New calcareous nannofossil taxa from the Ypresian (Early Eocene) of the North Sea Basin and the Turan Platform in West Kazakhstan

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STEURBAUT, E., 2011 – New calcareous nannofossil taxa from the Ypresian (Early Eocene) of the North Sea Basin and the Turan Platform in West Kazakhstan. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **81**: 247-277, 2 pls, 26 figs, Brussels, November 30, 2011 – ISSN 0374-6291.

Abstract

Twelve taxa, identified in Lower Eocene outcrop and borehole successions of the North Sea Basin and at Aktulagay in western Kazakhstan, are described here for the first time: *Zygrhablithus bijugatus galeiformis* subsp. nov., *Ellipsolithus irregulariporus* sp. nov., *Ellipsolithus heilmannclausenii* sp. nov., *Pontosphaera megapachydisca* sp. nov., *Dictyococcites chriskingii* sp. nov., *Toweius brusselensis* sp. nov., *Blackites aktulagayensis* sp. nov., *Blackites rugosus* sp. nov., *Blackites thiedei* sp. nov., *Chiphragmalithus vandenberghei* sp. nov., *Lophodolithus mytiliformis* sp. nov. and *Nannoturba jolotteana* sp. nov. In addition, one new taxonomic combination is proposed: *Blackites dupuisii* (STEURBAUT, 1991) new. com. Most of the new species have short stratigraphic ranges and, consequently, have great potential for high-resolution biostratigraphy and for refined dating of sedimentary sequences from middle to high latitudes of the northern hemisphere.

Keywords: Calcareous nannofossils, new taxa, Early Eocene, North Sea Basin, Kazakhstan.

Résumé

Douze taxons, identifiés dans des affleurements et forages d'âge éocène inférieur du Bassin de la Mer du Nord et en Aktulagay dans l'ouest de Kazakhstan, sont nouvellement décrits ici : *Zygrhablithus bijugatus galeiformis* subsp. nov., *Ellipsolithus irregulariporus* sp. nov., *Ellipsolithus heilmannclausenii* sp. nov., *Pontosphaera megapachydisca* sp. nov., *Dictyococcites chriskingii* sp. nov., *Toweius brusselensis* sp. nov., *Blackites aktulagayensis* sp. nov., *Blackites rugosus* sp. nov., *Blackites thiedei* sp. nov., *Chiphragmalithus vandenberghei* sp. nov., *Lophodolithus mytiliformis* sp. nov. et *Nannoturba jolotteana* sp. nov. En plus, une nouvelle combinaison taxinomique est proposée : *Blackites dupuisii* (STEURBAUT, 1991) nov. com. La plupart de ces espèces nouvelles ont une courte extension stratigraphique, et, en conséquence, ont un grand potentiel pour la biostratigraphie à haute résolution et pour la datation fine de séquences sédimentaires des latitudes moyennes et hautes du hémisphère nord.

Mots-clefs: Nannofossiles calcaires, nouveaux taxons, Eocène inférieur, Bassin de la Mer du Nord, Kazakhstan.

Introduction

During the high sea-levels of the Ypresian, the highest of the Cenozoic era (MILLER *et al.*, 2005; KOMINZ *et al.*, 2008), large parts of western Eurasia were flooded by 3 major water masses, respectively from north to south the Arctic, the Atlantic and the Tethyan oceans, which were permanently interconnected through epicontinental seas and narrow seaways (Fig. 1, essentially after AKHMET'EV & BENIAMOVSKI, 2006). In the North Sea Basin, a N-S oriented trough-shaped intracontinental basin, connected to the Northeast Atlantic, siliciclastic sedimentation persisted throughout the Ypresian, grading from shallow marine sands and silts fringing the emerged landmasses in the south and southwest to outer neritic and bathyal clays in its centre, including the Danish area (KING, 2006; STEURBAUT, 2006) (Fig. 2). On the relatively stable Turan platform, in present day Kazakhstan (THOMAS *et al.*, 1999), sedimentation conditions alternated from inner neritic to outer neritic during the Ypresian, probably as the result of sea-level fluctuations (KING *et al.*, in prep.).

The stratigraphy of the Ypresian of Belgium has been unraveled in the 1990's through a combined lithological and calcareous nannofossil investigation of a wide gamut of outcrop and borehole successions throughout the basin (STEURBAUT, 1991, 1998, synthesized and updated in STEURBAUT, 2006). MARTINI's (1971) standard calcareous nannofossil zones NP11, NP12, NP13 and NP14 were recognized and zones NP11 and NP12 furthermore subdivided into respectively 6 and 11 nannofossil units or subzones (STEURBAUT, 1998).

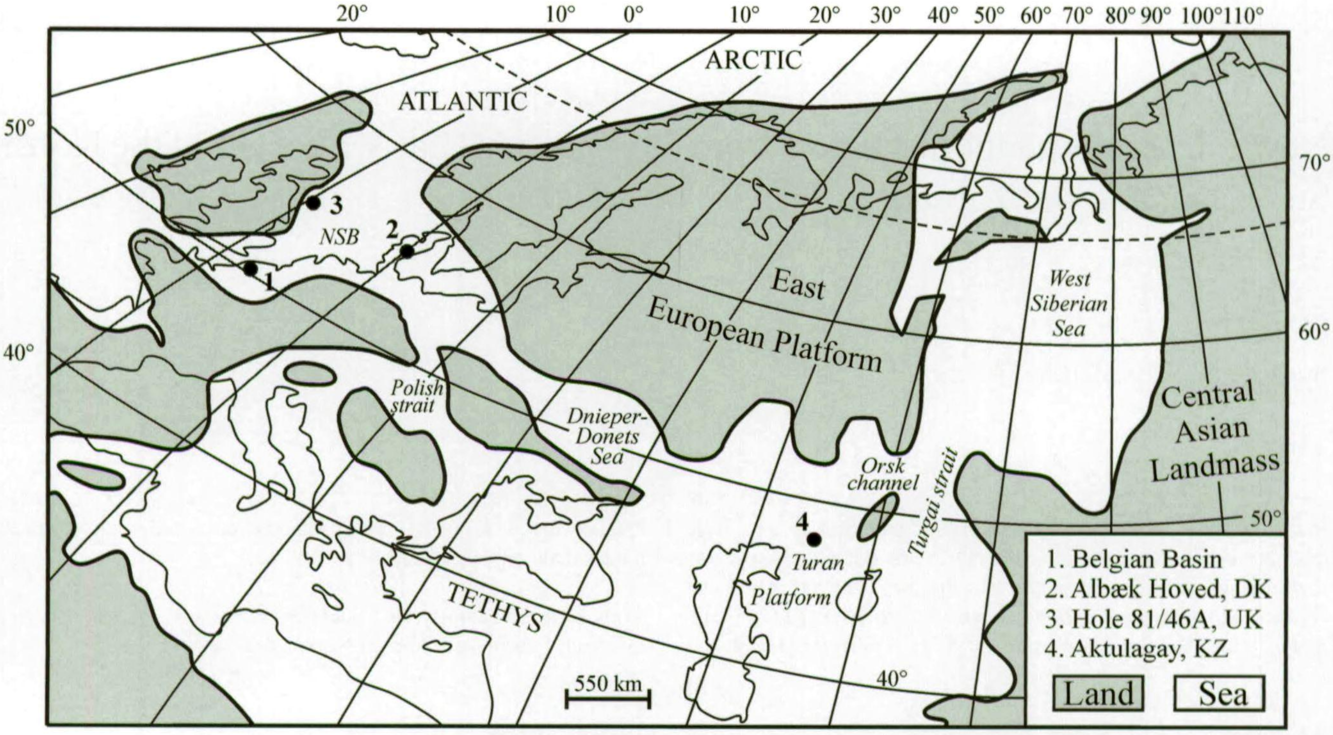


Fig. 1 – Palaeogeography of West-Eurasia during the Early Ypresian showing the locations of the studied areas and sections. Compilation of data from AKHMET'EV & BENIAMOVSKI (2006) for the republics of the Russian Federation and from MEULEKAMP *et al.* (2000) for West-Europe.

Some regional nannofossil markers were recorded in zone NP13 of the Knokke borehole (STEURBAUT, 1990) and in the interval NP13-NP14 of the Aalter Sand stratotype section (STEURBAUT & NOLF, 1989).

The high-resolution nannofossil zonation of STEURBAUT (1998), essentially established in the shallow marine sequences of Belgium, has been recognized in the bathyal clays of the Røsnæs Clay and Lillebælt Clay Formations at Albæk Hoved, Denmark (STEURBAUT in SCHMITZ *et al.,* 1996) and in outer neritic clays (Unit 3 of LOTT *et al.,* 1983) penetrated in borehole 81/46A 100 km off the Yorkshire Coast (unpublished; locations in Fig. 1). An almost identical nannofossil succession, at least within zones NP 11 and NP 12, has recently been recognized in the Aktulagay section in western Kazakhstan, as well as several additional events within the Upper Ypresian zones NP13 and NP 14a (KING *et al.*, in prep.; zones as defined in BERGGREN *et al.*, 1995). This Upper Ypresian sequence of nanno-events has not been recorded as such in the different subbasins of the North Sea Basin, because of anoxia and/or dissolution (essentially in Denmark), non-deposition (essentially in the Paris Basin), or episodes of marginal marine facies development (essentially in the Belgian Basin and the Hampshire Basin), or by a combination of these. The Upper Ypresian nannofossil associations in these subbasins show a fairly high degree of selective dissolution and are sometimes too marginal marine to hold the complete sequence of events as identified at Aktulagay, creating the false image of diachronous appearances between the North Sea Basin and Kazakhstan.

The present paper deals with the description of new Ypresian nannofossil species identified in a series of borehole and outcrop sections in the North Sea Basin and at Aktulagay (Figs 1-2). A short overview of each of the studied areas or sections is given below. For additional stratigraphical details the reader is referred to the initial descriptions in previous papers.

The Ypresian Stage

Over the last decades, as a result of the introduction of new GSSP's for the base of the successive Eocene Stages, the ages of the different stage boundaries underwent substantial shifts. Consequently, the GSSP-defined Standard Global Ypresian Stage fundamentally differs from the historical Ypresian stage concept or Ypresian Synthem, fully documented by STEURBAUT (2006). This concept, which clearly evolved in the course of the 19th and 20th century, was introduced by A. DUMONT in 1849 (minutes of the meeting published in 1850) to specify marine clays and overlying glauconitic

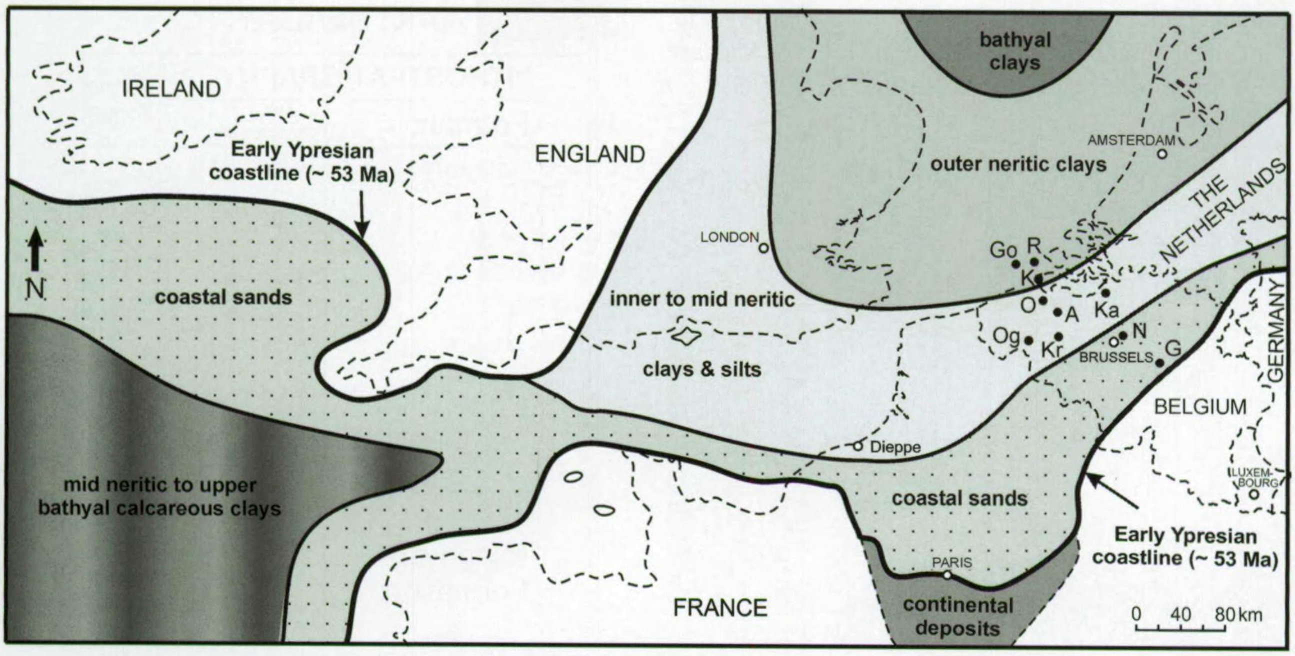


Fig. 2 – Early Ypresian palaeogeography and lithofacies distribution in the southern North Sea Basin at c. 53 Ma (compilation from KING, 2006 and STEURBAUT, 2006), with location of the different outcrop (Ou) and borehole (BH) sections studied. A = Aalter Ou, Go = Goote Bank II BH, G = Gobertange Ou, Ka = Kallo BH, K = Knokke BH, Kr = Kruishoutem BH, N = Nederokkerzeel Ou, O = Oedelem BH, Og = Ooigem BH and R = Vlakte van de Raan BH.

sands occurring in the Ieper area (W Belgium), although without mentioning stratotype or type locality. The GSSP for the base of the Ypresian, ratified by the International Union of Geological Sciences (IUGS) on August 2004, is located at 1.58 m above the base of Section DBH in the Dababiya Quarry, on the east bank of the Nile River, about 35 km south of Luxor, Egypt (AUBRY *et al*., 2007).

The base of the Lutetian and consequently, the top of the Ypresian, has in the past been defined at the first appearance datum (FAD) of the planktonic foraminiferid genus *Hantkenina* at c. 48.6 Ma (e.g. LUTERBACHER *et al*., 2004), corresponding approximately to the base of NP14. However, recent studies have shown this foraminiferid-event to be significantly diachronous (BERGGREN & PEARSON, 2005), which in turn initiated the search for valuable alternatives. The Gorrondatxe section (NW Spain) was recently proposed as a candidate stratotype for the Ypresian/Lutetian boundary (ORUE-EXTEBARRIA *et al*., 2006). This GSSP, based on the lowest occurrence (= LO) of *Blackites inflatus* (base of NP14b) as primary boundary criterion, was approved by the International Commission on Stratigraphy in early 2011, and finally ratified by the International Union of Geological Sciences in April 2011 (MOLINA *et al.,* 2011). Through adopting these new boundary definitions, the Ypresian Stage, representing the lowermost Eocene Standard Stage, ranges from 55.8 (± 0.2) to 47.8 (± 0.2) Ma (MOLINA *et al*., 2011). It also means that, in Belgium, the Tienen Formation, the Ieper Group, the totality of the Aalter Sand Formation and the main part of the Brussel Sand Formation (in ascending order), have to be included in the Ypresian. Up to now the Ypresian/Lutetian boundary was believed to fall within the Aalter Sand Formation, using the LO of *Discoaster sublodoensis* as boundary criterion (STEURBAUT, 2006). The same conclusion has to be drawn about the lowermost three formations identified in the Aktulagay section, in ascending order, the redefined or newly defined Alashen, Aktulagay and Tolagaysor Formations, which, in light of the new GSSP, all belong to the Ypresian.

Material

The new nannofossil taxa figuring in the present paper have been recorded from the following sections, listed in alphabetical order:

Aktulagay, western Kazakhstan

The Aktulagay section was sampled and logged by C. King and D. Ward in 2000, supplemented by more detailed studies of parts of the section during their later visits in 2001 and 2003. The main section is a steep slope in a small valley on the western flank of the

Aktulagay hills (47°32'31.47" N, 55°09'13.75" E) (Fig. 3), at approximately 150 km NE of the town of Kulsary and 35 km north of the Embi [Emba] River (KING *et al.*, in prep, for more details).

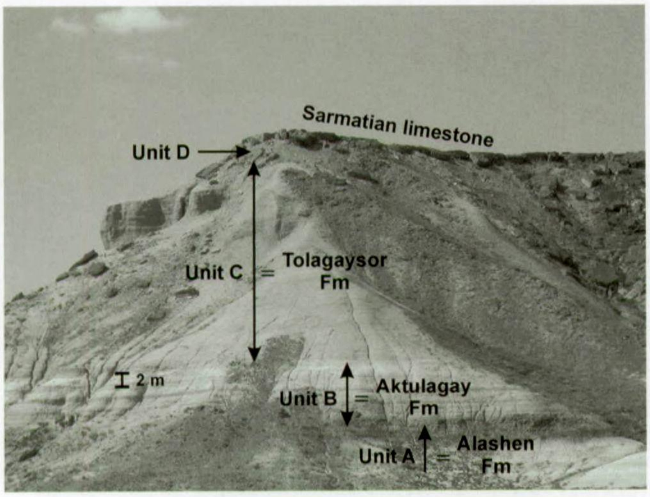


Fig. 3 – The Aktulagay section in western Kazakhstan, with location of the different units studied (by courtesy of C. King).

The Ypresian at Aktulagay consists of approximately 56.09 m of fine-grained sediments, essentially clays, marly clays and silts. According to KING *et al.* (in prep.), it is subdivided into three formations, a lower 13.37 m thick essentially marly Unit A, attributed to the Alashen Formation, a middle 10.12 m thick essentially clayey Unit B, newly defined as Aktulagay Formation, and an upper 32.60 m thick essentially silty Unit C, named Tolagaysor Formation. This newly proposed subdivision of the Ypresian is adopted here. It differs from its original subdivision into Alashen and Tolagaysor Fms by BENYAMOSKIY *et al.* (1990). A simplified stratigraphical interpretation, with location of samples yielding the material discussed here, is given in Fig. 4.

Albæk Hoved, Denmark

The Albæk Hoved section was initially described by HEILMANN-CLAUSEN *et al.* in 1985 (fig. 12), and subsequently detailed and illustrated by this author in 1990, when detailing the stratigraphy of the bathyal Røsnæs Clay and Lillebælt Clay Formations in Denmark. At Albæk Hoved (name refers to a small promontory on the coastline), both formations are outcropping in low cliffs, along the shore on the north side of the Vejle Fjord, at 1.4 km south of the hamlet of Klakring (55°41'44" N, 9°58'06" E). The 20.20 m thick Røsnæs Clay Formation consists of a lower 15

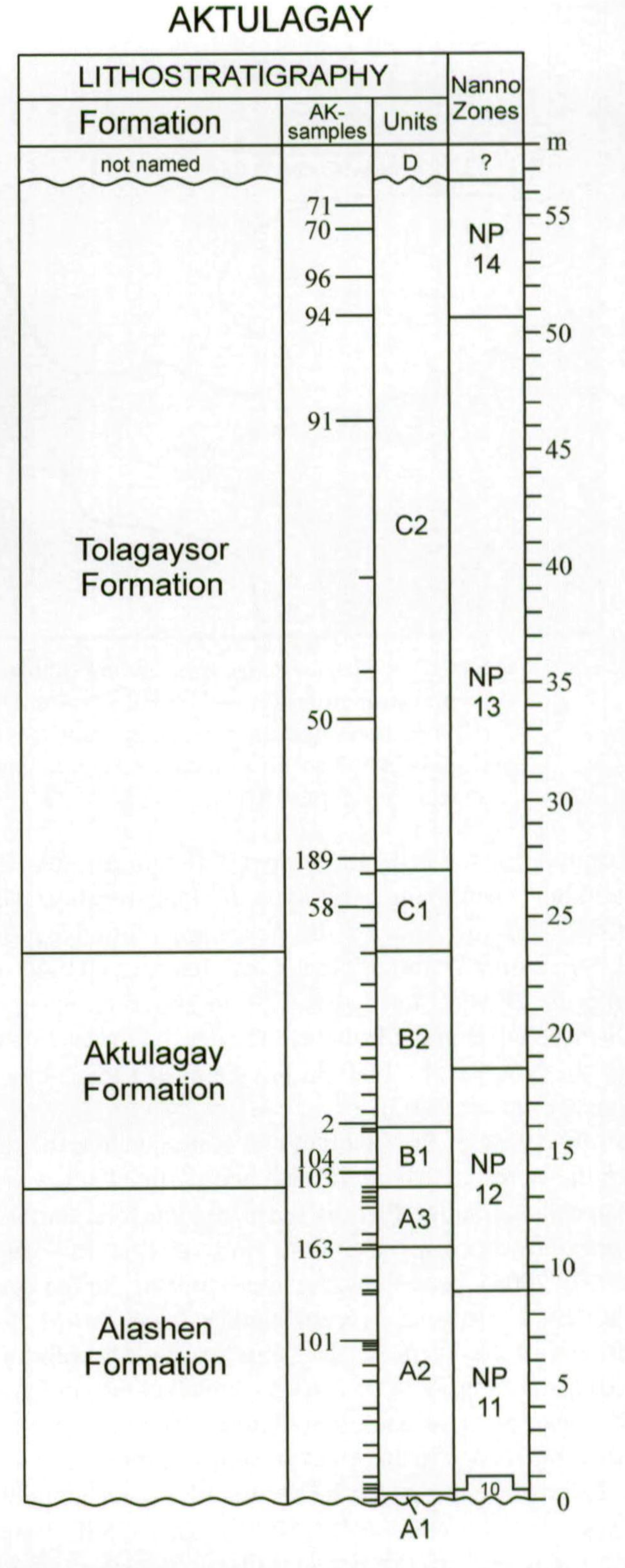


Fig. 4 – Lithostratigraphy of the Lower Eocene at Aktulagay, western Kazakhstan, with indication of MARTINI's (1971) NP calcareous nannofossil zones and location of the samples (dashes = studied by KING et al., in prep.; numbers = these mentioned in the present paper).

m thick essentially red-brown to pale red calcareous clay with 17 distinct ash beds (V1 to V17) and an upper ca 5 m thick whitish to pale greenish calcareous clay passing upwards in grey-green and light gray calcareous clays (Fig. 5). This upper unit, named R6, yields 2 ash layers. Several thin intervals, especially in the lower 11 m of this formation, are slightly to severely decalcified. SCHMITZ *et al.* (1996) performed high-resolution stable isotope analyses on bulk samples, the planktonic foraminiferid *Subbotina* spp. and the benthic foraminiferid *Cibicidoides ungerianus,* as well as multidisciplinary micropaleontological investigations, on the Albæk Hoved section. Sedimentation rates of 3 cm/k.y. on average were calculated for the upper Røsnæs Clay at Albæk Hoved, based on a cross-correlation of the calcareous nannofossil events, the geomagnetic polarity reversals and the geological time scale (STEURBAUT, 1998, fig. 11). In the coeval coastal Egem Sand Member in Belgium these rates appeared to be 13 times higher (41 cm/k.y.), whereas the duration of deposition of the totality of this member was estimated at ca 150 k.y.

Borehole 81/46A, 100 km E of the Yorkshire Coast, UK

This borehole (54° 59.99′ N, 00° 32.28′ E) was drilled by the British Geological Survey (BGS) in the early 1980s up to a depth of 151.80 m, including 12.64 m of Upper Cretaceous chalk, 113.96 m of Upper Paleocene to Middle Eocene mudstone and clay, overlain by a 25.20 m thick Quaternary mixed sand-clay cover (LOTT *et al.*, 1983). The Paleogene succession is subdivided into 4 units, of which only Unit 3, ranging from 101.32 m to ~52 m, consists of mainly calcareous sediments. Calcareous microfaunas, essentially foraminiferids and ostracods have been recorded from 97 m up to 56 m depth (KING, pers. com.), whereas, unexpectedly, the calcareous nannofossils had a much shorter range from 96.22 m to 68.21 m (Fig. 6). The nannofossil associations are generally well preserved throughout this almost 30 m thick succession, except for some thin intervals around 92 m, 90.50 m, 75 m and 70 m, presenting substantial dissolution. No samples were recovered between 89.49 m and 86.85 m because of core loss. MARTINI's (1971) standard zones NP11, NP 12 and the base of NP 13 have been identified, as well as

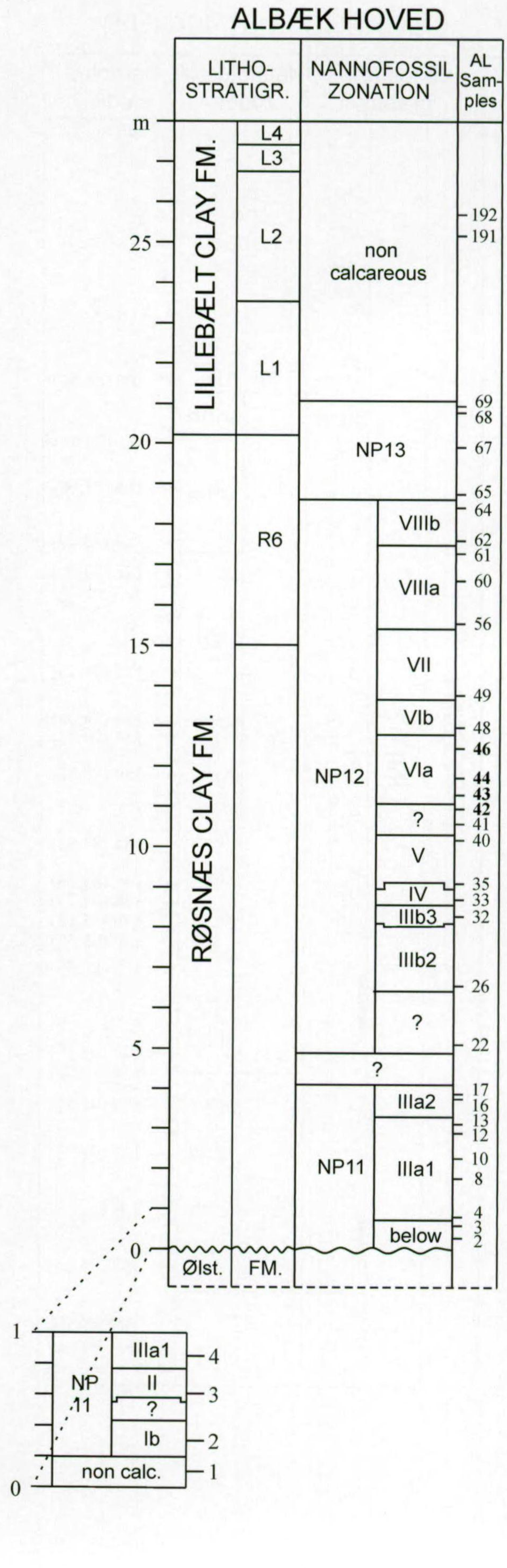


Fig. 5 – Lithostratigraphy of the Lower Eocene at Albæk Hoved, Denmark, with indication of MARTINI's NP and STEURBAUT's (1998) calcareous nannofossil zones and location of the samples studied (these in bold are mentioned in the present paper).

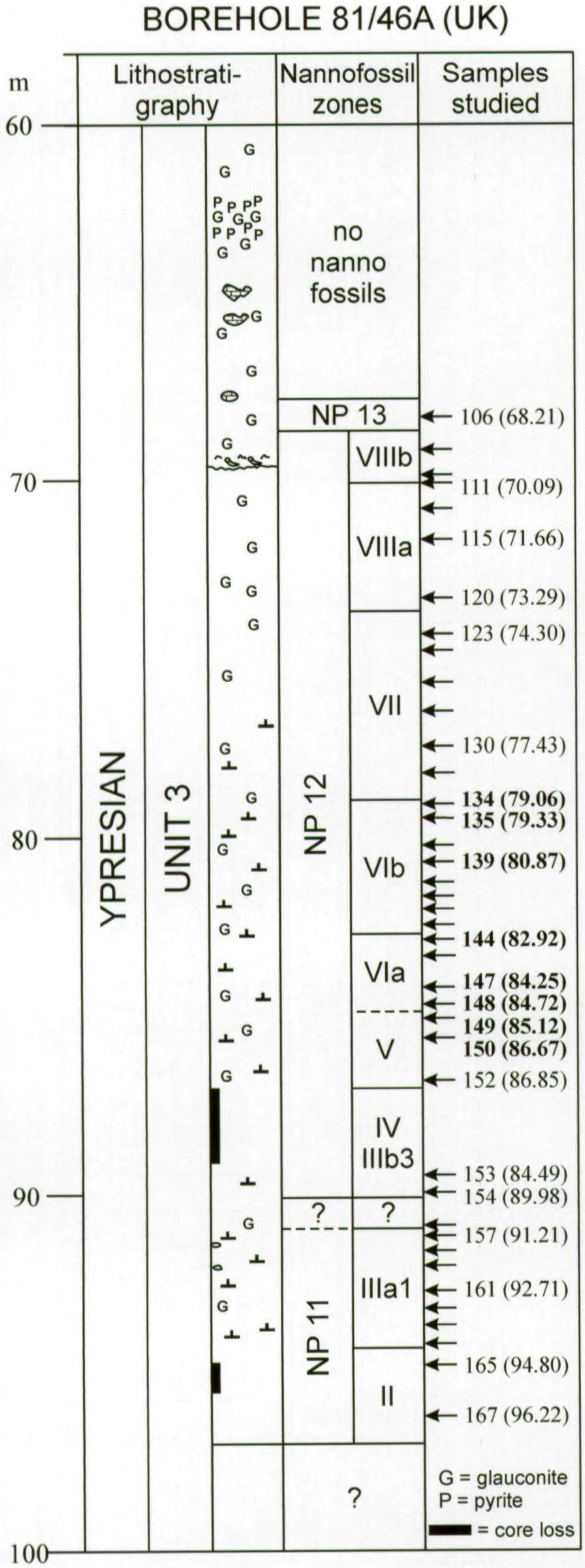


Fig. 6 – Lithostratigraphy of the Lower Eocene in BGS Borehole 81/46A off the Yorkshire Coast, with indication of MARTINI's (1971) NP and STEURBAUT's (1998) calcareous nannofossil zones, and location of the samples (arrows = studied by Steurbaut, but not published; bold = these mentioned in the present paper).

most of STEURBAUT's subdivisions (Fig. 6). However, several of the subdivisions of IIIa (a2, a3 and a4) and IIIb (b1 and b2) could not be specified because of a too strong dissolution, having led to the disappearance of many of the diagnostic taxa.

Belgian Basin

The stratigraphy of the Ypresian of Belgium is summarized in Figs 7 and 8. For details on the Middle and Upper Eocene stratigraphy the reader is referred to STEURBAUT (2006, fig. 4). Sections are discussed in alphabetical order.

Aalter, type locality of the Aalter Sand Formation, map 21/3-4, 2 major outcrops at Molenstraat: x = 85.900, y = 197.820 and Weibroekdreef: x = 86.150, y = 198.200 (Lambert coordinates of the Topographic maps of Belgium). STEURBAUT & NOLF (1989) described a 13 m thick succession, including 12 distinct beds, from the type locality, and assigned it to the top of NP13 and the lower part of NP 14. The specimen figured here comes from bed 2 (upper NP 13) recorded at +16.70 m in the Weibroekdreef outcrop.

Gobertange, type locality of the "Calcaires et sables de Gobertange", map 40/3-4, x = 183.525, y = 158.175. STEURBAUT (in DAMBLON & STEURBAUT, 2000) logged and sampled the Hussompont section at Gobertange in 1999. A 12.50 m thick alternation of calcareous silts and limestones, coarsening to fine glauconitic sand in the lowermost 3 m, were recorded. It was attributed to Martini's nannofossil zone NP14.

Goote Bank II, offshore borehole BGD 999A/0013; 51°27'15" N, 02°51'29" E. This hole was drilled in 1988 up to a depth of 80 m, penetrating 4.70 m of Quaternary deposits and 75.30 m Eocene clays, sand and silts. The upper part of the Eocene section (~5 to 24 m), which yields material discussed in the present paper, appears to belong to the Gentbrugge Formation (lower part of the upper Ypresian).

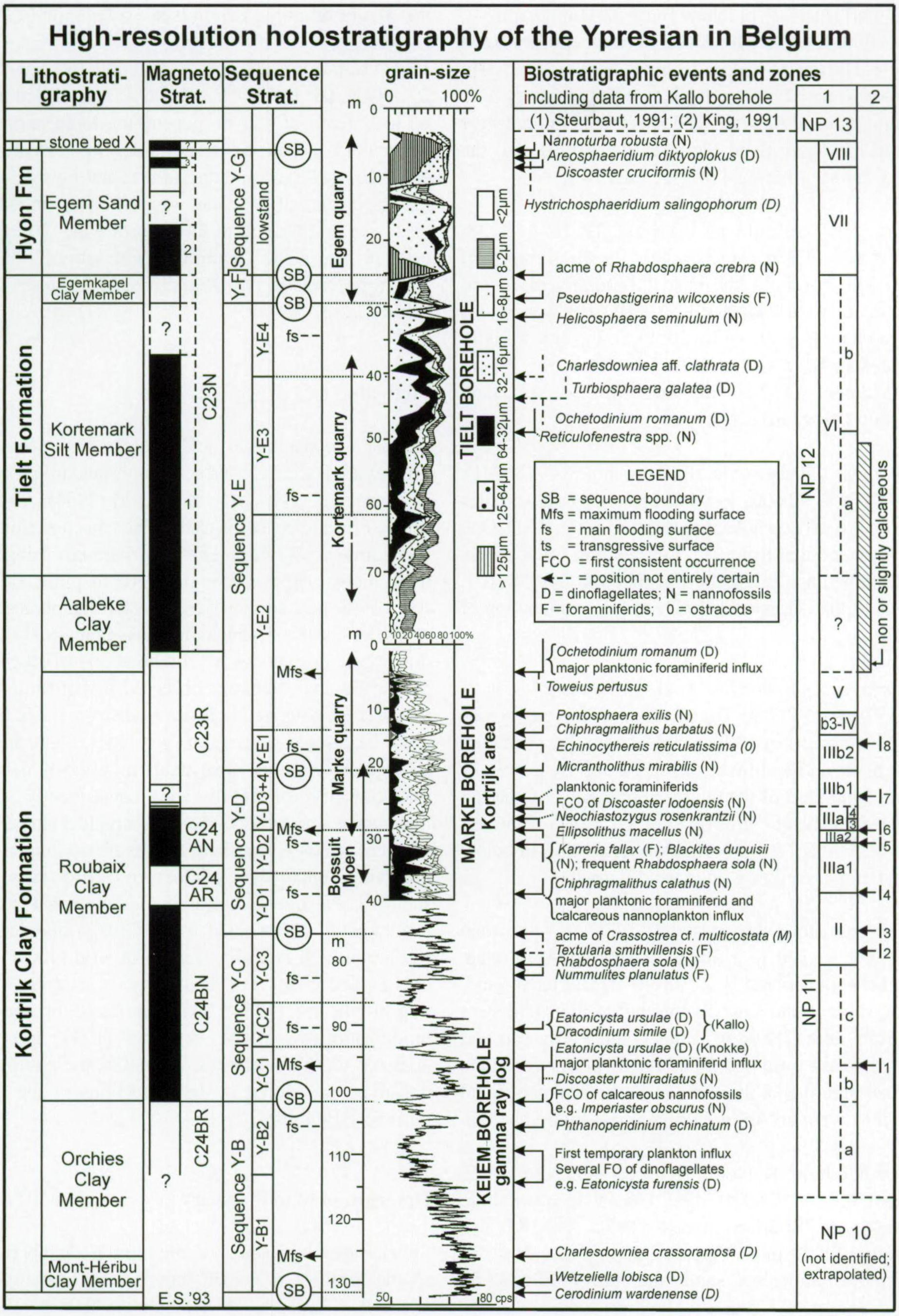


Fig. 7 – High-resolution holostratigraphy of the Lower and Middle Ypresian of Belgium (after STEURBAUT, 1998).

Kallo, "Fort la Perle", borehole BGD 27[E]-148; map 15/2, x = 144.860, y = 217.840. A 622 m deep, entirely cored borehole. The Ieper Group is recorded between ca. 210 m (core loss!) and 377.35 m depth (see STEURBAUT, 1991 for stratigraphical details). The specimens figured here are from the Egem Sand Member (242.60 m) and the Pittem Clay Member (234 m) (see Figs 7-8).

Knokke, Hazegraspolder, borehole BGD 11[E]-138; map 5/6, x = 78.776, y = 226.370. The stratigraphy of the Knokke borehole has been thoroughly discussed in LAGA & VANDENBERGHE (1990). The specimens refigured here (see Pl. 1 Fig. 20; Pl. 2, Fig. 18, initially illustrated in STEURBAUT, 1990) are from the Pittem Clay Member (132.50 m) and the Brussel Sand Formation (71.95 m).

Kruishoutem, Gendarmerie, BGD borehole 84[E]-1362 (I); map 29/4, x = 90.600, y = 177.350. Separate samples from this 116 m deep hole are preserved at the BGD. One specimen, recorded from 41.50 m depth in the Roubaix Clay Member, and originally illustrated in STEURBAUT, 1991 (pl. 2, fig. 4), is refigured here (see explanation of the plate).

Nederokkerzeel, Imbrechts sand pit; map 24/5, x = ~162.450, y = ~ 179.050. The east-flank of this quarry was sampled in november 2000 by J. Herman. The specimen figured here was identified in level A at approximately 25 cm above the base of the quarry, represented by the top of a sandstone bank ("grès de fond"). Level A is located within the Brussel Sand Formation, at about 3 m below the base of the overlying Lede Sand Formation.

Oedelem borehole, Egyptestraat, BGD 23[E]-88; map 13/1-2, x = 77.370, y = 208.970. This 65.00 m deep, cored hole penetrated 1.27 m of Quaternary sand, 2.82 m of clays and sands belonging to the Maldegem Formation, about 29 m of Aalter Sand Formation and 32 m of sands from the Gentbrugge Formation. One specimen recorded at 30 m depth in the Beernem Sand Member (lower part Aalter Formation) is figured herein.

Ooigem borehole, Keihoek, BGD 83[E]-407; map 29/2, x = 76.050, y = 177.200. This 185 m deep borehole terminated in Silurian shales (145.5 to 185 m), penetrating 92.20 m of Ypresian clays (1.80–94.0 m), 33.50 m of "Landenian" sands and clays (94.0–127.50 m) and 18 m of Cretaceous marls and sandstones (127.5–145.5 m). Two specimens, originally illustrated by STEURBAUT (1991) from respectively 33.50 m (op. cit., pl. 2, fig. 6) and 38.50 m depth (op. cit., pl. 2, fig. 3), are refigured herein (see explanation of Plate).

Vlakte van de Raan, offshore borehole 999A/0015; 51° 29' 08" N, 03° 09' 50" E. This hole was drilled in 1988 up to a depth of 160 m, penetrating large parts of the Upper and Middle Eocene Maldegem Formation, the entire Brussel Sand and the Aalter Sand Formations and the upper part of the Gentbrugge Formation. Material discussed and figured in the present paper comes from one horizon in the Gentbrugge Formation (122.60 m) and from levels in the Beernem Sand Member (106.62 m, 103.32 m).

Methods

Sample preparations and calcareous nannofossil investigation were carried out using standard procedures as described in STEURBAUT & KING (1994). About two square centimeters of glass-slide have been examined for each sample analysed (see heading material), using a Zeiss light microscope at 1000x or 1250x magnification. The types of the new species were selected and photographed with a M35-MC 63A analogue Zeiss Camera. Composite drawings, displaying a combination of the major diagnostic characteristics observed in transmitted light and in cross-polarized light are made from the holotypes, and, if necessary, from certain paratypes. These are based on light microscope investigation, using a maximum maginification of 1600x and, consequently, do not include the smallest details (e.g. individual elements, the width of which is less than 0.3 μm are no longer clearly observable under light microscopy). MARTINI's (1971) standard Paleogene calcareous nannofossil zonation (traditionally abbreviated to NP zones) and the high-resolution high latitude zonation of STEURBAUT (1998) are applied here. The taxonomy is essentially from PERCH-NIELSEN (1985), taking into account subsequent modifications by YOUNG & BOWN (1997) and AUBRY & BORD (2009). Materials, as well as the photographic negatives, are stored in the collections of the RBINS (Brussels, Belgium).

Description of new species

Species are discussed according to the alphabetic order of the families to which they belong. Abbreviations used: B = breadth, D = diameter, H = height, L = length, W = width; RBINS = Royal Belgian Institute of Natural Sciences, BGS = British Geological Survey, BGD = Belgische Geologische Dienst.

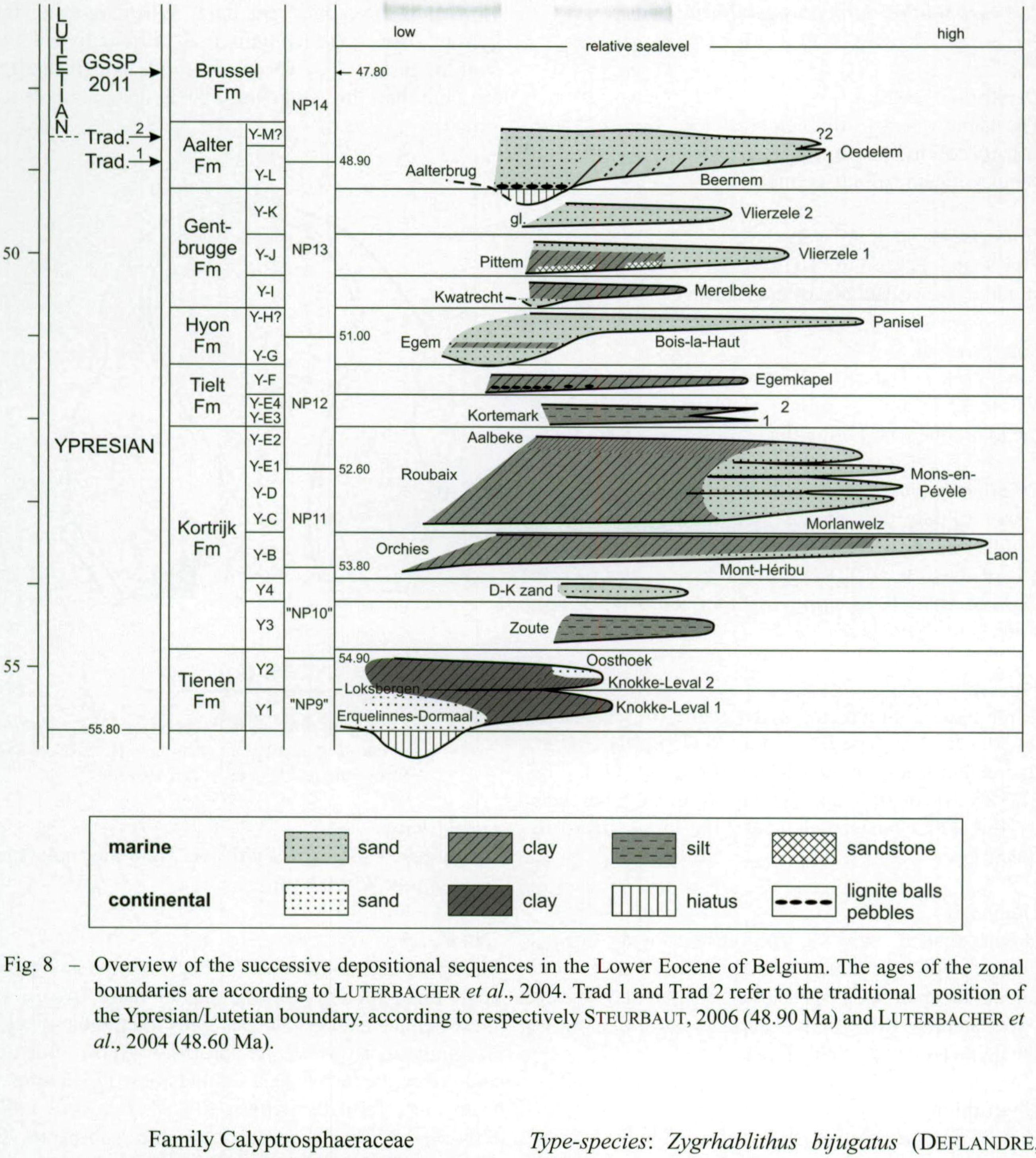


Fig. 8 – Overview of the successive depositional sequences in the Lower Eocene of Belgium. The ages of the zonal boundaries are according to LUTERBACHER *et al.*, 2004. Trad 1 and Trad 2 refer to the traditional position of the Ypresian/Lutetian boundary, according to respectively STEURBAUT, 2006 (48.90 Ma) and LUTERBACHER *et al.*, 2004 (48.60 Ma).

Family Calyptrosphaeraceae
BOUDREAUX & HAY, 1969
Genus *Zygrhablithus* DEFLANDRE, 1959

Diagnosis
This genus was introduced to specify coccoliths consisting of a zygolith base surmounted by a rhabdolith-like robust stem with quadrate cross-section and blade-like vanes at the distal end. The basal disk consists of an open elliptical rim, spanned by x-shaped cross-bars (DEFLANDRE, 1959; GARTNER & BUKRY, 1969).

Type-species: *Zygrhablithus bijugatus* (DEFLANDRE, 1954)

Remarks. This species, one of the first calcareous nannofossils in which the holococcolith structure was identified (STRADNER & ADAMIKER, 1966), has been thoroughly discussed and illustrated by AUBRY (1988). According to STEURBAUT (1991) several clusters of forms can be identified within this species, which are morphologically stable over a wide geographic area and, consequently, deserve subspecies status.

Zygrhablithus bijugatus galeiformis subsp. nov.
Fig. 9; Pl. 1, Figs 1-4

Derivatio nominis

The name refers to the helmet-shaped form of these holococcoliths, more precisely that of a fifteenth century Italian barbute helmet.

Holotype

Fig. 9 and Pl. 1, Fig. 1 (IRScNB b6382) (negatives stored in the collections of the RBINS).

Locus typicus

Albaek Hoved section, Klakring, Denmark; 55° 41' 44" N, 9° 58' 06" E; sample AL44 at ~11.70 m above the top of the Ølst Formation.

Stratum typicum

Upper middle part of the Røsnæs Clay Formation; middle part of NP12, lower part of nannofossil subzone VIa of STEURBAUT (1998); within base of chron C23n (STEURBAUT, 1998, fig. 11, based on ALI, 1988); Ypresian, ~ 51.6 Ma.

Paratypes

Three figured, of which the first comes from the same level as the holotype (Pl. 1, Fig. 2) (IRScNB b6383), the second from sample AK2 at Aktulagay (Pl. 1, Fig. 3) (IRScNB b6384), and the third from BGS borehole 81/46A at 85.67 m (sample 150) (Pl. 1, Fig. 4) (IRScNB b6385).

Diagnosis

Helmet-shaped, with a conspicuous wide medial groove, which becomes strongly inflated in a distal direction, creating a substantial internal cavity, and with, laterally, two elliptical depressions at the base of the helmet-shaped protuberance.

Description

Z. bijugatus galeiformis is characterized by its helmet-shaped outline and its very wide medial groove, which in a distal direction strongly widens to become almost circular, creating a conspicuous internal cavity (Fig. 9). Two smaller elliptical cavities are recorded laterally at the base of the helmet-shaped protuberance, when viewed at high focus. This new subspecies shows the strongest birefringence when seen parallel to the polarization directions. Several distinct areas with similarly oriented crystals can be distinguished, which optically react as single crystals. Thin extinction lines are recorded at the extremities of the basal plate when viewed in cross-polarized light. When inserting the gypsum plate, these extremities are differently colored than the rest of the adjacent coccolith half (if the tips are blue than the remaining half is orange, and vice versa).

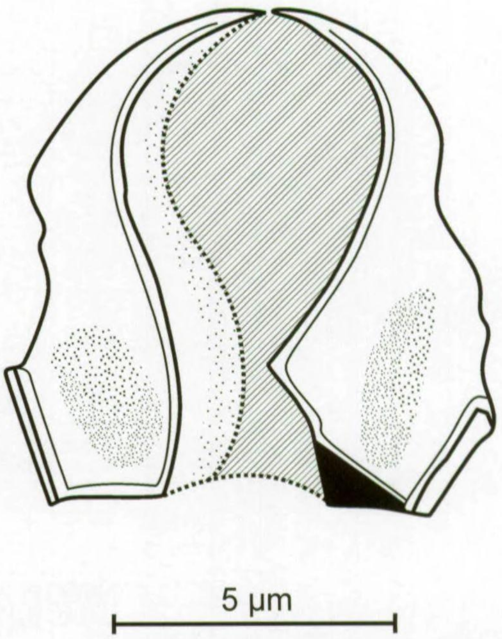


Fig. 9 – Composite drawing of the holotype of *Zygrablithus bijugatus galeiformis* subsp. nov. (IRSNB b6382) from sample AL44 at Albæk Hoved.

Dimensions

Height (z): 8 to 9 µm; Width (x): 7 to 8 µm (holotype: H = 8.8 µm, W = 8.0 µm).

Discussion

The general outline (basal plate, surmounted by a spine-like structure) and the optical characteristics of these helmet-shaped holococcoliths refer to the species *Z. bijugatus*. However, its particular hollow structure and typical helmet-shaped outline allow its separation from other formally defined (e.g. *Z. bijugatus nolfii* STEURBAUT, 1991) or potential new subspecies of *Z. bigugatus*. As the taxonomy of *Z. bijugatus* is not completely worked out yet, we retain the term "*Zygrhablithus bijugatus* s.l." for all not yet formally defined subspecies of *Z. bijugatus* (thus except *Z. b. nolfii* and *Z. b. galeiformis*).

Distribution

Known from the middle Ypresian of the central part of the North Sea Basin (Albaek Hoved, BGS core off Yorkshire), where it seems to be restricted to nannofossil subzones V and VI of STEURBAUT (1998), which correlate with the middle part of NP 12. This form also occurs in the middle Ypresian of the Turan Platform in Kazakhstan, where it was recorded in subzone VIIIb (? reworked), at the top of NP 12.

Family Ellipsolithaceae AUBRY, 2009
Genus *Ellipsolithus* SULLIVAN, 1964

Diagnosis
This genus was introduced to specify thin elliptical heterococcoliths with the central area bordered by a slightly raised elliptical ridge. These thin plates are barely visible in normal transmitted light, although are clearly birefringent under cross-polarized light, exposing sharp extinction lines.

Type-species: *Ellipsolithus macellus* (BRAMLETTE & SULLIVAN, 1961)

Ellipsolithus irregulariporus sp. nov.
Fig. 10; Pl. 1, Fig. 5

Derivatio nominis
Refers to the numerous irregularly distributed pores with varying diameters.

Holotype
Fig. 10 and Pl. 1, Fig. 5 (IRScNB b6386) (negatives stored in the collections of the RBINS).

Locus typicus
Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum
Alashen Formation, middle part Unit A2 (sample AK101); upper part NP11, nanno-subzone IIIa2 of STEURBAUT (1998); chron C24 AN *sensu* ALI *et al*., 1993 *(?* Chron C24 2n *sensu* BERGGREN & PEARSON, 2005), Ypresian, ~ 52.8 Ma.

Paratypes
1 non-figured specimen (L= 13.2 µm, W = 8.8 µm) from sample AK101 in Unit A2 of the Alashen Formation at Aktulagay (same level as holotype).

Diagnosis
Rather large elliptical thin plate with a relatively wide central area (~ 58 % of the total width of the heterococcolith), characterized by a large number (>20) of randomly oriented perforations with variable diameters and without a central ridge.

Description
This new taxon is marked by elliptical heterococcoliths, consisting of a thin nearly flat plate with slightly depressed central area, bordered by a somewhat raised ridge. The central area is relative large and contains a large number (>20) of randomly oriented perforations with variable diameters, although without any trace of a central longitudinal ridge. The coccoliths show high birefringence in cross-polarized light, presenting 2 sharp irregular V-shaped extinction lines, which do not longitudinally connect (central part remains bright), when viewed at 45° to the polarization directions.

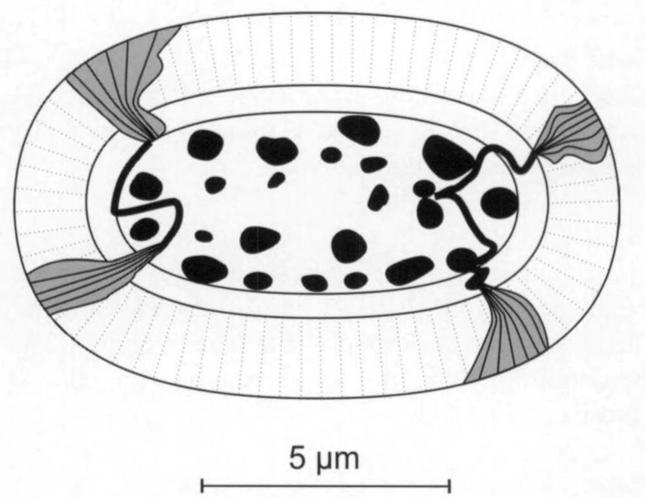


Fig. 10 – Composite drawing of the holotype of *Ellipsolithus irregulariporus* sp. nov. (IRSNB b6386) from sample AK101 at Aktulagay.

Dimensions
Length = 12.4 to 13.2 µm, Width = 8.4 to 8.8 µm (holotype: L = 12.4 µm, W = 8.4 µm; W of central area = 4.8 µm).

Discussion
The general elliptical outline, its thin construction and its optical characteristics (high birefringence and typical extinction lines in cross-polarized light) allow this taxon to be included in the genus *Ellipsolithus*. It is distinguished from all other up to now described *Ellipsolithus* taxa, including *E. macellus* (Pl. 1, Fig. 6) (IRScNB b6387) by its rather large and entirely flat central area, without any longitudinal crest and by the numerous irregularly distributed perforations, which present a high variability in diameter.

Distribution
Extremely rare, up to now only recorded in one sample (AK101) in the middle of Unit A2 of the Alashen Formation at Aktulagay.

Ellipsolithus heilmannclausenii sp. nov.
Fig. 11; Pl. 1, Figs 7-11

Derivatio nominis
In honour of Dr. Claus Heilmann-Clausen (Arhus Universitet, Denmark) in recognition of his contribution to the study of the stratigraphy of the Paleogene.

Holotype
Fig. 11 (IRScNB b6388).

Locus typicus
Albaek Hoved section, Klakring, Denmark; 55° 41' 44" N, 9° 58' 06" E; sample AL44 at ~11.70 m above the base of the Ølst Formation.

Stratum typicum
Upper middle part of the Røsnæs Clay Formation; middle part of NP12, lower part of nannofossil zone VIa of STEURBAUT (1998); within base of chron C23n (STEURBAUT, 1998, fig. 11, based on ALI, 1988); Ypresian, ~ 51.6 Ma.

Paratypes
4 specimens (Pl. 1, Figs 7-10) (IRScNB b6389-b6392) from samples 149, 148 and 139 in BGS borehole 81/46A and 1 specimen (Pl. 1, Fig. 8) (IRScNB b6393) from sample AL 43 at Albaek Hoved.

Diagnosis
This heterococolith consists of a very small, flattened elliptical thin plate, with relative small central area (width 1/3 to slightly more than 1/3 of the total width of the coccolith), marked by a small number (5 to 7 on each half) of relatively large irregularly outlined and radially oriented openings.

Description
This new taxon is primarily differentiated by its small dimensions, of which the length has a mean of about 7.5 µm, and never exceeds 8.5 µm. The general outline is flattened elliptical, with somewhat rounded endings. The central area is relatively small, occupying 1/3 to slightly more than 1/3 of the total width of the coccolith. It contains a small number of relatively large radially oriented openings, with irregular outline and variable diameters. There are 5 to 7 of these openings on each longitudinal half, without any obvious central longitudinal ridge. The coccoliths show high birefringence in cross-polarized light, presenting 2 sharp irregular V-shaped extinction lines, which are interconnected along the long axis of the coccolith when viewed at 45° to the polarization directions.

Dimensions
Length = 6.5 to 8.5 µm, Width = 4.4 to 6.7 µm (holotype: L = 7.2 µm, W = 4.8 µm; W of central area = 1.6 µm).

Discussion
The general elliptical outline and optical characteristics (high birefringence and typical extinction lines in cross-polarized light) allows this taxon to be attributed to the genus *Ellipsolithus*. It is distinct from all other up to now described *Ellipsolithus* taxa by its extremely small coccoliths, never exceeding 8.5 µm, and by the relatively small central area, with large irregular openings. It most closely resembles *E. lajollaensis*, described from the lower middle Eocene of California (BUKRY & PERCIVAL, 1971, pl. 4, figs 7-8), which also has small number of rather large radially oriented perforations, without a prominent longitudinal crest. The latter, however is much larger (8 to 12µm) and has a much smaller central area (less than 1/3 of the coccolith's width) marked by a series of more regularly outlined (quadrangular to slightly rectangular) perforations.

Distribution
Occurring throughout nannofossil subzone VIa and the base of VIb of STEURBAUT (1998) in the central North

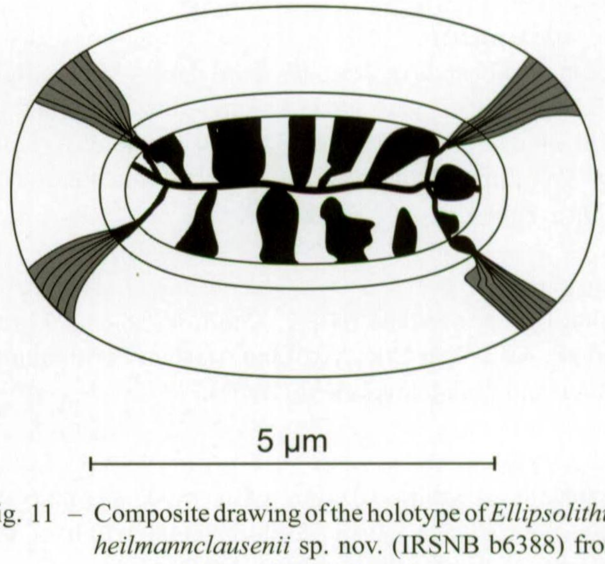


Fig. 11 – Composite drawing of the holotype of *Ellipsolithus heilmannclausenii* sp. nov. (IRSNB b6388) from sample AL44 at Albæk Hoved.

Sea Basin (middle part of NP 12), although not in large numbers. At Albaek Hoved it is known from a 1.70 m thick interval (AL42 to inclusive AL46) and in borehole 81/46A it is recorded from 79.33 m to 85.12 m. Not yet observed in the Belgian Basin and at Aktulagay, probably because of the non- to poorly calcareous condition of the strata (respectively Aalbeke Clay and lower part Kortemark Silt, see Fig. 8, and upper part Unit B1, from 14.50 to 15.50 m, see Fig. 4) during biochron VIa and the base of VIb. In conclusion, *E. heilmannclausenii* is a relatively short ranging species (~ 700 k.y.), with substantial correlation potential.

Family Pontosphaeraceae
LEMMERMANN, 1908
Genus *Pontosphaera* LOHMANN, 1902

Diagnosis
The term *Pontosphaera* is used here in a rather broad sense, as suggested by AUBRY (1990), including all the forms previously attributed to *Pontosphaera, Transversipontis*, *Discolithina* and *Koczyia*, but exluding *Scyphospaera*. In this sense it corresponds to unicellular haptophyte algae covered by discoliths: elliptical calcareous disks, slightly concavo-convex, consisting of a perforated central plate, surrounded by a flaring margin. The height of the margin is always substantially smaller than the longer diameter of the basal plate, whereas the central plate is very finely or strongly perforated by numerous or by few pores.

Type-species: *Pontosphaera syracusana* LOHMANN, 1902 (subsequently designated by LOEBLICH & TAPPAN, 1963).

Pontosphaera megapachydisca sp. nov.
Fig. 12; Pl. 1, Figs 12-14

Derivatio nominis
Refers to the very large and exceptionally thick heterococcoliths marking this new species.

Holotype
Fig. 12 and Pl. 1, Fig. 12 a,b (IRScNB b6394) (negatives stored in the collections of the RBINS).

Locus typicus
Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum
Tolagaysor Formation, base of Unit C2 (sample AK189); top of lower part of NP13 (9 m above its base), Ypresian, ~ 50.3 Ma.

Paratypes
2 figured specimens, both from the Tolagaysor Formation: one from the same sample as the holotype (Pl. 1, Fig. 13) (IRScNB b6395) and one from 6 m higher up within the lower part of unit C2 (AK50) (Pl. 1, Fig. 14) (IRScNB b6396).

Diagnosis
Very large elliptical heterococcoliths with a high, extremely thick rim and a much thinner basal plate, with 18 to 23 peripheral perforations of variable dimensions and a few (up to 5) irregularly distributed central pores.

Description
The heterococcoliths of this new taxon are extremely large, ranging from 16 to 18.5 μm in length and marked by a very thick complex rim. The latter consists of a small thick outer rim and a two to three times broader, thick inner rim, surrounding a much thinner basal plate. This plate is built up by a series of several smaller accessory plates (7 to 8 on each longitudinal half), which are separated along the long axis by a thin depression (line), running along the entire plate. The basal plate is peripherally perforated by 18 to 23 pores, of which the dimensions and shape are highly

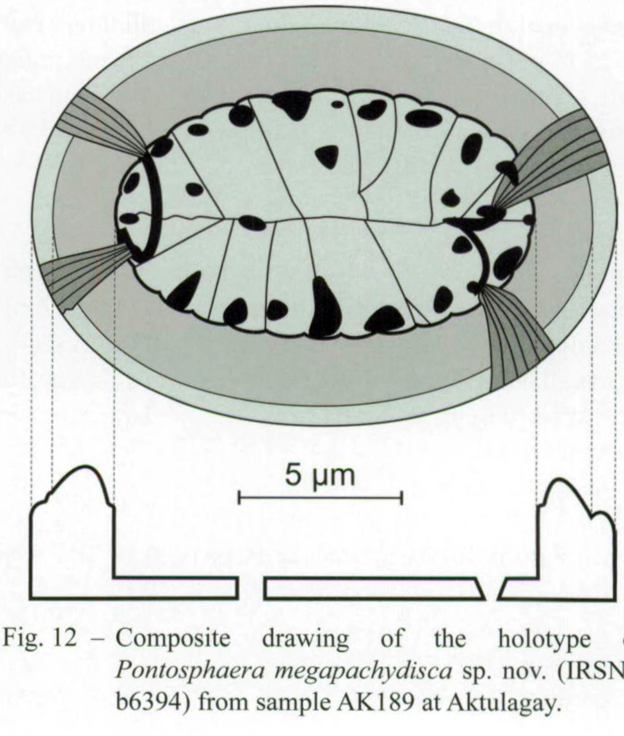


Fig. 12 – Composite drawing of the holotype of *Pontosphaera megapachydisca* sp. nov. (IRSNB b6394) from sample AK189 at Aktulagay.

variable. A very restricted number of pores (generally around 5) are randomly distributed over its central area. The robustness of this form is very distinctive and easily demonstrated in cross-polarized light. The outer rim and the transition of the inner rim towards the basal plate show high order birefringence colors from dark yellow to red, whereas the main part of the inner rim fluctuates from blue to green. Two rather sharp irregular V-shaped extinction lines appear when viewed in a position parallel to the polarization directions. Viewed at 45°, these lines are transformed into two L-shaped thin lines, following the axis of the ellipse, although without completely interconnecting in the center.

Dimensions
Length = 16.0 to 19.2 μm, Width = 11.2 to 13.2 μm (holotype: L = 18.4 μm, W = 13.2 μm).

Discussion
This taxon is included in the genus *Pontosphaera* because of its general outline, consisting of a perforated plate surrounded by an elevated rim, and its optical characteristics (high birefringence and typical extinction lines in cross-polarized light). Within all known *Pontosphaera* taxa it bears most resemblance to *P. distincta* (BRAMLETTE & SULLIVAN, 1961), by the large dimensions of the coccoliths and by their exceptional thick rim. The latter, described from the middle Eocene of California, has erroneously been synonymized with *P. multipora* (see AUBRY, 1990, p. 236). However, the material from Aktulagay indicates that coccoliths *of P. megapachydisca* are still larger (up to 25 %) than these of *P. distincta*, whereas the main part of their central plate, contradictory to what has been observed in the latter, is almost completely free of perforations.

Distribution
Up to now only known from Aktulagay, where it occurs episodically in the greater part of Unit C2 of the Tolagaysor Formation (samples AK189 to AK94), although not its topmost 5 m. Hence, its range seems to be restricted to the upper part of NP 13 and the extreme base of NP 14.

Family Noelarhabdaceae JERKOVIC, 1970
Genus *Dictyococcites* BLACK, 1967

Diagnosis
According to PERCH-NIELSEN (1985) the genus *Dictyococcites* includes all Prinsiaceae with an elliptical to subcircular outline, of which the central area is covered by two differently constructed layers, a simple reticulum proximally and a rather variable structure distally. The latter ranges from a complex net to a raised central structure, also known as the plug, which is perforated or not. Subsequently, YOUNG & BOWN (1997) transferred this genus to the family Noelarhabdaceae, indicating that some of the species might belong to *Reticulofenestra*. AUBRY & BORD (2009) adopted this family attribution and used the term *Reticulofenestra* in a broad sense, including species hitherto assigned to *Dictyococcites* and *Cribrocentrum*. However, as the taxonomy of the Noelarhabdaceae, at least in its earlier history, is not sufficiently well understood, PERCH-NIELSEN's 1985 definition of *Dictyococcites* is followed here.

Type-species: *Dictyococcites danicus* BLACK, 1967

Dictyococcites chriskingii sp. nov.
Figs 13-14; Pl. 1, Figs 15-19

Derivatio nominis
Named after Dr. Chris King, as token of our appreciation of his scientific contributions to the stratigraphy of the Paleogene, and to highlight his role as major supplier of research material from remote places on earth for many co-workers and enthusiasts.

Holotype
Fig. 13 and Pl. 1, Fig. 15 (IRScNB b6397) (negatives stored in the collections of the RBINS).

Locus typicus
Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum
Tolagaysor Formation, top of Unit C2 (sample AK71); within the lower part of NP14 (9 m above its base), Ypresian, ~ 50.3 Ma.

Paratypes
4 figured specimen, all from unit C2 of the Tolagaysor Formation, respectively from samples AK189 (Pl. 1, Fig. 16) (IRScNB b6398), AK91 (Pl. 1, Fig. 17) (IRScNB b6399), AK94 (Pl. 1, Fig. 18) (IRScNB b6400), and AK96 (Fig. 14; Pl. 1, Fig. 19) (IRScNB b6401). All are proximal views, except that on Fig. 14 - Pl. 1, Fig. 19, which is a distal view.

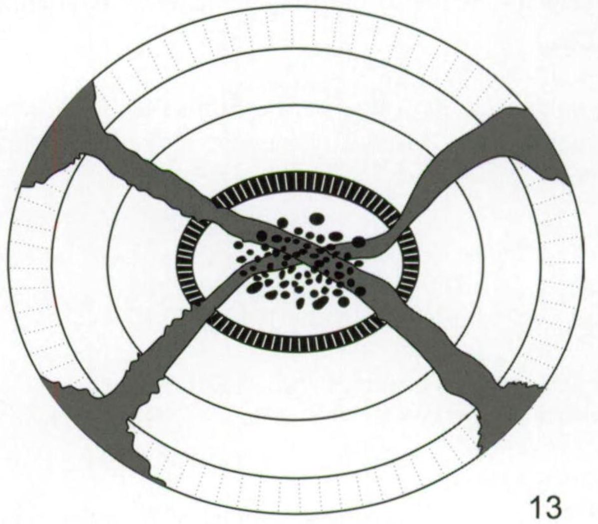
Diagnosis
Subcircular to slightly elliptical placoliths of which the central area is covered by a double complex network consisting of a dense reticulum proximally, and of a narrow elliptical ring of 7 large perforations distally. An elliptical ring of numerous small perforations, with extremely thin laths in between, surrounds this central network and connects it to the wall.

Description
The new taxon is characterized by medium-sized subcircular to slightly elliptical placoliths, the distal shield of which is larger than the proximal shield. The central area is elliptical and rather large, occupying around 40% of the placolith's length and 1/3 of its width. It consists centrally of a double complex network, which in proximal view (Fig. 13) is made up of large number (over 35) of small randomly oriented perforations. An elliptical ring of 7 larger perforations is recorded distally (Fig. 14). This central area is surrounded by a ring of fine perforations and even finer laths, separating these perforations, and connecting the central structure to the wall. The size of the perforations and the connecting laths are so small that they are almost invisible with the light microscope. This phenomenon creates an optical illusion, as if the wall seems to be disconnected from the central area by an elliptical continuous opening, leaving a black elliptical ring in cross-polarized light. Two extinction lines are recorded. Viewed at 45° to the polarization directions in proximal view, one of these lines is rather straight, whereas the second is slightly laevogyre in the central area, and widens in straight forward direction or slightly dextrogyre in the distal shield area (see Fig. 13).

Dimensions
Length (x) = 8.8 to 11,2 μm, width (y) = 8.0 to 9.6 μm (holotype: L = 10.4 μm, W = 8.4 μm).

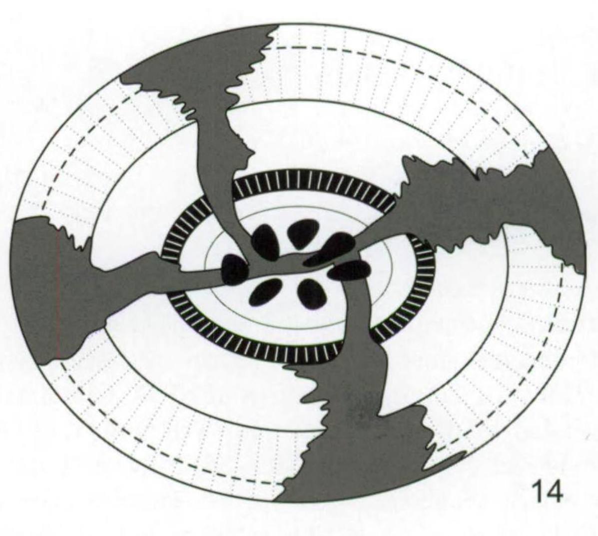
Discussion
Subcircular placoliths, of which the central area is spanned by a double complex network and of which both the distal and proximal shields show high birefringence, point to *Dictyococcites*. *D. chriskingii* differs from all known *Dictyococcites* taxa through the presence of a perforated elliptical ring, surrounding the perforated center. This ring remains almost completely dark in cross-polarized light (Pl. 1, Figs 15-19). It surrounds a central perforated area, which, distally, contains 7 rather large elliptically oriented perforations, but proximally, contains over 35 very small, randomly oriented pores.

Distribution
Up to now only known from Aktulagay, where it occurs throughout the Tolagaysor Formation (samples AK58 to AK71). Hence, its range seems to be restricted to the middle and upper part of NP 13 and the extreme base of NP 14.



13

5 μm



14

5 μm

Figs 13, 14 – Composite drawings of the holotype (Fig. 13, proximal view) (IRSNB b6397) and one paratype (Fig. 14, distal view) (IRSNB b6401) of *Dictyococcites chriskingii* sp. nov from respectively samples AK71 and AK96 at Aktulagay.

Family Prinsiaceae HAY & MOHLER, 1967
Genus *Toweius* HAY & MOHLER, 1967

Diagnosis
This genus includes circular to subcircular placoliths, which distally are marked by a distal shield and two walls, surrounding a single central perforated area. The walls are highly birefringent under cross-polarized light.

Type-species: *Toweius pertusus* SULLIVAN, 1965, senior synonym of *Toweius craticulus* HAY & MOHLER, 1967.

Toweius brusselensis sp. nov.
Figs 15-16; Pl. 1, Figs 20-22

Toweius sp. – STEURBAUT, 1990, p. 55, pl. 3, fig. 11.
Toweius n. sp. – DAMBLON & STEURBAUT, 2000, p. 28, fig. 7.

Derivatio nominis
The name refers to Brussel, capital of Belgium, which is the type locality of the Brussel Formation (Upper Ypresian-Lower Lutetian), in which this new species has been discovered.

Holotype
Fig. 15 (IRScNB b6402).

Locus typicus
71.95 m depth in Knokke borehole, NW Belgium; topographic map 5/6; x = 78.776, y = 226.370.

Stratum typicum
Brussel Formation, lithostratigraphic equivalent of the obsolete stage name Bruxellian (see STEURBAUT & HERMAN, 2006), middle part of NP14, traditionally included in the Early Lutetian (STEURBAUT, 2006). In view of the newly proposed GSSP for the Lutetian boundary, which is based on the lowest occurrence (= LO) of *Blackites inflatus* as the boundary criterion (MOLINA *et al.*, 2011), this unit should be transferred to the Late Ypresian.

Paratypes
Three figured specimens (negatives stored in the collections of the RBINS): one from the same level as the holotype (Pl. 1, Fig. 20) (IRScNB b6403), a second from Nederokkerzeel (Pl. 1, Fig. 21) (IRScNB b6404) and a third from AK 91 at Aktulagay (Fig. 16; Pl. 1, Fig. 22) (IRScNB b6405).

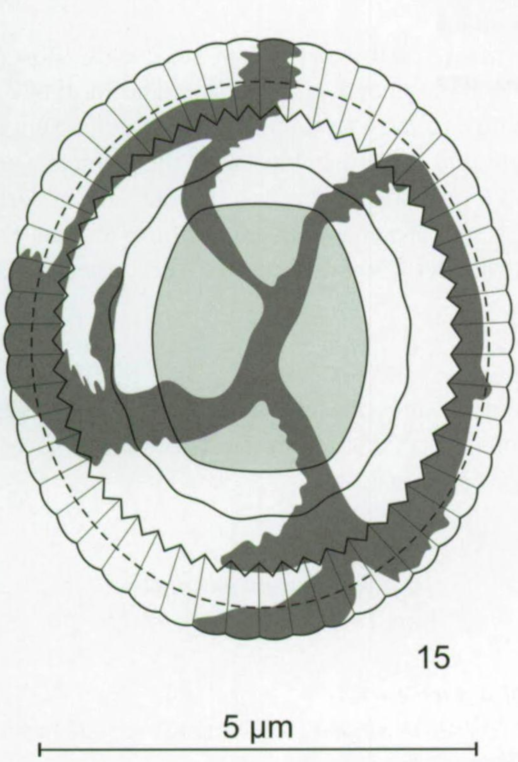
Diagnosis
Subcircular, slightly raised placoliths, marked distally by 2 walls and a large central network, subrectangular to rhombic in certain orientations, containing up to 60 irregularly distributed perforations, clearly visible in proximal view.

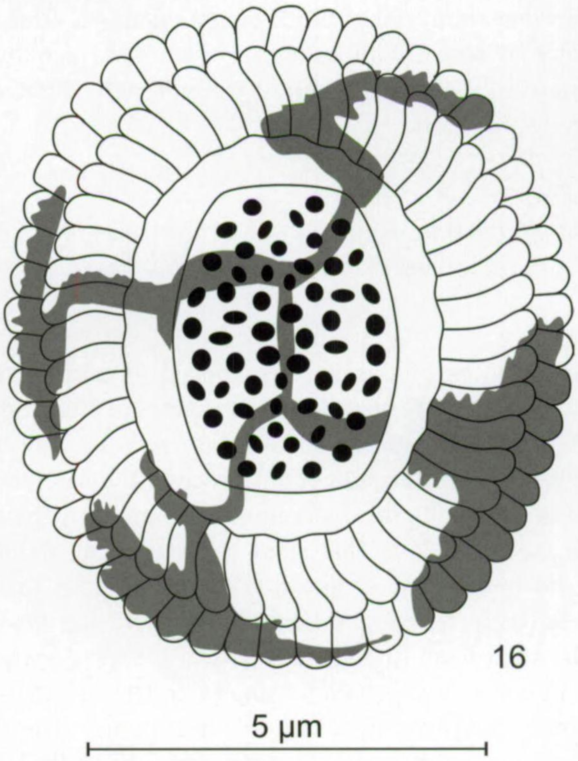
Dimensions
Length (x) = 6.8 to 8.0 μm, width (y) = 5.6 to 6.8 μm (holotype: L = 6.8 μm, W = 5.6 μm).

Description
These subcircular, slightly raised placoliths consist of a distal shield, marked by two walls and a smaller proximal shield. Both shields are built up by a ring of numerous small elements (probably over 50 in the proximal shield), barely visible with the light microscope. These from the proximal shield are slightly curved in anti-clockwise direction in proximal view. The inner wall is steep, and clearly sticks out above the central network. The latter is subrectangular to slightly rhombic in outline (see Pl. 1, Fig. 22) and consists of up to 60 irregularly distributed perforations, clearly visible in proximal view. Especially the inner wall is strongly birefringent in cross-polarized light. The proximal shield is also bright under crossed nicols, whereas the distal shield is rather faint. The extinction lines present a very irregular pattern (see Figs 15-16) and are dextrogyre in distal view.

Discussion
The presence of a double wall in the distal shield, the single central network and the typical interference figure in cross-polarized light (very bright inner wall, bright proximal shield, rather faint distal shield and the very complex extinction lines) allows this new taxon to be included in the genus *Toweius*. It is distinguished from all up to now described species by its large, subrectangular to slightly rhombic central network, reaching around 45 % of the total placolith length, and consisting of around 60 small openings.

Distribution
Known from several boreholes (e.g. Knokke: STEURBAUT, 1990; Vlakte van de Raan) and outcrops (e.g. Gobertange: DAMBLON & STEURBAUT, 2000; Nederokkerzeel), in Belgium, where it seems to be restricted to the Brussel Formation (lower NP 14). Rarely represented at Aktulagay, in the upper part of the Tolagaysor Formation (sample AK91), dated as uppermost NP 13.





Figs 15, 16 – Composite drawings of the holotype (Fig. 15, distal view) (IRSNB b6402); and one paratype (Fig. 16, proximal view) (IRSNB b6405) of *Toweius brusselensis* sp. nov from respectively samples AK71 and AK96 at Aktulagay.

Family Rhabdosphaeraceae LEMMERMANN, 1908

This family includes extant and fossil haptophyte algae, of which the cell coverings consist of circular to elliptical plates with a central process, termed rhabdoliths. Both the basal structure and the central process or stem, are highly variable in length, outline and structure. Its taxonomy, which has been a major point of discussion for long (see PERCH-NIELSEN, 1985) is very well explained in AUBRY's Handbook of Calcareous Nannofossils (1999).

Genus *Blackites* HAY & TOWE, 1962

Diagnosis
AUBRY's 1999 classification is adopted here. The term *Blackites* is restricted to rhabdoliths with circular base, consisting of two marginal cycles of radially arranged elements (M1 and M2) and three low central area cycles (CA1, CA2 and CA3), both in distal view, and a central stem, built up of a single cycle of elements (CA4).

Type-species: *Blackites spinosus (*DEFLANDRE & FERT, 1954) HAY & TOWE, 1962

Blackites aktulagayensis sp. nov.
Fig. 17; Pl. 1, Figs 23-24

Derivatio nominis
Referring to the locality name Aktulagay in Kazakhstan, where this species was first recorded.

Holotype
Fig. 17 and Pl. 1, Fig. 23 (IRScNB b6406) (negatives stored in the collections of the RBINS).

Locus typicus
Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum
Tolagaysor Formation, base of Unit C2 (sample AK189) (IRScNB b6407); top of lower part of NP13 (9 m above its base), Ypresian, ~ 50.3 Ma.

Paratypes
1 figured specimen, from the same sample as the holotype (Pl. 1, Fig. 24).

Diagnosis
Rhabdoliths with a circular, rather wide, basal plate and

a somewhat short, rather broad central stem (<2 times diameter of base), with smooth surface and, distally, over most of their length, almost straight, only slightly widening sidewalls.

Dimensions

Height (y) = 8.0 to 9.6 µm, width of the base (x) = 5.6 to 6.0 µm (holotype: H = 9.6 µm, W = 6.0 µm).

Description

The rhabdoliths of this species consist of a circular base with two easily distinguishable cycles of elements in side view (cycles M1 and CA1 of AUBRY, 1999) and a rather short broad central process, the sides of which are only slightly widening over most of their length (see Fig. 17). This stem is broadest at about ¾ of its height and is upwards (distally) from that point strongly tapering. At the level where the base and the stem meet (the upward part of the base *sensu* AUBRY) occurs a slight thickening (a collar), which is proximally followed by an inward indentation. These structures, probably representing cycles CA3 and CA2 of AUBRY (1999) respectively, are barely visible with the light microscope. The surface of the stem presents no conspicuous knobs or ridges, and appears rather smooth at light microscope magnifications. In cross-polarized light with the quartz plate inserted and viewed at 22.5°, sectors a, f and c of the rhabdolith (see Fig. 17) present the same interference colors (e.g. blue), while sectors b, d and e are all identically marked by their optical counterpart colors (in this case orange).

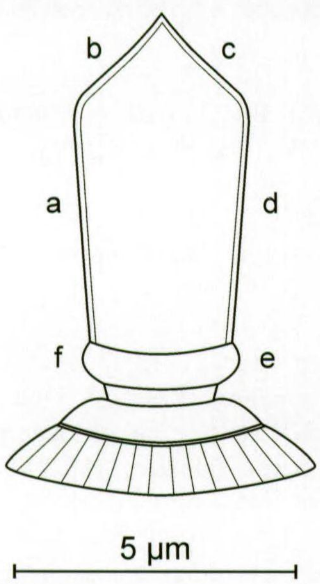


Fig. 17 – Composite drawing of the holotype (IRSNB b6406) of *Blackites aktulagayensis* sp. nov. from sample AK189 at Aktulagay.

Discussion

The structure of the different basal cycles allows this taxon to be included in *Blackites*. The outline of the stem with its almost straight, slightly widening contours and strongly tapering top, and the typical outline of the vertical top of the base (collar and underlying indentation), are characteristic features of this taxon, clearly distinct from all previously described *Blackites* taxa.

Distribution

Up to now only known from Aktulagay, where it occasionally occurs at the base of Unit C2 of the Tolagaysor Formation.

Blackites rugosus **sp. nov.**

Figs 18-19; Pl. 1, Figs 25-26

Derivatio nominis

Rugosus (latin) = rugose, referring to the rugose surface of the stem of these rhabdoliths.

Holotype

Fig. 18 and Pl. 1, Fig. 25 (IRScNB b6408) (negatives stored in the collections of the RBINS).

Locus typicus

Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum

Tolagaysor Formation, upper part of Unit C2 (sample AK94); base of NP14, Ypresian, ~ 49.7 Ma.

Paratypes

1 figured specimen, from sample AK189 at the base of Unit C2 of the Tolagaysor Formation (Fig. 19, Pl. 1, Fig. 26) (IRScNB b6409).

Diagnosis

Rhabdoliths with circular, rather wide, basal plate and rugose stem, of which the outline resembles a Second World War artillery shell, with lobed rim, and marked by striations, making an angle of about 45° with the direction of the main axis.

Dimensions

Height (y) = 10.4 (?) to 12.0 µm, width of the base (x) = 5.2 to 5.6 µm (holotype: H = 12.0 µm, W = 5.6 µm). The height of the paratype is probably underestimated because of its oblique position in the slide.

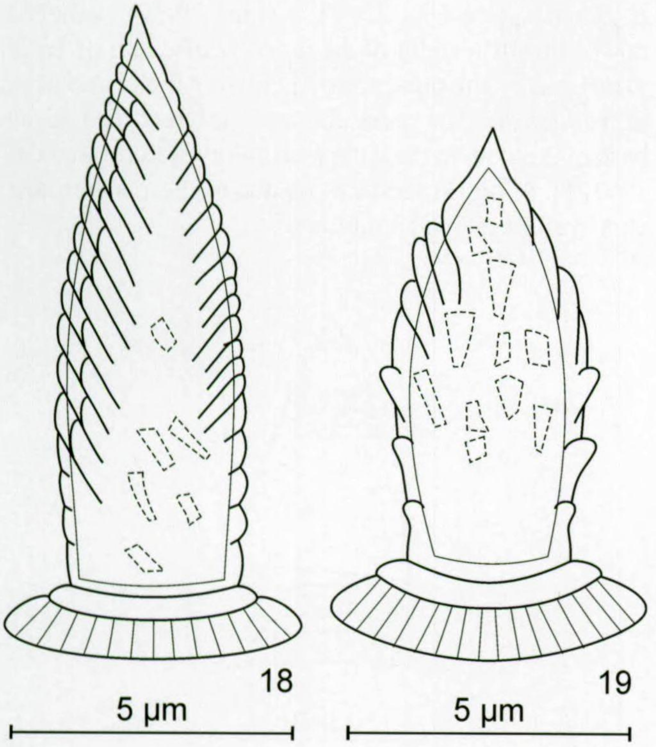


Fig. 18, 19 – Composite drawings of the holotype (Fig. 18) (IRSNB b6408) and one paratype (Fig. 19) (IRSNB b6409) of *Blackites rugosus* sp. nov. from samples AK94 and AK189 respectively at Aktulagay.

Description

The base of these rhabdoliths is circular with 2 easily distinguishable cycles of elements in side view (cycles M1 and CA1 of AUBRY, 1999) and a fairly long, rather broad central process, which in outline resembles a Second World War artillery shell with lobed rim (see Figs 18-19). This stem is broadest at about half of its height. It is only weakly widening in its lowermost half, and regularly tapering in its uppermost half. No obvious collar or other features are observed within the rhabdolith's base under light microscopy. The stem is heavily striated, causing a lobed outer rim. The striations make an angle of about 45° with respect to the vertical axis. In cross-polarized light with the quartz plate inserted and viewed at 22.5°, each longitudinal half of the stem present specific interference colors different from these of the other half (is left part blue, than right counterpart orange, and vice versa).

Discussion

B. rugosus differs from all up to now known *Blackites* taxa by its typical outline, its lobed rim and the many striations, making angles of 45° to the vertical axis. Other more or less resembling rugose forms, such as *B. inflatus* and *B. solus*, possess a less wide basal plate, whereas *B. gladius* has a prominent collar and a much slender basal part of the stem.

Distribution

Up to now only known from Aktulagay, where it rarely occurs within Unit C2 of the Tolagaysor Formation.

Blackites thiedei sp. nov.
Figs 20-21; Pl. 1, Figs 27-28

Derivatio nominis

This species is dedicated to Prof. J. Thiede (Kiel, Germany), Founder and Head of Geomar, Research Centre for Marine Geosciences at Kiel (1987-1997) and Director of Alfred Wegener Institute (AWI) for Polar and Marine Research (1997-2007), who attracted many young scientists whose researches he inspired and stimulated.

Holotype

Fig. 20 and Pl. 1, Fig.27 (IRScNB b6410) (negatives stored in the collections of the RBINS).

Locus typicus

Aktulagay, Western Kazakhstan; 47°32'31" N, 55°09'14" E.

Stratum typicum

Alashen Formation, top of Unit A2 (sample AK163); lower part NP12, Ypresian, ~ 52.65 Ma.

Paratypes

1 figured specimen, from sample AL43 in the middle of the Røsnæs Clay Formation (at ~11.20 m above its base) (Fig. 21; Pl. 1, Fig. 28) (IRScNB b6411).

Diagnosis

Rather thin inconspicuous rhabdoliths with circular, rather wide, basal plate, (including a collar), and slender stem, ornamented with striations, composed of slightly oblique to subhorizontal, helicoidally arranged, lath-like elements.

Dimensions

Height (y) = 8.0 to 8.8 µm, width of the base (x) = 4.8 to 5.2 µm (holotype: H = 8.4 µm, W = 4.8 µm).

Description

These rather tiny rhabdoliths are not easily seen with the light microscope because of their slender outline and their very weak birefringence in cross-polarized light. A close inspection at maximum magnification shows that they are marked by a circular base, consisting of several, in side view, clearly distinguishable cycles of elements, among which are cycles M1, CA1 and a conspicuous collar (CA2-CA3 of AUBRY, 1999). The central process or stem is slender (width of the stem just above collar is ~50% of width of basal plate), with a rather narrow base and almost vertical (holotype, Fig. 20) to slightly triangular (paratype, Fig. 21) sidewalls. These sidewalls are not smooth, but present jagged edges, due to the presence of well-developed striations. These striations are composed of slightly oblique to subhorizontal, helicoidally arranged, lath-like elements.

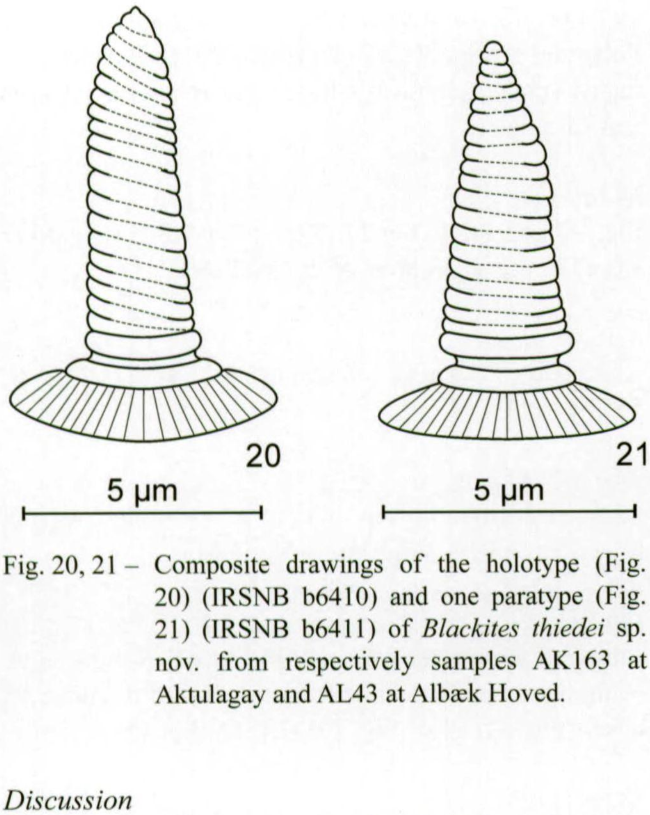


Fig. 20, 21 – Composite drawings of the holotype (Fig. 20) (IRSNB b6410) and one paratype (Fig. 21) (IRSNB b6411) of *Blackites thiedei* sp. nov. from respectively samples AK163 at Aktulagay and AL43 at Albæk Hoved.

Discussion

Blackites thiedei seems to be closely related to *Blackites dupuisii* (STEURBAUT, 1991) new. comb. (initially described as *Naninfula dupuisii*), known from many outcrop and borehole sections in Belgium (see STEURBAUT, 1991). Both are marked by the presence of an almost identical constructed stem, with the same type of ornamentation, consisting of several slightly oblique to subhorizontal, helicoidally oriented striations, composed of lath-like elements. *B. thiedei* differs by its more elongated and much slender stem, compared to the slightly shorter triangular stem of *B. dupuisii* (see Fig. 22; Pl. 1, Figs 29-30) (IRScNB b6412-b6414) (width of stem >65% of width of basal plate) and by the presence of a collar, which is missing in *B. dupuisii.* The particular structure recorded at the base of the stem in the latter (see holotype, STEURBAUT, 1991, pl. 4, fig. 3) seems to be due to the 2 lowermost very well developed striations.

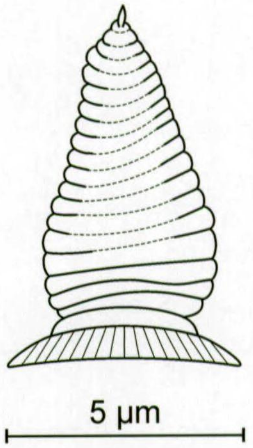


Fig. 22 – Composite drawing of the paratype of *Blackites dupuisii* (STEURBAUT, 1991) new. comb. from 38.50 m depth (IRSNB b6412) in the Ooigem borehole (see also STEURBAUT, 1991, pl. 2, fig. 3).

Distribution

Recorded in several outcrop and borehole sections in Belgium, in the Albæk Hoved section in Denmark, the Aktulagay section at Kazakhstan and the Central North Sea borehole 81/46A, from subzone III b1 up to subzone VIa, or lower (not base) to middle of NP12.

Family Zygodiscaceae HAY & MOHLER, 1967
Genus *Chiphragmalithus* BRAMLETTE & SULLIVAN, 1961

Diagnosis

This genus was introduced to delineate open basket-shaped heterococcoliths, consisting of a relatively high outer rim, build up of 2 adjacent cycles of elements, spanned by a cross- or H-shaped central structure. The outline ranges from almost circular up to flat elliptical.

Type-species: *Chiphragmalithus calathus* BRAMLETTE & SULLIVAN, 1961

Chiphragmalithus vandenberghei sp. nov.
Fig. 23; Pl. 2, Figs 1-6

Derivatio nominis
Very conspicuous solid construction, leaving a lasting impression, much in line with the personality traits of Prof. Dr. Noël Vandenberghe (K.U.Leuven, Belgium), to whom this new species is dedicated, in commemoration of his role in unraveling the stratigraphy of the Oligocene of Belgium.

Holotype
Fig. 23 and Pl. 2, Fig. 1 (IRScNB b6415) (negatives stored in the collections of the RBINS).

Locus typicus
Vlakte van de Raan borehole (999A/0015), Belgian offshore area; 52°34'35"N, 2°45'23"E; 103.32 m depth.

Stratum typicum
Aalter Formation, Beernem Sand Member, upper part NP13; early late Ypresian, ~ 49.8 Ma.

Paratypes
Five specimens figured, of which four are from the Vlakte van de Raan borehole: two from 103.32 m depth (Pl. 2, Figs 2-3) (IRScNB b6416-b6417), one from 106.62 m depth (Pl. 2, Fig. 4) (IRScNB b6418), and one from 122.60 m depth (Pl. 2, Fig. 5) (IRScNB b6419), all dated as uppermost NP13, and one from unit C2 (sample AK70) of the Tolagaysor Formation at Aktulagay (Kazakhstan), dated as basal NP14 (Pl. 2, Fig. 6) (IRScNB b6420).

Diagnosis basal
Large, robust, heterococcoliths, shaped like a reverse frustum of a cone. Elliptical outline at their proximal end and strongly flaring in distal direction, consisting of an irregular outer rim with multiple solid ribs and spines amalgamated with the protruding H-shaped internal structure.

Description
The heterococcoliths of this new form are shaped like a reverse frustum of a cone (Pl. 2, Fig. 6). They are marked by an extremely irregular high wall, the outline of which is elliptical at its proximal end, but strongly flaring distally (Fig. 23c). Its height is about 1.5 to twice as long as the width of its proximal end. Due to its particular form, the outline becomes quadrangular to slightly rectangular in a two-dimensional projection in

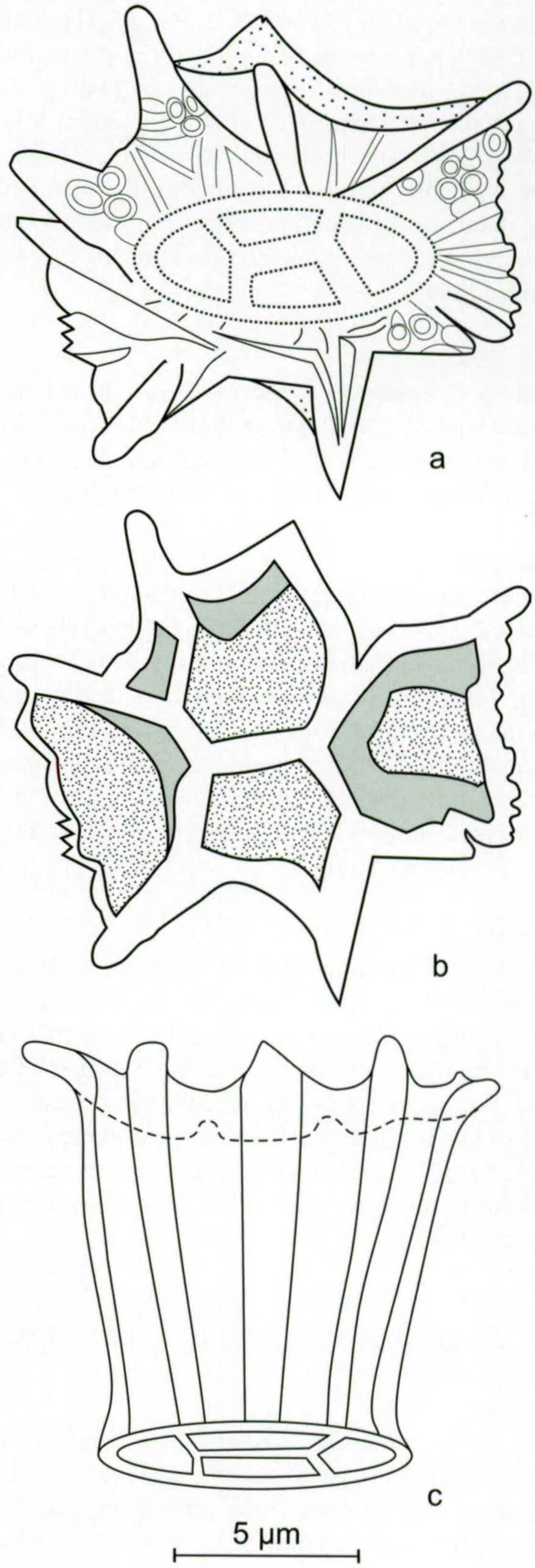


Fig. 23 – Composite drawing of the holotype of *Chiphragmalithus vandenberghei* sp. nov. (IRSNB b6415) from 103.32 m depth in the Vlakte van de Raan borehole: a = low focus, b = high focus, c = side view.

distal view (see Fig. 23a and Pl. 2, Fig. 4). The flaring wall, presenting a series of irregularly positioned ribs and spines, amalgamates with the protruding, also flaring and irregularly edged H-shaped central bridge (see Fig. 23b). The horizontal part of the H-shaped bridge is slightly oblique compared to the orientation of the diameters of the elliptical base of the coccolith. The entire structure is clearly birefringent in cross-polarized light.

Dimensions

Length (x = along the longest diameter of the basal elliptical structure) = 12.0 to 18.4 µm, Width (y = along the smallest diameter) = 11.2 to 16.0 µm, Height (z) = >15 µm (holotype: L = 13.6 µm, W = 12.8 µm).

Discussion

This new form is closely related to *Chiphragmalithus armatus* PERCH-NIELSEN, 1971 (Pl. 2, Fig. 7) (IRScNB b6421) in having an elliptical outline with H-shaped central bridge and a flaring wall. It is distinguished from the latter by its oversized dimensions (up to 18.5 µm in length), its shape resembling a reverse frustum of a cone, with very high flaring wall (at least double as high as in *C. armatus*) and ornamented with multiple spiny ribs (see Pl. 2, Fig. 6).

Distribution

Up to now known from offshore boreholes in Belgium (Vlakte van Raan, Goote Bank II), where it occurs in the lower upper Ypresian (upper part of the Gentbrugge Formation and in the Beernem Sand Member of the Aalter Formation). Also observed in the upper two thirds of the Tolagaysor Formation at Aktulagay (from sample AK50 to AK71). Hence, its range seems to be restricted to the upper part of NP 13 and the extreme base of NP 14.

Genus *Lophodolithus* DEFLANDRE, 1954

Diagnosis

This genus includes ovoid to kidney-shaped heterococcoliths, consisting of a slightly curved asymmetric central plate (light grey in Fig. 23) with flaring edges (wall and rim: white ring in Fig. 24) and an oblique asymmetric structure, called the flange, which represents the continuation of the wall and rim in outward-lateral direction (outmost dark grey zone in Fig. 24). The central area is open (black areas in Fig. 24) and spanned by a transverse structure named bar (white central structure in Fig. 24), which is structurally independent from the rest of the central plate. For further details the reader is referred to ROMEIN (1979) and AUBRY (1990).

Type-species: *Lophodolithus mochlophorus* DEFLANDRE, 1954

Lophodolithus mytiliformis sp. nov.
Fig. 24; Pl. 2, Figs 8-14

Derivatio nominis

The name refers to the strong asymmetrical structure of these heterococcoliths, resembling the outline of the valve of the edible blue mussel *Mytilus edulis* LINNAEUS, 1758.

Holotype

Fig. 24 and Pl. 2, Fig 8 (IRScNB b6422) (negatives stored in the collections of the RBINS).

Locus typicus

Albaek Hoved section, Klakring, Denmark; 55° 41’ 44” N, 9° 58’ 06” E; sample AL44 at ~11.70 m above the base of the Ølst Formation.

Stratum typicum

Upper middle part of the Røsnæs Clay Formation; middle part of NP12, lower part of nannofossil zone VIa of STEURBAUT (1998); within base of chron C23n (STEURBAUT, 1998, fig. 11, based on ALI, 1988); Ypresian, ~ 51.6 Ma.

Paratypes

Six paratypes figured, one from Albaek Hoved, sample AL43 (Pl. 2, Fig. 9) (IRScNB b6423), and five from borehole 81/46A, respectively from 85.12 m (Pl. 2, Fig. 10) (IRScNB b6424), 84.72 m (Pl. 2, Fig. 11) (IRScNB b6425), 84.25 m (Pl. 2, Fig. 12) (IRScNB b6426) and two from 82.92 m (Pl. 2, Figs 13-14) (IRScNB b6427-b6428) depth. For stratigraphical details see Figs 5 and 6.

Diagnosis

Asymmetric heterococcoliths, as well in longitudinal as transversal directions, of which the outline resembles that of a mussel valve; furthermore marked by a rather short, but extremely broad central bar.

Description

These heterococcoliths are highly asymmetric, the outline of which is very similar to that of the valve of the edible blue mussel *Mytilus edulis*. The central

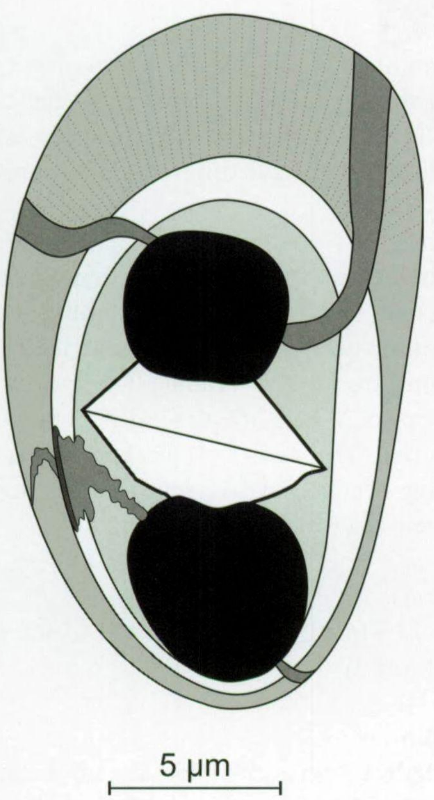


Fig. 24 – Composite drawing of the holotype of *Lophodolithus mytiliformis* sp. nov. (IRSNB b6422) from sample AL44 at Albæk Hoved.

plate, which is open over most of its surface (dark in cross-polarized light, see Fig. 24), is also asymmetric and slightly kidney-shaped. It contains a very robust, broad and slightly oblique central bar. Its width is about half of its length. It has a flattened hexagonal outline and is split into two trapezoidal structures along its longest diagonal. The central plate is surrounded by a raised wall and rim, which are also asymmetrical. The marginal flange is circumperipheral, although poorly developed at the smallest end and also less well developed at the less curved side (see Fig. 24). There are some fine traces of crenulation at the broadest end of the flange. The central plate is dark over most of its surface in cross-polarized light. Optically, the central bar acts as one single unit, with interference colors opposite to these of the rest of the central plate (when bar is orange colored with the quartz plate inserted, than the remainder of the plate is colored blue, and vice versa). The extinction lines are laevogyre in proximal view (e.g. holotype, Fig. 24). They are small when seen at intermediate position (22.5° to polarization directions).

Dimensions
Length = 11.6 to 16.4 µm (mean 14 µm), W = 8.4 to 12.0 µm (holotype: L = 16.4 µm, H = 12.0 µm).

Discussion
This new species is clearly distinguished from all described *Lophodolithus* species (*L. acutus*, *L. mochlophorus*, *L. nascens* (Pl. 2, Figs 15-16) (IRScNB b6429-b6430), *L. reniformis* and *L. rotundus;* see Aubry, 1990, p. 28-34 for descriptions and illustrations) through its strong asymmetric outline, the form of which reminds a mussel shell, its well developed marginal flange, and by the compact form and substantial width of its central bar (see Fig. 24 and Pl. 2, Figs 8-14). At its broadest end the flange is finely crenulated, much clearer than in *L. nascens*, but less well developed and much finer than in *L. mochlophorus*.

Distribution
Known from several localities in the North Sea Basin, occurring in a 1.20 m thick interval (AL42 to AL44, see Fig. 5) within the upper middle part of the Røsnæs Clay Formation in Denmark, a 6.30 m thick interval within the middle part of Unit 3 of offshore hole 81/46A (149 to inclusive 134, see Fig. 6) and in a 1.50 m thick interval in the middle of Unit B1 (AK103-AK104) of the Aktulagay Formation. It seems to be restricted to the interval top subzone V – subzone VI of Steurbaut (1998), within the middle of NP12.

Family Incertae Sedis
Genus *Nannoturba* Müller, 1979

Diagnosis
This genus includes nannoliths consisting of a complex structure of elongated blocky calcite elements, with variable configuration, which are strongly birefringent in cross-polarized light.

Type-species: *Nannoturba robusta* Müller, 1979

Nannoturba jolotteana sp. nov.
Fig. 25; Pl. 2, Figs 19-22

Derivatio nominis
The name is a combination of the Christian names Joachim and Annelotte, representing two marvellous young people whom I dearly love and admire and who I wish a wonderful future together.

Holotype

Fig. 25 and Pl. 2, Fig. 19 (IRScNB b6431) (negatives stored in the collections of the RBINS).

Locus typicus

Vlakte van de Raan borehole (999A/0015), Belgian offshore area; 52°34’35”N, 2°45’23”E; 103.32 m depth.

Stratum typicum

Aalter Formation, Beernem Sand Member, upper part NP13; Early late Ypresian, ~ 49.8 Ma.

Paratypes

Three specimens: one from the same level of the holotype (Pl. 2, Fig. 20) (IRScNB b6432), a second from 30.0 m depth in the Oedelem borehole, pertaining to the Beernem Sand Member (Pl. 2, Fig. 21) (IRScNB b6433); a third from bed 2 (16.70 m) of the Aalter Sand Formation at its type locality of Aalter (Pl. 2, Fig. 22) (IRScNB b6434).

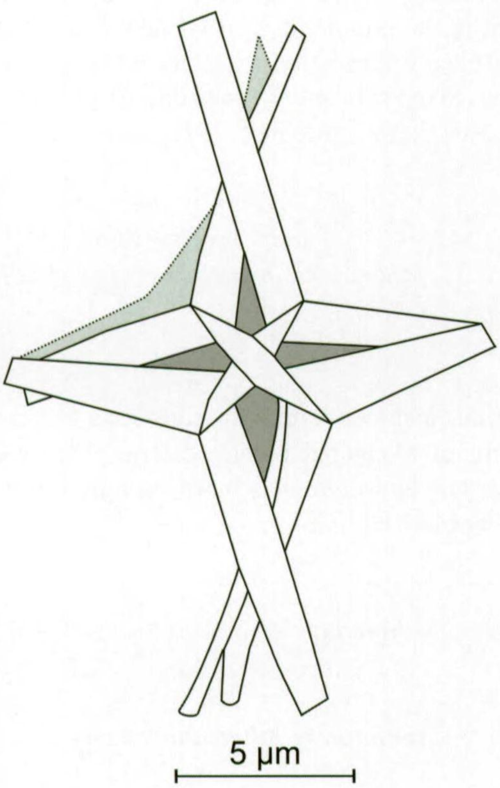


Fig. 25 – Composite drawing of the holotype of *Nannoturba jolotteana* sp. nov. (IRSNB b6431) from 103.32 m depth in the Vlakte van de Raan borehole.

Diagnosis

Large, unidirectionally compressed network of calcite laths, with a central protruding x-shaped wedge. The outline resembles a rhomb in cross-section, the diagonals of which have different dimensions.

Description

This taxon is composed of a unidirectionally compressed complex network of calcite laths, resembling a flattened octahedron, with rhombic cross-section (Fig. 25). The dimensions are highly variable. The longest diagonal reaches up to 20 µm, the second is generally around 30% shorter. The center is marked by an x-shaped protruding wedge. All calcite laths are strongly birefringent in cross-polarized light.

Dimensions

Height = 12.8 to 20.4 µm, W = 8.8 to 14.0 µm (holotype: H = 20.4 µm, W = 14.0 µm).

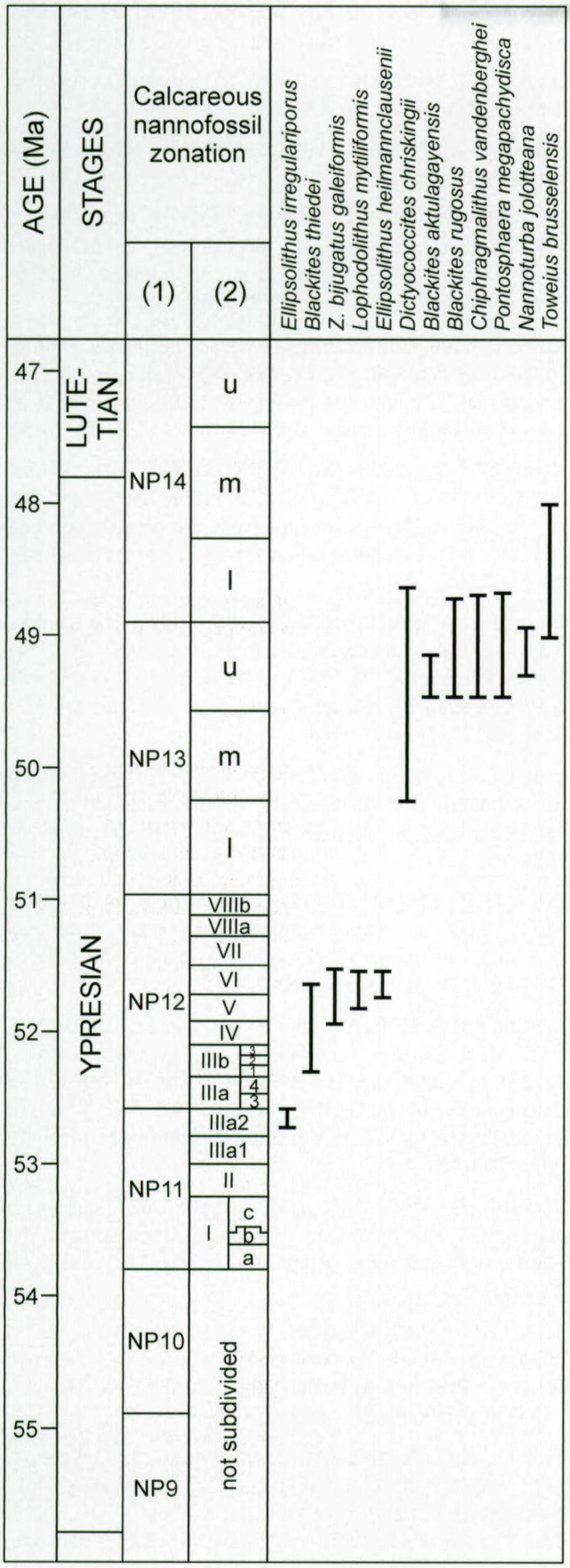
Discussion

Similar lathlike networks have already been recorded before and point to the genus *Nannoturba* (MÜLLER, 1979). *N. jolotteana* differs from all known *Nannoturba* taxa (*N. robusta* and *N. spinosa*) by its rhombic outline of which the diagonals have a different length, and which virtual shell should match an octahedron, an by its central x-shaped protruding wedge. *N. robusta* has a quadrangular disposition (Pl. 2, Fig. 17) (IRScNB b6435), the elements of which meet at angles of 90°, whereas *N. spinosa* (Pl. 2, Fig. 18) (IRScNB b6436) presents a triangular pattern, in which the elements meet at an angle of 120°.

Distribution

Up to now only known from outcrops and boreholes in Belgium, where it seems to be restricted to the Beernem Member, which corresponds to the lower part of the Aalter Sand Formation. Consequently, it has a very short range (100 to 200 k.y.) within the upper part of NP 13, and an extremely high biostratigraphical potential.

Fig. 26 – Overview of the stratigraphic ranges of the newly described taxa. Nannofossil zonations adopted: (1) MARTINI, 1971; (2) STEURBAUT, 1998 for the subdivision of zones NP 11 and NP 12; zones NP 13 and NP 14 are informally subdivided into lower (l), middle (m) and upper (u). Ages of the zonal boundaries are according to LUTERBACHER *et al.*, 2004.



Conclusions

Detailed calcareous nannofossil investigation carried out over the last decades on thousands of samples from the Lower Eocene of the North Sea Basin has led to the identification of many new taxa, twelve of which are newly described here. Some of these have also been recorded recently in the Aktulagay section in W Kazakhstan, one of the most complete calcareous Lower Eocene onshore sections worldwide, highlighting their correlation potential. Additionally, many of these new taxa present very short stratigraphic ranges (Fig. 26), which make them extremely useful for high-resolution biostratigraphy and for refined dating of sedimentary rocks from middle to high latitudes of the northern hemisphere.

Acknowledgements

The author is very grateful to J.R. Ali (Hong-Kong University), M. De Ceukelaire (RBINS), C. Dupuis (FPMons), P. Gerrienne (ULiège), C. Heilmann-Clausen (Arhus Universitet), J. Herman (RBINS), C. King (Bridport), R.W.O'B. Knox (BGS), P. Laga (RBINS), D. Nolf (RBINS) and N. Vandenberghe (K.U.Leuven), who kindly supplied samples, background information on sections and on taxonomical procedure. The author is also much obliged to H. De Potter and W. Miseur (both RBINS) for providing graphical assistance, and to F. Moorkens (RBINS) for help in sampling the borehole cores of the "Belgische Geologische Dienst". Thanks are due to A. Bornemann (Univ. Leipzig, Germany) and C. King (Bridport, UK) for the critical reading of the manuscript and helpful suggestions.

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Typescript submitted: August 31, 2011
Revised typescript received: October 3, 2011

Explanation of the Plates

The calcareous nannofossil specimens figured on the plates, as well as the negatives of micrographs, are stored at the Royal Belgian Institute of Natural Sciences (Brussels). Numbers (e.g. IRSNB b4975) refer to the collections of this institute. The following abbreviations are used: AK = Aktulagay (Kazakhstan), AL = Albæk Hoved (Denmark), ba = base, BH = borehole, c.p. = cross-polarised light, D = diameter, H = height, l = lower, L = length, m = middle, t.l. = transmitted light, u = upper and W = width.

PLATE 1

Figs 1-4 — *Zygrablithus bijugatus galeiformis* subsp. nov.
1: AL44, holotype, m-NP12, a = c.p., b = t.l., H = 8.8 µm, (IRSNB b6382); 2: AL44, paratype, m-NP12, c.p., H = 8.0 µm, (IRSNB b6383); 3: AK2, paratype, u-NP12, c.p., H = 8.0 µm, (IRSNB b6384); 4: BH 81/46A, 150 (85.67 m), l-NP12, paratype, c.p., H = 8.0 µm, (IRSNB b6385).

Fig. 5 — *Ellipsolithus irregulariporus* sp. nov.
AK101, holotype, u-NP11, c.p., a = 45°, b = 15°, L = 12.4 µm, (IRSNB b6386).

Fig. 6 — *Ellipsolithus macellus* (BRAMLETTE & SULLIVAN, 1961)
Kruishoutem BH, 41.50 m, ba-NP12, c.p., L = 13.5 µm, (IRSNB b6387).

Figs 7-11 — *Ellipsolithus heilmannclausenii* sp. nov.
7: BH 81/46A, 149 (85.12 m), paratype, l-NP12, c.p., L = 8.5 µm, (IRSNB b6389); 8: BH 81/46A, 149 (85.12 m), paratype, l-NP12, c.p., L = 7.2 µm, (IRSNB b6390); 9: BH 81/46A, 148 (84.72 m), paratype, l-NP12, c.p., L = 7.2 µm, (IRSNB b6391); 10: BH 81/46A, 139 (80.87 m), paratype, m-NP12, c.p., L = 7.2 µm, (IRSNB b6392); 11: AL43, paratype, m-NP12, c.p., L = 8.0 µm, (IRSNB b6393).

Figs 12-14 — *Pontosphaera megapachydisca* sp. nov.
12: AK189, holotype, top l-NP13, a = t.l., b = c.p., L = 18.4 µm, (IRSNB b6394); 13: AK189, paratype, top l-NP13, t.l., L = 16.0 µm, (IRSNB b6395); 14: AK50, paratype, m-NP13, t.l., L = 18.4 µm, (IRSNB b6396).

Figs 15-19 — *Dictyococcites chriskingii* sp. nov.
15: AK71, holotype, l-NP14, c.p., L = 10.4 µm, (IRSNB b6397); 16: AK189, paratype, top l-NP13, c.p., L = 8.8 µm, (IRSNB b6398); 17: AK91, paratype, u-NP13, c.p., L = 9.6 µm, (IRSNB b6399); 18: AK94, paratype, ba-NP14, c.p., L = 11.2 µm, (IRSNB b6400); 19: AK96, paratype, l-NP14, c.p., L = 9.6 µm, (IRSNB b6401).

Figs 20-22 — *Toweius brusselensis* sp. nov.
20: Knokke BH, 71.95 m, paratype, m-NP14, c.p., L = 7.6 µm, (IRSNB b6403); 21: Nederokkerzeel, level A, paratype, m-NP14, c.p., L = 6.8 µm, (IRSNB b6404); 22: AK91, paratype, u-NP13, c.p., L = 7.2 µm, (IRSNB b6405).

Figs 23-24 — *Blackites aktulagayensis* sp. nov.
23: AK189, holotype, top l-NP13, a = t.l., b = c.p., H = 9.6 µm, (IRSNB b6406); 24: AK189, paratype, top l-NP13, t.l., H = 8.0 µm, (IRSNB b6407).

Figs 25-26 — *Blackites rugosus* sp. nov.
25: AK94, holotype, ba-NP14, c.p., H = 12.0 µm, (IRSNB b6408); 26: AK189, paratype, top l-NP13, a = t.l., b = c.p., H = ? 10.4 µm, (IRSNB b6409).

Figs 27-28 — *Blackites thiedei* sp. nov.
27: AK163, holotype, l-NP12, t.l., H = 8.4 µm, (IRSNB b6410); 28: AL43, paratype, m-NP12, a = t.l., b = c.p., H = 8.0 µm, (IRSNB b6411).

Figs 29-30 — *Blackites dupuisii* (STEURBAUT, 1991) new. comb.
29: Mol BH, 388.50 m, paratype, u-NP11, c.p., H = 7.0 μm, (IRSNB b6413); 30: Mol BH, 394.70, paratype, u-NP11, a = t.l., b = c.p., H = 7.0 μm, (IRSNB b6414).

PLATE 2

Figs 1-6 — *Chiphragmalithus vandenberghei* sp. nov.
1: Vlakte van de Raan BH, 103.32 m, holotype, u-NP13, a = t.l. – low focus, b = t.l. – high focus, L = 13.6 μm, (IRSNB b6415); 2: Vlakte van de Raan BH, 103.32 m, paratype, u-NP13, a = t.l. – low focus, b = t.l. – high focus, L = 14.4 μm, x1234 (IRSNB b6416); 3: Vlakte van de Raan BH, 103.32 m, paratype, u-NP13, a = t.l. – low focus, b = t.l. – high focus, L = 13.6 μm, (IRSNB b6417); 4: Vlakte van de Raan BH, 106.62 m, paratype, u-NP13, t.l., L = 18.4 μm, (IRSNB b6418); 5: Vlakte van de Raan BH, 122.60 m, paratype, m/u-NP13, c.p., L = 16.0 μm, (IRSNB b6419); 6: AK70, paratype, l-NP14, a = t.l., b = c.p., L = 12.0 μm, (IRSNB b6420);

Fig. 7 — *Chiphragmalithus armatus* PERCH-NIELSEN, 1971
Kallo BH, 242.60 m, top-NP12, t.l., L = 10.0 μm, (IRSNB b6421).

Figs 8-14 — *Lophodolithus mytiliformis* sp. nov.
8: AL44, holotype, m-NP12, c.p., L = 16.4 μm, (IRSNB b6422); 9: AL43, paratype, m-NP12, a = c.p., b = t.l., L = 16.4 μm, (IRSNB b6423); 10: BH 81/46A, 149 (85.12 m), paratype, l-NP12, c.p., L = 11.6 μm, (IRSNB b6424); 11: BH 81/46A, 148 (84.72 m), paratype, l-NP12, c.p., L = 13.6 μm, (IRSNB b6425); 12: BH 81/46A, 147 (84.25 m), paratype, l-NP12, a = t.l., b = c.p., L = 15.2 μm, (IRSNB b6426); 13: BH 81/46A, 144 (82.92 m), paratype, l-NP12, c.p., L = 14.0 μm, (IRSNB b6427); 14: BH 81/46A, 144 (82.92 m), paratype, l-NP12, c.p., L = 14.0 μm, (IRSNB b6428).

Figs 15-16 — *Lophodolithus nascens* BRAMLETTE & SULLIVAN, 1961
15: Kruishoutem BH, 41.50 m, ba-NP12, c.p., L = 12.0 μm, (IRSNB b6429); 16: AK101, u-NP11, t.l., L = 14.4 μm, (IRSNB b6430).

Fig. 17 — *Nannoturba robusta* MÜLLER, 1979
Kallo BH, 234 m, l-NP13, c.p., L = 10.0 μm, (IRSNB b6435).

Fig. 18 — *Nannoturba spinosa* MÜLLER, 1979
Knokke BH, 234 m, l-NP13, t.l., L = 14.5 μm, (IRSNB b6436).

Figs 19-22 — *Nannoturba jolotteana sp. nov.*
19: Vlakte van de Raan BH, 103.32 m, holotype, u-NP13, t.l., H = 20.4 μm, (IRSNB b6431); 20: Vlakte van de Raan BH, 103.32 m, paratype, u-NP13, t.l., H = 14.4 μm, (IRSNB b6432); 21: Oedelem BH, 30 m, paratype, u-NP13, a = t.l., b = c.p., H = 17.6 μm, (IRSNB b6433); 22: Aalter, type-locality Molenstraat, bed 2 (16.70 m), paratype, u-NP13, c.p., H = 16.8 μm, (IRSNB b6434).

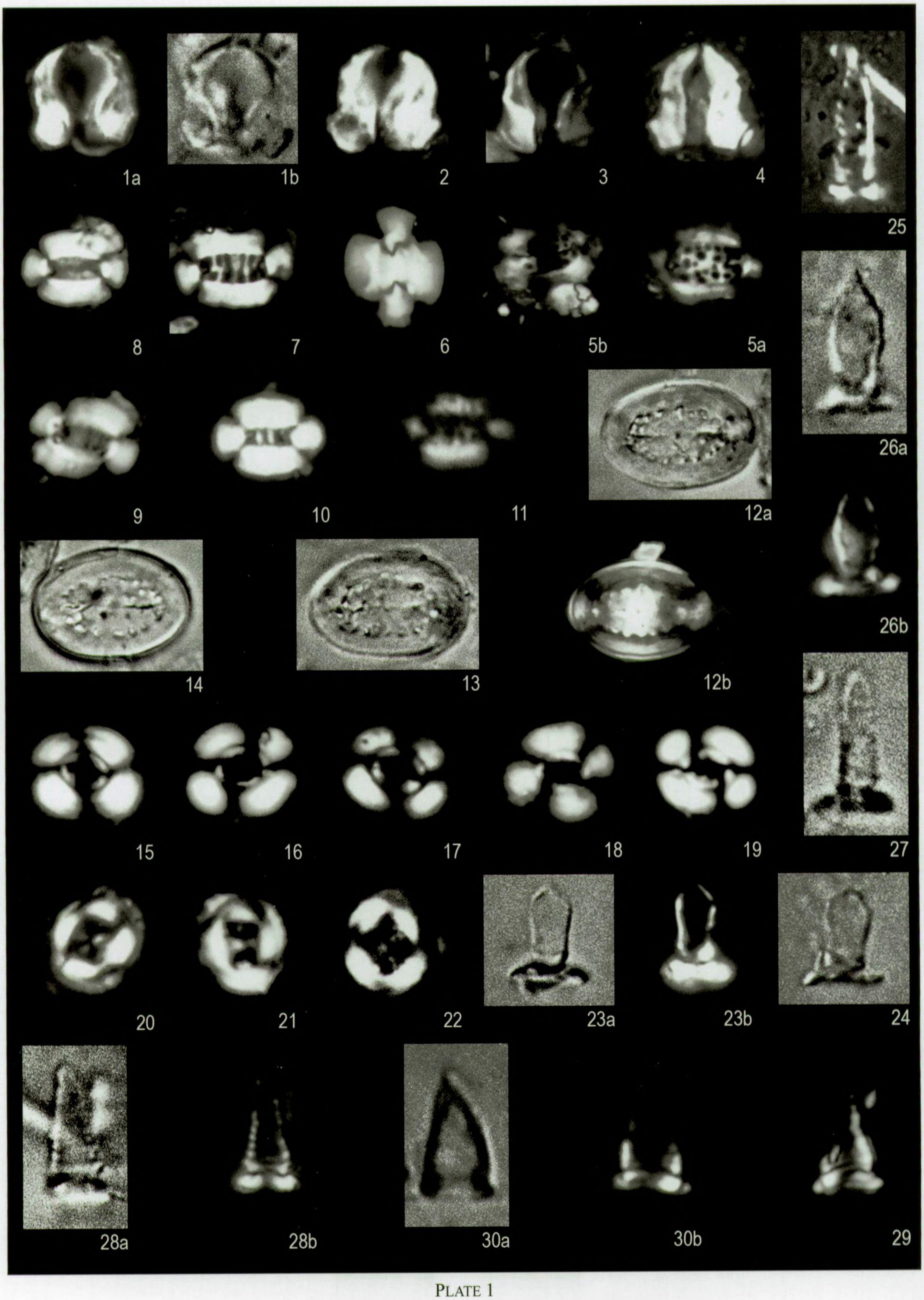
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PLATE 1


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PLATE 2