# Connecting the Chalk Group of the Campine Basin to the dinoflagellate cyst biostratigraphy of the Campanian to Danian in borehole Meer (northern Belgium)[*]

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## Abstract

A palynological study of the Chalk Group (Campanian-Danian) in the Meer borehole (northern Belgium), which penetrated the thickest succession known in the Campine Basin, has revealed diverse, well-preserved organic-walled dinoflagellate cyst assemblages. The succession contains numerous chronostratigraphically significant dinocyst events, which are based mainly on the highest consistent occurrences of index species. At least 35 bio-events have enabled a subdivision into nine intervals, at stage or substage level, within the Campanian to Danian interval, as based on comparison with coeval assemblages elsewhere in northwest Europe, inclusive of stratotypes of stages and stage boundaries. Bio-events allow correlation of the section studied with the Campanian *Exochosphaeridium*? *masureae*, *Areoligera coronata* and *Samlandia mayi* zones, the Maastrichtian *Pervosphaeridium tubuloaculeatum*, *Deflandrea galeata* and *Hystrichostrogylon coninckii* zones, and the Danian *Damassadinium californicum* Zone. In addition, a correlation with other zonal schemes for the southern North Sea Basin and with conventional northwest European belemnite zones is presented. Comparisons with Boreal and Tethyan realms confirm that most bio-events may also be useful for interregional and global correlation. The Campanian-Danian dinocyst biostratigraphy of the Meer borehole is put alongside geophysical well logs and an ecozonation, in order to check the validity of lithostratigraphical correlations across the Campine Basin. This first, detailed correlation attempt shows that sensitivities to facies change associated with differences in accommodation space and sediment supply appear to be at the base of slight, yet consistent, shifts between the local lithological succession and the standard lithostratigraphical scheme of the Maastricht type area.

*Keywords*: Upper Cretaceous, Danian, organic-walled dinoflagellate cysts, biostratigraphy, lithostratigraphy, southern North Sea Basin, correlation

## Introduction

Upper Cretaceous strata of the Campine Basin in northeast Belgium (Fig. 1) are not exposed but have been penetrated by exploration boreholes aiming for Upper Carboniferous (Westphalian) coal measures or the Dinantian (Lower Carboniferous) saline aquifer underneath. In view of the geographical continuity of the depositional system into the adjacent type area of the Maastrichtian Stage, the stratigraphic subdivisions of the latter area have been applied in the Campine area (W.M. Felder, 1975; W.M. Felder & Bosch, 2000; Robaszynski et al., 2002). Because Danian calcarenites are difficult to distinguish from the underlying Maastrichtian ones, and, in fact, have traditionally been included in stratigraphic studies of the underlying Cretaceous, it is convenient to refer to these sediments as the carbonate-dominated Chalk Group. The Chalk Group thus extends across the K/Pg boundary in Belgium. Stratigraphical interpretation based on lithological description of borehole cuttings during a century of deep drilling has not been particularly consistent in the rather monotonous lithologies (compare P.J. Felder et al., 1985). Borehole cores or samples collected from mineshafts are mostly discontinuous,

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*    *In:* Jagt, J.W.M., Jagt-Yazykova, E.A. & Schins, W.J.H. (eds): A tribute to the late Felder brothers – pioneers of Limburg geology and prehistoric archaeology.
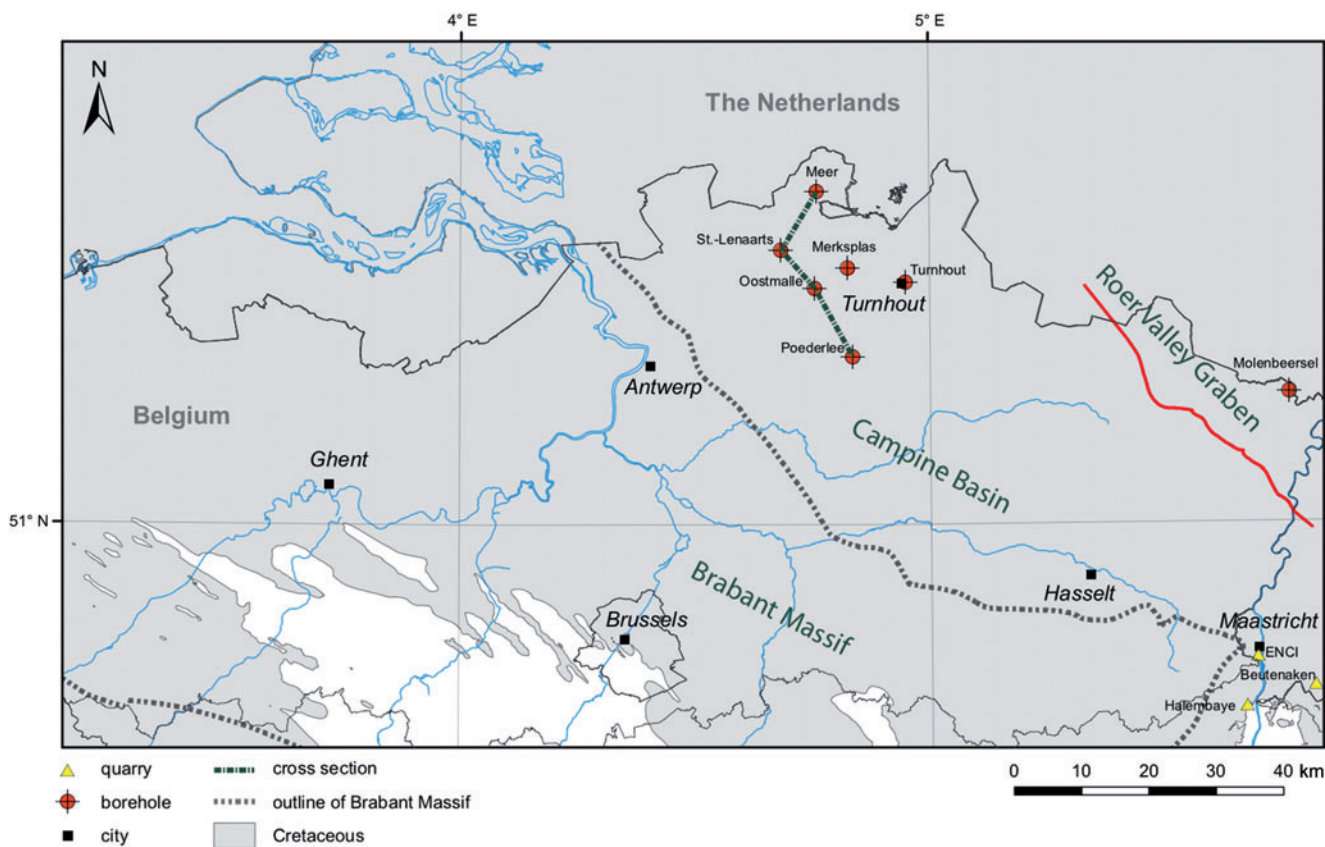
Fig. 1. Palaeogeography of the Chalk Group in northern Belgium, with location of boreholes and quarries and position of cross-section (see Fig. 9).

restricted to the top or base of the Chalk Group, or of poor quality in flint-bearing levels. Moreover, macro- and micro-palaeontological interest in the subsurface Cretaceous of the Campine Basin was limited. Therefore, geophysical well logs, mainly standard gamma-ray and resistivity logs, were used as the major tool for stratigraphical subdivision and correlation. Their correlation strength, however, suffers from the lack of identification of lithological boundaries in a basin subject to lateral facies change and inversion, in between basement highs and grabens (P.J. Felder et al., 1985; Lagrou et al., 2005). Geophysical well logging was complemented by an ecozonation based on frequency curves of bioclasts (1-2.4 mm size), developed as a stratigraphic tool by P.J. Felder (1981) and widely applied in the Campine Basin and adjacent parts of the London-Brabant Massif for wells drilled after 1980 (P.J. Felder et al., 1985; P.J. Felder, 1994, 2001). These ecozones characterise the lithostratigraphic units and allow the recognition of basin-wide events. Although relying on cuttings with an approximate depth, transitions between ecozones approach in precision the geophysical boundaries based on well logs and, hence, have increased the confidence level of correlations (e.g., Dusar & Lagrou, 2007a; Lagrou et al., 2005). However, with increasing distance from the reference sections in the Maastrichtian type area (i.e., 100 km for the Meer borehole), the reliability of the ecozonation method is affected by changes in carbonate production and sedimentary facies related to ecological and

tectonic differentiation of the sedimentary basin (Bless et al., 1987; Bless, 1989). While some boundaries are easily recognised by the various methods (e.g., the boundary between the Vaals Formation ('Vaals Green Sand') and the Zeven Wegen Member) and have remained stable throughout successive stratigraphic schemes, the general succession lacks precision (compare Bless et al., 1987). Biostratigraphical analysis with organic-walled dinoflagellate cysts (dinocysts) is considered a powerful tool for dating these sediments. Dinocyst stratigraphy has proved to be applicable to both the Maastrichtian type area and the subsurface Campine Basin (Slimani, 2000, 2001a) and can now be used as a tool to calibrate geophysical well logs and bioclast ecozones.

Moreover, particular correlation problems relate to different ages attributed to the same formation. A presumed Santonian age for the base of the Vaals Formation in colliery shafts (Jagt et al., 1995) was seen to be indicative of a Santonian marine transgression in the Campine area (Vandenberghe et al., 2004). However, other fossils generally favour an Early Campanian date for the Vaals Formation in the Campine Basin, and geophysical well log correlation suggests a great regularity in the depositional systems without diachronism.

Also inconsistencies in the application of the dinocyst bio-zonation needed to be resolved. Slimani (2000, 2001a) assigned a Danian age to samples 759.89 m and 722.40 m in the Turnhout borehole. As a consequence, the interval between the top of

the Chalk Group at 704 m and the underlying hardground at 762 m (i.e., 58 m in total) would be of Danian age, whereas geophysical well log correlations with adjacent boreholes, supported by P.J. Felder's ecozonation (P.J. Felder, 1994, 2001), assigned only the 734-704 m interval to the Danian Houthem Formation, totalling a 'normal' 30 m in thickness.

At the instigation of the Cretaceous Subcommission of the Belgian Commission for Stratigraphy, the Meer borehole (Fig. 1) was selected for a thorough biostratigraphic revision of the entire Chalk Group, because of the homogeneous distribution of available cutting samples of relatively good quality.

## Geological setting

The Campine Basin in northeast Belgium forms the transition between the West Netherlands Basin and the Roer Valley Graben in the north and the Lower Palaeozoic London-Brabant Massif in the south (Figs 1, 2). The main characteristic of this basin is the presence of a shallow wedge of Upper Palaeozoic (Middle Devonian-Upper Carboniferous) strata covering the folded Cambrian to Silurian strata of the London-Brabant Massif, completed by a wedge of Permian to Jurassic strata thickening stepwise into the Roer Valley Graben underneath a subhorizontal Cretaceous-Cenozoic sequence. Denomination as a basin is thus misleading and has been derived from the structural position of the coal deposits at depths accessible to mining in the Campine Basin.

Similarly, the thickness and completeness of the Cretaceous-Cenozoic sequence increases in a northerly direction. Therefore, the 378 m-thick Cretaceous interval in the Meer borehole (between 1186 and 808 m) is the thickest and deepest of the entire Campine Basin outside the the Roer Valley Graben, and, as such, is representative of the adjoining Dutch territory of western Noord-Brabant and for the Antwerp Campine area further south.

The Cretaceous strata dip slightly in a northerly to north-easterly direction away from the London-Brabant Massif and towards the West Netherlands Basin-Roer Valley Graben. Due to the northwardly increase in thickness, the dip is greater for the base Cretaceous than for its top (c. 1 ¼° vs ¾° around the Meer borehole). Seismic stratigraphy confirms a regular structure, whereby reflective events can be traced over the major part of the basin, despite some lateral lithological changes (Dreesen et al., 1987). The Cretaceous strata and the Danian calcarenites are conformably overlain by the Paleocene Heers Formation and the Landen Group.

The Cretaceous-Cenozoic sequence thus oversteps more deformed strata; the stratigraphic gap widens towards the Brabant Massif, from the Lower Jurassic to the Lower Cambrian. In the Meer borehole, the Cretaceous overlies unconformably the Westphalian (Upper Carboniferous) coal measures, eroded to just above the Westphalian A/B boundary (Vandenberghe et al., 1988). Despite its geographical location north of the Hoogstraten Fault and its proximity to the West Netherlands Basin, the Meer borehole is only 7 km north of the Heibaart Uplift, a site of natural gas storage, and 25 km from the nearest subcrop boundary with the London-Brabant Massif (Vandenberghe, 1984; Langenaeker, 2000).

The Cretaceous deposits of the Maastrichtian type area and, by geographical extension including those of the Campine Basin, are combined in the Chalk Group (Van Adrichem Bogaert & Kouwe, 1993-1997). The entire sequence was controlled by general sea level fluctuations and inversion tectonics (Bless et al., 1987; Bless, 1989). The sedimentation responded to the Cenomanian transgression, starting with deeply weathered alluvial to lacustrine deposits preserved in karstic depressions,



Fig. 2. Lithostratigraphical scheme linking the London-Brabant Massif and the Campine Basin to the Maastricht type area, based on W.M. Felder (1975), and confirmed and completed for the Beutenaken-2 unit by P.J. Felder (1994). The discrepancy between this zonation and the lithostratigraphical correlation of the white chalk facies to the Zeven Wegen Member of the Gulpen Formation, incorporating the Beutenaken-1 Member is indicated. The Froidmont Hardground separates the expanded Zeven Wegen Member from the Beutenaken-2, Vijlen Lixhe-1 sequence, all developed in the Vijlen facies.
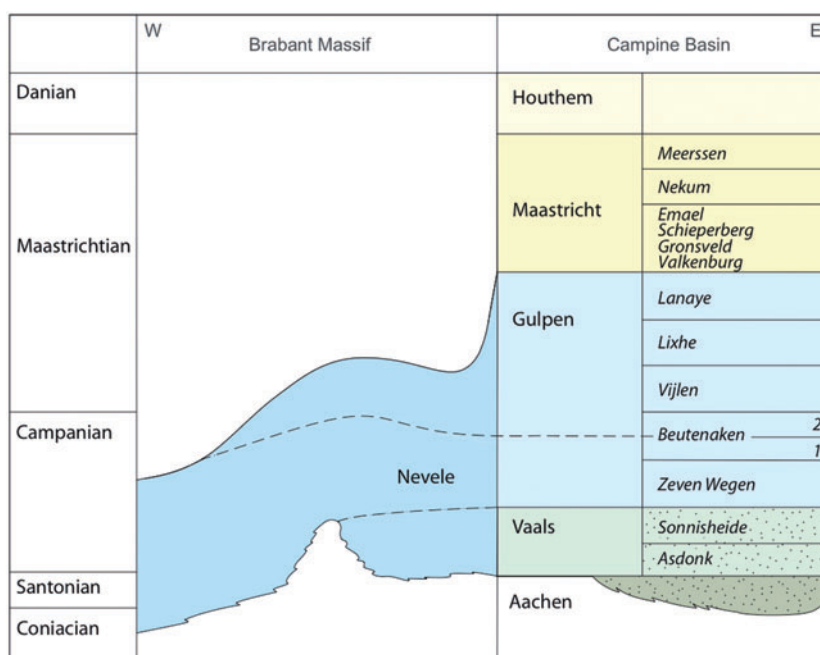
prograding into Santonian fluviatile, limnic to coastal deposits of the Aachen Formation (Demoulin et al., 2010). These early deposits are largely restricted to the intersection zone between the Roer Valley Graben and the Ardennes Massif. The flooding of the eastern part of the London-Brabant Massif is related mainly to sea level highstands during the Santonian-Campanian (Dusar & Lagrou, 2007a); it resulted in the deposition of chalk (Nevele Formation), the lateral equivalent of the Ommelanden Formation. Due to a punctuated relaxation of Subhercynian inversion, during the Campanian and Early to early Late Maastrichtian, chalk-dominated sediments were rapidly deposited over the entire area. Deposition of greensands took place near the boundary of the inverted Roer Valley Graben. In the Meer borehole, these deposits are predominantly calcareous, and can be considered as transitional between the lithologically more diverse Vaals and Gulpen formations, as defined in the Maastrichtian type area, and the Nevele Formation of the London-Brabant Massif. During the late Maastrichtian and Danian, two subsidence pulses resulted in the calcarenite-dominated sedimentation represented by the uppermost Gulpen, Maastricht and Houthem formations. These were geographically restricted to the Campine Basin and Roer Valley Graben depocentres and were interrupted by a short-lived inversion. The resulting regression, known as the Cretaceous/Paleogene boundary event, was more pronounced in both the Campine Basin and the Roer Valley Graben than in the Maastrichtian type area or the borderland to the London-Brabant Massif, and widened the hiatus between the Maastrichtian and Danian by removing the top part of the Maastricht Formation. Sedimentation of the Chalk Group was terminated by a regression caused by the Laramide inversion (Herngreen & Wong, 2007; Vejbæk et al., 2010).

## Material and methods

### Borehole Meer

The geothermal exploration well 'Meer' was drilled by the Geological Survey of Belgium in 1980/81 to a depth of 2517 m, in an attempt to reach the Dinantian limestone aquifer (Fig. 1). Drilling depths are measured from the drilling platform at +13.22 m TAW (Belgian Ordnance Datum). The geophysical data include gamma ray, induction, spherically focused laterolog, sonic, density, neutron, SP and caliper. The original geological descriptions, logs and samples are stored at the Geological Survey of Belgium, Brussels (GeoDoc 007E0205). On average, drill cuttings of the Meer borehole were sampled every 5 metres, and sieved and rinsed on a 1-mm mesh at the well site, in order to remove most of the drilling mud. The samples are stored in the core repository of the Geological Survey of Belgium. Samples lacking impurities, without flint horizons (which tend to eliminate cuttings from softer surrounding rock) and of sufficient volume (thus excluding intervals of

chalky silt which was difficult to separate from the mud) were selected for the present study, thereby trying not to exceed a targeted 20-metre sampling interval. The resultant sampling density was higher in the upper sequences of the Chalk Group (less than 10 m in the interval corresponding to the Houthem and Maastricht formations and the transition of the Gulpen-Maastricht formations) and lower towards its base (c. 20 m in the interval corresponding to the Gulpen Formation). The sampling thus reflects the local problems in stratigraphic correlation and complements previous studies which were based on more randomly selected samples.

### Sample preparation and palynological methods

Twenty-three 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. Oxidising agents were not used. The residues were sieved on a nylon screen with a mesh size of 20 μm, stained with methyl green and mounted in glycerin jelly on microscope slides. Photomicrographs were taken with a digital Olympus C-400 Zoom camera mounted on an Olympus BX51 microscope. All slides and figured specimens are housed in the botanical collection of the National Herbarium (RAB), Scientific Institute, Mohammed V-Agdal University, Rabat, Morocco.

Two slides per sample were systematically scanned at × 400 magnification in non-overlapping traverses. Only the presence per sample – without counting – of organic-walled palynomorphs was noted. Well-preserved specimens were selected for photomicrography. Pollen, spores, and foraminiferal test linings proved to be rare, but were not noted.

## Palynology

The nomenclature follows Fensome & Williams (2004) and database DINOFLAJ2 (Fensome et al., 2008) for taxa described prior to 2004; other species are referenced here. Many invalid dinocyst species described by Wilson (1974) in an unpublished PhD thesis, and later formally described by Slimani (1994, 1996, 2001b, 2003), were recorded (see their equivalent between brackets in Appendix A, according to Slimani, 2001a). The palynomorph assemblages from the Meer borehole consist of spores, pollen, foraminiferal linings, acritarchs, chlorophyte algae (*Palambages* spp.) and dinocysts. The dinocyst assemblages are diverse and well preserved, and represent more than 90 per cent of the total number of palynomorphs. A total of 465 species and subspecies of dinocysts, one acritarch species and two species of Palambages were identified during the present study

(Appendix A). The ranges of 191 stratigraphically important species are plotted in Table 1 in order of the highest occurrences in the borehole. Taxa listed in Appendix A, but not shown in Table 1 have less stratigraphic value for the scope of the present study. The presence of many post-Danian taxa in the assemblage suggests that significant contamination affected the samples, despite their careful selection. *Apectodinium* spp., *Areoligera sentosa*, *Areoligera tauloma*, *Cerodinium medcalfii*, *Deflandrea oebisfeldensis*, *Horologinella* sp. cf. *H. angulata*, *Hystrichokolpoma cinctum*, *Kallosphaeridium brevibarbatum*, *Kallosphaeridium orchiesense*, *Pentadinium laticinctum* and *Phthanoperidinium crenulatum* are presumed contaminations and are denoted as such in Appendix A. The taxa *Aldorfia dictyota* subsp. *papillata*, *Cribroperidinium edwardsii-orthoceras*, *Ctenidodinium* spp., *Dapcodinium priscus*, *Gonyaulacysta jurassica* subspp., *Nannoceratopsis* spp. and *Pseudoceratium pelliferum* are considered reworked from the Jurassic and Early Cretaceous and are denoted as such.

## Dinoflagellate event stratigraphy and age assignment

The biostratigraphy and relative dating of the section studied are based on comparisons with dinocyst assemblages described from numerous, biostratigraphically well-dated Campanian to Danian sequences, mainly in northwest Europe. The Campanian assemblages were compared with assemblages from Charente, the Campanian type area in France (Wilson, 1971; Masure, 1985), from Tercis les Bains (Campanian/Maastrichtian GSSP) (Antonescu et al., 2001a, 2001b; Schiøler & Wilson, 2001), from southern Limburg, the Netherlands (Wilson, 1971, 1974; Schumacker-Lambry, 1977; Robaszynski et al., 1985; Slimani, 1995, 2000, 2001a), from northwest Belgium (Louwye, 1991, 1993; Slimani, 1995, 2000, 2001a) and from Denmark (Wilson, 1971, 1974). The Maastrichtian dinocyst assemblages were compared mostly with those described from the type area of that stage in southern Limburg and adjacent areas in Belgium (Wilson, 1971, 1974; Schumacker-Lambry, 1977; Herngreen et al., 1986; Slimani, 1995, 2000, 2001a; Schiøler et al., 1997; Brinkhuis et al., 2000), from northern Germany (Marheinecke, 1992), from Denmark and the Central North Sea (Wilson, 1971, 1974; Schiøler & Wilson, 1993). Latest Maastrichtian to Danian dinocyst assemblages were compared with those of Cretaceous/Paleogene (K/Pg) sections, including Stevns Klint in the Danian type area (Hansen, 1977, 1979a, b; Brinkhuis et al., 1998), southern Scandinavia (Hultberg, 1985, 1986; Hultberg & Malmgren, 1986, 1987), the Campine Basin and southern Limburg (Slimani, 1995, 2000, 2001a; Brinkhuis and Schiøler, 1996). Other – mainly Maastrichtian and Danian – dinocyst assemblages from elsewhere in middle latitudes of the northern hemisphere are also useful for comparison: France (Foucher, 1979), southern Germany (Kirsch, 1991), the east coast of North America (Benson, 1976; May, 1980; Firth, 1987; Aurisano, 1989; Moshkovitz & Habib,

1993; Habib et al., 1996), Tunisia (El Kef: K/Pg GSSP) (Brinkhuis et al., 1998) and Morocco (Slimani et al., 2010). Dinocyst biozones of Campanian to Danian sections in northern Europe (i.e., the northern Boreal domain) are calibrated mainly with belemnite biostratigraphy, while those from southwest Europe and the Mediterranean (i.e., the Tethyan realm) were calibrated with foraminiferal zones.

The present dinocyst biostratigraphic interpretation of the Meer borehole relies on dinocyst events previously recorded from southern Limburg and northwest Belgium. In order to avoid contaminations caused by cuttings, the events are based mainly on the highest consistent occurrences (HOs) of index species. Furthermore, the dinocyst events must be interpreted carefully because of the paucity of certain index species. However, the rarity of some of the significant species – previously reported as rare – in the Meer section in comparison with the Turnhout section may be linked to the lower number of slides studied per sample (only 2 slides, rather than 4; compare Slimani, 2001a). The bio-events are described below in ascending stratigraphical order, and are correlated to the belemnite zones of northwest Europe (Fig. 3; Table 1). Selected dinocyst taxa are illustrated in Figures 4-8.

### Lower Campanian (sample 1152 m)

The lowest occurrences (LO) of *Biconidinium reductum*, *Exochosphaeridium*? *masureae* (Fig. 4b) and *Xenascus wetzelii* (Fig. 4f) have been noted at the base of the Upper Campanian (base of *Belemnitella mucronata* Zone) in southern Limburg and northwest Belgium. In the Meer well, *E*.? *masureae* occurs only at 1109 m, while the other species are present earlier in the oldest sample studied (1152 m). This single occurrence of *E*.? *masureae* is considered here as an LO and may be used to place tentatively the Lower/Upper Campanian boundary between samples at 1152 m and 1109 m.

### Upper Campanian (samples 1109-1020 m)

#### Lower part of the Upper Campanian (samples 1109-1089 m)

The following species with a well-known highest consistent occurrence within the basal part of the *Belemnitella woodi* Zone have been noted: *Spinidinium angustispinum* in Wilson, 1974 (Fig. 7s) in sample 1152 m, *Cyclonephelium filoreticulatum* in sample 1109 m, and *Cribroperidinium wilsonii* forma A (Fig. 5a, b), *Palaeohystrichophora infusorioides* (Fig. 7f) and *Rhynchodiniopsis*? sp. cf. *Gonyaulacysta prominoseptata* in Wilson, 1974 (Fig. 4 m) in sample 1089 m. These HOs suggest correlation of the interval 1109-1089 m with the lower part of the Upper Campanian. However, the highest irregular occurrences of *Cribroperidinium wilsonii* forma A at 1020 m and *Palaeohystrichophora infusorioides* at 980 m can be explained through reworking. The HOs of these two species were also

*Table 1.  Stratigraphic distribution of selected dinoflagellate cysts in the Meer borehole according to highest occurrences. Numbers refer to order of highest occurrences.*

STAGES and SUBSTAGES

| L. CAMP. | Upper CAMPAN | | | | | Lower MAAS. | | | | Upper MAASTRICHTIAN | | | | | | | | | DANIAN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | l. part | | m.p. | u. part | | upper part | | | | lower part | | | | | upper part | | | | Lower | | Upper | | |
| M1152 | M1109 | M1089 | M1066 | M1042 | M1020 | M995 | M980 | M964 | M948 | M925 | M904 | M895 | M888 | M880 | M869 | M857 | M848 | M841 | M832 | M825 | M817 | M814 | SAMPLES |
| | | | | | | | | | | | | × | × | × | × | × | × | × | | × | × | × | 1  Cordosphaeridium inodes subsp. longipes |
| | | | × | × | | | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | × | 2  Deflandrea galeata |
| | | | | × | × | | | | | | × | × | × | × | × | × | × | × | × | × | | × | 3  Diphyes colligerum |
| | | × | | | | | × | × | × | × | × | × | | | × | × | × | × | × | × | × | × | 4  Fibrocysta axialis |
| | | | | | | | | | | | | | | | × | × | × | × | × | × | | | 5  Fibrocysta lappacea |
| | | | | | | | | | | | | | | | | | | | | | | × | 6  Fibrocysta sp. A of B & S, 1996 |
| | | | | | | | | | | | × | × | × | × | × | × | × | × | × | × | × | × | 7  Hafniasphaera septata |
| | | | | | | | | | | | | | | | × | × | × | × | × | | | × | 8  Cannosphaeropsis fransisca |
| | | | | | | | | | | | × | × | | | × | | × | | | × | × | × | 9  Spinidinium densispinatum |
| | | | | × | × | | | | | | × | × | × | | | | × | × | × | × | × | × | 10  Spumadinium sp. cf. S. sp. of Brin. et al.,2000 |
| | | | | | | | | | | × | | | | | | | | | | | | × | 11  Turbiosphaera filosa |
| | | | | | | | | | | | | | × | | | × | × | × | × | × | × | × | 12  Xenicodinium lubricum |
| | | | | | | | | | | | | × | | | | × | × | × | × | × | | | 13  Damassadinium californicum |
| | | | | | | | | | | | | × | | | | | × | × | × | × | × | | 14  Hafniasphaera hyalospinosa |
| | | | | × | | | | | | | | | | × | × | × | × | × | × | | × | | 15  Horologinella coninckii |
| | × | × | × | × | × | × | × | | × | × | | × | × | × | × | × | × | × | × | × | × | | 16  Trithyrodinium evittii |
| | | | | | | | × | | | | | × | | | | × | × | × | × | | | | 17  Carpatella cornuta |
| × | × | | × | × | × | | | | | | × | × | × | × | × | × | | | × | × | | | 18  Cladopyxidium saeptum |
| | | | | | | | | | | | | × | | | | × | | × | × | × | | | 19  Disphaerogena carposphaeropsis |
| | | | | | | | | | | | | × | | | × | × | × | × | × | × | | | 20  Druggidium sp. A of Slimani, 1994 |
| | | | | | | | | | | | | | | | | × | | × | | × | | | 21  Fibrocysta bipolaris |
| | | | | | | | | | | | | × | × | | | × | × | × | × | × | | | 22  Fibrocysta ovalis |
| | | | | | | | | × | | × | | × | × | | | × | × | × | × | × | | | 23  Flandrecysta tubulosa |
| | × | × | | | | | × | × | | | | × | × | × | × | × | × | × | | × | | | 24  Glaphyrocysta perforata |
| | | | | | | | | | | | | × | × | × | × | | × | × | | × | | | 25  Hafniasphaera cryptovesiculata |
| | | | | | | | | | | | | | | × | × | | × | × | × | × | | | 26  Hafniasphaera graciosa |
| | | | | | | | | | × | × | | × | × | × | × | | × | × | × | × | | | 27  Hystrichokolpoma bulbosum subsp. bulbosum |
| | | | | | | | | | | | × | × | × | | × | × | × | × | × | × | | | 28  Hystrichostrogylon coninckii |
| | | | | | | | | | | | | | | × | × | × | × | × | × | × | | | 29  Kallosphaeridium parvum |
| × | | × | × | | × | × | × | × | × | × | | × | × | × | × | × | | | | × | | | 30  Rottnestia wetzelii subsp. wetzelii |
| | | × | | | | | | | | | | × | × | × | | × | × | × | | × | | | 31  Senoniasphaera inornata |
| | | | | | | | | | | | | | | × | | × | | × | × | × | | | 32  Spinidinium? pilatum |
| | | | | | | | | | | | | × | | | × | × | × | × | × | × | | | 33  Spinidinium sp. A |
| | | | | | | | | | | | | × | × | × | | × | × | × | × | × | | | 34  Tectatodinium rugulatum |
| | | | | | | | | | | | | | | | | | | | | × | | | 35  Thalassiphora pelagica |
| | | | | | | | | | | | | × | × | | | × | × | × | × | × | | | 36  Xenicodinium delicatum |
| | | | | | | | | | | | | × | | | | | | | × | × | | | 37  Xenicodinium meandriforme |
| | | | | | | | | | | | | × | | | × | × | | × | × | × | | | 38  Xenicodinium reticulatum |
| | | | | | | | | | | | | | | | | | | × | × | × | | | 39  Cordosphaeridium robustum |
| | | | | | | | | | | | | | | | × | | | × | × | × | | | 40  Hystrichostrogylon borisii |
| × | × | | | × | × | × | × | × | × | × | × | × | × | | | × | | | × | | | | 41  Microdinium sonciniae |
| | | | | × | | | × | | × | × | × | × | × | | × | | | × | × | × | | | 42  Raetiaedinium laevigatum |
| | | | | | | | | | | | | | | × | | × | × | × | × | × | | | 43  Samlandia pseudoreticulata |
| | | | | | | | | | | | | × | | | | | × | | × | | | | 44  Sepispinula ancorifera |
| × | × | × | × | × | × | | × | × | × | × | | × | | | | | | × | | × | | | 45  Alterbidinium minus |
| | | | | | × | | | | | | × | | | × | | | × | × | | | | | 46  Caligodinium goeranii |
| | | | | | | | | | | | | | | | | × | × | | | | | | 47  Druggidium? sp. C |
| | | | | | | | | | | | | | | | | × | × | | | | | | 48  Impagidinium aspinatum |
| | | | | | | | | | | | | × | × | × | | × | × | × | | | | | 49  Membranilarnacia? tenella |
| | | | | | | | | | | | | | | × | | × | × | | | | | | 50  Microdinium marheineckei |
| | | × | | | | | | | | | | × | × | × | | × | | × | | | | | 51  Palynodinium grallator |
| | | | | | × | | | | | | | | | × | | × | × | × | | | | | 52  Spinidinium uncinatum |
| | | | | | | | | | | | | | | | | | | × | | | | | 53  Spiniferites ramosus subsp. cavispinosus |
| | × | × | | | × | | | | | | | × | × | × | | | × | × | | | | | 54  Spiniferites ramosus subsp. pterocoelus |
| | | | | | | | | | | | | | | | | × | | × | | | | | 55  Spumadinium felderorum |
| × | | | | × | × | | | × | | | | × | | | | | | × | | | | | 56  Cladopyxidium paucireticulatum |
| × | | × | | × | × | × | | × | | × | × | × | | | | × | × | | | | | | 57  Leberidocysta chlamdata subsp. schiøeleri |
| | | × | | × | × | × | × | × | × | | | × | | | | | × | | | | | | 58  Spongodinium delitiense |
| | | | | | | | | | | | | | | | | | | × | | | | | 59  Ynezidinium pentahedrias |
| × | × | × | × | | × | × | × | × | × | | | | | | | | | × | | | | | 60  Cassiculosphaeridia reticulata |
| × | × | × | | × | | × | × | × | | | | × | × | × | × | | | × | | | | | 61  Circulodinium distinctum subsp. distinctum |
| | | × | × | × | × | × | × | | × | × | × | × | × | × | × | × | × | | | | | | 62  Cladopyxidium marheineckei |
| | | | | | × | × | | | | | | × | | | × | × | | | | | | | 63  Coronifera granulata |
| × | | | | | | | | | | | | × | × | × | | × | | | | | | | 64  Hystrichosphaeropsis ovum |
| | × | | | | × | | | | × | × | | × | | × | | × | | | | | | | 65  Impagidinium rigidaseptatum |

*Table 1 (continued).*

| | Upper CAMPAN | | | | | Lower MAAS. | | | | Upper MAASTRICHTIAN | | | | | | | | | DANIAN | | | | STAGES and SUBSTAGES |
| L. CAMP. | l. part | | m. p. | u. part | | upper part | | | | lower part | | | | | upper part | | | | Lower | | Upper | | |
| M1152 | M1109 | M1089 | M1066 | M1042 | M1020 | M995 | M980 | M964 | M948 | M925 | M904 | M895 | M888 | M880 | M869 | M857 | M848 | M841 | M832 | M825 | M817 | M814 | SAMPLES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ? | × | | | × | × | × | × | × | × | × | × | | | | | | | 66  Ithnacysta elongata |
| | | | | | × | × | × | × | × | | × | × | × | × | × | × | | | | | | | 67  Laciniadinium firmum |
| | | | | | × | × | | × | | × | × | × | × | × | × | × | | | | | | | 68  Microdinium carpentierae |
| | | × | × | | × | | | × | × | × | | × | × | | | × | | | | | | | 69  Microdinium mariae |
| ? | × | × | | | × | × | | × | × | | | × | | | × | × | | | | | | | 70  Microdinium sp. A of Slimani, 1994 |
| | | × | | | × | × | × | × | × | × | × | × | × | × | × | × | | | | | | | 71  Phanerodinium cayeuxii |
| | | | | | × | | | × | × | × | × | × | × | × | × | × | | | | | | | 72  Phanerodinium ovum |
| | | × | × | | × | × | × | | × | | × | × | × | × | × | × | | | | | | | 73  Phanerodinium? turnhoutensis |
| | | | | | | | | | | | | | | × | × | × | | | | | | | 74  Gillinia? sp. A |
| | | | | | | | | | | | | | | | | × | | | | | | | 75  Pierceites pentagonus |
| | | | | | | | | | | | | | | | | × | | | | | | | 76  Pterodinium cretaceum |
| | × | × | × | × | × | × | | | | × | × | | | | | × | | | | | | | 77  Rhiptocorys veligera |
| | | | | | | | × | | | × | | × | × | | | × | | | | | | | 78  Rigaudella apenninica |
| | | | | | | | | | | × | | | | | | × | | | | | | | 79  Wallodinium anglicum |
| | | | | | | × | × | | × | | | | | | × | × | | | | | | | 80  Alterbidinium varium |
| | × | × | | | × | × | × | | × | × | × | × | × | | | × | | | | | | | 81  Cannosphaeropsis utinensis |
| | | | | | | | | | | | | × | | | × | × | | | | | | | 82  Cladopyxidium septocrispum |
| × | × | × | × | × | × | × | × | × | × | × | | × | × | × | | × | | | | | | | 83  Diconodinium wilsonii |
| × | | × | | | | | | × | | | | | | | | × | | | | | | | 84  Dinogymnium acuminatum |
| × | × | × | × | × | × | × | × | × | × | × | | × | × | | | × | | | | | | | 85  Leberidocysta? microverrucosa |
| | | × | | | × | | × | × | × | × | | × | × | × | × | × | | | | | | | 86  Litosphaeridium fenestreconum |
| | | × | | | | × | × | × | × | | × | × | × | × | × | × | | | | | | | 87  Palaeotetradinium maastrichtiense |
| × | × | × | | × | | | | | | | × | × | × | × | × | × | | | | | | | 88  Pervosphaeridium monasteriense |
| | | × | | | | × | | | | | | × | × | | | × | | | | | | | 89  Phanerodinium sp. cf. D. fourmarieri of Slim,94 |
| | | × | × | × | × | | | | | | | × | × | × | × | × | | | | | | | 90  Raphidodinium fucatum |
| × | × | × | × | × | × | | | | | | | | | | × | × | | | | | | | 91  Multiplicisphaeridium? cruciatum |
| × | × | | × | | | | | | | | | | | | | × | | | | | | | 92  Wallodinium luna |
| | | | | | | | | | | × | × | × | × | × | | | | | | | | | 93  Chatangiella sp. A of Shiøler & Wilson, 1993 |
| | | | | × | | | | | | | | | | | | × | | | | | | | 94  Cladopyxidium? halembayense |
| | | | | | | × | | | × | | | | | | | × | | | | | | | 95  Gonyaulacysta? obscura |
| | | | × | × | | | | | | × | × | × | × | × | | × | | | | | | | 96  Kleithriasphaeridium truncatum |
| | | | | | | | | | | | | | | | | × | | | | | | | 97  Lasagniella herngreenii |
| | × | | | | × | × | × | | | | × | | × | × | | × | | | | | | | 98  Litosphaeridium siphoniphorum subsp. glabrum |
| | | | | | | | × | | × | | | × | | | | × | | | | | | | 99  Membranilarnax liradiscoides |
| | | | × | | × | | | × | | | × | | | | | × | | | | | | | 100  Multicorisphaeridium bisphaera |
| | | | | | | × | | × | × | | | | | × | × | × | | | | | | | 101  Pervosphaeridium tubuloaculeatum |
| | | | | | | | | × | | | | × | × | × | | × | | | | | | | 102  Phanerodinium septatum |
| | | | | × | | | | | × | | × | × | × | × | | × | | | | | | | 103  Phanerodinium setiferum |
| | | | | | | | | | | | | | | | × | × | | | | | | | 104  Phanerodinium sp. A of Slimani, 1994 |
| | | × | | | | | | | | × | × | × | × | × | | | | | | | | | 105  Raetiaedinium punctulatum |
| | × | × | | | × | × | × | × | | | | | | | | × | | | | | | | 106  Membranigonyaulax wilsonii |
| × | × | × | | | × | × | × | × | | | | × | × | | | × | | | | | | | 107  Turnhosphaera hypoflata |
| × | × | × | | × | × | × | × | | × | × | | × | × | | | | | | | | | | 108  Cribropridinium wilsonii forma B |
| | × | | | | | | | | | | | | | | | × | | | | | | | 109  Dinogymnium avellana |
| | | | | | | | | | | | | | | | | × | | | | | | | 110  Dinogymnium westralium |
| × | | × | | | × | × | | × | × | | × | × | × | | | | | | | | | | 111  Isabelidinium cooksoniae |
| × | × | × | × | × | × | × | × | × | × | × | × | × | × | | | | | | | | | | 112  Leberidocysta? flagellichnia |
| | | | | | | | | | | | | | | | × | | | | | | | | 113  Leptodinium porosum |
| | | | | | × | × | × | × | × | × | | × | × | | | | | | | | | | 114  Neonorthidium perforatum |
| | | | | | × | × | × | | | × | × | × | × | | | | | | | | | | 115  Palaeoperidinium? parvum |
| | × | × | × | × | × | × | | | | | | × | | | | | | | | | | | 116  Alterbidinium montanaense |
| | × | × | × | | × | × | × | × | × | | × | × | | | | | | | | | | | 117  Batiacasphaera reticulata |
| | | × | | × | × | × | × | | × | | × | × | | | | | | | | | | | 118  Microdinium setosum |
| × | × | × | × | × | × | × | | | | | × | × | | | | | | | | | | | 119  Wilsonisphaera petila |
| × | × | × | × | × | × | × | × | × | × | | × | | | | | | | | | | | | 120  Hystrichodinium pulchrum subsp. pulchrum |
| | × | × | × | × | × | | | × | | | × | | | | | | | | | | | | 121  Kleithriasphaeridium loffrense |
| | | | | | × | × | × | × | × | × | × | | | | | | | | | | | | 122  Ovoidinium membranaceum |
| × | × | × | | × | | | | | | | × | | | | | | | | | | | | 123  Platicystidia? sp. Indet. of De Coninck, 1986 |
| × | × | × | × | × | × | × | | | | | × | | | | | | | | | | | | 124  Trichodinium castanea subsp. castanea |
| | × | × | × | | × | | | | × | | × | | | | | | | | | | | | 125  Valensiella foucheri |
| | | | | | | | | | | | × | | | | | | | | | | | | 126  Canninginopsis maastrichtiensis |
| | | × | × | | | | | | | | × | | | | | | | | | | | | 127  Chatangiella ditissima |
| | | | | | | | | | × | × | | | | | | | | | | | | | 128  Fibrocysta klumppiae |
| | | × | | × | × | × | × | × | | | × | | | | | | | | | | | | 129  Isabelidinium bujakii |
| × | × | × | × | × | × | × | | × | × | × | | | | | | | | | | | | | 130  Lingulodinium varispinosum |

*Table 1 (continued).*

| L. CAMP. | Upper CAMPAN | | | | | Lower MAAS. | | | | Upper MAASTRICHTIAN | | | | | | | | | DANIAN | | | | STAGES and SUBSTAGES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | l. part | | m.p. | u. part | | upper part | | | | lower part | | | | | upper part | | | | Lower | | Upper | | |
| M1152 | M1109 | M1089 | M1066 | M1042 | M1020 | M995 | M980 | M964 | M948 | M925 | M904 | M895 | M888 | M880 | M869 | M857 | M848 | M841 | M832 | M825 | M817 | M814 | SAMPLES |
| | | × | | | | | | × | × | × | | | | | | | | | | | | | 131 Membranilarnacia polycladiata |
| | | × | × | × | | | | | | × | | | | | | | | | | | | | 132 Microdinium parvum |
| × | × | | | × | × | × | × | × | × | | | | | | | | | | | | | | 133 Alterbidinium acutulum |
| × | × | × | × | | | | | | × | | | | | | | | | | | | | | 134 Apteodinium deflandrei |
| × | × | | | | | | | | × | | | | | | | | | | | | | | 135 Exochosphaeridium brevitruncatum |
| | × | × | × | × | × | × | | | × | | | | | | | | | | | | | | 136 Histiocysta palla |
| | × | × | × | | × | × | | | × | | | | | | | | | | | | | | 137 Isabelidinium belfastense |
| | | | × | | × | × | | × | × | | | | | | | | | | | | | | 138 Membranilarnacia aff. leptoderma of Slim, 94 |
| | | | | | × | × | | × | × | | | | | | | | | | | | | | 139 Microdinium pauciscabrosum |
| | | | × | | × | | | | × | | | | | | | | | | | | | | 140 Turnhosphaera hyalina |
| | × | | × | × | × | × | × | × | | | | | | | | | | | | | | | 141 Batiacasphaera solida |
| × | | × | × | | × | × | × | × | | | | | | | | | | | | | | | 142 Histiocysta? variornata |
| × | × | × | × | | × | × | | | × | | | | | | | | | | | | | | 143 Neosphaerodictyon filosum |
| × | | | | × | × | × | × | × | | | | | | | | | | | | | | | 144 Surculosphaeridium longifurcatum |
| | | | | | | | | × | | | | | | | | | | | | | | | 145 Triblastula wilsonii |
| × | | | × | | × | × | | | | | | | | | | | | | | | | | 146 Areoligera microreticulata |
| | | | | | × | × | | | | | | | | | | | | | | | | | 147 Cerodinium albertii |
| × | × | × | | | × | | × | | | | | | | | | | | | | | | | 148 Palaeohystrichophora infusorioides |
| | × | × | × | | × | × | | | | | | | | | | | | | | | | | 149 Spinidinium? clavus |
| | | | | | × | | | | | | | | | | | | | | | | | | 150 Triblastula utinensis |
| | | × | | × | | | | | | | | | | | | | | | | | | | 151 Chatangiella? robusta |
| | | | × | × | | | | | | | | | | | | | | | | | | | 152 Cladopyxidium verrucosum |
| × | × | × | | × | × | | | | | | | | | | | | | | | | | | 153 Cribropridinium wilsonii forma A |
| | × | | | × | | | | | | | | | | | | | | | | | | | 154 Dinogymnium digitus |
| | × | × | | × | | | | | | | | | | | | | | | | | | | 155 Dinopterygium cladoides |
| | × | × | | × | | | | | | | | | | | | | | | | | | | 156 Membranilarnacia hapala |
| × | × | | × | × | × | | | | | | | | | | | | | | | | | | 157 Florentinia radiculata |
| × | × | × | × | × | × | | | | | | | | | | | | | | | | | | 158 Gillinia hymenophora |
| | | × | × | × | | | | | | | | | | | | | | | | | | | 159 Impagidinium scabrosum |
| | | | | × | | | | | | | | | | | | | | | | | | | 160 Odontochitina streelii |
| | | × | | × | | | | | | | | | | | | | | | | | | | 161 Palaeostomocystis foveolata |
| | | | | × | | | | | | | | | | | | | | | | | | | 162 Samlandia mayi |
| × | × | × | × | × | | | | | | | | | | | | | | | | | | | 163 Chatangiella madura |
| × | × | × | × | × | | | | | | | | | | | | | | | | | | | 164 Sepispinula ambigua |
| | × | × | × | × | | | | | | | | | | | | | | | | | | | 165 Membranigonyaulax granulata |
| | | | | × | | | | | | | | | | | | | | | | | | | 166 Pervosphaeridium intervelum |
| × | × | × | | × | | | | | | | | | | | | | | | | | | | 167 Xenascus ceratioides subsp. ceratioides |
| | | × | × | | | | | | | | | | | | | | | | | | | | 168 Callaiosphaeridium asymmetricum |
| | × | | × | | | | | | | | | | | | | | | | | | | | 169 Florentinia? flosculus |
| × | × | | × | | | | | | | | | | | | | | | | | | | | 170 Glyphanodinium facetum |
| × | × | | × | | | | | | | | | | | | | | | | | | | | 171 Odontochitina operculata |
| | × | × | × | | | | | | | | | | | | | | | | | | | | 172 Stephodinium? spinosum |
| | × | × | × | | | | | | | | | | | | | | | | | | | | 173 Vozzhennikovia microornata |
| | | × | | | | | | | | | | | | | | | | | | | | | 174 Alisogymnium euclaense |
| × | × | × | | | | | | | | | | | | | | | | | | | | | 175 Biconidinium reductum |
| | × | × | | | | | | | | | | | | | | | | | | | | | 176 Chatangiella granulifera subsp. granulifera |
| | × | × | | | | | | | | | | | | | | | | | | | | | 177 Chatangiella vnigrii subsp. vnigrii |
| | × | × | | | | | | | | | | | | | | | | | | | | | 178 Chatangiella williamsii |
| × | × | × | | | | | | | | | | | | | | | | | | | | | 179 Manumiella? cretacea |
| | | × | | | | | | | | | | | | | | | | | | | | | 180 Microdinium granocarinatum |
| | × | × | | | | | | | | | | | | | | | | | | | | | 181 Montanarocysta aemiliana |
| × | | × | | | | | | | | | | | | | | | | | | | | | 182 Rhynchodiniopsis? sp. cf. G. prominoseptata |
| × | × | × | | | | | | | | | | | | | | | | | | | | | 183 Xenascus wetzelii |
| | | × | | | | | | | | | | | | | | | | | | | | | 184 Xiphophoridium alatum |
| | × | | | | | | | | | | | | | | | | | | | | | | 185 Cyclonephelium filoreticulatum |
| | × | | | | | | | | | | | | | | | | | | | | | | 186 Exochosphaeridium? masureae |
| | × | | | | | | | | | | | | | | | | | | | | | | 187 Pervosphaeridium elegans |
| × | × | | | | | | | | | | | | | | | | | | | | | | 188 Pervosphaeridium septatum |
| × | × | | | | | | | | | | | | | | | | | | | | | | 189 Raetiaedinium truncigerum |
| × | | | | | | | | | | | | | | | | | | | | | | | 190 Odontochitina costata |
| × | | | | | | | | | | | | | | | | | | | | | | | 191 Spinidinium angustispinum in Wilson, 1974 |
| | | | | × | × | × | × | | | × | × | | | | | | | | | | | | 192 Cribroperidinium orthoceras-edwadsii |
| | | | × | × | × | × | × | × | × | | | | | | | | | | | | | | 193 Ctenidodinium spp. |
| | × | × | × | | | | | | | | | | | | | | | | | | | | 194 Gonyaulacysta jurassica subspp. |
| | | | | | | | | | | | | | | | | | | | × | | | | 195 Dapcodinium priscus |
| | | | | | × | | | | | | | | | × | | | × | × | | | | | 196 Nannoceratopsis spp. |

(Rows 192–196 marked *Reworked*.)

Fig. 3. Correlation of the studied section of the Meer well with dinoflagellate zonation schemes from Belgium, the Netherlands, northern Germany, Denmark, the Central North Sea and the conventional, northwest European belemnite zones, based on selected dinoflagellate cyst events; D. calif. = Damassadinium californicum Zone; S. in. = Senoniasphaera inornata Subzone; H. cryptov. = Hafniasphaera cryptovesiculata Subzone; CC = Carpatella cornuta Zonule; Tr = Tectatodinium rugulatum Zonule; Xl = Xenicodinium lubricum Zonule. NOTE: Belemnella kazimiroviensis is the proper name of Belemnella casimirovensis.

recorded from the Upper Campanian (lower to middle part) in northwest Europe by Foucher (1979) and Kirsch (1991). The single presence of *Exochosphaeridium? masureae* in sample 1109 m may be considered here as its LO (see above), since its HO in sample at 1089 m should coincide with the HO of *Rhynchodiniopsis? sp. cf. Gonyaulacysta prominoseptata* in Wilson, 1974, according to previous studies referred to in the latter paper.

### Middle part of the Upper Campanian (sample 1066 m)

The documented HOs of *Pervosphaeridium elegans*, *Xenascus wetzelii* and *Stephodinium? spinosum* (Fig. 8s1-2) within the middle to upper part of the *Belemnitella woodi* Zone are here recorded at depths of 1109 m, 1089 m and 1066 m, respectively. Therefore, the interval from above sample 1089 m to 1066 m may belong to the middle part of the Upper Campanian.

### Upper part of the Upper Campanian (samples 1042-1020 m)

Species with well-known HOs within the *Belemnitella minor* Zone have been recorded at 1152 m (*Odontochitina costata*), 1109 m (*Raetiaedinium truncigerum*; Fig. 5c), 1089 m (*Xiphophoridium alatum*), 1066 m (*Callaiosphaeridium asymmetricum* (Fig. 5m), *Florentinia? flosculus* (Fig. 7i)) and 1020 m (*Odontochitina streelii* (Fig. 4e)). The HO of the last-named taxon suggests correlation of the interval 1042-1020 m with the upper part of the Upper Campanian. Most probably, the earlier disappearance of the other species in the interval considered (1152-1066 m) is a reflection of their extreme rarity. This correlation is confirmed by the HOs of *Chatangiella madura* (Fig. 6k) and *Membranigonyaulax granulata* (Fig. 4l) at 1042 m, and of *Impagidinium scabrosum* at 1020 m, previously recorded by Slimani (2001a), and is supported by the fact that the Beutenaken Member at the type locality was correlated with part of the *Belemnitella minor* Zone by Keutgen & Jagt (1999).

### Lower Maastrichtian (samples 995-948 m)

The HOs of *Membranilarnacia hapala* (Fig. 5o), *Odontochitina operculata*, *Samlandia mayi* (Fig. 4j), *Xenascus ceratioides* subsp. *ceratioides* and, probably, *Chatangiella? robusta* (Fig. 6j), are within the lower part of the Lower Maastrichtian, more precisely at the boundary between the conventional *Belemnella lanceolata* and *Belemnella occidentalis* zones (Wilson, 1974; Schiøler & Wilson, 1993; Slimani 1995, 2000, 2001a). In the Meer borehole, the HOs of *Chatangiella? robusta*, *Membranilarnacia hapala* and *Samlandia mayi* coincide with those indicating the top of the uppermost Campanian at a depth of 1020 m, and therefore demonstrate the absence of the lower part of the Lower Maastrichtian in borehole Meer. The hiatus corresponds to the conventional *Belemnella lanceolata* Zone (= northwest European *Belemnella lanceolata* to *Belemnella sumensis* zones). Because

of their rarity, the HOs of *Odontochitina operculata* and *Xenacus ceratioides* subsp. *ceratioides* are located lower in the section, at 1066 m and 1042 m, respectively.

According to Slimani (2001a), the LO of *Pervosphaeridium tubuloaculeatum* (Fig. 4i) is at the base of the upper part of the Lower Maastrichtian. This species is here recorded for the first time at a depth of 995 m, and thus confirms the absence of the lower part of the Lower Maastrichtian as suggested above. The HOs and LOs of the dinocyst events are similar in our study and therefore permit the placement of the Campanian/Maastrichtian boundary between depths of 1020 m and 995 m. In the Meer borehole, this boundary coincides with the LOs at 995 m of other significant species such as *Alterbidinium varium* (Fig. 7d) and *Triblastula utinensis*. Both have previously been recorded from the base of the Lower Maastrichtian (Kirsch, 1991; Schiøler & Wilson, 1993; Slimani, 2001a), i.e., the lower limit of the conventional *Belemnella lanceolata* Zone.

The well-known HO of the index species *Alterbidinium acutulum* (Fig. 7c) at the top of the Lower Maastrichtian, the top of the *Belemnella occidentalis* Zone (Wilson, 1974; Schiøler & Wilson, 1993; Slimani, 2001a), is recorded here at a depth of 948 m. The HOs of *Neosphaerodictyon filosum* (Fig. 5l) and *Histiocysta? variornata* (Fig. 8q) are in the sample below, at a depth of 964 m. According to Wilson (1974) and Slimani (2001a), the latter HOs coincide with that of *Alterbidinium acutulum*. All these findings allow assignment of the interval 995-948 m to the upper part of the Lower Maastrichtian.

### Upper Maastrichtian (samples 925-841 m)

### Lower part of the Upper Maastrichtian (interval 925-880 m)

The well-known HOs of the index species *Isabelidinium cooksoniae* (Fig. 7a, b) and *Chatangiella* sp. A of Schiøler & Wilson (1993) (Fig. 6l) are close to the boundary between the lower and upper Upper Maastrichtian (i.e., uppermost part of the *Belemnitella junior* Zone), and are recorded here at depths of 888 m and 880 m, respectively. Thus, the interval from the HO of *Alterbidinium acutulum* to the HOs of *Isabelidinium cooksoniae* and *Chatangiella* sp. A (samples 925 to 880 m) can be assigned to the lower part of the Upper Maastrichtian. The HO of the index species *Triblastula utinensis* is below that of *Isabelidinium cooksoniae* within the lower part of the Upper Maastrichtian in northwest Europe. *Triblastula utinensis* occurs only at a depth of 995 m in the Lower Maastrichtian, which is a reflection of its extreme rarity. However, the HOs of other species such as *Ovoidinium membranaceum* (Fig. 4k), *Turnhosphaera hypoflata* (Fig. 6c) and *Wilsonisphaera petila* (Fig. 6d), with a known range within the lower part of the Upper Maastrichtian (*Belemnitella junior* Zone), also below the HO of *Isabelidinium cooksoniae*, but within the Lixhe 1 to 3 members at the quarries ENCI-HeidelbergCement Group (Schiøler et al., 1997) and Halembaye (Slimani, 2001a), are recorded here at depths of 880
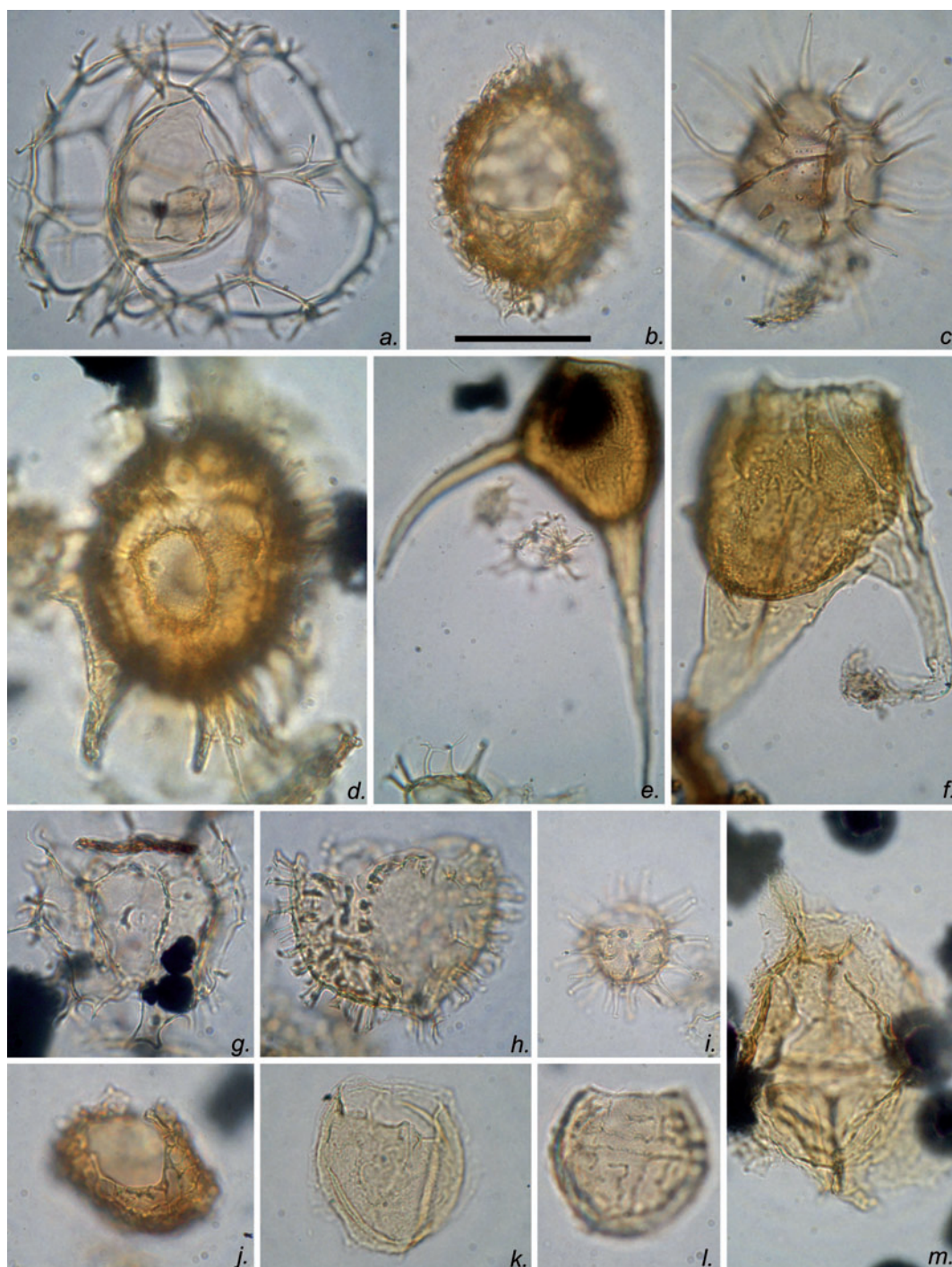
Fig. 4. *Selected dinocysts from the Meer borehole. Scale bar 40 μm. EF: England Finder specimen co-ordinates. a.* Cannosphaeropsis utinensis*; sample Meer 948 m, slide 2, EF E46. Left lateral view, low focus on central body, precingular archeopyle and operculum; b.* Exochosphaeridium? masureae*; sample Meer 1109 m, slide 1, EF D46/1. Ventral view, low focus on precingular archeopyle and processes; c.* Hystrichodinium pulchrum *subsp.* pulchrum*; sample Meer 1089 m, slide 2, EF C27/3. Ventral view of ventral surface; d.* Damassadinium californicum*; sample Meer 880 m, slide 2, EF W55/4. Right dorsolateral view, low focus on precingular and antapical processes; e.* Odontochitina streelii*; sample Meer 1020 m, slide 1, EF F39/4. Ventral view of dorsal surface; f.* Xenascus wetzelii*; sample Meer 1109 m, slide 2, EF Q51/4. Dorsal view of ventral surface; g.* Palynodinium grallator*; sample Meer 888 m, slide 2, EF G31/3. Ventral view of ventral surface; h.* Circulodinium distinctum *subsp.* distinctum*; sample Meer 1020 m, slide 1, EF 42/2. Dorsal view of dorsal surface; i.* Pervosphaeridium tubuloaculeatum*; sample Meer 964 m, slide 2, EF B34. Dorsal view, high focus on precingular 2P archeopyle; j.* Samlandia mayi*; sample Meer 1020 m, slide 2, EF V42/3. Dorsal view, high focus on precingular archeopyle and wall structure; k.* Ovoidinium membranaceum*; sample Meer 948 m, slide 1, EF M57/2. Ventral view, high focus on apical archeopyle; l.* Membranigonyaulax granulata*; sample Meer 1089 m, slide 2, EF O28/2. Ventral view of dorsal surface; m.* Rhynchodiniopsis? sp. cf. Gonyaulacysta prominoseptata in Wilson, 1974; sample Meer 1152 m, slide 1, EF L43/1. Left lateral view, high focus showing sutural septa.*
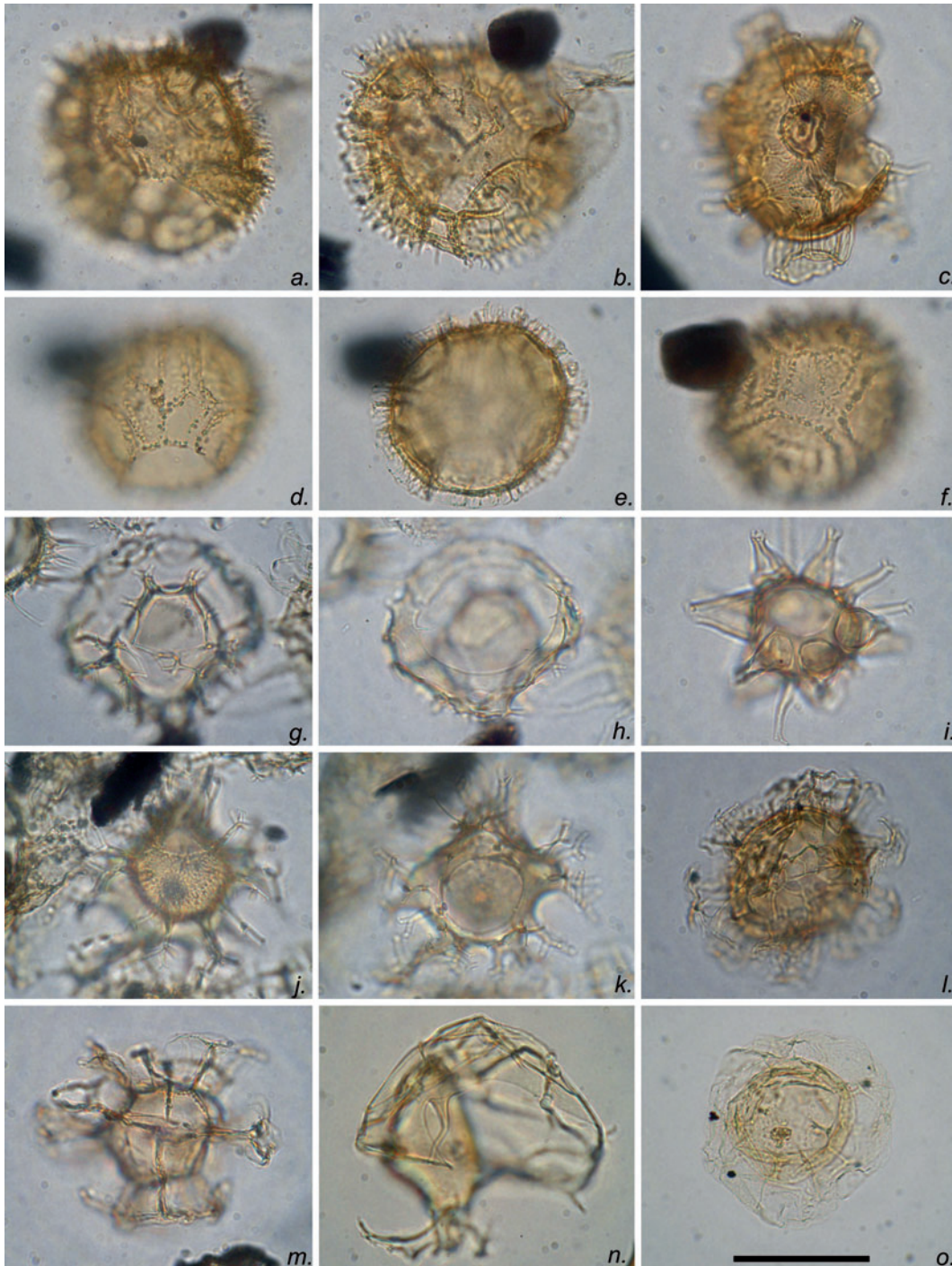
*Fig. 5. Selected dinocysts from the Meer borehole. Scale bar 40 µm. EF: England Finder specimen co-ordinates. a, b.* Cribroperidinium wilsonii *forma A; sample Meer 1152 m, slide 1, EF N37/1. Antapical view of (a) apical surface showing precingular archeopyle, and (b) antapical surface showing processes with free distal extremities; c.* Raetiaedinium truncigerum*; sample Meer 1109 m, slide 2, EF B47/4. Left lateral view, high focus on precingular 2P archeopyle, processes and wall structure; d-f.* Cribroperidinium wilsonii *forma B; sample Meer 1089 m, slide 2, EF O29/4. Apical view of (d) apical surface, (e) mid-focus showing processes interconnected distally, and (f) antapical surface; g, h.* Hystrichostrogylon coninckii*; sample Meer 888 m, slide 2, EF H29/3. Ventral view of (g) dorsal surface showing precingular archeopyle, and (h) ventral surface showing a large mid-ventral claustrum in the periphragm; i.* Hystrichokolpoma bulbosum *subsp.* bulbosum*; sample Meer 825 m, slide 1, EF U36. Apical view, high focus on apical archeopyle; j, k.* Hystrichostrogylon borisii*; sample Meer 869 m, slide 1, EF B34. Ventral view of (j) dorsal surface showing granulated wall and precingular archeopyle, and (k) ventral surface showing a large mid-ventral claustrum in the periphragm; l.* Neosphaerodictyon filosum*; sample Meer 1109 m, slide 1, EF P41. High focus on wall structure and processes; m.* Callaiosphaeridium asymmetricum*; sample Meer 1089 m, slide 2, EF F34/1. Dorsal view, high focus on wall surface and septa; n.* Flandrecysta tubulosa*; sample Meer 848 m, slide 1, EF T58. Right dorsolateral view of left ventrolateral surface; o.* Membranilarnacia hapala*; sample Meer 1109 m, slide 2, EF M47/4. Optical section showing wall structure of the central body, processes and periphragm.*
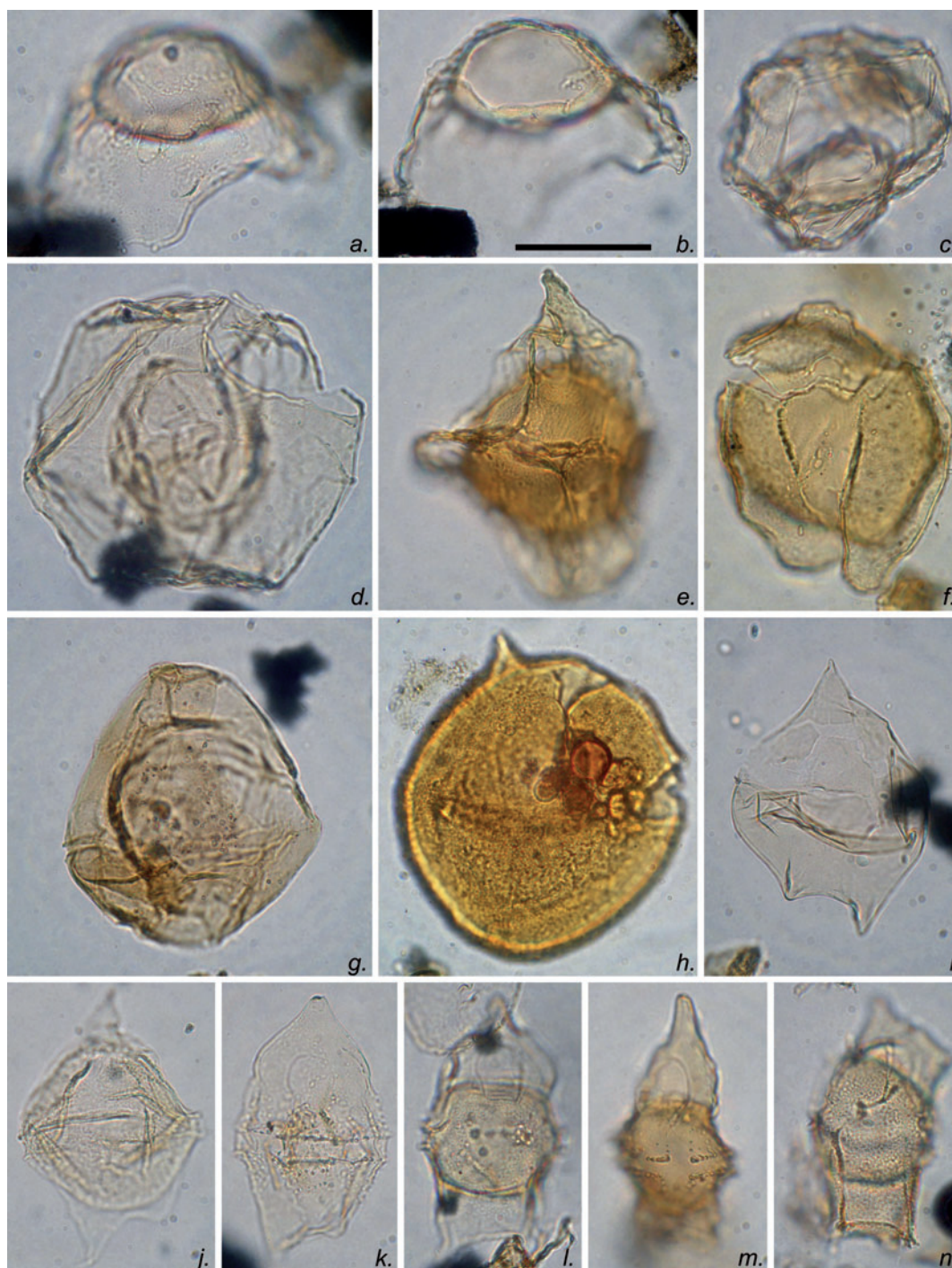
*Fig. 6. Selected dinocysts from the Meer borehole. Scale bar 40 µm. EF: England Finder specimen co-ordinates. a, b.* Glaphyrocysta perforata*; sample Meer 895 m, slide 2, EF E44. Antapical view of (a) antapical surface, and (b) apical surface showing apical archeopyle; c.* Turnhosphaera hypoflata*; sample Meer 1089 m, slide 1, EF G45. Dorsal view, high focus on precingular periarcheopyle; d.* Wilsonisphaera petila*; sample Meer 1109 m, slide 1, EF J46/4. Left ventrolateral view, low focus on precingular periarcheopyle; e.* Triblastula wilsonii*; sample Meer 964 m, slide 2, EF E34/2. Right dorsolateral view of right dorsolateral surface; f.* Senoniasphaera inornata*; sample Meer 848 m, slide 1, EF M53. Ventral view, high focus on sulcal area, apical archeopyle and operculum; g.* Cribroperidinium *sp. A; sample Meer 1109 m, slide 2, EF X52/1. Left ventrolateral view, low focus on wall surface and precingular archeopyle; h.* Carpatella cornuta*; sample Meer 841 m, slide 1, EF W44. Left dorsolateral view, high focus on wall structure, precingular archeopyle and operculum; i.* Pierceites pentagonus*; sample Meer 857 m, slide 1, EF L49. Ventral view, low focus on intercalary 3I archeopyle and 3 operculum pieces; j.* Chatangiella? robusta*; sample Meer 1089 m, slide 2, EF M48/4. Dorsal view of dorsal surface; k.* Chatangiella madura*; sample Meer 1089 m, slide 2, EF W38/1. Dorsal view, high focus on intercalary archeopyle and operculum; l.* Chatangiella *sp. A of Schiøler & Wilson, 1993; sample Meer 895 m, slide 2, EF F56/4. Dorsal view, high focus on intercalary archeopyle, granulated endocyst and cingular spines; m.* Chatangiella vnigrii *subsp.* vnigrii*; sample Meer 1089 m, slide 2, EF K49. Dorsal view of dorsal surface; n.* Hystrichosphaeropsis ovum*; sample Meer 888 m, slide 2, EF Y43. Right lateral view of right lateral surface.*

and 895 m, respectively. The HO of *Hystrichodinium pulchrum* subsp. *pulchrum* (Fig. 4c) has been recorded either lower (Wilson, 1974; Kirsch, 1991; Marheinecke, 1992; Schiøler & Wilson, 1993; Slimani, 2001a), in the middle part of the Vijlen Member at Halembaye, or higher (Schiøler et al., 1997; Slimani 2001a at Turnhout) at the Lower/Upper Maastrichtian boundary. The last consistent occurrence of this species coincides with the HO of *Alterbidinium acutulum* at a depth of 948 m. The LOs of *Flandrecysta tubulosa* (Fig. 5n) and *Canninginopsis maastrichtiensis* coincide here at a depth of 925 m; Slimani (2001a) recorded both from close to the Lower/Upper Maastrichtian boundary.

### Upper part of the Upper Maastrichtian (samples 869-841 m)

Numerous dinocyst species with characteristic HOs within the upper part of the Upper Maastrichtian, the uppermost part of the *Belemnitella junior* Zone and the *Belemnella kazimiroviensis* Zone, have their highest occurrence at 869 m (*Alterbidinium varium*, *Cannosphaeropsis utinensis* (Fig. 4a)), at 857 m (*Hystrichosphaeropsis ovum* (Fig. 6n), *Pierceites pentagonus* (Fig. 6i)), at 848 m (*Circulodinium distinctum* subsp. *distinctum* (Fig. 4h), *Leberidocysta chlamydata* subsp. *schioeleri*) and at 841 m (*Palynodinium grallator* (Fig. 4g), *Spiniferites ramosus* subsp. *cavispinosus*) (Wilson, 1974; Schiøler and Wilson, 1993; Schiøler et al., 1997; Slimani, 2001a).

*Palynodinium grallator* is widely used as an index species for the uppermost part of the Upper Maastrichtian in higher northern latitudes, where its HO is close to or coincident with the Maastrichtian/Danian boundary (Wilson, 1974; Hansen, 1977, 1979a; Hultberg, 1985; Schiøler & Wilson, 1993; Habib et al., 1996; Schiøler et al., 1997). The interval 869-841 m (i.e., from the HOs of *Isabelidinium cooksoniae* and *Chatangiella* sp. A to the HO of *Palynodinium grallator*) may be assigned to the upper part of the Upper Maastrichtian. The occurrence of the latest Maastrichtian species *Disphaerogena carposphaeropsis* and *Hystrichostrogylon borisii* (Fig. 5j, k) occur also within this interval and thus support the suggested age.

### Danian (samples 832-814 m)

Many Danian dinocyst index species are present down to a depth of 895 m, co-occurring with species usually restricted to the uppermost Maastrichtian. These co-occurrences are interpreted to be the result of downhole contamination caused by drilling mud recycling, but downward migration in the porous calcarenites during early Cenozoic inversions cannot be excluded either. The stratigraphic range of the Danian index species *Senoniasphaera inornata* (Fig. 6f) is restricted to the lower and middle Danian in widely separated areas of middle latitudes in the northern hemisphere (Williams et al., 2004) and southern latitudes in the southern hemisphere (Schellenberg et al., 2004). Therefore, the interval 841-825 m, between the

HOs of *Palynodinium grallator* and *Senoniasphaera inornata* is of early to middle Danian age. The HO of the latter species coincides with that of other index species, previously known from the Danian in northwest Europe (Hansen, 1977; Hultberg, 1985; Brinkhuis et al., 2000; Slimani, 2001a), such as *Carpatella cornuta* (Fig. 6h), *Glaphyrocysta perforata* (Fig. 6a, b), *Hystrichokolpoma bulbosum* subsp. *bulbosum* (Fig. 5i), *Tectatodinium rugulatum* (Fig. 7l) and *Xenicodinium reticulatum* (Fig. 8y). The persistent occurrence of *Xenicodinium lubricum* in samples 817 m and 819 m suggests an age not younger than late Danian for these samples.

## Comparison with dinocyst assemblages from other sections

More than 35 key dinocyst events (Fig. 3; Table 1) enable biostratigraphic comparison and correlation of the Campanian-Danian succession in the Meer borehole with sequences elsewhere in northwest Europe and contiguous areas.

### Belgium, the Netherlands, northern Germany, Denmark and Central North Sea

The Meer borehole can be correlated with the dinocyst zonal schemes of Wilson (1974; Denmark and Maastrichtian type area), Hansen (1977; Denmark), Marheinecke (1992; Hemmoor quarry, northern Germany), Schiøler & Wilson (1993; Central North Sea), Slimani (2001a; northern Belgium and Maastrichtian type area) and with the conventional, northwest European belemnite zones (Fig. 3). Slimani's (2001a) zonation proposed for the Turnhout borehole and the Halembaye and Beutenaken quarries appears to be the most useful for biostratigraphic subdivision and correlation of the Meer borehole, because of the close similarity between dinocyst assemblages of these sections. Moreover, this zonation is biostratigraphically more complete and covers the Campanian and Maastrichtian. This zonation was originally defined mostly on the LOs of zonal species, but in the present study the correlation relies on the HOs of species (see above). Thus, our comparison with the dinocyst zonations is based on selected bio-events – more specifically, highest consistent occurrences – since most of the LOs are not genuine in view of downhole contamination. The comparison allows a subdivision of the borehole studied into ten intervals which correspond to zones of Slimani (2001a). The dinocyst events (Fig. 3) used are (in ascending order): the LO and HO of *Exochosphaeridium*? *masureae*, the HO of *Rhynchodiniopsis*? sp. cf. *G. prominoseptata*, the HO of *Cribroperidinium wilsonii* forma A, the HO of *Palaeohystrichophora infusorioides*, the HO of *Stephodinium*? *spinosum*, the HO of *Odontochitina streelii*, the HO of *Chatangiella*? *robusta*, the HO of *Membranilarnacia hapala*, the HO of *Samlandia mayi*, the HO of *Alterbidinium acutulum*, the HO of *Ovoidinium membranaceum*, the HO of *Wilsonisphaera* petila, the HO of *Isabelidinium cooksoniae*, the

HO of *Turnhosphaera hypoflata*, the HO of *Alterbidinium varium*, the HO of *Cannosphaeropsis utinensis*, the HO of *Palynodinium grallator* and the HO of *Senoniasphaera inornata*.

## Campanian

Samples 1109-1089 m are characterised by the single and lowest occurrence of *Exochosphaeridium*? *masureae* and the HO of *Rhynchodiniopsis*? sp. cf. *G. prominoseptata*, respectively, and thus hold the *Exochosphaeridium*? *masureae* Zone (Slimani, 2001a). This zone is defined as the interval between the LOs of *Exochosphaeridium*? *masureae* and of *Hystrichokolpoma gamospina*. The HO of *Rhynchodiniopsis*? sp. cf. *G. prominoseptata* was, amongst others, considered as a characteristic event for the top of this zone by Slimani (2001a). Based on the latter dinocyst event, the upper boundary of this zone can be correlated with the top of Subzone Ia of Wilson (1974), while the base of Zone Ia cannot be recognised here since Wilson (1974) left it undefined. According to Slimani (2001a), the base of this zone can be correlated with the base of *Belemnitella mucronata* Zone, while its top falls within the lower part of the *Belemnitella woodi* Zone. Both boundaries are within the early Late Campanian.

The HOs of *Cribroperidinium wilsonii* forma A and *Palaeohystrichophora infusorioides* in sample 1089 m and the HO of *Stephodinium*? *spinosum* in sample 1066 m allow to correlate this interval with the *Areoligera coronata* Zone of Slimani (2001a). This zone is defined as the interval between the LOs of *Areoligera coronata* and of *Samlandia mayi* and is correlated with the upper part of the *Belemnitella woodi* Zone (mid-Late Campanian). The HO of *Stephodinium*? *spinosum* is synchronous with the HOs of *Pervosphaeridium elegans* (= *Cleistosphaeridium hallembaense* in Wilson, 1974) and *Xenascus wetzelii* (= *Odontochtina wetzelii* in Wilson, 1974), and mark the upper boundary of the *Areoligera coronata* Zone, as well as the upper boundary of Zone Ib of Wilson (1974). However, the coincidence of the HO of *Rhynchodiniopsis*? sp. cf. *G. prominoseptata* with those of *Cribroperidinium wilsonii* forma A and *Palaeohystrichosphaera infusorioides* in sample 1089 m, and also the lack of *Hystrichokolpoma gamospina*, suggest the absence of the *Hystrichokolpoma gamospina* Zone (Slimani 2001a) between the *Exochosphaeridium*? *masureae* and *Areoligera coronata* zones. The absence of *Hystrichokolpoma gamospina* might be a reflection of its extreme rarity.

The interval 1042-1020 m of the uppermost Campanian equates with the *Samlandia mayi* Zone, between the HO of *Stephodinium*? *spinosum* and the HOs of Campanian species such as *Odontochitina streelii*. According to Slimani (2001a), the HO of the latter species is reported from the top of this zone, and correlation with Zone II of Wilson (1974) and with the *Belemnitella minor* Zone of late Late Campanian age can be proposed.

## Maastrichtian

The interval between the HOs of *Membranilarnacia hapala* and of *Ovoidinium membranaceum* (995-925 m) holds the *Pervosphaeridium tubuloaculeatum* Zone and subzones a and b of Slimani (2001a). However, we should note that this zone was originally defined as the interval from the LO of *Pervosphaeridium tubuloaculeatum* to that of *Deflandrea galeata* (Fig. 7h). The boundary between subzones a and b is recognised at 948 m by the HO of *Alterbidinium acutulum*, immediately below the Lower/Upper Maastrichtian boundary. Subzone a correlates with the *Alterbidinium acutulum* Zone (Schiøler & Wilson, 1993) based on the same events (HOs of *Membranilarnacia hapala* and of *Alterbidinium acutulum*), and coincides with the conventional *Belemnella occidentalis* Zone (= northwest European *Belemnella sumensis* to *Belemnella fastigata* zones of late Early Maastrichtian age). Its upper boundary coincides with the top of Zone III of Wilson (1974), based also on the HO of *Alterbidinium acutulum*, and with the top of Zone A of Marheinecke (1992), defined on the highest consistent occurrence of *Hystrichodinium pulchrum* subsp. *pulchrum* at 948 m. Sample 925 m holds subzone b and is defined as the interval from the HO of *Alterbidinium acutulum* to the LO of *Deflandrea galeata* (Slimani, 2001a). The earliest documented LO of *Deflandrea galeata* is from within the lowermost part of *Belemnitella junior* Zone of early Late Maastrichtian age (Schiøler et al., 1997).

The co-occurrence of the HOs of Campanian species with the HOs of *Chatangiella*? *robusta*, *Membranilarnacia hapala* and *Samlandia mayi* (markers of the top of the earlier part of the Early Maastrichtian) at 1020 m suggests the absence of the *Membranilarnacia liradiscoides* Zone of early Early Maastrichtian age (Slimani, 2001a). This zone was originally defined as the interval between the LO of that species and the LO of *Pervosphaeridium tubuloaculeatum*. This corresponds to the absence of the conventional *Belemnella lanceolata* Zone (see above). The absence of this zone between the Samlandia *mayi* and *Pervosphaeridium tubuloaculeatum* zones suggests that the corresponding strata might either be simply lacking or were not sampled between 1020 and 995 m.

The interval 904-869 m is tentatively assigned to the *Deflandrea galeata* Zone (Slimani, 2001a), based on the HOs of *Ovoidinium membranaceum*, *Wilsonisphaera petila*, *Isabelidinium cooksoniae*, *Membranigonyaulax wilsonii* (Fig. 7o) and *Turnhosphaera hypoflata* within its subzone a and on the HO of *Alterbidinium* varium within its subzone b. The base of the *Deflandrea galeata* zone cannot be recognised here, based on the LO of the index, as defined by Slimani (2001a), since this taxon is recorded within the Campanian strata at a depth of 1020 m, as a result of downhole displacement. Furthermore, the top of the *Deflandrea galeata* Zone correlates with the top of subzone Va of Wilson (1974), the top of Zone C of Marheinecke (1992) and the top of the *Hystrichostrogylon borisii* Zone of Schiøler & Wilson (1993), on the basis of the HO of

*Cannosphaeropsis utinensis* at 869 m. The boundaries between the *Cannosphaeropsis utinensis* and *Isabelidinium cooksoniae* zones (Schiøler & Wilson, 1993), between Zone IV and subzone Va of Wilson (1974) and between zones B and C of Marheinecke (1992) cannot be identified because of the absence of significant bio-events. However, the upper boundary of the *Isabelidinium cooksoniae* Zone and Subzone C1 of Marheinecke (1992) are identified by the HOs of *Isabelidinium cooksoniae* at 888 m and *Chatangiella* sp. A at 880 m. The boundary between the *Palaeocystodinium denticulatum* and *Hystrichostrogylon borisii* zones of Schiøler & Wilson (1993) is uncertain since we cannot decide whether the LO of *Hystrichostrogylon borisii* at 869 m is real or apparent. The *Deflandrea galeata* Zone corresponds to most of the upper part of the *Belemnitella junior* Zone and is of mid-Late Maastrichtian age.

The interval between the HOs of *Cannosphaeropsis utinensis* and of *Palynodinium grallator* (857-841 m) correlates with *Hystrichostrogylon coninckii* Zone of Slimani (2001a), as follows. The bases of Hansen's (1977) *Palynodinium grallator* Zone, Zone D of Marheinecke (1992) and subzone Vb of Wilson (1974) were placed just above the highest consistent occurrence of *Cannosphaeropsis utinensis* at a depth of 869 m, following the stratigraphic distribution charts of the latter authors. However, the LOs of *Hystrichostrogylon coninckii* (Fig. 5g, h) and *Palynodinium grallator*, which define the bases of most of these zones, are here reported from lower within the Upper Maastrichtian due to downhole contamination. The top of the *Hystrichostrogylon coninckii* Zone and the top of *Palynodinium grallator* Zone are identified by the HO of *Palynodinium grallator*, while the top of Subzone Vb and top of Zone D are not identifiable because of the absence of significant bio-events. All these zones correspond to the *Belemnella kazimiroviensis* Zone and maybe also with the very latest part of the *Belemnitella junior* Zone of late Late Maastrichtian age, according to Wilson (1974), Schiøler & Wilson (1993) and Schiøler et al. (1997).

## Danian

The interval 832-814 m correlates with the Danian *Damassadinium californicum* Zone of Hansen (1977), and the *Senoniasphaera inornata* (832-825 m) and *Hafniasphaera cryptovesiculata* (817-814 m) subzones. The boundaries between the *Hystrichostrogylon coninckii* and *Damassadinium californicum* zones and between its *Senoniasphaera inornata* and *Hafniasphaera cryptovesiculata* (Fig. 7j) subzones are recognised by the HOs of *Palynodinium grallator* and of *Senoniasphaera inornata*, respectively. The boundaries between the *Carpatella cornuta*, *Tectatodinium rugulatum* and *Xenicodinium lubricum* (Fig. 7p) zonules, defined originally by the LOs of the zonal species, are not recognised because of downward displacement of these species.

## Southern France (Campanian stratotype in Charentes and Campanian/Maastrichtian GSSP of Tercis les Bains) and southern Germany (Oberbayern)

Tethyan dinocyst assemblages from the Campanian stratotype (Masure, 1985) and Campanian/Maastrichtian GSSP (Antonescu et al., 2001a, b; Schiøler & Wilson, 2001) demonstrate that the HOs of *Exochosphaeridium*? *masureae* and *Palaeohystrichosphora infusorioides* within the lower part of the Lower Campanian, and the LO of *Alterbidinium varium* within the Lower Maastrichtian corroborate our findings in the Meer borehole. However, the HOs of *Chatangiella*? *robusta*, *Odontochitina operculata* and *Xenascus ceratioides* subsp. *ceratioides* (upper part of the Upper Campanian) and *Samlandia mayi* (basal Lower Maastrichtian) at Tercis les Bains are generally stratigraphically lower than in the Meer borehole and elsewhere in northwest Europe, where these events are known in the Lower Maastrichtian, more specifically in the conventional *Belemnella lanceolata* Zone (Wilson, 1974; Costa & Davey, 1992). We must stress the fact

*Fig. 7. Selected dinocysts from the Meer borehole. Scale bars 40 µm; bar in Fig. p applying to Figs p-s; bar in Fig. j to all other figures EF: England Finder specimen co-ordinates. a, b.* Isabelidinium cooksoniae; *sample Meer 895 m, slide 2, EF A37. Dorsal view of (a) dorsal surface showing intercalary archeopyle and operculum, and (b) ventral surface; c.* Alterbidinium acutulum; *sample Meer 1020 m, slide 2, EF G49. Dorsal view, high focus on intercalary archeopyle, operculum and wall structure; d.* Alterbidinium varium; *sample Meer 995 m, slide 1, EF E50. Ventral view, low focus on intercalary archeopyle; e.* Batiacasphaera solida; *sample Meer 1042 m, slide 2, EF T31/4. High focus on wall structure and apical archeopyle margin; f.* Palaeohystrichophora infusorioides; *sample Meer 1109 m, slide 2, EF E49. Dorsal view of dorsal surface; g.* Spumadinium *sp. cf.* Spumadinium *sp. of Brinkhuis et al., 2000; sample Meer 888 m, slide 1, EF K28. Apical view, high focus on apical archeopyle and wall structure; h.* Deflandrea galeata; *sample Meer 880 m, slide 2, EF M37. Ventral view, low focus on intercalary archeopyle, operculum and wall structure; i.* Florentinia? flosculus; *sample Meer 1109 m, slide 2, EF N35/4. Dorsal view, high focus on precingular archeopyle and processes; j.* Hafniasphaera cryptovesiculata; *sample Meer 895 m, slide 1, EF Y32/4. Right dorsolateral view, high focus on precingular archeopyle and wall structure; k.* Renidinium *sp. A; sample Meer 814 m, slide 1, EF H36/4. Ventral view, high focus on ventral surface, apical archeopyle margin and operculum; l.* Tectatodinium rugulatum; *sample Meer 880 m, slide 1, EF B52/4. Dorsal view, high focus on wall structure and precingular archeopyle; m.* Apteodinium deflandrei; *sample Meer 1109 m, slide 2, EF O30/4. Left dorsolateral view, low focus on precingular archeopyle and wall structure; n.* Valensiella *sp. cf.* V.? clathroderma *of Slimani, 1995; sample Meer 895 m, slide 1, EF T55/4. High focus reticulum; o.* Membranigonyaulax wilsonii; *sample Meer 1020 m, slide 1, EF T45/4. Ventral view, high focus on apical archeopyle; p.* Xenicodinium lubricum; *sample Meer 832 m, slide 1, EF L52. Left lateroventral view, low focus on precingular archeopyle and wall structure; q.* Chlamydophorella *sp. A of Slimani, 1995; sample Meer 1109 m, slide 1, EF H38/4. High focus on processes connecting endo- and periphragm; r.* Diconodinium wilsonii; *sample Meer 1042 m, slide 1, EF D48/1. Ventral view of ventral surface; s.* Spinidinium angustispinum *in Wilson, 1974; sample Meer 1152 m, slide 2, EF O48/1.*

that these bio-events do not cross the Campanian/Maastrichtian boundary in the Meer borehole. This can be explained by the absence of the lower part of the Lower Maastrichtian (see previous pages). Kirsch (1991) recorded the HOs of *Odontochitina operculata* and *Xenascus ceratioides* subsp. *ceratioides* also in older Campanian strata in Oberbayern. The HO of *Raetiaedinium truncigerum*, which has been reported from the uppermost Campanian of Tercis les Bains, Oberbayern and northwest Europe, is apparently older in the Meer borehole due to its extreme rarity, while the LO of *Exochosphaeridium*? *masureae* is younger in comparison with Charentes (Lower Campanian). The HO of *Batiacasphaera* solida (Fig. 7e), commonly used as index for the uppermost Campanian (Wilson, 1974; Foucher *in* Robaszynski et al., 1985; Slimani, 2001a, 2003), has been recorded from the basal Lower Maastrichtian at Tercis les Bains. Its presence in the upper part of the Lower Maastrichtian in the Meer borehole may be explained through reworking. The slight age difference of some dinocyst events between Boreal and Tethyan realms might be related to palaeoenvironmental conditions, hence caution is called for when using these species in global correlation.

### Other areas

Important Campanian and Maastrichtian dinocyst events recorded in the Meer borehole have similar distribution patterns in other areas of the Boreal domain. The position of the HOs of *Palaeohystrichophora infusorioides* within the Upper Campanian and *Chatangiella*? *robusta*, *Odontochitina operculata*, *Samlandia mayi* (as *Samlandia angustivela*) and *Xenascus ceratioides* subsp. *ceratioides* within the Lower Maastrichtian are comparable to

records from northwest Europe and the east coast of North America (Aurisano & Habib, 1977; Benson, 1976; May, 1980; Firth, 1987; Tocher, 1987; Aurisano, 1989; Costa & Davey, 1992). Also, the HOs recorded at or close to the Lower/Upper Maastrichtian boundary (*Alterbidinium acutulum* and *Hystrichodinium pulchrum* subsp. *pulchrum*), the boundary between the lower and upper parts of the Upper Maastrichtian (*Isabelidinium cooksoniae*) and the Maastrichtian/Danian boundary (*Palynodinium grallator*) have a similar general distribution in certain regions of the Boreal realm (Firth, 1987; Aurisano, 1989; Costa & Davey, 1992). In the Tethyan realm, the HO of *Isabelidinium cooksoniae* has been recorded approximately at the same stratigraphic level (Kirsch, 1991) as in the Boreal domain. Furthermore, the HOs of *Senoniasphaera inornata* and *Hystrichokolpoma bulbosum* subsp. *bulbosum* (lower to middle Danian) in the Meer borehole match records from the Boreal and Tethyan realms at middle latitudes in the northern hemisphere (Brinkhuis & Zachariasse, 1988; Costa & Davey, 1992; Moshkovitz & Habib, 1993; Habib et al., 1996; Brinkhuis et al., 1998; Williams et al., 2004; Slimani et al., 2010). This global similarity may be the result of increased oceanic communication and a decrease in provincialism during Danian times.

## A refined stratigraphic framework for the Campine Basin

There was no consistent lithostratigraphical scale available for the concealed Cretaceous of the Campine Basin, until P.J. Felder demonstrated that the subdivision established in the Maastricht type area (W.M. Felder, 1975) could be extended to the

*Fig. 8. Selected dinocysts from the Meer borehole. Scale bar 40 μm. EF: England Finder specimen co-ordinates. a1, a2.* Gillinia*? sp. A; sample Meer 888 m, slide 1, EF D36. Ventral view of (a1) dorsal surface, and (a2) mid-focus on central body and two small lateral pericoels; b.* Phanerodinium *sp. A of Slimani, 1994; sample Meer 888 m, slide 2, EF H54/1. Dorsal view, high focus on precingular archeopyle; c.* Druggidium *sp. A of Slimani, 1994; sample Meer 848 m, slide 1, EF N48/4. Ventral view, low focus on precingular archeopyle and wall structure; d.* Microdinium *sp. A of Slimani, 1994; sample Meer 857 m, slide 1, EF G52. Apical view of apical surface; e.* Cladopyxidium paucireticulatum*; sample Meer 948 m, slide 2, EF M41/1. Dorsal view of dorsal surface; f1, f2.* Druggidium *sp. B; sample Meer 857 m, slide 1, EF W55/3. Ventral view of (f1) dorsal surface showing precingular archeopyle, and (f2) ventral surface; g.* Druggidium *sp. A; sample Meer 841 m, slide 1, EF D56/2. Apical view, high focus on precingular archeopyle; h.* Batiacasphaera aff. hirsuta *of Slimani, 1995; sample Meer 857 m, slide 1, EF S50/1. High focus on apical archeopyle and operculum; i.* Druggidium*? sp. C; sample Meer 841 m, slide 1, EF H40/3. Ventral view, low focus on precingular archeopyle and wall structure; j.* Xenicodinium delicatum*; sample Meer 888 m, slide 2, EF 58/1. Right dorsolateral view, high focus on precingular archeopyle and wall structure; k.* Cladopyxidium septocrispum*; sample Meer 880 m, slide 1, EF R56/2. Right lateral view of right lateral surface; l.* Cladopyxidium marheineckei*; sample Meer 880 m, slide 1, EF S50/2. Ventral view of ventral surface; m.* Elytrocysta *sp. A; sample Meer 1020 m, slide 2, EF K31/3. Left lateral view, high focus on wall structure, apical archeopyle margin and attached operculum; n.* Pyxidinopsis *sp. cf. P. densepunctata of Slimani, 1995; sample Meer 848 m, slide 1, EF O37/3, Ventral view, high focus on precingular archeopyle and wall structure; o.* Xuidinium*? sp. cf. X. laevigatum; sample Meer 1020 m, slide 1, EF J36. Ventral view, low focus on intercalary archeopyle; p.* ?Kallosphaeridium granulatum *of Slimani, 1994; sample Meer 1109 m, slide 2, EF R35. Ventral view, high focus on apical archeopyle and attached operculum; q.* Histiocysta*? variornata; sample Meer 1020 m, slide 1, EF X49. Dorsal view of dorsal surface; r.* Spinidinium *sp. A; sample Meer 888 m, slide 2, EF L49. Dorsal view of ventral surface; s1.* Stephodinium*? spinosum; sample Meer 1109 m, slide 2, EF E27/2. Antapical view, focus on equatorial pericoel; s2.* Stephodinium*? spinosum; sample Meer 1109 m, slide 2, EF E51. Dorsal view of dorsal surface; t.* Platicystidia*? sp. indet. of De Coninck, 1986; sample Meer 1089 m, slide 2, EF R54. u.* Melitasphaeridium *sp. A; sample Meer 1089 m, slide 1, EF R25.Left lateroventral view, high focus on precingular archeopyle; v.* Horologinella *sp. A; sample Meer 857 m, slide 1, EF M27/2; w.* Horologinella*? sp. B; sample Meer 857 m, slide 1, EF J54/3; x.* Apteodinium *sp. A of Slimani 1995; sample Meer 925 m, slide 1, EF A32. Right lateroventral view, high focus on ventral surface; y.* Xenicodinium reticulatum*; sample Meer 841 m, slide 1, EF R44/1. Dorsal view, high focus on precingular archeopyle; z.* Operculodinium*? sp. cf. O.? placitum; sample Meer 888 m, slide 1, EF G58/2. Ventral view, low focus on precingulare archeopyle.*

*a1.* *a2.* *b.* *c.* *d.* *e.* *f1.* *f2.* *g.* *h.* *i.* *j.* *k.* *l.* *m.* *n.* *o.* *p.* *q.* *r.* *s1.* *s2.* *t.* *u.* *v.* *w.* *x.* *y.* *z.*
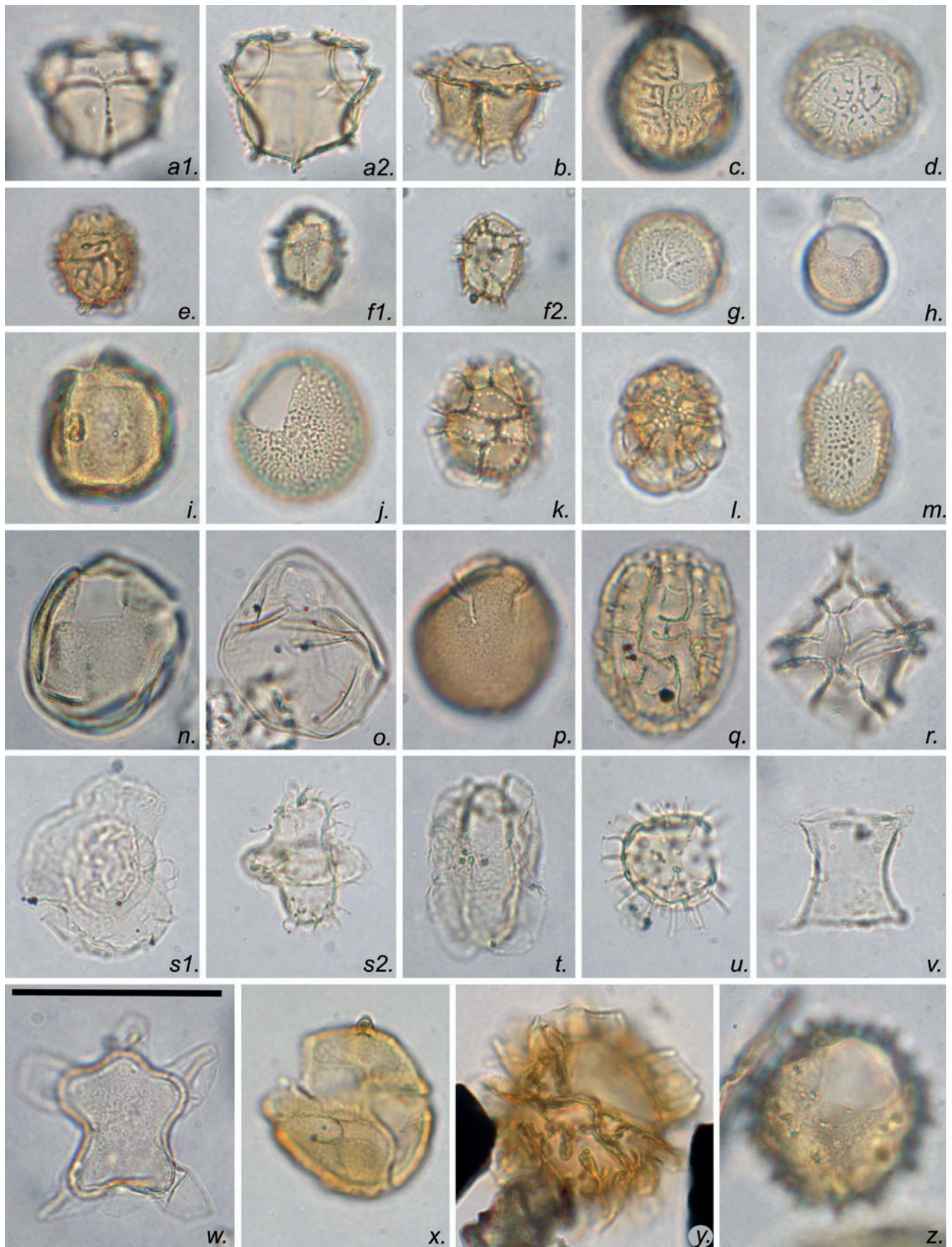
contiguous Campine Basin (P.J. Felder et al., 1985) (Fig. 2). Cuttings and occasional cores allowed to distinguish the calcarenite facies occurring towards the top (but not its lower boundary) and the white chalk and greensand facies towards the base. The flint-bearing chalks and calcarenites in between were not assigned lithostratigraphically. Currently, three stratigraphical tools are available for subdivision of the Chalk Group; these have been applied independently. Geophysical well logs have become the standard for lithostratigraphical subdivision (P.J. Felder et al., 1985; Lagrou et al., 2005; see Fig. 9). However, geophysical well logs need a calibration tool for regional correlation with the Maastrichtian type area, which is provided by P.J. Felder's bioclast ecozones (Felder, 1994, 2001), and for correlation with the chronostratigraphical scale, which is provided by dinocyst biozones (Slimani, 2000; the present study). The Meer borehole, at the opposite side of the Campine Basin, permits to test the validity of the correlation schemes across a sedimentary basin characterised by shifting depocentres and lateral facies changes (P.J. Felder et al., 1985; Lagrou et al., 2005).

### Lithostratigraphy based on geophysical well logs

#### Vaals Formation (1186-1146 m)

The top of the Carboniferous is, compared to the overlying Cretaceous, marked by a sharp increase in gamma-ray and electrical resistivity and a smaller, yet still notable, increase in density, sonic and SP (Fig. 9). The basal Cretaceous unit, assigned to the Vaals Formation, consists of clayey glauconitic chalks (1146-1186 m) and can best be distinguished by the higher gamma-ray, much lower resistivity, large break-out and corollary low sonic signals, compared to the overlying Gulpen Formation. The greensand facies is no longer present in this distal area from the Roer Valley Graben. The basal clay-rich interval (1177-1186 m) with highest gamma-ray and lowest resistivity readings is equivalent to the newly defined Asdonk Member of the Vaals Formation (accepted by the Belgian National Commission for Stratigraphy; see Fig. 2). Note that in the original description of the borehole Turnhout (Gulinck, 1954) only the latter section was identified as equivalent to the 'Herve smectite'. The overlying new Sonnisheide Member (also accepted by the Belgian National Commission for Stratigraphy; Fig. 2) covers the interval 1146-1177 m, and shows a transition at 1164 m from a lower marly section – not present in adjoining boreholes to the south – and an upper coarsening-upwards section with decreasing clay and increasing chalk content. In the Turnhout borehole, the Sonnisheide Member corresponds to the glauconitic unit at the base of the 'Craie blanche' (interval 966.50-987 m in Gulinck, 1954; 972-987 m in Lagrou et al., 2005), hence suggesting a transition to the all-chalk Nevele Formation, which covers the adjoining north-central part of the London-Brabant Massif (Dusar & Lagrou, 2007a).

#### Lower part of the Gulpen Formation: Zeven Wegen Member (1146-1016 m)

The white chalk unit assigned to the Zeven Wegen Member of the Gulpen Formation becomes much thicker (1016-1146 m) in the Meer borehole in comparison to the adjoining boreholes to the south or to any other section in the Campine Basin or Maastrichtian type area (Lagrou et al., 2005). This is not due to an increase in thickness of the member but to the intercalation of a new lithological unit, immediately displaying a great thickness. This characteristic compacted white chalk ('Schreibkreide') is interrupted by a less dense and more porous middle unit (1057-1116 m), lithologically not unlike the overlying members of the Gulpen Formation, also proving that intraformational hiatuses must be present elsewhere in the Campine Basin. Despite its striking appearance – the white chalk is the most easily recognised lithological unit and most easily delimited one of the whole Chalk Group in the Campine Basin – it is stratigraphically complex and incorporates the Beutenaken-1 Member, as will be shown below (compare Figs 2, 9). The white chalk appears throughout the Campine Basin as one single, mappable lithostratigraphic unit, whose facies and overall age correspond to the Zeven Wegen Member of the Gulpen Formation, and which used to be known as Craie de Heur St.-Romain in eastern Hesbaye or associated with the Craie de Nouvelles in the Mons Basin (for further discussion see P.J. Felder et al., 1985). The Beutenaken-1 Member of the Maastricht type area has become an inconspicuous part of this lithological unit. The top of the white chalk is, as usual, marked by the Froidmont Hardground, which is the most pronounced hardground in the entire Campine Basin with a varying importance of the hiatus on top of the white chalk (Calembert, 1953, 1957; Calembert & Meijer, 1955) (Fig. 10).

#### Middle part of the Gulpen Formation: chalk lithofacies overlying the Zeven Wegen Member (1016-912 m)

The overlying unit of the Gulpen Formation between the hardgrounds at 1016 m and 912 m, corresponds lithologically to the Beutenaken-2 to Vijlen members of the Gulpen Formation in the type area, and is characterised by an overall, yet very gradual, increase in density and lithification. Some weak cycles can be distinguished within this unit, enhancing the same trend, with inconspicuous boundaries at 1001, 985, 945 and 932 m (Fig. 9). The lowermost unit (1016-1001 m) with low density, compaction, resistivity and falling gamma-ray, probably due to decreasing glauconite content, is assumed to correspond to the 'Craie sablonneuse glauconifère' as described by Gulinck (1954) in the Turnhout borehole. The second lowest unit (1001-985 m) with glauconiferous chalk is assumed to be equal to the 'Craie grisâtre glauconifère'. The middle unit (985-945 m) with white chalk of upward-increasing density, compaction and resistivity is considered equivalent to the 'Craie blanchâtre grumeleuse'.
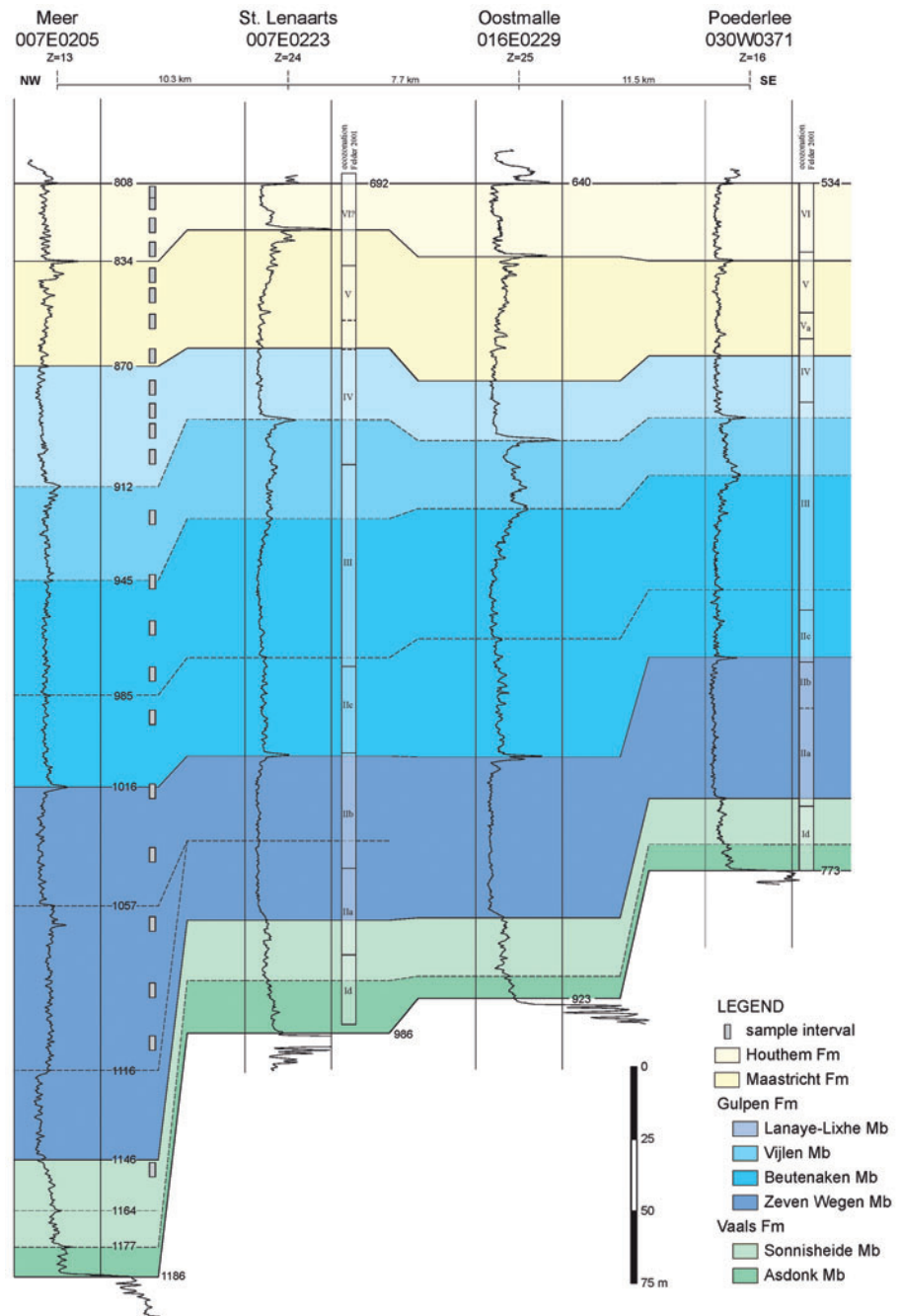
*Fig. 9. Cross section between the Meer and Poederlee boreholes showing gamma-ray logs, with lithological correlations based on geophysical well logs, checked by P.J. Felder's ecozones for the St.-Lenaarts and Poederlee boreholes. The position of the dinocyst samples in the Meer borehole is indicated. The Zeven Wegen Member incorporates the Beutenaken-1 lateral equivalent as upper unit; the Vijlen Member incorporates the Lixhe-1 lateral equivalent in the upper part.*

Flint becomes a regular constituent of the carbonate sequence. The upper unit (945-912 m), with more variable compact chalk, is assumed to correspond to the 'Craie sablo-marneuse' and the division at 932 m corresponds to a transition from a fining-upwards to a coarsening-upwards sequence, indicated by variations in glauconite content. The horizon at 912 m marks a lithological change. The upper part of the Gulpen Formation, equivalent to the greater part of the Lixhe-Lanaye members, becomes more difficult to distinguish from the Maastricht Formation west of the Maastrichtian type area. This process of replacement of chalk by fine calcarenite initially affects the Lanaye Member, but amplifies further west to encompass also (part of) the Lixhe Member.

## Upper part of the Gulpen Formation, Maastricht and Houthem formations: calcarenite lithofacies (912-808 m)

The calcarenite deposit (912-808 m) can be subdivided into several sequences. The lower unit, 902-912 m, is easily identified on the gamma-ray reflecting the change from glauconitic, mixed sediment to pure carbonate (Fig. 9). It probably represents the 'Craie grise glauconifère' in the Turnhout borehole (Gulinck, 1954).

The unit 902-870 m shows a coarsening-upward trend, again leading to pure carbonate. This unit probably represents the 'Craie jaunâtre grossière', the usual name for the Lanaye Member in earlier studies within the Campine Basin. The boundary at

*Fig. 10. Froidmont Hardground at the top of the Zeven Wegen Member in the Turnhout borehole (depth 932.40 m), displaying greening of lithified sea floor and burrows lined with phosphate (width of view 10.5 cm, height 14 cm).*

870 m is hardly noticeable on the gamma-ray log, marked by the shift from falling to rising gamma-ray levels (limit placed at 875.50 m by Lagrou et al., 2005), but is expressed as a peak on other geophysical logs. This peak is marked by a reduction in porosity, not by a change in mineralogy, i.e. an admixture of glauconite; hence it is least visible on the gamma-ray log. This boundary corresponds to a hardground at 766 m in the Turnhout borehole, which is correlated to the basal Maastricht Formation (Gulinck, 1954).

The unit 870-834 m is composed of rather fine calcarenite. Its base covers the 865-870 m interval and possesses a higher sediment density, but no increase in glauconite. Coarsening-upwards units are indicated by increasing resistivity and increasing carbonate or decreasing insolubles content, which testify to rapid sedimentation vs subsidence, hence a decrease in water depth. It was described together with the overlying Houthem Formation as 'Tuffeau calcaire tendre' by Gulinck (1954) in the Turnhout borehole.

The contact between the Maastricht Formation and the Paleogene Houthem Formation corresponds to the K/Pg boundary and is located at 834 m, by convention at the highest gamma-ray peak in an interval with higher gamma-ray readings between 834 and 840 m. Otherwise, the Houthem and Maastricht formations are lithologically and petrophysically indistinguishable, hence both are included in the Chalk Group. Cores from the Turnhout borehole indeed display similar fine calcarenite with coarse fossil hash intercalations, indurated

serpulid and sponge beds, and incomplete silicifications. The top of the Houthem Formation at 808 m is marked by a sudden increase in resistivity compared to the overlying, less consolidated 'clastic Tertiary' formations and by a strong breakout of the latter, testifying to a sudden increase in mechanical strength of the Chalk Group.

### P.J. Felder's ecozonation control on electrical stratigraphy

The ecozonation established by P.J. Felder (1981) is a semi-quantitative analysis of the bioclast content of the sediment and reflects both changes in marine biotopes and sediment distribution patterns. The ecozones based on bioclast frequencies are thus independent of the dinocyst zonation. A good dataset has been compiled for the Campine Basin (P.J. Felder, 1994, 2001). However, the Meer borehole was not previously investigated for its palaeontological content nor for its ecozones. Nevertheless, the ecozonation established in the Merksplas borehole (017W0265), where also Hofker's (1978) foram zones were documented for the Gulpen Formation, the St.-Lenaarts borehole (007E0223) and the Poederlee borehole (030W0371) (P.J. Felder, 2001), were correlated to geophysical well logs including that of the Meer borehole (Lagrou et al., 2005; see Fig. 9), and compared to spot sampling results of the cored Turnhout borehole (P.J. Felder, 1994).

### Ecozone I

Ecozone Id characterises the entire Vaals Formation (Figs 2, 9), unlike the situation in the eastern Campine with more typical greensand facies and more diversified bioclast successions. In the eastern Campine, Ecozone Id is encountered in the most calcareous upper section of the Vaals Formation. Carbonate is prevalent over the entire Vaals Formation in the Meer area. Therefore, the more elaborated subdivision of Ecozone I in the type area and the eastern Campine compared to the northwest Campine may be interpreted as a response to facies diversification instead of representing an incomplete succession in the latter area (compare P.J. Felder, 2001, fig. 9).

### Ecozone II

Ecozone II encompasses the Zeven Wegen and Beutenaken members of the Gulpen Formation in the type area (southeast Netherlands) (Figs 2, 9). This ecozone is thickest and most complete in the northwest Campine area. Whereas the Zeven Wegen Member is characterised by Ecozone IIa only in the type area (corresponding to the interval 1116-1146 m), it also encompasses ecozone IIb in the Campine, meaning that the Beutenaken-1 Member has become incorporated into the white chalk facies (interval 1016-1058 m). The intercalation of a middle unit in the white chalk (interval 1058-1116 m), not

known further south and thus not characterised by bioclast analysis, supports the expansion of the white chalk facies and the transition from a more proximal facies along the southern border of the Roer Valley Graben to the more distal environments, better described by the Nevele or Ommelanden formations (Dusar & Lagrou, 2007a). In the more proximal environments of the type area and the Campine Basin, southeast of the Meer borehole, the top of the incomplete Zeven Wegen Member is marked by a series of hardgrounds, of which only the Froidmont Hardground prevails in the Meer borehole at a depth of 1016 m, where it terminates the white chalk deposition.

Ecozone IIc is characteristic of the Beutenaken-2 Member in the Campine Basin and corresponds to the glauconitic and rather marly interval 1016-985 m, by log correlation with the adjoining boreholes (Lagrou et al., 2005). Whereas the strata characterised by Ecozone IIb are lithologically incorporated in the white chalk facies of the Zeven Wegen Member, those characterised by Ecozone IIc are incorporated in a sedimentary sequence which includes the overlying Vijlen Member.

## Ecozone III

By log correlation, Ecozone III, characteristic of the major part of the Vijlen Member in the type area (P.J. Felder, 2001) would cover the 985-912 m silty chalk interval in the Meer borehole (Fig. 9). Note that P.J. Felder et al. (1985) tentatively placed the lower boundary at 972 m. The log response at the boundary between ecozones II and III does not show much evidence of tectonic activity, hardgrounds or hiatuses, associated with the basal Maastrichtian sea level fall. However, hardgrounds occur at depths of 888 and 892 m in the Turnhout borehole, below the base of the 'Craie blanchâtre grumeleuse', which is the typical facies of the Vijlen Member (Gulinck, 1954).

There are some discrepancies in the lithological boundary between chalk and calcarenite and the ecozonation boundary between ecozones III and IV in St.-Lenaarts and Merksplas boreholes. It is not clear whether this is due to delay in depth range between the drilling and the cuttings (sampling of cuttings delayed compared to depth of drilling, hence marked with too deep a depth) or whether this indicates a divergence between ecozonation and lithostratigraphy, hence diachronism.

Recently, P.J. Felder (unpublished data) was inclined to link sediments containing Ecozone IIc (Beutenaken-2) with those of Ecozone III (Vijlen), because both postdated the basal Maastrichtian incision phase, the major difference being that Beutenaken-2 would essentially consist of reworked sediment, liberated by the incision phase. Therefore, it seems natural that Beutenaken-2 and Vijlen-type sediments belong to the same sequence covering the interval 1016-912 m.

## Ecozone IV

Ecozone IV marks the upper part of the Gulpen Formation, from the top of the Vijlen to the Lanaye members, possibly including the base of the Maastricht Formation (P.J. Felder, 2001). This ecozone is locally developed in calcarenite lithofacies. In the Turnhout borehole, with low sampling density (Felder, 1994), the boundary between ecozones III and IV is rather inconspicuous: between 800 m and 766 m (set as base for Ecozone V) sampling resolution is insufficient to document if Ecozone V started earlier or not.

## Ecozone V

Ecozone V is characteristic of the Maastricht Formation, maybe not from its absolute base as established at the ENCI-HeidelbergCement Group quarry type section, but from the first hardground above the base (P.J. Felder, 2001). In the Turnhout borehole, the appearance of Ecozone V follows a hardground at 766 m, which separates the 'Craie jaunâtre grossière', now interpreted as the Lanaye Member, from the 'Tuffeau calcaire tendre', now interpreted as the Maastricht and Houthem formations. This hardground is set as the local base of the Maastricht Formation.

Several boreholes in the northwest Campine clearly show peaks of thecideid brachiopods at the transition between ecozones IV and V. This suggests the presence of the lower members of the Maastricht Formation in a condensed section. By geophysical well logs, it was not possible to discriminate between members of the Maastricht Formation developed in normal calcarenite lithofacies.

## Ecozone VI

Ecozone VI is assigned exclusively to the Houthem Formation, without overlap with other formations (P.J. Felder, 2001). The Maastricht/Houthem boundary is arbitrarily set at the highest gamma-ray peak in a higher gamma-ray interval, which means that the boundary may vary slightly between different boreholes with respect to the K/Pg boundary. Although the overlap between ecozone boundary V/VI, based on cuttings samples and the base Houthem defined by geophysical well logs, might slightly fluctuate, it never becomes obscured or uncomfortably divergent.

It should be noted that in the first studies (Gulinck, 1954), the presence of the Houthem Formation in the northwest Campine was not yet proved. Moreover, this uppermost geophysical well log peak in the Chalk Group of the Meer-Merksplas area diverges from the Maastricht/Houthem boundary well log sections in the eastern Campine Basin by the absence of the erosional and karstification event at the K/Pg boundary. Hence, this level was previously interpreted as an intra-Maastrichtian horizon (P.J. Felder et al., 1985).

## Lithostratigraphic correlation by relating the dinocyst biostratigraphy to electrical stratigraphy and ecozonation

Correlations based on geophysical well logs are available for around 50 boreholes in the Campine Basin, more particularly at Merksplas and St.-Lenaarts (see Fig. 9). Ecozonations based on bioclast assemblages are available for c. 20 boreholes in the Campine Basin, of which the Merksplas and Turnhout boreholes are of particular relevance. The subdivision of the Chalk Group in the Meer borehole (Fig. 2), based on dinocyst biostratigraphy and compared with the Knokke borehole (Louwye, 1993), the Bunde borehole (Brinkhuis et al., 2000), the Turnhout borehole and the Beutenaken, Halembaye (Wilson, 1974; Robaszynski et al., 1985; Slimani, 2001a) and ENCI-HeidelbergCement Group quarries (Wilson, 1974; Schiøler et al., 1997) is put alongside electrical stratigraphy and ecozonation in order to enhance lithostratigraphical correlations with the Maastrichtian type area.

### Campanian

The Lower Campanian sample 1152 m corresponds to the Sonnisheide Member of Vaals Formation and to Ecozone Id.

The interval 1109-1066 m holds the *Exochosphaeridium*? *masureae* and *Areoligera coronata* zones and is contained within the middle section (1116-1057 m) of the Zeven Wegen Member (lower and middle part of the Upper Campanian). The *Exochosphaeridium*? *masureae* and *Areoligera coronata* zones correlate with the *Belemnitella woodi* Zone recorded from most of the Zeven Wegen Member in the Halembaye section (Keutgen & Jagt, 1999), hence also with Ecozone IIa. Elsewhere in the Campine Basin, the underlying white chalk (corresponding to the lower section 1146-1116 m of the Zeven Wegen Member in the Meer borehole) is also characterised by Ecozone IIa (P.J. Felder, 1994, 2001; see Fig. 9). Although this middle section does not occur further south in the Campine Basin, nor – most probably – in the type area, it remains within the same biostratigraphic zones as the Zeven Wegen Member of the type area and obviously represents a more complete time-equivalent sedimentary sequence. For these reasons, the vertical extension of the Zeven Wegen Member to incorporate both lower and middle units is justified.

The interval 1042-1020 m holds the *Samlandia mayi* Zone and corresponds to the upper white chalk unit (1057-1016 m), the lateral equivalent of the Beutenaken-1 Member, and Ecozone IIb (upper part of the Upper Campanian) in the Campine Basin. The fact that the Beutenaken Member at its type locality correlates in part with the *Belemnitella minor* Zone (Keutgen & Jagt, 1999) supports the dinocyst findings well. This upper white chalk unit is lithologically indistinguishable from the lower white chalk unit deposited holding the *Exochosphaeridium*? *masureae* and *Areoligera coronata* zones (the *Belemnitella woodi* Zone recorded from the Zeven Wegen

Member sensu stricto). The white chalk forms in the Campine Basin, south of Meer, a single lithological unit, hence also a single lithostratigraphical unit, of which the lower part falls within Ecozone IIa and the upper part within Ecozone IIb (Fig. 9). This implies that the lateral equivalent of the Beutenaken-1 Member, characterised by Ecozone IIb, has become incorporated in the Zeven Wegen Member.

### *Lithostratigraphic significance of the Campanian/ Maastrichtian boundary*

The Froidmont Hardground at 1016 m is the logical level for placing the Campanian/Maastrichtian boundary. However, the gap between the last undoubted Campanian sample at 1020 m and the first Maastrichtian sample at 995 m leaves some room for interpretation. An alternative explanation is that the corresponding strata were not sampled and in that case might correspond to the interval 1001-1016 m, identified by its rather marly log response. The Campanian/Maastrichtian boundary might then be situated at 1001 m, as a best fit with the log response below the first truly Maastrichtian sample at 995 m. However, based on geophysical well logs and ecozonation, the Beutenaken-2 Member covers the interval 1016-985 m in the Meer borehole, without apparent hardgrounds, and thus might seem 'too young', as the upper part of this interval is already in the upper part of the Lower Maastrichtian. In the cored Turnhout borehole, the Campanian/Maastrichtian boundary was drawn by Slimani (2000, 2001a) at hardground level 888 m which, according to Gulinck (1954), forms the boundary between the lower 'Craie marno-sableuse glauconifère' and the upper 'Craie blanchâtre grumeleuse', now considered as Beutenaken and Vijlen chalk, respectively. P.J. Felder (1994) placed the corresponding boundary between ecozones II and III in the Turnhout borehole at nearly the same depth, between samples 874 and 883.16 m, thus slightly above the Beutenaken/ Vijlen boundary. P.J. Felder's latest, unpublished opinion suggests that the Beutenaken-2 Member, identified by its Ecozone IIc bioclast content, might already form part of the Vijlen sequence, hence the lower Lower Maastrichtian Ecozone IIc from the eastern Campine was largely deposited during the upper Lower Maastrichtian in the northwest Campine. Nevertheless, it cannot be excluded that sedimentation of the lowermost part of this sequence had already started during earliest Early Maastrichtian times. The Campanian/Maastrichtian boundary generally coincides with a hardground that may develop between different lithostratigraphic levels, even at short distance as observed in boreholes located in adjoining parts of the Campine Basin (Lagrou et al., 2005).

### *Maastrichtian*

The apparent absence of the lower part of the Lower Maastrichtian, representing the conventional *Belemnella*

*lanceolata* Zone, is determined by the apparent absence of the *Membranilarnacia liradiscoides* Zone between samples 1020 and 995 m, and may correspond to an absence of the lowermost part of the Beutenaken-2 Member.

The interval 995-948 m, which corresponds to subzone a of the *Pervosphaeridium tubuloaculeatum* Zone, correlates with the Beutenaken-2 Member and Ecozone IIc and with the major, lower part of the Vijlen Member and Ecozone III (upper part of the Lower Maastrichtian).

Sample 925 m belongs to subzone b of the *Pervosphaeridium tubuloaculeatum* Zone (lower part of the Upper Maastrichtian) (see above), and may correlate with the Lixhe1 Member, as defined lithostratigraphically in the type area. This correlation is based on the L0 of the zonal species *Deflandrea galeata*, recorded from the basal Lixhe 2 Member at the ENCI-HeidelbergCement Group quarry (Schiøler et al., 1997). This means that the Vijlen/Lixhe boundary occurs at a lower level, and is tentatively placed at the base of a coarsening-upward sequence at 932 m. This interpretation creates a discrepancy with the lithostratigraphy based on the ecozonation, placing the Vijlen/Lixhe boundary at a higher level (912 m). Different explanations are possible for this discrepancy. The most unlikely one is that the cuttings sample is downplaced and should in reality be derived from strata above 912 m. This is contradicted by the regularity of the other cuttings samples. A second explanation is that the boundary between ecozones III and IV is misplaced and in reality should occur at a lower level than the recorded lithological change from chalk to calcarenite. Because of the occasionally uncertain depth range of the cuttings samples this cannot be excluded, but is not considered very probable in view of the total correlation scheme including dozens of boreholes. More plausibly, the longer duration of Ecozone III in the Meer borehole, beyond the time of deposition of the Vijlen Member into the time of deposition of the Lixhe Member in the type area, might be explained by the less conspicuous variation in lithology and their biotopes in the northwest Campine, maintaining a 'conservative' appearance in the faunas, which then ended abruptly at the next facies change (Fig. 9). We conclude that the biostratigraphy supports an explanation of this anomaly due to diachroneity of both facies and ecozonation, and hence previous lithostratigraphical interpretations.

## Boundary between the Gulpen and Maastricht formations

The HOs of *Isabelidinium cooksoniae* and *Chatangiella* sp. A of Schiøler & Wilson (1993) at 880 m may correlate with the Romontbos Horizon between the Schiepersberg and Emael members within the lower part of the Maastricht Formation, according to Schiøler et al. (1997) and Brinkhuis et al. (2000). However, the HOs of *Ovoidinium membranaceum* at 904 m, *Wilsonisphaera petila* at 895 m and *Turnhosphaera hypoflata* at

880 m suggest that the boundary between the Gulpen and Maastricht formations may not be placed below 880 m, because these events do not cross this boundary. They occur in the Lixhe 3 and Lanaye members at Halembaye and ENCI-HeidelbergCement Group according to the records of Schiøler et al. (1997) and Slimani (2001a). This means that the interval between 912 and 870 m (boundaries located from geophysical well logs) of the *Deflandrea galeata* Zone (subzone a) correlates with the Lixhe 2, Lixhe 3 and Lanaye members (upper part of the Gulpen Formation), while the lowermost part of the Maastricht Formation (Valkenburg, Gronsveld and Schiepersberg members) below the Romontbos Horizon might be lacking or were not sampled between 880 and 869 m. However, the high density interval 865-870 m above the base of the Maastricht Formation might represent a condensed section containing these members. Sample 869 m (HO of *Cannosphaeropsis utinensis*) holds the *Deflandrea galeata* Zone (subzone b) and can be correlated to the Emael Member, directly below the *Palynodinium grallator* Zone of Hansen (1977), following the records of Schiøler et al. (1997). In view of the lithological interpretation of the depth interval 865-870 m, sample 869 m should then be derived from the sediments directly overlying the 865 m horizon. Either a depth delay in the cuttings sampling of 4 m, or downward migration of dinocysts in a porous medium into a tighter sediment over this distance seem to be plausible explanations.

## Maastrichtian/Danian boundary

Directly above, from the HO of *Cannosphaeropsis utinensis* up to the HO of *Palynodinium grallator*, the interval from 869 to 834 m with samples 857 m to 841 m, holding the *Hystrichostrogylon coninckii* Zone (equivalent to the *Palynodinium grallator* Zone of Hansen, 1977), can be correlated to the Nekum and Meerssen members (upper part of the Maastricht Formation) (Schiøler et al., 1997; Brinkhuis et al., 2000). This means that there is a significant change between the eastern and western Campine successions. In the eastern Campine, closer to the Roer Valley Graben, the upper part of the Maastricht Formation was not deposited or is represented by the hiatus below the karstified K/Pg boundary (Lagrou et al., 2005; Dusar & Lagrou, 2007b). On the other hand, the lower part of the Maastricht Formation is well represented (P.J. Felder, 2001). The western Campine, with the Meer borehole, is better connected to the Maastricht type area which contains similar deposits (Dusar & Lagrou, 2007b). This differentiation between the eastern and western Campine at the K/Pg boundary is corroborated by the different signature of the gamma-ray logs, showing an extensive weathering zone in the eastern Campine with multiple peaks versus a much smaller gamma-ray enhanced interval with a single peak, without noticeable change for other geophysical parameters in the western Campine.

According to Brinkhuis et al. (2000), the Danian interval recorded from 832-825 m just above the Maastrichtian/Danian boundary at 834 m up to the HO of *Senoniasphaera inornata* (the *Senoniasphaera inornata* Subzone) can be correlated to the Geulhem Member, the basal unit of the Houthem Formation. Directly above, the interval 817-814 m, corresponding to the *Hafniasphaera cryptovesiculata* Subzone, can be correlated to the Bunde and probably the Geleen members of the same formation. The Geulhem/Bunde boundary is tentatively placed at 822 m because of a small interruption in well log response. This suggests that the top of the Houthem Formation remains of the same age throughout the basin, which is further supported by its remarkably uniform sediment thickness in response to a temporary relaxation of the basin inversion history (Rossa, 1986).

## Remarks on the Turnhout borehole and the Hallembaye quarry

The Lixhe 2, Lixhe 3 and Lanaye members in the Halembaye section are now correlated with the *Deflandrea galeata* Zone, instead of subzone b of the *Pervosphaeridium tubuloaculeatum* Zone (compare Slimani, 2001a), based on the record of the LO of *Deflandrea galeata* at ENCI-HeidelbergCement Group (Schiøler et al., 1997). Therefore, the interval 836.95-807.90 m containing the *Deflandrea galeata* Zone (836.95-815.89 m) and basal part of the *Hystrichostrogylon coninckii* Zone (807.90 m) in the Turnhout borehole (see Slimani, 2001a), may correlate with the Lixhe 2, Lixhe 3 and Lanaye members. This is supported by the HO at 807.90 m of the index species Triblastula utinensis, recorded previously in the Lanaye Member at Halembaye (Slimani, 2001a) and ENCI-HeidelbergCement Group (Schiøler et al., 1997), and by the HOs of *Turnhosphaera hypoflata* at 836.95 m and *Ovoidinium membranaceum* at 815.89 m, which do not reach the Maastricht Formation (see above). According to P.J. Felder (1994), this interval is situated in Ecozone IV.

A supplementary palynological analysis of six samples from the Turnhout cored borehole (772 m, 765 m, 754 m, 748 m, 739 m and 723.9 m) within the framework of the present study revealed that the HO of *Isabelidinium cooksoniae* is located at 765 m, rather than at 807.90 m (compare Slimani, 2001a) and the HO of *Palynodinium grallator* can be placed at 748 m. The HO of *Isabelidinium cooksoniae* at 765 m suggests that the boundary between the lower and upper part of the Maastricht Formation, correlated to the Romontbos Horizon in the type area, may be situated between 765 m and 795.24 m. However, the HO of *Palynodinium grallator* at 748 m indicates that the Maastrichtian/Danian boundary can be placed between samples 748 and 739 m, instead of the interval 775.01 and 759.89 m (compare Slimani, 2001a). This means that the interval 807.90-765 m with the uppermost part of 'Craie grise glauconifère' (Gulinck, 1954; associated with the upper part of the Gulpen Formation) and

the 'Craie jaunâtre grossière' (provisionally interpreted as Lanaye Member by P.J. Felder et al., 1985) would already be the lateral equivalent of Valkenburg, Gronsveld and Schiepersberg members. The interval 765-748 m of the 'Tuffeau calcaire tendre' would then at least correlate with the Emael, Nekum and Meerssen members of the Maastricht Formation. These new dinocyst findings corroborate those of the geophysical well log interpretation and P.J. Felder's ecozonation, at least in correlating the 'Tuffeau calcaire tendre' to the Maastricht and Houtem formations. In the 'Tuffeau calcaire tendre', *Palynodinium grallator* is present in only one sample (748 m). Its high frequency points to an in situ occurrence, and therefore the interval 759.89-748 m can be assigned to the uppermost Maastrichtian. As a consequence, the presence of Danian dinocyst species below this interval is interpreted as downward migration through porous sediments down to a permeability barrier, here represented by the hardground at 766 m. This migration can only be envisaged during the brief period of falling groundwater level prior to consolidation of the calcarenitic sediment (i.e., after termination of the carbonate sedimentation assigned to the Houthem Formation by the Laramide inversion event). Lignite chunks and grains from the younger Paleocene Opglabbeek Formation (no longer present as a stratiform deposit overlying the Chalk Group) deposited inside a well-consolidated serpulid bank 5 m below the top Cretaceous provide some evidence for this hypothesis (Fig. 11). A similar process of karstic funnelling was invoked by P.J. Felder (MS) to explain the discrepancies between the biostratigraphic range of foraminifera and the supposed age of the Maastricht Formation from which they were collected, and which made Hofker (1978) plead to include the whole Maastricht Formation in the Paleogene, by definition impossible.



*Fig. 11.   Serpulid bed, stained by lignite that migrated downwards from overlying Cenozoic Opglabbeek Formation (not preserved in situ as stratiform unit) through porous fine-grained calcarenite at a depth of 708.13 m (top Chalk Group at 703 m) in the Turnhout borehole (core diameter 8 cm).*

## Conclusions

The Meer borehole is located in the northern part of the Belgian Campine Basin, close to its junction with the western part of the London-Brabant Massif and the West Netherlands Basin. With 378 m it is the thickest sequence of the Chalk Group in the Campine Basin (Vandenberghe et al., 1988). The Chalk Group of the Campine Basin is concealed but contiguous with the Maastricht type area whose lithostratigraphical scale can be applied (W.M. Felder, 1975). Geophysical well log correlation (Lagrou et al., 2005) supported by P.J. Felder's ecozonation (P.J. Felder, 1994, 2001) of more than 50 boreholes in the Campine Basin shows a concordance in the succession of lithostratigraphical formations, but revealed uncertainty at the level of the boundaries in a sedimentary basin sandwiched between an inverted Roer Valley Graben and the London-Brabant Massif. For these reasons, the Meer borehole was selected for detailed bio- and lithostratigraphical studies, in order to check the validity of correlations at a distance of 100 km from Maastricht. The dinocyst biozonation proved to be a successful tool applicable to borehole cuttings samples, thus mostly relying on the concept of highest consistent occurrence. Special care was taken to apply these three stratigraphic tools – lithostratigraphy based on geophysical well logs, ecozonation and dinocyst biozonation – independently so as to obtain consistent stratigraphical schemes useful for regional and interregional correlation.

### *Biostratigraphy*

The palynological analysis of the Chalk Group in the Meer borehole has revealed a succession of at least 35 chronostratigraphically significant dinocyst events based on the highest consistent occurrence and rarely on the lowest occurrence of index species. These events are, in ascending order, the LO of *Exochosphaeridium*? *masureae*, the HOs of *Rhynchodiniopsis*? sp. cf. *Gonyaulacysta prominoseptata* in Wilson, 1974, *Xenascus wetzelii, Cribroperidinium wilsonii* forma A, *Stephodinium*? *spinosum, Palaeohystrichophora infusorioides, Chatangiella madura, Membranigonyaulax granulata, Odontochitina streelii, Chatangiella robusta, Membranilarnacia hapala, Samlandia mayi*, LOs of *Alterbidinium varium, Pervosphaeridium tubuloaculeatum, Triblastula utinensis*, HOs of *Histiocysta*? *variornata, Neosphaerodictyon filosum, Alterbidinium acutulum, Hystrichodinium pulchrum* subsp. *pulchrum, Ovoidinium membranaceum, Wilsonisphaera petila, Turnhosphaera hypoflata, Isabelidinium cooksoniae, Chatangiella* sp. A, *Cannosphaeropsis utinensis, Palynodinium grallator, Spiniferites ramosus* subsp. *cavispinosus, Senoniasphaera inornata* and *Hystrichokolpoma bulbosum* subsp. *bulbosum*.

These bio-events allow a subdivision of the Meer borehole into six intervals: the Lower Campanian (sample 1152 m), the Upper Campanian with a subdivision into lower, middle and upper parts (samples 1109 to 1020 m), the upper part of the Lower Maastrichtian (samples 995 to 948 m), the Upper Maastrichtian subdivided into a lower and an upper part (samples 925 to 841 m), the lower Danian (samples 832 to 825 m) and the upper Danian (samples 817 to 814 m).

Other bio-events previously assessed as good markers for the uppermost Campanian (HOs of *Odontochitina costata, Raetiaedinium truncigerum, Xiphophoridium alatum, Callaiosphaeridium asymmetricum* and *Florentinia*? *flosculus*), lowermost Maastrichtian (HOs of *Odontochitina operculata* and *Xenascus ceratioides* subsp. *ceratioides*) and lower part of the Upper Maastrichtian (HO of *Triblastula utinensis*) were not used here, because they are recorded slightly earlier than in previous records. This can be attributed to their rarity.

Comparisons with other dinocyst assemblages indicate that these events can be useful for local, regional, interregional and global correlation since they have a similar distribution pattern throughout northwest Europe and other parts of the Boreal domain, such as the east coast of North America. The similar distribution of Danian events such as the HOs of *Senoniapshaera inornata* and *Hystrichokolpoma bulbosum* subsp. *bulbosum* (early to middle Danian) is also reported from the Tethyan domain. Some Campanian dinocyst events such as the HOs of *Chatangiella*? *robusta, Odontochitina operculata, Xenascus ceratioides* subsp. *ceratioides* and *Samlandia mayi* appear to be slightly older in the Tethyan domain than in the Meer borehole and elsewhere in the Boreal realm. The HOs of *Odontochitina streelii* and *Stephodinium*? *spinosum*, together with the LO of *Pervosphaeridium tubuloaculeatum*, appear to have a local biostratigraphic significance in the Campine Basin and the Maastrichtian type area.

The dinocyst events allow a correlation of the borehole studied with Slimani's (2001a) *Exochosphaeridium*? *masureae, Areoligera coronata, Samlandia mayi, Pervosphaeridium tubuloaculeatum, Deflandrea galeata* and *Hystrichostrogylon coninckii* zones, as defined previously in the Campine Basin and the Maastrichtian type area, and with other dinocyst zonation schemes from Belgium, the Netherlands, northern Germany, Denmark, the Central North Sea, and with conventional, northwest European belemnite zones.

### *Biostratigraphical control on the lithostratigraphical scheme*

The Cretaceous transgression over the Campine Basin, and hence the age of the Vaals Formation (interval 1186-1146 m) is Early Campanian, not Santonian. The lateral facies change from greensand facies into chalk away from the Roer Valley Graben is stepwise, affecting more pervasively the upper Vaals Formation (Sonnisheide Member).

The Upper Campanian white chalk (interval 1146-1016 m) remains as a highstand deposit the most easily recognised lithological unit in the entire Campine Basin. A more complete

succession occurs in the northwesternmost Campine, and in addition to the Zeven Wegen Member of the Gulpen Formation also includes the lateral equivalent of the Beutenaken-1 Member (interval 1146-1016 m). The presumed Campanian/Maastrichtian boundary coincides with a hiatus, marked by the Froidmont Hardground at 1016 m.

A new chalk sequence with only weakly expressed lithological differentiation succeeds the white chalks; this was deposited during the late Early Maastrichtian. Sedimentation possibly started already during the early Early Maastrichtian but there is no proof for this. The sequence continues over the Early/Late Maastrichtian boundary (interval 1016-912 m). Geophysical well logs do not yield clues for large hiatuses in this sequence. The succession from the Beutenaken-2 to Lixhe-1 members seems part of one large coarsening-upward Vijlen-type sequence. The lithological boundary between the Beutenaken-2 and Vijlen members becomes inconspicuous. The facies yielding bioclasts characteristic of Ecozone III for the Vijlen Member in the Maastrichtian type area and the eastern Campine is maintained during the time of deposition of the Lixhe-1 Member. The upper boundary at 912 m is marked by a sudden facies change to calcarenite.

The calcarenite facies characterises 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 appearance of the calcarenite is diachronous in the Campine Basin. Calcarenite sedimentation appears in the Lixhe 2-3 interval of the upper Gulpen Formation. The transition from the Gulpen Formation to the Maastricht Formation, set at 870 m, is condensed. Subdivision of the Maastricht Formation into its members is difficult to apply in a consistent way across the Campine Basin, hence it is not known whether the succession suggested for the Meer borehole can be recognised in neighbouring areas. The uplift and karstification of the top Maastricht Formation, which is strongly expressed in the eastern Campine can hardly be observed in the northwest Campine, where the late Maastrichtian hiatus below the K/Pg boundary event becomes less well developed, more in line with the situation in the Maastrichtian type area.

The Houthem Formation (interval 834-808 m) presents a marked regularity in thickness and time span over the entire Campine Basin, irrespective of distance to the Roer Valley Graben, indicating that both base and top reacted to basin-wide tectonic pulses.

The stratigraphical scheme established in the Maastrichtian type area (Felder & Bosch, 2000; summarised for Belgium in Robaszynski et al., 2002) can be extended to the northwest Campine. However, its application calls for caution, as discrepancies observed in the Meer borehole demonstrate.

The upper Upper Campanian Beutenaken-1 Member has become incorporated in the white chalk facies of the Zeven Wegen Member sensu lato, underneath the Froidmont Hardground, which puts the Vijlen Member on top of the Zeven Wegen Member sensu stricto in the Halembaye type section, south of Maastricht. The upper Lower Maastrichtian Beutenaken-2 Member, defined in the Campine Basin and absent in the Maastricht type area, is part of a sedimentary sequence continuing with the Vijlen Member. Without biostratigraphic control, the Vijlen-type facies equivalent of the Lixhe-1 Member was obviously interpreted as 'real' Vijlen. Lithological correlation thus tends to shift the Gulpen lithostratigraphical scheme upwards in the northwestern Campine, compared to the type area. The more regular subsidence rate at greater distance from the Roer Valley Graben inverted basin likely is the reason for this more conservative facies distribution. The Meer borehole already shows a transition to the stratigraphy on the central part of the London-Brabant Massif by increasing 'chalkiness' of the Vaals Formation and announces Ommelanden-type stratigraphy of the North Sea Basin by the increased chalk thickness.

## Taxonomic remarks

### Cribroperidinium wilsonii *(Yun Hyesu, 1981) Poulsen, 1996, forma A and forma B*

Fig. 5a, b, d-f.

*Cribroperidinium wilsonii* forma A is synonymous with *Acanthaulax wilsonii* of Kirsch (1991, pl. 11, fig. 4) and Slimani (2001a, pl. 2, fig. 11), while forma B is synonymous with *Acanthaulax wilsonii* of Kirsch (1991, pl. 11, figs 7, 10) and Slimani (2000, pl. 7, fig. 11).

*Cribroperidinium wilsonii* forma A differs from forma B by its free, rather than interconnected, penitabular processes. Forma A occurs for the last time within the Upper Campanian (middle part), while forma B ranges into the Upper Campanian (upper part), Lower Maastrichtian and Upper Maastrichtian (lower part) in the Meer borehole. In the Turnhout borehole (H. Slimani, pers. obs.) forma B has its highest occurrence within the Lower Maastrichtian.

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## Appendix A – Taxonomy

A complete list of taxa from the Meer borehole, arranged alphabetically by genera. Numbers refer to the order of last occurrences in the range chart (Table 1). Species marked (*) are not plotted in Table 1, because they are not considered to be significant enough in the present study. Taxa illustrated in this paper are shown in bold and have figure references. The nomenclature follows Fensome & Williams (2008) and database DINOFLAJ2 for taxa prior to 2004; other species are referenced here.

*   *Achilleodinium biformoides*
*   *Achomosphaera alcicornu*
*   *Achomosphaera crassipellis*
*   *Achomosphaera regiensis*
*   *Aldorfia dictyota* subsp. *papillata* - presumed reworked
174   *Alisogymnium euclaense*
**133**   ***Alterbidinium acutulum* (Fig. 7c)**
*   *Alterbidinium kirschii*
45   *Alterbidinium minus*
**80**   ***Alterbidinium varium* (Fig. 7d)**
116   *Alterbidinium montanaense*
*   *Amphidiadema? similis*
*   *Amphorosphaeridium fenestratum* subsp. *fenestratum*
*   *Amphorosphaeridium fenestratum* subsp. *dividum*
*   *Amphorosphaeridium majus*
*   *Amphorosphaeridium multibrevum*
*   *Amphorosphaeridium multispinosum*
*   *Apectodinium* sp. - presumed post-Danian contamination
**134**   ***Apteodinium deflandrei* (Fig. 7m)**
**\***   ***Apteodinium* sp. A of Slimani 1995 (Fig. 8x)**
*   *Areoligera coronata*
*   *Areoligera* sp. cf. *Areoligera coronata*
*   *Areoligera flandriensis*
*   *Areoligera guembelii*
*   *Areoligera medusettiformis*
146   *Areoligera microreticulata* (*Areoligera reticulata* in Wilson, 1974)
*   *Areoligera senonensis*
*   *Areoligera* sp. cf. *Areoligera senonensis*
*   *Areoligera* aff. *senonensis* of Lejeune Carpentier, 1938
*   *Areoligera sentosa* - presumed post-Danian contamination
*   *Areoligera tauloma* - presumed post-Danian contamination
*   *Areoligera tenuicapillata*
*   *Areoligera volata*
117   *Batiacasphaera reticulata*
**141**   ***Batiacasphaera solida* (*Chytroeisphaeridia solida* in Wilson, 1974) (Fig. 7e)**
**\***   ***Batiacasphaera* aff. *hirsuta* of Slimani, 1995 (Fig. 8h)**
175   *Biconidinium reductum* (*Svalbardella parva* in Wilson, 1974)
*   *Bitectatodinium tepikiense* - presumed post-Danian contamination
*   *Caligodinium aceras*
46   *Caligodinium goeranii*

**168**   ***Callaiosphaeridium asymmetricum* (Fig. 5m)**
*   *Canninginopsis bretonica*
126   *Canninginopsis maastrichtiensis* (*Canninginopsis verrucosa* in Wilson, 1974)
8   *Cannosphaeropsis fransisca*
*   *Cannosphaeropsis? hyperacantha*
**81**   ***Cannosphaeropsis utinensis* (Fig. 4a)**
**17**   ***Carpatella cornuta* (Fig. 6h)**
60   *Cassiculosphaeridia reticulata*
*   *Cassiculosphaeridia? intermedia* (*Chytroeisphaeridia everrecula* in Wilson, 1974)
*   *Cassiculosphaeridia? tocheri*
*   *Cauveridinium membraniphorum* - presumed reworked
*   *Cerodinium medcalfii* - presumed post-Danian contamination
147   *Cerodinium albertii*
*   *Cerodinium diebelii* subsp. *diebelii*
*   *Cerodinium diebelii* subsp. *rigidum*
*   *Cerodinium leptodermum*
*   *Cerodinium pannuceum*
*   *Cerodinium speciosum* subsp. *elongatum*
*   *Cerodinium speciosum* subsp. *glabrum*
*   *Cerodinium speciosum* subsp. *speciosum*
*   *Cerodinium striatum*
*   *Cerodinium warrenii*
127   *Chatangiella ditissima*
176   *Chatangiella granulifera* subsp. *granulifera*
**163**   ***Chatangiella madura* (Fig. 6k)**
**151**   ***Chatangiella? robusta* (*Trithyrodinium inequale* in Wilson, 1974) (Fig. 6j)**
*   *Chatangiella spectabilis*
*   *Chatangiella tripartita?*
*   *Chatangiella turbo*
*   *Chatangiella verrucosa*
*   *Chatangiella victoriensis*
**177**   ***Chatangiella vnigrii* subsp. *vnigrii* (Fig. 6m)**
178   *Chatangiella williamsii*
**93**   ***Chatangiella* sp. A of Schiøler & Wilson, 1993 (Fig. 6l)**
*   *Chlamydophorella discreta*
**\***   ***Chlamydophorella* sp. A of Slimani, 1995 (Fig. 7q)**
*   *Chytroeisphaeridia baetica*
*   *Circulodinium brevispinosum*
*   *Circulodinium colliveri*
**61**   ***Circulodinium distinctum* subsp. *distinctum* (Fig. 4h)**
94   *Cladopyxidium? halembayense*
**62**   ***Cladopyxidium marheineckei* (Fig. 8l)**
**56**   ***Cladopyxidium paucireticulatum* (Fig. 8e)**
18   *Cladopyxidium saeptum*
**82**   ***Cladopyxidium septocrispum* (Fig. 8k)**
152   *Cladopyxidium verrucosum*
*   *Cleistosphaeridium placacanthum*
*   *Cometodinium obscurum*
*   *Cometodinium whitei*
*   *Conneximura fimbriata*
*   *Conosphaeridium* cf. *Conosphaeridium striatoconum*

| | |
|---|---|
| * | *Cordosphaeridium commune* |
| * | *Cordosphaeridium exilimurum* |
| * | *Cordosphaeridium fibrospinosum* |
| * | *Cordosphaeridium gracile* |
| * | *Cordosphaeridium inodes* subsp. *inodes* |
| 1 | *Cordosphaeridium inodes* subsp. *longipes* |
| 39 | *Cordosphaeridium robustum* |
| * | cf. *Cordosphaeridium varians* |
| 63 | *Coronifera granulata* |
| * | *Coronifera oceanica* subsp. *hebospina* |
| * | *Coronifera striolata* |
| * | *Cribroperidinium cooksoniae* |
| 192 | *Cribroperidinium edwardsii-orthoceras* - presumed reworked |
| * | *Cribroperidinium graemei* (*Gonyaulacysta filosa* in Wilson, 1974) |
| * | *Cribroperidinium ventriosum* |
| * | *Cribroperidinium wetzelii* |
| **153** | ***Cribroperidinium wilsonii* forma A (*Acanthaulax saetosa* in Wilson, 1974) (Fig. 5a, b)** |
| **108** | ***Cribroperidinium wilsonii* forma B (Fig. 5d-f)** |
| **\*** | ***Cribroperidinium* sp. A (Fig. 6g)** |
| 193 | *Ctenidodinium* spp. - presumed reworked |
| 185 | *Cyclonephelium filoreticulatum* |
| * | *Cyclopsiella* sp. of Schiøler et al., 1997 |
| **13** | ***Damassadinium californicum* (Fig. 4d)** |
| 195 | *Dapcodinium priscus* - presumed reworked |
| * | *Dapsilidinium laminaspinosum* |
| * | *Dapsilidinium*? *pumilum* |
| * | *Deflandrea denticulata* |
| * | *Deflandrea oebisfeldensis* - presumed post-Danian contamination |
| **2** | ***Deflandrea galeata* (Fig. 7h)** |
| * | *Desmocysta plekta* |
| * | *Diacrocanthidium echinulatum* |
| **83** | ***Diconodinium wilsonii* (*Diconidinium parvum* in Wilson, 1974) (Fig. 7r)** |
| 84 | *Dinogymnium acuminatum* |
| 109 | *Dinogymnium avellana* |
| 154 | *Dinogymnium digitus* |
| 110 | *Dinogymnium westralium* |
| 155 | *Dinopterygium cladoides* |
| 3 | *Diphyes colligerum* |
| * | *Diphyes recurvatum* |
| 19 | *Disphaerogena carposphaeropsis* |
| * | *Dissiliodinium* sp. |
| * | *Downiesphaeridium*? *aciculare* |
| * | *Downiesphaeridium armatum* |
| * | *Downiesphaeridium flexuosum* |
| * | *Druggidium*? *fourmarieri* |
| **20** | ***Druggidium* sp. A of Slimani, 1994 (Fig. 8c)** |
| **\*** | ***Druggidium* sp. A (Fig. 8g)** |
| **\*** | ***Druggidium* sp. B (Fig. 8f1, f2)** |
| **47** | ***Druggidium*? sp. C (Fig. 8i)** |
| * | *Eisenackia circumtabulata* |
| * | *Eisenackia*? *knokkensis* |
| * | *Eisenackia margarita* |

| | |
|---|---|
| * | *Elytrocysta druggii* |
| **\*** | ***Elytrocysta* sp. A (Fig. 8m)** |
| * | *Exochosphaeridium bifidum* |
| 135 | *Exochosphaeridium brevitruncatum* |
| * | *Exochosphaeridium* sp. complex of Benson, 1976 |
| **186** | ***Exochosphaeridium*? *masureae* (*Exochosphaeridium*? *acuminatum* in Wilson, 1974) (Fig. 4b)** |
| * | ?*Exochosphaeridium multifurcatum* subsp. *multifurcatum* |
| * | *Exochosphaeridium phragmites* |
| * | *Exochosphaeridium* sp. cf. *Coronifera striolata* |
| * | *Eyra nubulosa* |
| * | *Fibradinium annetorpense* |
| * | *Fibradinium annetorpense* of Slimani, 1994 |
| * | *Fibradinium densibaculatum* |
| 4 | *Fibrocysta axialis* |
| 21 | *Fibrocysta bipolaris* |
| 128 | *Fibrocysta klumppiae* |
| 5 | *Fibrocysta lappacea* |
| 22 | *Fibrocysta ovalis* |
| * | *Fibrocysta vectensis* |
| 6 | *Fibrocysta* sp. A of Brinkhuis & Schiøler, 1996 |
| * | *Flandrecysta furcata* |
| **23** | ***Flandrecysta tubulosa* (Fig. 5n)** |
| * | *Florentinia aculeata* |
| * | *Florentinia buspina* |
| * | *Florentinia clavigera* |
| * | *Florentinia ferox* |
| **169** | ***Florentinia*? *flosculus* (*Eurysphaeridium fibratum* in Wilson, 1974) (Fig. 7i)** |
| * | *Florentinia mantellii* |
| 157 | *Florentinia radiculata* |
| * | *Fromea apiculata* |
| * | *Fromea chytra* |
| * | *Fromea fragilis* |
| * | *Fromea*? *laevigata* |
| * | *Fromea nicosia* |
| * | *Geiselodinium*? *psilatum* |
| 158 | *Gillinia hymenophora* |
| **74** | ***Gillinia*? sp. A (Fig. 8a1, a2)** |
| * | *Glaphyrocysta divaricata* |
| * | *Glaphyrocysta exuberans* |
| * | *Glaphyrocysta ordinata* |
| * | *Glaphyrocysta pastielsii* |
| **24** | ***Glaphyrocysta perforata* (Fig. 6a, b)** |
| * | *Glaphyrocysta retiintexta* |
| * | *Glaphyrocysta wilsonii* (*Cyclonephelium perforatum* in Wilson, 1974) |
| 95 | *Gonyaulacysta*? *obscura* |
| 194 | *Gonyaulacysta jurassica* subspp. - presumed reworked |
| 170 | *Glyphanodinium facetum* |
| **25** | ***Hafniasphaera cryptovesiculata* (Fig. 7j)** |
| * | *Hafniasphaera fluens* |
| 26 | *Hafniasphaera graciosa* |
| 14 | *Hafniasphaera hyalospinosa* |

7    *Hafniasphaera septata*

\*    *Halophoridia xena*

\*    *Heterosphaeridium conjunctum*

\*    *Heterosphaeridium heteracanthum*

136  *Histiocysta palla*

**142  *Histiocysta*? *variornata* (*Chlamydophorella inconscripta* in Wilson, 1974) (Fig. 8q)**

\*    *Horologinella* sp. cf. *Horologinella angulata* - presumed post-Danian contamination

15   *Horologinella coninckii*

**\*    *Horologinella* sp. A (Fig. 8v)**

**\*    *Horologinella*? sp. B (Fig. 8w)**

**120  *Hystrichodinium pulchrum* subsp. *pulchrum* (Fig. 4c)**

**27   *Hystrichokolpoma bulbosum* subsp. *bulbosum* (Fig. 5i)**

\*    *Hystrichokolpoma cinctum* - presumed post-Danian contamination

\*    *Hystrichokolpoma unispinum*

\*    *Hystrichokolpoma* cf. *Conosphaeridium striatoconum*

\*    *Hystrichosphaeridium costatum*

\*    *Hystrichosphaeridium dowlingii*

\*    *Hystrichosphaeridium recurvatum* subsp. *recurvatum*

\*    *Hystrichosphaeridium salpingophorum*

\*    *Hystrichosphaeridium tenuitubatum*

\*    *Hystrichosphaeridium tubiferum* subsp. *tubiferum*

\*    *Hystrichosphaeridium tubiferum* subsp. *brevispinum*

**64   *Hystrichosphaeropsis ovum* (Fig. 6n)**

\*    *Hystrichosphaeropsis quasicribrata*

**40   *Hystrichostrogylon borisii* (Fig. 5j, k)**

**28   *Hystrichostrogylon coninckii* (*Spiniferites palliatus* in Wilson, 1974) (Fig. 5g, h)**

\*    *Hystrichostrogylon membraniphorum*

48   *Impagidinium aspinatum*

\*    *Impagidinium cristatum*

65   *Impagidinium rigidaseptatum* (*Spiniferites cingulatus* var. *prominoseptatus* in Wilson, 1974)

159  *Impagidinium scabrosum*

\*    *Impagidinium* sp. 1 of Thomsen & Heilmann-Clausen, 1985

\*    *Impletosphaeridium clavulum*

\*    *Isabelidinium acuminatum*

\*    *Isabelidinium bakeri*

137  *Isabelidinium belfastense*

129  *Isabelidinium bujakii*

**111  *Isabelidinium cooksoniae* (Fig. 7a, b)**

\*    *Isabelidinium microarmum*

\*    *Isabelidinium thomasii*

66   *Ithnacysta elongata*

\*    *Kallosphaeridium brevibarbatum* - presumed post-Danian contamination

\*    *Kallosphaeridium orchiesense* - presumed post-Danian contamination

29   *Kallosphaeridium parvum*

\*    *Kallosphaeridium yorubaense*

**\*    ?*Kallosphaeridium granulatum* of Slimani, 1994 (Fig. 8p)**

\*    *Kiokansium polypes*

21   *Kleithriasphaeridium loffrense*

96   *Kleithriasphaeridium truncatum* (*Cordosphaeridium digitatum* in Wilson, 1974)

67   *Laciniadinium firmum*

\*    *Laciniadinium williamsii*

97   *Lasagniella herngreenii*

57   *Leberidocysta chlamydata* subsp. *schioeleri*

112  *Leberidocysta*? *flagellichnia*

85   *Leberidocysta*? *microverrucosa* (*Hexagonifera verrucosa* in Wilson, 1974)

\*    *Lejeunecysta communis*

\*    *Lejeunecysta fallax*

\*    *Lejeunecysta hyalina*

113  *Leptodinium porosum*

\*    *Lingulodinium machaerophorum*

130  *Lingulodinium varispinosum* (*Lingulodinium* sp. A in Wilson, 1974)

\*    *Litosphaeridium arundum*

98   *Litosphaeridium siphoniphorum* subsp. *glabrum*

86   *Litosphaeridium fenestreconum*

179  *Manumiella*? *cretacea*

\*    *Manumiella raijae*?

\*    *Manumiella seelandica*

\*    *Melitasphaeridium pseudorecurvatum*

**\*    *Melitasphaeridium* sp. A (Fig. 8u)**

**165  *Membranigonyaulax granulata* (Fig. 4l)**

**106  *Membranigonyaulax wilsonii* (*Meiourogonyaulax membranacea* in Wilson, 1974) (Fig. 7o)**

**156  *Membranilarnacia hapala* (*Membranilarnacia hapala* in Wilson, 1974) (Fig. 5o)**

138  *Membranilarnacia* aff. *leptoderma* of Slimani, 1994

99   *Membranilarnax liradiscoides*

131  *Membranilarnacia polycladiata* (*Membranilarnacia multifibrata* in Wilson, 1974)

49   *Membranilarnacia*? *tenella*

\*    *Michrystridium fragile*

\*    *Microdinium* cf. *Fibradinium annetorpense* (*Microdinium obscuriplicatum* in Wilson, 1974)

\*    *Microdinium bensonii* subsp. *bensonii*

\*    *Microdinium bensonii* subsp. *pilatum*

\*    *Microdinium* sp. cf. *Microdinium carinatum*

68   *Microdinium carpentierae*

\*    *Microdinium* aff. *cassiculus*

\*    *Microdinium cretaceum* (*Microdinium ovatum* in Wilson, 1974)

\*    *Microdinium deconinckii*

\*    *Microdinium densigranulatum*

\*    *Microdinium dentatum*

180  *Microdinium granocarinatum*

\*    *Microdinium inornatum* (*Microdinium glabrum* in Wilson, 1974)

50   *Microdinium marheineckei*

69   *Microdinium mariae*

\*    *Microdinium minutum*?

132  *Microdinium parvum*

139  *Microdinium pauciscabrosum*

41   *Microdinium sonciniae* (*Microdinium perplexum* in Wilson, 1974)

118  *Microdinium setosum*

70 *Microdinium* **sp. A of Slimani, 1994 (Fig. 8d)**

181 *Montanarocysta aemiliana*

100 *Multicorisphaeridium bisphaera*

91 *Multiplicisphaeridium? cruciatum*

\* *Multicorispharidium* sp. of Cookson & Eisenack, 1982

\* *Muratodinium fimbriatum*

\* *Nematosphaeropsis philippotii* (*Nematosphaeropsis delicata* in Wilson, 1974)

196 *Nannoceratopsis* spp.

143 *Neosphaerodictyon filosum* (*Sphaerodictyon filosum* in Wilson, 1974) **(Fig. 5l)**

114 *Neonorthidium perforatum* (*Eurysphaeridium glabrum* in Wilson, 1974)

\* *Nummus similis*

190 *Odontochitina costata*

171 *Odontochitina operculata*

160 *Odontochitina streelii* **(Fig. 4e)**

\* *Oligosphaeridium buciniferum*

\* *Oligosphaeridium complex* subsp. *complex*

\* *Oligosphaeridium intermedium*

\* *Oligosphaeridium poculum*

\* *Oligosphaeridium pulcherrimum*

\* *Oligosphaeridium* sp. cf. *Homotryblium* sp. of Brinkhuis & Zachariasse, 1988

\* *Oligosphaeridium totum*

\* *Operculodinium centrocarpum*

\* *Operculodinium corradinii*

\* *Operculodinium israelianum*

\* *Operculodinium microtriainum*

\* *Operculodinium? sp. cf. Operculodinium? placitum* **(Fig. 8z)**

\* *Ophiobolis lapidaris*

122 *Ovoidinium membranaceum* **(Fig. 4k)**

\* *Palaeocystodinium australinum*

\* *Palaeocystodinium lidiae*

\* *Palaeocystodinium golzowense*

148 *Palaeohystrichophora infusorioides* **(Fig. 7f)**

\* *Palaeoperidinium cretaceum*

\* *Palaeoperidinium pyrophorum*

115 *Palaeoperidinium? parvum*

161 *Palaeostomocystis foveolata*

\* *Palaeostomocystis reticulata*

\* *Palaeostomocystis sphaerica*

87 *Palaeotetradinium maastrichtiense*

\* *Palaeotetradinium silicorum*

\* *Palambages morulosa*

\* *Palambages* sp. of Rauscher & Doubinger, 1982

51 *Palynodinium grallator* **(Fig. 4g)**

\* *Paralecaniella indentata*

\* *Paucilobimorpha apiculata*

\* *Pentadinium laticinctum* - presumed post-Danian contamination

187 *Pervosphaeridium elegans* (*Cleistosphaeridium hallembaense* in Wilson, 1974)

166 *Pervosphaeridium intervelum*

88 *Pervosphaeridium monasteriense*

\* *Pervosphaeridium morgenrothii*

\* *Pervosphaeridium multispinum*

\* *Pervosphaeridium pseudohystrichodinium*

188 *Pervosphaeridium septatum*

101 *Pervosphaeridium tubuloaculeatum* **(Fig. 4i)**

\* *Pervosphaeridium* sp. A of Louwye, 1991

71 *Phanerodinium cayeuxii*

89 *Phanerodinium* sp. cf. *Druggidium fourmarieri* of Slimani, 1994

72 *Phanerodinium ovum*

102 *Phanerodinium septatum*

103 *Phanerodinium setiferum*

73 *Phanerodinium? turnhoutensis*

104 *Phanerodinium* **sp. A of Slimani, 1994 (Fig. 8b)**

\* *Phelodinium magnificum*

\* *Phelodinium tricuspe*

\* *Phthanoperidinium crenulatum* - presumed post-Danian contamination

75 *Pierceites pentagonus* **(Fig. 6i)**

\* *Pierceites* cf. *Pierceites schizocystis* Kirsch, 1991

123 *Platicystidia? sp. indet. of De Coninck, 1986* **(Fig. 8t)**

\* *Prolixosphaeridium? nanum*

\* *Pseudoceratium pelliferum* - presumed reworked

\* *Pterodinium cingulatum* subsp. *cingulatum*

\* *Pterodinium cingulatum* subsp. *granulatum*

\* *Pterodinium cingulatum* subsp. *reticulatum*

76 *Pterodinium cretaceum* Slimani et al., 2008

\* Pterodinium? sp. C of Schiøler & Wilson, 1993

\* *Pulchrasphaera minuscula*

\* *Pyxidiella? scrobiculata*

\* *Pyxidinopsis* **sp. cf. P. densepunctata of Slimani, 1995 (Fig. 8n)**

\* *Pyxidinopsis tuberculata*

42 *Raetiaedinium laevigatum*

105 *Raetiaedinium punctulatum*

189 *Raetiaedinium truncigerum* (*Laticavodinium latispinosum* in Wilson, 1974) **(Fig. 5c)**

90 *Raphidodinium fucatum*

\* *Renidinium* **sp. A (Fig. 7k)**

182 *Rhynchodiniopsis? sp. cf. Gonyaulacysta prominoseptata* **in Wilson, 1974 (Fig. 4m)**

77 *Rhiptocorys veligera*

78 *Rigaudella apenninica* (*Adnatosphaeridium* cf. *aemulum* in Wilson, 1974)

\* *Rottnestia borussica*

30 *Rottnestia wetzelii* subsp. *wetzelii* (*Hystrichosphaeropsis forficata* in Wilson, 1974)

162 *Samlandia mayi* (*Samlandia solida* of Wilson, 1974) **(Fig. 4j)**

43 *Samlandia pseudoreticulata*

\* *Senegalinium bicavatum*

\* *Senegalinium dilwynense*

\* *Senegalinium laevigatum*

\* *Senegalinium microgranulatum*

\* *Senegalinium obscurum*

31 *Senoniasphaera inornata* **(Fig. 6f)**

\* *Sentusidinium eisenackii*

164 *Sepispinula ambigua*

44 *Sepispinula ancorifera*

191 *Spinidinium angustispinum* **in Wilson, 1974 (Fig. 7s)**

\* *Spinidinium balmei*