Shallow marine Lower and Middle Miocene deposits at the southern margin of the North Sea Basin (northern Belgium): dinoflagellate cyst biostratigraphy and depositional history

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Abstract – Detailed dinoflagellate cyst analysis of the Lower–Middle Miocene Berchem Formation at the southernmost margin of the North Sea Basin (northern Belgium) allowed a precise biostratigraphical positioning and a reconstruction of the depositional history. The two lower members of the formation (Edegem Sands and decalcified Kiel Sands) are biostratigraphically regarded as one unit since no significant break within the dinocyst assemblages is observed. The base of this late (or latest) Aquitanian–Burdigalian unit coincides with sequence boundary Aq3/Bur1 as defined by Hardenbol and others, in work published in 1998. A hiatus at the Lower–Middle Miocene transition separates the upper member (the Antwerpen Sands) from the underlying member. The greater part of the Antwerpen Sands were deposited in a Langhian (latest Burdigalian?)–middle Serravallian interval. The base of this unit coincides with sequence boundary Bur5/Lan1. Biostratigraphical correlation points to a diachronous post-depositional decalcification within the formation since parts of the decalcified Kiel Sands can be correlated with parts of the calcareous fossil-bearing section, up to now interpreted as Antwerpen Sands. The dinoflagellate cyst assemblages are dominated by species with a inner neritic preference, although higher numbers of oceanic taxa in the upper part of the formation indicate incursions of oceanic watermasses into the confined depositional environment of the southern North Sea Basin.

1. Introduction

The foraminifera and calcareous nannofossils from the Lower–Middle Miocene Berchem Formation of northern Belgium have been extensively studied (Hooyberghs, 1983, 1996; Hooyberghs & De Meuter, 1972; Martini & Müller, 1973; Verbeek, Steurbaut & Moorkens, 1988). However, the assessment of the biostratigraphical position of the formation remained unsatisfactory since the boreal calcareous microfossil associations are difficult to relate to the standard biozonations defined in lower latitudes. Moreover, decalcification within this shallow marine formation seriously hampers regional and interregional biostratigraphical correlation of the sandy members. Dinoflagellate cysts are being used more frequently for unravelling the stratigraphical relationships and the determination of the biostratigraphical position of Neogene shallow marine deposits in the North Atlantic realm and the North Sea Basin (de Verteuil & Norris, 1996; Head, 1996, 1997, 1998; Louwye, De Coninck & Verniers, 1999). A preliminary biostratigraphical study with dinoflagellate cysts of the Berchem Formation revealed the presence of well-preserved associations of these cysts (Louwye & Laga, 1998). This paper attempts to circumscribe more precisely the stratigraphical position and the depositional chronology of the earliest Neogene deposits at the southernmost margin of the North Sea Basin.

2. Geological background

The lowest Neogene deposits along the southernmost margin of the North Sea Basin crop out in the Antwerp area (Fig. 1) and are grouped in the Lower/Middle Miocene Berchem Formation (De Meuter & Laga, 1976). This formation directly overlies the Lower Oligocene (Rupelian) Boom Formation. The hiatus of about 10 Ma between these formations is related to the Late Oligocene tectonic uplift which affected northern Belgium (Vandenberghe et al. 1998).

De Meuter & Laga (1976) formally described the Berchem Formation and redefined two of the four members. The formation is described as a fine to medium-grained, slightly clayey and very glauconitic, sandy unit, characterized by the abundant occurrence of shells, often in massive layers, and locally decalcified. The type area of the formation is Antwerp, Berchem and Borgerhout and the type section is the temporary outcrop of the excavations for the E17 motorway around the city of Antwerp (Fig. 2). The lowermost member of the formation, the Edegem Sands, is a clayey, glauconitic, fine-grained sandy unit with locally a basal gravel and reworked septaria from the underlying Boom Formation. The granulometry of the Edegem Sands displays an upwardly coarsening...
trend (Bastin, 1966). This member was first described by Nyst (1861) as “Sables d’Edeghem à *Panopea menardii*” in a now submerged quarry near Wilrijk, and later regarded as the lower unit of the twofold Middle Miocene “Anversien” stage of northern Belgium (de Heinzelin, 1955). The overlying glauconitic, medium- to coarse-grained Kiel Sands contain no calcareous fossils. They were formerly considered as the local decalcified upper part of the Edgem Sands in the southern and central part of Antwerp (Vanden Broeck, 1876). A gravel at the base of the Kiel Sands has been found only in one exposure (Vandenberghhe *et al.* 1998). De Meuter & Laga (1976) nevertheless considered this decalcified unit as a formal member, but remarked that the Kiel Sands become fossiliferous to the north and east of Antwerp where they are indistinguishable from the overlying Antwerpen Sands. The latter member is a slightly clayey, medium fine-grained sandy unit, rich in glauconite and *Glycymeris lunulata baldii* specimens. Levels with phosphate nodules, bones and shark teeth occur. Friable sandstones are found in the base of the unit. Nyst (1845) first observed this member during the excavations for a canal and the fortifications around Antwerp. They were described as “Sable noir du fort d’Herenthals”, later as “Sables à *Pectunculus pilosus*” (= *Glycymeris lunulata baldii*) (Vanden Broeck, 1876) and finally as the “Sables noirs d’Anvers” (de Heinzelin, 1955), the upper unit of the “Anversien” stage. The fourth member, the Zonderschot Sands, is a clayey lateral equivalent of the Antwerpen Sands with a restricted occurrence, southwest of Antwerp. It is not discussed further here. The top of the Berchem Formation is erosional in the Antwerp area and overlain by a thin Quaternary cover or, locally, more to the north by the Pliocene Kattendijk Formation.

Vandenberghhe *et al.* (1998) interpret the three members of the Berchem Formation tentatively as incomplete sequences. The transgressive basal gravel of the Edgem Sands and the upwardly coarsening trend in the grain size are considered indicative of a highstand system tract. The pebble layer at the base of the Kiel Sands, observed only in one exposure, could be indicative of a new sequence. The phosphate nodules and the
authigenic glauconite in the Antwerpen Sands are tentatively linked to a new transgressive phase.

3. Biostratigraphy and radiometric data

Foraminiferal, calcareous nannoplankton and Gadidae otolith biozonations have been established in the Berchem Formation (Fig. 3). Although the Edegem Sands contain a considerable amount of reworked Oligocene foraminifera (Hooyberghs & De Meuter, 1972; Hooyberghs, 1983), the in situ planktonic foraminifera point to a correlation with Biozone N4 of Blow (1969). This indicates an Aquitanian age, although the eponymous species *Globorotalia kugleri* was not found near the type area (Hooyberghs, 1996). The calcareous nannoplankton in the Edegem Sands belong to the Zones NN2 to NN3 (Aquitanian–early Burdigalian) (Martini & Müller, 1973; Verbeek, Steurbaut & Moorkens, 1988). Both the planktonic foraminifera and calcareous nannoplankton point to a late Burdigalian to Langhian age for the Antwerpen Sands (Hooyberghs, 1983; Martini & Müller, 1973; Verbeek, Steurbaut & Moorkens, 1988). Although the diversity and preservation of planktonic foraminifera is poor to moderate, Hooyberghs (1983) remarks that the upper part of the Antwerpen Sands is considerably younger than the lower part, but without indicating a possible hiatus within the unit. Until now, no biostratigraphical data for the decalcified Kiel Sands have been available.

Radiometric analysis with the K–Ar and Rb–Sr methods of glauconite from the Berchem Formation pointed to different glauconization phases (Odin et al. 1974). The K–Ar and Rb–Sr apparent ages from the Edegem Sands lie respectively between 26.6–23.3 and 30–24 Ma. The same method applied to the Kiel Sands gives apparent ages of 25.3–23.0 and 30 Ma. These results would indicate middle Oligocene to Early Miocene ages. Odin & Kreuzer (1988) re-evaluated the data and considered the glauconites from the Edegem Sands and Kiel Sands as reworked. The glauconites from the Antwerpen Sands are thought to be authigenic with apparent ages from 25–20 Ma (K–Ar) and 21.5–18.5 Ma (Rb–Sr).

4. Material and methods

Large outcrops of the Berchem Formation were created during the construction of the E19 motorway around the city of Antwerp. The lithology and position of the temporary outcrops were described by De Meuter, Wouters & Ringele (1976). The samples are stored in the collection of the ‘Historical Geology’ department of the Katholieke Universiteit Leuven, Belgium. Five sections, in which the compiled lithostratigraphical column is considered to be most complete, were chosen for palynological sampling (Figs 2, 4). For the studied sections, the lithostratigraphy of De Meuter, Wouters & Ringele (1976) is used. A total of 44 samples was taken for palynological analysis, and the numbers and codes of the studied samples (Fig. 4) are as given in De Meuter, Wouters & Ringele (1976). The preparation of the sediment followed standard palynological maceration techniques. Fifty grams of

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<td><strong>Biozonation</strong></td>
<td><strong>Member</strong></td>
<td><strong>ICGP 124 Working Group</strong></td>
<td><strong>Doppert et al. (1979) based on De Meuter &amp; Laga (1976)</strong></td>
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<td>N9 - <em>Globorotalia peripheroranda</em> Zone to N6 - <em>Glaberigeninoides</em> trilobus Zone</td>
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<td><strong>Edegem Sands</strong></td>
<td>N4 - <em>Glaberigeninoides</em> primordius Zone</td>
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Figure 3. Foraminiferal, calcareous nannoplankton and Gadidae otolith biozonations of the Berchem Formation.
Figure 4. Stratigraphical correlation of the Edegem, Kiel and Antwerpen Sands members (Berchem Formation). Highest (HO) and lowest (LO) occurrences of selected dinocysts relevant for correlation and biozonation (de Verteuil & Norris, 1996). Lithostratigraphical interpretation of the sections is after De Meuter, Wouters & Ringele (1976). Time scale after Berggren et al. (1995). Q: Quaternary, Bm.: Boom Formation, Kt.: Kattendijk Formation.
dried sediment were decalcified with 10% HCl, followed by digestion for one or two hours in 40% HF at 70°C. The sediment was stirred thoroughly to suspend all fine particles and decanted. This step was repeated several times until all fine particles were recovered. The remaining sand fraction was discarded. A further treatment with 40% HF was applied to dissolve the remaining fine silica fraction, followed by repeated hot baths (70–80°C) of 20% HCl. The samples were rinsed to neutrality between each step. No ultrasonic treatment or heavy liquid separation was applied. All samples were oxidized in 90% HNO₃ for 30 seconds, followed by repeated washing in 10% KOH. The residues were sieved on a nylon screen with 20 µm mesh size, stained with Safranin-O and mounted with glycerine jelly. A total of 250 complete individuals were counted in each sample with 250× magnification. The rest of the slide was scanned for rare or exceptionally well-preserved specimens. Photographs were taken with interference contrast on a NIKON Optiphot microscope.

The dinoflagellate cyst associations recovered are moderately to well preserved, except in the Kiel Sands of the A.G. section (samples A.G. 1 and A.G. 4) where preservation is poor. Reworked dinoflagellate cysts from the underlying Boom Formation (Rupelian) are present in the Edegem Sands (maximum 7% of the number of individuals counted) and to a lesser degree in the Kiel Sands and Antwerpen Sands (maximum 3%).

The biostratigraphical evaluation of dinoflagellate cysts from the Berchem Formation is based on the dinoflagellate cyst biozonation of de Verteuil & Norris (1996) from the Miocene of the Salisbury Embayment, Atlantic Margin, USA. This biozonation was defined in mostly shallow marine environments and indirectly calibrated to the time scale of Berggren et al. (1995). Its calibration is based on records of calcareous nannoplankton and planktonic foraminifera. Furthermore, this biozonation evaluates and incorporates dinocyst data from earlier biozonations from the North Sea Basin and contiguous areas, such as those proposed by Powell (1992), Manum et al. (1989) and Head, Norris & Mudie (1989). However, the biozonation and the stratigraphical distribution of certain key species, given by de Verteuil & Norris (1996), is based on the distribution of the zonal species without reference to a specific stratotype. For clarification, the allostratigraphical units of the Salisbury Embayment are also given together with the distribution of the species (Fig. 5). The nomenclature of the dinoflagellate cysts follows Williams, Lentin & Fensome (1998). The sections are correlated graphically, the correlation being based on the lowest and highest occurrences of key species. The distribution of the dinoflagellate cysts in the Berchem Formation, relevant for the recognition of the biozones, stratigraphical interpretation and correlation is given in Figure 6a,b. These relevant taxa are illustrated in Figures 7 and 8.

5. Results

5a. Edegem Sands

The Edegem Sands in the section A.M. and the lower part of section A.V. (Fig. 4) contain a dinoflagellate cyst association characteristic of the Sumatradinium soucouyantiae Interval Zone DN2 (de Verteuil & Norris, 1996), defined as the interval from the highest occurrence (HO) of Chiropteridium galea to the HO of Exochosphaeridium insigne. The latter species is found throughout the Edegem Sands. Chiropteridium galea is rare in the basal samples of the A.M. section and probably reworked from the underlying Boom Formation together with other rare pre-Neogene species such as Deflandrea phosphoritica phosphoritica, Enneadocysta pectiniformis, Homotryblium pallidum pallidum, Homotryblium tenuspinosum and Wetzeliella spp. Associated characteristic species in the Edegem Sands, with a HO or lowest occurrence (LO) in the DN2 Zone, are Cerebrocysta satchelliae (HO), Cordosphaeridium cantharellus (HO), Operculodinium piaseckii (LO), Operculodinium longispinigerum (LO), Saturnodinium sp. cf. S. perforata sensu de Verteuil & Norris (1996) (LO), Sumatradinium hamulatum (LO) and S. soucouyantiae (LO). Cordosphaeridium cantharellus is restricted to the Edegem Sands. The absence of Caligodinium amicum suggests that the lower part of the DN2 Zone is not represented in the Edegem Sands. The upper boundary of the DN2 Zone is not recognized in the Edegem Sands.

5b. Kiel Sands

The DN2 Zone is recognized in the Kiel Sands of section A.V. and in the lower part of the Kiel Sands in section A.G. (HO of E. insigne in sample A.G. 8). It is noteworthy that Erymnodinium cf. delectabilis and S. cf. perforata disappear before the top of the DN2 Zone (Figs 5, 6b). The whole upper part of the Kiel Sands in section A.G. can be placed within the Cousteaudinium aubryae Interval Zone DN3, which is defined as the interval from the HO of E. insigne to the LO of Labyrinthispinum truncatum. There is a remarkable co-occurrence of E. insigne and Sumatradinium druggii in the upper part of the DN2 Zone of sections A.V. and A.G., a phenomenon also observed in the Kalmthout well north of Antwerp by Louwye & Laga (1998). In the Salisbury Embayment, however, the LO of S. druggii is recorded above the HO of E. insigne, within the DN3 Zone, probably because of a hiatus between allostratigraphical units SE1 and SE2 in that area (Fig. 5). The overlap between both ranges in the Kiel Sands is thus not incompatible with the situation in the Salisbury Embayment.
Figure 5. For legend see facing page.
5c. Antwerpen Sands

According to De Meuter, Wouters & Ringele (1976), the Antwerpen Sands are recognized in the upper part of section A.G. and in sections A.K. and B.R. The presence of *E. insignis* and *S. druggii* and the absence of *C. cantharellus*, *E. cf. delectabilis* and *S. sp. cf. S. perforatum* in the basal part of section A.K. indicate the presence of the upper part of Zone DN2 in the Antwerpen Sands (Fig. 4). Zone DN3 is entirely missing in the Antwerpen Sands. The *Distatodinium paradoxum* Interval Zone DN4, defined as the interval from the LO of *L. truncatum* to the HO of *D. paradoxum*, is recognized in the Antwerpen Sands of the A.G. section and the upper and lower part of the Antwerpen Sands in the A.K. and B.R. sections, respectively. *Labyrinthodinium truncatum* subsp. *modicum* pre-dates the autonym in the A.K. and B.R. sections, a feature also observed in some sections of the Salisbury Embayment (de Verteuil & Norris, 1996). A hiatus at the base of the Antwerpen Sands in the A.G. section can be inferred from the simultaneous LO of both latter subspecies. This also indicates that the DN3 Zone in the underlying Kiel Sands might not be fully present. The abrupt disappearance of *Apteodinium spiridoides* in the Antwerpen Sands can probably be used to subdivide the DN4 Zone. The *Batiacasphaera sphaericus* Interval Zone DN5, defined as the interval from the HO of *D. paradoxum* to the HO of *Systematophora placacantha*, is only encountered in the Antwerpen Sands of the B.R. section. Remarkable are the LOs of *Unipontedinium aquaeductum* and *Habibacysta tectata* in the DN4 Zone of the B.R. section, that is, below the HO of *D. paradoxum*. According to de Verteuil & Norris (1996), both species have their LO within the DN5 Zone. However, according to Williams et al. (1998), the first appearance data of *U. aquaeductum* at 14.93 Ma and *H. tectata* at 14.27 Ma (a low latitude record from the western North Atlantic) pre-date the last appearance datum of *D. paradoxum* at 13.60 Ma (record from northwestern Europe). Poulsen et al. (1996) give another record from a LO of *U. aquaeductum* below the HO of *D. paradoxum* from a Langhian–Serravallian interval in the Norwegian–Greenland Sea. A single well-preserved specimen of *Camposphaeropsis passio* was encountered in the upper part of the Antwerpen Sands in the B.R. section. The range of this species defines the upper Serravallian *Camposphaeropsis passio* Zone DN7 in the Salisbury Embayment (East coast USA). The LO of the latter species is stratigraphically distinct above the HO of *U. aquaeductum*, located at the upper boundary of the DN5 Zone (de Verteuil & Norris, 1996). Lund, Lund-Christensen & Strauss (1993) found *C. passio* (as *Camposphaeropsis utinensis*) restricted to the upper Langenfeldian (upper Middle Miocene) of the Nieder Ochtenhausen well, northwest Germany, also with its LO above the HO of *U. aquaeductum*. The co-occurrence of *U. aquaeductum* and *C. passio* in our material is therefore noteworthy. The stratigraphically restricted occurrence of this species with an oceanic preference (Lund, Lund-Christensen & Strauss, 1993) in the above mentioned areas might be environmentally controlled and for this reason the top of the Antwerpen Sands in the B.R. section is only tentatively assigned to DN6–DN7 Zone (the *Selenopemphix donacaeacysta* Interval Zone DN6 is defined as the interval from the HO of *S. placacantha* to the LO of *C. passio*). *Apteodinium tectatum* and *C. aubryae* apparently also range into the upper Middle Miocene deposits of the southern North Sea Basin. Williams et al. (1998) set the last appearance datum of *C. aubryae* at 11.80 Ma and of *Apteodinium spp.* at 11.55 Ma, well above the last appearance datum of *U. aquaeductum* at 12.16 Ma.

6. Age

The Edegem Sands were deposited during late or latest Aquitanian to early Burdigalian times. However, the LO of the key species *E. insignis* is difficult to assess and, until more data become available, renders a precise estimation of the start of the deposition of the Edegem Sands hypothetical (Fig. 5). The Kiel Sands have a slightly younger age and were deposited sometime in an interval of the Burdigalian age, inferred from the presence of the upper part of the DN2 Zone and the DN3 Zone.

A hiatus of about 2.2 Ma in the basal part of the A.K. section is deduced from the absence of the DN3 Zone (see preceding Section). If the lithostratigraphical interpretation of the basal part of the A.K. section as Antwerpen Sands by De Meuter, Wouters & Ringele (1976) is correct, then a hiatus within the Antwerpen Sands spanning the upper Burdigalian to lowermost Langhian can be postulated. The greater part of the Antwerpen Sands in the study area was deposited in an interval from the Langhian (possibly latest Burdigalian) to the middle Serravallian. Louwye, De Coninck & Verniers (1999) also recognized the DN5 Zone in the top of the Berchem Formation (Antwerpen Sands) of the Oostmalle and Poederlee wells (Fig. 1) and inferred a late Langhian–middle Serravallian age. Louwye & Laga (1998) proposed a late

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**Figure 5.** Stratigraphical interpretation of the Edegem, Kiel and Antwerpen Sands members (Berchem Formation). Distribution of key species of the biozonation of de Verteuil & Norris (1996) in the allostratigraphical units of the Salisbury Embayment are given together with the distribution of selected species in the Berchem Formation. Time scale after Berggren et al. (1995).
Aquitanian–early Burdigalian age for the Berchem Formation in the Kalmthout well (Fig. 1). However, it has to be stressed that the uppermost six metres of the Berchem Formation, probably Antwerpen Sands, in the Kalmthout well contain no calcareous or organic-walled fossils, and a younger age for this barren section is most probable.

The tentative recognition of the DN6/7 Zone in the upper part of the Antwerpen Sands in the study area might indicate deposition during slightly later Serravallian times. If this is corroborated by further studies, then the youngest deposits of the Antwerpen Sands with a late Serravallian age are found in the type area.

7. Discussion and conclusions

No hiatus between the Edegem Sands and the decalcified Kiel Sands can be inferred from the dinocyst record. The gravel at the base of the Kiel Sands, observed in one outcrop by Vandenberghe et al. (1998), is probably indicative of a break in sedimentation that is not resolvable with the dinocyst zonation used here for the Lower Miocene. A correlation of the base of the Edegem Sands with sequence boundary Aq3/Bur1 at 20.52 Ma (Hardenbol et al. 1998) is proposed. Vandenberghe et al. (1998) advance a correlation with sequence boundary 21 (Haq, Hardenbol & Vail, 1987) and interpret the Edegem Sands as a
Figure 7. Dinoflagellate cysts of the Berchem Formation. Photographs are all interference contrast images. (a) *Apteodinium tec-
tatum* Piaseckii. High focus, ventral view of hypocyst, max. width = 85 µm. Sample B.R.19/1, Q49/1. (b) *Apteodinium spirido-
oides* Benedek. High focus, archeopyle and wall ornamentation, max. length archeopyle = 30 µm. Sample A.V. 65/1, N30/3.
highstand system tract. This interpretation is underscored by the upwardly coarsening trend in the grain size (Bastin, 1966). The pebble layer at the base of the Edegem Sands and the presence of reworked dinoflagellate cysts from the underlying Lower Oligocene Boom Clay indicate the transgressive character of at least, the base of this unit.

The unconformity, marked by a sandstone layer, between the Kiel Sands and the Antwerpen Sands in the A.G. section reflects a hiatus inferred from the absence of both the upper part of the DN3 Zone and the lower part of the DN4 Zone. The sandstone layer and the hiatus are indicative of a new sequence. The considerable authigenic glauconite fraction and hardgrounds in the Antwerpen Sands are considered to be associated with a transgressive surface (Sturrock, 1996). Phosphate nodules have been encountered at the base of the Antwerpen Sands (Vandenbergh et al. 1998) and occur within the sequence (De Meuter & Laga, 1976). The Antwerpen Sands have a transgressive character and the lower boundary of the member coincides with sequence boundary Bur5/Lan1 (Hardenbol et al. 1998).

Parts of the Kiel Sands in the A.G. and A.V. sections and the sediments below the hiatus in the A.K. section, interpreted as Antwerpen Sands by De Meuter, Wouters & Ringele (1976), belong to the DN2 Zone and can be regarded as age-equivalents. Apparently, the sedimentary difference between both correlated sections lies only in a different glauconite content and the presence or absence of calcareous fossils, that is, the spatial distribution of the decalcification front. De Meuter, Wouters & Ringele (1976) describe this part of the Antwerpen Sands in the A.K. section as a “dark green medium fine-grained very glauconitic sand, slightly clayey with variable shell layers of the index fossil Glycymeris lunulata baldii”, while they describe the correlative part of the Kiel Sands in the A.G. and A.V. sections as a “grey-green medium fine- to coarse-grained glauconitic sand, very slightly clayey and nearly unfossiliferous”. However, they mention the presence of rare, vague shell ghosts and rare, friable shell fragments preserved in clay streaks or sandstones in the Kiel Sands.

Preservation and diversity of the dinoflagellate cyst assemblages in the lowermost part of the Kiel Sands of the A.G. section (samples A.G.1 and A.G.4) are poor and probably caused by mild post-depositional oxidizing conditions. Notwithstanding the limited number of sections examined, these findings give a first indication that the decalcification is a phenomenon with restricted spatial extent, and which only affected the southern part of the study area in the vicinity of the A.V. and A.G. sections. This underscores the necessity for a re-evaluation and redefinition of the Berchem Formation, especially of the Kiel and Antwerpen Sands, when new outcrops become available.

The dinoflagellate cyst assemblages of the Berchem Formation confirm deposition in a shallow marine environment, as already demonstrated by Doppert, Laga & De Meuter (1979) using the benthic foraminifera. Representatives of the marginal marine–inner neritic taxa Apteodinium spp., Dapsillidinium spp., Lingulodinium spp., Polysphaeridium spp., Systematophora spp. and Tuberculodinium vancampoae (Zevenboom, Brinkhuis & Visscher, 1994) are prominent in the three members studied. However, Polysphaeridium zoharyi, a species with a lagoonal–estuarine preference is encountered more frequently in the Antwerpen Sands. Representatives of the oceanic taxa Impagidinium and Nematopsphaeropsis are encountered sporadically and in low numbers in the Antwerpen Sands. This suggests incursions of oceanic waters, possibly during periods of higher sea level, in the confined shallow depositional area of the southern North Sea Basin.

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(c) Distotadinium paradoxum (Brosius). Optical section, length central body = 68 µm. Sample A.V. 65/1, R.54/1. (d) Cousteaudinium aubrae de Verteuil & Norris. High focus on archeopyle and operculum, max. width pericyst = 104 µm. Sample A.K. 79/1, Z57/2. (e, f) Cannosphaeropsis passio de Verteuil & Norris. (e) Optical section, central body and trabeculae, max. diameter central body = 44 µm. (f) High focus, trabeculae. Sample B.R. 19/1, J35/1. (g-i) Elytrocyta cf. detectabile (de Verteuil & Norris). (g) Optical section, reticulum of epi- and hypocyst, total width = 102 µm, total length = 100 µm. (h) Low focus, hypocyst with incomplete sutural crests. (i) High focus, archeopyle, reticulum and incomplete sutural crests. Sample A.V. 36/1, P29/1. (j, k) Habibacyta testata Head et al. (j) High focus on archeopyle, length archeopyle = 20 µm. (k) Optical section, central body diameter = 40 µm. Sample B.R. 19/1, S29/3. (l) Batiacasphaera sphaerica Stover. High focus on archeopyle, diameter = 38 µm. Sample A.M. 54/1, H34/4. (m, n) Operculodinium piasectii Strauss & Lund. (m) Optical section, outline and processes, length central body = 34 µm, length processes = 2–4 µm. (n) High focus on wall ornamentation. Sample B.R. 6/1, N53/2.
Figure 8. Dinoflagellate cysts of the Berchem Formation. Photographs are all interference contrast images. (a, b) Sumatradinium hamulatum de Verteuil & Norris. (a) Low focus on archeopyle margin and hypocyst, width = 84 µm, height ornamentation = 1–2 µm. (b) High focus on cingulum and hypocyst (dorsal). Sample B.R. 9/2, F35/3. (c) Exochosphaeridium insigne de
References


HOOYBERGHS, H. 1996. The stratigraphical position of the Edegem Sands (Berchem Formation, Miocene) in its type area at Wilrijk (N Belgium), based on planktonic foraminifera. Geologie en Mijnbouw 75, 33–42.

HOOYBERGHS, H. & DE MEUTER, F. 1972. Biostratigraphy and interregional correlation of the Miocene deposits of Northern Belgium based on planktonic foraminifera; the Oligocene–Miocene boundary on the southern edge of the North Sea Basin. Mededelingen van de Koninklijke Academie voor Wetenschappen, Letteren en Schone Kunsten van België, Klasse der Wetenschappen 34(3), 1–47.


