

Calcareous nannofossils from the boreal Upper Campanian–Maastrichtian chalk of Denmark

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Abstract Boreal calcareous nannofossil assemblages have been documented from three sections in Denmark, from the Upper Campanian to Upper Maastrichtian (nannofossil zones UC16a^{BP} to UC20d^{BP}): the Stevns-1 borehole, next to the Cretaceous/Palaeogene boundary section of Stevns Klint, eastern Sjælland, the Rørdal-1 borehole and the Rørdal quarry section, North Jylland. The moderately-preserved nannofossil assemblages consist of a total of 138 species, comprising several rarely-documented species, several species that were recently described from lower latitudes, two new species of heterococcolith (*Prediscosphaera borealensis*, *Tranolithus stemmerikii*), and one new combination (*Staurolithites dicandidula*).

Keywords Calcareous nannofossils, taxonomy, Campanian, Maastrichtian, boreal, Denmark

1. Introduction

In 2005, the Cretaceous Research Centre (CRC) was established jointly at the Geocenter Copenhagen by the Department of Geography and Geology, University of Copenhagen, and the Geological Survey of Denmark and Greenland (GEUS). CRC projects aim to study the Earth System in a Greenhouse World, with special emphasis on the Upper Cretaceous to Danian chalcs of NW Europe. One of the main CRC projects was a drilling campaign at Stevns Klint in Sjælland (eastern Denmark), where two coreholes (Stevns-1 and Stevns-2) were drilled and logged from near the base of the Lower Danian Bryozoan Limestone, down through the upper 350m and 450m, respectively, of the thick Upper Cretaceous Chalk Group (Stemmerik *et al.*, 2006).

The investigation of calcareous nannofossil assemblages from the chalk of the Stevns-1 (Sjælland) and Rørdal-1 coreholes, and the Rørdal quarry section (northern Jylland; Figure 1) allowed for the testing of nannofossil biozonation schemes (Sheldon, 2008), and will be used to document the palaeoecological changes throughout the latest Cretaceous of Denmark. The sediments are moderately preserved and yield a diverse assemblage, including two new species, and several species recently described from Tanzania (Lees, 2007) that have not been recorded previously from boreal latitudes. The aim of this study is to provide a catalogue of the species encountered in the Danish Upper Campanian–Upper Maastrichtian Chalk Group, to serve as a guide for future studies in the area, and to complement the atlas presented in Burnett *et al.* (1998).

2. Material

The investigated succession belongs to the upper part of the Upper Cretaceous Chalk Group (Surlyk *et al.*, 2003). The Stevns-1 shallow corehole was drilled approximately 2km east of Sigerslev, immediately adjacent to the coastal cliff of Stevns Klint, in eastern Sjælland (Denmark; Fig-

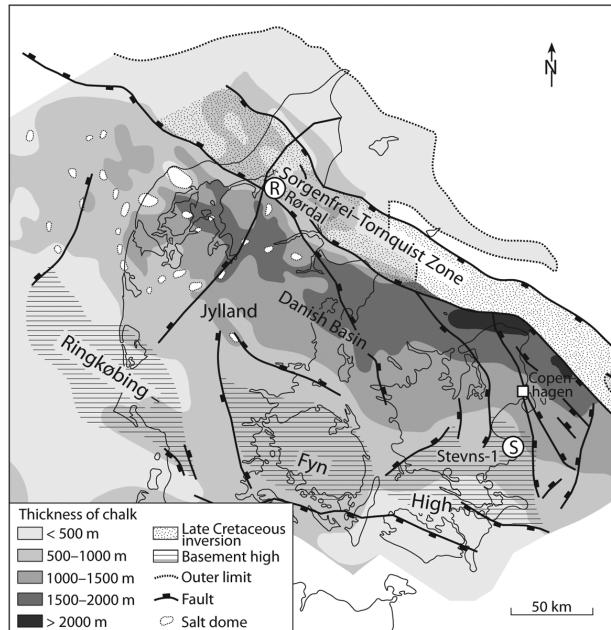


Figure 1: Late Cretaceous palaeogeography of the Danish area, showing locations of the Stevns-1 corehole and Rørdal

ure 1). The drilled succession was deposited on the eastern end of the Ringkøbing-Fyn High. The Stevns-1 corehole recovered 456m of sediment from the Lower Danian down into an Upper Campanian chalk-marl succession with near 100% recovery. The nannofossil biostratigraphy of the core was near-complete (Sheldon, 2008). Thus, to date, Stevns-1 represents the first complete onshore sequence through the Upper Campanian–Maastrichtian chalk of NW Europe (compare with Surlyk & Birkelund, 1977; Bailey *et al.*, 1983; Schulz *et al.*, 1983; Villain, 1988; Schönfeld *et al.*, 1996; Mutterlose *et al.*, 1998; Surlyk & Håkansson, 1999) and one of the most expanded Maastrichtian sections, worldwide, in the published literature (compare with sections in von der Borch *et al.*, 1974; Tucholke *et al.*, 1979;

Hay *et al.*, 1984; de Graciansky *et al.*, 1985; Heath *et al.*, 1985; Monechi & Thierstein, 1985; Huber, 1992; Mutterlose *et al.*, 1998; Li & Keller, 1998; Li *et al.*, 1999; Bralower *et al.*, 2002; Howe *et al.*, 2003; Erbacher *et al.*, 2004; Zachos *et al.*, 2004; Huber *et al.*, 2008).

The Rørdal quarry is situated in the town of Aalborg in northern Jylland. It is located in the inverted Aalborg Graben, which forms part of the NW-SE-orientated Sorgenfrei-Tornquist Zone, a region of the Danish Basin characterised by Late Cretaceous and Paleogene structural inversion (EUGENO-S Working Group, 1988). The quarry exposes up to 40m of Upper Maastrichtian chalk, including a c.10m-thick, cyclic chalk-marl unit at the top. Sediments are highly bioturbated and exhibit trace fossils, such as *Thallassinoides*, *Zoophycos* and *Chondrites*. The Rørdal-1 corehole was drilled in 1967 at a location immediately adjacent to the quarry wall. It penetrated about 100m of Upper Campanian-lowermost Upper Maastrichtian chalk, with a few clay laminae and thin marl layers occurring in the lowermost and uppermost parts of the core (Stenestad, 2005). Only chalk samples were examined during this analysis. Locality and age details for the samples mentioned here are given in Table 1.

The UC^{BP} (Boreal Province) part of the global nannofossil biozonation scheme of Burnett *et al.* (1998) was used to provide a nannofossil biostratigraphy for these cores. Biostratigraphic information about Stevns-1 is presented in Sheldon (2008). Full biostratigraphic information about Rørdal-1 and the Rørdal quarry section will be provided in a separate publication (Thibault *et al.*, in prep.). Preservation of the investigated samples is moderate.

Species richness varies between 40 and 80 species in the material investigated. This corresponds to 27 to 53% of the global compilation of nannofossil species for the Campanian–Maastrichtian interval (between 135 and 150; Bown *et al.*, 2004). This global estimation needs revision, because a number of new species from this interval have been recently described (Lees & Bown, 2005; Lees, 2007).

3. Methods

The species documented here are based on light-microscope (LM) observations only. Nannofossil smear-slides were prepared following the standard procedure (Bown & Young, 1998), and examination of nannofloras was performed using a Leica DMRP transmitting light microscope at 1600x magnification. Digital images were captured with a Leica DFC320 digital camera at 512 x 512 pixels, using UTHSCSA ImageTool 3.0 freeware (available at <http://ddsdx.uthscsa.edu/dig/itdesc.html>). All images were taken in either cross-polarised light (XPL), or in bright-field (BF), the latter being indicated on the plates. Morphometric measurements were performed using UTHSCSA ImageTool 3.0, a digital-image processing program. At a microscope magnification of 1600x, the pixel scale is 30

Sample	Depth (m)	Age	Biozone
Stevns-1 corehole (S1)			
1475	13.28	Upper Maastrichtian	UC20d ^{BP}
1474	14.29	Upper Maastrichtian	UC20d ^{BP}
1473	15.37	Upper Maastrichtian	UC20d ^{BP}
1471	17.25	Upper Maastrichtian	UC20d ^{BP}
1469	19.00	Upper Maastrichtian	UC20d ^{BP}
1467	21.39	Upper Maastrichtian	UC20d ^{BP}
1466	22.10	Upper Maastrichtian	UC20d ^{BP}
1463	24.42	Upper Maastrichtian	UC20d ^{BP}
1462	26.62	Upper Maastrichtian	UC20d ^{BP}
1447	40.24	Upper Maastrichtian	UC20d ^{BP}
1442	45.95	Upper Maastrichtian	UC20d ^{BP}
1432	55.90	Upper Maastrichtian	UC20d ^{BP}
1422	64.80	Upper Maastrichtian	UC20d ^{BP}
1411	75.00	Upper Maastrichtian	UC20b-c ^{BP}
8180	90.34	Upper Maastrichtian	UC20b-c ^{BP}
1390	95.53	Upper Maastrichtian	UC20b-c ^{BP}
8157	97.69	Upper Maastrichtian	UC20b-c ^{BP}
5623	99	Upper Maastrichtian	UC20b-c ^{BP}
1386	99.43	Upper Maastrichtian	UC20b-c ^{BP}
8147	101.74	Upper Maastrichtian	UC20b-c ^{BP}
5260	102.7	Upper Maastrichtian	UC20b-c ^{BP}
5256	102.87	Upper Maastrichtian	UC20b-c ^{BP}
5253	103	Upper Maastrichtian	UC20b-c ^{BP}
5235	103.72	Upper Maastrichtian	UC20b-c ^{BP}
1380	104.91	Upper Maastrichtian	UC20b-c ^{BP}
5209	105.3	Upper Maastrichtian	UC20b-c ^{BP}
5620	106.37	Upper Maastrichtian	UC20b-c ^{BP}
1370	114.81	Upper Maastrichtian	UC20b-c ^{BP}
1364	120.35	Upper Maastrichtian	UC20b-c ^{BP}
1353	130.73	Upper Maastrichtian	UC20b-c ^{BP}
1337	145.25	Upper Maastrichtian	UC20a ^{BP}
1310	170.50	Upper Maastrichtian	UC20a ^{BP}
1305	175.22	Lower Maastrichtian	UC19
1300	179.79	Lower Maastrichtian	UC19
1287	191.24	Lower Maastrichtian	UC19
1283	194.84	Lower Maastrichtian	UC19
1272	205.38	Lower Maastrichtian	UC19
1262	214.60	Lower Maastrichtian	UC19
1240	234.89	Lower Maastrichtian	UC19
1229	244.95	Lower Maastrichtian	UC19
1207	265.49	Lower Maastrichtian	UC17-18
1203	269.11	Lower Maastrichtian	UC17-18
1186	284.81	Campanian/Maastrichtian	UC16d ^{BP}
1175	295.04	Campanian/Maastrichtian	UC16d ^{BP}
1170	299.63	Campanian/Maastrichtian	UC16d ^{BP}
1164	305.29	Campanian/Maastrichtian	UC16d ^{BP}
7398	310.10	Campanian/Maastrichtian	UC16d ^{BP}
1153	315.41	Campanian/Maastrichtian	UC16d ^{BP}
7370	320.53	Campanian/Maastrichtian	UC16d ^{BP}
1141	325.77	Campanian/Maastrichtian	UC16d ^{BP}
1131	335.06	Campanian/Maastrichtian	UC16d ^{BP}
1119	345.85	Campanian/Maastrichtian	UC16d ^{BP}
1114	350.72	Campanian/Maastrichtian	UC16d ^{BP}
1109	355.34	Upper Campanian	UC16a-c ^{BP}
1087	375.86	Upper Campanian	UC16a-c ^{BP}
1083	379.61	Upper Campanian	UC16a-c ^{BP}
1066	395.40	Upper Campanian	UC16a-c ^{BP}
1055	405.77	Upper Campanian	UC16a-c ^{BP}
1044	415.78	Upper Campanian	UC16a-c ^{BP}
1034	425.24	Upper Campanian	UC16a-c ^{BP}
1029	429.71	Upper Campanian	UC16a-c ^{BP}
7086	430.25	Upper Campanian	UC16a-c ^{BP}
7084	430.75	Upper Campanian	UC16a-c ^{BP}
7081	431.5	Upper Campanian	UC16a-c ^{BP}
7076	432.88	Upper Campanian	UC16a-c ^{BP}
7074	433.57	Upper Campanian	UC16a-c ^{BP}
7072	433.97	Upper Campanian	UC16a-c ^{BP}
7070	434.69	Upper Campanian	UC16a-c ^{BP}
5028	434.92	Upper Campanian	UC16a-c ^{BP}
1017	441.13	Upper Campanian	UC15
1011	446.67	Upper Campanian	UC15
1007	450.48	Upper Campanian	UC15
1004	453.29	Upper Campanian	UC15
Rørdal-1 corehole (R1)			
10276	14.87	Lower Maastrichtian	UC19
10239	27.10	Lower Maastrichtian	UC19
10180	49.00	Lower Maastrichtian	UC19
10113	70.15	Campanian/Maastrichtian	UC16d ^{BP}
10071	81.00	Upper Campanian	UC16a-c ^{BP}
Rørdal quarry outcrop (Rq)			
461720	9.1	Upper Maastrichtian	UC20b-c ^{BP}
461716	10	Upper Maastrichtian	UC20b-c ^{BP}

Table 1 (right): Sample locations and biostratigraphy

pixels/ μm (1 pixel = $0.033\mu\text{m}$), with an accuracy of measurement of ± 2 pixels ($0.066\mu\text{m}$).

4. Systematic palaeontology

The terminology used in the descriptions below follows the guidelines of Young *et al.* (1997). In the taxonomic descriptions, L = length, W = width, WCA = width of the central area, LCA = length of the central area, E = ellipticity (ratio between coccolith length and width), central area opening (= mean ratio between LCA/L and WCA/W). Recorded occurrences in the studied sections: FO = first occurrence, LO = last occurrence. The higher taxonomy follows the classification of Bown & Young (1997). All references prior to 1998 can be found in Perch-Nielsen (1985) and Bown (1998). Others are given in the reference list.

4.1. Heterococcoliths

Imbricating muroliths (loxoliths)

Order EIFELLITHALES Rood *et al.*, 1971

Family CHIASTOZYGACEAE Rood *et al.*, 1973 emend. Varol & Girgis, 1994

Central-area axial cross or bars

Ahmuellerella octoradiata (Górka, 1957) Reinhardt, 1966
Pl.1, fig.1

Ahmuellerella regularis (Górka, 1957) Reinhardt &
Górka, 1967
Pl.1, figs 2, 3

Bukrylithus ambiguus Black, 1971
Pl.1, figs 4, 5

Heteromarginatus bugensis (Górka, 1957) Crux in Crux
et al., 1982
Pl.1, figs 6, 7

Monomarginatus quaternarius Wind & Wise in Wise &
Wind, 1977
Pl.1, fig.8

Staurolithites dicandidula (Bergen in Bralower &
Bergen, 1998) comb. nov.
Pl.1, figs 9-11

Basionym: *Vagalapilla dicandidula* Bergen in Bralower &
Bergen, 1998: p.76, pl.1, figs 1a, 1b (holotype). (Bralower,
T.J. & Bergen, J.A. 1998. Cenomanian-Santonian calcareous
nannofossil biostratigraphy of a transect of cores drilled
across the western interior seaway. In: M.A. Arthur & W.E.
Dean (Eds). *Stratigraphy and Paleoenvironments of the
Cretaceous Western Interior Seaway, USA. SEPM Concepts in Sedimentology and Paleontology*, 6: 59–77.)

Staurolithites elongatus (Bukry, 1969) Burnett, 1997a
Pl.1, fig.12

Staurolithites flavus Burnett, 1997a
Pl.1, fig.13

Staurolithites imbricatus (Gartner, 1968) Burnett, 1997a
Pl.1, figs 14, 15

Staurolithites laffitei Caratini, 1963
Pl.1, fig.16

Staurolithites mielnicensis (Górka, 1957) Perch-Nielsen,
1968 *sensu* Crux in Lord, 1982
Pl.1, figs 17, 18

Staurolithites zoensis Burnett, 1997a
Pl.1, figs 19, 20

Central-area transverse bar

Gorkaea pseudanthophorus (Bramlette & Martini, 1964)
Varol & Girgis, 1994
Pl.1, figs 21, 22

Placozygus fibuliformis (Reinhardt, 1964) Hoffmann,
1970
Pl.1, figs 23-25

Reinhardtites anthophorus (Deflandre, 1959)
Perch-Nielsen, 1968
Pl.1, figs 26-28

Reinhardtites levis Prins & Sissingh in Sissingh, 1977
Pl.1, figs 29-31

Tranolithus minimus (Bukry, 1969) Perch-Nielsen, 1984
Pl.1, fig.32
Tranolithus orionatus (Reinhardt, 1966a) Perch-Nielsen,
1968
Pl.1, fig.33

Tranolithus stemmerikii Thibault & Sheldon sp. nov.
Pl.1, figs 34, 35, Pl.2, figs 1-3. **Derivation of name:** After
Lars Stemmerik, Head of the Department of Geography
and Geology at the University of Copenhagen, co-founder
of the CRC group. **Diagnosis:** A medium-sized species of
Tranolithus with a reduced and small transverse bar and a
strongly birefringent inner cycle. The inner cycle appears
to extend into four plates that almost fill the central area.
Opposing plates go into extinction together when rotated
through 30° (Pl.1, figs 33, 34; Pl.2, figs 1, 2). The plates
covering the central area surround two openings, aligned
with the long axis of the coccolith (Pl.1, fig.33; Pl.2, fig.1).
The bar is apparent only in well-preserved specimens and
only through certain angles when rotated. **Differentiation:**
This new species is distinguished from other species of
Tranolithus by its small transverse bar and by its strongly
birefringent inner cycle, composed of four plates that fill
the central area and surround two openings that are aligned
with the long axis. In recrystallised specimens, the central
area is entirely covered by the four plates (Pl.2, fig.3). This
species is documented and referred to as *Zeugrhabdotus*
praesigmoides in Sheldon (2008, Pl.1, figs 15-18).
Holotype: Pl.1, figs 33-35 (L = $6.8\mu\text{m}$, W = $5\mu\text{m}$).
Paratypes: Pl.2, figs 1-4. **Type locality:** Stevns-1 corehole,
Denmark. **Type level:** S1-7076, Upper Campanian
(UC16a^{BP}-c^{BP}). **Occurrence:** Stevns-1, Rørdal-1; Upper
Campanian–Campanian/Maastrichtian boundary interval
(UC15e^{BP}-UC16). **Remarks:** Both in Stevns-1 and Rørdal-

1, the LO of this species was recorded within UC16d^{BP}. It thus has potential as a biostratigraphic indicator of the Campanian/Maastrichtian boundary interval.

Zeugrhabdotus acanthus Reinhardt, 1965
Pl.2, figs 5-7

Zeugrhabdotus bicrescenticus (Stover, 1966) Burnett in Gale et al., 1996
Pl.2, fig.8

Zeugrhabdotus blowii Lees, 2007
Pl.2, figs 9, 10

Zeugrhabdotus diplogrammus (Deflandre in Deflandre & Fert, 1954) Burnett in Gale et al., 1996
Pl.2, figs 11, 12

Zeugrhabdotus cf. Z. erectus (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
Pl.2, fig.13

Zeugrhabdotus erectus (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
Pl.2, fig.14

Zeugrhabdotus sigmoides (Bramlette & Sullivan, 1961)
Bown & Young, 1997
Pl.2, figs 15-17

Zeugrhabdotus trivectis Bergen, 1994
Pl.2, figs 18, 19

Central-area net or vacant

Loxolithus armilla (Black in Black & Barnes, 1959)
Noël, 1965
Pl.2, fig.20

Loxolithus thiersteinii (Roth, 1973) Lees & Bown, 2005
Pl.2, fig.21

Central-area diagonal cross

Chiastozygus amphipons (Bramlette & Martini, 1964)
Gartner, 1968
Pl.2, fig.22

Chiastozygus antiquus (Perch-Nielsen, 1973) Burnett, 1997a
Pl.2, figs 23-25

Chiastozygus bifarius Bukry, 1969
Pl.2, figs 26-28

Chiastozygus litterarius (Górka, 1957) Manivit, 1971
Pl.2, fig.29

Chiastozygus spissus Bergen in Bralower & Bergen, 1998
Pl.2, figs 30, 31

Central-area closed

Neocrepidolithus cf. N. cohenii (Perch-Nielsen, 1968)
Perch-Nielsen, 1984
Pl.2, figs 32-35

Neocrepidolithus ruegenensis Burnett, 1997a
Pl.3, fig.1

Family EIFFELLITHACEAE Reinhardt, 1965

Eiffellithus collis Hoffman, 1970
Pl.3, fig.2

Eiffellithus eximus (Stover, 1966) Perch-Nielsen, 1968
Pl.3, figs 3, 4

Eiffellithus gorkae Reinhardt, 1965
Pl.3, fig.5

Eiffellithus parallelus Perch-Nielsen, 1973
Pl.3, figs 6, 7

Eiffellithus turriseiffelii (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
Pl.3, figs 8, 9

Helicolithus anceps (Górka, 1957) Noël, 1970
Pl.3, figs 10, 11

Helicolithus trabeculatus (Górka, 1957) Verbeek, 1977
Pl.3, fig.12

Family RHAGODISCACEAE Hay, 1977

Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971
Pl.3, figs 13, 14

Rhagodiscus plebeius Perch-Nielsen, 1968
Pl.3, fig.15

Rhagodiscus reniformis Perch-Nielsen, 1973
Pl.3, fig.16

Rhagodiscus splendens (Deflandre, 1953) Verbeek, 1977
Pl.3, fig.17

Non-imbricating muroliths (loxoliths and/or protoliths)

Order STEPHANOLITHIALES Bown & Young, 1997

Family STEPHANOLITHIACEAE Black, 1968

Corollithion completum Perch-Nielsen, 1973
Pl.3, fig.18

Corollithion exiguum Stradner, 1961
Pl.3, fig.19

Corollithion? madagaskarensis Perch-Nielsen, 1973
Pl.3, fig.20

Cylindralithus serratus Bramlette & Martini, 1964
Pl.3, fig.21

Cylindralithus nudus Bukry, 1969
Pl.3, fig.22

Cylindralithus? nieliae Burnett, 1997a
Pl.3, figs 23, 24

Perchnielsenella stradneri (Perch-Nielsen, 1973) Watkins in Watkins & Bowdler, 1984
Pl.3, fig.25

Rhombolithion rhombicum (Stradner & Adamiker, 1966)
Black, 1973
Pl.3, fig.26

Rotelapillus Noël, 1973
Rotelapillus sp.
Pl.3, figs 27, 28

**Non-imbricating (or radial) placoliths
and related taxa**

**Order PODORHABDALES Rood *et al.*
emend. Bown, 1987**

Family AXOPODORHABDACEAE Bown & Young, 1997

Cribrocorona gallica (Stradner, 1963) Perch-Nielsen, 1973
Pl.3, fig.29

Cribrosphaerella circula (Risatti, 1973) Lees, 2007
Pl.3, fig.30

Cribrosphaerella daniæ Perch-Nielsen, 1973
Pl.3, figs 31, 32

Cribrosphaerella ehrenbergii (Arkhangelsky, 1912)
Deflandre in Piveteau, 1952
Pl.3, figs 33-35

Nephrolithus miniporus Reinhardt & Górká, 1967
Pl.4, figs 1, 5

Nephrolithus frequens Górká, 1957
Pl.4, figs 2-5

Perissocyclus fenestratus (Stover, 1966) Black, 1971
Pl.4, figs 6-10

Tetrapodorhabdus decorus (Deflandre in Deflandre & Fert, 1954) Wind & Wise in Wise & Wind, 1977
Pl.4, figs 11, 12

Family BISCUTACEAE Black, 1971

Biscutum constans (Górká, 1957) Black in Black & Barnes, 1959 var. *constans*
Pl.4, figs 13, 14

Biscutum constans (Górká, 1957) Black in Black & Barnes, 1959 var. *ellipticum* (Górká, 1957)
Pl.4, fig.15

Remarks: *B. constans* and *B. ellipticum* are herein considered to be morphotypes, rather than distinct species, following the work of Bornemann & Mutterlose (2006), who found the overall population of *constans* to have a smaller range of sizes than *ellipticum*, but strongly overlapped with the latter, and so size was determined not to be a useful criterion upon which to distinguish between the taxa; these can only be differentiated by the structure of the central area - small in *constans* and large and perforated in *ellipticum*.

Biscutum coronum Wind & Wise in Wise & Wind, 1977
Pl.4, figs 16, 17

Biscutum magnum Wind & Wise in Wise & Wind, 1977
Pl.4, fig.18

Biscutum melaniae (Górká, 1957) Burnett, 1997a
Pl.4, figs 19, 20

Biscutum notaculum Wind & Wise in Wise & Wind, 1977
Pl.4, figs 21, 22

Discorhabdus ignotus (Górká, 1957) Perch-Nielsen, 1968

Pl.4, figs 23-26

Family CRETARHABDACEAE Thierstein, 1973

Cretarhabdus conicus Bramlette & Martini, 1964
Pl.4, fig.27

Grantarhabdus coronadventis (Reinhardt, 1966) Grün in Grün & Allemann, 1975

Pl.4, figs 28, 29

Miravetesina bergenii Lees, 2007
Pl.4, fig.30

Retecapsa angustiforata Black, 1971
Pl.4, figs 31-33

Retecapsa crenulata (Bramlette & Martini, 1964) Grün in Grün & Allemann, 1975

Pl.4, figs 34, 35; Pl.5, fig.1

Retecapsa ficula (Stover, 1966) Burnett, 1997a
Pl.5, figs 2, 3

Retecapsa schizobrachiata (Gartner, 1968) Grün in Grün & Allemann, 1975
Pl.5, figs 4, 5

Retecapsa surirella (Deflandre in Deflandre & Fert, 1954) Grün in Grün & Allemann, 1975

Pl.5, figs 6-13. **Remarks:** A central cross is not routinely observed in *R. surirella* with the LM in this material. In some better-preserved specimens, the axial cross can be observed by rotating and focusing up and down (Pl.5, figs 10-13).

Family PREDISCOSPHAERACEAE Rood *et al.*, 1971

Prediscosphaera arkhangelskyi (Reinhardt, 1965) Perch-Nielsen, 1984

Pl.5, figs 14-17. **Remarks:** The occurrence of this species in Stevens-1 and Rørdal-1 is consistent until the top of UC16d^{BP}, where it becomes more sporadic. The LO of this rare species was recorded within UC20a^{BP} in Rørdal-1 and at the base of UC20b^{BP}-c^{BP} in Stevens-1. Perch-Nielsen (1979) noted its LO within CC23b (equivalent to UC17 of Burnett, 1998).

Prediscosphaera stoveri (Perch-Nielsen, 1968) Shafik & Stradner, 1971
Pl.5, figs 18, 19

Prediscosphaera borealensis sp. nov.

Pl.5, figs 20-25. **Derivation of name:** Referring to the northern high latitudes, from where this species is described. **Diagnosis:** A small, elliptical species of *Prediscosphaera* with a thin, axial cross, a thin outer cycle, and a wide inner cycle, which tends to enclose the central area (Pl.4, figs 20, 21). The inner cycle exhibits an anticlockwise spiral interference pattern and almost fills the central area around the axial cross. The axial cross appears very slightly offset from the axes of the coccolith, and its arms are slightly sigmoidal. Only a few better-preserved speci-

mens were found with the axial cross present in this study. In most specimens encountered, the cross was absent (Pl.5, figs 22-25). It is possible that the cross is not visible in proximal view, where the inner cycle virtually fills the central area (Pl.5, figs 24, 25). **Differentiation:** This species exhibits the same size range as *P. stoveri* (Table 2, Figure 2). It can be distinguished from the latter, and from *P. spinosa* (Pl.6, figs 8-10), by the spiral pattern exhibited by the inner cycle, the relatively thinner outer cycle, the more enclosed central area (Figure 2, and compare Pl.5, figs 18, 19

with Pl.5, figs 20-25), and the different composition of the axial cross. In *P. stoveri* and *P. spinosa*, the arms of the cross are straight and aligned with the axes of the coccolith (Pl.5, figs 18, 19; Pl.6, figs 8-10), whilst in the new species, the arms are slightly offset from the axes and slightly sigmoidal (Pl.5, figs 20, 21). The new species differs from *P. arkhangelskyi* (Pl.5, figs 14-16) by its smaller size, the more enclosed central area, and the slightly offset and slightly sigmoidal axial cross. **Holotype:** Pl.5, fig.20 ($L = 5.1\mu m$, $W = 3.6\mu m$; see Table 2 for range of dimensions).

Sample	Species	Length	Width	Ellipticity	Length central area (LCA)	Width central area (WCA)	Ratio LCA/length	Ratio WCA/width	Central area opening	Outer cycle width	
7081	<i>P. borealensis</i> (holotype)	5.10	3.60	1.42	1.70	1.30	0.33	0.36	0.35	0.50	
7081	<i>P. borealensis</i>	5.00	3.40	1.47	1.90	1.30	0.38	0.38	0.38	0.60	
7081	<i>P. borealensis</i>	5.20	3.60	1.44	1.80	1.30	0.35	0.36	0.35	0.60	
1131	<i>P. borealensis</i>	3.80	2.63	1.44	1.15	0.77	0.30	0.29	0.30	0.50	
1131	<i>P. borealensis</i>	4.17	3.26	1.28	1.05	1.20	0.25	0.37	0.31	0.50	
1131	<i>P. borealensis</i>	3.99	2.95	1.35	1.27	0.93	0.32	0.32	0.32	0.50	
1131	<i>P. borealensis</i>	3.99	2.54	1.57	1.39	0.65	0.35	0.26	0.30	0.50	
1131	<i>P. borealensis</i>	4.07	3.17	1.28	1.16	0.89	0.29	0.28	0.28	0.60	
1131	<i>P. borealensis</i>	4.15	2.91	1.43	0.98	0.74	0.24	0.25	0.25	0.60	
1131	<i>P. borealensis</i>	4.01	2.88	1.39	0.85	0.55	0.21	0.19	0.20	0.60	
1131	<i>P. borealensis</i>	3.79	2.64	1.44	0.78	0.55	0.21	0.21	0.21	0.60	
1131	<i>P. borealensis</i>	3.86	2.94	1.31	0.93	0.64	0.24	0.22	0.23	0.60	
1131	<i>P. borealensis</i>	3.87	3.13	1.24	0.90	0.52	0.23	0.17	0.20	0.70	
7076	<i>P. borealensis</i>	4.85	3.40	1.43	1.40	0.90	0.29	0.26	0.28	0.60	
7076	<i>P. borealensis</i>	5.30	3.50	1.51	1.70	1.00	0.32	0.29	0.30	0.60	
		Mean	4.34	3.10	1.40	1.26	0.88	0.29	0.28	0.28	0.57
		Maximum	5.30	3.60	1.57	1.90	1.30	0.38	0.38	0.38	0.70
		Minimum	3.79	2.54	1.24	0.78	0.52	0.21	0.17	0.20	0.50
<hr/>											
1131	<i>P. stoveri</i>	4.24	3.21	1.32	1.89	1.18	0.45	0.37	0.41	0.80	
1131	<i>P. stoveri</i>	4.20	3.13	1.34	1.60	1.31	0.38	0.42	0.40	0.60	
1131	<i>P. stoveri</i>	3.41	2.52	1.35	1.45	0.88	0.43	0.35	0.39	0.60	
1131	<i>P. stoveri</i>	4.89	3.62	1.35	2.36	1.57	0.48	0.43	0.46	0.80	
1131	<i>P. stoveri</i>	3.74	3.59	1.04	1.50	1.29	0.40	0.36	0.38	0.90	
1131	<i>P. stoveri</i>	3.74	3.05	1.23	1.92	1.25	0.51	0.41	0.46	0.70	
1131	<i>P. stoveri</i>	3.52	2.65	1.33	1.37	1.03	0.39	0.39	0.39	0.60	
1131	<i>P. stoveri</i>	3.78	2.42	1.56	1.82	0.95	0.48	0.39	0.44	0.80	
1131	<i>P. stoveri</i>	5.20	4.00	1.30	2.20	1.44	0.42	0.36	0.39	0.70	
1131	<i>P. stoveri</i>	4.59	3.71	1.24	2.13	1.56	0.46	0.42	0.44	1.00	
1131	<i>P. stoveri</i>	4.15	3.02	1.37	1.89	1.41	0.46	0.47	0.46	0.80	
1463	<i>P. stoveri</i>	4.00	3.40	1.18	1.60	0.80	0.40	0.24	0.32	0.90	
1463	<i>P. stoveri</i>	3.50	2.80	1.25	1.40	1.00	0.40	0.36	0.38	0.60	
1463	<i>P. stoveri</i>	4.30	3.60	1.19	2.00	1.20	0.47	0.33	0.40	0.80	
1463	<i>P. stoveri</i>	4.00	3.20	1.25	1.50	0.90	0.38	0.28	0.33	0.80	
		Mean	4.08	3.19	1.29	1.78	1.18	0.43	0.37	0.40	0.76
		Maximum	5.20	4.00	1.56	2.36	1.57	0.51	0.47	0.46	1.00
		Minimum	3.41	2.42	1.04	1.37	0.80	0.38	0.24	0.32	0.60

Table 2: Dimensions and other morphometric parameters for *Prediscosphaera borealensis* sp. nov. and *P. stoveri* (15 specimens each)

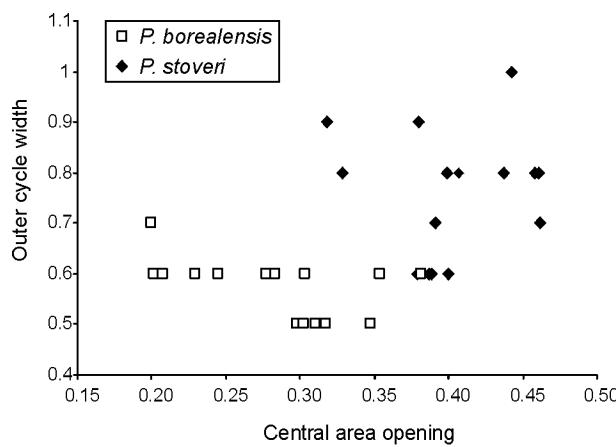


Figure 2: Cross-plot of outer-cycle width versus central-area opening for *Prediscosphaera borealensis* and *P. stoveri* (15 specimens each)

Paratypes: Pl.5, figs 21-25. **Type locality:** Stevns-1 core-hole, Denmark. **Type level:** S1-7081, Upper Campanian (UC16a^{BP}-c^{BP}). **Occurrence:** Stevns-1, Rørdal-1; Upper Campanian-Lower Maastrichtian (UC16a^{BP}-UC19).

- Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968
Pl.5, figs 26-30
Prediscosphaera grandis Perch-Nielsen, 1979
Pl.5, fig.31
Prediscosphaera incohatus (Stover, 1966) Burnett, 1997a
Pl.5, figs 32, 33
Prediscosphaera majungae Perch-Nielsen, 1973
Pl.5, figs 34, 35

Prediscosphaera mgayae Lees, 2007
Pl.6, figs 1-3. **Remarks:** This species may have potential as a stratigraphic tool. Both in Stevns-1 and Rørdal-1, its FO lies within UC16d^{BP} and its LO was recorded at the same stratigraphic level as that of *Reinhardtites levis*, which marks the top of UC18. Lees (2007), who described this species, noted its occurrence within UC17 in Tanzania.

- Prediscosphaera microrhabdulina* Perch-Nielsen, 1973
Pl.6, figs 4, 5
Prediscosphaera ponticula (Bukry, 1969) Perch-Nielsen, 1984
Pl.6, figs 6, 7
Prediscosphaera spinosa (Bramlette & Martini, 1964)
Gartner, 1968
Pl.6, figs 8-10

Family **TUBODISCACEAE** Bown & Rutledge in Bown & Young, 1997

- Manivitella pemmatoida* (Deflandre in Manivit, 1965)
Thierstein, 1971
Pl.6, fig.11

Imbricating placoliths

Order WATZNAUERIALES Bown, 1987

Family WATZNAUERIACEAE Rood *et al.*, 1971

Cyclagelosphaera alta Perch-Nielsen, 1979

Pl.6, fig.12

Cyclagelosphaera margerelii Noël, 1965

Pl.6, figs 13, 14

Cyclagelosphaera reinhardtii (Perch-Nielsen, 1968)

Romein, 1977

Pl.6, fig.15

Cyclagelosphaera rotaclypeata Bukry, 1969

Pl.6, fig.16

Cyclagelosphaera cf. C. tubulata Grün & Zweili, 1980

Pl.6, fig.18

Watznaueria barnesiae (Black, 1959) Perch-Nielsen,

1968

Pl.6, figs 19, 20, 31

Watznaueria biporta Bukry, 1969

Pl.6, figs 21, 22

Watznaueria britannica (Stradner, 1963) Reinhardt, 1964

Pl.6, figs 23, 24. **Remarks:** This species has been assumed to become extinct in the Lower Cenomanian (Burnett *et al.*, 1998), although a few specimens were found in the Coniacian (Burnett *in* Burnett *et al.*, 1998, fig.6.4). In this study, very rare specimens were found in one sample from the Campanian–Maastrichtian interval (UC16d^{BP}) and three samples from the Upper Maastrichtian (UC20a^{BP} and UC20d^{BP}).

Watznaueria manivitiae sensu lato Bukry, 1973

Pl.6, figs 25-27

Watznaueria cf. W. ovata Bukry, 1969

Pl.6, figs 28, 29

Watznaueria ovata Bukry, 1969

Pl.6, fig.30

Other placolith-like coccoliths

Family **ARKHANGELSKIELLACEAE** Bukry, 1969
emend. Bown & Hampton *in* Bown & Young, 1997

Arkhangelskiella confusa Burnett, 1997a

Pl.6, fig.32

Arkhangelskiella cymbiformis Vekshina, 1959

Pl.6, figs 33, 34

Arkhangelskiella maastrichtiensis Burnett, 1997a

Pl.6, fig.35; Pl.7, fig.1

Broinsonia enormis (Shumenko, 1968) Manivit, 1971
Pl.7, fig.2

Broinsonia parca constricta Hattner *et al.*, 1980

Pl.7, fig.3

Broinsonia parca parca (Stradner, 1963) Bukry, 1969
Pl.7, fig.4

Broinsonia signata (Noël, 1969) Noël, 1970
Pl.7, figs 5, 6

Deflandre, 1947
Pl.8, figs 3, 4

- Family **KAMPTNERIACEAE** Bukry, 1969 emend.
Bown & Hampton in Bown & Young, 1997
- Gartnerago segmentatum* (Stover, 1966) Thierstein, 1974
Pl.7, figs 7, 8
- Gartnerago nanum* Thierstein, 1974
Pl.7, figs 9, 10
- Kamptnerius magnificus* Deflandre, 1959
Pl.7, fig.11

Placoliths of uncertain affinity

- Markalius apertus* Perch-Nielsen, 1979
Pl.7, fig.12
- Markalius inversus* (Deflandre in Deflandre & Fert, 1954) Bramlette & Martini, 1964
Pl.7, figs 13, 14
- Repagulum parvidentatum?* (Deflandre in Deflandre & Fert, 1954) Forchheimer, 1972
Pl.7, figs 19-21

Muroliths

- Tortolithus caistorensis* Crux in Crux et al., 1982
Pl.7, figs 15, 16
- Tortolithus hallii* (Bukry, 1969) Crux in Crux et al., 1982
Pl.7, figs 17, 18
Coccolith sp.
Pl.7, figs 22-26

4.2. Holococcoliths

- Family **CALYPTROSPHAERACEAE** Boudreault & Hay, 1969
- Acuturris scotus* (Risatti, 1973) Wind & Wise in Wise & Wind, 1977
Pl.7, fig.27
- Calculites paulus* Lees, 2007
Pl.7, figs 28-30
- Calculites obscurus* (Deflandre, 1959) Prins & Sissingh in Sissingh, 1977
Pl.7, fig.29
- Calculites* cf. *C. rosalyiae* Lees, 2007
Pl.7, figs 32, 33
- Octolithus multiplus* (Perch-Nielsen, 1973) Romein, 1979
Pl.7, figs 34, 35
- Lucianorhabdus cayeuxii* Deflandre, 1959
Pl.8, figs 1, 2

4.3. Nannoliths

- Family **BRAARUDOSPHERACEAE** Deflandre, 1947
- Braarudosphaera bigelowii* (Gran & Braarud, 1935)

Family **LAPIDEACASSACEAE** Bown & Young, 1997

Lapideacassis Black, 1971
Lapideacassis sp.

Pl.8, fig.5. **Remarks:** Three specimens of *Lapideacassis* were found in Stevns-1 sediments. All of them were broken and lacked the tapering termination(s) which allow identification at the species level.

Family **MICRORHABDULACEAE** Deflandre, 1963

- Lithraphidites carniolensis* Deflandre, 1963
Pl.8, fig.6
- Lithraphidites quadratus* Bramlette & Martini, 1964
Pl.8, fig.7
- Microrhabdulus undosus* Perch-Nielsen, 1973
Pl.8, figs 8-10
- Microrhabdulus decoratus* Deflandre, 1959
Pl.8, figs 11-15

Family **POLYCYCLOLITHACEAE** Forchheimer, 1972 emend. Varol, 1992

- Micula concava* (Stradner in Martini & Stradner, 1960)
Verbeek, 1976
Pl.9, figs 16, 17
- Micula cubiformis* Forchheimer, 1972
Pl.9, fig.18

Micula decussata Vekshina, 1959

Pl.9, fig.19. **Remarks:** As stated by Perch-Nielsen (1985), *M. decussata* should be used rather than its synonym *M. staurophora*, because the latter was poorly described from Miocene sediments into which it may have been re-worked.

Micula murus (Martini, 1961) Bukry, 1973

Pl.9, fig.20. **Remarks:** *M. murus* is generally restricted to tropical regions (Thierstein, 1981; Lees, 2002). It occurs in a very few samples of the uppermost Maastrichtian of Stevns-1 (upper part of UC20d^{BP}).

Micula swastica Stradner & Steinmetz, 1984

Pl.9, figs 21-23

- Uniplanarius gothicus* (Deflandre, 1959) Hattner & Wise, 1980
Pl.9, fig.24
- Quadrum svabenickae* Burnett, 1997a
Pl.9, fig.25

INCERTAE SEDIS

- Ceratolithoides indiensis* Burnett, 1997b
Pl.9, figs 26-28

Ceratolithoides self-trailiae Burnett, 1997b
Pl.9, figs 29, 30. **Remarks:** *Ceratolithoides* species are generally restricted to tropical regions (Lees, 2002). A few specimens occur in samples from the Campanian/Maastrichtian boundary interval (UC16d^{BP}), close to the Lower/Upper Maastrichtian boundary (UC20a^{BP}), and in the uppermost Maastrichtian (upper part of UC20d^{BP}).

Biantholithus sparsus Bramlette & Martini, 1964
Pl.9, figs 31, 32

4.4. Calcareous dinocysts

Thoracosphaera Kamptner, 1927

Thoracosphaera sp.

Pl.9, fig.33

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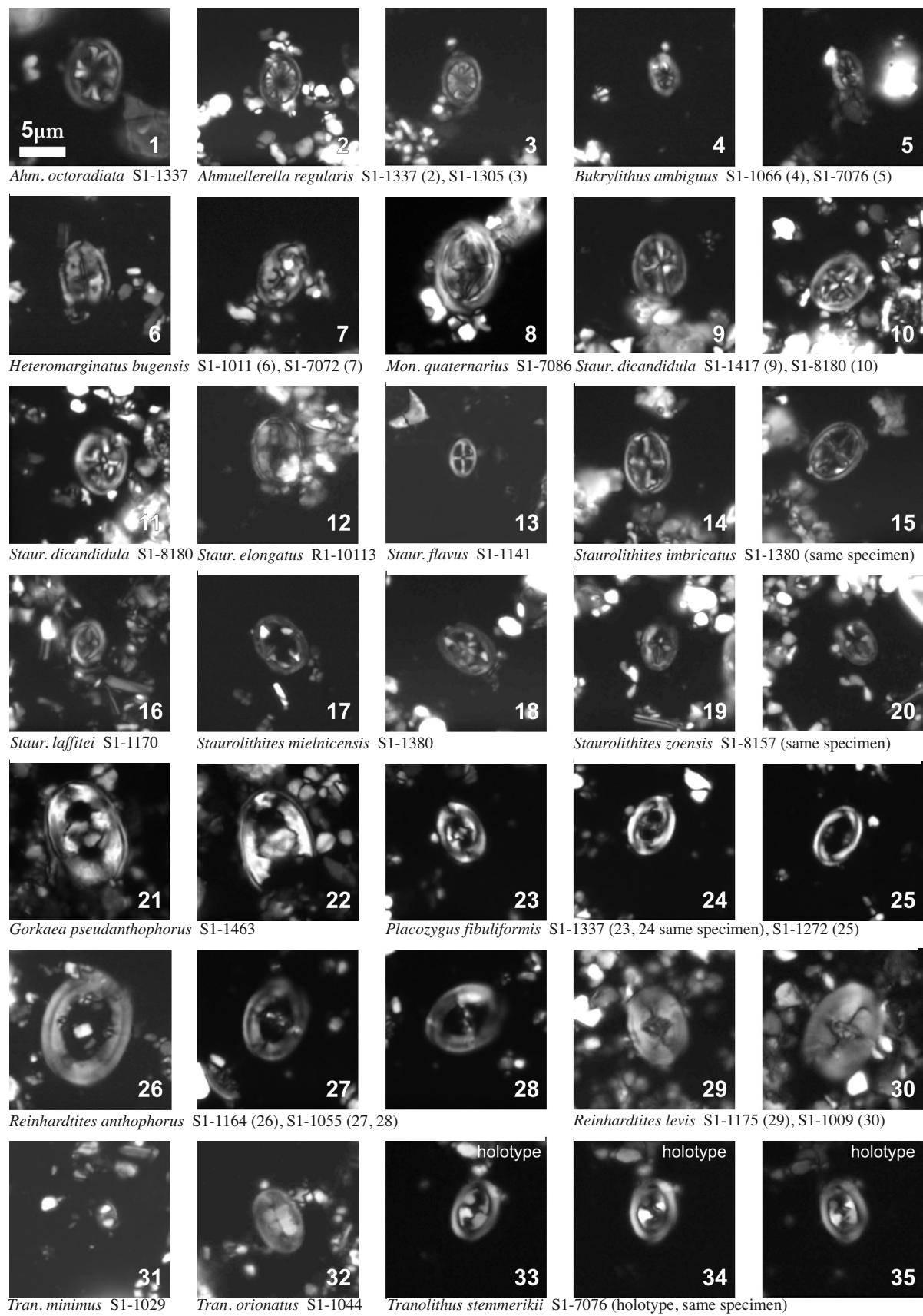
Plate 1**Chiastozygaceae**

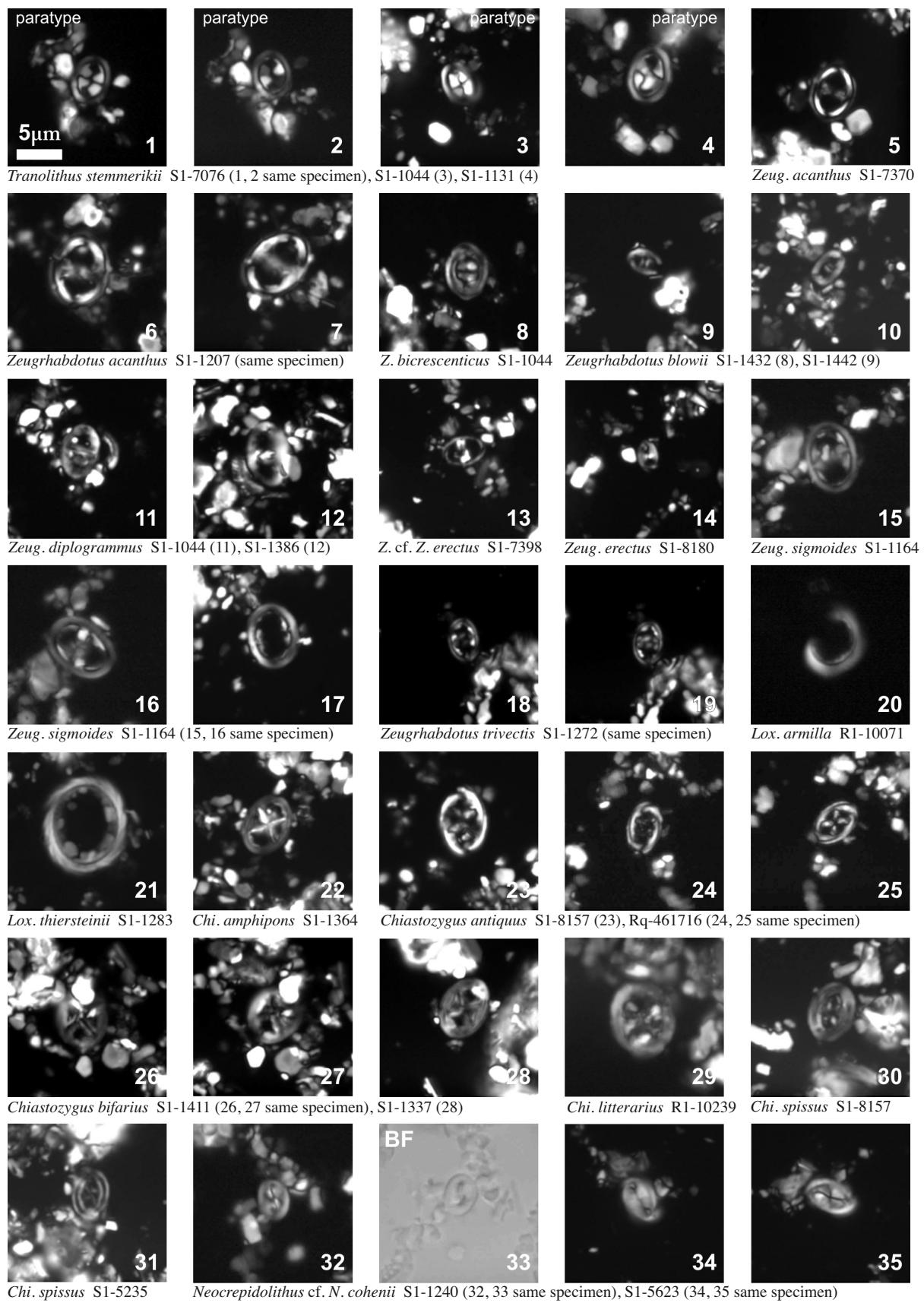
Plate 2**Chiastozygaceae**

Plate 3

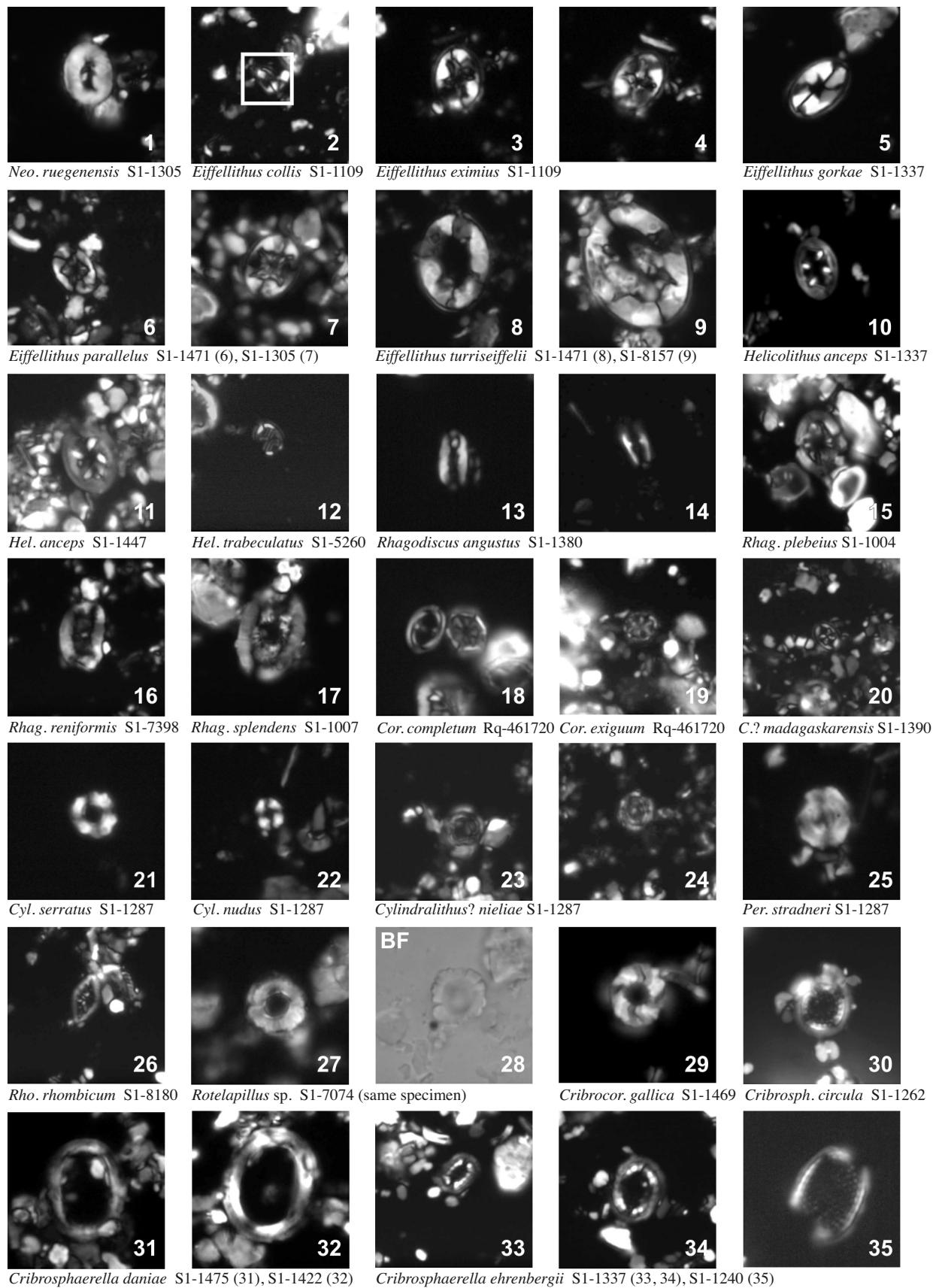
Chiastozygaceae, Eiffellithaceae, Rhagodiscaceae, Stephanolithiaceae, Axopodorhabdaceae


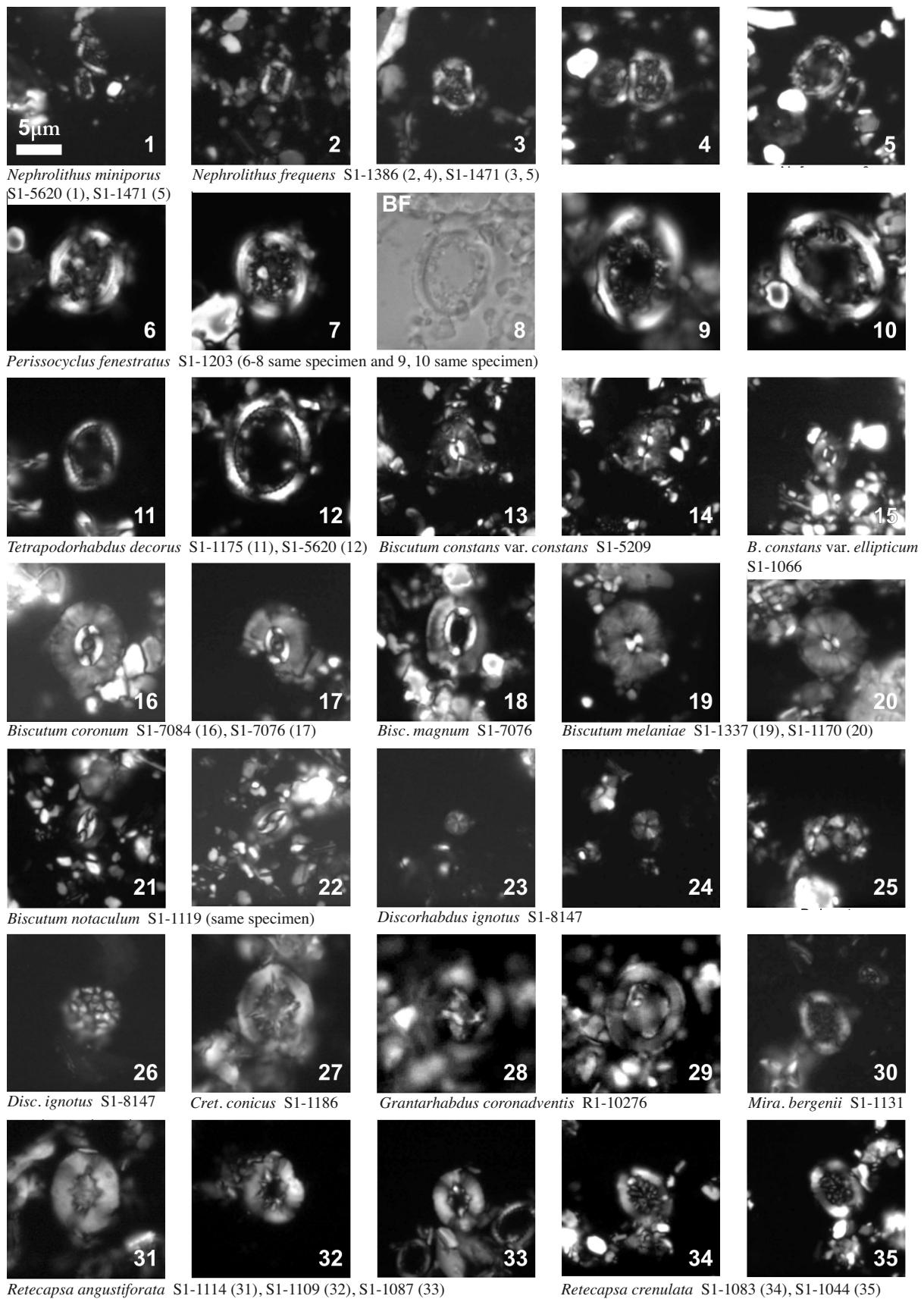
Plate 4**Axopodorhabdaceae, Biscutaceae, Cretarhabdaceae**

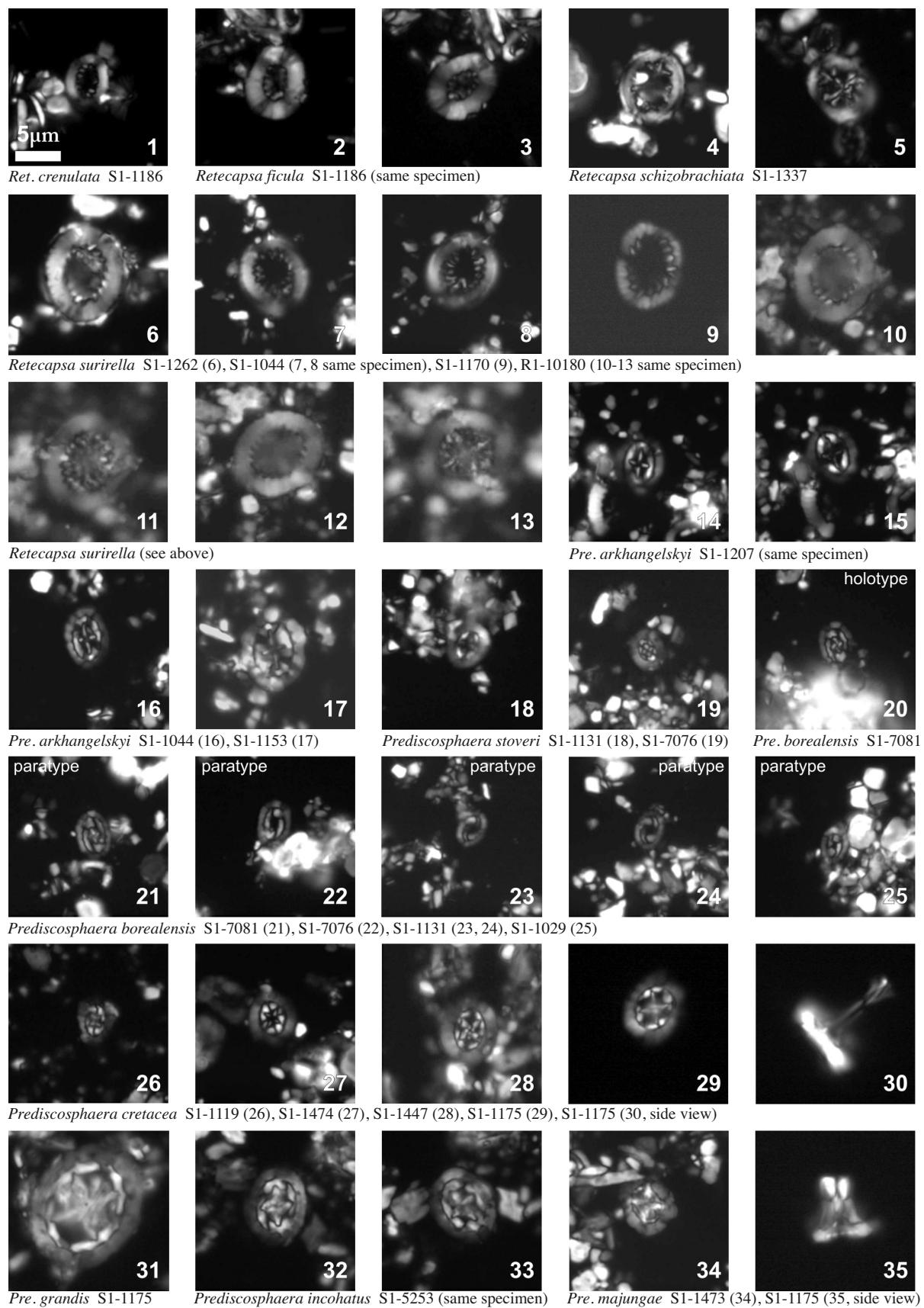
Plate 5**Cretarhabdaceae, Prediscosphaeraceae**

Plate 6

Prediscosphaeraceae, Tubodiscaceae, Watznaueriaceae, Arkhangelskiellaceae

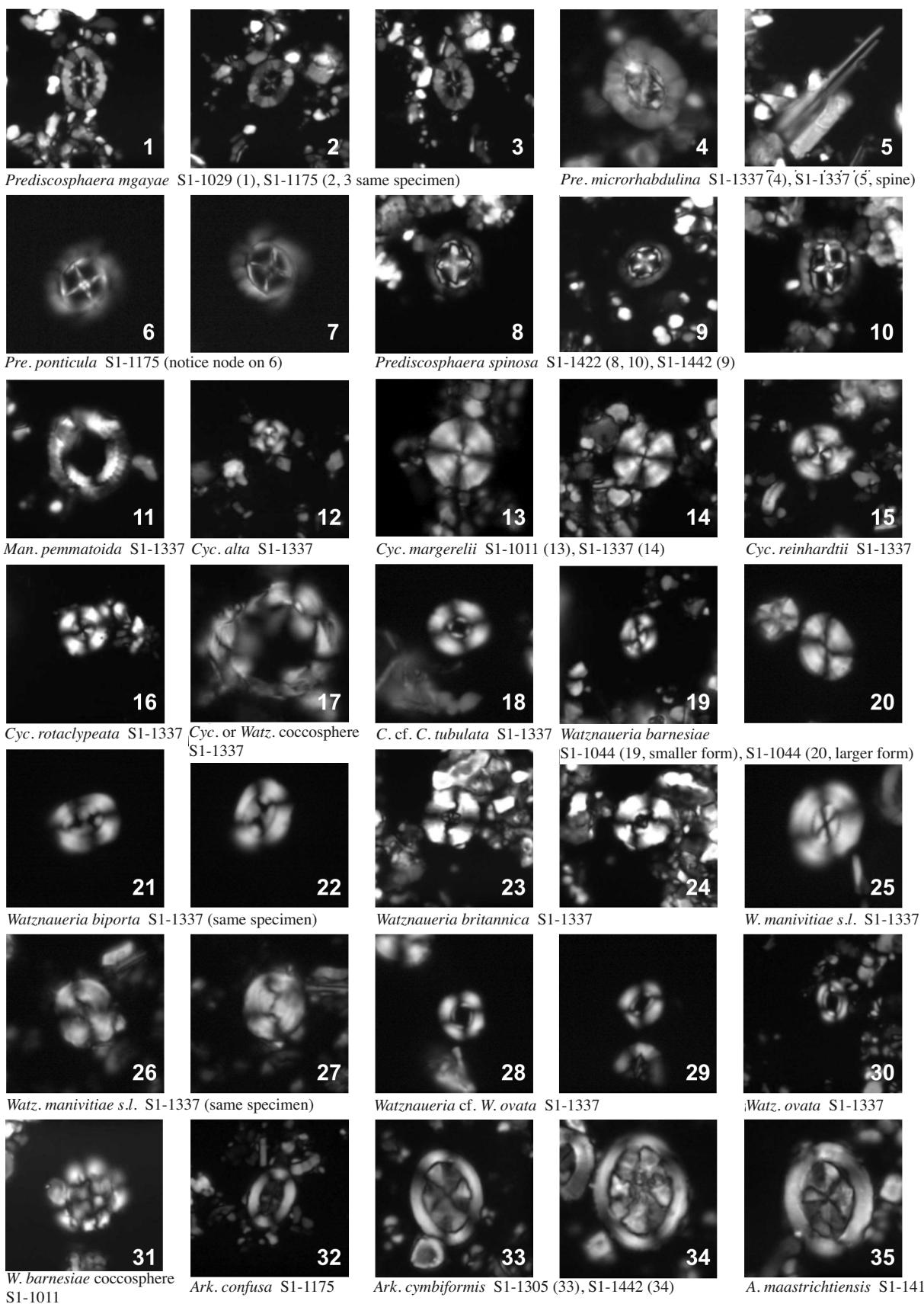


Plate 7

Arkhangelskiellaceae, Kamptneriaceae, incertae sedis heterococcoliths, holococcoliths

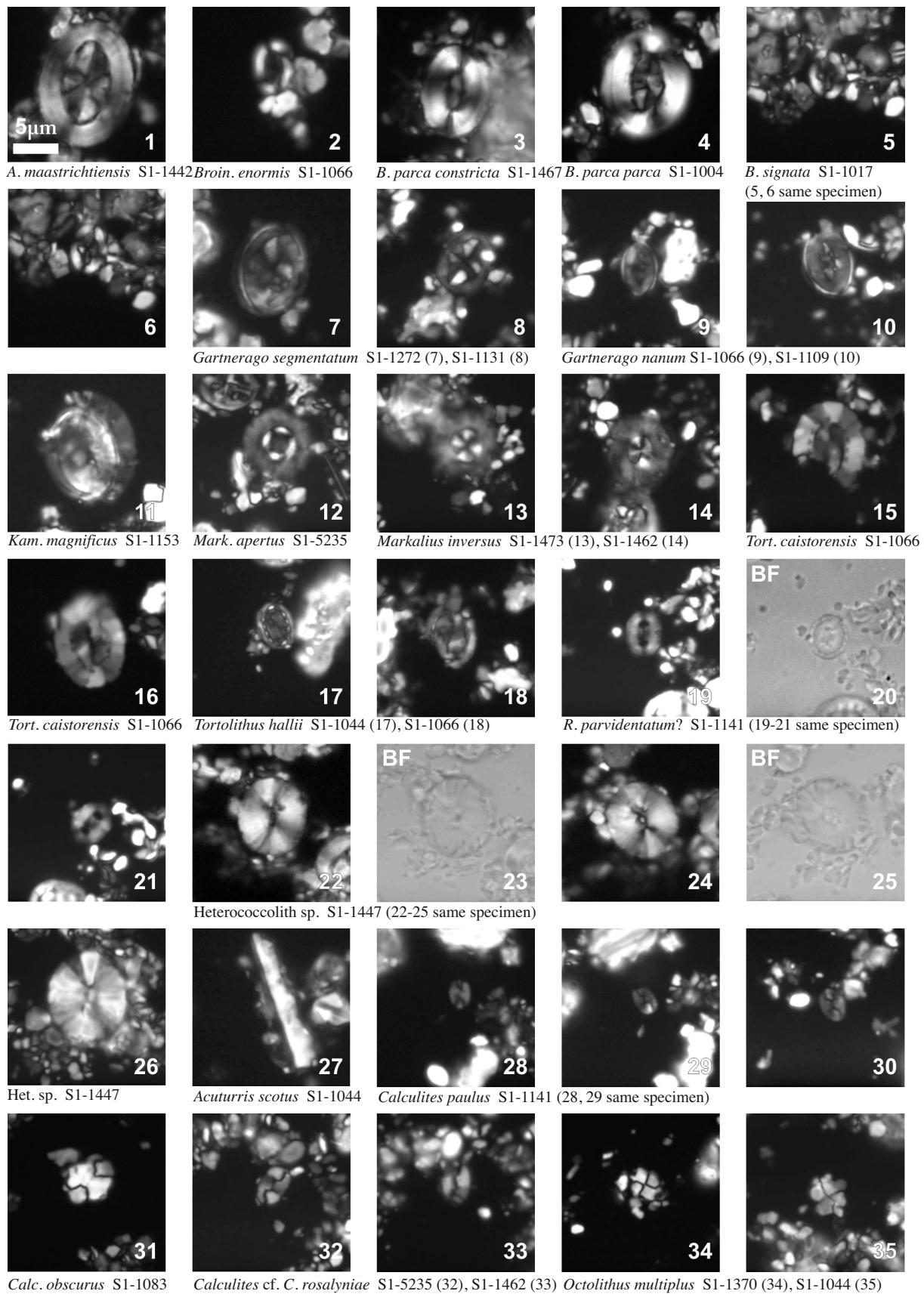


Plate 8

Holococcoliths, nannoliths

