



## Research paper

# New dinoflagellate cyst species of the *Microdinium* and *Phanerodinium* Complexes (Evitt) from the Upper Cretaceous–Lower Paleogene Chalk Group in the Meerborehole, northern Belgium

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## ABSTRACT

A high-resolution palynological study of the Campanian to Danian Chalk Group from the Meerborehole in northern Belgium has revealed the presence of four new smaller organic-walled dinoflagellate cyst species previously left in open nomenclature, within rich, diverse and well-preserved assemblages. A formal description of the new species, an emendation of *Phanerodinium fourmarieri* Lejeune–Carpentier based on a comparison of well preserved specimens with the type material, and as a result a re-assessment of the stratigraphic occurrences of each of these species are provided. *Druggidium discretum* sp. nov. is characterized by a finely spongy wall surface and a discreet indication of tabulation, while *Druggidium meerensis* sp. nov. is suturocavate with a granulate, vermiculate to rarely pseudoreticulate ornamentation. *Gillinia denticulata* sp. nov. is distinguishable by its high and denticulate crests. *Phanerodinium belgium* sp. nov. has a microgranulate to vermiculate surface wall and membranous crests. We retain *Phanerodinium fourmarieri* in the genus *Phanerodinium*, and reject the transfer of the species to the genus *Druggidium* by Lejeune–Carpentier and Sarjeant, as we demonstrate that the ventral surface of the species is untabulated and that the anterior intercalary plates are lacking. Both features are characteristic of every *Phanerodinium* species.

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## 1. Introduction

Many Campanian to Danian dinoflagellate cyst taxa – including the many never formally described species by Wilson (1974) in its unpublished PhD thesis – have been formally described from deposits in northwestern Europe. These new taxa are from Belgium and the Netherlands (Slimani, 1994, 1996, 2001b, 2003; Louwye, 1997; Schiøler et al., 1997; Brinkhuis et al., 2000) and other adjacent areas in Denmark and the Central North Sea (Schiøler, 1993; Schiøler and Wilson, 1993), Germany (Kirsch, 1991; Marheinecke, 1992) and England (Prince et al., 1999; Pearce, 2010). However, the Campanian to Danian strata from the northwestern European realm in the northern Boreal domain still hold many undescribed taxa, which need to be formally defined in the literature.

During studies of dinoflagellate assemblages from Campanian and Maastrichtian chalks of the Maastricht area and northern Belgium, Slimani (1994, 1995, 2000) and Slimani et al. (2011) recorded several previously undescribed dinoflagellate taxa, which were published in open nomenclature (Slimani, 1994; Slimani et al., 2011): *Druggidium* sp. A, *Druggidium?* sp. C, *Phanerodinium* sp. A, *Gillinia?* sp. A and

*Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune–Carpentier, 1951) Lejeune–Carpentier and Sarjeant, 1983. These taxa are herein formally described as *Druggidium discretum* sp. nov. (*Druggidium?* sp. C), *Druggidium meerensis* sp. nov. (*Druggidium* sp. A), *Gillinia denticulata* sp. nov. (*Gillinia?* sp. A), *Phanerodinium belgium* sp. nov. (*Phanerodinium* sp. A) and *Phanerodinium fourmarieri* (*Phanerodinium* sp. cf. *Druggidium fourmarieri*).

## 2. Materials and methods

The palynological slides studied herein were previously prepared from the Campanian to Danian Chalk Group from the Meerborehole (northern Belgium: Slimani et al., 2011). The geographical location and the chronostratigraphy of the studied section are documented in Figs. 1 and 2. The original geological description, core log and samples are stored at the Geological Survey of Belgium in Brussels (Geo-Doc 007E0205). Twenty-three borehole cuttings samples were processed following standard palynological preparation techniques. Processing involved an initial treatment of 50 g of sediment per sample with cold HCl (20%), followed by a digestion in HF (40% at 70 °C), in order to dissolve carbonates and silicates, respectively. Samples were rinsed with distilled water until neutral between the acid treatments. Silicofluorides were removed by repeated hot baths (60 °C) with 20% HCl. Oxidizing agents were not used. The residues were

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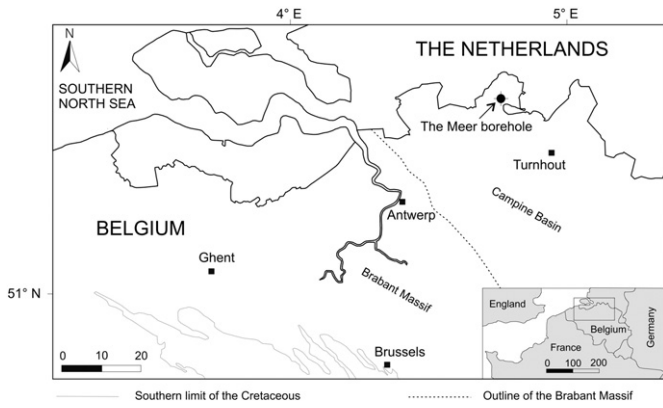


Fig. 1. Location of the Meer borehole.

sieved on a nylon screen with a mesh size of 20 µm, stained with methyl green and mounted in glycerine jelly on microscope slides. Photomicrographs were taken with a digital Olympus C-400 Zoom camera mounted on an Olympus BX51 microscope.

3. Stratigraphy

The Cretaceous Chalk Group deposits in the Meer borehole represent the thickest succession known in the Campine Basin. The lithostratigraphy of the Chalk Group in the Meer borehole was initially based on geophysical well logs (Felder et al., 1985; Lagrou et al.,

2005). It was later calibrated by P.J. Felder's ecozonation based on bioclast assemblages (Felder, 1994, 2001) to permit a regional correlation with the Maastricht type area. The correlation of the Cretaceous section with other boreholes was however hampered by the lateral facies changes in the sedimentary basin.

A stratigraphic control of the subdivision was provided by a recent biostratigraphical study with dinoflagellate cysts (Slimani et al., 2011). This dinocyst biozonation is calibrated to belemnite biostratigraphy, and has allowed correlation with the chronostratigraphical scale (Slimani, 2000, 2001a; Slimani et al., 2011) (Fig. 2).

Slimani's et al. (2011) dinoflagellate cyst biostratigraphic subdivision of the Meer core is based on the highest occurrences of index species, and was compared with the Bunde borehole (Brinkhuis et al., 2000), the Beutenaken quarry, the Hallembaye quarry (Wilson, 1974; Foucher, 1985; Slimani, 1995, 2000, 2001a) and the ENCI quarry (Wilson, 1974; Schiøler et al., 1997) in the Maastrichtian type area. It was also compared to other adjacent areas from northern Belgium such as the Knokke borehole (Louwye, 1993) and the Turnhout borehole (Slimani, 1995, 2000, 2001a), northern Germany (Marheinecke, 1992), Denmark and the Central North Sea (Wilson, 1971, 1974; Schiøler and Wilson, 1993). The comparison in the Meer borehole of the dinoflagellate cyst biostratigraphy to the wireline log stratigraphy and ecozonation has enhanced lithostratigraphical correlations with the Maastricht type area, and led to the subdivision (Fig. 2) of the Campanian to Danian deposits at Meer (Slimani et al., 2011) as detailed below.

The Lower Campanian Vaals Formation (interval 1186–1146 m) consists of clayey glauconitic chalks, and represents the lateral

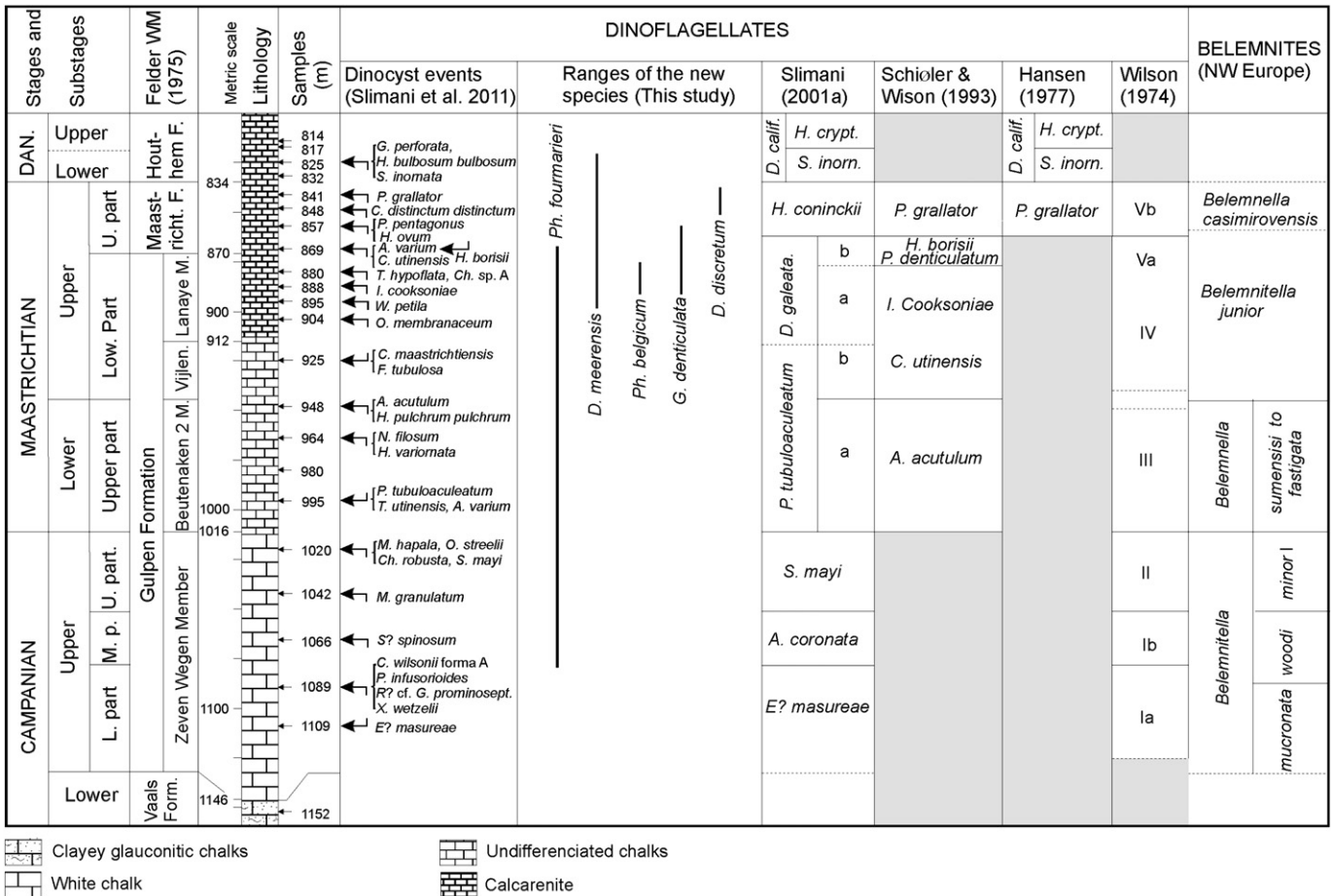


Fig. 2. Correlation of the studied section of the Meer well with the lithostratigraphic subdivision of the Maastricht type area, the dinoflagellate cyst zonation schemes from Belgium, The Netherlands, the Central North Sea, and the northwest European belemnite zones (Ernst, 1964; Schulz, 1979; Christensen, 1995, 1999). *D. calif.* = *Damassadinium californicum* Zone, *S. inorn.* = *Senoniasphaera inornata* Subzone, *H. crypt.* = *Hafniasphaera cryptovesiculata* Subzone (modified from Slimani et al., 2011).

equivalent of the greensand facies in the Roer Valley Graben. The Upper Campanian white chalk (interval 1146–1016 m) is assigned to the Zeven Wegen Member of the Gulpen Formation. The uppermost Campanian white chalk (interval 1042–1016 m) represents the lateral equivalent of the Beutenaken-1 Member in the Beutenaken type section, Maastricht region. This member is thus incorporated in the white chalk facies of the Zeven Wegen Member (lateral facies changes), below the Froidmont Hardground, rather than above in the Hallembaye type section, south of Maastricht. The Campanian–Maastrichtian boundary coincides with a hiatus, and corresponds to the Froidmont Hardground at 1016 m. Above this, a new Lower Maastrichtian chalk sequence with only weakly-expressed lithological differentiation succeeds the white chalks (interval 1016–912 m), and is assigned to the Beutenaken-2, Vijlen and Lixhe-1 members of the Gulpen Formation. The top of this sequence at 912 m is marked by a sudden change in facies to calcarenites characteristic of the upper part of the Chalk Group, and includes the upper part of the Gulpen Formation, the Maastricht Formation and the Houthem Formation (interval 912–808 m). The transition from the Gulpen Formation to the Maastricht Formation, placed at 870 m, is condensed. The calcarenite (834–808 m) corresponds to the Houthem Formation.

#### 4. Systematic palaeontology

The holotypes of *Druggidium discretum* sp. nov., *Druggidium meerenensis* sp. nov., *Gillinia denticulata* sp. nov., *Phanerodinium belgicum* sp. nov. and the figured specimens of *Phanerodinium fourmarieri* are housed in the botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco. England Finder (EF) specimen coordinates are provided both in the text and in the plate captions. Species mentioned in the systematic section are referenced in Fensome and Williams (2004) and the database DINOFLAJ2 (Fensome et al., 2008). The morphological terminology follows Stover and Evitt (1978) and Williams et al. (2000). Suprageneric classification follows Fensome et al. (1993).

Division DINOFLAGELLATA (Bütschli, 1885) Fensome et al., 1993

Subdivision DINOKARYOTA Fensome et al., 1993

Class DINOPHYCEAE Pascher, 1914

Subclass PERIDINIPHYCIDAE Fensome et al., 1993

Order GONYAULACALES Taylor, 1980

Suborder CLADOPYXIINEAE Fensome et al., 1993

Family CLADOPYXIACEAE Stein, 1883

DRUGGIDIUM Habib, 1973, emend. Harding, 1986

Type: *Druggidium apicopaucicum* Habib, 1973

***Druggidium discretum*** sp. nov. (Plate I, 1–15)

In press *Druggidium?* sp. C of Slimani et al., table 1, fig. 8i.

Holotype: Slide Meer 848 m, preparation 1, EF V34/1 (Plate I, 1–4).

Repository: Botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco.

Type locality: Meer (Antwerp province, northern Belgium), well no. 007E0205 of the Geological Survey of Belgium.

Stratigraphic horizon: Uppermost Maastrichtian, Meer 848 m borehole depth.

Etymology: Latin, *discretus*, discreet, with reference to the discreet indication of tabulation.

Diagnosis: An ovoidal species of *Druggidium* characterized by a finely spongy wall with a discreet indication of tabulation, except for the cingulum and the sulcus, which are delimited by very low crests. The archeopyle is formed by the release of one or more precingular plates or consists of a combination involving apical, anterior intercalary and precingular plates.

Description: This small proximate dinoflagellate cyst has an ovoidal shape. The hypocyst length comprises about 2/3 of the total cyst length, the rest is shared equally by the cingulum and epicyst. The

cyst wall is composed of two closely addressed layers. The endophragm is smooth and has a maximum thickness of 1 µm. The periphragm has a finely spongy structure and a maximum thickness of 2 µm. The cingulum is indicated by an unsegmented transverse depression limited by 2 parallel low ridges. The cingulum is slightly laevorotatory and has a maximum width of 6 µm. The sulcus presents a flagellar scar and a large postcingular omega-shaped area. Apart from the unsegmented cingulum and sulcus, the cyst wall surface does not show clear tabulation. The archeopyle may be precingular of type P with a free monoplacoid operculum (plate 3'') or 2P with a compound biplacoid operculum formed by plates 3'' and 4'', both free or one of them attached adcingularly. The archeopyle may also be a combination of type 2P(AI)a with a compound operculum consisting of one ventrally-attached part (apical and anterior intercalary plates) and two free plates (3'' and 4'').

Discussion: The finely spongy periphragm with a weak indication of tabulation, plus the characteristic unsegmented cingulum distinguishes *Druggidium discretum* sp. nov. from all other *Druggidium* species. Specimens of the new species with a precingular archeopyle of type P are similar to *Tectatodinium pellitum* Wall, 1967 in the possession of a spongy periphragm, but differ distinctly in being smaller and in having a cingulum and sulcus. The new species is conspecific with *Druggidium?* sp. C of Slimani et al. (2011).

Dimensions: Holotype length 30 µm, width 25 µm. Range: length 30 (31)33 µm, width 25(27)30 µm. Number of specimens measured: 10.

Stratigraphic occurrence: Uppermost Maastrichtian of Turnhout (personal observation in prepared microscope slides, H. Slimani) and Meer (Slimani et al., 2011), northern Belgium.

***Druggidium meerenensis*** sp. nov. (Plate I, 16–25; Plate II, 1–5)

1994 *Druggidium* sp. A; Slimani, pp. 12–13, pl. 1, figs. 16–18, 31–32.

1995 *Druggidium* sp. A; Slimani, unpublished Ph.D. Thesis, p. 171, table 3, pl. 1, figs. 16–18, 31–32, table 6.

2000 *Druggidium* sp. A; Slimani, table 3.

In press *Druggidium* sp. A of Slimani, 1994; Slimani et al., fig. 8c.

In press *Druggidium* sp. A of Slimani et al., table 1, fig. 8g.

Holotype: Slide Meer 848 m, preparation 1, EF N48/4 (Plate I, 16–19).

Repository: Botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco.

Type locality: Meer (Antwerp province, northern Belgium), well no. 007E0205 of the Geological Survey of Belgium.

Stratigraphic horizon: Uppermost Maastrichtian, Meer 848 m borehole depth.

Etymology: Named for the Meer village, which is the type locality.

Diagnosis: An ovoidal to ellipsoidal, suturocavate *Druggidium* species with a granulate, vermiculate to rarely pseudoreticulate intratabular ornamentation. The archeopyle is precingular or combination, involving apical, anterior intercalary and precingular plates.

Description: This small proximate and suturocavate dinoflagellate cyst has an ovoidal to ellipsoidal ambitus. The hypocyst length is about 1/3 to 2/3 of the total cyst length, the rest is shared equally by the cingulum and epicyst. The cyst wall consists of a smooth endophragm with a maximum thickness of 1 µm and a smooth, hyaline and thin periphragm with a maximum thickness of 0.5 µm. The endophragm bears granules, short pillars and/or low irregular ridges, which support the periphragm distally. These ornaments may be thinly or densely dispersed, free or proximally interconnected and show a granulate to vermiculate or rarely pseudoreticulate wall surface. The endophragm in the sutural area is devoid of ornaments, and separated from the periphragm by cavate sutures, which reflect the tabulation. The periphragm in optical section is continuous, and protrudes rarely at the cavate sutures to form an apparent relief of crests. The reflected tabulation is ?1pr, 4', 4a, 6''–7'', 6c, 5''–6'', 1p, 1''', 2s. The cingulum is relatively wide (up to 6 µm width) and slightly laevorotatory. The

large posterior sulcal plate is omega-shaped. Some specimens possess a flagellar scar. The posterior intercalary (1p) and posterior sulcal (ps) plates show a partiform hypocystal arrangement. The archeopyle may be precingular of type P, 2P or rarely combination of type (Al)a2P. The type P archeopyle involves the release of plate 3", while type 2P consists of a compound biplacoid operculum with both plates 3" and 4" free, or plate 4" free and plate 3" attached adcingularly. The type 2P(Al)a archeopyle has a compound operculum formed by one piece (apical and anterior intercalary plates) attached ventrally and two free pieces (plates 3" and 4").

**Discussion:** *Druggidium meerenensis* sp. nov. is conspecific with *Druggidium* sp. A of Slimani (1994) and *Druggidium* sp. A of Slimani et al. (2011). The new species differs from all other *Druggidium* species in being suturocavate and in having a granulate, vermiculate to rarely pseudoreticulate intratabular ornamentation. The tabulation of this species is similar to that of *Microdinium* Cookson and Eisenack, 1960, emend. Slimani, 1994, which may be suturocavate. Specimens of *Druggidium meerenensis* with intratabular processes resemble to *Microdinium bensonii* subsp. *pilatum* Slimani, 1994 and *Microdinium mariae* Slimani, 1994, while those with irregular intratabular ridges resemble *Microdinium* sp. A of Slimani (1994) and *Microdinium minutum* Louwye, 1997, but differ in having archeopyle types P, 2P or (Al)a2P, rather than type (tAtI)a. Specimens of the new species with a precingular archeopyle differ from species of the genus *Corrudinium* Stover and Evitt, 1978 in being suturocavate and partiform gonyaulacoid. *Corrudinium* species usually possess accessory intratabular ridges and are sexiform gonyaulacoid. *Alisocysta breviallata* Harker et al., 1990 and *Histiocysta palla* of Foucher (1974) have a similar morphological appearance to the specimens of the new species with intratabular ridges, but differ distinctly in having an apical archeopyle.

**Dimensions:** Holotype length 28 µm, width 25 µm. Range: length 28 (29)33 µm, width 25(26)28 µm. Number of specimens measured: 10

**Stratigraphic occurrence:** Lower Danian of Turnhout (Slimani, 1994, 1995, 2000) and Upper Maastrichtian–Lower Danian of Meer (Slimani et al., 2011), northern Belgium.

*GILLINIA* Cookson and Eisenack, 1960

**Type:** *Gillinia hymenophora* Cookson and Eisenack, 1960

***Gillinia denticulata* sp. nov.** (Plate II, 6–11)

1951 *Phanerodinium* cf. *fourmarieri*; Lejeune-Carpentier, p. B313, fig. 8.

1983 *Druggidium* cf. *fourmarieri* Lejeune-Carpentier, 1951; Lejeune-Carpentier and Sarjeant, pp. 3–4, pl. 6, fig. 1.

?1994 *Gillinia?* sp. A; Slimani, p. 17, pl. 7, figs. 12, 45–47.

?1995 *Gillinia?* Sp. A; Slimani, unpublished Ph.D. Thesis, pp. 198–199, table 1–3, pl. 7, figs. 12, 45–46

?2000 *Gillinia?* sp. A; Slimani, tables 1–3.

In press *Gillinia?* sp. A; Slimani et al., table 1, figs. 8a1–a2

**Holotype:** Slide Meer 888 m, preparation 1, EF D36 (Plate II, 6–8).  
**Repository:** Botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco.

**Type locality:** Meer (Antwerp province, northern Belgium), well no. 007E0205 of the Geological Survey of Belgium.

**Stratigraphic horizon:** Lower part of the Upper Maastrichtian, Meer 888 m borehole depth.

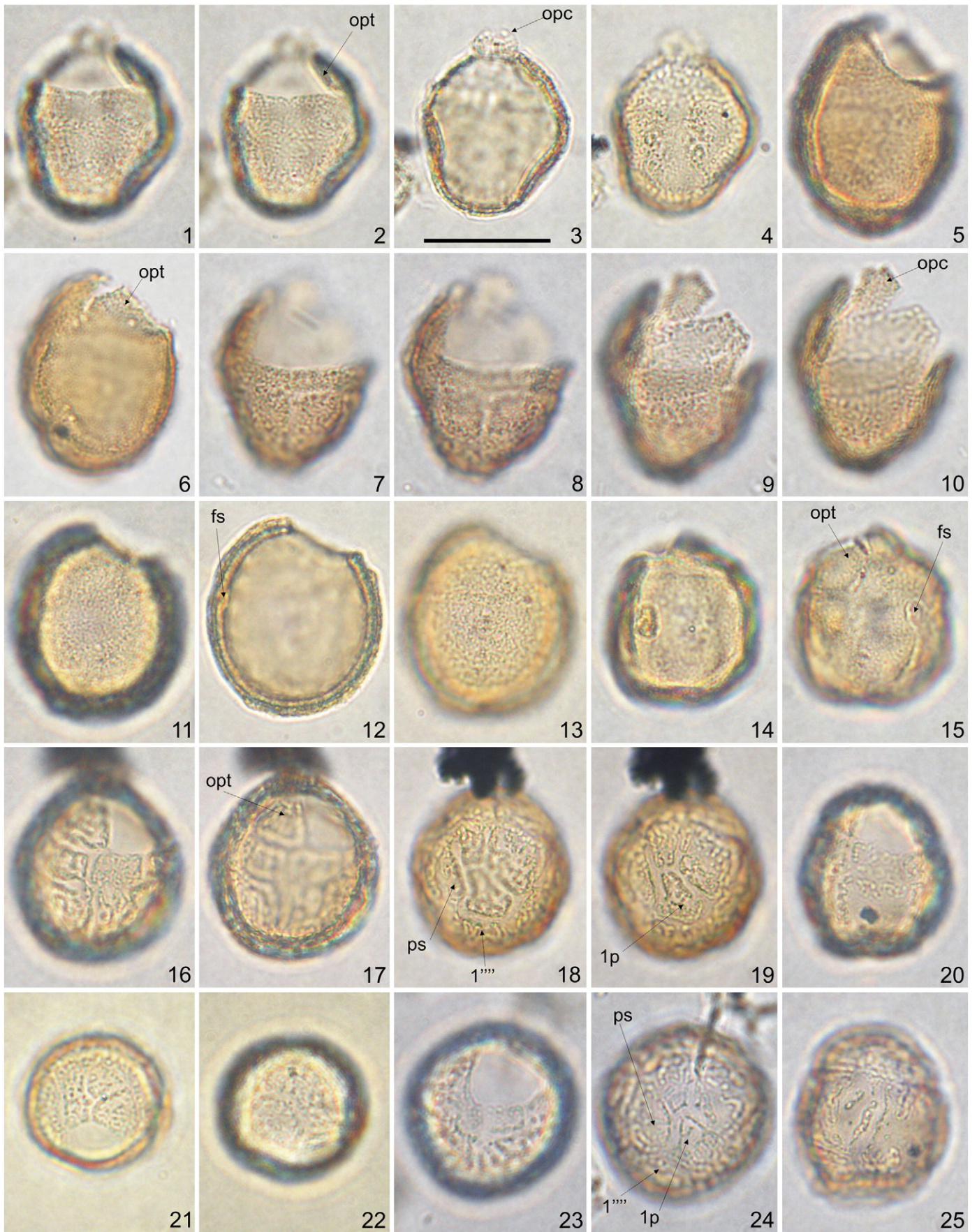
**Etymology:** Latin, *denticulus*, diminutive of dens, tooth, with reference to the denticulate crests.

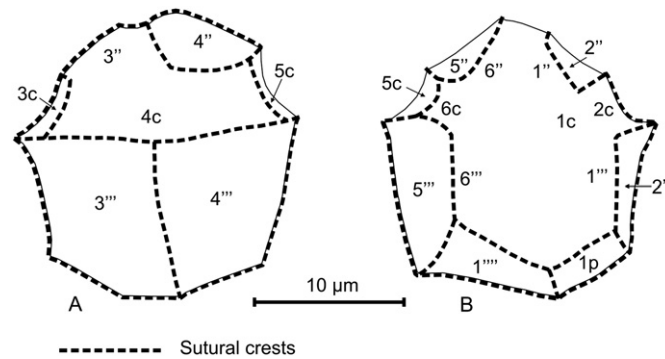
**Diagnosis:** A species of *Gillinia* with a pear-shaped central body outline and denticulate sutural crests. The tabulation is present on the dorsal surface, and is indicated by denticulate crests, which may be variable in height. The cyst is dorsally divided into a hypocyst and a cingulum, the epicyst is undivided. The ventral surface does not have crests.

**Description:** The small dinoflagellate cyst is dorsoventrally slightly compressed and has a pear-shaped central body outline. Furthermore it bears one small subspherical pericoel or low funnel-shaped pericoel on each lateral side of its anterior part. The hypocyst length is about 2/3 of the total cyst length, the rest is mostly occupied by the cingulum and two lateral vesicles. The cyst wall is composed of two layers, a smooth endophragm with a maximum thickness of 1 µm and a smooth, hyaline and thin periphragm with a maximum thickness of 0.5 µm. Both layers are separated at both lateral sides of the anterior part of the cyst, and form the two lateral pericoels. The layers are elsewhere closely adpressed. The dorsal surface of the cyst is convex and is supported by denticulate crests, which indicate the tabulation. The ventral surface is flat and shows no indication of tabulation. Four postcingular plates (2"–5") and an unsegmented cingulum (up to

**Plate I.** Scale bar in 3 represents 20 µm for all specimens.

- 1–15. *Druggidium discretum* sp. nov.
- 1–4. Holotype, slide Meer 848 m, P 1, EF V34/1; specimen in ventral view.
- 1, 2. Slightly differing low foci on wall surface, cingulum, archeopyle and opercular plate (3") attached adcingularly (opt).
3. Optical section, wall structure and one opercular piece (apical and anterior intercalary plates) attached ventrally (opc).
4. High focus on wall surface, cingulum and sulcus.
- 5, 6. Slide Meer 848 m, P 1, EF O29/2; specimen in left dorsolateral view.
5. Low focus on archeopyle.
6. High focus on opercular plate (3") attached adcingularly (opt).
- 7–10. Slide Meer 848 m, P 1, EF E57; specimen in left dorsolateral view.
- 7, 8. Slightly differing high foci on wall surface, archeopyle and postcingular plates.
- 9, 10. Slightly differing low foci on wall surface and on opercular piece (apical and anterior intercalary plates) attached ventrally (opc).
- 11–13. Slide Meer 848 m, P1, EF X38; specimen in left lateral view.
11. Low focus on wall surface.
12. Optical section, archeopyle, wall structure and flagellar scar (fs).
13. High focus on wall surface and cingulum.
- 14, 15. Slide Meer 841 m, P 1, EF H40/3; specimen in right ventrolateral view.
14. Low focus on archeopyle margin, wall surface and cingulum.
15. High foci on opercular plate (3") attached adcingularly (opt), sulcus and flagellar scar (fs).
- 16–25. *Druggidium meerenensis* sp. nov.
- 16–19. Holotype, slide Meer 848 m, P 1, EF N48/4; specimen in left ventrolateral view.
- 16, 17. Slightly differing low foci on ornamentation, archeopyle and opercular plate (4") attached adcingularly (opt).
- 18, 19. Slightly differing high foci on postcingular (1", 2"), posterior sulcal (ps), posterior intercalary (1p) and antapical (1") plates.
- 20, 25. Slide Meer 895 m, P 1, EF E52/1; specimen in left ventrolateral view.
20. Low focus on archeopyle.
25. High focus on ornamentation.
- 21, 22. Slide Meer 841 m, P 1, EF D56/2; specimen in apical view.
21. High focus on archeopyle, ornamentation and apical, intercalary and precingular plates.
22. Low focus on antapical surface.
- 23, 24. Slide Meer 880 m, P 2, EF C49/1. specimen in left ventrolateral view.
23. Low focus on archeopyle.
24. High focus on posterior sulcal (ps) omega-shaped and adjacent plates.





**Fig. 3.** Schematic tabulation of *Phanerodinium fourmarieri* Lejeune-Carpentier, 1951 emend. based on the specimen from slide Meer 857 m, preparation 1, EF X29/2; A. dorsal view; B. ventral view.

6 µm width) are indicated on the dorsal surface, the antapical 1''' and posterior intercalary 1p are not delimited by crests. The sulcal area and other adjacent plates are undifferentiated. The low crests are present on the dorsal surface, where the endo- and periphragm are addressed, while the high crests are generally present at the lateral margins. They are often inclined towards the ventral surface. Elongate gonial spines may be present. An archeopyle is occasionally observed as a small apical opening at the apex.

**Discussion:** *Gillinia denticulata* sp. nov. differs from *Gillinia hymenophora* Cookson and Eisenack, 1960 by its denticulate crests and its pear-shaped rather than subcircular to ovoidal central body outline. It differs from *Gillinia pyriformis* Marshall, 1990, which has also a pear-shaped central body outline, by its denticulate crests. The new species is conspecific with *Gillinia?* sp. A of Slimani et al. (1994, 1995, 2000) and Slimani et al. (2011) and maybe with *Phanerodinium* cf. *fourmarieri*

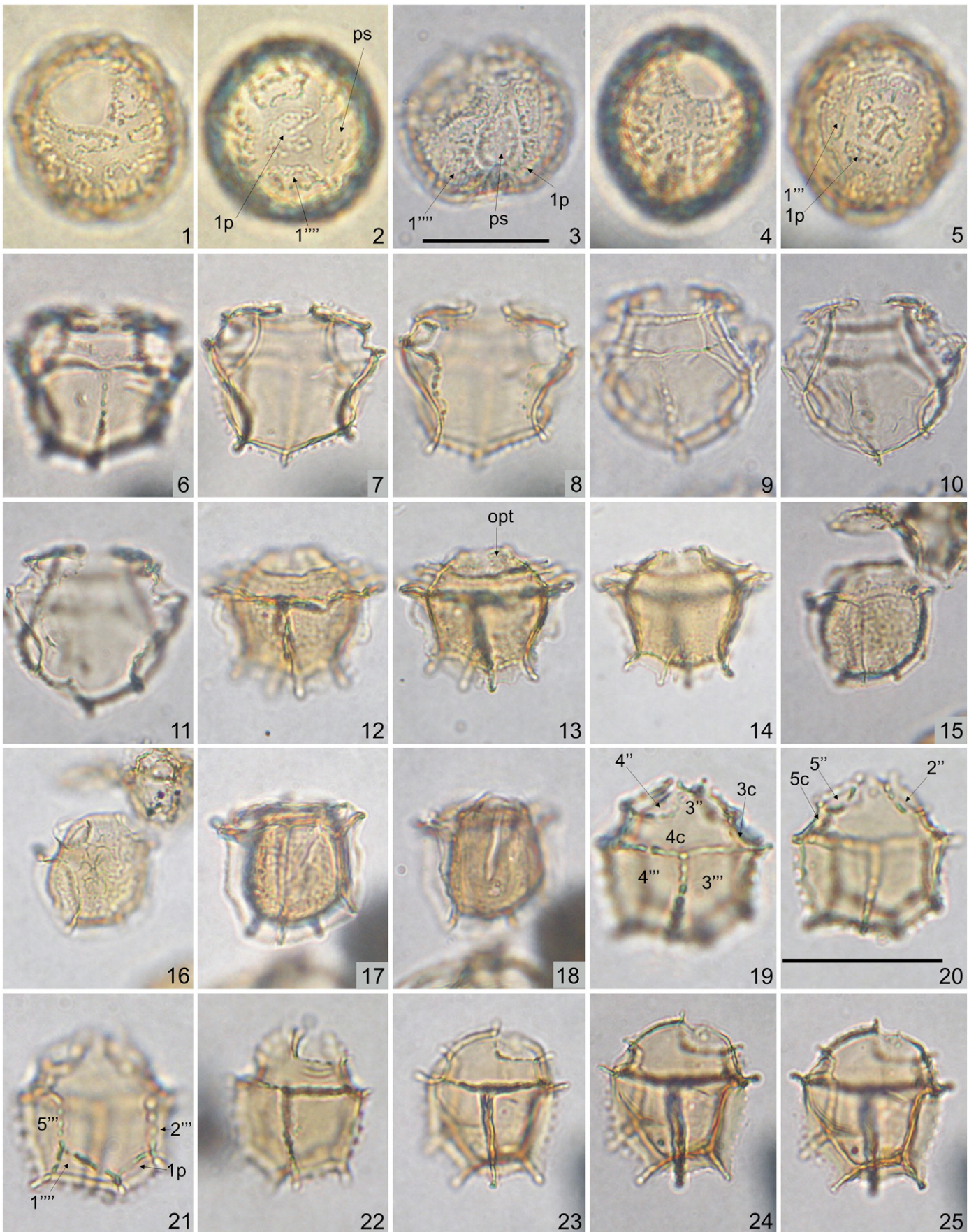
of Lejeune-Carpentier (1951). *Phanerodinium* sp. of Foucher (1974, p. 33, pl. 8, figs. 1–2) also resembles the new species but differs by its granulated surface. *Phanerodinium?* *turnhoutensis* Slimani, 1994 resembles the new species because of the shape of its central body, but differs in having a rectangular pericoel with a rectangular opening (?precingular archeopyle), elongated transversally on the epicyst rather than two lateral, subspherical pericoels.

**Dimensions:** Holotype maximal length 25 µm, hypocyst width 25 µm, maximal width (including lateral pericoels), 30 µm. Range: overall length 20(22)25 µm, maximal hypocyst width 20(23)26 µm, overall width (including lateral pericoels) 30(30.6)34 µm. Number of specimens measured: 10

**Stratigraphic occurrence:** Maastrichtian of Hainaut (southwestern Belgium) (Lejeune-Carpentier, 1951; Lejeune-Carpentier and Sarjeant, 1983); Lower–Upper Campanian of Hallembaye and Beutenaken

**Plate II.** Scale bars represent 20 µm; scale bar in 20 applies to the specimens 20–22; scale bar in 3 applies to all the other specimens.

- 1–5. *Druggidium meerensis* sp. nov.
- 1–2. Slide Meer 841 m, P 1, EF Z44/3; specimen in left ventroantapical view.
1. Low focus on ornamentation and archeopyle.
2. High focus on posterior intercalary (1p) and adjacent plates.
3. Slide Meer 880 m, P 1, EF X36/2; specimen in ventral view. High focus on posterior sulcal (ps) omega-shaped and adjacent plates.
- 4, 5. Slide Meer 869 m, P 1, EF F49; specimen in left lateroventral view.
4. Low focus on archeopyle and ornamentation.
5. High focus on posterior sulcal (ps), postcingular (1'', 2'') and posterior intercalary (1p) plates.
- 6–11. *Gillinia denticulata* sp. nov.
- 6–8. Holotype, Meer 888 m, P 1, EF D36; specimen in ventral view.
6. Low focus on dorsal surface and cingular and postcingular denticulate crests.
7. Optical section, ambitus, lateral pericoels and atypical archeopyle.
8. High focus on marginal denticulate crests.
- 9–11. Slide Meer 880 m, P 1, EF X37/1; specimen in dorsal view.
9. High focus on dorsal surface and cingular and postcingular denticulate crests.
10. Optical section, ambitus, lateral vesicles and atypical archeopyle.
11. Low focus on marginal denticulate crests.
- 12–18. *Phanerodinium belgicum* sp. nov.
- 12–14. Holotype, Slide Meer 888 m, P 2, EF H54/1; specimen in dorsal view.
12. High focus on wall surface and membranous crests.
13. Optical section, opercular plate attached adcingularly (opt).
14. Low focus on ventral surface.
- 15, 16. Slide Meer 880 m, P 2, EF N36; specimen in ventral view.
15. Low focus on wall surface and membranous crests.
16. High focus on ventral surface.
- 17, 18. Slide Meer 880 m, P 2, EF G58/3; specimen in ventral view.
17. Low focus on wall surface and membranous crests.
18. High focus on ventral surface.
- 19–25. *Phanerodinium fourmarieri* Lejeune-Carpentier, 1951 emend.
- 19–21. Slide Meer 857 m, P 1, EF X29/2; specimen in ventral view.
19. Low focus on archeopyle.
- 20, 21. Slightly differing high foci on phractate crests, precingular (2'', 5''), cingular (2c–5c), postcingular (2'', 5'') antapical (1''') and posterior intercalary (1p) plates and ventral surface.
22. Slide Meer 869 m, P 1, EF R36; specimen in dorsal view. High focus on archeopyle and crests.
- 23–25. Slide Meer 888 m, P 1, EF C35/3; specimen in dorsal view.
23. High focus on archeopyle.
24. Optical section, vaginate to scalloped crests.
25. Low focus on ventral surface.



(Maastricht area) and Upper Campanian of Turnhout (northern Belgium) (Slimani, 1994, 1995, 2000); Upper Maastrichtian of Meer (northern Belgium) (Slimani et al., 2011).

Family UNCERTAIN (order Gonyaulacales, suborder uncertain)

*PHANERODINIUM* Deflandre, 1937, emend. Slimani, 1994

Type: *Phanerodinium cayeuxii* Deflandre, 1936, ex Deflandre, 1937, emend. Slimani, 1994.

***Phanerodinium belgicum*** sp. nov. (Plate II, 12–18)

1994 *Phanerodinium* sp. A; Slimani, pp. 50–51, pl. 7, figs. 51–53.

1995 *Phanerodinium* sp. A; Slimani, unpublished Ph.D. Thesis, pp. 313–314, pl. 7, table 3, figs. 51–53.

In press *Phanerodinium* sp. A of Slimani, 1994; Slimani et al., table 1, fig. 8b.

Holotype: Slide Meer 888 m, preparation 2, EFH54/1 (Plate II, 12–14).

Repository: Botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco.

Type locality: Meer (Antwerp province, northern Belgium), well no. 007E0205 of the Geological Survey of Belgium.

Stratigraphic horizon: Lower part of the Upper Maastrichtian, Meer 880 m borehole depth.

Etymology: Latin, *Belgica*, Belgium, with reference to country where this study has been done.

Diagnosis: An ovoidal *Phanerodinium* species characterized by a microgranulate to vermiculate cyst wall. The cyst bears membranous sutural crests with entire to slightly undulate distal edges and occasional gonal distal extensions.

Description: The small proximate dinoflagellate cyst is dorsoventrally slightly compressed and has an ovoidal shape with the maximum width across the posterior cingular sutural crest. The hypocyst is hemi-ovoidal and represents about 3/4 of the total cyst length. The epicyst is subtriangular and shares the anterior part of the cyst equally with the cingulum. The autophragm is microgranulate to vermiculate with a maximum thickness of 1.5  $\mu\text{m}$ . The tabulation is reflected on the dorsal surface by membranous sutural crests. The ventral surface shows no indication of a tabulation pattern. Four precingular plates are observed (2''–5''), an unsegmented cingulum, four postcingular plates (2'''–5'''), one antapical plate (1''') and a posterior intercalary (1p) plate. The two latter plates are not separated from the ventral surface by crests. The sulcal plates and the other adjacent plates are undifferentiated. The cingular crests and the postcingular sutural crests have entire to slightly undulate distal edges and gonal extensions, which are occasionally apparent distally. The suture between 3'' and 4'' is not visible. The rarely visible archeopyle is precingular and of type P. The operculum is formed by one plate (4''), attached adcingularly.

Discussion: The new species is characterized by its ovoidal shape, the granulate to vermiculate wall surface and the membranous sutural crests. It is conspecific with *Phanerodinium* sp. A of Slimani (1994, 1995) and Slimani et al. (2011). It differs from all other *Phanerodinium* species by its granulate to vermiculate cyst wall. *Phanerodinium septatum* Slimani, 1994 has also membranous sutural crests, but differs moreover from the new species by its elongate polygonal shape, the thinner cyst wall, and its higher septa with concave distal edges supported by long protruding gonal processes. *Phanerodinium septatum* Slimani, 1994 is furthermore distinguished by its antapical (1''') and posterior intercalary (1p) plates, which are completely delimited by sutural crests. The other species of *Phanerodinium* differs from the new species mainly in having ornamented crests.

Dimensions: Holotype overall length 25  $\mu\text{m}$ , overall width 28  $\mu\text{m}$ . Range: overall length 16(22)25  $\mu\text{m}$ , overall width 17(22)28  $\mu\text{m}$ , maximal high of crests 6  $\mu\text{m}$ . Number of specimens measured: 10

Stratigraphic occurrence: Upper Maastrichtian of Turnhout (Slimani, 1994, 1995) and Meer (Slimani et al., 2011), northern Belgium.

***Phanerodinium fourmarieri*** Lejeune-Carpentier, 1951 emend. (Fig. 3; Plate II, 19–25)

1951 *Phanerodinium fourmarieri*; Lejeune-Carpentier, p. B311, fig. 7.

1974 *Phanerodinium fourmarieri* Lejeune-Carpentier; Foucher, p. 33.

1977 *Phanerodinium fourmarieri* Lejeune-Carpentier; Foucher and Robaszynski, p. 9.

1983 *Druggidium fourmarieri* (Lejeune-Carpentier); Lejeune-Carpentier and Sarjeant, pp. 2–3, text-figs. 1–2, pl. 1, figs. 1–2.

1994 *Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune-Carpentier) Lejeune-Carpentier and Sarjeant; Slimani, pp. 45–46, pl. 7, figs. 9–11, 23–26.

1995 *Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune-Carpentier) Lejeune-Carpentier and Sarjeant; Slimani, unpublished Ph.D. Thesis, pp. 309–10, pl. 7, figs. 9–11, 23–26.

2000 *Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune-Carpentier) Lejeune-Carpentier and Sarjeant; Slimani, Tables 2–3.

In press *Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune-Carpentier) Lejeune-Carpentier and Sarjeant; Slimani et al., table 1.

Emended diagnosis: An ovoidal to rounded sub-polygonal *Phanerodinium* species characterized by its stiff, phractate or vaginate to scalloped sutural crests and by the absence of sutural crests between the adjacent precingular (3'') and cingular (4c) plates.

Modified description: This small proximate dinoflagellate cyst is dorsoventrally slightly compressed and has an ovoidal to sub-polygonal shape. The hypocyst is rounded quadrate to pentagonal and represents about 3/4 of the total cyst length. The epicyst is hemispheroidal and shares the anterior part of the cyst equally with the cingulum. The autophragm is smooth to punctate with a maximum thickness of 0.5 to 1  $\mu\text{m}$ . The tabulation is that of the genus *Phanerodinium*, and is reflected on the dorsal surface by strong, phractate or vaginate to scalloped sutural crests, which are higher on the hypocyst. The ventral surface lacks sutures. The crests might be two times higher at their confluences, producing gonal distal extensions. The reconstructed tabulation consists of 4 precingular (2''–5''), 3 cingular (3c–5c), 4 postcingular (2'''–5'''), an antapical (1''') plates and a posterior intercalary (1p) plate. The apical plates are undistinguishable. The suture between the precingular (3'') and adjacent cingular (4c) plates is absent. The sulcal plates and the plates adjacent to it are not expressed by raised features. The archeopyle is precingular of type P. It is located closely to the right of a dorsal longitudinal median line and is formed by the release of the precingular plate 4''. The operculum is free.

Discussion: Our specimens of *Phanerodinium fourmarieri* and also those recorded from Belgium as *Phanerodinium* sp. cf. *Druggidium fourmarieri* by Slimani (1994, 1995, 2000) and Slimani et al. (2011) are comparable to the type material described by Lejeune-Carpentier (1951). *Phanerodinium fourmarieri* differs from all the other *Phanerodinium* species by its characteristic phractate or vaginate to scalloped sutural crests and by the typical absence of sutural crests between the adjacent precingular (3'') and cingular (4c) plates. This species was originally considered as a species of *Phanerodinium* Deflandre, 1937, but was reassigned later to the genus *Druggidium* Habib, 1973 by Lejeune-Carpentier and Sarjeant (1983), based on their re-examination of the type material. In our opinion, this reassignment was based on an erroneous interpretation of the tabulation of poorly preserved specimens observed in a flint matrix. The dorsal surface of the holotype (Lejeune-Carpentier and Sarjeant, 1983, text-fig. 1, pl. 1, fig. 1) shows two postcingular plates (3''', 4'') and a very broad cingulum with its invaginations clearly developed laterally and a high posterior crest. However, the plates interpreted by the authors on the illustration of the holotype (text-fig. 1), as precingular 2'' and apical (1') represent respectively the cingular plate (4c) and the precingular plate (3''). The real archeopyle is then of type P and is smaller than interpreted by the authors (text-fig. 1); it is visible as the clear square at the right part of the apex of the holotype (pl. 1, fig. 1). The paratype (Lejeune-Carpentier and Sarjeant, 1983, text-fig. 2, pl. 1, fig. 2) is not oriented in apical view as indicated by the authors (text-fig. 2), but in dorsal view and oriented transversally with the apex at the left side. It shows, as does the

holotype, a small precingular archeopyle and a broad cingulum characterised by the absence of sutural crests between the adjacent precingular (3'') and cingular (4c) plates. Consequently, there is no indication of apical, anterior intercalary and precingular (5'', 6'') plates as indicated by Lejeune-Carpentier and Sarjeant (1983, text-fig. 2) on the illustration of the paratype. According to the latter authors (p. 3), the ventral surface "could not be determined with sufficient precision for full illustration". This means that the ventral surface is in fact devoid of sutural features, as observed on our specimens. The morphological characters displayed by our specimens, and the new interpretation of the type material figured by Lejeune-Carpentier and Sarjeant (1983), are distinctly different from those known for the genus *Druggidium*, and justify the transfer of this species back into *Phanerodinium*.

**Dimensions:** Range: overall length 18(22)26 µm, overall width 18(21)26 µm, maximal high of crests 2 µm. Number of specimens measured: 10

**Stratigraphic occurrence:** Upper Maastrichtian of Hallembaye (Maastricht area) (Lejeune-Carpentier, 1951); Turonian, Pas-De-Calais (France) (Foucher, 1974); Lower–Upper Maastrichtian of Mons (southern Belgium) (Foucher and Robaszynski, 1977); Upper Maastrichtian of Hallembaye (Maastricht area) and Lower–Upper Maastrichtian of Turnhout (northern Belgium) (Slimani, 1994, 1995, 2000); Upper Campanian–Upper Maastrichtian of Meer (Slimani et al., 2011), northern Belgium.

## 5. Conclusions

Organic-walled dinoflagellate cyst assemblages from the Campanian–Danian Chalk Group in the Meer borehole (northern Belgium) are diverse and well-preserved, and constitute the greater part of the organic-walled palynomorphs (more than 90%). A formal description of four new gonyaulacoid species (*Druggidium discretum* sp. nov., *Druggidium meerensis* sp. nov., *Gillinia denticulata* sp. nov., *Phanerodinium belgicum* sp. nov.), and an emendation of one species (*Phanerodinium fourmarieri* Lejeune-Carpentier, 1951 emend.) is proposed. The stratigraphic distribution of the species in the Upper Cretaceous and Lower Cenozoic is discussed (Fig. 2).

We suggest that the two new *Druggidium* species belong to the *Microdinium* Complex of Gp-cysts (Evitt, 1985, pp. 215–216) since they display anterior intercalary plates associated with at least six precingular plates, and show a partiform hypocystal arrangement – well seen here in *Druggidium meerensis* – characteristic of *Microdinium* species. We agree however with Harding (1986, pp. 18–19), who suggests that the genus *Druggidium* should be placed in the *Microdinium* complex of Gp-cysts rather than in the *Phanerodinium* complex (Evitt, 1985, pp. 215–216). Whereas, *Phanerodinium fourmarieri* together with the new species of *Gillinia* and *Phanerodinium* can be placed in the *Phanerodinium* Complex of Gp-cysts since they lack anterior intercalary plates and ventral sutures.

The new species were reported under open nomenclature and without formal description, firstly in the Maastricht region and Turnhout area (Slimani, 1994, 1995, 2000), and subsequently in the Meer borehole (Slimani et al., 2011). *Druggidium discretum*, *Druggidium meerensis* and *Phanerodinium belgicum* are recorded in the Upper Maastrichtian–Lower Danian interval at Meer and Turnhout in northern Belgium, and in the Maastricht region respectively as *Druggidium?* sp. C, *Druggidium* sp. A and *Phanerodinium* sp. A (Slimani, 1994, 1995, 2000; Slimani et al., 2011). The latter authors have reported *Gillinia denticulata* (as *Gillinia?* sp A) within the Lower Campanian–Upper Maastrichtian interval of northern Belgium and the Maastricht area. *Phanerodinium fourmarieri*, formerly recorded as *Phanerodinium* sp. cf. *Druggidium fourmarieri* (Lejeune-Carpentier, 1951) Lejeune-Carpentier and Sarjeant, 1983 by Slimani (1994, 1995, 2000) and Slimani et al. (2011), is recorded within the Upper Turonian in northern France (Foucher, 1974) and the Lower–Upper Maastrichtian interval in Belgium (Lejeune-Carpentier, 1951; Foucher

and Robaszynski, 1977; Slimani, 1994, 1995, 2000; Slimani et al., 2011). Although these new species are rare to common in the samples from which they have been recorded, their restricted occurrences in more than one region may suggest that they are important stratigraphical markers.

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