. **Type level:** Lower Oligocene, Sample TDP11/15-1, 24cm (Zone NP21). **Occurrence:** NP21; TDP Site 11.

*Youngilithus pyxis* sp. nov.

Pl.4, figs 1-10. **Derivation of name:** From *pyxis*, meaning 'box', referring to the overall shape of this coccolith. **Diagnosis:** A rectangular to square, box-like coccolith constructed of four crystallographically-distinct units, with at least two protrusions on each side. **Differentiation:** Has a squarer shape than *Youngilithus oblongatus* Bown, 2005, and lacks the cross-bars seen in *Y. quadraeformis* Bown, 2005. **Dimensions:**  $L = 4.0\text{--}5.5\mu\text{m}$ . **Holotype:** Pl.4, fig.1 (figs 2-5 same specimen). **Paratype:** Pl.4, fig.7 (figs 6, 8 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/8-2, 23cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

*Quadrilateris imparidividuus* Varol, 1991

Pl.4, figs 16-20. **Remarks:** A small, narrowly rectangular coccolith formed of four thin blocks that are birefringent in XPL. Similar to *Youngilithus oblongatus* in overall shape, but exhibits high birefringence and lacks lateral rim projections. **Dimensions:**  $L = 2.1\text{--}3.7\mu\text{m}$ . **Occurrence:** NP19/20; TDP Site 12. NP15 (Varol, 1991).

*Varolia boomeri* sp. nov.

Pl.4, figs 21-32. **Derivation of name:** After Dr. Ian Boomer (Universities of Newcastle and Birmingham, UK), micropalaeontologist. **Diagnosis:** A multi-element, cavate, box-like coccolith with a pointed apical structure. The walls of the box and apical structure comprise narrow, birefringent, crystallographically-distinct elements that are birefringent in XPL. **Differentiation:** More complexly constructed than other species of *Varolia*. **Dimensions:**  $H = 4.4\text{--}5.5\mu\text{m}$ ;  $W = 3.5\text{--}5.6\mu\text{m}$ . **Holotype:** Pl.4, fig.24 (fig.25 same specimen). **Paratype:** Pl.4, fig.21 (fig.22 same specimen). **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Lower Oligocene, Sample TDP12/10-1, 55cm (Zone NP21). **Occurrence:** NP19/20-21; TDP Site 12.

*Varolia macleodii* sp. nov.

Pl.5, figs 1-10. **Derivation of name:** After Dr. Ken MacLeod (University of Missouri, USA), palaeontologist and palaeoceanographer. **Diagnosis:** In side-view, a thin-walled, cavate coccolith with a domed upper surface. The cavate central-area space is filled with small, birefringent elements and at least two prominent, vertical plates. **Differentiation:** Similar to *Varolia cistula* Bown, 2005, but with a filled central cavity. **Dimensions:**  $H = 2.4\text{--}3.0\mu\text{m}$ ;  $L = 3.5\text{--}4.2\mu\text{m}$ . **Holotype:** Pl.5, fig.3 (fig.4 same

specimen). **Paratypes:** Pl.5, fig.1 (fig.2 same specimen); Pl.5, fig.6. **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Upper Eocene, Sample TDP12/46-1, 40cm (Zone NP19/20). **Occurrence:** NP19/20; TDP Site 12.

*Varolia sicca* sp. nov.

Pl.5, figs 11-15. **Derivation of name:** From *siccus*, meaning 'of simple style', referring to the morphology of this holococcolith. **Diagnosis:** A small, elliptical to lens-shaped coccolith with a narrow, birefringent rim (as viewed in LM). When orientated at  $0^\circ$ , the rim is crossed by narrow N-S and E-W extinction lines. **Differentiation:** Distinguished from *Varolia cistula* and *V. macleodii* sp. nov. by its narrower and pinched outline. **Dimensions:**  $L = 2.8\text{--}3.2\mu\text{m}$ . **Holotype:** Pl.5, fig.11 (figs 12, 13 same specimen). **Paratype:** Pl.5, fig.14 (fig.15 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/4-2, 40cm (Zone NP16). **Occurrence:** NP16; TDP Site 13. *NB* A number of different Middle and Upper Eocene holococcoliths are shown for comparative purposes on Plate 5 (figs 26-35).

*Semihololithus biskayae* Perch-Nielsen, 1971

Pl.5, figs 16-25. **Remarks:** This species is a common component of the Late Paleocene assemblages of TDP Site 14. The coccoliths are seen in side-view, from which they were originally described, and plan-view, as illustrated here (Pl.5, figs 18-25). The plan-views can be divided into two varieties, dependent on the presence (Pl.5, figs 21-25) or absence (Pl.5, figs 18-20) of a birefringent, transverse bar. The forms with bars may represent side-views of *Semihololithus dimidius* Bown, 2005. **Occurrence:** Upper NP9; TDP Site 14.

*Dakylethra* Gartner in Gartner & Bukry, 1969

Pl.6, figs 1-22. A number of different holococcolith morphologies conform to Gartner's original description of helmet-shaped holococcoliths with surficial, shallow pits (Gartner & Bukry, 1969). Specimens identical to the type species, *Dakylethra punctulata*, are shown in Plate 6 (figs 1, 2), but two new species, *D. unitatis* and *D. prober-tii*, are also described below.

*Dakylethra punctulata* Gartner in Gartner & Bukry, 1969

Pl.6, figs 1, 2. **Remarks:** Tall, thick-walled, cavate, dome-shaped coccolith, seen in side-view, with a distinctly undulating outer surface. The crystallites form crystallographically-continuous blocks that are bright in XPL when the long axis is parallel to the polarising direction. **Occurrence:** NP16; TDP Site 13. NP16-17 (Gartner, 1971).

*Dakylethra unitatis* sp. nov.

Pl.6, figs 3-10. **Derivation of name:** From *unitas*, meaning 'oneness' or 'unity', referring to the crystallographic continuity of this holococcolith. **Diagnosis:** A cavate

holococcolith, seen in side-view, with a thin basal plate, walls and domed distal cover made up of crystallites that are crystallographically-continuous and dark at 0° in XPL, brightening when rotated to 45°. The surface is covered with shallow perforations/pits. **Differentiation:** The crystallographic orientation and general construction is different to that of other species of *Daktylethra*. **Dimensions:** H = 3.0-5.2 µm; L = 4.0-5.3 µm. **Holotype:** Pl.6, fig.6 (figs 7-9 same specimen). **Paratype:** Pl.6, fig.10. **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/1-1, 42cm (Zone NP16). **Occurrence:** NP15b-16; TDP Sites 2, 13.

*Daktylethra probertii* sp. nov.

Pl.6, figs 11-22 (see also Bown, 2005, pl.31, figs 26-35). **Derivation of name:** After Dr. Ian Probert (University of Caen, France), algologist. **Diagnosis:** A cavate holococcolith, seen in side-view, comprising a thin proximal plate and rim that are structurally/crystallographically distinct from a large, perforate, domed distal process. Typically, birefringent at 0° in XPL, darkening when rotated to 45°. **Differentiation:** Made up of more crystallographically-distinct blocks than other species of *Daktylethra*. **Dimensions:** H = 3.6-6.5 µm; W = 3.6-7.7 µm. **Holotype:** Pl.6, fig.13 (figs 14, 15 same specimen). **Paratype:** Pl.6, fig.18 (figs 19, 20 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/4-2, 40cm (Zone NP16). **Occurrence:** NP14b/15a-16; TDP Sites 2, 6, 13.

*Orthozygus sudis* sp. nov.

Pl.6, figs 27-30. **Derivation of name:** From *sudis*, meaning a 'spike' or 'point', referring to the tapering spine of this holococcolith. **Diagnosis:** A holococcolith that, in side-view, comprises a low basal coccolith and a relatively tall, hollow spine that tapers to a point. Both coccolith and spine are birefringent and crystallographically-continuous in XPL. **Differentiation:** The spine is taller and narrower than that of *Orthozygus aureus* (Stradner, 1962), and has a relatively broad central cavity that is quite distinct from the spines of *Zygrhablithus bijugatus* (Deflandre, 1954). It also lacks the crystallographically-distinct rim-cycle of the latter. **Dimensions:** H = 4.4-4.8 µm; L = 4.4-4.9 µm. **Holotype:** Pl.6, fig.27 (figs 28, 29 same specimen). **Paratype:** Pl.6, fig.30. **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Lower Oligocene, Sample TDP12/10-1, 55cm (Zone NP21). **Occurrence:** NP21; TDP Site 12.

*Orthozygus suggrandis* sp. nov.

Pl.6, figs 31-35. **Derivation of name:** From *suggrandis*, meaning 'somewhat large', referring to the relative size of this holococcolith. **Diagnosis:** A large, rather coarsely constructed, elliptical holococcolith with a central-area spanned by a transverse, bridge-like structure that broadens at each end. The rim and bridge are crystallographically disjunct. **Dimensions:** L = 6.9-7.0 µm. **Holotype:**

Pl.6, fig.34 (figs 33, 35 same specimen). **Paratype:** Pl.6, fig.32 (fig.31 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/17-2, 16cm (Subzone NP15c). **Occurrence:** NP15c; TDP Site 13.

## 5.4 Nannoliths

Family **BRAARUDOSPHERACEAE** Deflandre, 1947

*Micrantholithus minimus* sp. nov.

Pl.7, figs 1-5. **Derivation of name:** From *minimus*, meaning 'smallest', referring to the relatively small size of this pentolith. **Diagnosis:** A small (typically <4 µm) *Micrantholithus* with raised ridges along the line of the segment sutures that give the appearance of a deeply-indented pentolith. Many specimens, however, appear to have thin calcite between the raised, birefringent areas. **Dimensions:** L = 3.2-3.7 µm. **Holotype:** Pl.7, fig.4 (fig.5 same specimen). **Paratype:** Pl.7, fig.3. **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Upper Eocene, Sample TDP12/47-4, 35cm (Zone NP19/20). **Occurrence:** NP19/20-21; TDP Sites 11, 12.

Family **DISCOASTERACEAE** Tan, 1927

*Discoaster spinescens* sp. nov.

Pl.7, figs 9-14. **Derivation of name:** From *spinescens*, meaning 'becoming spiny', referring to the spine on one side of this discoaster. **Diagnosis:** A rosette, multirayed (around 12 rays) discoaster with short, free rays with triangular terminations, bearing a tall, thin spine on one side. **Differentiation:** Similar to *Discoaster barbadiensis* Tan, 1927, but with a taller spine that is distinctly conspicuous in side- and plan-views. *D. bifax* Bukry, 1971 also occurs at the same stratigraphic level, but has spines on both faces of the discoaster (Pl.7, figs 6-8). **Dimensions:** L = 7.7-10.1 µm. **Holotype:** Pl.7, fig.13 (fig.14 same specimen). **Paratype:** Pl.7, fig.9. **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/16-3, 90cm (Zone NP16). **Occurrence:** NP15b-16; TDP Site 13.

*Discoaster tanii* Bramlette & Riedel, 1954 group

Pl.7, figs 16-24. **Remarks:** Three Late Eocene-Early Oligocene discoaster taxa exhibit close morphological affinities, and they are frequently classified as subspecies, or closely-related species, of *Discoaster tanii*, namely *D. tanii* Bramlette & Riedel, 1954, *D. nodifer* Bramlette & Riedel, 1954 and *D. ornatus* Bramlette & Wilcoxon, 1967 (arguably, *D. istanbulensis* Sadek & Ozer, 1981 is a fourth). *D. nodifer* is typically six-rayed, while the others are typically five-rayed, and are further differentiated by variably-developed lateral nodes on their rays, and ray-end notches or bifurcations. *D. tanii* has the least well-developed notches and nodes (Pl.7, figs 16-18), and *orna-*



*tus* and *istanbulensis* have the largest, together with a central boss (Pl.7, figs 19-23, with the *istanbulensis* morphotype represented by figs 20 and 21). *D. ornatus* was originally described as having sharp, paired nodes (Bramlette & Wilcoxon, 1967), but this may have been a preservational artefact. We have observed continuous morphological variation between these five-rayed varieties, but differentiate *D. ornatus* from *D. tanii*, with *D. ornatus* typically larger and with distinct nodes, terminal notches and central boss.

#### Family HELIOLITHACEAE Hay & Mohler, 1967

##### *Bomolithus supremus* sp. nov.

Pl.7, figs 25-34. **Derivation of name:** From *supremus*, meaning 'highest', 'uppermost' or 'last', referring to the stratigraphic position of this species, with respect to others in the genus. **Diagnosis:** A circular nannolith that typically appears to comprise three distinct cycles, with only the innermost exhibiting birefringence in XPL; the central-area is a narrow hole or closed. The outermost cycle is dark in PC and the distinct elements show obliquity. The innermost cycle shows white interference colours and is crossed by thick extinction lines that are rotated approximately 5° from axial. **Differentiation:** Not as elevated as other species of *Bomolithus* Roth, 1973, and younger in age than all but *Bomolithus/Discoaster megastypus* Bramlette & Sullivan, 1961 (e.g. Perch-Nielsen, 1985; Steurbaut, 1998). Similar to *Bomolithus conicus* (Perch-Nielsen, 1971), but with a more distinctly birefringent inner cycle and a younger stratigraphic range (Zone NP9 vs. Zone NP6). **Dimensions:** D = 5.3-8.3µm. **Holotype:** Pl.7, fig.30 (figs 31, 32 same specimen). **Paratype:** Pl.7, fig.27 (fig.28 same specimen). **Type locality:** TDP Site 14, Pande, Tanzania. **Type level:** Upper Paleocene, Sample TDP14/10-1, 75cm (upper Zone NP9). **Occurrence:** NP9; TDP Site 14.

#### Family SPHENOLITHACEAE Deflandre, 1952

##### *Sphenolithus tribulosus* Roth, 1970

Pl.8, figs 1-5. **Remarks:** Like *Sphenolithus predistentus* Bramlette & Wilcoxon, 1967, but the basal part of the sphenolith is considerably broader than the spine, giving an inverted 'T'-shaped outline. This unusual morphology may be the result of differential overgrowth. **Occurrence:** NP21; TDP Site 11. NP21-23 (Roth, 1970)

##### *Sphenolithus strigosus* sp. nov.

Pl.8, figs 6-15. **Derivation of name:** From *strigosus*, meaning 'thin', referring to the tall, narrow, duocrystalline spine of this species. **Diagnosis:** A tall, narrow sphenolith with a low base and a duocrystalline spine that bifurcates distally. The base consists of two quadrants when viewed at 0° in XPL, and the spine goes into extinction at 45°. **Differentiation:** Similar to *Sphenolithus furcatolithoides* Locker, 1967, but the spine bifurcates at a

far higher level up the spine. **Dimensions:** L = 6.3-16.7µm. **Holotype:** Pl.8, fig.6 (figs 7, 8 same specimen). **Paratype:** Pl.8, fig.13 (fig.14 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/16-1, 75cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

##### *Sphenolithus runus* sp. nov.

Pl.8, figs 16-24. **Derivation of name:** From *runa* meaning 'dart', referring to the overall shape of this species. **Diagnosis:** A spinose, dart-shaped sphenolith with a low base comprising a single cycle of triangular quadrants when viewed at 0°. The relatively tall, tapering spine is in extinction at 0° and bright at 45°. The quadrants appear larger, and are extended distally at 45°. **Differentiation:** Similar to *Sphenolithus obtusus* Bukry, 1971, but the spine does not show a split extinction pattern when rotated, and the basal quadrants appear larger, with distal extensions at 45°. **Dimensions:** L = 5.4-6.8µm. **Holotype:** Pl.8, fig.18 (figs 19, 20 same specimen). **Paratype:** Pl.8, fig.23 (fig.24 same specimen). **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/1-1, 42cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

### 5.5 *Incertae sedis* nannoliths

##### *Leesella* gen. nov.

Pl.8, figs 25-30. **Type species:** *Leesella procera* sp. nov. **Derivation of name:** After Dr. Jackie Lees (University College London, UK), nannopalaeontologist. **Diagnosis:** Relatively tall nannoliths that flare from a small basal disc to form a trumpet shape. They have a narrow, axial canal and are usually seen in side-view.

##### *Leesella procera* sp. nov.

Pl.8, figs 25-30. **Derivation of name:** From *procera*, meaning 'tall', referring to the general shape of this nannofossil. **Diagnosis:** Variably tall nannoliths that flare from a small basal disc to form a trumpet shape. They appear to be formed from a single crystallographic unit, have a narrow axial canal, and are usually seen in side-view. **Differentiation:** Reminiscent, in overall shape, of the Early Jurassic *Carinolithus superbus* (Deflandre, 1954), but does not have a separate proximal cycle. **Dimensions:** H = 2.0-6.9µm. **Holotype:** Pl.8, fig.28. **Paratypes:** Pl.8, figs 26, 27. **Type locality:** TDP Site 13, Pande, Tanzania. **Type level:** Middle Eocene, Sample TDP13/1-1, 42cm (Zone NP16). **Occurrence:** NP16; TDP Site 13.

##### *Pemma? triquetra* sp. nov.

Pl.9, figs 1-8. **Derivation of name:** From *triquetrus*, meaning 'triangular', referring to the outline of these nannoliths. **Diagnosis:** Relatively large (typically >5µm), triangular-shaped nannoliths that thicken along the longer sides, and exhibit low birefringence in XPL. **Remarks:**

Similar to disaggregated *Pemma* or *Micrantholithus* segments, but the angle between the longer sides is more acute (~50°-60°, compared to 72° in typical *Pemma*/*Micrantholithus*). The *c*-axis orientation is similar to that of *Pemma*/*Micrantholithus*, *i.e.* tangential, but appears to be higher-angled, hence the tentative generic designation. Some specimens have crenulated edges (Pl.9, fig.4) or additional thickened ridges that run parallel to one of the sides (Pl.9, fig.5). **Dimensions:** L = 5.3-8.5µm. **Holotype:** Pl.9, fig.6 (figs 7, 8 same specimen). **Paratype:** Pl.9, fig.2 (figs 1, 3, same specimen). **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Lower Oligocene, Sample TDP12/10-1, 55cm (Zone NP21). **Occurrence:** NP19/20-21, ranging slightly higher (25m) than *Pemma papillatum* Martini, 1959 in TDP Site 12; TDP Sites 11, 12.

*Pemma? uncinata* sp. nov.

Pl.9, figs 9-20. **Derivation of name:** From *uncinatus*, meaning 'hooked', referring to the general appearance of these nannoliths. **Diagnosis:** Large (typically >7µm), triangular-, rectangular- or rhomb-shaped nannoliths that are thickened along two sides to give a hook-shaped appearance. They exhibit low birefringence in XPL. **Remarks:** Somewhat comparable to *Pemma? triquetra* (see above), but the *c*-axis orientation is radial, *i.e.* parallel to the long axis, and the generic designation is highly speculative; however, we are reluctant to propose a new genus for this form until its nature is better understood. **Dimensions:** L = 6.9-17.7µm. **Holotype:** Pl.9, fig.17 (figs 16, 18, 19 same specimen). **Paratype:** Pl.9, fig.13 (figs 14, 15 same specimen). **Type locality:** TDP Site 12, Pande, Tanzania. **Type level:** Upper Eocene, Sample TDP12/47-4, 35cm (Zone NP19/20). **Occurrence:** NP19/20-21; TDP Sites 11, 12.

## 5.6 Indeterminate nannoliths

Pl.8, figs 21-30. **Remarks:** The Upper Eocene-Lower Oligocene sediments from Tanzania include rather common, nannofossil-sized, crystal-like objects that may or may not be biogenic. These possible nannoliths are roughly oval/polygonal shapes with a central hole that may (Type 2 - Pl.9, figs 26-30) or may not be (Type 1 - Pl.9, figs 21-25) lined with a cycle of birefringent crystals. **Dimensions:** L = 4.7-6.1µm. **Occurrence:** Type 1 - NP19/20-21, Site 12; Type 2 - NP16-19/20, Sites 4, 12, 13.

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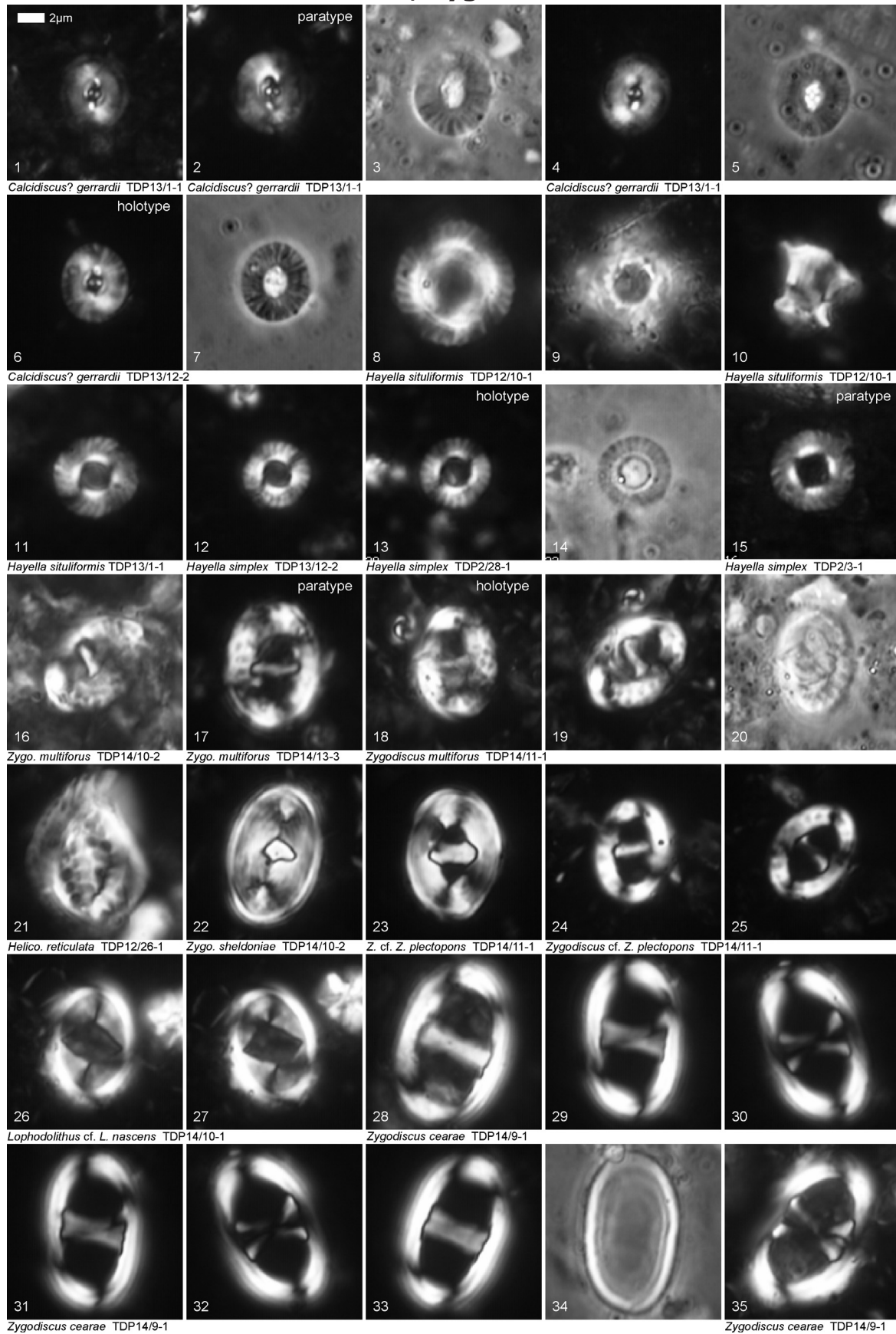
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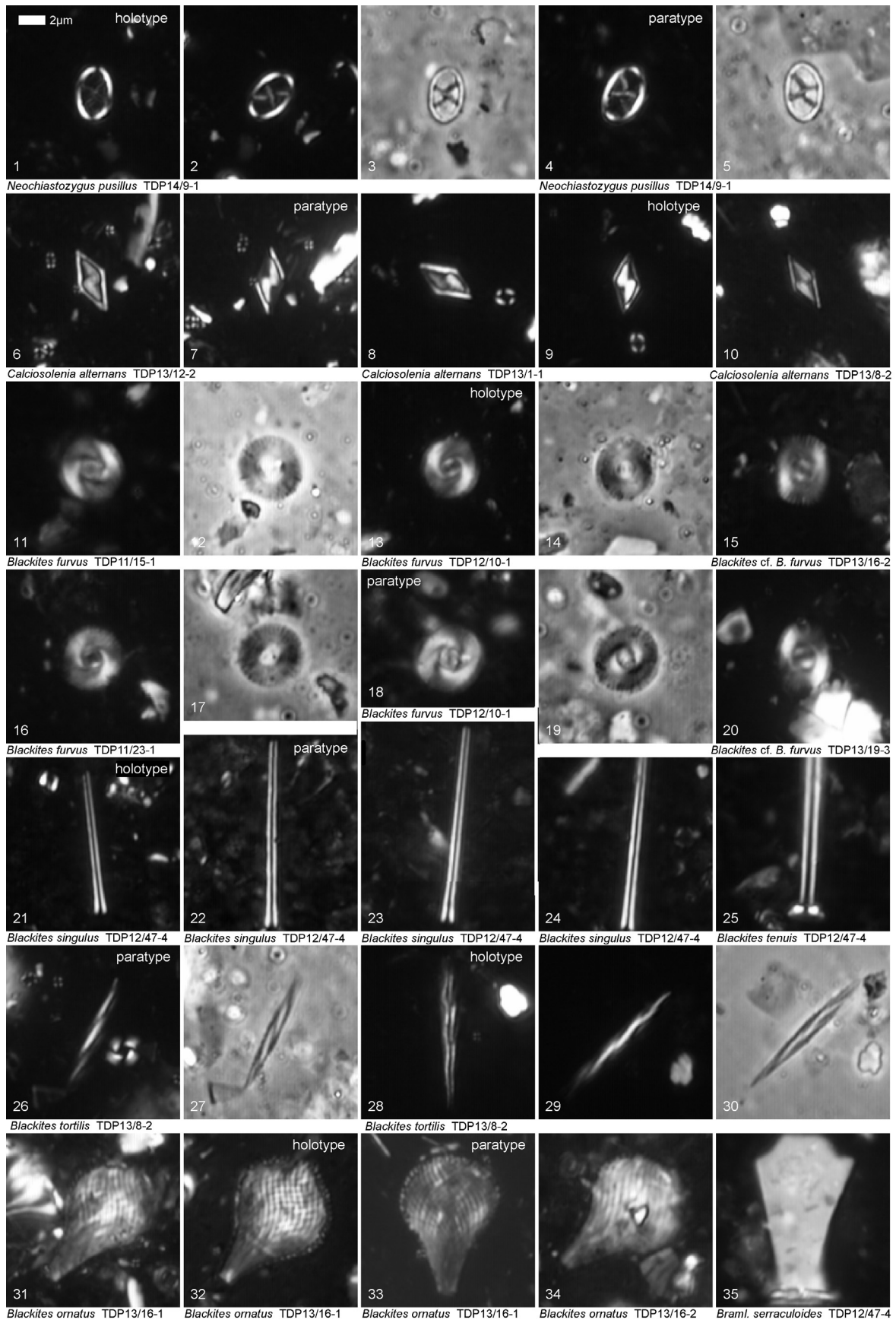
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## Plate 1

## Placoliths, Zygodiscaceae

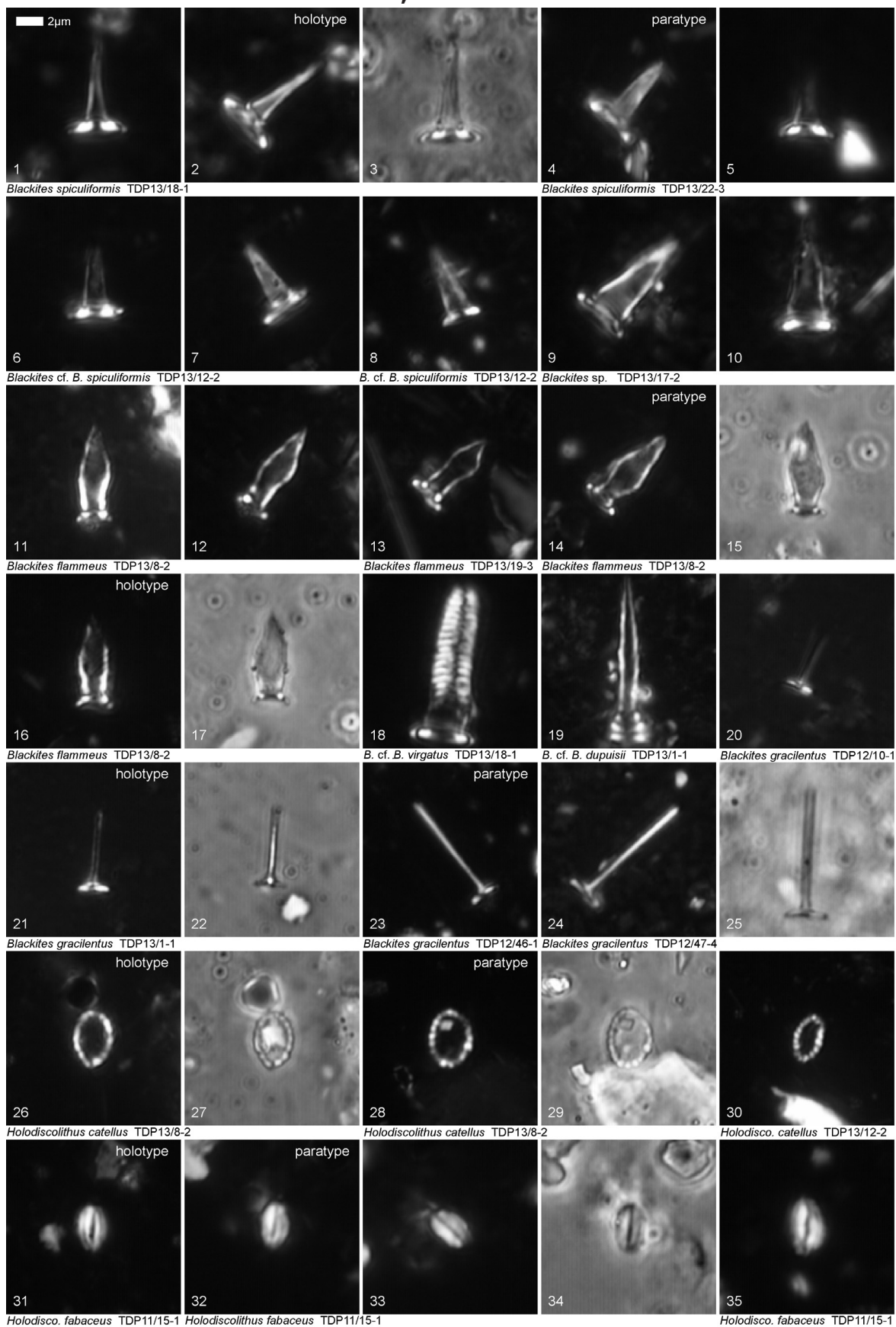


## Plate 2

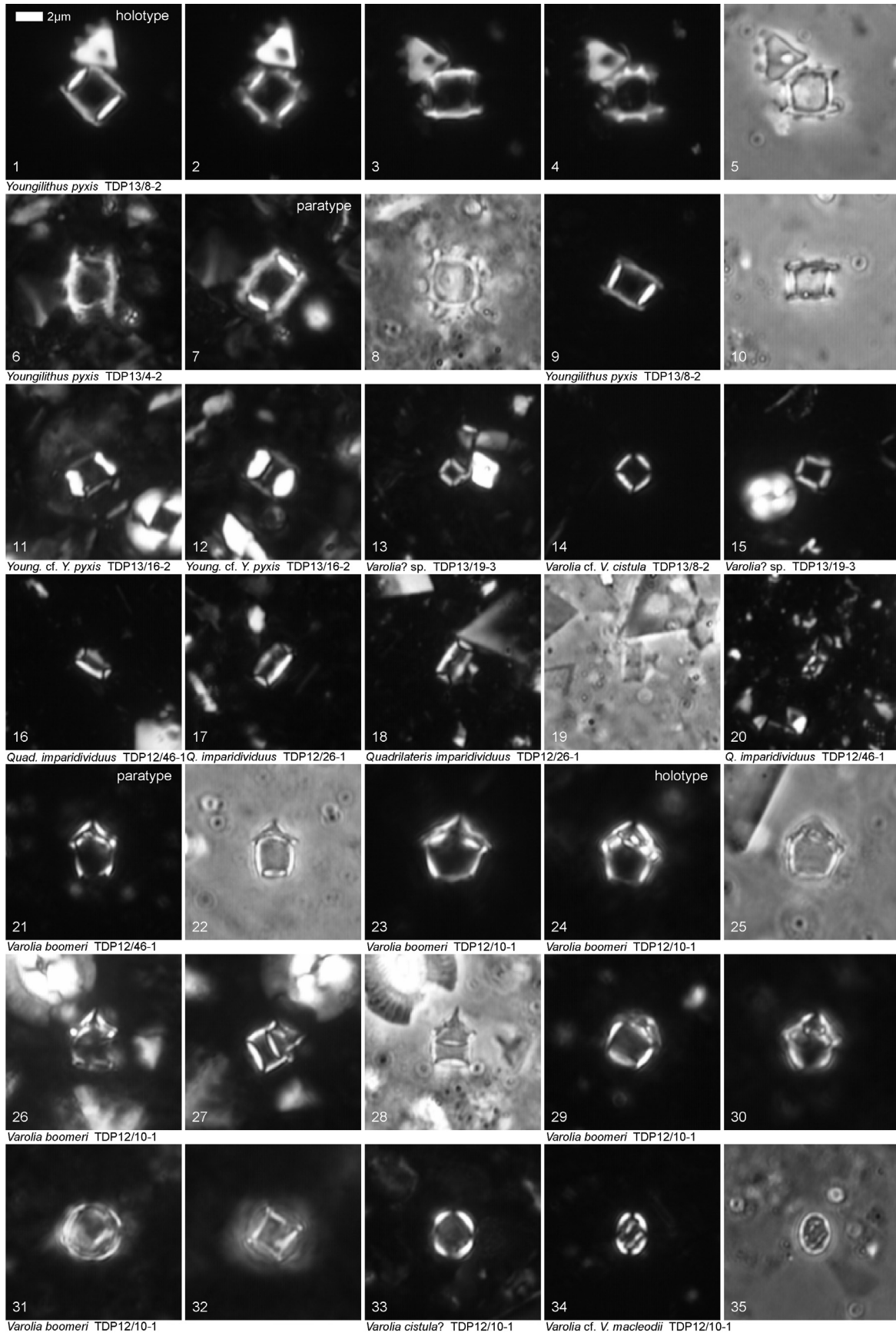
*Neochiastozygus*, *Calciosolenia*, *Blackites*, *Bramletteius*



## Plate 3

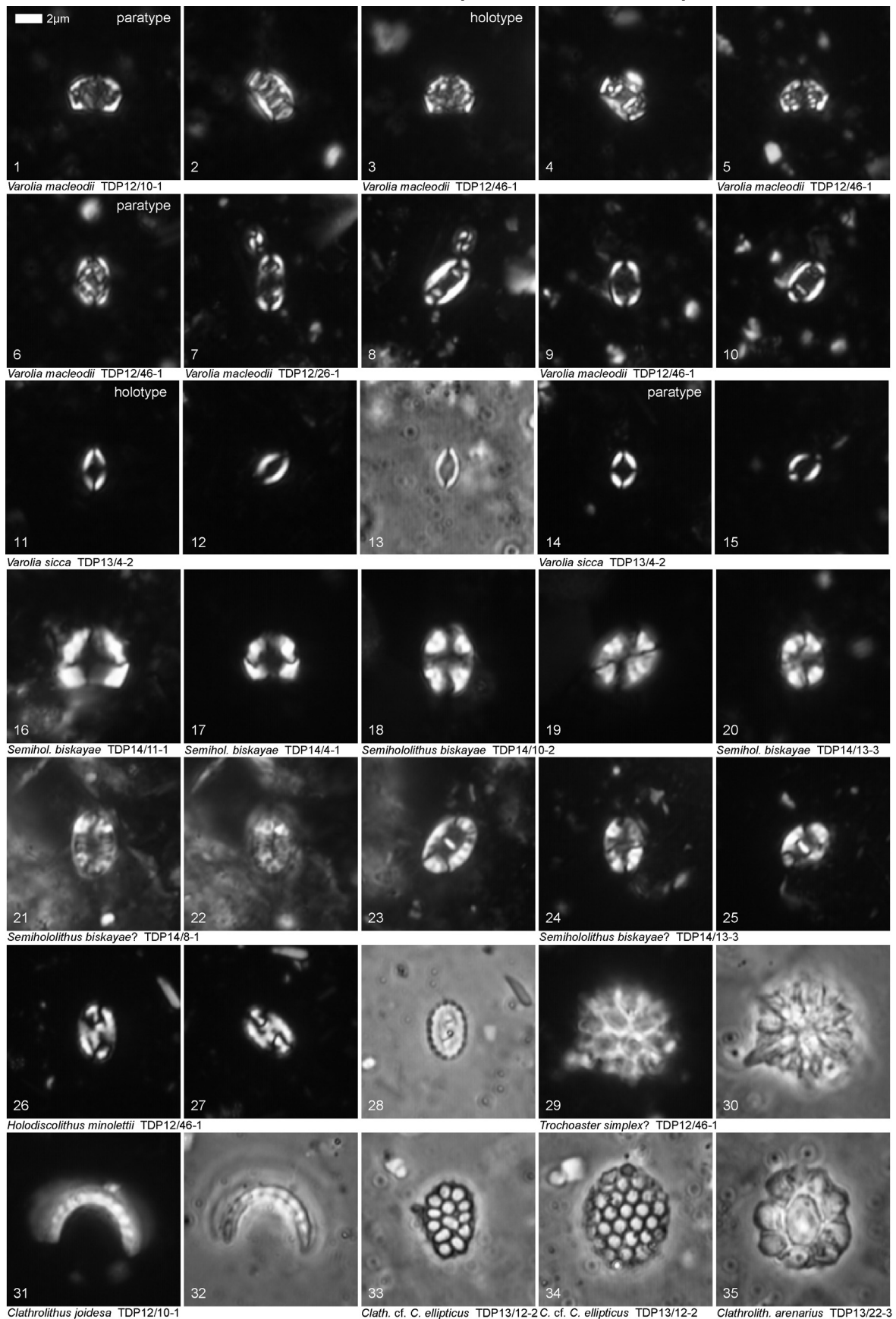
*Blackites, Holodiscolithus*

## Plate 4

Holococcoliths: *Youngilithus*, *Quadrilateris*, *Varolia*

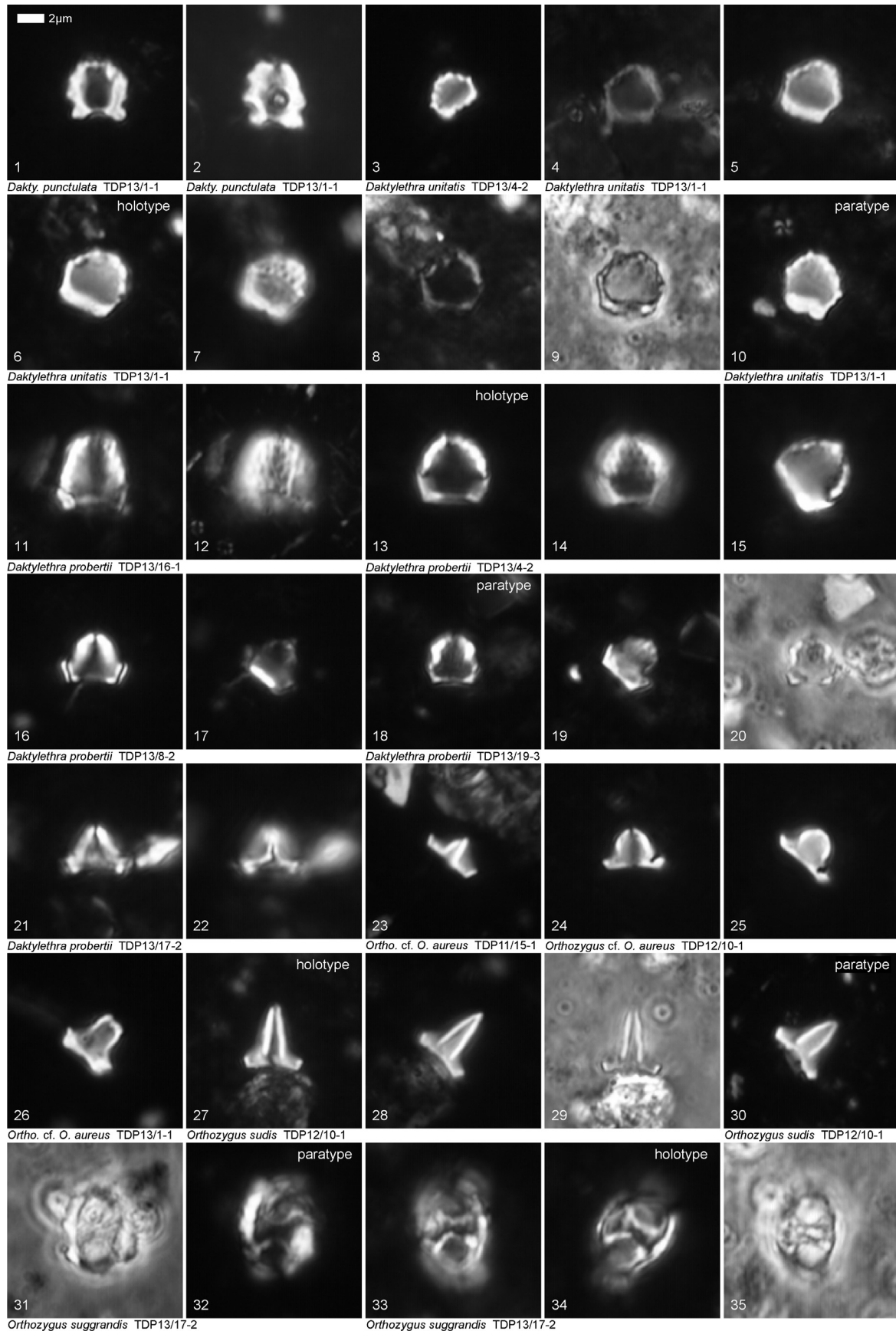
## Plate 5

### Holococcoliths: *Varolia*, *Semihololithus*, etc.

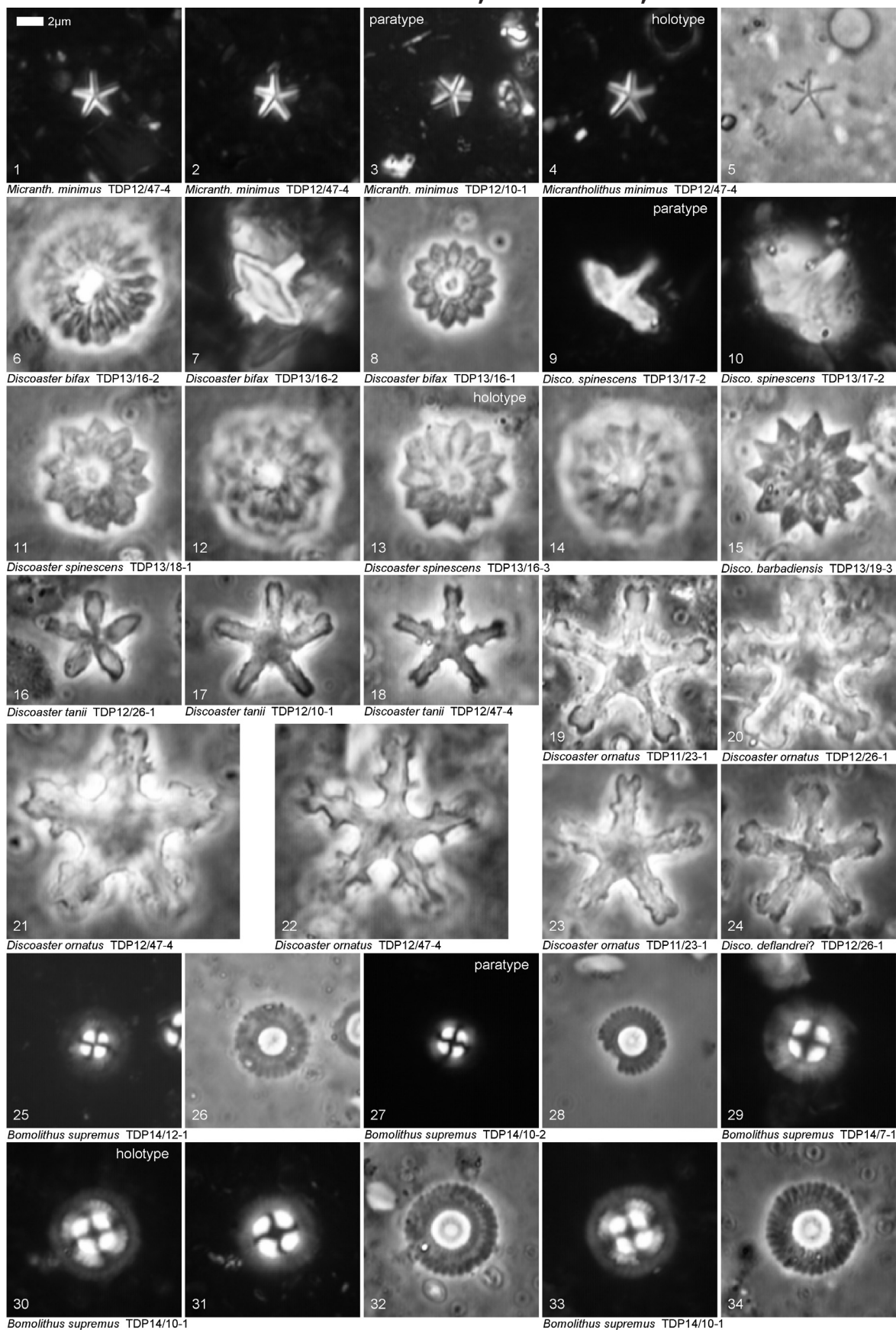




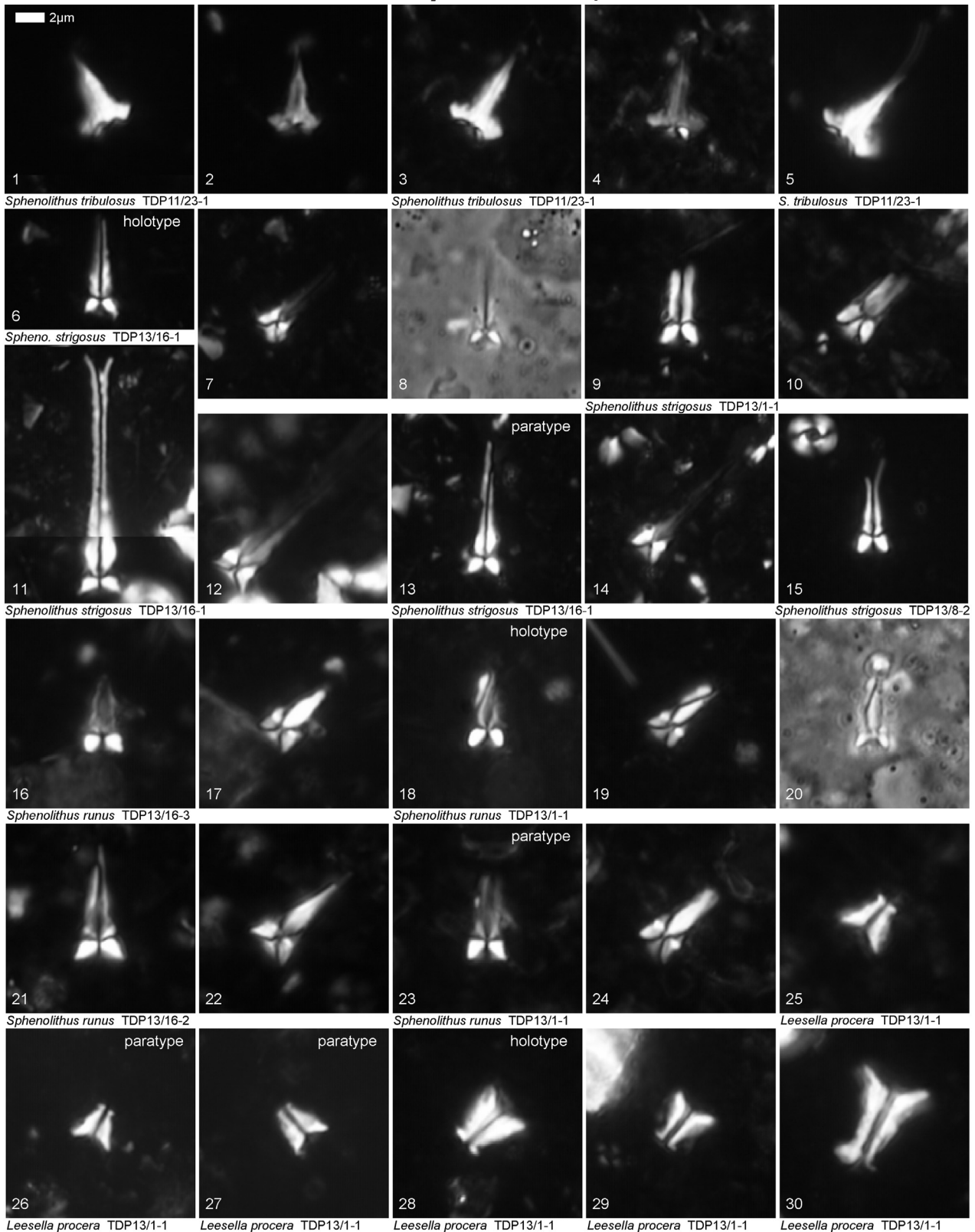
## Plate 6

Holococcoliths: *Dakylethra*, *Orthozygus*

## Plate 7

Nannoliths: *Micrantholithus*, *Discoaster*, *Bomololithus*

## Plate 8

Nannoliths: *Sphenolithus*, *Leesella*



# Plate 9

## Nannoliths: *Pemma?*, indeterminate

