geodiversitas

2021 • 43 • 11

The Mont-des-Récollets section (N France): a key site for the Ypresian-Lutetian transition at mid-latitudes – reassessment of the boundary criterion for the base-Lutetian GSSP

Etienne STEURBAUT &
Dirk NOLF

art. 43 (11) — Published on 25 May 2021
www.geodiversitas.com

PUBLICATIONS SCIENTIFIQUES
MUSÉUM NAL HIST NATURELLE

Couverture / *Cover* :
Réalisée à partir des Figures de l'article/*Made from the Figures of the article*.

Geodiversitas est indexé dans / Geodiversitas *is indexed in:*
- Science Citation Index Expanded (SciSearch®)
- ISI Alerting Services®
- Current Contents® / Physical, Chemical, and Earth Sciences®
- Scopus®

Geodiversitas est distribué en version électronique par / Geodiversitas *is distributed electronically by:*
- BioOne® (http://www.bioone.org)

Les articles ainsi que les nouveautés nomenclaturales publiés dans *Geodiversitas* sont référencés par / *Articles and nomenclatural novelties published in* Geodiversitas *are referenced by:*
- ZooBank® (http://zoobank.org)

Geodiversitas est une revue en flux continu publiée par les Publications scientifiques du Muséum, Paris
Geodiversitas *is a fast track journal published by the Museum Science Press, Paris*

Les Publications scientifiques du Muséum publient aussi / *The Museum Science Press also publish:* ***Adansonia***, ***Zoosystema***, ***Anthropozoologica***, ***European Journal of Taxonomy***, ***Naturae***, ***Cryptogamie*** **sous-sections** ***Algologie***, ***Bryologie***, ***Mycologie, Comptes Rendus Palevol***

Diffusion – Publications scientifiques Muséum national d'Histoire naturelle
CP 41 – 57 rue Cuvier F-75231 Paris cedex 05 (France)
Tél. : 33 (0)1 40 79 48 05 / Fax : 33 (0)1 40 79 38 40
diff.pub@mnhn.fr / http://sciencepress.mnhn.fr

ISSN (imprimé / *print*) : 1280-9659/ ISSN (électronique / *electronic*) : 1638-9395

The Mont-des-Récollets section (N France): a key site for the Ypresian-Lutetian transition at mid-latitudes – reassessment of the boundary criterion for the base-Lutetian GSSP

Etienne STEURBAUT
Royal Belgian Institute of Natural Sciences, OD Earth and History of Life,
Vautierstraat 29, B-1000 Brussel (Belgium)
and Department of Earth, and Environmental Sciences,
KU Leuven, Celestijnenlaan 200E, B-3001 Leuven (Belgium)
etienne.steurbaut@naturalsciences.be (corresponding author)

Dirk NOLF
Royal Belgian Institute of Natural Sciences, OD Earth and History of Life,
Vautierstraat 29, B-1000 Brussel (Belgium)

Submitted on 2 October 2018 | accepted on 20 January 2020 | published on 25 May 2021

urn:lsid:zoobank.org:pub:07D1F5A8-98E2-40F1-A716-D25CB975EA4C

Steurbaut E. & Nolf D. 2021. — The Mont-des-Récollets section (N France): a key site for the Ypresian-Lutetian transition at mid-latitudes — reassessment of the boundary criterion for the base-Lutetian GSSP. *Geodiversitas* 43 (11): 311-363. https://doi.org/10.5252/geodiversitas2021v43a11. http://geodiversitas.com/43/11

ABSTRACT
Re-excavation of the famous Mont-des-Récollets quarry in northern France and re-interpretation of the adjacent Cassel borehole have led to the reconstruction of one of the most complete Upper Ypresian and Lutetian stratigraphic successions of the southern North Sea Basin. It includes the entire suite of formations and members, from the top of the Hyon Sand Formation (top NP12) to the base of the Maldegem Formation (mid-NP15), originally defined in central Belgium, extending the lateral distribution of most of these units up to northern France. The similarity in lithofacies and calcareous nannofossil assemblages and the identification of *in situ* specimens of *Nummulites laevigatus* (Bruguière, 1792) and *Campanile giganteum* (Lamarck, 1804) at the Mont-des-Récollets bear witness to direct north-south connections between the Belgian Basin and the Paris Basin during Biochron NP14 and early Biochron NP15. However, direct connections have only been intermittent. During late Biochron NP12 and Biochron NP13, both basins became disconnected because of lowering of the global sea level in combination with uplift of the Paris Basin. The massively reworked large-sized *N. laevigatus* and the presence of *N. laevigatus*-bearing sandstone blocks and lignitic pebbles at the base of the Lede Formation indicate a major erosion phase at the NP14-NP15 Biochron transition in the Belgian Basin. This was probably due to uplift of the Brabant Massif. The new Mont-des-Récollets data, including the introduction of a new genus (*Luminocanthus* n. gen.) and ten new species (*Blackites minusculus* n. sp., *Blackites praeinflatus* n. sp., *Luminocanthus eolutetiensis* n. gen., n. sp., *Luminocanthus plenilutetiensis* n. gen., n. sp., *Martiniaster cecellanoriae* n. sp., *Nannoturba joceliniae* n. sp., *Sphenolithus quadricornutus* n. sp., *Sphenolithus recolletensis* n. sp., *Trochoaster nodosus* n. sp. and *Trochastrites pyramidalis* n. sp.) have allowed to substantially refine the calcareous nannofossil stratigraphy. The subdivision of Zone NP13 into 3 subzones (NP13-a to NP13-c) as well as the major nannofossil

turnover at the base of Zone NP14 and the nine nannofossil-events within Zone NP14 have been recognised throughout the Belgian Basin. Several of these have been recorded in the Paris Basin, the Hampshire Basin and the Aquitaine Basin, highlighting their interbasinal correlation potential. The nannofossil data provide for the first time evidence that the base of the 'Chaumont-en-Vexin sands' (term informally introduced herein to designate the base of the historical Lutetian stratotype) and the base of Unit A4 in the upper Aalter Sand Fomation are coeval or nearly coeval. This is also the case for the base of the overlying units, the 'Glauconie Grossière s.s.' (as redefined in the Paris Basin by Blondeau in 1980) and the Brussel Sand Formation ('Bruxellian' as originally defined in Belgium by Dumont in 1839). This investigation and its continuation, detailed in a forthcoming study of the Brussel Sand Formation, also revealed that the internationally accepted base-Lutetian boundary criterion (lowest occurrence or LO of *Blackites inflatus*) is difficult to apply in the North Sea Basin because of the extreme rarity of this marker species (e.g. not recorded at the Mont-des-Récollets). Worst of all, its strict application would imply that the major part of the Brussel Sand Formation and both the 'Chaumont-en-Vexin sands' and the lower part of the overlying 'Glauconie Grossière s.s.', base of the historical Lutetian stratotype, should be of Ypresian age, which is a *contradictio in terminis*. To resolve this contradiction, it is suggested to amend the original criterion (LO of *B. inflatus*), proved to be inadequate at middle and high latitudes and diachronous at low latitudes, and to replace it by the lowest occurrence (LO) of *Discoaster sublodoensis*. The latter is part of a major calcareous nannofossil turnover (= BALCAT-event), which has been identified at the base of the historical Lutetian stratotype. This new proposal would mean that the base of the Lutetian should be lowered down in the Gorrondatxe GSSP, probably by about 130 m (*c.* 1.3 Myr), to a level within the middle of Chron C22n, around 800 kyr earlier than the LO of *Turborotalia frontosa*. If this is the case, then the base would range in age between 49.11 Ma and 49.20 Ma, depending on the age model used.

KEY WORDS
France,
Mont-des-Récollets,
lithostratigraphy,
biostratigraphy,
calcareous nannofossils,
Ypresian-Lutetian
transition,
new genus,
new combination,
new species.

RÉSUMÉ

La coupe du Mont-des-Récollets (N de la France): un site-clé pour la transition Yprésien-Lutétien aux latitudes moyennes – réévaluation du critère du GSSP de la base du Lutétien.

De nouvelles fouilles dans la célèbre carrière du Mont-des-Récollets, dans le nord de la France, associées à la réinterprétation du sondage de Cassel adjacent, ont permis de reconstituer une succession stratigraphique d'âge Yprésien supérieur et Lutétien, parmi les plus complètes de la partie méridionale du Bassin de la Mer du Nord. Cette succession comprend l'entièreté des formations et membres, à partir de la Formation d'Hyon (sommet de la zone NP12) jusqu'à la Formation de Maldegem (milieu de la zone NP15), tous originellement définis dans le centre de la Belgique. Cela montre pour la première fois que la plupart de ces unités s'étendent jusqu'au nord de la France. La similitude des lithofaciès et assemblages à nannofossiles calcaires, ainsi que la présence de spécimens *in situ* de *Nummulites laevigatus* (Bruguière, 1792) et de *Campanile giganteum* (Lamarck, 1804) dans la coupe du Mont-des-Récollets, témoignent des connections marines directes nord-sud entre le Bassin belge et le Bassin parisien au cours du Biochron NP14 et au début du Biochron NP15. Toutefois, ces connections directes n'étaient qu'épisodiques; entre la fin du Biochron NP12 et le début du Biochron NP14 les deux bassins furent complètement déconnectés suite à l'action combinée de la baisse du niveau marin global et du soulèvement du Bassin parisien. Le remaniement massif de *N. laevigatus* de grande taille et la présence de fragments de grès à *N. laevigatus* et de boules de lignites à la base de la Formation de Lede sont les témoins d'une phase d'érosion majeure ayant affecté l'ensemble du Bassin belge. Probablement initié par le soulèvement du Massif de Brabant, cet évènement se manifeste à la transition du Biochron NP14 au Biochron NP15. Les données nouvelles sur le Mont-des-Récollets, y compris l'introduction d'un genre nouveau (*Luminocanthus* n. gen.) et de dix espèces nouvelles (*Blackites minusculus* n. sp., *Blackites praeinflatus* n. sp., *Luminocanthus eolutetiensis* n. gen., n. sp., *Luminocanthus plenilutetiensis* n. gen., n. sp., *Martiniaster cecellanoriae* n. sp., *Nannoturba joceliniae* n. sp., *Sphenolithus quadricornutus* n. sp., *Sphenolithus recolletensis* n. sp., *Trochoaster nodosus* n. sp. et *Trochastrites pyramidalis* n. sp.), permettent d'affiner substantiellement la résolution biostratigraphique sur base des nannofossiles calcaires. Les trois sous-zones de la Zone à nannofossiles NP13 (NP13a à NP13c), le renouvellement de la nannoflore à la base de la Zone NP14 et les 9 événements biotiques présents au sein de cette Zone NP14 sont reconnus à travers le Bassin belge. Certains d'entre eux ont été identifiés dans le Bassin parisien, le Bassin du Hampshire et le Bassin d'Aquitaine, ce qui met en évidence leur grand potentiel de corrélation au niveau européen. Les données des nannofossiles calcaires démontrent pour la première fois que la base des 'sables de Chaumont-en-Vexin' (terme introduit ici de façon informelle pour désigner la base du Lutétien du Bassin parisien) et la base de l'Unité A4 dans le sommet de la Formation d'Aalter sont contemporaines ou quasi contemporaines. Il en est de même pour la base des unités sus-jacentes, la 'Glauconie Grossière s.s ' (telle que redéfinie par Blondeau 1980) et la Formation de Bruxelles ('Bruxellian' comme originellement défini par

Dumont en 1839). Cette étude et sa continuation, détaillée dans une note prochaine sur la Formation de Bruxelles, ont également révélé que la définition originelle de la base du Lutétien telle qu'adoptée internationalement (la première occurrence de *Blackites inflatus*) est difficile à appliquer dans le Bassin de la Mer du Nord, vue l'extrême rareté du taxon marqueur (par exemple non retrouvé au Mont-des-Récollets). Pire encore, l'application stricte de cette définition impliquerait que la majeure partie de la Formation de Bruxelles, ainsi que les 'sables de Chaumont-en-Vexin' et la partie inférieure de la 'Glauconie Grossière s.s.', marquant la base du stratotype historique du Lutétien, seraient d'âge Yprésien, ce qui est une *contradictio in terminis.* Afin de résoudre ce problème, nous suggérons d'amender le critère initial (PO de *B. inflatus*), qui s'avère être inadéquat aux latitudes hautes et moyennes et diachronique aux latitudes basses, et de le remplacer par la première occurrence (PO) de *Discoaster sublodoensis*. Cette apparition fait partie d'un renouvellement majeur des assemblages à nannofossiles calcaires (l'événement BALCAT), identifié à la base du stratotype historique du Lutétien. Cela signifierait que la base du Lutétien devrait être abaissée d'environ 130 m (*c.* 1.3 Ma) dans le GSSP de Gorrondatxe, jusqu'à un niveau au milieu du Chron C22n, à quelques 800 ka en dessous de la base de la PO de *Turborotalia frontosa*. Ainsi, en fonction du modèle d'âge adopté, l'âge de la base du Lutétien varierait entre 49.11 Ma et 49.20 Ma.

MOTS CLÉS
France,
Mont-des-Récollets,
lithostratigraphie,
biostratigraphie,
nannofossiles calcaires,
transition Yprésien-Lutétien,
genre nouveau,
combinaison nouvelle,
espèces nouvelles.

INTRODUCTION

The Mont-des-Récollets or Récollets Hill (highest point at 159 m above sea-level: 50°48'02.74"N, 2°30'23.06"E; map-sheet: XXIII-Cassel; x = 62.000, y = 344.500; z = 159.000) and its nearby twin Cassel Hill constitute the western end of an east-west oriented range of hills, extending through central Belgium and northern France (Fig. 1). These Flemish Hills roughly subdivide the Flemish Plain into a northern Dutch-speaking sector and a southern French-speaking sector. Their tops, which rise about 100 m above the surrounding plain, are formed of lower Eocene glauconitic sands and middle Eocene calcareous sands and clays. Ferruginous sandstones, which were recently assigned to the Flemish Hills Formation and for which a late Eocene age has been suggested (Houthuys 2014), make up the hills' caps. Their presence protected the hill-zone from post-Miocene erosion and denudation, which in the adjacent areas exceeded 100 m.

The stratigraphy of the Cassel area has been discussed since the dawn of geology (Desmyttere 1826; Elie de Beaumont 1833; d'Archiac 1839; Lyell 1852; amongst many others). Ortlieb & Chellonneix (1870) were the first to give a detailed description of the Mont-des-Récollets outcrop, identifying 27 beds in the main quarry ('La Grande Carrière'). Leriche (1921) carried out the most comprehensive and best-documented study of the geology of the Cassel area, mainly focusing on the Mont-des-Récollets outcrop (Fig. 2). In his remarkable monograph he described several sections on the Mont-des-Récollets, based on observations dating back to 1905, when the sands and clays were intensely quarried for industrial applications and brick-making. In the early 1920s the 'Grande Carrière' was already abandoned and soon afterwards progressively filled in. As a result, subsequent references to the stratigraphy of the 'Grande Carrière', e.g. in Feugueur (1963), rely entirely upon the observations of Ortlieb & Chellonneix (1870) and Leriche (1921). However, additional information was gained through the study of the Western quarry at the Mont-des-Récollets (Leriche 1938) and the Cassel borehole (Blondeau *et al.* 1972) (Fig. 3). The different units in the Cassel borehole were dated on the basis of multidisciplinary microfossil investigations, including calcareous nannofossils, although with only poor resolution (Lezaud 1972).

In the middle of the 1980s the authors of the present study re-investigated the Mont-des-Récollets outcrop zone. The discovery of a small, 10 m-wide flat zone, surrounded by gentle hill slopes with dense vegetation and a few large trees, led to retracing the famous central quarry or 'Grande Carrière'. During the successive fieldwork campaigns the old quarry front was re-exposed after removing tons of quarry fill. A 14 m deep step-wise constructed pit was dug out from the top of the Lede Sand Formation down to the top of the Aalter Sand Formation (Figs 4; 8; 9). The front of the Western quarry, along the Dunkerque-Lille road, first described by Leriche in 1938 (1938: 81), was freshened up with a bulldozer (Figs 5; 6). Several shallow auger holes were drilled in the floor of both quarries in order to provide good overlaps between the quarries themselves and with a series of boreholes carried out at the 'Tir des Anglais' (= shooting-range of the English Army during the second World War), at about 300 m SE of the 'Grande Carrière'. These holes, drilled with water-injection, reached depths of about 16 m (Fig. 4). The Mont-des-Récollets sections were visited during the geological field trip of the 'Association des Géologues du Bassin de Paris' (AGBP) in May 1990. The geological outline of this field trip, including a location map and a simplified lithological draft of the Mont-des-Récollets sections, was published shortly thereafter (Nolf & Steurbaut 1990). The map and some of the logs were refigured in the excursion guide presented at the occasion of the 8th International Palynological Congress at Aix-en-Provence, France (Schuler *et al.* 1992). Some of the figures were redrawn subsequently and included in the compilation work on the sequence stratigraphic interpretation of the Belgian Tertiary (Vandenberghe *et al.*

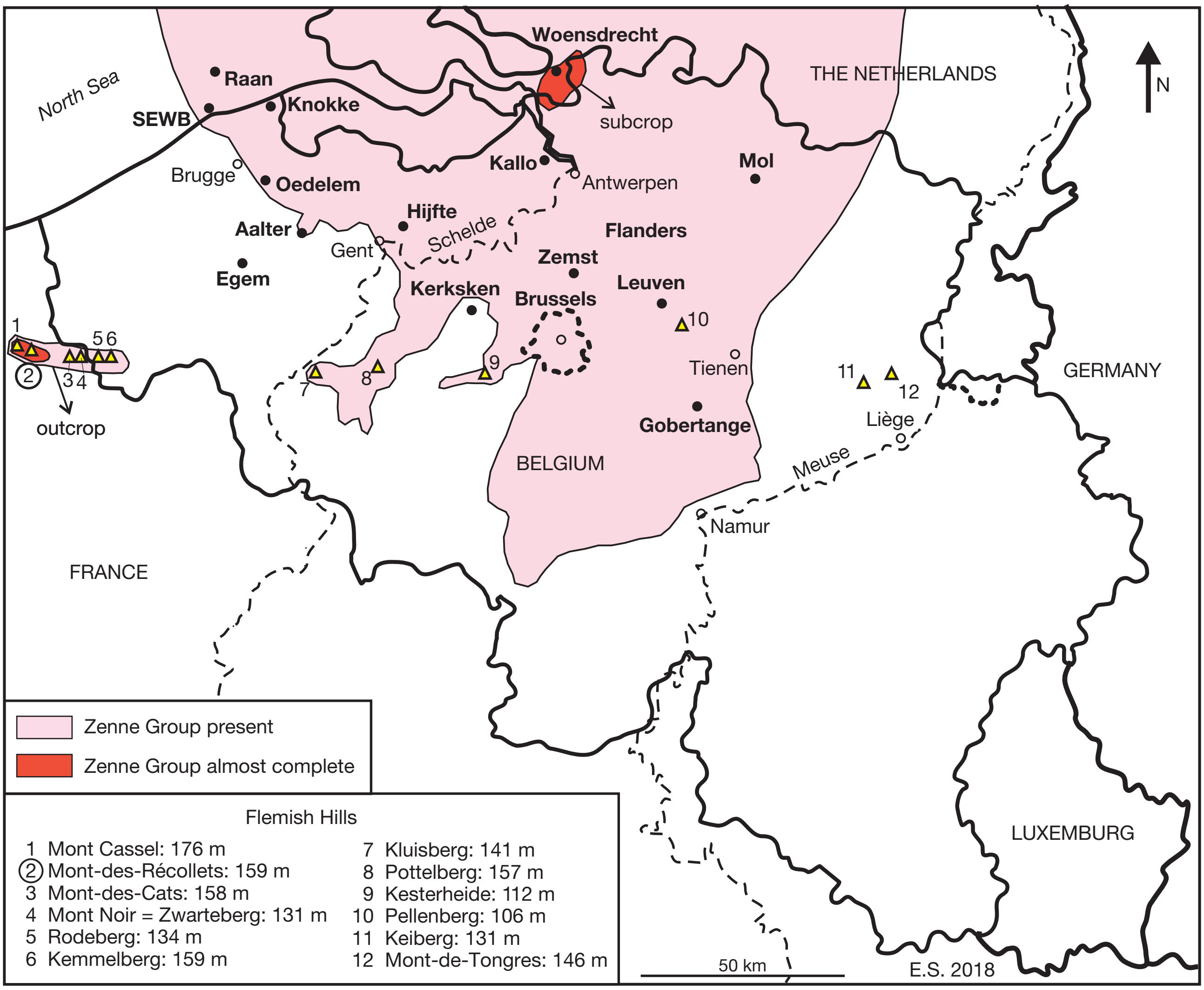


Fig. 1. — Current distribution of the upper Ypresian to lower Lutetian Zenne Group in the southern North Sea Basin, with location of the Mont-des-Récollets and additional outcrop and borehole (**BH**) sections studied herein (see Appendix 1 for details). The dark red coloured zones mark the areas where the Zenne Group, including in ascending order the Aalter Sand Formation, the Brussel Sand Formation and the Lede Sand Formation, is almost complete.

1998). Fobe & Spiers (1992) and, later on, Hooyberghs (1999) used these documents to calibrate their respective lithological and foraminiferal data. During the last decade the Mont-des-Récollets outcrops have not been subject of further investigations. However, progress was made in the understanding of the stratigraphy of the different units encountered at Mont-des-Récollets: Gentbrugge Formation in the Zemst area (Steurbaut *et al.* 2015), Brussel Sand Formation in the Brussels area (Damblon & Steurbaut 2000) and Lede Sand Formation in the Brussels area (Herman *et al.* 2001) and in the Oosterzele-Balegem area (Smith *et al.* 2004). Interpretation and correlation of the Mont-des-Récollets strata were greatly advanced by the recent introduction of several new calcareous nannofossil taxa (Steurbaut 2011) and by the high resolution nannofossil studies of a series of ODP borehole sections in the Atlantic (Agnini *et al.* 2014) and of several outcrop sections in Belgium (Steurbaut *et al.* 2015) and in the Aquitaine Basin (Lin *et al.* 2017).

This study discusses the stratigraphical significance of the almost 100 m thick Mont-des-Récollets succession, believed to represent one of the most complete and most expanded upper Ypresian to middle Lutetian outcrop sections of the North Sea Basin (Fig. 1). It aims at clarifying the biostratigraphical and sequence stratigraphical context of the Ypresian-Lutetian boundary interval, through detailed analyses of lithological units and calcareous nannofossils. Consequently, it will represent one of the first mid-latitude test-cases for the identification of the base of the Lutetian Stage, outside its GSSP-defined stratigraphical context in Northern Spain (Gorrondatxe Section: Payros *et al.* 2009, 2012; Molina *et al.* 2011) and other low latitude contemporaneous sections in Southeast Spain (Tori & Monechi 2013) and Northern Italy (Franceschi *et al.* 2015). The upper, about 20 m thick, post-Eocene or late Eocene (*sensu* Houthuys 2014) part of the section, which is badly exposed and heavily weathered, has not been studied in detail.

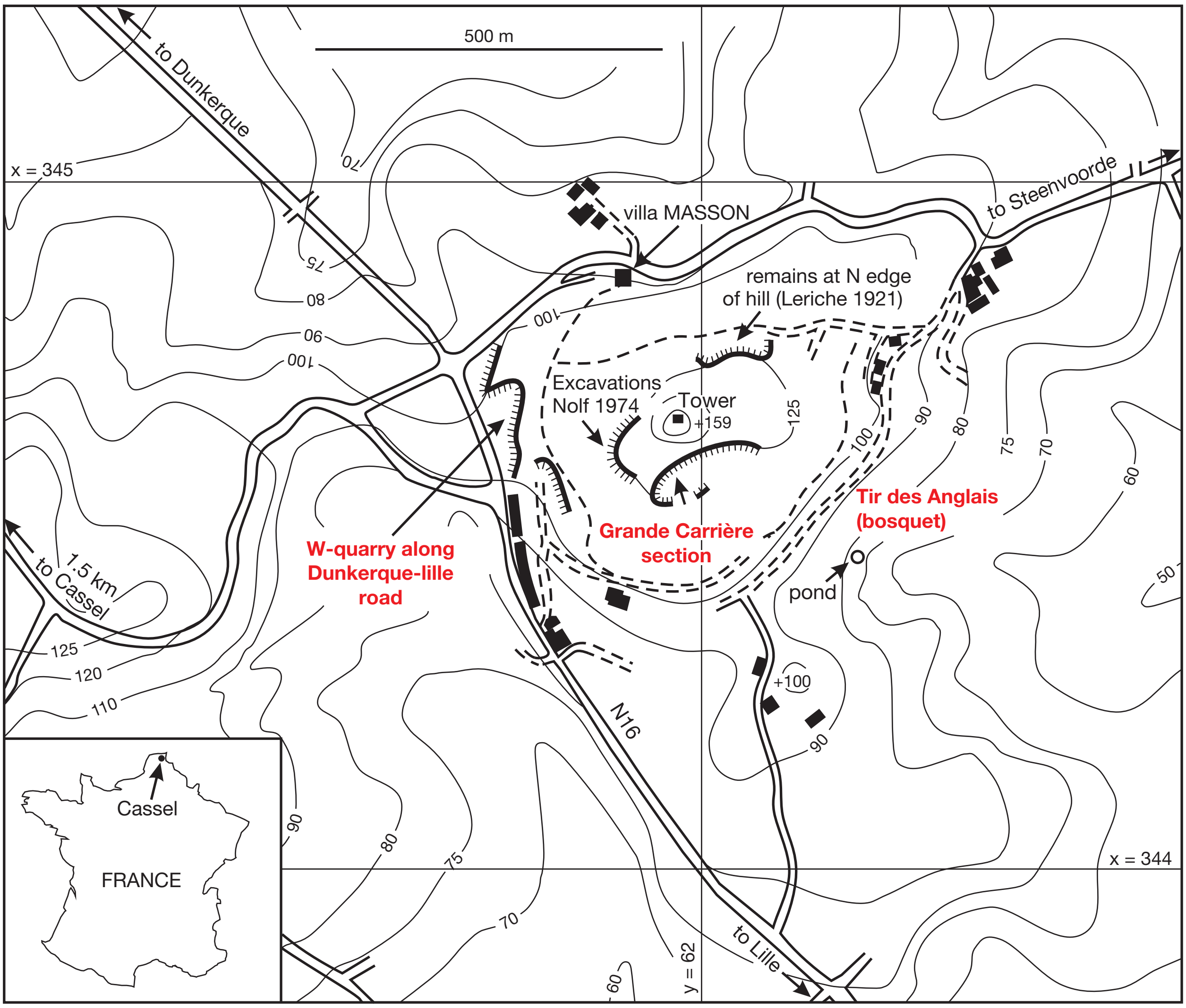


Fig. 2. — Map with the location of the major Mont-des-Récollets quarries and sections studied herein.

PREVIOUS LITHOSTRATIGRAPHIC INTERPRETATIONS OF THE MONT-DES-RÉCOLLETS SECTION

Leriche (1921) up to the late 1980's

For his interpretation of the stratigraphical succession in the Cassel area, Leriche (1921) integrated the commonly accepted late 19th century views and concepts on Belgian Tertiary stratigraphy with his own paleontologically driven new insights in NW European geology. He grouped the different strata into six major categories or stages, in ascending order the Ypresian, the Bruxellian, the Ledian, the Bartonian, and last but not least the Diestian and Amstelian, both incorporated into the Pliocene (Fig. 3). Feugueur (1963) and Blondeau *et al.* (1972) essentially adopted Leriche's stratigraphic framework in their study of the Mont-des-Récollets outcrop and of the Cassel borehole respectively. However, the lower part of Leriche's Bruxellian, the glauconitic sands, were incorporated into the upper Ypresian by these authors and termed 'Zone à Turritelles et à *Cardita planicosta*' (Feugueur 1963) or Aalter Sands (Blondeau *et al.* 1972).

Leriche's detailed observations resulted in the introduction of a detailed chronostratigraphic framework, the general structure (units and limits) of which is more or less valid today (Fig. 3). The terminology, however, underwent substantial modifications. Through the years most of the stage names used by Leriche have become obsolete (Bruxellian, Ledian; see De Geyter *et al.* 2006 for a review) or were progressively reconverted into a new lithostratigraphic terminology (see material and methods).

Nolf & Steurbaut (1990)

In their summary on the stratigraphy of the Mont-des-Récollets, presented on the occasion of the AGBP geological field trip, Nolf & Steurbaut (1990) identified the following units (in descending order): the "Diestian", resting on the Ursel Member, the Asse Member and the 'Bande Noire', which were grouped into the Kallo Formation. The latter overlies a series of formations, including, in descending order, the Lede Formation, the Brussel Formation, the Aalter Formation, the Vlierzele Formation and the Ieper Formation. No further stratigraphic details were given by these authors, except for the location of the stone layers and some conspicuous fossiliferous levels.

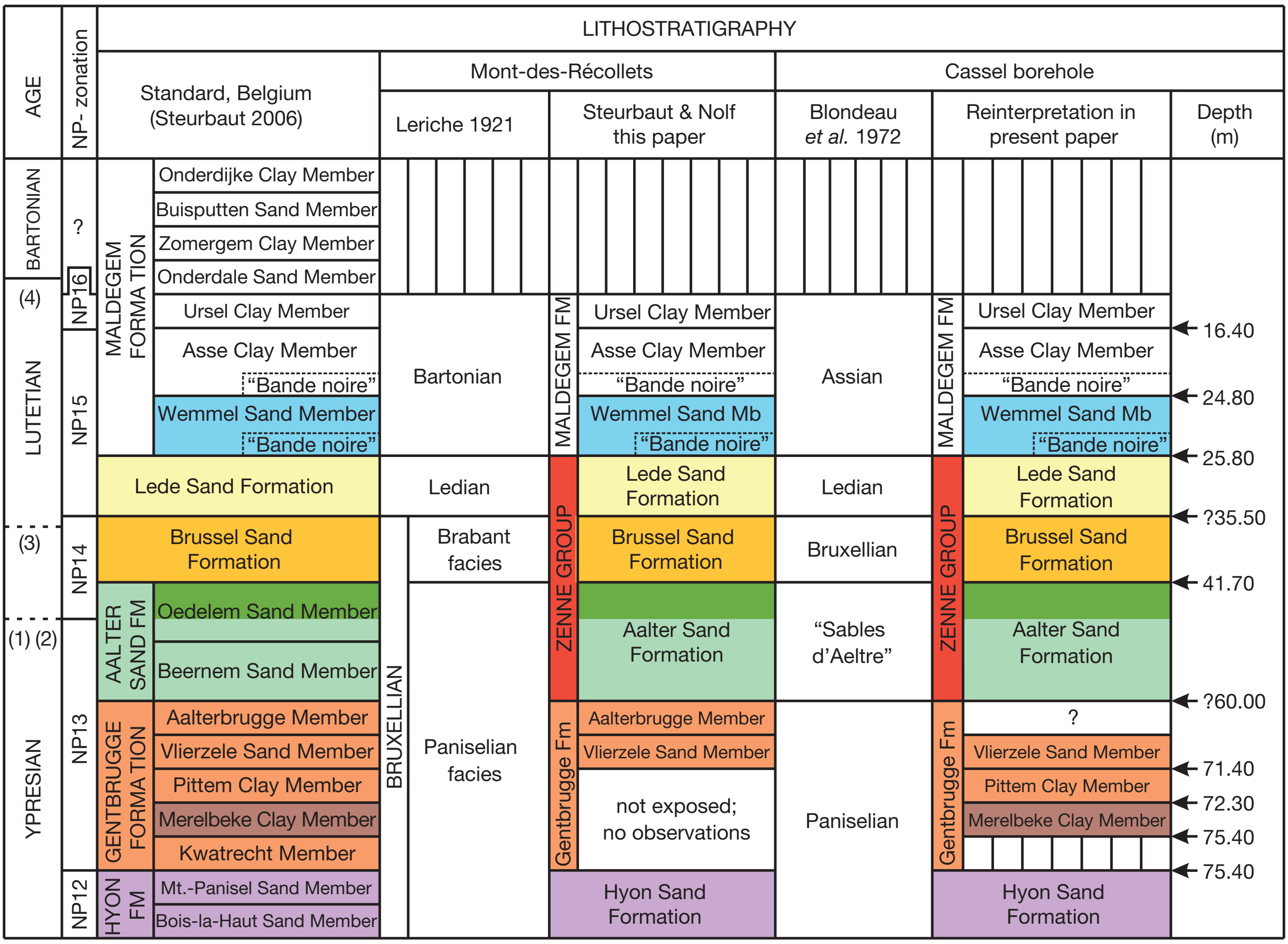


FIG. 3. — Lithostratigraphic interpretation of the Mont-des-Récollets outcrop section and the Cassel borehole section and its correlation with previous classifications (the coloured intervals are studied herein): **1**, base of the Lutetian as defined until 2004 (*Hantkenina*-event, close to the LO of *Discoaster sublodoensis*); **2**, base of the Lutetian Stage as proposed herein, based on investigation of the historical Lutetian stratotype (LO of *Discoaster sublodoensis*); **3**, base of the Lutetian as defined by its GSSP in northern Spain (LO of *Blackites inflatus*); **4**, base of the Bartonian based on dinoflagellate cyst correlations with the Barton Beds in England (De Coninck 1995).

MATERIAL AND METHODS

The Mont-des-Récollets section is a composite of several outcrop and borehole sections, ranging from the top of the hill at 159 m above mean sea level standard N.G.F. ('le nivellement general de la France') to about 63 m N.G.F. The absolute height indications are obtained through precise levelling starting from the top of the hill at 159 m. All the values mentioned here are calibrated against this N.G.F. standard. For reasons of readability the notion 'N.G.F.' will not be endlessly repeated throughout the text. The oldest sediments were penetrated in a borehole on the southeast flank of the Mont-des-Récollets (at the 'Tir des Anglais'). Due to the drilling methodology (flushing), only small sandy clay chips could be recovered, together with some macrofossils and glauconite grains. Taking into account the exact position of the different sections (Fig. 4), it is clear that about 14 m section could not be investigated, mainly because of the drilling technique (shallow auger holes; the water-injection method could not be applied in the western quarry) and of the presence of a rather thick Quaternary cover or of slope debris on the southeast flank of the hill. Fortunately, analysis of the topographic situation and the lithological descriptions of the sediments in the nearby Cassel borehole, allowed the reconstruction of the entire succession.

The lithostratigraphic nomenclature adopted here is from Steurbaut (2015), following earlier recommendations by Steurbaut (1998; first formal subdivision of the lower Ieper Group in formations and members), Laga *et al.* (2002; nomenclature of the Paleogene formations) and Steurbaut (2006; review of Ypresian stratigraphy). It differs from that in Nolf & Steurbaut (1990), essentially because of updating of the Ypresian terminology, including downgrading of the Vlierzele Formation to Member status and upgrading the Ieper Formation to group status. The Egem Sand Member, the Bois-la-Haut Sand Member and the Mont-Panisel Sand Member, subdivisions of the former Ieper Formation, were in 2015 regrouped into the Hyon Sand Formation (the latter was introduced by Steurbaut & King 1994 and updated in Steurbaut 2011). The Kwatrecht Member (De Moor & Geets

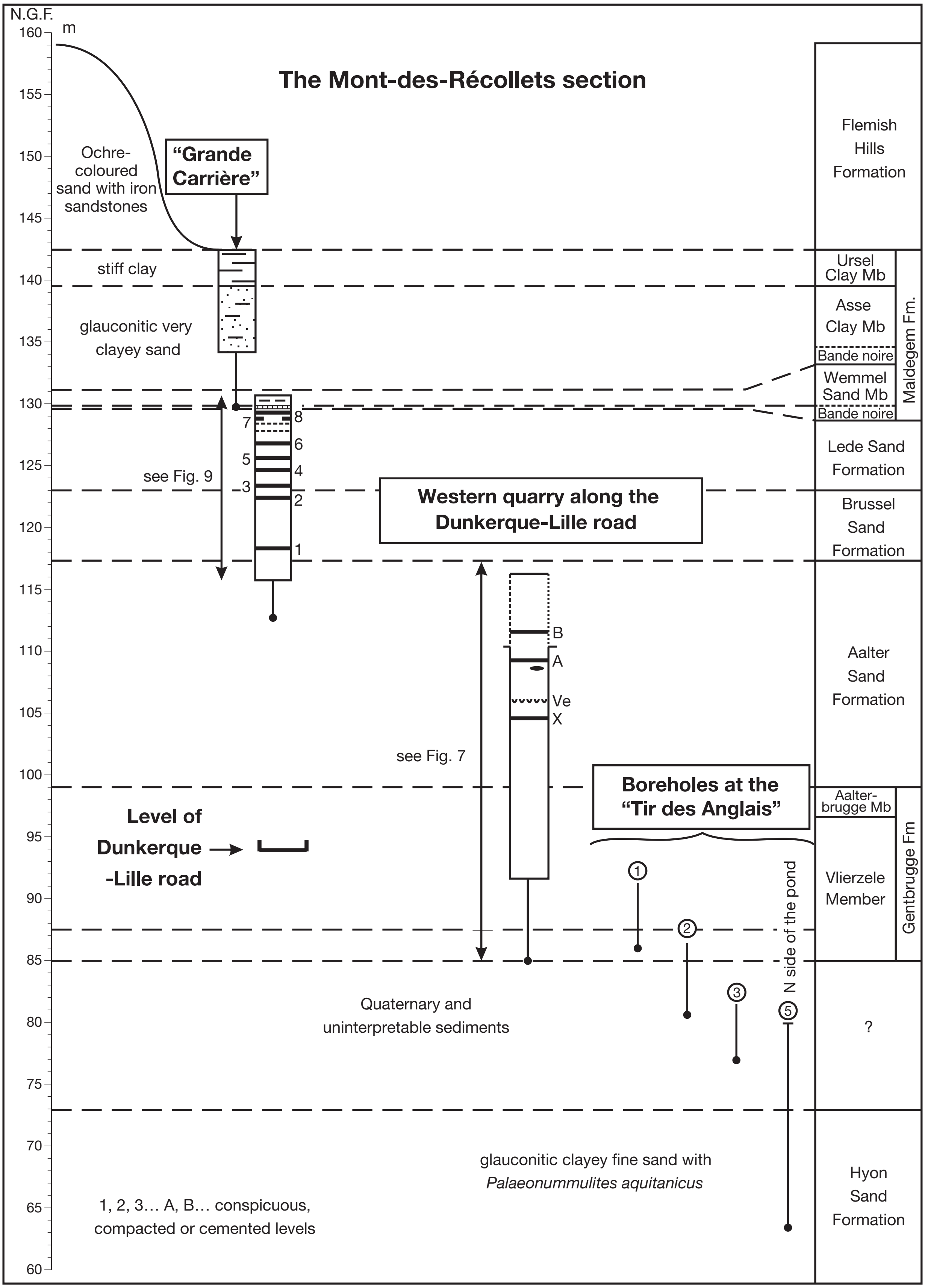


Fig. 4. — Lithostratigraphic and topographic positioning of the main quarries and boreholes investigated at the Mont-des-Récollets.

1974; a controversial term validated by Steurbaut & Nolf 1986), the Merelbeke Clay Member (De Moor & Germis 1971), the Pittem Clay Member (Geets 1979), the Vlierzele Sand Member (Kaasschieter 1961) and the Aalterbrugge Sand Member (Hacquaert 1939) are incorporated into the Gentbrugge Formation. This term replaces the previous term Gent Formation (Maréchal 1994; Wouters & Vandenberghe 1994), preoccupied for a unit within the Quaternary of Belgium (Laga *et al.* 2002: 140). An extended overview of the lithostratigraphy of the Ieper Group is given in Steurbaut *et al.* 2016a. The term Brussel Sand Formation, as used herein, corresponds to the classical Bruxellian concept of Dumont (1839), subsequently adopted by Leriche (1912, 1939). In its type-area this formation consists of poorly glauconitic whitish fine to medium-grained quartz sands, generally between 5 m to 10 m thick. Its thickness increases up to several tens of meters (? 80 m) in a 15 km wide trough between Brussel and Leuven (Houthuys 1990, 2011; Damblon & Steurbaut 2000: fig. 5). The Maldegem Formation (Jacobs & Sevens 1994) equals the earlier terms Kallo Complex (Gulinck 1969), Meetjesland Formation (Jacobs 1978) and Kallo Formation (Jacobs & Sevens 1988), preoccupied for other lithostratigraphic units in Belgium. It consists of an alternation of clays and sands, the succession of which is shown in Fig. 3. The base of the Maldegem Formation is complex and very heterogeneous throughout the Belgian Basin. It is represented by the Wemmel Sand Member (Vincent & Lefèvre 1872) in the area north and east of Brussels (Wemmel, Schepdaal, Zemst, etc.) with thickness of about 9 m (cf. Steurbaut *et al.* 2015). In the centre of Gent (Blandijnberg or 'Colline de Saint-Pierre' auct.) it is reduced to about 1 m, including a basal, 5 to 10 cm thick, glauconite bed (Delvaux 1886; Hacquaert 1936; Leriche 1943a). A second somewhat thicker glauconite bed, which rapidly passes upward into glauconitic clays of the Asse Clay Member, overlies the Wemmel Sands in the Gent area.

The chronostratigraphic interpretation of the Mont-des-Récollets section has also undergone fundamental modifications since Leriche. The term Bruxellian (obsolete now) as used by Leriche (1921, 1943a) corresponds in modern terminology to the combination of Hyon Sand Formation, Gentbrugge Formation, Aalter Sand Formation and Brussel Sand Formation, while the term Lede Sand Formation has replaced the ancient stage name Ledian. Calcareous nannofossil (Steurbaut 1986) and dinoflagellate cyst investigations (De Coninck 1995) also revealed that the 'Bande Noire' and the overlying Asse and Ursel Clays do not belong to the Bartonian, as thought by Leriche, but have to be included, together with the Brussel Sand Formation (or part of it, depending on the placement of the base of the Lutetian, see Fig. 3) and the Lede Sand Formation in the Lutetian.

Sixty samples were processed for calcareous nannofossil investigation following the preparation and investigation procedures explained by Steurbaut & King (1994) and Steurbaut & Sztrákos (2008), of which 39 proved to be productive. The taxonomy adopted in this work is essentially based on Perch-Nielsen (1985), taking into account the modifications by Wei & Wise (1989), Varol (1992), Young & Bown (1997), Aubry (1999), Bown (2005), Aubry & Bord (2009), Shamrock (2010b) and Steurbaut (2011). The new and poorly known taxa are discussed according to the alphabetic order of the families to which they belong.

Abbreviations

Calcareous nannofossil species ranges.

HO	highest occurrence;
HCO	highest consistent occurrence;
LO	lowest occurrence;
LCO	lowest consistent occurrence;
NP	calcareous nannoplankton zone – Paleogene.

Dimensions

d	diameter;
l	length;
h	height;
hab	height apical blades;
hds	height dorsal spine;
hle	height lateral elements;
hpc	height proximal column;
hpp	height proximal portion;
wm	maximum width;
wmab	maximum width apical blades;
wbp	width basal plate;
wpp	width proximal portion.

RESULTS

Lithostratigraphic review of the Mont-des-Récollets section

The Mont-des-Récollets is one of the few places in the southern North Sea Basin where the upper Ypresian to lower Lutetian Zenne Group is almost complete (Fig. 1). The lithostratigraphic units identified at this site and in the adjacent Cassel area are displayed in Fig. 3. The topographic and stratigraphic positions of the different subsections of the Mont-de-Récollets are outlined on Fig. 4. Detailed descriptions and photographs of the two main quarries, the lower Western quarry and the upper 'Grande Carrière' are given in Figures 6-7 and 8-9 respectively. The structure of the Western quarry, which is composed of several faulted blocks, is displayed on Figure 5. The stratigraphic units are discussed in ascending order.

Hyon Sand Formation: at least 10 m thick (63-?72.90 m)

Close inspection of the sieve residues from a depth of 7 m to 16 m in borehole 5 at the 'Tir des Anglais' has allowed recognising the Mont-Panisel Sand Member. This is based on the identification of clayey sediment chips, fine to medium-grained glauconite and tests of *Palaeonummulites aquitanicus* (see taxonomic discussion in Baccaert 2007, 2017). At the Mont-des-Récollets, as well as in all up to now investigated outcrops and boreholes (Steurbaut *et al.* 2015), these glauconitic clayey sands correspond to the top of calcareous nannofossil zone NP12. They were first described at the Mont-Panisel near Mons (d'Omalius d'Halloy 1862) and have recently been included in the Hyon Sand Formation (Steurbaut 2015). They occur throughout the southern part of the Belgian Basin, with maximum thickness of about 25 m.

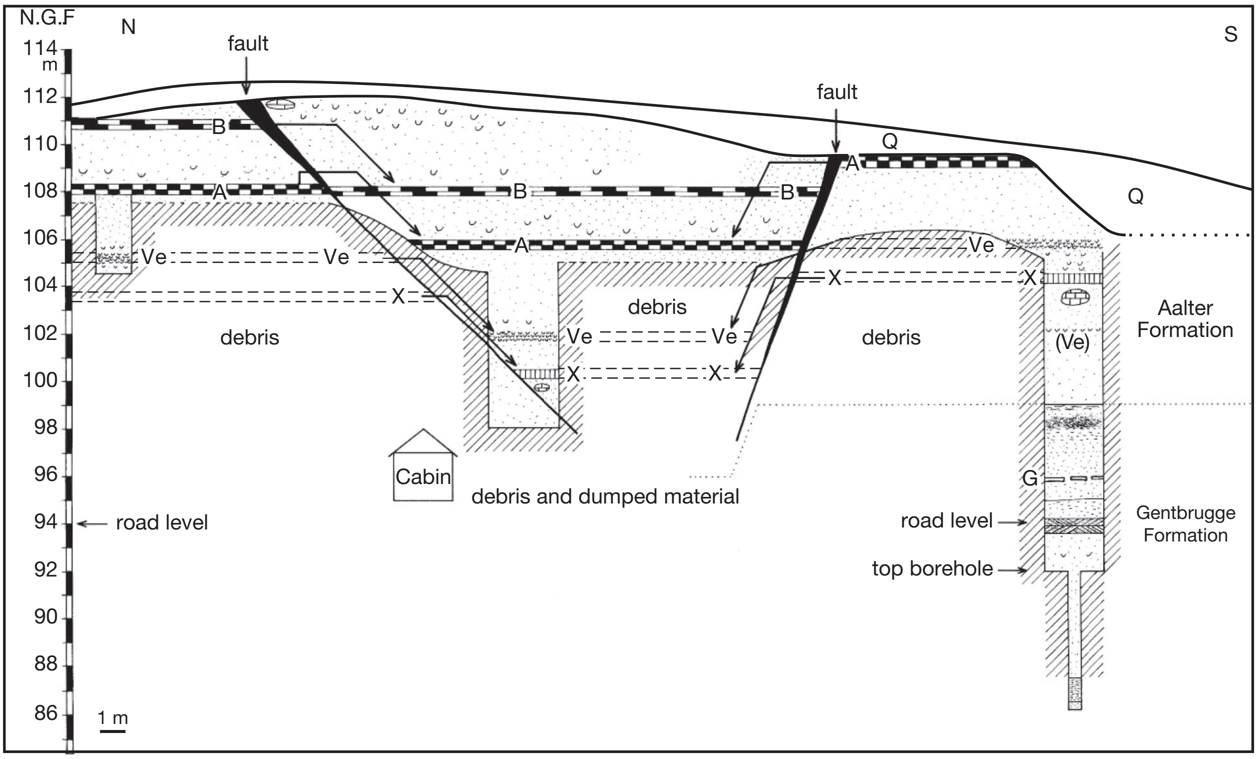


Fig. 5. — Quarry face of the Western Quarry along the Dunkerque-Lille road showing the disposition of the different faulted blocks. Beds with excellent correlation possibilities: **G**, glauconitic sandstone; **Ar**, brown clay ('argile') bed; **X**, **A**, **B**, conspicuous calcareous sandstones; **Tu**, turruline coquina; **Ve**, concentration of Venericor planicosta.

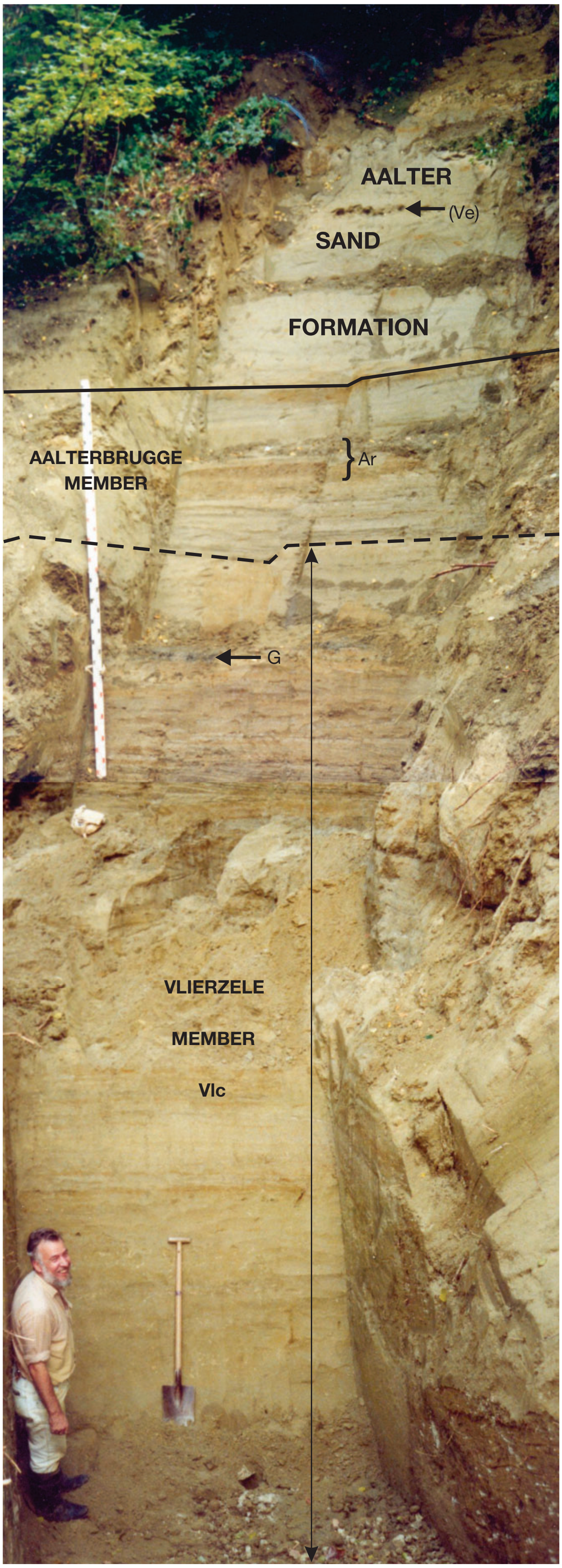
Gentbrugge Formation: at least 13 m thick (? 86.15 m-99.10 m)
The Gentbrugge Formation is well developed in the Gent area, reaching over 30 m in thickness, and in the Flemish Hills, which includes the Mont-de-Récollets area. It is not always represented by all its members.

Kwatrecht Member. This member, which has been identified in the Gent area (De Moor & Geets 1974) and recently in the Zemst borehole (Steurbaut *et al.* 2015), has not been recognized as a separate unit in the Mont-des-Récollets area and in the adjacent Cassel Hill (outcrops and borehole). However, the available data are not sufficiently detailed to decide upon its presence in the Cassel borehole.

Merelbeke Clay Member. 3.10 m of grey stiff clay, tentatively attributed to the "Paniselian", has been penetrated in the Cassel borehole between 72.30 m and 75.40 m depth (Blondeau *et al.* 1972). Its lithological description as well as its stratigraphic position point to the Merelbeke Clay. The latter, widespread in the area between Gent and Brussels, has also been identified in the Rodeberg borehole, 18 km east of the Mont-des-Récollets (Gulinck, unpublished data from 1968) (see Fig. 1 for location). It should also be present at the Mont-des-Récollets, although not yet identified because of falling within the non-exposed interval (see Fig. 4, also above).

Pittem Clay Member. The sandy clay with basal glauconitic sand observed in the nearby Cassel borehole (between 72.30 m and 71.40 m) and included in the "Paniselian" by Blondeau *et al.* (1972: 23) is believed to represent the Pittem Clay. This interpretation is based on lithologic characteristics, supported by calcareous nannofossil dating (NP 13; interpretation based on Lezaud 1972). The Pittem Clay has not been recognised at the Mont-des-Récollets because of falling within the non-exposed interval.

Vlierzele Sand Member. Exposures of these heterogeneous glauconitic fine to medium-grained sands have been frequently observed in the area between the Kluisberg (Fig. 1[point 7]), Gent and Brussels (Kaasschieter 1961; Steurbaut & Nolf 1986; Steurbaut 2006), although almost never in their full extent. The study of the Oedelem borehole, 8 km southeast of Brugge (Figs 1; 12) has allowed identification of three facies within this member, labeled (in ascending order) Vli a, Vli b and Vli c (details in Steurbaut & King pers. comm.). The lowermost clayey 2.5 m recognised in a hand auger drill hole in the Western quarry floor of the Mont-des-Récollets (between 85 and 87.50 m) seems to correspond to facies Vli b, although the increase of quartz grains and glauconite at the very base of this interval might already point to the top of facies Vli a (Fig. 7). The overlying package, from 87.50 to 97.20 m, consisting of an alternation of bioturbated, horizontally stratified and cross-bedded fine sands (see Fig. 6), is attributed to facies Vli c. A conspicuous partly cemented glauconite bed with mollusc moulds occurs at level 95.90 m. Similar beds in an almost identical position are known from the Hijfte borehole, 20 km east of Gent (level G at 54.90-55.00 m, Fig. 13).



Aalterbrugge Member. Several sets of obliquely and horizontally laminated glauconitic fine sand and thin dark chocolate-coloured clay laminae occur in the Western quarry of the Mont-des-Récollets, between 97.15 m and 99.10 m (see Figs 6; 7). This almost 2 m thick sequence is interpreted as belonging to the Aalterbrugge Member because of similarity with the stratotype deposits (presence of thin dark clay laminae; Hacquaert 1939) and with new observations along motorway E40 at Wetteren and in the Hijfte borehole (see Appendix 1 and Fig. 13). In the Mont-des-Récollets area, the junction with the underlying Vlierzele Sand is slightly erosive and marked by a decrease in grain size and the income of thin undisturbed dark clay beds. The contact with the overlying Aalter Sand Formation is sharp.

Aalter Sand Formation: 18.25 m thick (99.10-117.35 m)
The yellowish green glauconitic fine sands, rich in molluscs, exposed between 117.35 and 99.10 m in the lower part of the 'Grande Carrière' and in the Western quarry at the Mont-des-Récollets are attributed to the Aalter Sand Formation. This attribution is based on lithological similarity with the Aalter Sand stratotype (Steurbaut & Nolf 1989): presence of khaki-coloured glauconitic fine sand, turritelline-beds, *Venericor* (previously *Megacardita*) *planicosta* beds, and some incompletely indurated calcareous sandstones. At the Mont-des-Récollets this 18.25 m thick Aalter Sand succession can be subdivided into four units. Detailed lithological desciptions of these units are given in Figures 7 and 9.

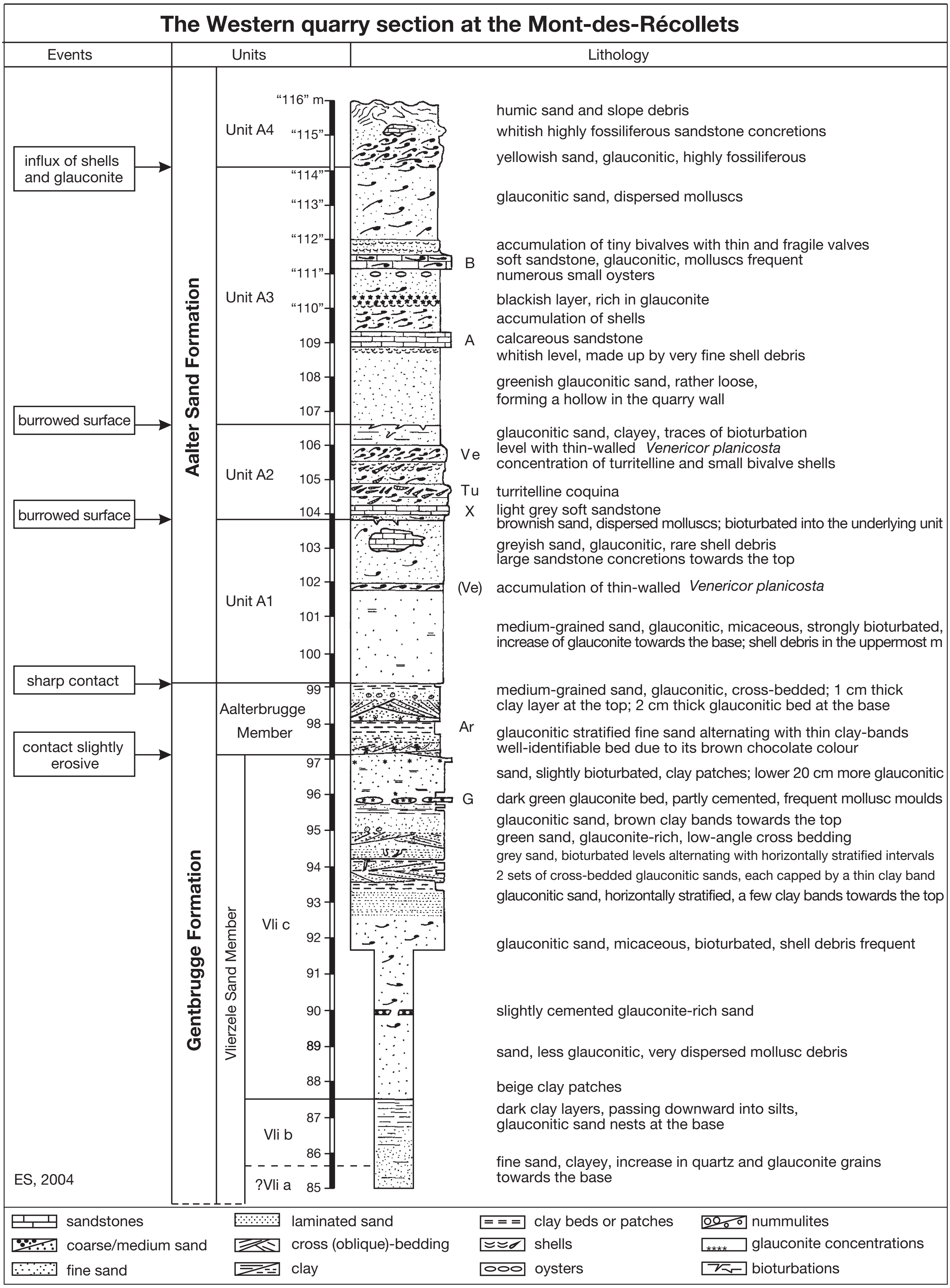
Unit A1. It is represented by 4 m greyish bioturbated medium-grained sand. The contact with the underlying Aalterbrugge Member is sharp and marked by a slight increase in grain size and in glauconite content. In the middle of the unit occurs an accumulation of *V. planicosta,* labelled (Ve) on Figs 5-7.

Unit A2. This unit, which is about 3 m thick, is bounded above and below by bioturbated surfaces. It differs from the underlying Unit A1 by the presence of almost monospecific shell beds, composed of either turritelline or *V. planicosta* shells.

Unit A3. It ranges from the bioturbated surface at 106.60 m to the base of glauconitic highly fossiliferous sand located at *c.* 114.20 m, at 1.5 m below the top of the Western quarry. The contact with the overlying unit could not be precisely specified (sharp, burrowed, etc.?) because it occurs beneath the quarry floor of the 'Grande Carrière', where it was only penetrated in the borehole, and was beyond reach in the Western quarry. However, there seems to be a substantial increase in glauconite at the junction (*c.* 114.60 m level in the 'Grande Carrière' outcrop).

Fig. 6. — Photograph of the lower part of the Western Quarry section at the Mont-des-Récollets during the late-1980s fieldwork campaign, with stratigraphic interpretation and location of the beds with high correlation potential (for Abbreviations see Fig. 5) (by courtesy of E. Steurbaut).

Fig. 7. — Detailed log of the Western Quarry section at the Mont-des-Récollets with location of the beds with high correlation potential and the significant lithologic events (for Abbreviations see Fig. 5).


The Western quarry section at the Mont-des-Récollets
Events
Units
Lithology
influx of shells and glauconite
burrowed surface
burrowed surface
sharp contact
contact slightly erosive
ES, 2004
Aalter Sand Formation
Gentbrugge Formation
Unit A4
Unit A3
Unit A2
Unit A1
Aalterbrugge Member
Vlierzele Sand Member
Vli c
Vli b
?Vli a
"116" m
"115"
"114"
"113"
"112"
"111"
"110"
109
108
107
106
105
104
103
102
101
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
B
A
Ve
Tu
X
(Ve)
Ar
G
humic sand and slope debris
whitish highly fossiliferous sandstone concretions
yellowish sand, glauconitic, highly fossiliferous
glauconitic sand, dispersed molluscs
accumulation of tiny bivalves with thin and fragile valves
soft sandstone, glauconitic, molluscs frequent
numerous small oysters
blackish layer, rich in glauconite
accumulation of shells
calcareous sandstone
whitish level, made up by very fine shell debris
greenish glauconitic sand, rather loose, forming a hollow in the quarry wall
glauconitic sand, clayey, traces of bioturbation
level with thin-walled Venericor planicosta
concentration of turritelline and small bivalve shells
turritelline coquina
light grey soft sandstone
brownish sand, dispersed molluscs; bioturbated into the underlying unit
greyish sand, glauconitic, rare shell debris
large sandstone concretions towards the top
accumulation of thin-walled Venericor planicosta
medium-grained sand, glauconitic, micaceous, strongly bioturbated, increase of glauconite towards the base; shell debris in the uppermost m
medium-grained sand, glauconitic, cross-bedded; 1 cm thick clay layer at the top; 2 cm thick glauconitic bed at the base
glauconitic stratified fine sand alternating with thin clay-bands
well-identifiable bed due to its brown chocolate colour
sand, slightly bioturbated, clay patches; lower 20 cm more glauconitic
dark green glauconite bed, partly cemented, frequent mollusc moulds
glauconitic sand, brown clay bands towards the top
green sand, glauconite-rich, low-angle cross bedding
grey sand, bioturbated levels alternating with horizontally stratified intervals
2 sets of cross-bedded glauconitic sands, each capped by a thin clay band
glauconitic sand, horizontally stratified, a few clay bands towards the top
glauconitic sand, micaceous, bioturbated, shell debris frequent
slightly cemented glauconite-rich sand
sand, less glauconitic, very dispersed mollusc debris
beige clay patches
dark clay layers, passing downward into silts, glauconitic sand nests at the base
fine sand, clayey, increase in quartz and glauconite grains towards the base
sandstones
coarse/medium sand
fine sand
laminated sand
cross (oblique)-bedding
clay
clay beds or patches
shells
oysters
nummulites
glauconite concentrations
bioturbations

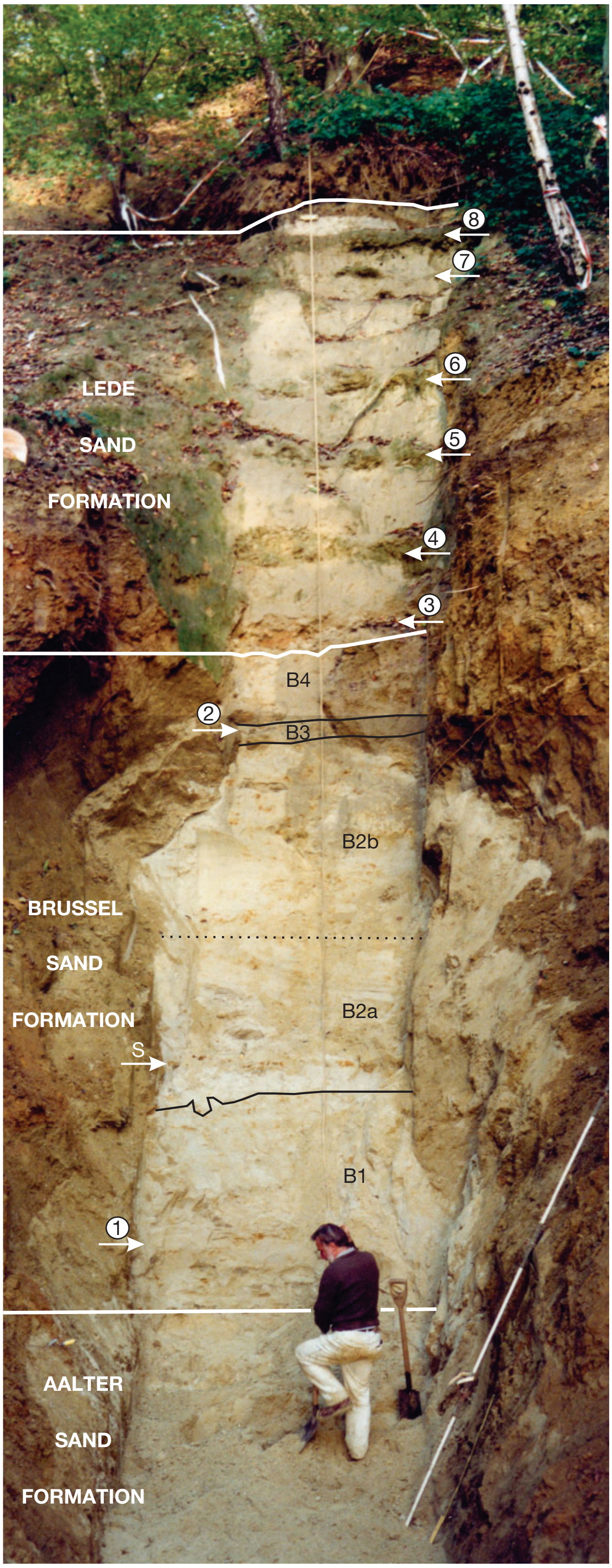


FIG. 8. — Photograph of the 'Grande Carrière' section at the Mont-des-Récollets during the late-1980s fieldwork campaign, with stratigraphic interpretation and location of the major sandstone beds (by courtesy of E. Steurbaut). Abbreviation: **S**, sandstone with rusty surface.

Unit A4. Sandstone concretions, rich in the bivalve *Orthocardium porolosum*, occur frequently within this unit, which is furthermore characterised by its texture (fine sand) and the presence of fine-grained glauconite and other bivalves (oysters). The contact with the overlying Brussel Formation is sharp and marked by an increase in grain size.

Brussel Sand Formation: 5.65 m thick (117.35-123.00 m)
In the Mont-des-Récollets area the Brussel Sand Formation is very similar to what has been observed in the Brussel area (Burtin 1784; Galeotti 1837; Rutot 1882; Leriche 1912, 1923; Gulinck 1963; Houthuys 1990). It consists of 5.65 m thick whitish fine to medium-grained quartz sand with shell debris and several beds of sandstone with typical "quartzitic" patina. On the basis of lithologic features it can be subdivided into four units (see Fig. 9).

Unit B1 (117.35-118.95 m). This unit consists of uniform whitish fine to medium-grained sand with echinoid (among which *Maretia omaliusi*) and bryozoal debris and a few sandstone banks. Its boundary with the underlying Aalter Sand Formation is marked by a major increase in grain size and a substantial decrease in glauconite.

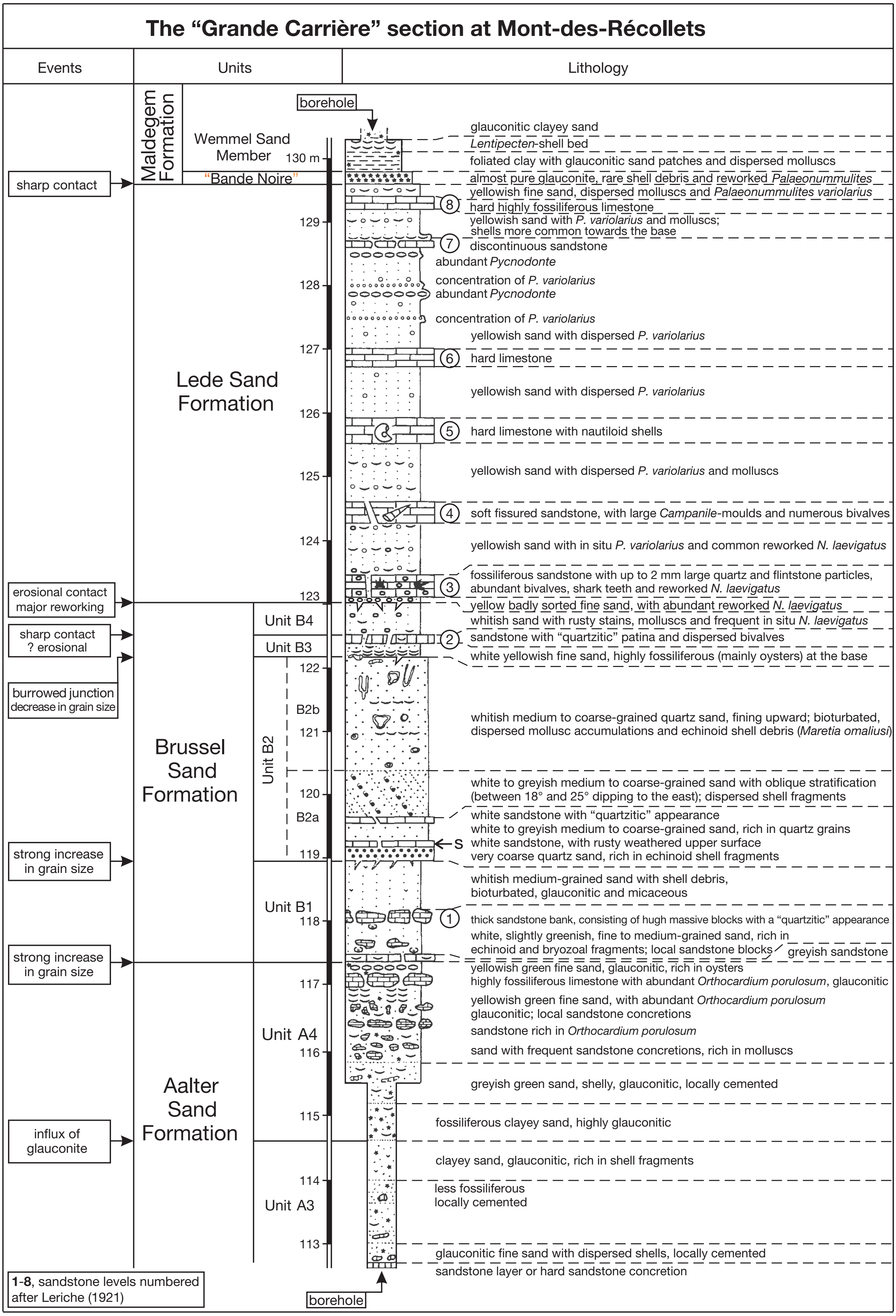
Unit B2 (118.95-122.15 m). There is a substantial break in sedimentation between Unit B1 and Unit B2, as shown by the interburrowed surface. Unit B2 differs from Unit B1 by a much stronger heterogeneity and a coarser grain-size, becoming extremely coarse at the base. Its lower part (Subunit B2a) includes two sandstone levels, which seem to be consistently occurring, and which are overlain by obliquely stratified medium-grained sand. Its upper part (Subunit B2b) essentially consists of whitish bioturbated, locally shelly, medium-grained sand (Figs 8; 9).

Unit B3 (122.15-122.55 m). This unit, consisting of 20 cm thick white yellowish shelly fine sand, capped by a 20 cm thick bivalve-bearing sandstone yielding large nautiloid shells, is separated from the underlying unit by an interburrowed junction. It is furthermore marked by a finer grain size and the common occurrence of oyster shells, especially at the base.

Unit B4 (122.55-123.00 m). This white yellowish shelly fine sand with rusty stains is above all marked by the occurrence of common small-sized (5 to 8 mm in diameter) *Nummulites laevigatus in situ* (around 5 specimens/kg sediment). There is a sharp contact with the underlying sandstone.

Lede Sand Formation: 6.60 m thick (123.00-129.60 m)
At the Mont-des-Récollets the Lede Sand Formation ('Sables de Lède', Mourlon 1873) is represented by an almost 6.60 m thick, progressively fining upward succession (Fobe & Spiers 1992: fig. 6), marked by an alternation of yellowish fossil-

FIG. 9. — Detailed log of the 'Grande Carrière' section at the Mont-des-Récollets with location of the major sandstone levels and the significant lithologic events. Abbreviation: **S**, sandstone with rusty surface.


The "Grande Carrière" section at Mont-des-Récollets
Events
Units
Lithology
borehole
Maldegem Formation
Wemmel Sand Member
"Bande Noire"
130 m
129
128
127
126
125
124
123
122
121
120
119
118
117
116
115
114
113
Lede Sand Formation
Brussel Sand Formation
Aalter Sand Formation
Unit B4
Unit B3
Unit B2
B2b
B2a
Unit B1
Unit A4
Unit A3
sharp contact
erosional contact major reworking
sharp contact ? erosional
burrowed junction decrease in grain size
strong increase in grain size
strong increase in grain size
influx of glauconite
glauconitic clayey sand
Lentipecten-shell bed
foliated clay with glauconitic sand patches and dispersed molluscs
almost pure glauconite, rare shell debris and reworked Palaeonummulites
yellowish fine sand, dispersed molluscs and Palaeonummulites variolarius
8 hard highly fossiliferous limestone
yellowish sand with P. variolarius and molluscs; shells more common towards the base
7 discontinuous sandstone
abundant Pycnodonte
concentration of P. variolarius
abundant Pycnodonte
concentration of P. variolarius
yellowish sand with dispersed P. variolarius
6 hard limestone
yellowish sand with dispersed P. variolarius
5 hard limestone with nautiloid shells
yellowish sand with dispersed P. variolarius and molluscs
4 soft fissured sandstone, with large Campanile-moulds and numerous bivalves
yellowish sand with in situ P. variolarius and common reworked N. laevigatus
3 fossiliferous sandstone with up to 2 mm large quartz and flintstone particles, abundant bivalves, shark teeth and reworked N. laevigatus
yellow badly sorted fine sand, with abundant reworked N. laevigatus
whitish sand with rusty stains, molluscs and frequent in situ N. laevigatus
2 sandstone with "quartzitic" patina and dispersed bivalves
white yellowish fine sand, highly fossiliferous (mainly oysters) at the base
whitish medium to coarse-grained quartz sand, fining upward; bioturbated, dispersed mollusc accumulations and echinoid shell debris (Maretia omaliusi)
white to greyish medium to coarse-grained sand with oblique stratification (between 18° and 25° dipping to the east); dispersed shell fragments
white sandstone with "quartzitic" appearance
white to greyish medium to coarse-grained sand, rich in quartz grains
S white sandstone, with rusty weathered upper surface
very coarse quartz sand, rich in echinoid shell fragments
whitish medium-grained sand with shell debris, bioturbated, glauconitic and micaceous
1 thick sandstone bank, consisting of hugh massive blocks with a "quartzitic" appearance
white, slightly greenish, fine to medium-grained sand, rich in echinoid and bryozoal fragments; local sandstone blocks
greyish sandstone
yellowish green fine sand, glauconitic, rich in oysters
highly fossiliferous limestone with abundant Orthocardium porulosum, glauconitic
yellowish green fine sand, with abundant Orthocardium porulosum glauconitic; local sandstone concretions
sandstone rich in Orthocardium porulosum
sand with frequent sandstone concretions, rich in molluscs
greyish green sand, shelly, glauconitic, locally cemented
fossiliferous clayey sand, highly glauconitic
clayey sand, glauconitic, rich in shell fragments
less fossiliferous locally cemented
glauconitic fine sand with dispersed shells, locally cemented
sandstone layer or hard sandstone concretion
1-8, sandstone levels numbered after Leriche (1921)
borehole

iferous fine sand and calcareous sandstone and limestone banks with particular characteristics (Figs 8; 9). The sandstone bank at 124.3 to 124.5 m (level 4) contains several large fragments of *Campanile giganteum* and represents one of the few records of this extremely large gastropod outside the Paris Basin (see Discussion). The overlying sandstone level 5 is known for the commonly occurring nautiloid shells. The Lede Sand Formation differs from overlying and underlying units by the presence of small *Palaeonummulites variolarius*. It is widespread in central and north Belgium, reaching a mean thickness of about 6 m. A gravel bed, consisting of rolled sandstone pebbles, shark teeth and other fossil debris, always marks its base. The latter presents a wide range of textures, sometimes loose (e.g. at Oosterzele, Smith *et al.* 2004), but often (semi-)lithified (e.g. at Balegem, Jacobs & Sevens 1994). At the Mont-des-Récollets it consists of large fossiliferous sandstone blocks, some extremely rich in large-sized *N. laevigatus,* which are locally underlain by a very thin rusty badly sorted fine sand with up to several mm thick quartz grains and abundant reworked large-sized *N. laevigatus* and other fossils (molluscs and a few shark teeth).

Maldegem Formation: 12.85 m thick (129.60-142.45 m)
At the Mont-des-Récollets the base of the Maldegem Formation consists of an appoximately 1 m thick heterogeneous unit, including a basal 25 cm thick pure glauconite with some rare shell debris and *Palaeonummulites variolarius,* 40 cm of clay, a 30 cm thick *Lentipecten*-shell bed and glauconitic clayey sands (Fig. 9), very similar to what has been observed in the centre of Gent (Blandijnberg or 'Colline de Saint-Pierre' auct., see Material and Methods). Lyell (1852: 327) introduced the term 'Bande Noire' for the basal glauconite bed situated in a similar position in a pit on the eastern slope of the Cassel Hill. The above mentioned 1 m thick heterogeneous complex, also recorded in the Cassel borehole, is considered to represent the Wemmel Sand Member. As only the lower half a meter yielded calcareous nannofossils it is not clear up to now if this unit only represents the lower part of the member, the top of which has been eroded, or if it corresponds to the complete, but very condensed, Wemmel Sand Member. This heterogenous unit is overlain by very clayey sands and glauconitic sandy clays, which are not studied here. In the Cassel borehole (Blondeau *et al.* 1972) this predominantly clayey succession (clay content around 40%) is about 8 m thick, and believed to represent the Asse Clay Member, The overlying 6 m thick non-glauconitic grey stiff clay is attributed to the Ursel Clay Member.

Calcareous nannofossils

General characteristics of the nannoflora
The distribution of calcareous nannofossils in the Eocene of the Mont-des-Récollets is complex and directly related to the paleoenvironmental characteristics and burial history of the deposits. The absence of nannofossils in the Asse Clay Member and in the base of the Ursel Clay Member is probably due to local post-depositional (? Pliocene or Pleistocene) weathering, as these deposits are generally calcareous throughout the Belgian Basin. Their absence in the upper part of the Ursel Clay is an early diagenetic feature, as pyritic moulds of foraminifera and molluscs have been recognized in this interval in all sections studied in Belgium (King 1990). The upper part of the Vlierzele Member, the overlying Aalterbrugge Member, and Unit A1 of the Aalter Formation are also devoid of nannofossils (Fig. 10). This results from the estuarine/coastal character of these units, which are too coarse-grained or too marginal marine to yield interpretable nannofossil assemblages. Fortunately, the main part of the section is calcareous and contains poorly to fairly well-preserved assemblages. As a whole these are poor in numbers (less than 5 specimens/field of view in the lower half and between 5 and 10 in the upper half of the section) and in taxa (generally less than 25) (Fig. 10). They are marked by substantial selective dissolution, and, therefore, strong taphonomic bias. The highest species diversity (maximum of 35 taxa) is recorded in the upper part of the Brussel Sand Formation and in the Wemmel Sand Member. Small and middle-sized Noelaerhabdaceae (between 40% and 85%) and *Coccolithus pelagicus* (between 5% and 45%) dominate (Fig. 11B), as in most of the Paleogene nannofossil assemblages worldwide. The relative paucity in warm-water groups, such as Discoasteraceae (except for the lowermost two samples), Helicosphaeraceae and Sphenolithaceae, could be brought in relation to the middle to high-latitude position of the Mont-des-Récollets outcrop area during early and middle Eocene times (paleotemperature interpretation after Wei & Wise 1990). However, this seems to be an artifact, due to the erosional removal of the major part of Unit B3 at Mont-des-Récollets. This part of Unit B3, preserved in many outcrop sections around Brussels, includes a series of blooms of *Pemma*, *Sphenolithus* and *Discoaster*, all considered to be thermophilic taxa (Steurbaut, unpublished, detailed in a forthcoming study). The Brussel Sand Formation was governed by a shallow marine deposition regime, with a nearby coastline, as evidenced by the relatively high numbers of *Zygrhablithus bijugatus*, *Micrantholithus* and *Pontosphaera*, throughout the section, and of *Lanternithus minutus*, *Blackites creber* and *Pemma* spp. in certain intervals (Fig. 11B). Some particular levels (bases of B4 and the Lede Formation) are very rich in *Braarudosphaera. Braarudosphaera bigelowii*, which is known to occur in hyposaline turbulent turbid shallow water (Bukry 1974; Takayama 1972; Moshkovitch & Ehrlich 1982) and *B. stylifera* may reach up to 13% of the assemblage just above the basal sandstone of the Lede Formation.

One hundred and two different taxa have been identified at the Mont-des-Récollets, ten of which represent new species. Two of these belong to *Luminocanthus* n. gen., a new genus introduced herein. The stratigraphically important taxa are shown in Fig. 11A, those with quantitative importance in Fig. 11B. The new, badly known and biostratigraphically relevant taxa are displayed on Figures 18 to 20. Their taxonomy is detailed in the last chapter of this paper.

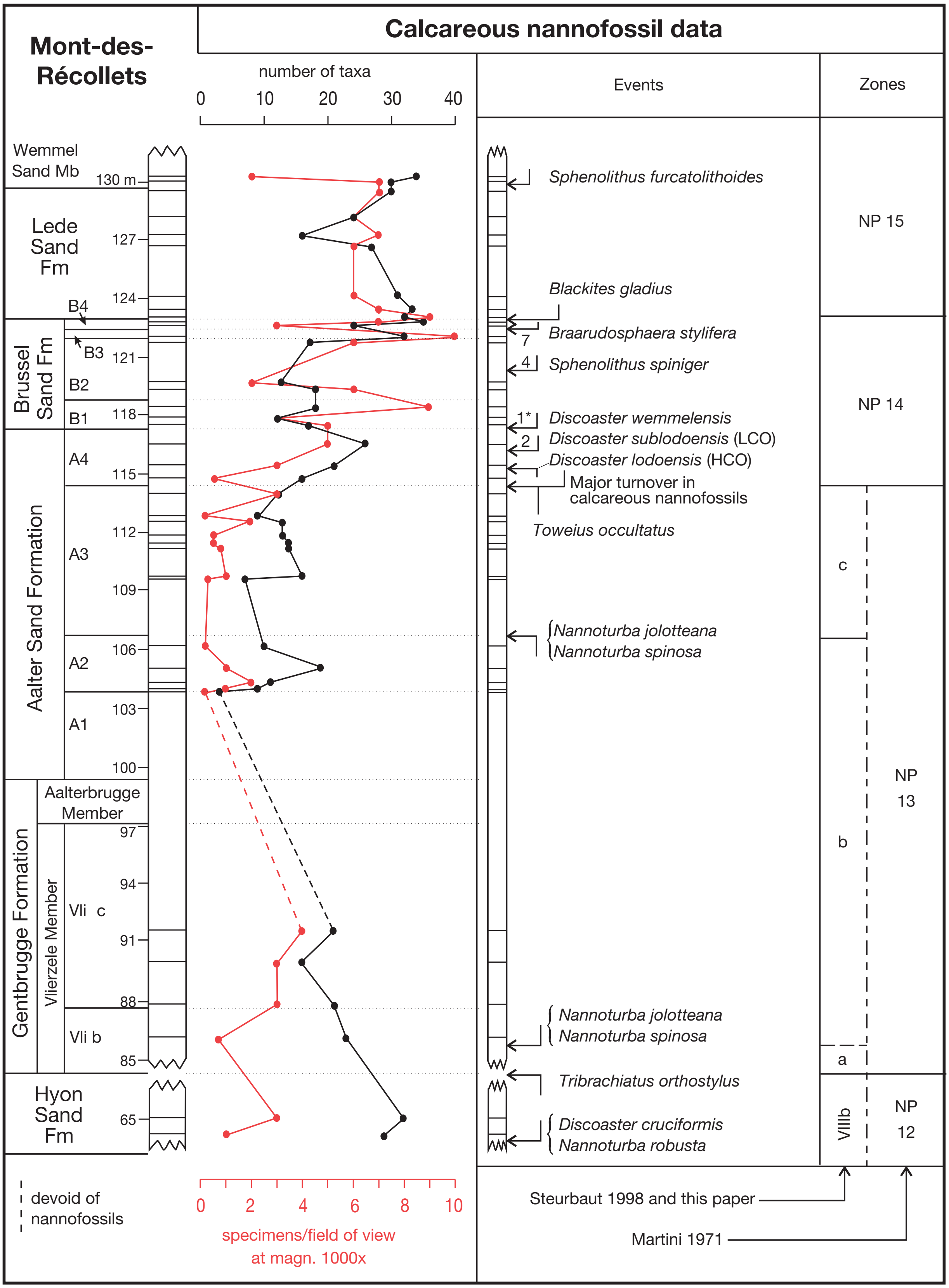


FIG. 10. — Quantitative analysis and biozonation of the upper Ypresian and lower Lutetian calcareous nannofossil assemblages of the Mont-des-Récollets section (events 1 to 7 within NP 14 refer to the standard sequence of events, as identified in the present paper). Note that the occurrence of event 1 is slightly delayed at Mont-des-Récollets compared to the standard sequence of events. This seems to be due to the poor preservation of the assemblages in Unit A4 at this site.

FIG. 11A. — Distribution of stratigraphically most important calcareous nannofossil taxa in the upper Ypresian and lower Lutetian of the Mont-des-Récollets section.

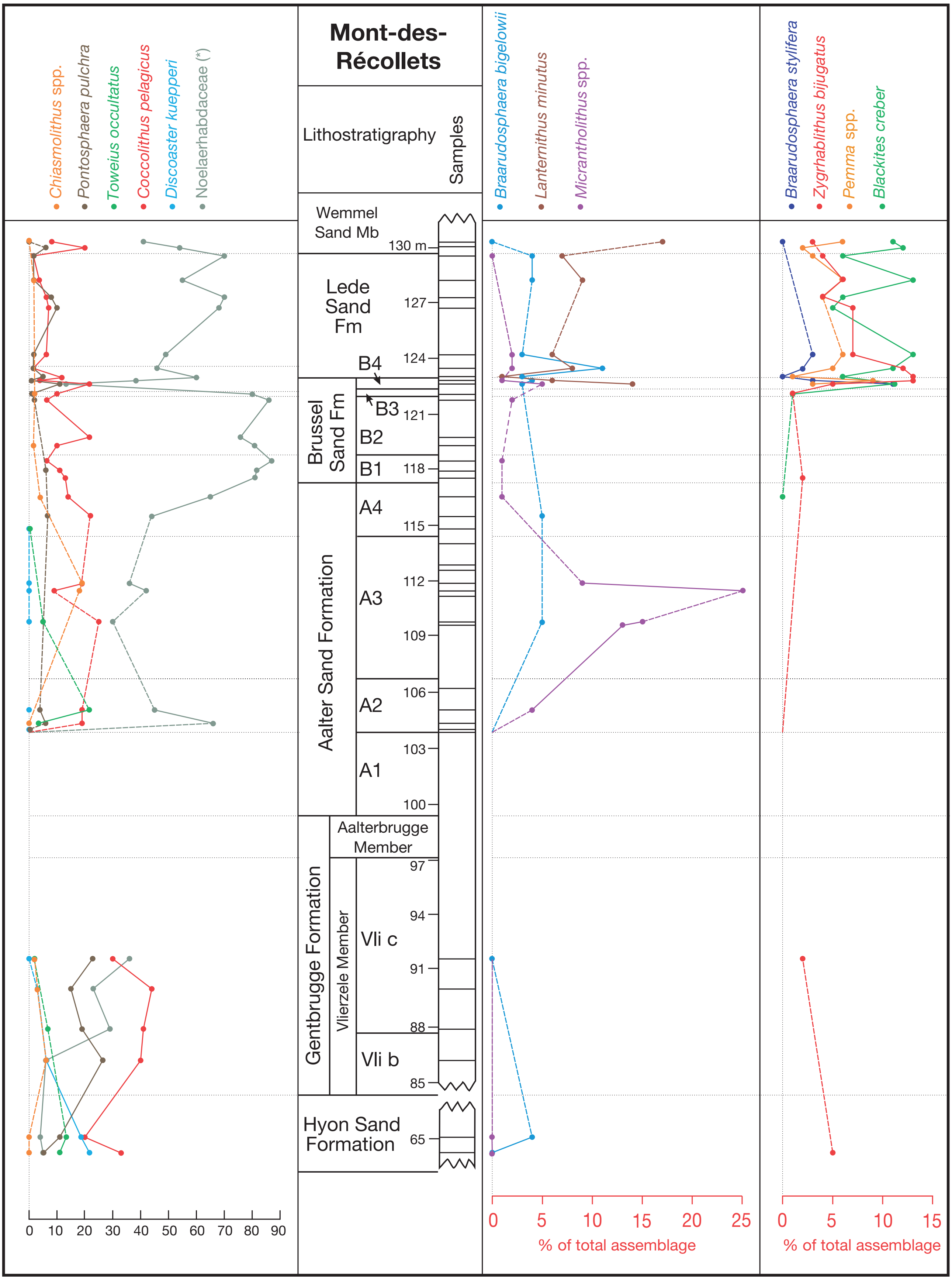


FIG. 11B. — Quantitative distribution of dominant nannofossil taxa in the upper Ypresian and lower Lutetian of the Mont-des-Récollets section (coloured bullet = present in sample; coloured interrupted line = absent in that interval; Noelaerhabdaceae (*) = Noelaerhabdaceae + *Toweius* spp., except *Toweius occultatus*).

Calcareous nannofossil distribution throughout the Mont-des-Récollets section (Figs 10; 11)

The assemblages from the Hyon Sand Formation are well diversified (around 30 taxa/sample) but very poor in number of specimens (1 to 3 per field of view at magnification 1000×) (Fig. 10). They are dominated by *Coccolithus pelagicus* (20-30% of the total number of specimens), *Discoaster kuepperi* (*c.* 20%), *Toweius occultatus* (*c.* 13%) and *Pontosphaera pulchra* (up to 11%), all four together making up about 65% of the assemblage (Fig. 11B). The co-occurrence of *Discoaster lodoensis* and *Tribrachiatus orthostylus* allows their attribution to nannofossil zone NP12, more specifically to its top part, according to the presence of *Discoaster cruciformis* and *Nannoturba robusta* (subzone VIIIb of Steurbaut 1998).

The Vlierzele Member is less rich in nannofossils. The upper 5 m are completely devoid; the lower 7 m are relatively poor (*c.* 20 taxa/sample, richest levels around 4 specimens per field of view). *C. pelagicus* (*c.* 40%) and *Pontosphaera pulchra* (between 15 to 27 %) dominate the assemblages. There is a substantial increase in small Noelaerhabdaceae up section (from *c.* 5% to 36%). As *T. orthostylus* is no longer encountered and *Discoaster sublodoensis* not yet present, the associations are attributed to zone NP13. According to outcrop and borehole data from N Belgium (Steurbaut 1990 and unpublished, see also Figs 12, 13) they seem to belong to the middle part of this zone (subzone NP13-b, as defined herein): co-occurrence of *Nannoturba robusta, N. spinosa, N. jolotteana* and *Imperiaster* sp. and only few *Micrantholithus aequalis* and *M. inaequalis*.

The overlying Aalterbrugge Member and the basal Unit A1 of the Aalter Formation do not yield nannofossils. They recur at the base of Unit A2, although in very low numbers. Assemblages throughout this unit remain poor (10 taxa/sample, 1 specimen per field of view), except for these in the interval between the *Venericor* shell bed (Ve) and the turritelline coquina (Tu) (Fig. 7), that present a much higher species diversity (19 taxa/sample, 1 specimen per field of view). The assemblages are quite similar to these of the Vlierzele Sand Member, although richer in Noelaerhabdaceae (*c.* 50% of number of specimens), and also belong to zone NP13. The only substantial difference is that *Nannotetrina cristata* (LO within turritelline bed Tu) and *Girgisia* (formerly *Toweius*) *gammation* (LO in interval between Tu and Ve, see Fig. 7) have their first occurrences in Unit A2, while *Imperiaster* is no longer present (Fig. 11A). The co-occurrence of *N. robusta, N. spinosa* and *N. jolotteana* allows its correlation to subzone NP13-b.

The assemblages of unit A3 are quantitatively poor (often less than 1 specimen per field of view), but rather well diversified (*c.* 13 taxa/sample). They are attributable to the upper part of NP13 (subzone NP13-c, as defined herein) and marked by the disappearances of *Nannoturba spinosa* and *N. jolotteana*. The most diversified samples (16 taxa) occur between sandstone beds A and B (Fig. 7). *Discoaster cruciformis*, a typical late Ypresian form, disappears just below a conspicuous glauconite bed, a few meters above the base of A3 (110 m in Western quarry). It almost coincides with the lowest consistent occurrence of *Reticulofenestra* aff. *umbilica* (small forms: largest diameter *c.* 8 to 9 µm) and an increase of *Chiasmolithus* specimens. *Toweius occultatus*, another typical Ypresian form, disappears around the top of A3 (1 specimen recorded in the base of A4) (Fig. 11A). The assemblages in the upper part of Unit A3 (above bed B) are furthermore marked by the income of *Zygrhablithus bijugatus crassus* (111.70 m) and the presence of *Ectalithus* (formerly *Coccolithus) crassus*.

Unit A4 is slightly richer in nannofossils (between 15 and 25 taxa/sample, generally 3/maximum 5 specimens per field of view). Major changes are recorded within its lowermost metre, including the LO of *Martiniaster cecellanoriae* n. sp., the LO of *Trochoaster nodosus* n. sp., the LCO of *Nannotetrina cristata* and the HCO of *Discoaster lodoensis* at 114.85 m and the LOs of *Discoaster praebifax* and *Pemma* spp. slightly higher up (at 115.10 and 115.60 m repectively). Typical 5-rayed *Discoaster sublodoensis* specimens are consistently recorded from the middle of Unit A4 (116.45 m). The LOs of *Blackites minusculus* n. sp. and *Sphenolithus recolletensis* n. sp. are at the same level (116.45 m).

The assemblages of the lower part of the Brussel Formation (Unit B1) are similar to these of the top of the Aalter Formation, except for a somewhat lower species diversity (*c.* 17 taxa/sample) and a higher proportion of Noelaerhabdaceae in B1. The same species content is recorded in Unit B2, which, however, shows a decrease in number of specimens and, although less severe, in species diversity (maximum 15 taxa/sample). The LO of *Discoaster wemmelensis* is just bove the base of Unit B1. It is the earliest record at the Mont-des-Récollets, but not in the Belgian Basin as this species is known to occur in low numbers in the top of the underlying Aalter Sand Formation (one specimen in the Oedelem BH and two in the Vlakte van de Raan BH) (Fig. 12). *D. wemmelensis* remains extremely rare up to the middle of B2. Higher up, from the upper part of Unit B2 onward, it is more consistently recorded and coincident with the LOs of *Blackites praeinflatus* n. sp. and *Sphenolithus spiniger*. The associations in Unit B3 considerably differ from the underlying ones through a sudden influx of *Luminocanthus plenilutetiensis* n. gen., n. sp., some last records, such as *Girgisia gammation and Trochastrites pyramidalis* n. sp., and a much higher species diversity (30 to 35 taxa/sample). Small Noelaerhabdaceae dominate the associations (80%). Substantial changes also occur at the base of Unit B4, marked by the lowest occurrences of *Braarudosphaera stylifera*, *Martiniaster fragilis*, *Sphenolithus quadricornutus* n. sp. and the LCO of *Lanternithus minutus* and *Toweius brusselensis.* This unit is also distinguished from the underlying units by the sharp rise in Braarudosphaeraceae (including *Braarudosphaera*, *Micrantholithus* and *Pemma*: from <1% to 17-22%), *Lanternithus minutus* (from 0% to 6-14%), *Blackites creber* (from 1% to 9-11%) and *Zygrhablithus bijugatus* (from 1% to 13-16%).

The assemblages above the basal limestone of the Lede Sand Formation are quite similar to these of Unit B4, in frequency (7 specimens/field of view) as well as in composition, as they are made up of the same dominant groups: Braarudosphaeraceae (among which *B. stylifera*) = 19%, *Z. bijugatus* = 12%, *B. creber* = 11% and *L. minutus* = 8%. The assemblage of the non-lithified lowermost 5 to 10 cm of the Lede Formation (below the basal limestone) is richer in small Noelaerhabdaceae, but less rich in Braarudosphaeraceae (6%) and *L. minutus* (1%). Among the main differences with Unit B4 are the first, but rare, record of *Blackites gladius* and the disappearance of *D. sublodoensis* at the base of the Lede Sand Formation. The assemblages remain fairly unchanged throughout the Lede Formation, except for the disappearance of *Toweius brusselensis* just above the basal sandstone and the frequency in Braarudosphaeraceae, which systematically decreases up section (from 19% at 123.50 m to 10%, 9% and 7 % at respectively 124.10, 128.55 and 129.55 m).

No nannofossils were encountered in the coarse-grained glauconitic base of the Wemmel Sand Member ('Bande noire' *sensu* Lyell 1852). The overlying beds (still part of the base of the member) yield fairly rich assemblages (between 30 and 35 taxa/sample; between 2 and 7 specimens/field of view), belonging to the middle part of NP 15 (presence of *Blackites gladius*). They differ from these of the underlying Lede Formation (lower NP 15) by the decrease in *Braarudosphaera stylifera* (a few specimens are present in the base of the member), the LO of *Sphenolithus furcatolithoides* and *Naninfula deflandrei*, and the LCO of *Pontosphaera wechesensis*.

At the Mont-des-Récollets the assemblages of the overlying Asse Clay Member are strongly dissolved, and cannot be dated satisfactorily. This is also true for this interval in the Cassel borehole (Lezaud 1972). *Sullivania gigas* (*Coccolithus gigas sensu* Lezaud 1972) has not been identified in the present study. Its presence in the Lede Formation and the base of the Maldegem Formation in the Cassel borehole, as claimed by Lezaud (1972), is doubted and believed to be a misinterpretation.

Identification of Martini's NP-Zones and subdivision of Zone NP13

Martini's (1971) standard calcareous nannofossil zones NP12, NP13 and NP14 are easy to recognize in the sections of the southern North Sea Basin, including Mont-des-Récollets (Fig. 10), because of the frequency of *Discoaster lodoensis*, *Tribrachiatus orthostylus* and *Discoaster sublodoensis*, species which are used to define the lower boundaries of these zones. However, although the presence of Zone NP14 is easy to establish, the identification of its base is less straightforward in the southern North Sea Basin. This is due to the scarcity of typical five-rayed specimens of *Discoaster sublodoensis* at the start of its range. Fortunately, the LO of the latter coincides with the LO of many other species and with the HO of *Toweius occultatus*. This major bio-event is defined herein as the Base Lutetian calcareous nannofossil turnover (abbreviated as BALCAT), marked by fundamental changes in the shallow-water nannofossil assemblage (see next chapter).

The Mont-des-Récollets data allow subdivision of Zone NP13 into three subzones (Fig. 10). The LOs of *Nannoturba jolotteana* and *Nannoturba spinosa*, which are coeval and clearly postdate the HO of *T. orthostylus* (representing the base of Zone NP13 or NP13-a), are used to define the base of a second subzone NP13-b. Their HOs, which are also coeval, allow to define the base of a third subzone NP13-c. The events used to subdivide NP13 have been identified throughout the Belgian Basin (see biostratigraphic interpretation of the assemblages and chapter 'Discussion' below) and may be excellent candidates for enhancing interbasinal correlations within the Northwest Atlantic realm. *N. spinosa*, initially described by Müller (1979) from DSDP Site 404, at the Rockall Plateau, about 423 km NW of Ireland, was subsequently recorded in the middle of Unit C1 (sample at 25.5 m) of the Aktulagay section in Kazakhstan (King *et al.* 2013). The decalcification of the late Ypresian nannofossil assemblages in Denmark and the central North Sea Basin (as noted by Steurbaut 2011) may explain the apparent absence of *N. jolotteana* outside the Belgian Basin.

The lower boundary definition of NP15, is also difficult to apply in the southern North Sea Basin, because of the scarcity of the marker species *Nannotetrina alata*. Up to now, only two specimens have been recored in Belgium, one from the Zaventem-Brussel Airport section (Steurbaut in Herman *et al.* 2001) and one from the Nederokkerzeel outcrop (Steurbaut pers. comm.). Identification of zone NP 15 is based on the LO of *Nannotetrina quadrata* (Steurbaut in Smith *et al.* 2004), or on the LO of *Blackites gladius* (Steurbaut 1990), which according to Martini (1971) and Aubry (1983: 105, based on data from the North Atlantic Ocean) are coincident or very close to the LO of *N. alata*. The additional *Nannotetrina* taxa (*N. fulgens* and *N. pappii*) occur slightly later, although still in NP15 (in Belgium, in the upper part of the Wemmel Sand Member and the base of the Asse Clay Member respectively; Steurbaut *et al.* 2015).

A major turnover in shallow-water calcareous nannoflora at the base of NP14

The calcareous nannofossil investigation of the Mont-des-Récollets section reveals a fundamental change in assemblage composition at the base of Unit A4 of the Aalter Sand Formation. This change is marked, among many other things (see below), by the transition from *Discoaster lodoensis* to *Discoaster sublodoensis*. The latter is abrupt, apparently taking place during the hiatus between Unit A3 and Unit A4. It includes several stepwise transformations. Typical multirayed (5 to 8) specimens of *Discoaster lodoensis* are characterized by curved rays with the conspicuous peripheral ridge, running along the less curved edge of the ray towards the centre. At first, specimens with almost straight rays are popping up, while keeping all other characteristics of *D. lodoensis* (this form is defined herein as the 'late form' of *D. lodoensis*). Subsequently, these *D. lodoensis* specimens with straight rays transform into six-rayed discoasters without peripheral ridges (known as *Discoaster strictus* and allies) and finally into a five-rayed form. The latter has much shorter rays and is marked by a small low stem and low crests along the margin of the rays, ending at the interstices between the rays. This five-rayed form is considered herein to represent *D. sublodoensis* (Fig. 18I-M), and its LO is used to define the base of NP14, as already suggested by Agnini *et al.* (2006, 2014).

The assemblages at the base of Unit A4 are fairly rich in discoasters, essentially consisting of the 'late form' of

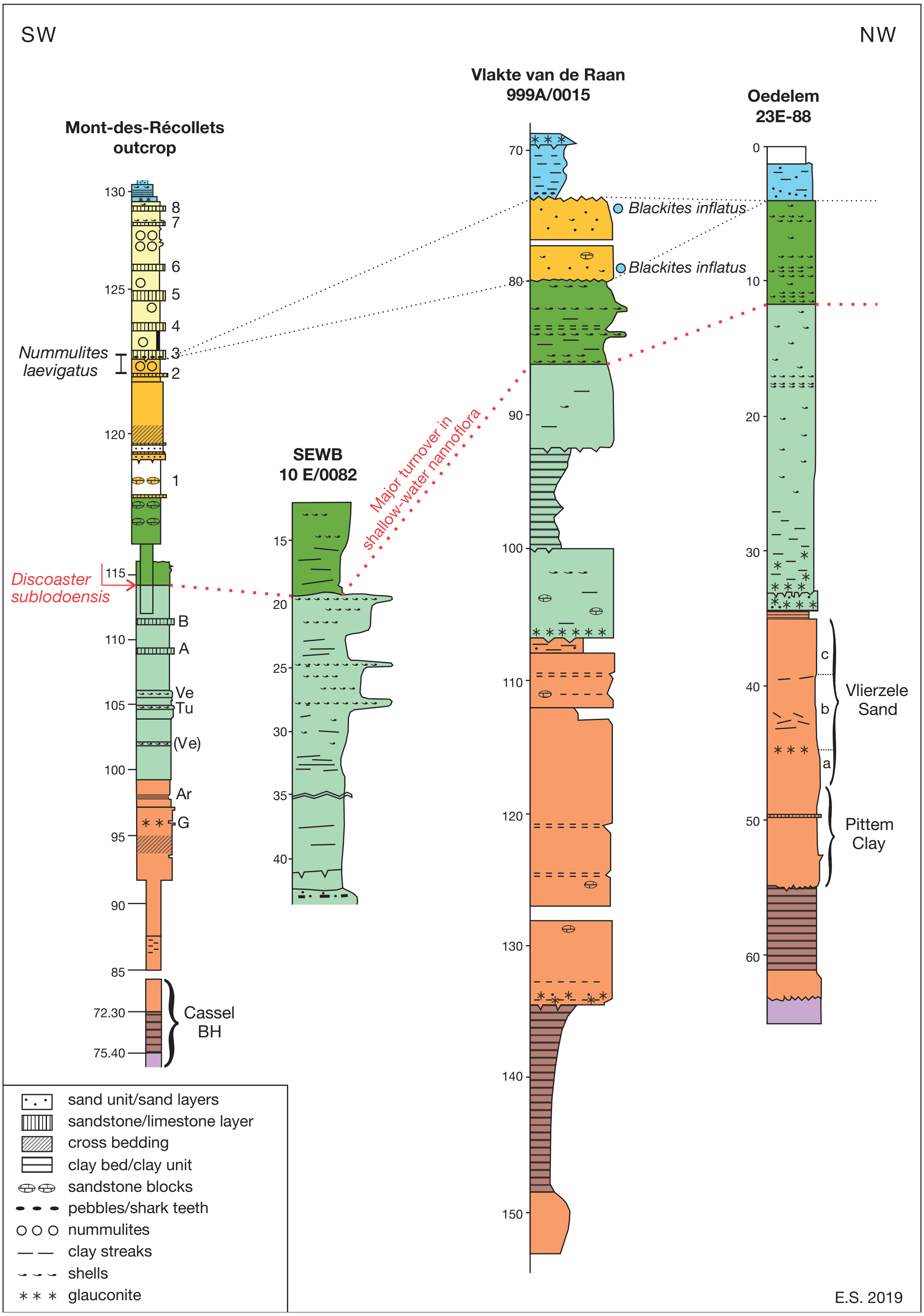


Fig. 12. — Lithostratigraphic interpretation of a series of Ypresian-Lutetian boundary sections in western Belgium with position of the major calcareous nannofossil events (see Fig. 13 for additional legend).

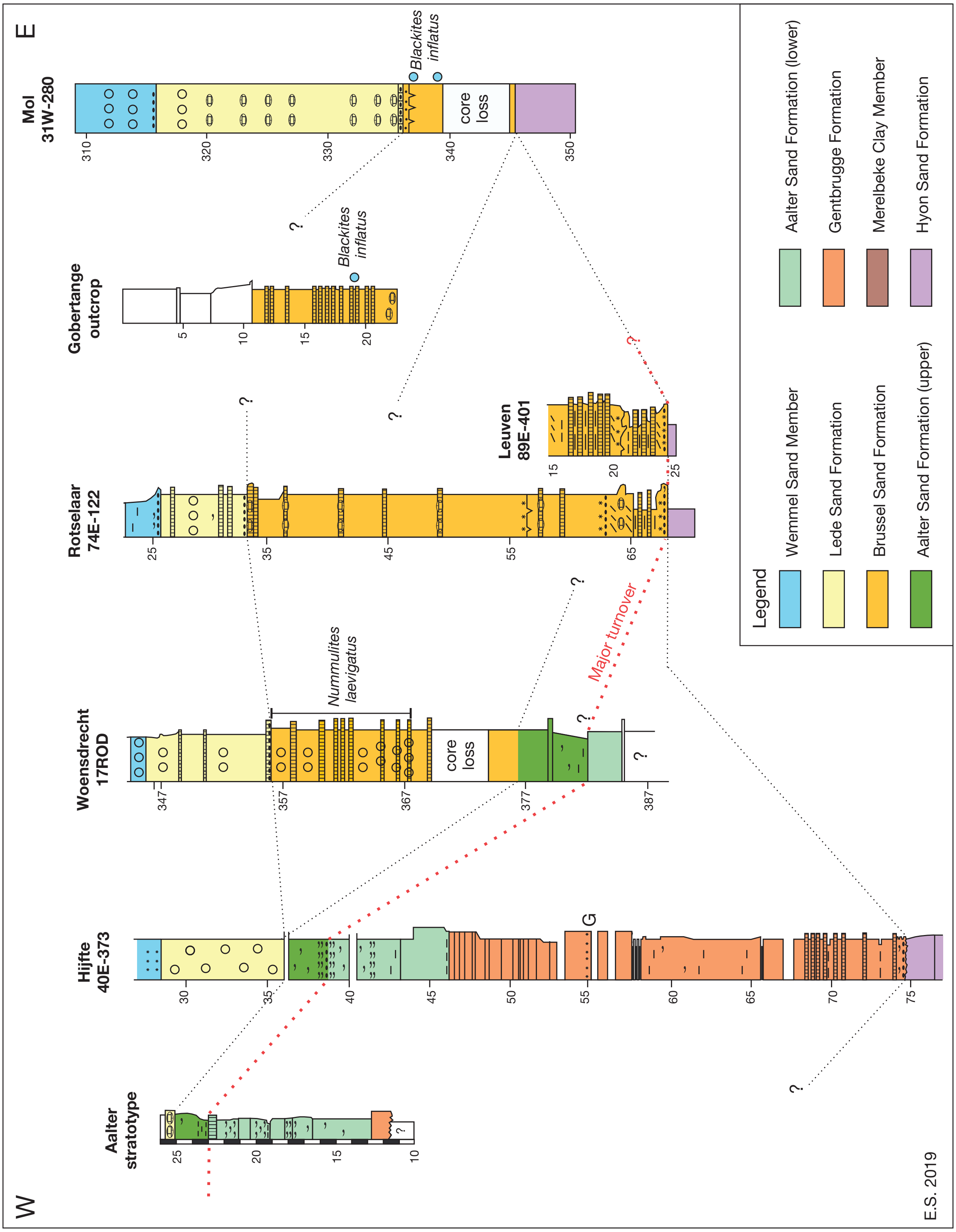


Fig. 13. — Lithostratigraphic interpretation of a series of Ypresian-Lutetian boundary sections in central and eastern Belgium with position of the major calcareous nannofossil events (see Fig. 12 for additional legend).

D. lodoensis (form with practically straight rays). The typical form of *D. lodoensis* with curved rays as well as *D. strictus* are also present, although very rarely and are co-existing with very rare five-rayed specimens of *D. sublodoensis*. The extreme rarity of *D. sublodoensis* at the start of its range may hamper the identification of the base of Zone NP14. Fortunately, the LO of *D. sublodoensis* is linked to a major change in calcareous nannofossil composition, essentially due to diversification in shallow-water groups. This is clearly expressed in the well-preserved nannofossil assemblages of the Vlakte van de Raan BH in Belgium and in the 'Chaumont-en-Vexin sands' (term informally introduced herein) in the Paris Basin, but is less obvious in the poorly preserved assemblages of the Mont-des-Récollets. It consists of a series of lowest occurrences among which are these of *Blackites minusculus* n. sp., *Blackites praeinflatus* n. sp., *Lanternithus minutus*, *Luminocanthus eolutetiensis* n. gen., n. sp., *Martiniaster cecellanoriae* n. sp., *Trochoaster nodosus* n. sp. and a major radiation in *Trochastrites*. The latter includes the LOs of *Trochastrites bramlettei* and *Trochastrites pyramidalis* n. sp., and the LOs of three other not yet described new species. This major bio-event, marked by the above mentioned lowest occurrences and by the highest occurrence of *Toweius occultatus*, is defined here as the Base Lutetian calcareous nannofossil turnover (BALCAT). Higher up in Unit A4 the number of *D. lodoensis* specimens ('late form' and typical form) is rapidly declining (= HCO of *D. lodoensis*), while the number of *D. sublodoensis* is rapidly increasing (= LCO of *D. sublodoensis*). In the Belgian Basin, the HCO of *D. lodoensis* precedes the LCO of *D. sublodoensis*, whereas, in well-preserved assemblages (not at Mont-des-Récollets, see Fig. 10), both are preceded by the LO of *Discoaster wemmelensis*.

DISCUSSION

The Mont-des-Récollets section: new insights in Belgian Eocene stratigraphy

Most complete upper Ypresian-lower Lutetian sedimentary succession of the Belgian Basin

Due to its protective cap rock, preventing substantial post-Miocene erosion, and its key position in the tectonically relatively quiescent southwest edge of the Belgian Basin (Fig. 1), the Mont-des-Récollets outcrop has preserved a very complete upper Ypresian and Lutetian succession. Its particular geological situation allows delineating more accurate spatial distribution patterns of the Ypresian and Lutetian lithostratigraphic units, which were nearly all defined in areas north and east of the Mont-des-Récollets (Steurbaut *et al.* 2015, 2016a).

The identification of the Mont-Panisel Sand Member on the southern flank of the Mont-des-Récollets is not really a surprise, as this unit is known from many outcrops and boreholes along the southern edge of the Belgian Basin (e.g. Mont-Panisel at Mons, Steurbaut & King 1994; Mont-Saint-Aubert, North of Tournai, Steurbaut unpublished information). However, this is the first undoubted record of the Mont-Panisel Sand Member in France. The detection of high frequencies of *Discoaster kuepperi* (over 20%) (Fig. 11B) is in line with earlier records at Zemst (central Belgium), where these peak abundances were linked to the development of warm sea surface waters during the Early Eocene Climatic Optimum (EECO) (Steurbaut *et al.* 2015). Identical lithologies, also belonging to upper NP12 (co-occurrence of *Tribrachiatus orthostylus* and *Discoaster cruciformis*) have been described from the nearby (1.5 km) Cassel borehole (interval *c.* 83 m to *c.* 77 m), but were erroneously attributed to the 'Argile de Roubaix' (Blondeau *et al.* 1972).

In the Cassel borehole the Mont-Panisel Member is overlain by a 3 m thick stiff clay of which the base contains *Palaeonummulites aquitanicus* (*N. planulatus auctoris*) and the uppermost 1 m is slightly calcareous, indicating NP13 (attributed to the 'faciès d'Aeltre azoïque' by Blondeau *et al.* 1972: tab. 1). Its attribution to the Merelbeke Clay Member is supported by its typical lithology and stratigraphic position, implying that this Merelbeke Clay record is the first of its kind in France. A few years earlier, in 1968, a similar 2.5 m thick clay unit, termed P1m, has been described from the Rodeberg borehole (municipality of Westouter, W Belgium, see Appendix 1), 18 km to the east of the Mont-des-Récollets (57.7-60.0 m; Gulinck unpublished information). Although it has surprisingly complete sections, the underlying Kwatrecht Member could not be unequivocally identified in any of the discussed outcrops or boreholes of the Mont-des-Récollets area (possibly recorded at the Rodeberg between 60 and *c.* 62.5 m depth). Nevertheless, these new records and interpretations indicate that the Merelbeke Clay Member covers a much vaster area of the Belgian Basin than previously thought, probably as far as the Artois Anticline in northern France, but that in its eastern direction it did not overstep the Brussels-Turnhout area (recorded at Kester and Merksplas: Steurbaut *et al.* 2016a). This is also true for the Pittem Clay Member, which is shown to be present in the Cassel borehole (72.30-71.40 m) and the Rodeberg borehole (57.7-48.5 m). A 20 cm thick shelly glauconite-rich sandstone with small pebbles, very similar to the Hooglede Bed in the Egem quarry, about 56 km north-eastward (Steurbaut 2006), has been recorded at the base of the Pittem Member in the Rodeberg borehole. About 12 m of the overlying Vlierzele Sand Member is exposed in the 'Western Quarry' of the Mont-des-Récollets, attributed to Units Vli b (essentially alternation of sand and clay beds) and Vli c (essentially bioturbated or low angle laminated glauconitic fine to very fine sand). The increase in quartz grains and glauconite towards the base of the section might suggest that the top of Unit Vli a (loose bioturbated fine sand) has been penetrated or is very close. These units are part of the threefold subdivision of the Vlierzele Sand Member, as observed in the Oedelem borehole (7 km east of Brugge), where this unit is remarkably complete (*c.* 13 m thick, Fig. 12). The lowermost part of the Vlierzele Member and its transition with the Pittem Clay Member could not be unearthed at the Mont-des-Récollets because of practical (essentially safety) restrictions. The identification of the Aalterbrugge Member indicates that the Gentbrugge Formation is extremely complete

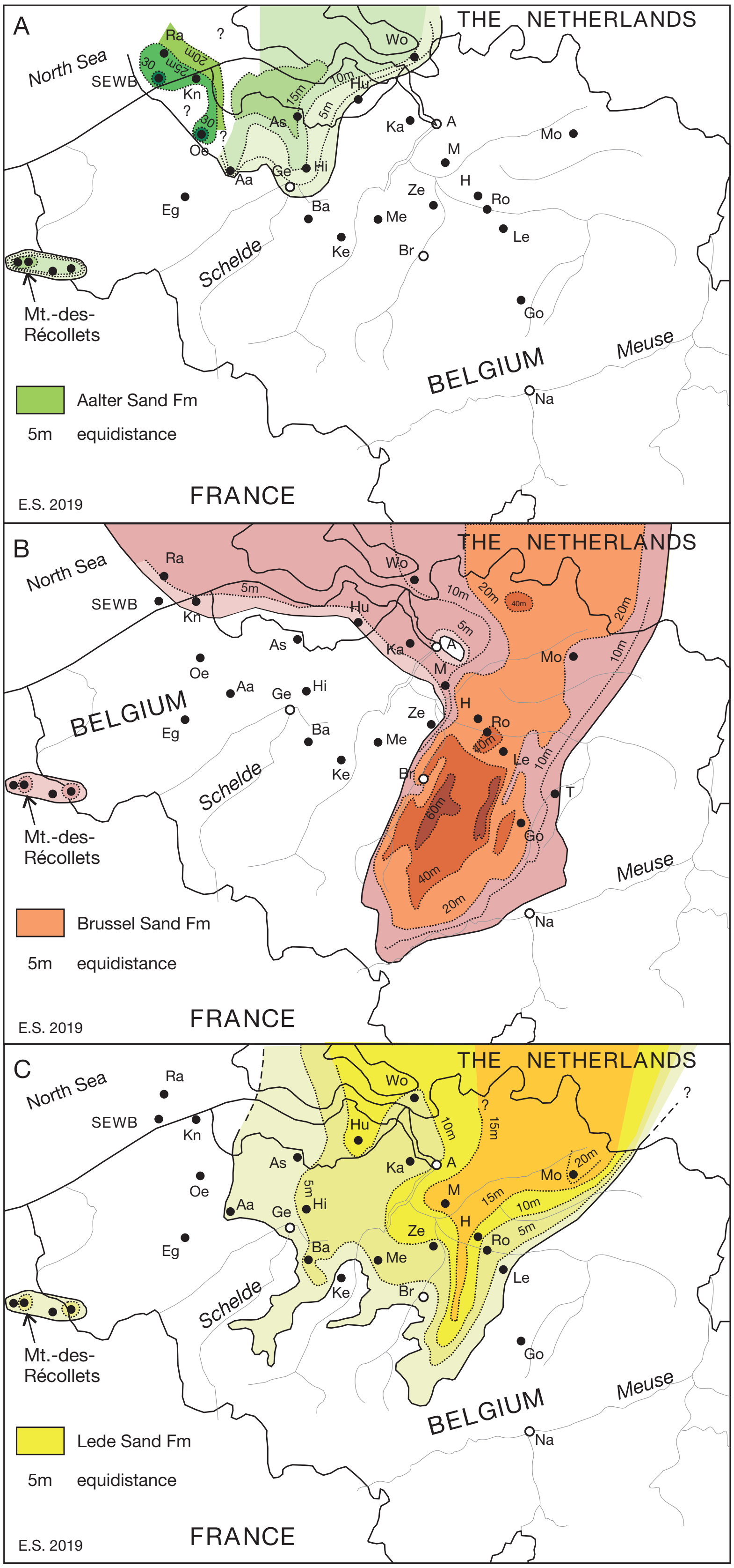


FIG. 14. — Current distribution and thickness fluctuations of the three subdivisions of the Zenne Group, displayed in ascending order: **A**, Aalter Sand Formation; **B**, Brussel Sand Formation; **C**, Lede Sand Formation (based on personal investigations, cf. Fig. 12-Fig. 13 and reinterpretations of data from Kaasschieter 1961, Fobe 1986 and Houthuys 1990).

Fig. 15. — Section through a *Nummulites laevigatus*-bearing sandstone sampled by D. Nolf from the base of the Lede Sand Formation at the Mont-des-Récollets. General picture with the delimitation of the three lithofacies, corresponding to the three phases of lithification (see text). **B**, bioturbation; **N**, *Nummulites laevigatus*. Scale bar: 2 cm.

at the Mont-des-Récollets. It probably includes the complete suite of members (only the presence of Kwatrecht Member is questionable), with lithologies very comparable to those in their respective type areas in central Flanders (essentially the province of East Flanders).

The combined lithofacies and calcareous nannofossil investigation given herein has revealed that the Aalter Sand Formation is very expanded (18.25 m) at the Mont-des-Récollets (Fig. 14A). Its lithofacies succession shows strong affinities with the stratotype section at Aalter (12.35 m thick; Steurbaut & Nolf 1989) and with the Hijfte borehole section (*c.* 10 m thick, Fig. 13), although has its own particularities. The Mont-des-Récollets Units A1 and A2 contain *Venericor planicosta* beds, one bed in each unit, with turritelline coquinas in between. This contrasts with the Aalter stratotype where the turritelline coquinas overlie the interval with *V. planicosta* (Steurbaut & Nolf 1989). In the Oedelem borehole this lower part of the Aalter Formation is much finer and clayier (clayey very fine sand), representing the Beernem Sand Member. The correlation between the top of Unit A2 and the top of the Beernem Sand Member at Oedelem is established on the basis of the synchronous disappearances of *Nannoturba jolotteana* and *N. spinosa* (Fig. 12).

The base of Unit A4 corresponds to a sequence boundary, which can be traced throughout the Belgian Basin (Aalter stratotype, Oedelem borehole, SEWB borehole off Blankenberge, etc.; base of dark green coloured interval in Figures 12 and 13 and Appendix 1 for locations). At Aalter and Mont-des-Récollets this contact could not be properly investigated because of the rudimentary drilling technique (shallow auger boreholes), but in the SEWB offshore borehole it is marked by an undulating omission surface at 19.17 m depth (Jacobs & Sevens 1993: fig. 10). In each of the investigated sites this sequence consists of a thin glauconitic fining upward fine sand to clayey fine sand, overlain by a much thicker coarsening upward sandy succession (Unit A4 at Mont-des-Récollets; bed 12 in the Aalter stratotype section: Steurbaut & Nolf 1989; units 19 and 20 of SEWB hole: Jacobs & Sevens 1993). The base of Unit A4 is marked by a major change in calcareous nannofossil composition, including many lowest occurrences (among which the LO of *D. sublodoensis*) and the HO of *Toweius occultatus* (see previous chapter). This turnover at the base of NP14 is well expressed in the well-preserved nannofossil assemblages of the Vlakte van de Raan BH in Belgium's offshore zone and in the 'Chaumont-en-Vexin sands' in the Paris Basin, but is less obvious in the poorly preserved assemblages of the Mont-des-Récollets. However, the highest consistent occurrence (HCO) of *Discoaster lodoensis* and the lowest consistent occurrence (LCO) of *Discoaster sublodoensis* are easy to localise at the Mont-des-Récollets. They are recorded within Unit A4, at the top of the lower clayey sand unit (114.85 m), and in the middle of the coarsening upward unit (116.40 m) respectively. The identification of the HCO of *D. lodoensis* and the LCO of *D. sublodoensis* in the Oedelem BH (at *c.* 11 m and *c.* 7 m respectively) and the Leuven–Artois BH (around 23.70 m and 20.70 m respectively) (Figs 12; 13) indicates that these events are basin-wide phenomena. This is also true for the LO of *Trochastrites pyramidalis* n. sp., recorded at 11.70 m in the Oedelem BH, at 23.90 m in the Aalter stratotype and at 23.70 m in the Leuven–Artois BH. These events suggest that the interburrowed junction (associated with coarse quartz grains and a glauconite influx) at 24.35 m depth in the Leuven-Artois borehole, represents a sequence boundary, and, more precisely, the same as the one recorded at the base of Unit A4 at Mont-des-Récollets and at the base of bed 12 in the Aalter stratotype (Steurbaut & Nolf 1989). This means that, at least in the Leuven area, the start of the major scouring event, producing the Brussels megachannel (Houthuys 1990; Damblon & Steurbaut 2000), dates from the start of Biochron NP14, around 49.11 Ma (according to Payros *et al.* 2015). This megachannel is in fact a deeply incised 25 km wide estuary, marked by several tens of meter deep ebb- and flood-dominated channels (Fig. 14B). It also indicates that the lower part of this channel fill is coeval with the upper part of the Aalter Sand Formation.

The contact of the Aalter Sand Formation with the overlying Brussel Sand Formation has not yet been studied in much detail, as both units are only rarely recorded in superposition (e.g. in the Flemish Hills and in some offshore boreholes) or because of the many coring difficulties related to the sandstone levels in the latter (e.g. Kallo and Mol boreholes). The typical whithish medium-grained sand with echinoid (among which *Maretia omaliusi*) and bryozoal fragments, occurring between 117.35 m and 118.95 m at the Mont-des-Récollets, are included in the Brussel Sand Formation (Unit B1). However, there is no omission surface at their base, as already observed by Leriche (1912: 713); there is only a sudden increase in grain size, and the nannofossil assemblage is very similar to that at the top of the underlying Aalter Formation. This contrasts with the boundary between Units B1 and B2, which is marked by an omission surface, directly overlain by very coarse quartz sand. At the Mont-des-Récollets the LO of *Discoaster wemmelensis* is recorded at the base of B1, whereas the LOs of *Blackites praeinflatus* n. sp. and *Sphenolithus spiniger* and the HO of *S. recolletensis* n. sp. are about 2 m higher up, in the upper part of the bioturbated sands of Unit B2b. There is an interburrowed junction and a sharp decrease in grain size at the base of Unit B3, which coincides with the influx of *Luminocanthus plenilutetiensis* n. gen., n. sp. Comparison with the nannofossil assemblages from the offshore Vlakte van de Raan borehole section and different outcrop sections in the Brussels area (e.g. at Neerijse, Sint-Stevens-Woluwe, Vossem, etc.; see Figs 12, 13 and Appendix 1 for locations) indicates that *D. wemmelensis*, *L. plenilutetiensis* n. gen., n. sp. and *B. praeinflatus* n. sp. show somewhat delayed first records at the Mont-des-Récollets, probably due to the low quality and low diversity of the assemblages in Units A4 and B1 (Fig. 10). It also suggests that initially Unit B3 was probably much thicker at the Mont-des-Récollets and that this unit was completely removed during the following transgression, except for a thin 40 cm thick sedimentary succession, left as relict (Fig. 9). This is evidenced by the absence of the *Sphenolithus*, *Pemma* and *Discoaster* blooms at Mont-des-Récollets, which in many outcrop sections (Diegem, Vossem, Zaventem,…), start a little above the base of Unit B3 (Steurbaut unpublished, detailed in forthcoming study). Unit B4, the base of which is sharp and believed to be erosional, is characterized by the frequent occurrence of *Nummulites laevigatus* (*c.* 5 specimens/kg sediment). It is one of the very few *in situ* occurrences of this taxon in the Belgian Basin (see next chapter). The nannofossil assemblages are also quite distinct, marked by rather high values of *Braarudosphaera bigelowii*, *B. stylifera*, *Pemma* spp., *Lanternithus minutus* and *Blackites creber* (Fig. 11B). This points to substantial paleoenvironmental changes within the Belgian Basin, with a tendency to develop coastal hyposaline conditions along its southern border. The base of Unit B4 is also a major biostratigraphic boundary, marked by the LOs of *B. stylifera*, *Martiniaster fragilis* and *Sphenolithus quadricornutus* n. sp. and by the LCO of *L. minutus.*

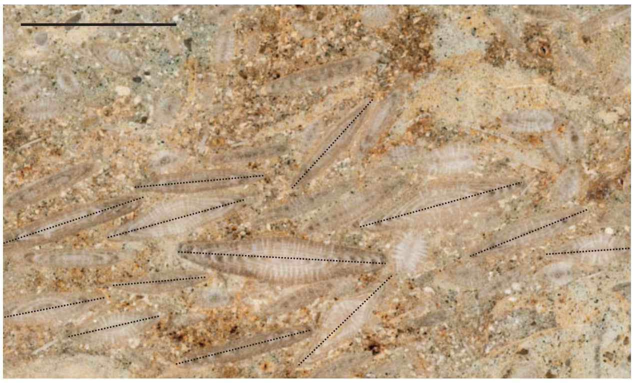


Fig. 16. — Detail of the central core of the *Nummulites laevigatus*-bearing sandstone from the base of the Lede Sand Formation at the Mont-des-Récollets with clearly aligned *N. laevigatus* shells (see dotted lines). Scale bar: 1 cm.

At the Mont-des-Récollets the texture, composition (presence of several sandstone banks) and thickness of the Lede Sand Formation is very similar to that of the stratotype section at Balegem (Jacobs & Sevens 1994). At both sites the basal surface is erosive and overlain by a basal gravel including reworked shell fragments, pebbles and shark teeth. However, there is a fundamental difference in the reworked shell fragments, which essentially consist of loose shells and loose or consolidated aggregates of *Nummulites laevigatus* at the Mont-des-Récollets (see next chapter) and of *Venericor planicosta* and very few *N. laevigatus* at Balegem (Fobe 1986: 15). At both sites, the nannofossil assemblage of the basal Lede Sand Formation is quite similar to that of B4. Other similarities between both sites are the rare records of *Blackites gladius* in the lowermost 1 m of the Lede Sand Formation and the absence of *Nannotetrina* species throughout this formation. Conditions are substantially different in the Oosterzele outcrop (Smith *et al.* 2004), where the basal 1.2 m of the Lede Sand Formation (unit A of Steurbaut in Smith *et al.* 2004) is represented by glauconitic shelly sand with numerous reworked elements from the Aalter Sand Formation (*Venericor planicosta* and reworked medium-grained glauconite) and probably the Brussel Sand Formation (sandstone pebbles and mammal teeth; Franzen & Mörs 2007). This unit, which is characterised by the total range of *Nannotetrina quadrata*, is missing at the Mont-des-Récollets and at Balegem. It is a remnant of what was previously called the 'Lakenian' transgression, nearly everywhere removed by the subsequent 'Ledian' transgression (Mourlon 1888: 275; Anonymous 1893). The only substantial difference between the Belgian sections and the Mont-des-Récollets section (Fig. 14C) is the virtual absence of *Campanile giganteum* in the Lede Sand Formation in Belgium (only 2 specimens recorded, see below), while it is consistenly recorded in this unit at the Mont-des-Récollets, although restricted to a single bed (bed 4 on Fig. 9).

At the Mont-des-Récollets the Wemmel Sand Member is surprisingly similar to what has been observed in the centre of Gent (Blandijnberg or 'Colline de Saint-Pierre': Delvaux 1886; Nolf 1974), including a 10 cm basal glauconite bed, a 20 cm thick clay bed, a 10 cm thick accumulation of *Lentipecten*, overlain by clayey fine sand. At the Mont-des-Récollets the basal clays and *Lentipecten* bed contain fairly rich nannofossil assemblages, marked by the LO of *Sphenolithus furcatolithoides* and the HO (a few specimens) of *Braarudosphaera stylifera*. *Blackites gladius* is present, but rarely recorded, while *Nannotetrina* taxa are absent. Identical assemblages have been observed at the base of the Wemmel Sand Member in the Zemst borehole (Steurbaut *et al.* 2015; Lin *et al.* 2017).

Among the oldest and rare in situ *records of* Nummulites laevigatus *in the Belgian Basin*

Nummulites laevigatus (Bruguière, 1792) has been reported from many outcrops in Belgium (see Depret & Willems 1983 for an overview), although it is not always clear whether these are *in situ* records or not. Their presence in Belgium was first noted by Burtin (1784: 103, pl. 22 B). D'Omalius d'Halloy (1842: 83) and Lyell (1852: 329, fig. 4) were among the first to mention their presence at Mont Cassel and Mont-des-Récollets. Van den Broeck (1902) discussed the reworking of *N. laevigatus* shells at the base of the Lede Sand Formation (= base Laekanian *sensu* Van den Broeck). He stressed on the presence of two types of *N. laevigatus*, silicified forms without glauconite infill co-occurring with non-silicified, glauconite-containing forms, which seems to point to different source areas. Leriche (1906: 395; 1912: 711) suggested that probably all of the *N. laevigatus* records of Belgium and northern France were due to reworking, except for these at Cassel and Fayat (between Charleroi and Namur), which were believed to be *in situ*, as already suggested by Rutot (1887). In his subsequent review of the spatial distribution of *N. laevigatus* in the Belgian Basin Leriche (1923) confirmed that the occurrences in the Flemish Hills (Mont Cassel, Mont-des-Récollets, Mont des Cats and Mont Aigu, see Fig. 1) and in the zone between Leuven-Charleroi-Namur represented *in situ* records. He expressed serious doubt about other previous records, such as these at Aalter, Gobertange, Westerlo, etc., and did not mention any record from the Brussels area (Leriche 1923: 94). Blondeau (1966) listed several additional sites, especially around Brussels (Forest, Diegem) and presented some morphometric data on specimens from Jodoigne and Isnes, located respectively 28 km north and 10 km northwest of Namur. The *in situ* records in the Woensdrecht borehole (southern Netherlands) (Van Waterschoot van der Gracht *et al.* 1913) and in Zeebrugge borehole 19.6 (Depret & Willems 1983) provide the necessary evidence to refute Blondeau's hypothesis (Blondeau *et al.* 1972) that the Flemish Hills and the Brussels area define the northern limit of the distribution of *N. laevigatus* in the Belgian Basin.

Our personal observations at Gobertange (Damblon & Steurbaut 2000) and Zaventem (Herman *et al.* 2001), as well as those from other geologists at Diegem (Fobe 1986; Hooyberghs 1986), Nederokkerzeel (Fobe 1986), Neerijse (Fobe 1986; Hooyberghs 1992) and Sint-Stevens-Woluwe (Hooyberghs 1992), which did not lead to *in-situ* finds of *N. laevigatus*, indicate that this species is rarely recorded *in situ* in the Brussels area. However, there is sufficient evidence to assume that a thin *N. laevigatus* bearing sand and/or sandstone layer(s) with abundant large microspheric forms of *N. laevigatus*, covered the greater part of the Belgian Basin (equivalent of the 'assise de la pierre à liards' in the Paris Basin), as already postulated by Gosselet (1883), Leriche (1906: pl. VII) and Dartevelle (1934). We also agree with their conclusion that during the deposition of the *N. laevigatus* beds the Belgian Basin was directly connected with the Paris Basin. The *N. laevigatus* beds were almost completely dismantled in central Belgium, due to substantial tectonic uplift of the Brabant Massif, whereas in the tectonically relatively quiescent zones (e.g. the Flemish Hills) parts of these remained preserved. Moreover, in the north of the province of Namur (Nalinnes, Isnes, etc.), erosion of the *N. laevigatus* bearing beds was least pronounced or was even neutralized by local subsidence, as shown by their strong increase in thickness, up to more than 2 m at Nalinnes (Briart 1890: 263) and more than 3 m at Saint-Denis-lez-Namur (Halet 1937), Noville-sur-Mehaigne (Leriche 1943b) and Isnes (Hooyberghs 1986: fig. 11).

Nummulites laevigatus*-bearing sandstone blocks at the base of the Lede Formation*

The abundance of *N. laevigatus*-bearing sandstone blocks in the base of the Lede Sand Formation (also known as base Laekenian in older literature) has systematically been reported from the Mont-des-Récollets for almost two centuries (Rutot 1882; Leriche 1921; Depret & Willems 1983; and Fobe 1986, for overviews). Some of these blocks, such as the one displayed herein (Fig. 15), are composed of different lithofacies types, witnessing multiple lithification phases, and as a whole, revealing a complex depositional and tectonic history of this part of the Belgian Basin.

The core of the sandstone block studied herein consists of an amalgamation of abundant, almost unidirectional oriented large-sized *N. laevigatus* shells (Fig. 16), a mixture of essentially fine-grained and some coarse-grained glauconite (the latter in burrows ?), some larger quartz grains (1 mm), within a fine-grained matrix, all solidly cemented (probably ferro-calcitic cement) (phase 1). The presence of large grains may be due to bioturbation (burrowing molluscs; B on Fig. 15). This core is irregularly surrounded by a thin greenish coloured coarse sandstone, less well consolidated and containing a mixture of *Nummulites laevigatus*, *Palaeonummulites variolarius*, some small molluscs, echinoid debris and *Ditrupa*, and above all marked by huge (up to 2.5 mm) quartz grains and coarse-grained glauconite (phase 2). The upper zone consists of a rusty stained, finer grained sandstone, presenting an irregular basal surface, and containing abundant fine-grained glauconite, large molluscs, *P. variolarius*, *Ditrupa* and bryozoa, but only very few *N. laevigatus* (phase 3).

The *N. laevigatus*-rich core appears to have been formed during a first lithification phase of initially relatively fine-grained nummulitic shallow marine sand of the Brussel Sand Formation. This lithification took place under continental conditions, probably shortly after the sea retreated. Remains of this continental phase have been reported from the base of the Lede Formation at the Mont-des-Récollets by Leriche (1921), who mentioned the presence of reworked lignitic pebbles and crocodile remains. During the next sea-level rise the continental cover as well as the underlying *N. laevigatus*-bearing sandstones and associated badly sorted sand with large quartz grains were eroded. The most solid elements (rolled sandstone blocks) were abraded and colonized by lithofageous bivalves. These blocks resedimented together with reworked loose *N. laevigatus* and many *in situ* fossils, such as *P. variolarius*, several mollusc species and *Ditrupa* tubes. Initially the winnowing of sediment by coastal currents and storm events was probably important enough to restrict sediment accumulation, explaining its coarse-grained texture (phase 2). In a later stage, when sea-level progressively rose, the winnowing decreased, which led to the deposition of a somewhat finer sediment (phase 3), rich in molluscs, *Ditrupa*, bryozoa and *P. variolarius*. Coastal conditions remained, with very reduced sediment supply, initiating compaction and, when the sea temporarely retreated, the start of calcite cementation of the sea bottom, including the earlier lithified *N. laevigatus*-bearing boulders. Because marine and non-marine conditions rapidly shifted, the coarse-grained and finer grained sandstone components of phases 2 and 3, are poorly cemented, much less than the cementation in the core of the block (phase 1). Subsequently, when sea-level further rose, the effect of the coastal and storm currents reduced, initiating the progressive accumulation of fine shallow marine sand of the Lede Sand Formation.

Campanile giganteum *in the Lede Sand Fm and its paleoenvironmental consequences*

Campanile giganteum (Lamarck, 1804) (previously in the genus *Cerithium*), a giant gastropod reaching up to 1 m in length (Houbrick 1984), is known from many outcrops and subsurface galleries in the central part of the Paris Basin (Boussac 1912; Gély 2008: 84, fig. 55). It is consistently occurring in the middle Lutetian sands and sandy limestones (beds 4 and 5 of Blondeau & Renard 1980) from the Paris city centre up to the Yvelines area, 30 km westward (e.g. Grignon), the Oise area, 45 km northward (e.g. at Saint-Vaast-lès-Mello) and the Epernay area, 110 km eastward (e.g. at Fleury-la-Rivière) (Merle & Courville 2008). The highest concentrations, up to 5 specimens/m² (Scaut, unpublished information), are recorded in the eastern sector of their range (in the 'Tuffeau de Damery', around Damery, Courville 2012). Measurements on the orientation and preservation of the Fleury-la-Rivière specimens suggest that the shells had been displaced over short distances in a northwestward direction, towards the open sea, where they accumulated (Scaut, unpublished information). This was probably caused by a major storm event, intensifying the normal coastal currents. The Compiègne High and the Pays de Bray Isle may have protected the more southwestern areas of the Paris Basin (Yvelinnes and Paris areas) from these storms, or at least may have strongly diminished their effect, as shown by the scattered occurrences of *C. giganteum* in these areas.

Records outside the Paris Basin are very rare and need to be interpreted with caution. Jung (1987) mentioned three incomplete specimens from the middle Eocene of the Lesser Antilles (Caribbean Islands), which he referred to *Campanile* cf. *giganteum*. Much closer, in the North Sea Basin, these giant gastropods have systematically been reported from the Bracklesham Beds of the Hampshire Basin (Fisher 1862; Wrigley 1940; amongst many others), although their exact position has been uncertain for a long time. Fisher's Bed 12 or the *Campanile* Bed was relocated at Bracklesham Bay by C. King (in Curry *et al.* 1977), at about 1.75 m above the base of the Selsey Division (unit S2i). About 20 years later King (1996) rediscussed its position and equated Fisher's Bed 12 with unit S4i. Almost simultaneously, Tracey *et al.* (1996) tabulated the stratigraphic distribution and relative abundance of the molluscs within this Selsey Formation. *C. giganteum* was shown to be restricted to units S2 to S4. In southern England this species is known to co-exist with *Nummulites variolarius* (King 1996: text-fig. 1). Its range clearly postdates that of *N. laevigatus*, very similar to what has been encountered in the Paris Basin (Gély 1996: fig. 2) and at the Mont-des-Récollets (Figs 9; 12; 13).

Occasional records (moulds) of *C. giganteum* have regularly been reported from the Eocene of the Cassel area, already since the earliest stratigraphic observations (Elie de Beaumont 1833; d'Archiac 1839; Lyell 1852; etc.). According to Ortlieb & Chellonneix (1870: fig. 9) they are restricted to a single limestone bank in the lower part of the 'Assise Laëkenienne' (bed 17) at the Mont-des-Récollets. This marker bed exactly corresponds to our limestone bed 4 in the lower third of the Lede Sand Formation (Fig. 7). The correlation between this limestone bed and the *C. giganteum*-bearing beds in the Paris Basin was already established by Gosselet (1896: 164). The presence of *C. giganteum* in Belgium has been confirmed, although from two localities only and without any detail. Burtin (1784: 106, pl. 16G) and Galeotti (1837: 36 and 59) mentioned a find from Affligem (18 km west of Brussels), but it is unclear if both cited the same specimen or specimens, whereas Wesselingh *et al.* (2013: fig. 1H) reported 1 specimen from the Lede Formation of the Balegem area (collector unknown). A third internal mould has been dredged from the Flemish Banks, offshore the northern Belgian Coast (Wesselingh *et al.* 2013: 160). According to the available data it is logically to assume that all the Belgian finds come from the Lede Sand Formation.

From the foregoing it is clear that *Campanile giganteum* is present in the lower part of the Lede Sand Formation, but with strongly decreasing numbers towards the north. This suggests a direct connection between the Paris Basin and the Belgian Basin during early Biochron NP15 (middle Lutetian) and the development of similar paleoenvironmental conditions in these areas. The sedimentology of the sandy limestone banks in the Lede Formation indicates reduced sedimentation rates, storm-induced winnowing and hardground formation under a relatively thin water cover (<20 m, probably much less) (Fobe 1986: 177-180; Jacobs & Sevens 1994). This type of paleoenvironment is comparable to the current habitat of the only survivor of the family Campanilidae, *C. symbolicum* Iredale, 1917 from southwestern Australia. According to Houbrick (1984) large populations of this survivor taxon may be found on sandy patches between rocks in depths of one to four meters.

The spatial distribution of *C. giganteum* suggests that the shallow marine conditions, which led to the development of the Lede Sand Formation, persisted up to central Flanders, as far northward as the Aalter (outcrop)-Assenede (borehole 25E-123)-Kallo (borehole 27E-148)-Woensdrecht (ROD borehole 17, southern Netherlands) area (Fig. 14C and Appendix 1 for details). Further northwestward, the Lede Sand Formation is missing (e.g. in the onshore Oedelem borehole and the offshore Vlakte van de Raan borehole in Belgium (Fig. 14C) as well as in the E-55 Rotterdam borehole in the Netherlands, Steurbaut unpublished information), most probably because of non-deposition, although subsequent erosion cannot be excluded either. The Aalter-Assenede area is likely to represent the most northern distribution limit of *C. giganteum* in the North Sea Basin. Its presence in dredgings from the offshore 'Flemish Banks', 50 km north, is believed to be due to northwest transport of reworked material from southern source areas via Quaternary river systems.

Enhancing the upper Ypresian-Lutetian calcareous nannofossil record in the southern North Sea Basin

The calcareous nannofossil record of the Mont-des-Récollets outcrop allows fine tuning of the distribution patterns of many important index taxa, resulting in the subdivision of the standard NP13 and NP14 Zones of Martini (1971). This new succession of bio-events has been identified in many borehole and outcrop sections of the Belgian Basin. It has been recorded in the Bracklesham Group in southern England and, in part, in the lower Lutetian deposits of the Paris Basin, including the fine-grained 'Chaumont-en-Vexin sands' (term informally introduced herein) and in the overlying coarser grained 'Glauconie Grossière s.s.'. Combined with the Zemst borehole data, which led to the subdivision of Zone NP15 (Steurbaut *et al.* 2015), it is considered to be a standard for upper Ypresian-Lutetian calcareous nannofossil biostratigraphy of the southern North Sea Basin. Among the most relevant conclusions are:

1) Steurbaut's (1998) nannofossil subzone VIIIb, corresponding to uppermost NP12, has been identified at the Mont-des-Récollets (Fig. 10), as well as in many other outcrop and borehole sections in the North Sea Basin (Steurbaut 2011) and Kazakhstan (King *et al.* 2013). The LO of *Nannoturba robusta* and the LO's of *Ectalithus* (previously *Coccolithus*) *crassus* and *Pentaster lisbonensis*, located at the base and in the upper part of the middle Ypresian subzone VIIIb respectively (e.g. at Zemst, Steurbaut *et al.* 2015 and Kerksken, Steurbaut unpublished information) are shown to be important datum planes in mid-latitudes of western Eurasia.

2) The acme of *Discoaster kuepperi* (around 20%), known from the Mont-Panisel Member (Hyon Sand Formation) in the Zemst borehole and associated with high sea surface water temperatures during the EECO (Steurbaut *et al.* 2015), is recorded in the same unit at the Mont-des-Récollets (Fig. 11B).

3) In the Cassel borehole the Merelbeke Clay Member is slightly calcareous at its top, indicating the lower part of NP13 (Lezaud 1972). This is the first calcareous nannofossil record of the Merelbeke Clay Member, which is secondarily decalcified elsewhere in the Belgian Basin (e.g. mollusc moulds at Roborst, Steurbaut unpublished information). It is in line with its generally accepted, but only indirectly established, biostratigraphic position (above the Kwatrecht Member dated as lower NP13) (Steurbaut *et al.* 2015).

4) The Mont-des-Récollets data allow subdivision of Zone NP13 into three subzones (Fig. 10), all recorded throughout the Belgian Basin. The coincident LOs of *Nannoturba jolotteana* and *N.spinosa,* defining the base of subzone NP13-b, have been identified at the base of the Pittem Clay in many Belgian boreholes (e.g. the Oedelem, Knokke and Kallo boreholes; see Figs 12, 13), although they were not mentioned in Lezaud's work on the Cassel borehole. Their coincident HOs are recorded at the top of Unit A2 in the Mont-des-Récollets section, as well as at the top of the Beernem Sand Member in the Oedelem borehole, indicating that these tops are coeval (base of subzone 13-c). *Chiphragmalithus vandenberghei* (see Steurbaut 2011) appears to be restricted to subzone NP13–b. *Discoaster praebifax, Nannoturba joceliniae* n. sp. and *Pemma* spp. first appear in subzone NP13-c, just above the base and in the middle (the last two) respectively.

5) The LO of typical five-rayed *Discoaster sublodoensis*, which is used to define the base of NP14, has been identified at the base of Unit A4 in the Vlakte van de Raan borehole and at the base of the 'Chaumont-en-Vexin sands' in the Paris Basin. Its LO is slightly delayed in the more poorly preserved assemblages of the Belgian Basin, such as at the Mont-des-Récollets, although still within the lowerpart of Unit A4. Fortunately, this bio-event is part of a major turnover in calcareous nannofossil assemblages, which is recorded throughout the Belgian Basin, including the Mont-des-Récollets, and in the Paris Basin. It involves the identification of many lowest occurrences (e.g. these of *Blackites minusculus* n. sp., *Blackites praeinflatus* n. sp., *Lanternithus minutus*, *Martiniaster cecellanoriae* n. sp., *Luminocanthus eolutetiensis* n. gen., n. sp., *Trochoaster nodosus* n. sp.), a major radiation of *Trochastrites* (the LOs of *T. bramlettei*, *T. pyramidalis* n. sp. and 3 other undescribed new species) and the HO of *Toweius occultatus* (a few isolated specimens of *T. occultatus* may linger on in the base of A4). The HCO of *D. lodoensis* and the LCO of *D. sublodoensis*, which occur higher up in Unit A4, are also basin wide phenomena.

6) The data from Mont-des-Récollets and many other Belgian localities (e.g. Zaventem, Neerijse, Nederokkerzeel, Oedelem, Gobertange, etc.; see Figs 12, 13 and Steurbaut in a forthcoming study) and some French sites (e.g. Chaumont-en-Vexin, Prémontré, etc.) reveal that: 1. *Discoaster wemmelensis*; 2. *Discoaster sublodoensis* (lowest consistent occurrence

of typical forms); 3. *Luminocanthus plenilutetiensis* n. gen., n. sp.; 4. *Sphenolithus spiniger*; 5. *Toweius brusselensis* (lowest consistent occurrence)-*Micrantholithus hebecuspis*; 6. *Martiniaster fragilis*; 7. *Braarudosphaera stylifera*-*Sphenolithus quadricornutus* n. sp.; 8. *Blackites inflatus*; and 9. *Blackites* aff. *gladius* (form with slightly inflated stem, although much less than the type specimens) constitute a chronological sequence of appearances within the Lutetian nannofossil zone NP14. The HCO of *Discoaster lodoensis* (essentially the late form with straight rays) is slightly preceding the LCO of *D. sublodoensis*.

7) The LO's of *Nannotetrina alata* (Zaventem section, Herman *et al.* 2001) and *Nannotetrina quadrata* (Oosterzele section, Smith *et al.* 2004) have been used to define the base of NP15 in the Belgian Basin, as *Blackites gladius* is often rarely represented in the earliest part of its range (e.g. at Mont-des-Récollets, Balegem and Oosterzele). At the Mont-des-Récollets, where *Nannotetrina* is missing in the Lede Sand Formation, the LO of *B. gladius* is used to define the base of NP15. The HOs of *Discoaster sublodoensis* and, to a lesser degree, *Toweius brusselensis* (still present in the basal 20 cm of the Lede Formation, but not higher up) may be considered as reliable substitutes for the lower boundary of NP15.

8) *Sphenolithus perpendicularis*, initially described from the middle Lutetian in offshore West Australia (throughout CP13a, lower part of NP15), has been identified in the middle of the Lede Sand Formation at Balegem. This is the first record of this species in the North Sea Basin.

and 9) The subdivision of Zone NP15, as established in the Zemst borehole (Steurbaut *et al.* 2015; Lin *et al.* 2017) appears to be applicable to the Mont-des-Récollets, at least for the studied interval (up to mid-NP15). The clay bed and overlying *Lentipecten* bed, composing the base of the Wemmel Sand Member at the Mont-des-Récollets, are marked by the co-occurrence of *Sphenolithus furcatolithoides* and *Braarudosphaera stylifera*, allowing correlation with the top of subunit W1 of the Wemmel Sand Member at Zemst (Steurbaut *et al.* 2015: 152).

The Ypresian-Lutetian boundary in the Belgian Basin and its impact on global chronostratigraphic classification

A close inspection of the relevant outcrop and borehole data of Belgium (Steurbaut 2006, 2011; Steurbaut *et al.* 2015; Figs 12, 13) reveals that the Ypresian-Lutetian transition is very incomplete in large parts of the Belgian Basin. Complete or almost complete Ypresian-Lutetian transition sections may have been preserved north of the Antwerp area and in the southern part of the province of Zuid-Brabant in the Netherlands (Woensdrecht borehole; Halet 1913; Van Waterschoot *et al.* 1913) (Fig. 1). However, this is difficult to evaluate or to confirm because of substantial core loss and related displacements of core material at the contact of hard banks and sandy sediments, which are quite common in that interval. In the northwest edge of the Belgian mainland (Zeebrugge borehole 19, Depret & Willems 1983 and Knokke borehole, King 1990) and its prolongation offshore ('Vlakte van de Raan' borehole, Fig. 12) the Brussel Sand Formation is represented by very fine glauconitic sand, in the offshore borehole erroneously attributed to the Wemmel Sands (Jacobs & Sevens 1993; De Batist & Henriet 1995), while the Lede Sand Formation is totally missing. At the Mont-des-Récollets both formations are very well developed and the underlying Aalter Sand Formation is among the most complete ever recorded, justifying the peculiar status of the Mont-des-Récollets section as 'the' reference for the Ypresian-Lutetian transition in the southern North Sea Basin. Nevertheless, the identification of the base of the Lutetian in the Belgian Basin remains a moot point.

The base of the Lutetian has in the past been defined at the 'first occurrence datum' of the planktonic foraminiferal taxon *Hantkenina* at c. 48.6 Ma (e.g. Luterbacher *et al.* 2004), corresponding approximately to the base of calcareous nannofossil zone NP14 (Fig. 3[point 1]), but recent studies have shown this *Hantkenina* event to be significantly diachronous. In April 2011 the International Union of Geological Sciences ratified the proposal that the base of the Lutetian is defined by the Gorrondatxe GSSP (NW Spain) (Molina *et al.* 2011). This boundary is placed at the 167.85 m level, corresponding to the lowest occurrence (LO) of the nannofossil taxon *Blackites inflatus* (Fig. 3[point 3]). The latter is well known from many low and middle latitude outcrop and borehole sections worldwide (Southern USA: Siesser 1983; Russia: Shcherbinina 2000; off NW Australia: Shamrock 2010a,b; etc.), but seems to be missing at higher mid latitudes, such as the North Sea Basin (not mentioned by Perch-Nielsen 1971; Bigg 1982; Depret & Willems 1983; Steurbaut 1988; Verbeek *et al.* 1988; Varol 1998 and Köthe 2012; partially misinterpreted by Aubry 1983: figured specimens belong in fact to *B. praeinflatus* n. sp.). *In situ* specimens of *B. inflatus* have not been recorded at the Mont-des-Récollets during the present investigation. However, new intensive research on about 100 samples of the Brussel Sand Formation (Figs 12, 13; detailed by Steurbaut in a forthcoming study) has currently led to the identification of 13 specimens of *Blackites inflatus* on a total of about 100 000 specimens screened. Two specimens come from the Vlakte van de Raan borehole (one at 78.5 m and one at 74.5 m depth) in the extreme NW of Belgium and four from the Mol borehole in the northeast of Belgium; three were recorded in one out of twelf studied samples from the Isnes quarry (Fig. 20H, J), 10 km northwest of Namur, and the remaining four in one out of nine studied samples of the Gobertange quarry, about 30 km north of Isnes (Fig. 20I, K). At Isnes *B. inflatus* seem to co-occur with abundant *Nummulites laevigatus in situ,* whereas the latter was not reported from the Mol BH and only sporadically from Gobertange (Rutot 1893, 1910), although not encountered by us.

The extremely rare records of *B. inflatus* in Belgian sections seem to represent its most northern occurrence in NW Europe, which has up to now been thougth to correspond to the 'Glauconie Grossière s.s.' in the Paris Basin (Aubry 1983). Calcareous nannofossil investigation of the base of the historical Lutetian stratotype (e.g. at Margival and Gisors, Steurbaut 1988; Prémontré, Steurbaut *et al.* 2016b; Chaumont-en Vexin, in the present paper; see also Appendix 1) has revealed that *B. inflatus* is absent in the 'Chaumont-en-Vexin sands', representing the oldest Lutetian deposit of the Paris Basin (Ott d'Estevou *et al.* 2014; probably corresponding to level ('niveau') 1 of the Lower Lutetian of Merle 2008), and in he lowermost 2 to 3 meters of the overlying 'Glauconie Grossière s.s.' (as defined by Blondeau 1980). This interval seems to be devoid of *Nummulites laevigatus* (Fig. 17). The similarity in nannofossil succession between the Belgian Basin and the Paris Basin indicates that the base of the 'Chaumont-en-Vexin sands' is coeval with the base of Unit A4 in the upper part of the Aalter Sand Formation. This is essentially based on the identification of the major nannofossil turnover in both areas. It also shows that the base of the 'Glauconie Grossière s.s.' is coeval with the base of the Brussel Sand Formation, as evidenced by the LO of *Luminocanthus plenilutetiensis* n. gen., n. sp. Furthermore, the nannofossil succession indicates that the 'Glauconie Grossière s.s.' is a highly condensed deposit, which was synchronously developing with the Brussel Formation, although with quite distinct sedimentation rates (2.5 m at Margival equates 5 m at Mont-des-Récollets and *c.* 40 m of infill in the Brussels megachannel). This is also true for the 'Chaumont-en-Vexin sands' with regard to Unit A4 (0.9 m at Chaumont-en-Vexin equates *c.* 3.15 m at Mont-des-Récollets and 8.6 m in the Oedelem BH).

The stratigraphic significance of *B. inflatus* can be questioned, as, although it is quite common, this species is also irregularly distributed at low latitudes, especially in the lower part of its range. Its LO is located in the middle of chron C21r at the GSSP in the Gorrondatxe section (Payros *et al.* 2007), dated at 47.84 Ma (Payros *et al.* 2015), and at Agost (Larrasoaña *et al.* 2008: fig. 11), while in contemporaneous Italian (Bottacione, Monechi & Thierstein 1985: fig. 2; Smirra, Franceschi *et al.* 2015: fig. 12) and Australian sections (Shamrock *et al.* 2012: fig. 16) its LO has been recorded within the lower part of Chron C21n, about 500 kyr later (Franceschi *et al.* 2015, including supplementary material) (Fig. 17).

If the internationally accepted Lutetian boundary criterium (LO of *B. inflatus*) should be applied to Belgium, it would mean that almost the entire Brussel Sand Formation is Ypresian in age, a conclusion that cannot be upheld neither historically nor paleontologically. Indeed, the Brussel Sand Formation (equating the "Bruxellian" of Dumont 1839, Rutot 1882; Gosselet 1883: 318; and many others), has always been considered to correspond to the lower part of the Lutetian (see Leriche 1939 for an overview). Moreover, the application of the boundary criterium would imply that the 'Chaumont-en-Vexin sands' and the lower part of the 'Glauconie Grossière s.s.' (as defined by Blondeau 1980), both constituting the base of the historical Lutetian stratotype, should also be of Ypresian age, and that is completely absurd.

Taking into account these historical considerations and the fact that the detection of the LO of *B. inflatus* is very problematic, even at low latitudes, it may appear that the LO of *Discoaster sublodoensis* would be a much more realistic and reliable alternative criterion for defining the base of the Lutetian. This event has been identified worldwide (offshore Australia, Shamrock 2010b; Italy, Tori & Monechi 2013, Agnini *et al.* 2014; Franceschi *et al.* 2015; Spain, e.g. Payros *et al.* 2015). Most importantly, it is recorded at the base of the historical Lutetian stratotype and is always associated, at least in NW Europe, with a major turnover in calcareous nannofossils. The latter is marked by many lowest occurrences (*c.* 10 taxa), which in turn coincide with the highest occurrence of *Toweius occultatus*, a widespread long ranging Ypresian taxon.

In conclusion, in order to meet the historical concept of the Lutetian Stage and to allow consistent identification throughout lower and middle latitudes it is proposed to amend the original definition of its lower boundary criterion (LO of *B. inflatus*) and to replace it by the LO of *Discoaster sublodoensis.* This nannofossil event is located in the middle of Chron C22n (Agnini *et al.* 2006, 2014; Franceschi *et al.* 2015: supplementary material, table 1R), around 800 kyr earlier than the LO of the planktonic foraminiferal taxon *Turborotalia frontosa* (recorded in the lower part of C21r by Payros *et al.* 2015; located higher up, in the middle of C21r, by Franceschi *et al.* 2015). Adopting this new boundary criterion would mean that the base of the Lutetian should be lowered down by about 130 m at the Gorrondatxe GSSP, which would make this Lutetian base about 1.3 Myr older, falling at about 49.11 Ma *sensu* Payros *et al.* (2015) and at about 49.20 Ma *sensu* Franceschi *et al.* (2015) (Fig. 17).

CONCLUSIONS

The key conclusions that emerge from the integrated lithostratigraphic and calcareous nannofossil investigation of the Mont-des-Récollets section, along with data from other sections in the southern North Sea Basin, are:

1) The entire suite of upper Ypresian and Lutetian formations and members, from the top of the Hyon Sand Formation (Mont-Pansisel Sand Member, upper NP12) to the base of the Maldegem Formation (Wemmel Sand Member, mid-NP15), is represented at the Mont-des-Récollets by lithofacies quite similar to that of their respective type areas in central Belgium. The upper Ypresian units, except for the Aalter Sand Formation, had never before been recorded in France, extending their spatial distribution considerably southwestward.

2) The lithofacies and thickness of the stratigraphic units in the Mont-des-Récollets outcrop indicate that deposition took place in a tectonically relatively quiescent area during late Ypresian and most of Lutetian times, in contrast to western Belgium, which underwent distinct uplift pulses of the Brabant Massif. However, this relative tectonic quiescence was temporarily disrupted at the Mont-des-Récollets, as the deposition of the interval with *in situ Nummulites laevigatus* (Unit B4) was preceded and followed by a substantial erosion phase. The lowermost erosion event, dated as mid-Biochron

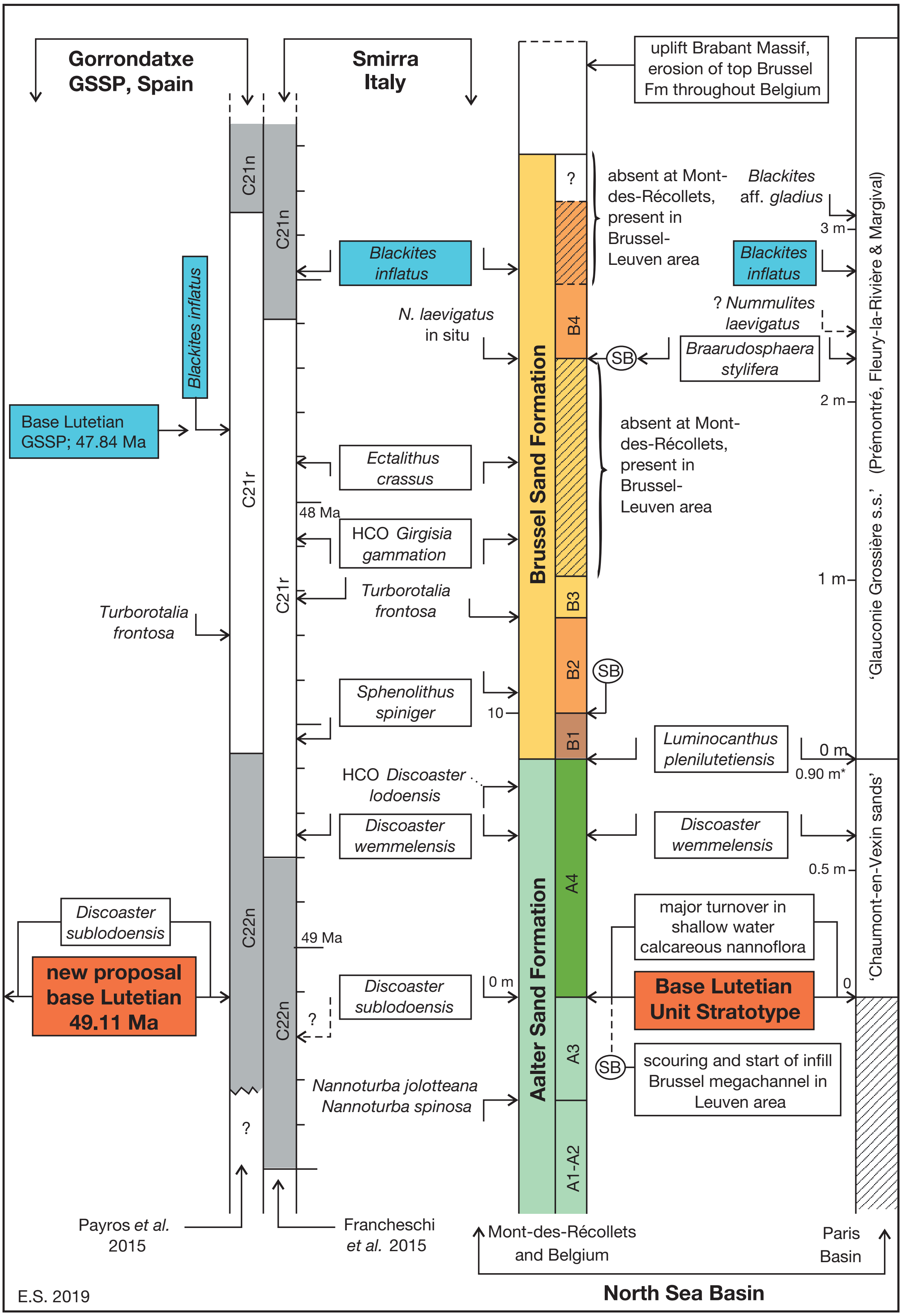


FIG. 17. — Magnetobiochronologic calibration of the Mont-des-Récollets section and its significance for southern North Sea Basin geology and for global stratigraphy. *, total thickness of the 'Chaumont-en-Vexin sands'; **SB**, sequence boundary.

NP14 (*c.* 48.00 Ma sensu Payros *et al.* 2015), destroyed most of the underlying Unit B3. This event seems to be local and linked to uplift of the Artois Anticline. The uppermost, dated as latest-Biochron NP14 (*c.* 46.50 Ma *sensu* Payros *et al.* 2015), almost totally dismantled the *N. laevigatus* bearing beds in the entire Belgian Basin, or only left some remnants, such as at the Mont-des-Récollets. These remnants represent the lower part of the *N. laevigatus*-bearing interval. The massively reworked large-sized *N. laevigatus* and *N. laevigatus*-bearing sandstone blocks at the base of the Lede Formation are unique relics of the upper part of this interval.

3) The subdivision of calcareous nannofossil Zone NP13 into three subzones, the major calcareous nannofossil turnover at the base of Zone NP14 (tentatively named BALCAT-event) and the 9 bio-events within NP14 have been recorded throughout the Belgian Basin, including the Mont-des-Récollets, despite its impoverished assemblages. Several of these zonal boundaries and events have been identified in the Paris Basin, the Hampshire Basin (Steurbaut, *in* King 2016 and unpublished) and the Aquitaine Basin (Lin *et al.* 2017), highlighting their interbasinal correlation potential.

4) This study provides the first evidence that the 'Chaumont-en Vexin sands', base of the Lutetian historical stratotype, and Unit A4 of the Aalter Sand Formation, as well as the overlying 'Glauconie Grossière s.s.' and the Brussel Sand Formation (Bruxellian" *sensu* Dumont 1839), are time-equivalent deposits, the bases of which are coeval or almost coeval.

5) The similarity in calcareous nannofossil assemblages, the *in situ* specimens of *Nummulites laevigatus* and *Campanile giganteum* at the Mont-des-Récollets suggest that, after *c.* 2.3 Myr of isolation (latest Biochron NP12 and Biochron NP13), the direct north-south connection between the Belgian Basin and the Paris Basin was temporarely re-established during Biochron NP14 and during early Biochron NP15.

and 6) The internationally accepted base-Lutetian boundary criterion (LO of *Blackites inflatus*) is difficult to apply in the North Sea Basin because of the extreme rarity of the marker taxon (not recorded *in situ* at the Mont-des-Récollets). Worst of all, its application would imply that the major part of the Brussel Sand Formation and, more important, the 'Chaumont-en-Vexin sands' and lower part of the overlying 'Glauconie Grossière s.s.', base of the historical Lutetian stratotype, should be of Ypresian age, which is a *contradictio in terminis*. To resolve this contradiction it is suggested to replace the original criterium (LO of *B. inflatus*) by the LO of *Discoaster sublodoensis,* which is recorded in many sections worldwide, including the base of the 'Chaumont-en-Vexin sands' and the base of the Unit A4 of the Aalter Sand Formation. This bio-event is located within the middle of Chron C22n, about 800 kyr earlier than the LO of *Turborotalia frontosa*. This would also mean that the base of the Lutetian should be lowered down by about 130 meters at the Gorrondatxe GSSP, and consequently should range in age between 49.11 Ma (*sensu* Payros *et al.* 2015) and 49.20 Ma (*sensu* Franceschi *et al.* 2015).

TAXONOMY AND REMARKS ON NEW AND BIOSTRATIGRAPHICALLY RELEVANT TAXA

Family Braarudosphaeraceae Deflandre, 1947

Genus *Braarudosphaera* Deflandre, 1947

Type species. — *Pontosphaera bigelowi* Gran & Braarud, 1935 by subsequent designation of Deflandre (1947).

Braarudosphaera stylifera Troelsen & Quadros, 1971
(Fig. 18A-D)

Braarudosphaera stylifera Troelsen & Quadros, 1971: 212, pl. 1, figs 8-14.

Distribution. — This taxon is recorded in several middle Eocene outcrop and borehole sections in Belgium (Steurbaut in Herman *et al.* 2001 and in Smith *et al.* 2004; Steurbaut *et al.* 2015). In the Mont-des-Récollets section it consistently ranges from the uppermost part of the Brussel Sand Formation (base of Unit B4) to the base of the Wemmel Sand Member. In terms of calcareous nannoplankton zones, its occurrence encompasses the upper part of NP14 and the lower part of NP15, as it appears to do in the Paris Basin (Aubry 1983, 1986) and the Aquitaine Basin (Lin *et al.* 2017). In the Paris Basin it seems to recur in the Bartonian (Chavençon Marls: NP17 or NP18, Aubry 1983: pl. 8, figs 10-11), although this has not been observed in the other basins.

Discussion

B. stylifera differs from all up to now known *Braarudosphaera* taxa by its very high slightly tapering outline, resembling a pentagonal pyramid with truncated top, the margin sides of which are often slightly bowed inward (Fig. 18B). Both pentagonal ends can clearly be observed viewed from above when over-focusing and under-focusing with the microscope.

Family Calyptrosphaeraceae Boudreaux & Hay, 1969

Genus *Lanternithus* Stradner, 1962

Type species. — *Lanternithus minutus* Stradner, 1962 by original designation.

Lanternithus minutus Stradner, 1962
(Fig. 18E)

Lanternithus minutus Stradner, 1962: 375, pl. 2, figs 12-15.

Distribution. — *L. minutus* is biostratigraphically significant, despite its rather long range (upper lower Eocene-lower Oligocene). In the North Sea Basin it has a synchronous lowest consistent occurrence (LCO) within the upper middle of NP14: from the base of unit B4 (upper part of the Brussel Sand Formation) at the Mont-des-Récollets, where its occurrence coincides with the LO of *Nummulites laevigatus*, from about 2.5 to 3 m above the base of the 'Glauconie Grossière s.s.' (as defined by Blondeau 1980) in the Paris Basin (appearance level of *Blackites inflatus*) and from the *Nummulites laevigatus* Bed (F6) at Bracklesham Bay, UK. Isolated specimens occur earlier. In the Belgian Basin they are known from many localities within the lower middle of unit B3, which corre-

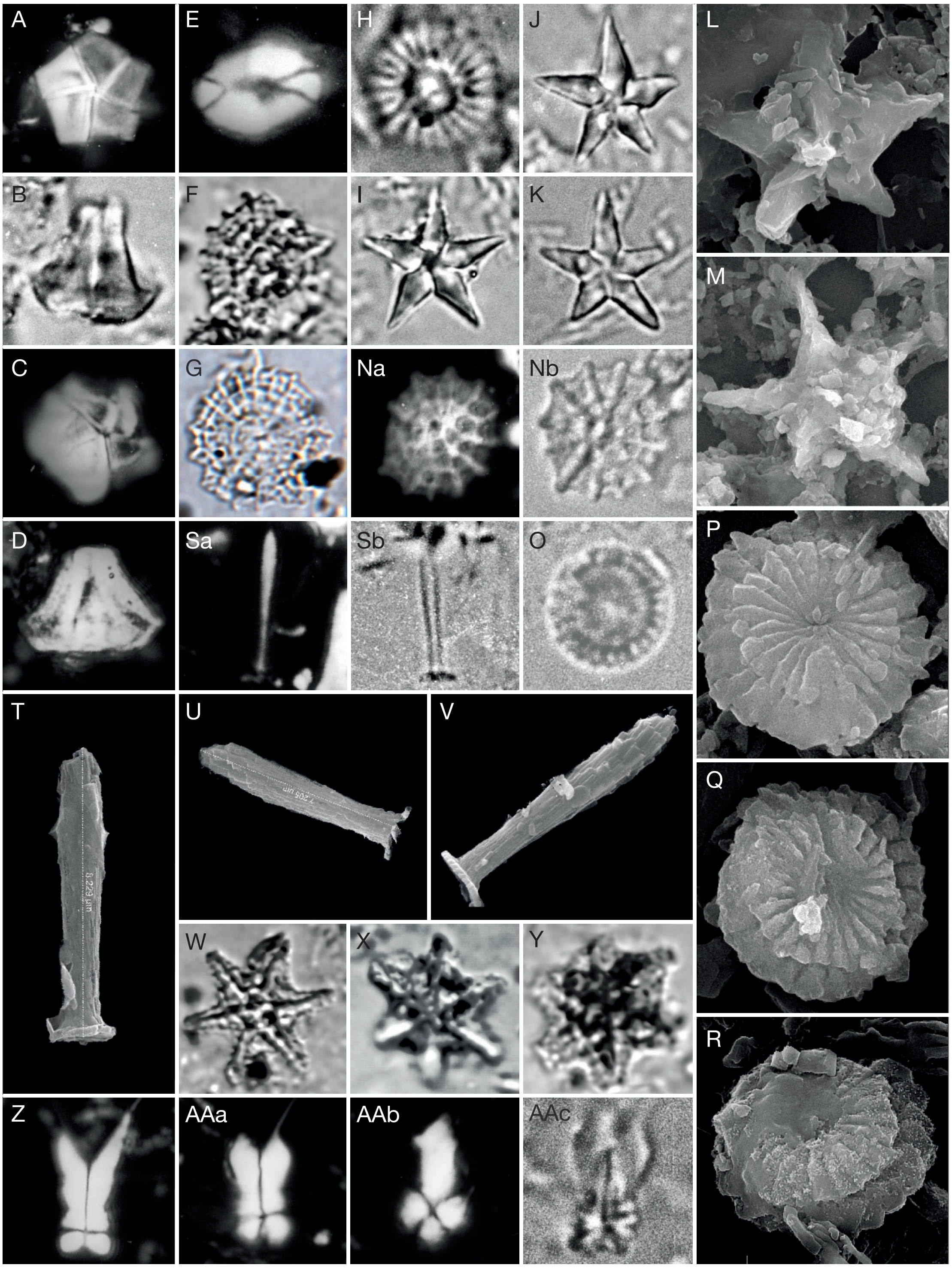


Fig. 18. — New or less known calcareous nannofossil taxa from the Eocene of the Mont-des-Récollets and other localities in Belgium; **a**, **b**, **c**, views of the same specimen, in transmitted light or cross-polarized light or *vice versa*, and in different positions with respect to the polarisation directions. Numbers (e.g. IRSNB bXXXX) refer to the collections of the Royal Belgian Institute of Natural Sciences (Brussels). Pars 1: **A**-**D**, *Braarudosphaera stylifera* Troelsen & Quadros, 1971, Mont-des-Récollets, 122.85 m (IRSNB b7093, b7094, b7096); **A**, wm = 13 µm; **B**, wm = 12 µm; **D**, wm = 14.5 µm; **C**, Mont-des-Récollets, 124.10 m (IRSNB b7095), wm = 13 µm; **E**, *Lanternithus minutus* Stradner, 1962, Mont-des-Récollets, 122.85 m, l = 5.6 µm (IRSNB b7097); **F**, **G**, *Martiniaster cecellanoriae* n. sp.: **F**, Chaumont-en-Vexin, sample 11, 0.55 m above base of the Lutetian, paratype, d = 13 µm (IRSNB b7098); **G**, Leuven BH, 23.70 m depth, holotype, d = 14 µm (IRSNB b7099); **H**, *Discoaster praebifax* Wei & Wise, 1989, Mont-des-Récollets, 116.45 m, d = 7 µm (IRSNB b7100); **I**-**M**, *Discoaster sublodoensis* Bramlette & Sullivan, 1961, Mont-des-Récollets, 116.45 m (IRSNB b7101, b7102); **J**, d = 15.2 µm; **I**, d = 16 µm; **K**, Mont-des-Récollets, 118.35 m, d = 11.6 µm (IRSNB b7103); **L**, Vossem, otolith sample Nolf 1974, d = 7 µm (IRSNB b7104); **M**, Gisors, Bassin de Paris, sample 3, d = 14 µm (IRSNB b7105); **N**, *Martiniaster fragilis* (Martini, 1961), Mont-des-Récollets, 122.85 m, wm = 12 µm (IRSNB b7106); **O**-**R**, *Discoaster wemmelensis* Achuthan & Stradner, 1969; **O**, Mont-des-Récollets, 122.85 m, d = 5.6 µm (IRSNB b7107); **P**-**R**, Vossem, otolith sample Nolf 1974 (IRSNB b7108, b7109, b7110); **P**, d = 5.3 µm; **Q**, d = 4.4 µm; **R**, d = 4.3 µm; **S**-**V**, *Blackites minusculus* n. sp.; **S**, Mont-des-Récollets, 117.46 m, paratype, l = 8.8 µm (IRSNB b7111); **T**-**V**, Vossem, otolith sample Nolf 1974; **T**, **U**, paratypes (IRSNB b7112, b7113); **T**, l = 8.2 µm; **U**, l = 7.2 µm; **V**, holotype, l = 8.56 µm (IRSNB b7114); **W**-**Y**, *Trochoaster nodosus* n. sp.; **W**, Chaumont-en-Vexin, sample 16, 0.80 m above base of the Lutetian, holotype, d = 16 µm (IRSNB b7115); **X**, Vilvoorde BH, 5.80 m depth, paratype, d = 15 µm (IRSNB b7116); **Y**, Oedelem BH, 11.70 m depth, paratype, d = 15 µm (IRSNB b7117); **Z**-**AA**, *Sphenolithus recolletensis* n. sp.; **Z**, Mont-des-Récollets, 116.45 m, paratype, htot = 20 µm (IRSNB b7118); **AA**, Mont-des-Récollets, 117.46 m, holotype (**a**, **c**, parallel to the polarization directions; **b**, at 45°), htot = 11.4 µm (IRSNB b7119).

lates with lower middle NP14. A single specimen is known from the lower part of Unit A4 (top of the Aalter Sand Formation) in the Vlakte van de Raan borehole, one from the turritellid level at Whitecliff Bay (at 225 m above the base of the London Clay, *dixit* D. Curry), and two from the upper part of the 'Chaumont-en-Vexin sands' in the Paris Basin, all attributable to the base of NP14. In west Kazakhstan (e.g. Aktulagay), *L. minutus* seems to appear still earlier (within the middle of NP13) (King *et al.* 2013).

Discussion

This small nannolith with a box-like shape has a very distinctive morphology and optical interference pattern, allowing unambiguous and easy recognition.

Family Calcidiscaceae Young & Bown, 1997

Genus *Luminocanthus* n. gen.

urn:lsid:zoobank.org:act:872DDF1A-35F0-4369-9812-7B1D5A0DF8F7

Type species. — *Luminocanthus plenilutetiensis* n. sp.

Derivatio nominis. — Refers to the bright outer rim of these fairly thick circular coccoliths (luminus = light, canthus = 'rim of the wheel'), when viewed in cross-polarized light.

Diagnosis. — This new genus is erected to include circular coccoliths consisting of a non-perforated, practically closed, central disk and a much smaller outer rim with many slightly bent elements (n > 30). The outer rim is always highly birefringent in cross-polarized light, the central disk sometimes (e.g. in the type species).

Discussion

Four species are currently included in this genus (in stratigraphical order): *L. eolutetiensis* n. gen., n. sp. from the lowermost Lutetian of the Belgian Basin (see below), *L. plenilutetiensis* n. gen., n. sp. from the lower middle Lutetian of the Belgian Basin and the Paris Basin (see below), *L. hirsitus* (Müller, 1970) n. comb. from the lower middle Oligocene of Belgium and Germany (Müller 1970; Steurbaut 1986) and *L. hoerstgensis* (Müller, 1970) n. comb from the upper middle Oligocene of Northern Germany (Müller 1970). Both Oligocene species have been synonymized with the upper Eocene species *Cribrocentrum reticulatum* (Gartner & Smith, 1967) (cf. Nannotax 3, http://www.mikrotax.org/Nannotax3/index.html), although erroneously, as these taxa are fundamentally different (e.g. in construction of distal shield and number of elements in the shields).

Luminocanthus eolutetiensis n. gen., n. sp. (Fig. 19B, C)

urn:lsid:zoobank.org:act:B9D3C0AA-736A-4785-9B04-D58126482E0E

Holotype. — Fig. 19B (IRSNB b7121) (negatives stored in the collections of the RBINS).

Paratypes. — 1 figured specimen (d = 9 µm) from the upper part of the Aalter Sand Formation in the Vlakte van de Raan BH, 79.95 m depth (Fig. 19C) (IRSNB b7122).

Diagnosis. — Circular coccoliths consisting of two appressed shields and including a central disk covered by a series of radially oriented calcite laths and a smaller outer rim with numerous almost indistinct slightly curved elements. Only the outer rim is highly birefringent in cross-polarized light.

Derivatio nominis. — Refers to the total range of this species, which seems to be restricted to the earliest part of the Lutetian.

Locus typicus. — Vlakte van de Raan borehole, 81.45 m depth, 51°29'08"N, 03°09'50"E.

Stratum typicum. — Aalter Sand Formation, upper part of Oedelem Sand Member; base of NP14.

Dimensions. — Diameter = all around 9 µm (holotype: d = 9 µm).

Distribution. — *Luminocanthus eolutetiensis* n. gen., n. sp. is known from boreholes in the Belgian sector of the North Sea (SEWB and Vlakte van de Raan, see Appendix 1), where it seems to be retricted to the top of the Aalter Sand Formation (base of NP 14). Up to now it has not been recorded in coeval deposits from onshore Belgium.

Description

These medium-sized (d = *c.* 9 µm) rather thick subcircular forms consist of a prominent outer rim including numerous (probably *c.* 50) vaguely visible elements and an inner area with radially oriented elements. Both zones are sharply delimited in distal view. The outer rim is rather thick and exhibits high birefringence under crossed nicols, especially the outer rim of the proximal shield (Fig. 19Ba). The inner area is only faintly birefringent, although shows a clear extinction cross with laevogyre curvation in distal view. It widens and is somewhat blurry in the outer rim.

Discussion

This taxon differs from *L. plenilutetiensis* n. gen., n. sp. (Fig. 19G-J) by the configuration of the outer rim and the central area. The outer rim of *L. eolutetiensis* n. gen., n. sp. is much more elevated, smaller and sharply separated from the central area. This rim is also highly birefringent as in *L. plenilutetiensis* n. gen., n. sp., but contrarely to the latter, the central area remains only faintly illuminated in cross-polarized light. The extinction lines are rather sharp in the central area and become wider and vague in the outer rim.

Luminocanthus plenilutetiensis n. gen., n. sp. (Fig. 19G-J)

urn:lsid:zoobank.org:act:AEAC0171-1130-4C9B-B8B0-CAD63145C860

Cyclococcolithus sp. – Steurbaut 1990: 187, pl. 1, figs 9, 10 (non figs 8, 11).

Cyclococcolithus sp. – Damblon & Steurbaut 2000: 28.

Holotype. — Fig. 19G (IRSNB b7126) (negatives stored in the collections of the RBINS).

Paratypes. — 2 figured specimens from the Brussel Sand Formation: 1 from from Vossem, Unit B3 (Fig. 19H) (IRSNB b7127) and 1 from the Knokke BH (Steurbaut 1990: pl. 1, fig. 9), 71.95 m depth (Fig. 19J) (IRSNB b7129); 1 from Prémontré (sample 12), Paris Basin, base of the 'Glauconie Grossière s.s.' (Fig. 19I) (IRSNB b7128).

DIAGNOSIS. — Circular coccoliths consisting of two closely appressed shields, including a central disk covered by a series of irregularly oriented calcite laths and a smaller outer rim with numerous conspicuous slightly curved elements. Both areas are highly birefringent in cross-polarized light.

DERIVATIO NOMINIS. — Refers to its position within the Lutetian, as its lowest occurrence is at the base of the coarse-grained sand facies of the Lutetian (base of Brussel Sand Formation in Belgium, base of 'Glauconie grossière s.s.' in the Paris Basin), which overlie the basal Lutetian fine-grained glauconitic sand facies, as identified in many outcrop and borehole sections in Belgium (Unit A4) and at Chaumont-en-Vexin ('Chaumont-en-Vexin sands') in the Paris Basin.

LOCUS TYPICUS. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

STRATUM TYPICUM. — Brussel Sand Formation, base of Unit B3 (122.26-122.21 m); lower middle part of NP14.

DIMENSIONS. — Diameter = 5.0 to 9.6 µm (holotype: d = 8.4 µm).

DISTRIBUTION. — *Luminocanthus plenilutetiensis* n. gen., n. sp. is known from many Lutetian outcrop and borehole sections in the southern North Sea Basin, including the historical stratotype area (e.g. from the base and the upper part of the 'Glauconie Grossière s.s.' at Prémontré (Fig. 19I) and Margival respectively). In Belgium it is consistently present from the base (Unit B1) up to the top of the Brussel Sand Formation (e.g. Isnes quarry) and seems to be restricted to it. At the Mont-des-Récollets there is a major influx (also the first occurring specimens) at the base of Unit B2b. It has been recorded in Unit C2 (sample 50.8 m) of the Aktulagay section, attributed to NP14, although in very low numbers (Steurbaut in King *et al.* 2013).

DESCRIPTION

These rather small (generally around 7 µm in diameter) and thick circular coccoliths consist of two closely appressed shields. The distal shield has a prominent outer rim including 32 to 38 elements, displaying laevogyre element curvature in distal view (Fig. 19G), and an inner concave area with less-well visible irregularly oriented elements. Both zones are not sharply delimited in distal view and show high birefringence under crossed nicols. The conspicuous swastika-like extinction cross has a laevogyre outline in the central area in distal view. It widens and is somewhat blurry in the outer rim.

DISCUSSION

The extinction figure of the type species is quite similar to that of *L. hirsitus* (Müller, 1970) n. comb. from the lower Middle Oligocene of Belgium, suggesting a close relationship. However, coccoliths of the latter seem to have a much broader outer rim. The differences with *L. eolutetiensis* n. gen., n. sp. are discussed above.

Family DISCOASTERACEAE Tan Sin Hok, 1927

Genus *Discoaster* Tan Sin Hok, 1927

TYPE SPECIES. — *Discoaster pentaradiatus* Tan Sin Hok, 1927 (by original designation).

Discoaster praebifax Wei & Wise, 1989 (Fig. 18H)

Discoaster praebifax Wei & Wise, 1989b: 11, fig. 3.

DISTRIBUTION. — In the southern North Sea Basin the LO of *D. praebifax* slightly precedes the LO of *Discoaster sublodoensis* (e.g. at Aalter, beds 4 to 9: Steurbaut & Nolf 1989, erroneously interpreted as *D. bifax*), and is, consequently, within the top of NP13. At the Mont-des-Récollets, *D. praebifax* first occurs in the upper part of the Aalter Sand Formation (lower NP14) and ranges up to the base of the Wemmel Sand Member. Its earliest record is from Aktulagay (west Kazakhstan), where it appears at the base of NP13 (King *et al.* 2013).

DISCUSSION

In their investigation of middle Eocene calcareous nannofossil associations of two DSDP holes, Wei & Wise (1989b) separated the discoasters with high numbers of rays (16-27) and one prominent central stem from similar forms with fewer rays (10-15), known as *Discoaster bifax* Bukry, 1971, to which they previously have been attributed (e.g. in Perch-Nielsen 1985; Aubry 1986). The populations with high ray numbers were grouped into *D. praebifax*, which, in view of its morphological similarities and stratigraphic relationship, was suggested to be the ancestor of the latter. The number of rays in the Mont-des-Récollets specimens ranges between 20 and 22, evidencing the presence of *D. praebifax* only.

Discoaster sublodoensis Bramlette & Sullivan, 1961 (Fig. 18I-M)

Discoaster sublodoensis Bramlette & Sullivan, 1961: 162, pl. 12, fig. 6a-b.

DISTRIBUTION. — Typical 5-rayed specimens.of *Discoaster sublodoensis* are recorded at the base of Unit A4 in the well-preserved assemblages of the Vlakte van de Raan borehole and at the base of the 'Chaumont-en-Vexin sands' in the Paris Basin, although always in very low numbers. They co-occur with numerous 6-rayed specimens with straight rays (considered herein as 'late form' of *D. lodoensis*) and other, although more rarely, 6-rayed forms with straight rays without ridges (*D. strictus* and alies). In the less well preserved assemblages of the Mont-des-Récollets the typical 5-rayed specimens seem to pop up only from the middle of Unit A4. *D. sublodoensis* remains quite rare within the totality of its range at the Mont-des-Récollets, although it is consistently found up to the top of Unit B3. It is extremely rare from the base of B4 onward and has not been observed in the base of the overlying Lede Sand Formation.

DISCUSSION

Specimens from the Paris Basin and the Hampshire Basin (Aubry 1986) are almost identical to these from Belgium, but slightly differ from the holotype (Lodo Formation, California, Bramlette & Sullivan 1961: pl. 12/6), material collected in DSDP holes (Wei & Wise 1989a: fig. 3/2), and some of the forms recorded at the Ypresian/Lutetian GSSP in Spain (Molina *et al.* 2011: plate 1, fig. 2). The latter are marked by a rather wide central area rapidly narrowing and extending into 5 or 6 (exceptionally 7) slender rays and by ray margins, which are slightly bowed inwards near the base of each ray. The area where the rays meet is not sharp and angular, but, on the contrary, distinctly rounded (see Fig. 18M). The rays of the North Sea Basin specimens have triangular free ends, with straight margins, which meet at clear angles (see Fig. 18I-K). The central disk, which is marked by a small low stem and low crests along the margin of the rays, ending at the interstices between the rays, is similar within the total population range of the species.

Discoaster wemmelensis Achuthan & Stradner, 1969 (Fig. 18O-R)

Discoaster wemmelensis Achuthan & Stradner, 1969: 5, 6, text-fig. 2; pl. 4, figs 3-4.

Distribution. — *D. wemmelensis* is consistently recorded in Lutetian nannofossil assemblages worldwide, although generally in low concentrations (Perch-Nielsen 1985; Aubry 1986; Varol 1998; Tori & Monechi 2013; Franceschi *et al.* 2015). It occurs in very low numbers at the Mont-des-Récollets, from the base of the Brussel Sand Formation (its LO is at the base of Unit B1, lower NP14) up to the base of the Wemmel Sand Member (middle NP15). A few isolated specimens have been recorded slightly earlier at the top of the Aalter Sand Formation in boreholes north of the Mont-des-Récollets, but not at the Mont-des-Récollets itself (2 in the Vlakte van de Raan borehole and 1 specimen in the Oedelem borehole, a few meters above the base of NP14 as defined herein). This might not correspond to its total range, as in Belgium *D. wemmelensis* is known to occur throughout the Wemmel Sand Member (middle NP15) up to the Ursel Clay Member (base of NP16) (Steurbaut 1986).

Discussion

This small (d = *c.* 5 µm) discoaster with serrate outline is marked by two superimposed cycles of elements, consisting of 20 to 30 wedge-shaped rays, and lacks a central knob.

Family Lithostromationaceae Deflandre, 1959

Genus *Martiniaster* Loeblich & Tappan, 1963

urn:lsid:zoobank.org:act:D80B2B4E-D12E-4D53-8DBB-5081853FBC7D

Type species. — *Coronaster fragilis* Martini, 1961 by subsequent designation of Loeblich & Tappan (1963).

Martiniaster cecellanoriae n. sp. (Fig. 18F, G)

urn:lsid:zoobank.org:act:BC34435D-E488-4BDF-A956-093AA0FA4C44

Martiniaster fragilis – Aubry 1983: 156, pl. 4, fig. 23; 1986: 327, pl. 4, fig. 23 (non *C. fragilis* Martini, 1961).

Holotype. — Fig. 18G (IRSNB b7099) (negative stored in the collections of the RBINS).

Paratypes. — 1 from the "Chaumont-en-Vexin sands" at Chaumont-en-Vexin (sample CHA11, 0.55 m above the base of the Lutetian (Fig. 18F, IRSNB b7098) and 2 non-figured specimens from the base of Unit A4 of the Aalter Sand Formation (Mont-des-Récollets: 114.85 m and Vlakte van de Raan borehole: 82.95 m depth).

Diagnosis. — Circular fragile structure, slightly conical in side view, consisting of a series of concentric rings, supported by 17 to 19 radially oriented pillars, resembling a spider's web.

Derivatio nominis. — The species name is a combination of Cecile, the Christian name of the first author's spouse, who passed away recently, and of Ella-Noor, the first name of his grand-daughter.

Locus typicus. — Leuven borehole, 23.70 m depth, 50°53'24.36"N, 4°42'33.69"E.

Stratum typicum. — Brussel Sand Formation, base of Unit BE; base of NP14.

Dimensions. — Diameter = 13 to 14 µm (holotype: d = 14 µm).

Distribution. — At the Mont-des-Récollets it is known from 1 specimen in the upper part of the Aalter Sand Sand Formation (lower Unit A4, base NP14). It has also been recorded in the Vlakte van de Raan borehole at the top of the Aalter Sand Formation (upper Unit A4, 82.95 m depth, lower NP14) and in the Leuven-Artois borehole (base of Unit BE, base of NP14). It has been identified in several samples of the lower part of the 'Chaumon-en-Vexin sands' at the Darcy site at Chaumont-en-Vexin (Steurbaut, unpublished information). These records led us to conclude that the LO of *M. cecellanoriae* n. sp. is a major stratigraphical marker, as it is coincident with the base of NP14 and the base of the historical Lutetian stratotype.

Description

This circular slightly inflated body consists of a number of (generally three) peripheral concentric rings surrounding a central network, which are supported by 17 to 19 radially oriented pillars. This concentric structure, which resembles a spider's web, shows no birefringence under crossed nicols.

Discussion

This taxon has many similarities with *Martiniaster fragilis*, but instead of the 12 radially arranged peripheral ridges, it has a much larger number of radial pillars (generally between 17 and 19), which are less prominently developed. It appears to be also less globular.

Martiniaster fragilis (Martini, 1961) Loeblich & Tappan, 1963 (Fig. 18N)

Coronaster fragilis Martini, 1961: 102, text-fig. 2.

Martiniaster fragilis – Loeblich & Tappan 1963: 193.

Distribution. — This species is consistently but rarely present in the shallow marine Middle Eocene strata from the North Sea Basin. At the Mont-des-Recollets it ranges from the upper part of the Brussel Sand Formation (Unit B4) to the middle of the Lede Sand Formation. This does not represent its total range, as in other Belgian localities it is known to occur up to the Asse Clay Member (upper NP15) (Steurbaut 1986). Additional occurrences in adjacent basins are from the lower Lutetian sands at Grand-Alléré (NP14) in the Paris Basin (see Appendix 1) and from Fisher Beds 20 and 21 in the Hampshire Basin (NP15) (Aubry 1983). Hence, its occurrence seems to be restricted to upper NP14 and NP15.

Discussion

With its globular outline consisting of 12 radially arranged peripheral ridges and several large central openings this taxon is easily recognisable.

Genus *Trochoaster* Klumpp, 1953

urn:lsid:zoobank.org:act:780A5297-7230-4AAE-A3EE-0C6992F3B1E6

Type species. — *Trochoaster simplex* Klumpp, 1953 (by original designation).

Trochoaster nodosus n. sp. (Fig. 18W-Y)

urn:lsid:zoobank.org:act:BEE661BF-859D-4C27-AC92-BF41326F94A1

Holotype. — Fig. 18W (IRSNB b7115) (negative stored in the collections of the RBINS).

Paratypes. — 2 figured specimens; 1 from the Vilvoorde borehole at 5.80 m depth (d = 15 µm) (Fig. 18X) (IRSNB b7116) and 1 from the middle part of the Oedelem Sand Member (Aalter Sand Formation) in the Oedelem BH (11.70 m) (d = 15 µm) (Fig. 18Y) (IRSNB b7117); both base of NP14.

Diagnosis. — Six-rayed body, enterily covered with bumps, and marked by strong median ridges along the rays, which are connected with a central circular ring.

Derivatio nominis. — The species name refers to the presence of numerous small bumps popping up all over this robust six-rayed holococcolith.

Locus typicus. — Quarry at Chaumont-en-Vexin, sample 16, Paris Basin; *c.* 49°15'33.59"N, 1°52'44.20"E.

Stratum typicum. — 'Chaumont-en-Vexin sands'; base of NP14; basal Lutetian.

Dimensions. — Diameter = 15 to 16 µm (holotype: d = 16 µm).

Distribution. — *Trochoaster nodosus* n. sp. has been identified in many outcrop and borehole sections in the Belgian Basin and the Paris Basin. At the Mont-des-Récollets it has been recorded at the base of Unit A4 in the upper part of the Aalter Sand Formation. It has been found in the same position (Unit A4) in the Oedelem BH and the Vlakte van de Raan BH. It has been encountered in the Vilvoorde BH at the base of the Brussel Sand Formation (Unit BA) and is present throughout the 'Chaumont-en-Vexin sands' at Chaumont-en-Vexin. The LO of *T. nodosus* n. sp. is also part of the famous calcareous nannofossil turnover, marking the base of NP14 and the base of the historical Lutetian stratotype.

Description

This *Trochoaster* species is characterised by six symmetrically positioned protruding rays with strong median ridges along the rays. The ridges are connected with a central circular ring, which surrounds a triradiate central bridge. The entire body, also the areas between the centrally positioned ridges of the arms, is covered with numerous bumps. These flat interray areas show no furher ornamentation. Specimens of this taxon do not exhibit birefringence under crossed nicols.

Discussion

This taxon differs from all known *Trochoaster* taxa by its rugged and knobby outline and the configuration of the central ring, where the median ridges along the rays meet. It presents a vague resemblance with *T. martinii* from the Early Miocene of Germany because of the presence of six protruding rays. The latter is less knobby and presents some fundamental differences in configuration of the central structure and the interray areas.

Genus *Trochastrites* Stradner, 1961

urn:lsid:zoobank.org:act:9DFE30A4-E474-4861-8FDD-DE1A1491F8D4

Type species. — *Discoaster bramlettei* Martini, 1958 by subsequent designation of Stradner (1961).

Trochastrites hohnensis (Martini, 1958) Bouché, 1962 (Fig. 20S)

Discoaster hohnensis Martini, 1958: 358, pl. 1, fig. 10a-b.

Trochastrites hohnensis – Bouché 1962: 91, pl. 4, figs 13, 14.

Distribution. — At the Mont-des-Récollets it is known from Unit B4 at the top of the Brussel Sand Formation and in the overlying Lede Sand Formation, up into the base of the Wemmel Sand Member. It rarely occurs elsewhere in the Lede Sand Formation (e.g. recorded at Balegem, Oosterzele, etc.).

Discussion

Three rather long thin arms with bifurcating endings, which are lined with a narrow weblike fringe.

Trochastrites pyramidalis n. sp. (Fig. 20T-W)

urn:lsid:zoobank.org:act:1A5F4964-D75A-4631-A0A4-E948EF2E29FF

Holotype. — Fig. 20U (IRSNB b7161) (negative stored in the collections of the RBINS).

Paratypes. — Three figured specimens from the upper part of the Oedelem Sand Member (top of the Aalter Formation) in the Oedelem BH (Fig. 20T, V) (IRSNB b7160, IRSNB b7162) and the Vlakte van de Raan BH (Fig. 20W) (IRSNB b7163); all from the lower part of NP14.

Diagnosis. — Three irregularly bifurcated arms interconnected with a fourth arm to form a pyramidal construction surrounded by a weblike structure.

Derivatio nominis. — Refers to the outline of the solid inner structure of these globular bodies, representing a triangular pyramid.

Locus typicus. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

Stratum typicum. — Brussel Sand Formation, base of Unit B3; (sample 122.16 - 122.21 m), lower middle part of NP14.

Dimensions. — Diameter = 10 to 13 µm (holotype: d = 12 µm).

Distribution. — *Trochastrites pyramidalis* n. sp. is restricted to the lower part of the Brussel Sand Formation at the Mont-des-Récollets, with rare records in Unit B1 and Unit B3 (lower NP14). It is also known from Unit BE in the Leuven BH (base of NP14) and from the Aalter-Oedelem area and the offshore Vlakte van de Raan borehole, where it has been identified in the upper part of the Aalter Sand Formation (Unit A4, base of NP14). In this offshore borehole it seems to range up to the base of Unit B4 (sample 79.15 m, Steurbaut unpublished).

Description

These nannoliths present a pyramidal structure consisting of three irregularly bifurcated arms lying in a plane and interconnected with a fourth arm almost perpendicular to that plane (Fig. 20U). This structure is surrounded by a weblike network. The bifurcated part of the arms is quite large compared to the total length of the arms.

Discussion

This taxon differs from *Trochastrites hohnensis* (Fig. 20S) by its pyramidal outline and the greater length of the bifurcated parts of the arms. In *T. bramlettei* (Martini, 1958) the bifurcation of the arms starts much earlier, not far from the central point where the arms meet.

Family NOELAERHABDACEAE Jerkovič, 1970

Genus *Cribrocentrum* Perch-Nielsen, 1971

Type species. — *Coccolithus foveolatus* Reinhardt, 1966 by subsequent designation of Perch-Nielsen (1971).

Cribrocentrum sp.
(Fig. 19O)

Distribution. — *Cribrocentrum* sp. is known only from a single specimen, occurring at Isnes, in the upper part of the Brussel Sand Formation.

Discussion

The outline of this unique specimen, as well as the construction of the central network, resemble that of *Cribrocentrum martinii* (Hay & Towe, 1962), allowing its inclusion in the genus.

Family Prinsiaceae Hay & Mohler, 1967

Genus *Toweius* Hay & Mohler, 1962

Type species. — *Toweius craticulus* Hay & Mohler, 1967 by original designation.

Toweius brusselensis Steurbaut, 2011
(Fig. 19K-N)

Toweius brusselensis Steurbaut, 2011: figs 15-16; pl. 1, figs 20-22.

Distribution. — This species is known from several boreholes (e.g. Knokke, Vlakte van de Raan) and outcrops (e.g. Gobertange, Nederokkerzeel, Vossem) in Belgium, where it ranges from the middle of the Brussel Sand Formation (middle part of Unit B3) up to the basal part of the overlying Lede Sand Formation. In Belgium its range seems to extend from lower middle NP14 to the base of NP15. Some rare small-sized specimens have been identified in the 'Chaumont-en-Vexin sands' and the 'Glauconie Grossière s.s.' of the Paris Basin (base NP14). Occurrences outside Europe are scarce and up to now restricted to the Aktulagay section in Kazakhstan (a few specimens in uppermost NP13, Steurbaut 2011).

Discussion

This taxon is represented by relatively small forms (d = *c.* 5 µm) in the early part of its range (e.g. middle of Unit B3 at Vossem; Fig. 19M, N). Late forms from the upper part of the Brussel Sand Formation reach up to 8 µm in length (Fig. 19K).

Family Rhabdosphaeraceae Lemmermann, 1908

Genus *Blackites* Hay & Towe, 1962

urn:lsid:zoobank.org:act:B15DB477-B681-4595-B2E5-0A0BCEAC6AA1

Type species. — *Discolithus spinosus* Deflandre & Fert, 1954 by subsequent designation of Hay & Towe (1962).

Blackites minusculus n. sp.
(Fig. 18S-V)

urn:lsid:zoobank.org:act:9B705E57-195D-405F-A8C0-51A169BE9B57

Blackites perlongus – King *et al.* 2013: 187 (non *B. perlongus* Deflandre *in* Grassé, 1952).

Holotype. — Fig. 18V (IRSNB b7114) (negative stored in the collections of the RBINS).

Paratypes. — 3 figured specimens (l = 7.2-8.8 µm, w = 1.0 µm) from the Brussel Sand Formation, 1 from the Mont-des-Récollets (Unit B1) (Fig. 18S) (IRSNB b7111) and 2 from Vossem (Unit B3) (Fig. 18T-U) (IRSNB b7112, b7113).

Diagnosis. — Tiny rhabdoliths, without a basal enlargement or collar, including a tapering stem wirh irregular surface surmounting a thin basal plate.

Derivatio nominis. — Refers to the thin and delicate rhabdoliths, which are minuscule compared to most of the other representatives of the genus.

Locus typicus. — Vossem: otolith sample taken in middle of the quarry by D. Nolf in 1974, about 1.50 m beneath a conspicuous sandstone (map 32/1, x = 164.175, y = 169.290; 50°50'01.96"N, 4°34'08.96"E).

Stratum typicum. — Brussel Sand Formation, middle of Unit B3; lower middle part of NP14.

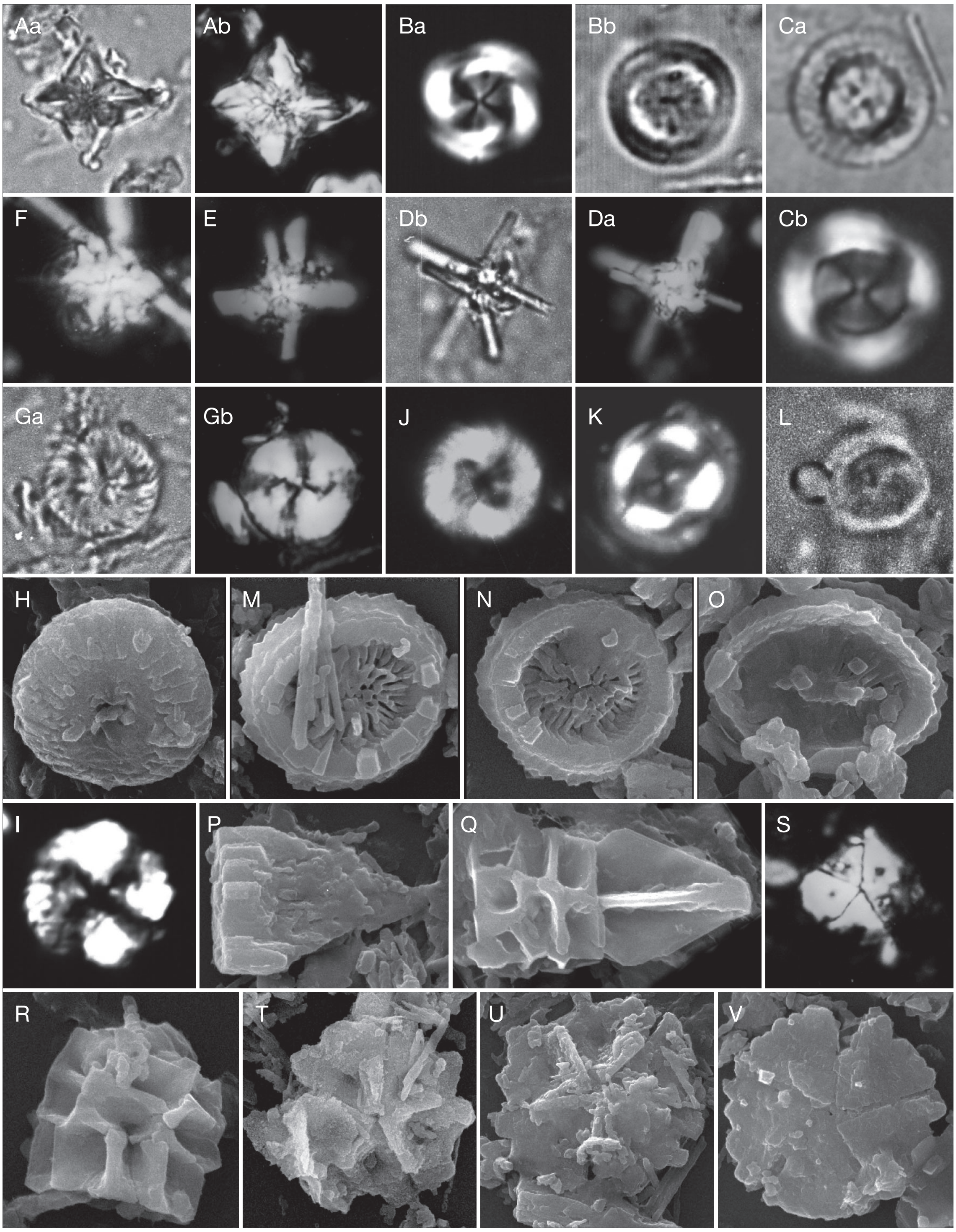


Fig. 19. — New or less known calcareous nannofossil taxa from the Eocene of the Mont-des-Récollets and other localities in Belgium. Pars 2: **A**, *Nannoturba jolotteana* Steurbaut, 2011, Mont-des-Récollets, 104.35 m, d = 15.2 µm (IRSNB b7120); **B**, **C**, *Luminocanthus eolutetiensis* n. gen., n. sp.; **B**, Vlakte van de Raan BH, 81.45 m depth, holotype, d = 9 µm (IRSNB b7121); **C**, Vlakte van de Raan BH, 79.95 m depth, paratype, d = 9 µm (IRSNB b7122); **D**-**F**, *Nannoturba joceliniae* n. sp., Mont-des-Récollets; **D**, 122.85 m, holotype, wm = 17 µm (IRSNB b7123); **E**, 123.50 m, paratype, wm = 13 µm (IRSNB b7124); **F**, 122.85 m, paratype, wm = 13 µm (IRSNB b7125); **G**-**J**, *Luminocanthus plenilutetiensis* n. gen., n. sp.; **G**, Mont-des-Récollets, 122.26-122.21 m, holotype, d = 8.4 µm (IRSNB b7126); **H**, Vossem, otolith sample Nolf 1974, paratype, d = 5.2 µm (IRSNB b7127); **I**, Prémontré, sample 12, paratype, d = 9.6 µm (IRSNB b7128); **J**, Knokke BH, 71.95 m depth, paratype, d = 6.7 µm (IRSNB b7129); **K**-**N**, *Toweius brusselensis* Steurbaut, 2011; **K**, Knokke BH, 97.50 m, paratype, d = 8.4 µm (IRSNB b6403); **L**, Mont-des-Récollets 122.85 m, l = 6 µm (IRSNB b7130); **M**, **N**, Vossem, otolith sample Nolf 1974, l = 4.6 µm (IRSNB b7131, b7132); **O**, *Cribrocentrum* sp. Isnes, sample 8, l = 5.9 µm (IRSNB b7133); **P**, *Sphenolithus spiniger* Bukry, 1971, Vossem, otolith sample Nolf 1974, h = 6.2 µm (IRSNB b7134); **Q**, *Sphenolithus radians* Deflandre *in* Grassé, 1952, Vossem, otolith sample Nolf 1974, h = 4.2 µm (IRSNB b7135); **R**, *Sphenolithus moriformis* (Bronnimann & Stradner, 1960), Vossem, otolith sample Nolf 1974, h = 3.3 µm (IRSNB b7136); **S**-**V**, *Pemma* spp.; **S**, Mont-des-Récollets, 115.50 m, d = 9 µm (IRSNB b7137); **T**-**V**, Vossem, otolith sample Nolf 1974 (IRSNB b7138, b7139, b7140); **T**, d = 8.3 µm; **U**, d = 8.4 µm; **V**, d = 6.5 µm.

Dimensions. — Length = 7.5 to 10.4 µm; Maximum width of stem = 1.0 to 1.1 µm; Maximum width of basal plate = 1.7 to 2.1 µm (holotype: l = 8.6 µm, wm = 1.1 µm, wbp = 1.8 µm).

Distribution. — At the Mont-des-Récollets *B. minusculus* n. sp. ranges from the top of the Aalter Formation (upper part of Unit A4) up to the upper part of the Brussel Sand Formation (top Unit B3), although inconsistently and in low numbers. It has not been recorded in Unit B4, and rarely in the overlying Lede Sand Formation at this locality. It occurs in many outcrops of the Brussel Sand Formation in its type-area (Vossem, Neerijse, St-Lambrechts-Woluwe, Nederokkerzeel, etc.), essentially in Unit B3 and is known from Unit B4 in the Vlakte van de Raan BH (Steurbaut unpublished). This species is consistenly present in the 'Chaumont-en-Vexin sands' of the Paris Basin, attributable to the base of NP14. Hence, its range in the North Sea Basin seems to be restricted to NP14 and the lower part of NP15, with a major influx in the lower middle part of NP14 (Unit B3). *B. minusculus* n. sp. has been encountered in west Kazakhstan, also in low numbers, but appearing at a slightly lower position (middle of NP13) (King *et al.* 2013).

Description

The rhabdoliths of this new taxon are tiny, ranging from 7.5 to 10.4 µm in length. They consist of a slender tapering stem, without a collar, surmounting a thin basal plate. The stem is slightly inflated in its upper part, reaching its maximum thickness at about 1/5 of its length, measured from the rounded distal tip. Its surface is rugose. The basal plate consists of 1 layer of radially oriented elements.

Discussion

The presence of an elongated stem, rising vertically from a rather small and thin basal plate, and its optical characteristics (typical vertical extinction line and interference colours of the stem) allow this taxon to be attributed to the genus *Blackites.* It is distinct from all other described *Blackites* taxa by its tiny rhabdoliths (generally around 8.5 µm in length, maximum width *c.* 1 µm). Its silhouette resembles that of *B. perlongus*, although the latter is twice as long (17-18 µm for holotype, see Deflandre & Fert 1954: pl. XII, figs 34-35, text fig. 86) and has its maximum thickness in a more central position (*c.* at the middle of the stem) (see also Bown 2005: pl. 24).

Blackites praeinflatus n. sp.
(Fig. 20A-G)

urn:lsid:zoobank.org:act:1B1CD3C8-D67B-4DF3-B110-1F390FBA6203

Rhabdosphaera inflata – Aubry 1983: pl. 4, figs 18-19; 1986: pl. IV, figs. 18-19 (non *R. inflata* Bramlette & Sullivan, 1961).

Blackites aff. *inflatus* – Herman *et al.* 2001: 238.

Holotype. — Fig. 20A (IRSNB b7141) (negatives stored in the collections of the RBINS).

Paratypes. — 6 figured specimens from the Brussel Sand Formation, 3 from he Mont-des-Récollets (lower part of Unit B3) (Fig. 20B, C, E) (IRSNB b7142, b7143, b7145), 1 from Zaventem, sample 17 (middle part of Unit B3) (Fig. 20D) (IRSNB b7144) and 2 from Vossem, otolith sample Nolf 1974 (Fig. 20F, G) (IRSNB b7146, b7147).

Diagnosis. — Slightly and somewhat asymmetrically inflated robust rhabdoliths, with faintly rugose surface but without a basal enlargement or collar, of which the maximum width of the stem is much less than the width of the more or less complexly structured basal plate.

Derivatio nominis. — Refers to the outline of these rhabdoliths, which is inflated, although only slightly and asymmetrically compared to that of *B. inflatus*, to which it bears a certain resemblance.

Locus typicus. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

Stratum typicum. — Brussel Sand Formation, lower part of Unit B3 (122.26-122.21 m); lower middle part of NP14.

Dimensions. — Length = 22 to 29 µm (top is generally broken off); Maximum width of stem = 2.5 to 3.8 µm; Width of basal plate = 3.3 to 5.0 µm (holotype: l = 23.0 µm, wm = 3.0 µm, wbp = 4.0 µm).

Distribution. — At the Mont-des-Récollets *Blackites praeinflatus* n. sp. occurs in very low numbers in the middle and upper part of the Brussel Sand Formation (Units B2, B3 and B4). It seems to recur at the base of the Lede Sand Formation and the base of the Wemmel Sand Member, but this may be due to reworking. This species has been recorded slightly earlier (top of Unit B1) at Sint-Stevens-Woluwe, and occurs regularly in Units B2 and B3 of many outcrop and borehole sections in Belgium (Vossem, Neerijse, Zaventem; Mol borehole, from 336 to 338 m depth). The earliest records are from the upper part of the Aalter Sand Formation (base of Unit A4) in the Vlakte van de Raan BH (85.55 m) and from the 'Chaumont-en-Vexin sands' at Chaumont-en-Vexin in the Paris Basin, both attributable to the base of NP14. It is also known from the base of the 'Glauconie Grossière s.s.' at Prémontré and at the top of the 'Glauconie Grossière s.s.' at Gisors (Steurbaut unpublished). Thus, its range appears to be restricted to NP14, if the spotty occurrences in lower NP15 (base Lede Sand Formation and base Wemmel Sand Member) are considered to be due to reworking.

Description

This species is marked by weakly inflated half-long rhabdoliths with slightly rugose surface and which distally gradually taper to a sharp tip (length = 22 to 29 µm, about 6 times greater than the diameter of the base, which is about 3.3 to 5 µm). The stem starts thickening distally, although only slightly and somewhat asymmetrically, at about 1/6 of its length (not at the base, where the width is only 80% of the maximum width), to reach its greatest diameter at about 1/3 of its length. The maximum width of the stem (*c.* 2.8 µm) measures about 14% of the total length of the rhabdolith, and is always substantially smaller than the diameter of the basal plate. The latter is complexly structured and seems to consist of two cycles of elements (Fig. 20G), each with alternating different optical behaviour (clearly seen when inserting the gypsum or quartz plate).

Discussion

This form is identical to what has been figured and erroneously attributed to *Rhabdosphaera inflata* by Aubry (1983:

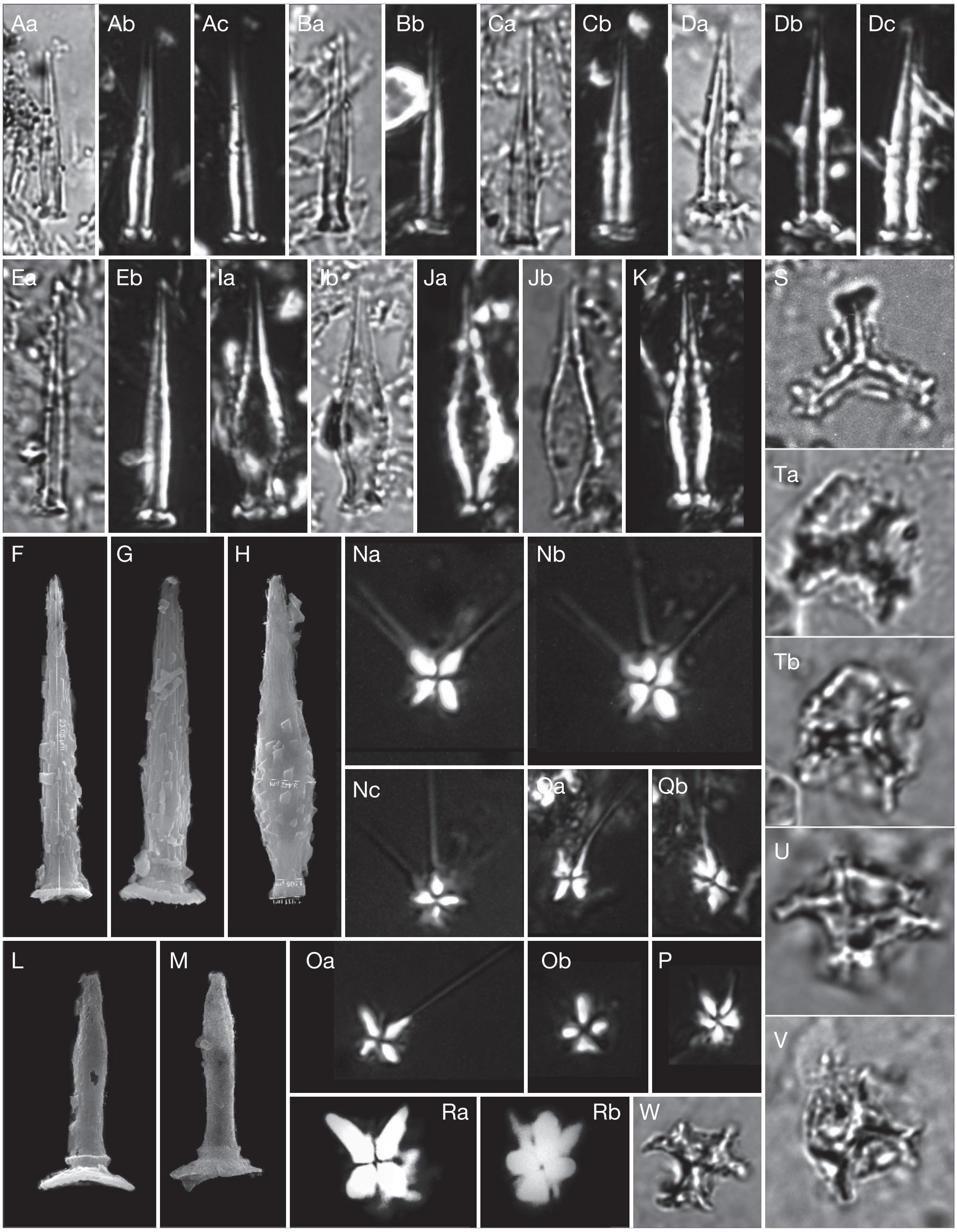


Fig. 20. — New or less known calcareous nannofossil taxa from the Eocene of the Mont-des-Récollets and other localities in Belgium. Pars 3: **A**-**G**, *Blackites praeinflatus* n. sp.; **A**, Mont-des-Récollets, 122.26-122.21 m, holotype, l = 23.0 μm (IRSNB b7141); **B**, paratype, Mont-des-Récollets, 122.16 m, paratype, l = 22.5 μm (IRSNB b7142); **C**, Mont-des-Récollets, 122.26-122.21 m, paratype, l = 24.0 μm (IRSNB b7143); **D**, Zaventem, sample 17, paratype, l = 24.0 μm (IRSNB b7144); **E**, Mont-des-Récollets, 122.26-122.21 m, paratype, l = 29.0 μm (IRSNB b7145); **F**, **G**, Vossem, otolith sample Nolf, 1974, paratypes (IRSNB b7146, b7147); **F**, l = 23.05 μm; **G**, l = 15.2 μm; **H**-**K**, *Blackites inflatus* (Bramlette & Sullivan, 1961); **H**, Isnes, sample 8, l = 17.5 μm (IRSNB b7148); **I**, Gobertange, sample Go5, l = 28 μm (IRSNB b7149); **J**, Isnes, sample 8, l = 18 μm (IRSNB b7150); **K**, Gobertange, sample Go5, l = 26 μm (IRSNB b7151); **L**-**M**, *Blackites* aff. *gladius* (Locker, 1967), Isnes, sample 8 (IRSNB b7152, b7153); **L**, l = 10.46 μm; **M**, l = 11.76 μm; **N**-**Q**, *Sphenolithus quadricornutus* n. sp.; **N**, Mont-des-Récollets, 126.50 m, holotype, htot = 9 μm, hpc = hle = 2 μm (IRSNB b7154); **O**, Balegem, level 6, paratype, hpc + hle = 4 μm (IRSNB b7155); **P**, Mont-des-Récollets 126.50 m, paratype, htot = 6 μm, hpp + hle = 3 μm (IRSNB b7156); **Q**, Mont-des-Récollets, 122.85 m, paratype, htot = 9 μm, hpc + hle = 3 μm (IRSNB b7157); **R**, *Sphenolithus perpendicularis* Shamrock, 2010, Balegem, level 6, h = 5 μm (IRSNB b7158); **S**, *Trochastrites hohnensis* (Martini, 1958). Mont-des-Récollets, 122.85 m, wm = 12 μm (IRSNB b7159); **T**-**W**, *Trochastrites pyramidalis* n. sp.; **T**, Oedelem BH, 5.50 m, paratype, wm = 10 μm (IRSNB b7160); **U**, Mont-des-Récollets, 122.16 m, holotype, wm = 12 μm (IRSNB b7161); **V**, Oedelem BH, 5.50 m, paratype, wm = 13 μm (IRSNB b7162) ; **W**, Vlakte van de Raan BH, 80.27 m, paratype, wm = 12 μm (IRSNB b7163).

pl. 4, figs 18-19; 1986: pl. IV, figs 18-19). By the distally slightly inflating stem and the rugose surface it bears a vague resemblance to *Blackites inflatus.* However, the latter is clearly much more inflated, undoubtedly pointing to a different taxon: the maximum width measures about *c.* 20 to 25% (mean of 24%) of the length of the rhabdolith and is equal or larger than the width of the basal plate (Fig. 20H: l = 17.5 µm, tip is missing; wm = 3.4 µm; wbp = 2.0 µm, incomplete?). *Blackites praeinflatus* n. sp. differs from *B. spinosus* by the general outline of the stem, reaching its maximum thickness at about 1/3 of its length, while in *B. spinosus* the stem is widest at its base (see Bown 2005: pl. 24, figs 21-25). It differs also from *B. scabrosus* (see Deflandre & Fert 1954: pl. XII, fig. 30, text-fig. 85) by its more elongated, less compact stem.

Blackites **aff.** ***gladius*** (Locker, 1967) Varol, 1989 (Fig. 20L, M)

Rhabdosphaera gladius Locker, 1967: 766, pl. 1, fig. 1; pl. 2, fig. 12.

Blackites gladius – Varol 1989: 286.

Distribution. — *Blackites* aff. *gladius* is only known from three records, one in Belgium, one in the Paris Basin and one in the Aquitaine Basin. It rarely co-occurs with *Blackites inflatus* in the Isnes quarry in SW Belgium, where its presence seems to be restricted to the top of the Brussel Sand Formation. A few specimens have been identified in the Donzacq Marl (upper NP14) at Saint-Geours-d'Auribat (Aquitaine Basin) (Lin *et al.* 2017) and in the upper part of the 'Glauconie Grossière s.s.' at Margival (Paris Basin, sample 3 in Steurbaut 1988), where it also co-occurs with *B. inflatus*. *B.* aff. *gladius* seems to indicate late Biochron NP14, also known as Biochon NP14b (*sensu* Berggren *et al.* 1995). It has not been recorded at the Mont-des-Récollets because of major erosion of the top of the Brussel Sand Formation in N France.

Discussion

This medium-sized rhabdolith (*c.* 11 µm length) is marked by a very wide basal plate (*c.* 4.8 µm) and a lensiform stem, which maximum width is located in the upper half of the stem. The latter, which presents a basal collar, seems to be thin-walled (Fig. 20L) and rugose towards the top. These rhabdoliths bear great resemblance with those of *B. gladius* (Varol 1989: pl. 4, fig. 5; Bown 2005: pl. 21, figs 10-14). However, they differ by certain features of the stem, which is relatively longer and more slender in *B.* aff. *gladius*, especially in the top part, as well as by the position of its maximum width. The latter is less distal compared to its position in *B. gladius*.

Family Sphenolithaceae Deflandre *in* Grassé, 1952

Genus *Sphenolithus* Deflandre in Grassé, 1952

urn:lsid:zoobank.org:act:5EE32ED4-8082-410F-A611-83ED3AB45B46

Type species. — *Sphenolithus radians* Deflandre *in* Grassé, 1952 by original designation.

Sphenolithus quadricornutus n. sp. (Fig. 20N-Q)

urn:lsid:zoobank.org:act:129C12D5-F3FE-47C6-849A-EE69215A1E64

Holotype. — Fig. 20N (IRSNB b7154) (negatives stored in the collections of the RBINS).

Paratypes. — 3 figured specimens (h without spines = 3.8-4.8 µm): 1 from the Lede Sand Formation, at Balegem (Fig. 20O) (IRSNB b7155) and 2 from Mont-des-Récollets: 1 from the Lede Sand Formation (Fig. 20P) (IRSNB b7156) and 1 from the Brussel Sand Formation (Unit B4) (Fig. 20Q) (IRSNB b7157).

Diagnosis. — Small hourglass-shaped sphenoliths, consisting of a conical proximal column, surmounted by a series of blocky distally widening lateral elements, both of almost equal height, supporting four equally spread diverging spines.

Derivatio nominis. — Refers to the four conspicuous diverging spines which rise from the corners of the sphenolith.

Locus typicus. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

Stratum typicum. — Lede Sand Formation (sample 126.50 m); lower part of NP15.

Dimensions. — Height = 11.2 to 12.8 µm with spine; Height body, without spine = 5 to 6.5 µm; Maximum width (wmab) = 4.4-5.2 µm (holotype: htotal = 11.2 µm, hpp = 2.5 µm, hle = 2.5 µm, hds = 6.2 µm; wpp = 3.4 µm).

Distribution. — This species has a rather restricted range. It occurs in the top of the Brussel Sand Formation (Unit B4) and in the Lede Sand Formation at Mont-des-Récollets, and in several outcrops of the Lede Sand Formation (Balegem, Oosterzele) and the base of the overlying Wemmel Sand Member (Oedelem borehole). Its range seems thus to be restricted to the top of NP14 and lower NP15.

Description

These sphenoliths are very tiny, consisting of a conical proximal column and a series of blocky lateral elements, which seem to widen distally, producing the typical hourglass shape. The latter is also easily observed in cross polarized light (see discussion below). Both the proximal column and the area with the lateral elements are of almost equal height (each *c.* 2.5 µm). Half long diverging spines (maximum 1.5 times as long as the sphenolith's body) emerge from each of the four corners.

Discussion

Sphenolithus quadricornutus n. sp. bears a striking resemblance to *Sphenolithus quadrispinatus*, described from the Late Miocene (Tortonian, NN10) of the southern Atlantic (Perch-Nielsen 1980), especially in its dimensions and the length and the position of the spines. They essentially differ in general outline, which is cylindrical in *S. quadrispinatus*, but hourglass-shaped in *S. quadricornutus* n. sp. This is also clearly observed in cross-polarized light when seen at 0°. In this position *S. quadrispinatus* is highly birefringent, consisting of four almost equal rectangular blocks (height is greater than width), separated by extinction lines with cross pattern.

S. quadricornutus n. sp. is also strongly birefringent in that position, but presents an x-shaped interference figure, of which the four bright parts are rather rhombic instead of rectangular and separated by extinction lines with cross pattern. Viewed at 45° this cross pattern turns into an x-pattern.

Sphenolithus recolletensis n. sp.
(Fig. 18Z-AA)

urn:lsid:zoobank.org:act:C09F103A-DD50-4227-AE6E-3B228A020AC9

Holotype. — Fig. 18AA (IRSNB b7119) (negatives stored in the collections of the RBINS).

Paratypes. — 1 figured specimen from the upper part of the Aalter Sand Formation (Unit A4) at Mont-des-Récollets (sample 116.45-116.50 m) (Fig. 18Z) (IRSNB b7118).

Diagnosis. — Rather large sphenoliths, consisting of an almost cubical lower portion, including the proximal shield and lateral elements, and a conspicuous apical spine with particular optical characteristics, made up of a solid centre and two diverging sword-like blades, which remained joined together over more than half of their length, before diverging distally and finally ending in a long distal threadlike structure. Both blades diverge at an angle of about 70°.

Derivatio nominis. — Named after the Mont-des-Récollets at Cassel (N France), refers to the type locality and unique locality record of this species.

Locus typicus. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

Stratum typicum. — Brussel Sand Formation, base of Unit B1 (sample 117.46-117.51 m); lower part of NP14.

Dimensions. — Height = 11.2 to 13.6 µm (exceptionally 20 µm, see Fig. 18Z) with spine; Height body, without spine = 7.4 to 9 µm; Maximum width (wmab) = 4.4-5.2 µm (holotype: htotal = 11.4 µm, hpp = 3.0 µm, hab = 4.4 µm, hds = 4 µm, wpp = 3.2 µm, wmab = 4.4 µm).

Distribution. — This species has a very restricted range, both in time and in space. Up to now it has only been recorded at Mont-des-Récollets, and only in the top of the Aalter Sand Formation (upper part of Unit A4) and the base of the Brussel Sand Formation (Units B1 and B2) (lower middle of NP14).

Description

These sphenoliths are robust and rather large, ranging from 11.2 to 14.0 µm in height. Their proximal portion consists of an irregular lattice, almost quadrangular in lateral view (width slightly larger than height), including a basal layer of radial elements (proximal cycle) surmounted by layers of lateral elements (lateral cycle). The apical spine consists of a solid centre and two diverging sword-like blades. These blades remain joined together over more than half of their length, before diverging at an angle of *c.* 70°. The top of each blade is tapering and ends in a thin and moderately long distal threadlike structure. These structures, as well as the top of the blades, are fragile and are often abraded or broken off.

The outline of these sphenoliths is unique, as well as their optical behaviour. Viewed between crossed nicols at 0° (in position parallel to the polarization directions) the entire sphenolith shows maximum birefringence, with a conspicuous extinction cross in the proximal portion and a vertical extinction line in the apical spine, separating the two halves. Maximum birefringence occurs every 90°. When viewed at 45° the extinction lines in the proximal portion have shifted from a cross-pattern into an x-pattern, whereas only the central part of the apical spine remains strongly birefringent and the blades only faintly. At 32° from maximum birefringence one of the blades becomes completely extinct (also most of its centre). The other blade fades out at *c.* 26° further clockwise (at *c.* 58° from the initial starting point).

Discussion

The outline, structure and optical behaviour of the proximal portion of this new *Sphenolithus* taxon is very similar to that of *Sphenolithus radians* (Fig. 19Q). Both differ by the outline of the apical spine, which consist of 2 diverging blades in *S. recolletensis* n. sp. The outline of the apical spine of the latter presents some similarities with these of *S. furcatolithoides* and *S. perpendicularis* (see Shamrock 2010a: pl. 1), but clearly differs from these by its massive strongly birefringent candle-shaped form, when viewed at 45°. The angle between the 2 diverging blades of the apical spine (*c.* 70°) is intermediate to that of *S. furcatolithoides* (*c.* 35°) (see Bown 2005: pl. 45) and that of *S. perpendicularis* (*c.* 96°) (Fig. 20R). The latter, which has been discovered in the middle Lutetian offshore W Australia (lower part of Zone NP15, restricted to Zone CP13a) (Shamrock 2010a, b), has not been identified at the Mont-des-Récollets. However, a single specimen has been encountered in the middle of the Lede Sand Formation at Balegem (Fig. 20R). This is the first record of *S. perpendicularis* in the Belgian Basin.

Sphenolithus spiniger Bukry, 1971
(Fig. 19P)

Sphenolithus spiniger Bukry, 1971: 321, pl. 6, figs 10-12; pl. 7, figs 1-2.

Distribution. — The lowest occurrence of typical *Sphenolithus spiniger* (as defined below) is in the lower part of the Brussel Sand Formation (at Mont-des-Récollets in Unit B2). It is known from many outcrop and borehole sections of the Brussel Sand Formation and increases in numbers during the *Sphenolithus* bloom, as recorded in the Diegem and Zaventem outcrop sections (Steurbaut, detailed in forthcoming study). It occurs rarely in the Lede Sand Formation.

Discussion

This sphenolith differs from the other *Sphenolithus* taxa described herein by its small triangular outline and very distinctive extinction pattern under crossed nicols. Viewed parallel to the polarisation directions it consists of 4 lobes separated by an extinction cross. The 2 proximal lobes are large and oval; the upper 2, which correspond to the lateral elements and spine, are much smaller and triangular. The extinction cross is much broader at its proximal end, so that the separation between the two lower lobes increases in proximal direction. Forms with a similar outline, but with a clearly different extinction pattern, are attributed to *Sphenolithus* aff. *spiniger*, known from the upper part of the Aalter Sand Formation and the Brussel Sand Formation. In these foms the lower 2 lobes are also triangular and the extinction cross is not enlarged proximally.

Family *Incertae sedis*

Genus *Nannoturba* Müller, 1979

urn:lsid:zoobank.org:act:0CDB0D30-8848-48BC-8849-89A35A3820F0

Type species. — *Nannoturba robusta* Müller, 1979 by original designation.

Nannoturba joceliniae n. sp.
(Fig. 19D-F)

urn:lsid:zoobank.org:act:86C68780-D532-4C0E-9AB7-8C5749A5D19A

Holotype. — Fig. 19D (IRSNB b7123) (negatives stored in the collections of the RBINS).

Paratypes. — 2 figured specimens from the Mont-des-Récollets (lmax = 17.6 µm): 1 from the sample that yielded the holotype (Unit B4, sample 122.85 m) (Fig. 20F) (IRSNB b7125) and 1 from the base of the Lede Sand Formation (123.50 m) (Fig. 20E) (IRSNB b7124).

Diagnosis. — Large, irregular network of calcite laths, joining at the centre in a central protruding x- shaped wedge.

Derivatio nominis. — The name is a combination of the Christian names Joachim and Celine, introduced to commemorate and celebrate the wedding day of these two lovely persons.

Locus typicus. — Mont-des-Récollets, 'Grande Carrière', N France; 50°48'02.74"N, 2°30'23.06"E.

Stratum typicum. — Brussel Sand Formation, Unit B4 (sample 122.85 m); upper part of NP14.

Dimensions. — Height = 16.8 to 17.6 µm; width = 15.6 to 14.6 µm (holotype: h = 16.8 µm, w = 15.2 µm).

Distribution. — At the Mont-des-Récollects this species is consistently present from the upper part of the Brussel Sand Formation (Unit B4), and ranges through the Lede Sand Formation up to the base of the Wemmel Sand Member (upper NP14 to lower NP15). However, there are earlier records from the Oedelem borehole (13.50 m depth, middle of Oedelem Sand Member), assignable to the extreme top of NP13, and from the Mont-des-Récollets (Unit B2) and the Nederokkerzeel and Vossem outcrops (upper Unit B3 of the Brussel Sand Formation), all assignable to the lower middle part of NP 14.

Description

This taxon is composed of an irregular complex network of several long calcite laths (up to 7), meeting at different angles in the centre of a more or less cubic structure. The dimensions are highly variable, as the different laths are often broken off. The longest diagonal reaches up to 17.6 µm, the second is generally slightly shorter. The centre is marked by an x-shaped protruding wedge. All calcite laths are strongly birefringent in cross-polarized light.

Discussion

Similar lathlike networks with central X-shaped to diamond-shaped wedges were described from upper Ypresian deposits of the southern North Sea Basin (Steurbaut 2011). *Nannoturba joceliniae* n. sp. differs from all previously described *Nannoturba* species (*N. robusta, N. spinosa* and *N. jolotteana*) by a reduced number (up to 7) of long, almost completely free, irregularly distributed laths, which only meet at the centre in an x-shaped to diamond-shaped wedge. In all others taxa the laths are joined over most of their length with different configurations, according to the species (*N. robusta* with quadrangular disposition and laths meeting at 90°; *N. spinosa* with triangular disposition with laths meeting at 120°; *N. jolotteana* (Fig. 19A) resembling a flattened octahedron, with rhombic cross-section). It differs from specimens described as *Nannotetrina nitida* by Aubry (1983: pl. 5, figs 13-14), as well as from the latter's holotype (originally described as *Tetralithus nitidus* by Martini 1961: pl. 1, fig. 5, pl. 4, fig. 41), by its large number of different sized laths. In fact, the specimens figured by Aubry also seem to belong to the genus *Nannoturba*, but probably represent another new species, different from *Tetralithus nitidus* Martini, 1961.

Acknowledgements

This paper could not have been finalised without the help of many enthusiastic co-workers, the authors' family members and local personalities, among which, above all, are the Masson family, who have owned the quarry at Mont-des-Récollets for many generations. Dirk Vancraeynest (Brugge) is thanked for topographically recording and positioning of the different outcrops and boreholes along the 'Mont-des-Récollets' Hill and the Van den Abeele firm (Cassel, France) for the mechanically deepening of the different pits. The authors are also much obliged to Daniel Bavay (Gent), Guido Burggraeve (Westkapelle), Cecile Deboudt (Nevele), Jan De Zwart (Sluis, NL), Emmanuel Dumoulin (Heist-aan-Zee), Dora Cuvelier (Brugge), Magda Cuvelier (Westkapelle), Vera Cuvelier (Loppem), Jef and Nicole Godderis (Brugge), Sylvie Nolf (Brugge), Hans Nuyts (Duffel), Jasper & Tiesten Provoost (Brugge), Omer Rappé (Knokke-Heist), Hans Van Hulle (Nijlen) and Rudy Van Hulle (Loppem) for their help in excavating or sampling during the different fieldwork campaigns. They are also grateful to Thierry Hubin (RBINS), Alexandre Chevalier (RBINS) and Wilfied Miseur (RBINS) for assistance given in photographic work and to Daniel Bavay (Gent), Hugo De Potter (RBINS), Adriano Vandersypen (RBINS) and Harry Van Paesschen (RBINS) for help in production of the figures. Special thanks are given to Dr X. Devleeschouwer (RBINS) and Mrs. V. Scaut (Bruxelles) for granting permission to use unpublished data and samples from Chaumont-en-Vexin and Fleury-la-Rivière, and to Dr J. Tyler (honorary deputy director of the Smithsonian Institute, Washington) for his careful review of the English language. Thomas Goovaerts (RBINS) and Stéphane Berton (RBINS) are responsible for cutting and polishing of the sandstone samples. Drs Florence Quesnel (BRGM, France) and Monechi Simonetta are thanked for their constructive comments and suggestions, improving the manuscript.

REFERENCES

ANONYMOUS 1893. — Légende de la Carte géologique de la Belgique dressée par ordre du Gouvernement à l'échelle du 40.000e. *Bulletin de la Société belge de Géologie, de Paléontologie & d'Hydrologie* 6 (1892): 217-229. https://www.biodiversitylibrary.org/page/45090735

ACHUTHAN M. V. & STRADNER H. 1969. — Calcareous nannoplankton from the Wemmelian stratotype, *in* BRÖNNIMANN P. & RENZ H. H. (eds), Proceedings of the First International Conference on Planktonic Microfossils, Geneva 1967. Brill, Leiden, Geneva 1: 1-13.

AGNINI C., MUTTONI G., KENT D. V. & RIO D. 2006. — Eocene biostratigraphy and magnetic stratigraphy from Possagno, Italy: The calcareous nannofossil response to climate variability. *Earth and Planetary Science Letters* 241: 815-830. https://doi.org/10.1016/j.epsl.2005.11.005

AGNINI C., FORNACIARI E., RAFFI I., CATANZARITI R., PÄLIKE H., BACKMAN J. & RIO D. 2014. — Biozonation and Biochronology of Paleogene Calcareous Nannofossils from Low and Middle Latitudes. *Newsletters on Stratigraphy* 47: 131-181. https://doi.org/10.1127/0078-0421/2014/0042

AUBRY M.-P. 1983. — Biostratigraphie du Paléogène épicontinental de l'Europe du Nord-Ouest. Étude fondée sur les nannofossiles calcaires. *Documents des Laboratoires de Géologie de Lyon* 89: 1-317.

AUBRY M.-P. 1986. — Paleogene calcareous nannoplankton biostratigraphy of northwestern Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology* 55: 267-334. https://doi.org/10.1016/0031-0182(86)90154-9

AUBRY M.-P. 1999. — *Handbook of Cenozoic Calcareous Nannoplankton*. Book 5: *Heliolithae (Zygoliths and Rhabdoliths)*. Micropaleontology Handbook Series, Micropaleontology Press, American Museum of Natural History, 368 p.

AUBRY M.-P. & BORD D. 2009. — Reshuffling the cards in the photic zone at the Eocene: Oligocene boundary, *in* KOEBERL C. & MONTANARI A. (eds), *The Late Eocene Earth*. The Geological Society of America, Special Paper 452: 279-301. https://doi.org/10.1130/2009.2452(18)

BACCAERT J. 2007. — Analysis of some nummulite populations of the Belgian Early Eocene and (re)determination of their taxa. 10th Joint Meeting RCNNS/RCNPS, Krakow, Poland, 3-7 September 2007. Abstract volume: 10-12.

BACCAERT J. 2017. — First record of *Nummulites involutus* Schaub in the Early Eocene of Belgium: a taxonomic-ecologic approach. *Memoirs of the Geological Survey of Belgium* 63: 1-45.

BERGGREN W. A., KENT D. V., SWISSER C. C. III & AUBRY M.-P. 1995. — A revised Cenozoic geochronology and chronostratigraphy, *in* BERGGREN W. A., KENT D. V., AUBRY M.-P. & HARDENBOL J. (eds), *Geochronology, Time Scales and Global Stratigraphic Correlation*. Society for Sedimentary Geology (SEPM), Special Publication 54: 129-212. https://doi.org/10.2110/pec.95.04.0129

BIGG P. J. 1982. — Eocene Planktonic foraminifera and calcareous nannoplankton of the Paris Basin and Belgium. *Revue de Micropaléontologie* 25 (2): 69-89.

BIGNOT G., MAUCORPS J, PERREAU M & SOLAU J.-L. 1980. — Le stratotype du Cuisien et l'Éocène du Nord du Bassin Parisien. Excursion B-12 du 26ème Congrès géologique international. *Bulletin d'Information des Géologues du bassin de Paris*, n° h-s., 12 p.

BLONDEAU A. 1966. — Les Nummulites de l'Éocène de Belgique. *Bulletin de la Société géologique de France*, série 7, 8: 908-919. https://doi.org/10.2113/gssgfbull.S7-VIII.6.908

BLONDEAU A. 1980. — Glauconie grossière, *in* MÉGNIEN C. (ed.), *Lexique des noms de formation. Synthèse géologique du Bassin de Paris.* Mémoire du Bureau de recherches géologiques et minières 103, vol. 3: 378.

BLONDEAU A. 1981. — Lutetian, *in* POMEROL Ch. (ed.), Stratotypes of Paleogene Stages. *Bulletin d'Information des Géologues du Bassin de Paris, mémoire hors série* 2: 167-180.

BLONDEAU A. & RENARD M. 1980. — Le Lutétien stratotypique de la région de Creil (Oise). Excursion B-15 du 26ème Congrès géologique international. *Bulletin d'Information des Géologues du Bassin de Paris*, n° h-s., 11 p.

BLONDEAU A., ODIN G.-S. & POMEROL CH. 1972. — Description du sondage, *in* Étude géologique du sondage de Cassel (Nord). *Bulletin d'Information des Géologues du Bassin de Paris* 32: 22-23.

BOUCHÉ P.-M. 1962. — Nannofossiles calcaires du Lutétien du Bassin de Paris. *Revue de Micropaléontologie* 5 (2): 75-103.

BOUSSAC J. 1912. — Essai sur l'évolution des cérithidés dans le Mésonummuliique du Bassin de Paris. *Annales Hébert* 6: 1-93. https://doi.org/10.5962/bhl.title.11786

BOWN P. R. 2005. — Palaeogene calcareous nannofossils from the Kilwa and Lindi areas of coastal Tanzania (Tanzania Drilling Project 2003-4). *Journal of Nannoplankton Research* 27 (1): 21-95.

BRAMLETTE M. N. & SULLIVAN F. R. 1961. — Coccolithophorids and related Nannoplankton of the early Tertiary in California. *Micropaleontology* 7 (2): 129-188. https://doi.org/10.2307/1484276

BRIART A. 1890. — Note sur une faune marine landénienne dans l'Entre-Sambre-et-Meuse. *Annales de la Société géologique de Belgique* 17: 259-265.

BUKRY D. 1971. — Cenozoic calcareous nannofossils from the Pacific Ocean. *Transactions of the San Diego Society of Natural History* 16 (14): 303-328.

BUKRY D. 1974. — Coccoliths as paleosalinity indicators – evidence from Black Sea, *in* DEGENS E. T. & ROSS D. A. (eds), *The Black Sea – Geology, Chemistry and Biology*. American Association of Petroleum Geologists Memoir 20: 353-363. https://doi.org/10.1306/M20377C2

BURTIN F.-X. 1784. — *Oryctographie de Bruxelles ou Description des fossiles tant naturels qu'accidentels découverts jusqu'à ce jour dans les environs de cette Ville*. De le Maire, Bruxelles, 152 p. https://doi.org/10.5962/bhl.title.145344

COURVILLE P. 2012. — *Campanile* et autres gastéropodes lutétiens (Éocène) de Fleury-la-Rivière, Marne. *Fossiles* 10: 51-53.

CURRY D., KING A. D., KING C. & STINTON F. C. 1977. — The Bracklesham Beds (Eocene) of Bracklesham Bay and Selsey, Sussex. *Proceedings of the Geologists' Association* 88 (4): 243-254. https://doi.org/10.1016/S0016-7878(77)80010-2

DAMBLON F. & STEURBAUT E. 2000. — Gobertange : site géologique remarquable, *in La Gobertange – Une pierre, des hommes*. ASBL Gobertange 2000, Cera Holding: 19-48.

D'ARCHIAC A. 1839. — Essais sur la coordination des terrains tertiaires du Nord de la France, de la Belgique et de l'Angleterre. *Bulletin de la Société géologique de France*, série 1, 10: 168-225.

DARTEVELLE E. 1934. — Les Nummulites de l'Éocène belge (Suite et fin.). *Bulletin mensuel les Naturalistes belges*, 15ème année, 11: 206-211.

DE BATIST M. & HENRIET J.-P. 1995. — Seismic sequence stratigraphy of the Palaeogene offshore of Belgium, southern North Sea. *Journal of the Geogical Society, London* 152: 27-40. https://doi.org/10.1144/gsjgs.152.1.0027

De Coninck J. 1995. — Corrélations entre les dépôts du Lutétien au Rupélien du Bassin belge, et des Bassins de Hamsphire et de Paris. *Mededelingen Rijks Geologische Dienst* 53: 107-118.

Deflandre G. 1947. — *Braarudosphaera* nov. gen., type d'une famille nouvelle de Coccolithophoridés actuels à éléments composites. *Compte Rendus hebdomadaires des Séances de l'Académie des Sciences* 225: 439-441. https://gallica.bnf.fr/ark:/12148/bpt6k3177x/f439.item

Deflandre G. 1952. — Classe des Coccolithophoridés, *in* Grassé P. P. (ed.), *Traité de Zoologie*. Vol. 1. Masson et Cie, Paris: 439-470.

Deflandre G. & Fert C. 1954. — Observations sur les Coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique. *Annales de Paléontologie* 40: 115-176.

De Geyter G., De Man E., Herman J., Jacobs P., Moorkens T., Steurbaut E. & Vandenberghe N. 2006. — Disused Paleogene regional stages from Belgium: Montian, Heersian, Landenian, Paniselian, Bruxellian, Laekenian, Ledian, Wemmelian and Tongrian, *in* Dejonghe L. (ed.), Current Status of Chronostratigraphic Units Named from Belgium and Adjacent Areas. *Geologica Belgica* 9 (1-2): 203-213. https://popups.uliege.be/1374-8505/index.php?id=1213

Dégremont E., Duchaussois F., Hautefeuille F., Laurain M., Louis P. & Tétu R. 1985. — Paléontologie : découverte d'un gisement du Cuisien tardif à Prémontré (Aisne). *Bulletin d'Information des Géologues du Bassin de Paris* 22 (2): 11-18.

Delvaux E. 1886. — Visite aux gites fossilifères d'Aeltre et Exploration des travaux en cours d'exécution à la Colline de Saint-Pierre à Gand. *Annales de la Société royale malacologique de Belgique* 21: 274-296. https://www.biodiversitylibrary.org/page/5636062

De Moor G. & Geets S. 1974. — Sedimentologie en lithostratigrafie van de Eocene afzettingen in het zuidoostelijk gedeelte van de Gentse agglomeratie. *Natuurwetenschappelijk Tijdschrift* 55 (1973): 129-192.

De Moor G. & Germis A. 1971. — Hydromorphologie du Bassin de la Molenbeek (Melle). *Bulletin de la Société belge d'Études géographiques* 40: 29-68.

Depret M. & Willems W. 1983. — A record *in situ* of *Nummulites laevigatus* (Bruguière 1792) in sediments of Lutetian age in the area around Zeebrugge (NW-Belgium) and its stratigraphic consequences. *Tertiary Research* 5 (1): 25-37.

Desmyttere J. 1826. — Mémoire sur la nature du sol de la montagne de Cassel, département du Nord. *Recueil des travaux de la Société des Sciences, de l'Agriculture et des Arts de Lille* (Année 1825): 500-504. https://gallica.bnf.fr/ark:/12148/bpt6k5831746g/f513.item

D'Omalius d'Halloy J. J. 1842. — *Coup d'œil sur la géologie de la Belgique*. M. Hayez, Bruxelles, 132 p.

D'Omalius d'Halloy J. J. 1862. — *Abrégé de géologie*. 7ème édit. A. Schnée, Bruxelles, Leipzig; F. J. Leiber, Paris, 626 p.

Dumont A. 1839. — Rapport sur les travaux de la carte géologique pendant l'année 1839. *Bulletin de l'Académie royale de Bruxelles* 6 (11): 464-485. http://hdl.handle.net/2268/207965

Elie de Beaumont L. 1833. — Observations sur l'étendu du système tertiaire inférieur dans le Nord de la France, et sur les dépôts de lignite qui s'y trouvent. *Mémoires de la Société géologique de France* 1: 107-121. https://www.biodiversitylibrary.org/page/42352369

Eaton G. L. 1976. — Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, southern England. *Bulletin of the British Museum (Natural History) Geology* 26 (6): 227-332. https://www.biodiversitylibrary.org/page/36530970

Feugueur L. 1963. — L'Yprésien du Bassin de Paris – essai de monographie stratigraphique. *Mémoires pour servir à l'explication de la carte géologique détaillée de la France*. Imprimerie nationale: 1-568.

Fischer O. 1862. — On the Bracklesham Beds of the Isle of Wight Basin. *Quaterly Journal of the Geological Society* 18: 65-94. https://doi.org/10.1144/GSL.JGS.1862.018.01-02.18

Fobe B. 1986. — *Petrografisch onderzoek van de coherente gesteenten van het Eoceen van Laag- en Midden-België*. Unpublished PhD, Rijksuniversiteit Gent, part I, 215 p., part II, 138 p.

Fobe B. & Spiers V. 1992. — Sedimentology and facies distribution of the Lede Formation (Eocene) in Belgium and Northern France. *Contributions to Tertiary and Quaternary Geology* 29: 9-20.

Franceschi M., Penasa L., Coccioni R., Gattacceca J., Smit J., Cascella A., Mariani S. & Montanari A. 2015. — Terrestrial Laser Scanner imaging for the cyclostratigraphy and astronomical tuning of the Ypresian-Lutetian pelagic section of Smirra (Umbria-Marche Basin, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology* 440: 33-46 (+ Supplementary material). https://doi.org/10.1016/j.palaeo.2015.08.027

Franzen J. L. & Mörs T. 2007. — Das Nördlichste Vorkommen paläogener Saugetiere in Europa. *Paläontologische Zeitschrift* 81 (4): 447-456. https://doi.org/10.1007/BF02990256

Galeotti P. H. 1837. — Mémoire sur la constitution géognostique de la province de Brabant. *Mémoires couronnés par l'Académie royale de Bruxelles* 12: 1-192.

Galeotti S., Moretti M., Sabatino N., Sprovieri M., Ceccatelli M., Francescone F., Lanci L., Lauretano V. & Monechi S. 2017. — Cyclochronology of the Early Eocene carbon isotope record from a composite Contessa Road-Bottaccione section (Gubbio, central Italy). *Newsletters on Stratigraphy* 50 (3): 231-244. https://doi.org/10.1127/nos/2017/0347

Geets S. 1979. — De overgang Ieperiaan-Paniseliaan in de streek van Roeselare en Tielt. *Natuurwetenschappelijk Tijdschrift* 60: 41- 69.

Gély J.-P. 1996. — Le Lutétien du Bassin de Paris : de l'analyse séquentielle haute-résolution à la reconstitution paléogéographique. *Bulletin d'Information des Géologues du Bassin de Paris* 34 (2): 3-27.

Gély J.-P. 2008. — La stratigraphie et la paléogéographie du Lutétien en France, *in* Merle D. (ed.), *Stratotype Lutétien*. Muséum national d'Histoire naturelle, Paris; Biotope, Mèze; BRGM, Orléans: 76-104 (Patrimoine géologique; 1).

Gerits M., Hooyberghs H. & Voets R. 1981. — Quantitative distribution and paleoecology of benthonic foraminifera recorded from some Eocene deposits in Belgium. *Professional Paper* 182: 1-53.

Gosselet J. 1883. — Note sur les collines de Cassel. *Annales de la Société géologique du Nord* 10: 207-214. https://gallica.bnf.fr/ark:/12148/bpt6k5748296v/f238.item

Gosselet J. 1896. — Coup d'œil sur le calcaire grossier du Nord du Bassin de Paris. Sa comparaison avec les terrains de Cassel et de la Belgique. *Annales de la Société géologique du Nord* 23: 160-170. https://gallica.bnf.fr/ark:/12148/bpt6k5723984z/f178.item

Gran H. H. & Braarud T. 1935. — A qualitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). *Journal of the Biological Board of Canada* 1: 279-467. https://doi.org/10.1139/f35-012

Gulinck M. 1963. — Étude des facies du Bruxellien (Éocène moyen). 6° Congrès International de Sédimentologie Belgique et Pays-Bas 1963. Excursions M/N-2°partie, 11 p.

Gulinck M. 1969. — Coupe résumée des terrains traversés au sondage de Kallo et profil géologique NS passant par Woensdrecht-Kallo-Halle. *Mémoires pour servir à l'explication des Cartes géologiques et minières de la Belgique* 11: 1-7.

Hacquaert A. 1936. — Compte rendu de l'excursion du 28 mai 1936 aux chantiers des nouveaux bâtiments universitaires, à Gand. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 46: 273-276.

Hacquaert A. 1939. — De overgang van Ieperiaan tot Lutetiaan te Aalter (Kanaal). *Natuurwetenschappelijk Tijdschrift* 21 (7): 323-325.

Halet F. 1913. — Le sondage de Woensdrecht (Pays-Bas). *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 27: 169-176. https://www.biodiversitylibrary.org/page/45184439

Halet F. 1937. — Sur un gisement de Nummulites laevigatus dans le Bruxellien, à saint-Denis-lez-Namur. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 47: 169-176.
Hay W. W. & Towe K. M. 1962. — Electronmicroscopic examination of some coccoliths from Donzacq (France). *Eclogae Geologicae Helvetiae* 55: 497-517. https://doi.org/10.5169/seals-162934
Herman J., Steurbaut E. & Vandenberghe N. 2001. — The boundary between the Middle Eocene Brussel Sand and the Lede Sand Formations in the Zaventem-Nederokkerzeel area (Northeast of Brussels, Belgium). *Geologica Belgica* 3 (3-4): 231-255. https://doi.org/10.20341/gb.2014.031
Hooyberghs H. J. F. 1986. — Palaeoecology of benthonic foraminifera from the Brussels Sands Formation (Middle Eocene) in Belgium. *Aardkundige Mededelingen* 3: 107-124.
Hooyberghs H. J. F. 1992. — A new dating of the Brussels Sands Formation (Lower-Middle Eocene) on planktonic foraminifera from St-Stevens-Woluwe and Neerijse, Belgium. *Tertiary Research* 14 (1): 33-49.
Hooyberghs H. J. F. 1999. — Foraminifera of the Lower to Middle Eocene deposits in the Mont-de-Récollets at Cassel (N. France). *Aardkundige Mededelingen* 9: 147-152.
Houbrick R. S. 1984. — The Giant Creeper, *Campanile symbolicum* Iredale, an Australian Relict Marine Snail, *in* Eldridge N. & Stanley S. M. (eds), *Living Fossils.* Springer-Verlag, New York 26: 232-235. https://doi.org/10.1007/978-1-4613-8271-3_27
Houthuys R. 1990. — Vergelijkende studie van de afzettingsstruktuur van getijdenzanden uit het Eoceen en van de huidige Vlaamse Banken. *Aardkundige Mededelingen* 5: 1-137.
Houthuys R. 2011. — A sedimentary model of the Brussels Sands, Eocene, Belgium. *Geologica Belgica* 14 (1-2): 55-74. https://popups.uliege.be/1374-8505/index.php?id=3205
Houthuys R. 2014. — A reinterpretation of the Neogene emersion of central Belgium based on the sedimentary environment of the Diest Formation and the origin of the drainage pattern. *Geologica Belgica* 17 (3-4): 211-235. https://popups.uliege.be/1374-8505/index.php?id=4602
Jacobs P. 1978. — Litostratigrafie van het Boven-Eoceen en van het Onder-Oligoceen in Noordwest België. *Professional Paper, Belgische Geologische Dienst* 151 (3): 1-92.
Jacobs P. & Sevens E. 1988. — Lithostratigrafie van de Eo-Oligocene overgangslagen in Noordwest België. *Professional Paper, Belgische Geologische Dienst* 235 (5): 1-60.
Jacobs P. & Sevens E. 1993. — Eocene Silicilastic Continental Shelf Sedimentation in the Southern Bight North Sea, Belgium, *in* Progress in Belgian Oceanographic Research. Royal Academy of Belgium, National Committee of Oceanology, Brussels: 95-118.
Jacobs P. & Sevens E. 1994. — Middle Eocene sequence stratigraphy in the Balegem quarry (Western Belgium, Southern North Sea Bight. *Bulletin van de Belgische Vereniging voor Geologie* 102: 203-213.
Janssen A. W. 2010. — Pteropods (Mollusca, Euthecasomata) from the Early Eocene of Rotterdam (The Netherlands). *Scripta Geologica,* Special Issue 7: 161-175. https://repository.naturalis.nl/pub/361978
Jung P. 1987. — Giant gastropods of the genus Campanile from the Caribbean Eocene. *Eclogae Geologicae Helvetiae* 80 (3): 889-896. https://doi.org/10.5169/seals-166030
Kaasschieter J. P. M. 1961. — Foraminifera of the Eocene of Belgium. *Verhandelingen Koninklijk Belgisch Instituut Natuurwetenschappen* 147: 1-271.
King C. 1990. — Eocene stratigraphy of the Knokke borehole (Belgium), *in* Laga P. & Vandenberghe N. (eds), The Knokke well (11E/138) with a description of the Den Haan (22W/276) and Oostduinkerke (35E/142) wells. *Mémoires pour servir à l'Explication des Cartes géologiques et minières de la Belgique* 29: 67-102.
King C. 1996. — The stratigraphy of the Bracklesham group of Bracklesham Bay and Selsey (West Sussex, England): an update 1977-1995. *Tertiary Research* 16 (1-4): 15-23.
King C. 2016. — A Revised Correlation of Tertiary rocks of the British Isles and adjacent areas of NW Europe. *Geological Society Special Report* 27: 1-719. https://doi.org/10.1144/SR27
King C., Iakovleva A., Steurbaut E., Heilmann-Clausen C. & Ward D. 2013. — The Aktulagay section, west Kazakhstan: a key site for northern mid-latitude Early Eocene stratigraphy. *Stratigraphy* 10 (3): 171-209.
Köthe A. 2012. — A revised Cenozoic dinoflagellate cyst and calcareous nannoplankton zonation for the German sector of the southern North Sea Basin. *Newsletters on Stratigraphy* 45 (3): 189-220 https://doi.org/10.1127/0078-0421/2012/0021
Laga P., Louwye S. & Geets S. 2002. — Paleogene and Neogene lithostratigraphic units (Belgium). *Geologica Belgica* 4 (1-2) (2001): 135-152. https://popups.uliege.be/1374-8505/index.php?id=1954
Laga P. & Vandenberghe N. 1990. — The Knokke well (11E/138) with a description of the Den Haan (22W/276) and Oostduinkerke (35E/142) wells. *Toelichtende Verhandelingen voor de Geologische en Mijnkaarten van België* 29: 1-118.
Larrasoaña J. C., Gonzalvo C, Molina E., Monechi S., Ortiz S., Tori, F. & Tosquella J. 2008. — Integrated magnetobiochronology of the Early/Middle Eocene transition at Agost (Spain): Implications for defining the Ypresian/Lutetian boundary stratotype. *Lethaia* 41: 395-415. https://doi.org/10.1111/j.1502-3931.2008.00096.x
Leriche M. 1906. — Sur l'extension des grès à *Nummulites laevigatus* dans le nord de la France et sur les relations des Bassins parisien et belge à l'époque lutétienne, *in* Association française pour l'Avancement des Sciences, Compte rendu de la 34ème Session, Cherbourg, 1905. *Notes et Mémoires*: 394-402. https://gallica.bnf.fr/ark:/12148/bpt6k201201n/f395.item
Leriche M. 1912. — L'Éocène des Bassins parisien et belge. *Bulletin de la Société géologique de France*, série 4, 12: 692-724.
Leriche M. 1921. — Monographie géologique des Collines de la Flandre Française et de la Province belge de la Flandre occidentale (Collines de Cassel et des environs de Bailleul). *Mémoires pour servir à l'explication de la carte géologique détaillée de la France*. Imprimerie nationale: 1-112.
Leriche M. 1923. — Les gisements de « *Nummulites laevigatus* » Brug., dans le Bassin belge. *Bulletin de la Société belge de Géologie de Paléontologie et d'Hydrologie* 32 (1922): 93-99.
Leriche M. 1938. — Les Sables d'Aeltre ; leur place dans la classification des assises éocènes du Bassin anglo-franco-belge. *Annales de la Société géologique du Nord* 62 (1937): 77-96.
Leriche M. 1939. — Les rapports entre les formations tertiaires du bassin belge et du bassin de Paris, *in* Session extraordinaire de la Société belge de Géologie, de Paléontologie et d'Hydrologie et de la Société géologique de Belgique dans le Nord et l'Est de l'Ile-de-France du 18 au 22 septembre 1937. *Annales de la Société géologique de Belgique* 62 (4): 178-252.
Leriche M. 1943a. — Les couches de base du Bartonien dans le bassin belge. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 52 (1): 104-121.
Leriche M. 1943b. — Le Bruxellien nummulitique à Noville-sur-Mehaigne. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 52: 179-183.
Lezaud L. 1972. — Nannofossiles calcaires, *in* Étude géologique du sondage de Cassel (Nord). *Bulletin d'Information des Géologues du Bassin de Paris* 32: 41-42.
Lin C.-H., Nolf D., Steurbaut E. & Girone A. 2017. — Fish otoliths from the Lutetian of the Aquitaine Basin (SW France), a breakthrough in the knowledge of the European Eocene ichthyofauna. *Journal of Systematic Palaeontology* 15 (11): 879-907. https://doi.org/10.1080/14772019.2016.1246112
Locker S. 1967. — Neue, stratigraphisch wichtige Coccolithophoriden (Flagellata) aus dem norddeutschen Alttertiär. *Monatsberichte der Deutschen Akademie der Wissenschaften zu Berlin* 9 (9/10): 758-768.

Loeblich A. R. & Tappan H. 1963. — Type fixation and validation of certain calcareous nannoplankton genera. *Proceedings of the Biological Society of Washington* 76: 191-198.

Luterbacher H.-P., Ali J. R., Brinkhuis H., Gradstein F. M., Hooker J. J., Monechi S., Ogg J. G., Powell J., Röhl U., Sanfilippo A. & Schmitz B. 2004. — The Paleogene Period, *in* Gradstein F. M., Ogg J. G. & Smith A. (eds), *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge: 384-408.

Lyell C. 1852. — The Tertiary strata of Belgium and French Flanders. *Quarterly Journal of the Geological Society* 8: 277-370. https://doi.org/10.1144/GSL.JGS.1852.008.01-02.34

Maréchal R. 1994. — A new lithostratigraphic scale for the Palaeogene of Belgium. *Bulletin de la Société belge de Géologie* 102: 215-229.

Martini E. 1958. — Discoasteriden und verwandte Formen in N.W. deutschen Eozän (Coccolithophorida). II Teil. *Senckenbergiana Lethaea* 39 (5-6): 353-388.

Martini E. 1961. — Nannoplankton aus dem Tertiär und der obersten Kreide von SW-Frankreich. *Senckenbergiana lethaea* 42 (1/2): 1-41.

Martini E. 1971. — Standard Tertiary and Quaternary calcareous nannoplankton zonation, *in* Proceedings 2nd Planktonic Conference (Roma, 1970). Vol. 2. Technoscienza, Rome: 739-785.

Merle D. (coord.) 2008. — *Stratotype Lutétien*. Muséum national d'Histoire naturelle, Paris; Biotope, Mèze; BRGM Orléans, 288 p. (Patrimoine géologique; 1)

Merle D. & Courville P. 2008. — Les sites remarquables, *in* Merle D. (ed.), *Stratotype Lutétien*. Muséum national d'Histoire naturelle, Paris; Biotope, Mèze; BRGM, Orléans: 64-75 (Patrimoine géologique; 1).

Molina E., Alegret L., Apellaniz E., Bernaola G., Caballero F., Dinarès-Turell J., Hardenbol J., Heilmann-Clausen C., Larrasoaña J. C., Luterbacher H., Monechi S., Ortiz S., Orue-Etxebarria X., Payros A., Pujalte V., Rodríguez-Tovar F. J., Tori F., Tosquella J. & Uchman A. 2011. — The Global Standard Stratotype Section and Point (GSSP) for the base of the Lutetian Stage at the Gorrondatxe section (Spain). *Episodes* 34 (2): 86-108. https://doi.org/10.18814/epiiugs/2011/v34i2/006

Monechi S. & Thierstein H. R. 1985. — Late Cretaceous – Eocene nannofossil and magnetostratigraphic correlations near Gubbio, Italy. *Marine Micropaleontology* 9: 419-440. https://doi.org/10.1016/0377-8398(85)90009-X

Moshkovitch S. & Ehrlich A. 1982. — Biostratigraphical problems of the Middle Miocene calcareous nannofossils and the paleoecological significance of the Braarudosphaerids in the Coastal plain and offshore of Israel. *Current Research (Geological Survey of Israel)*: 43-47.

Mourlon M. 1873. — Géologie, *in* van Bemmel E. (ed.), *Patria Belgica*. T. 1, *Belgique physique*. Bruylant Christophe, Bruxelles, 4: 95-192.

Mourlon M. 1888. — Sur l'existence d'un nouvel étage de l'Éocène moyen dans le bassin franco-belge. *Bulletin de l'Académie royale des Sciences, des Lettres et des Beaux-Arts de Belgique* 3 (16): 252-276. https://www.biodiversitylibrary.org/page/35498262

Müller C. 1970. — Nannoplankton aus dem Mittel-Oligozän von Norddeutschland und Belgien. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 135 (1): 82-101.

Müller C. 1979. — Calcareous nannofossils from the North Atlantic (Leg 48), *in* Montadert L. & Roberts D. G. (eds), *Initial Reports of the Deep Sea Drilling Project*. Vol. 48. U.S. Government Printing Office, Washington: 589-639. https://doi.org/10.2973/dsdp.proc.48.125.1979

Nolf D. 1974. — *De Teleostei-otolieten uit het Eoceen van het Belgisch Bekken – reconstructie van de fauna en biostratigrafische toepassing*. Unpublished PhD dissertation, Rijksuniversiteit Gent, 173 p.

Nolf D. & Steurbaut E. 1990. — Stratigraphie de l'Éocène en Flandre occidentale et dans les régions limitrophes. *Bulletin d'Information des Géologues du Bassin de Paris* 27 (3): 9-36.

Ortlieb J. & Chellonneix E. 1870. — *Étude géologique des collines tertiaires du département du Nord comparées avec celles de la Belgique*. Quarré & Castiaux, Lille, 228 p. https://gallica.bnf.fr/ark:/12148/bpt6k5478233f

Ott d'Estevou P., Barrier P., Romanek C. & Maille T. 2014. — Mise en évidence d'un "beachrock" dans le Lutétien inférieur de Chaumont-en-Vexin (Sud-Ouest de l'Oise) : conséquences paléogéographiques et environnementales. *Bulletin d'Information des Géologues du Bassin de Paris* 51 (1) (non vol. 50 [4]): 3-15.

Payros A., Bernaola G., Orue-Etxebarria X., Dinarès-Turell J., Tosquella J. & Apellaniz E. 2007. — Reassessment of the Early-Middle Eocene biomagnetochronology based on evidence from the Gorrondatxe section (Basque Country, western Pyrenees). *Lethaia* 40: 183-195. https://doi.org/10.1111/j.1502-3931.2007.00016.x

Payros A., Orue-Etxebarria X., Berneola G., Apellaniz E., Dinarès-Turell J., Tosquella J. & Caballero F. 2009. — Characterization and astronomically calibrated age of the first occurrence of *Turborotalia frontosa* in the Gorrondatxe section, a prospective Lutetian GSSP: implications for the Eocene time scale. *Lethaia* 42: 255-264. https://doi.org/10.1111/j.1502-3931.2008.00142.x

Payros A., Ortiz S., Alegret L., Orue-Etxebarria X., Apellaniz E. & Molina E. 2012. — An early Lutetian carbon-cycle perturbation: Insights from the Gorrondatxe section (western Pyrenees, Bay of Biscay). *Paleoceanography* 27: PA2213. https://doi.org/10.1029/2012PA002300

Payros A., Ortiz S., Millán I., Arostegi J., Orue-Etxebarria X. & Apellaniz E. 2015. — Early Eocene climatic optimum: Environmental impact on the North Iberian continental margin. *Geological Society of America Bulletin* 127 (11-12): 1632-1644. https://doi.org/10.1130/B31278.1

Perch-Nielsen K. 1971. — Elektronenmikroskopische Untersuchungen an coccolithen und verwandten Formen aus dem Eozän von Dänemark. *Det Kongelige Danske Videnskabernes Selskab Biologiske Skrifter* 18 (3): 1-76.

Perch-Nielsen K. 1980. — New Tertiary calcareous nannofossils from the South Atlantic. *Eclogae Geologicae Helvetiae* 73 (1): 1-7. https://doi.org/10.5169/seals-164942

Perch-Nielsen K. 1985. — Cenozoic calcareous nannofossils, *in* Bolli H. M., Saunders J. B. & Perch-Nielsen K. (eds), Plankton Stratigraphy. *Cambridge Earth Science Series* 1, 11: 427-554.

Rutot A. 1882. — Note sur la constitution des collines tertiaires de la Flandre franco-belge, *in* Résultats de nouvelles recherches dans l'Éocène supérieur de la Belgique. *Annales de la Société royale malacologique de Belgique* 17: 168-178. https://www.biodiversitylibrary.org/page/5631549

Rutot A. 1887. — Sur l'âge du Grès de Fayat. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 1: 43-48. https://www.biodiversitylibrary.org/page/46074731

Rutot A. 1893. — Le gisement des Grès de Gobertange. *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie* 7: 67-69. https://www.biodiversitylibrary.org/page/45076210

Rutot A. 1910. — *Texte explicatif du levé géologique de la planchette de Meldert n° 104*. Ministère de l'Industrie et du Travail, Administration des Mines, Service géologique de Belgique, 23 p. http://hdl.handle.net/1908/3812

Schuler M., Cavelier C., Dupuis C., Steurbaut E. & Vandenberghe N. 1992. — The Paleogene of the Paris and Belgian Basins. Standard-Stages and regional stratotypes. *Cahiers de Micropaléontologie* N. S., 7 (1-2): 29-92.

Shamrock J. L. 2010a. — Eocene calcareous nannofossil biostratigraphy, paleoecology and biochronology of ODP Leg 122 hole 762C, eastern Indian Ocean (Exmouth Plateau). *Dissertations & Theses in Earth and Atmospheric Sciences, Paper* 42, 1-5: 1-152. http://digitalcommons.unl.edu/geoscidiss/42

Shamrock J. L. 2010b. — A new calcareous nannofossil species of the genus *Sphenolithus* from the Middle Eocene (Lutetian) and its biostratigraphic significance. *Journal of Nannoplankton Research* 31 (1): 5-10.

Shamrock J. L., Watkins D. K. & Johnston K. W. 2012. — Eocene biogeochronology and magnetostratigraphic revision of ODP Hole 762C, Exmouth Plateau (northwest Australian shelf). *Stratigraphy* 9 (1): 55-75.

Shcherbinina E. A. 2000. — Middle Eocene nannofossils and geological events of the northeastern peri-Tethys. *GFF* 122: 143-145. https://doi.org/10.1080/11035890001221143

Siesser W. G. 1983. — Paleogene calcareous nannoplankton biostratigraphy: Mississippi, Alabama and Tennessee. *Bulletin of Mississippi Bureau of Geology* 125: 1-61.

Smith T., De Wilde B. & Steurbaut E. 2004. — Primitive Equoid and Tapiroid mammals: keys for interpreting the Ypresian-Lutetian transition of Belgium. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, 74, Supplément: 165-175.

Steurbaut E. 1986. — Late Middle Eocene to Middle Oligocene calcareous nannoplankton from the Kallo well, some boreholes and exposures in Belgium, and a description of the Ruisbroek Sand Member. *Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie* 23 (2): 49-83.

Steurbaut E. 1988. — New Early and Middle Eocene calcareous nannoplankton events and correlations in middle to high latitudes of the northern hemisphere. *Newsletters on Stratigraphy* 18 (2): 99-115. https://doi.org/10.1127/nos/18/1988/99

Steurbaut E. 1990. — Calcareous nannoplankton assemblages from the Tertiary in the Knokke borehole, *in* Laga P. & Vandenberghe N. (eds), The Knokke well (11E/138) with a description of the Den Haan (22W/276) and Oostduinkerke (35E/142) wells. *Mémoires pour servir à l'Explication des Cartes géologiques et Minières de la Belgique* 29: 47-62.

Steurbaut E. 1991. — Ypresian calcareous nannoplankton biostratigraphy and palaeogeography of the Belgian Basin, *in* Dupuis C., De Coninck J. & Steurbaut E. (eds), The Ypresian stratotype. *Bulletin de la Société belge de Géologie* 97 (3-4): 251-285.

Steurbaut E. 1998. — High-resolution holostratigraphy of Middle Paleocene to Early Eocene strata of Belgium and adjacent areas. *Palaeontographica A*, 247 (5-6): 91-156.

Steurbaut E. 2006. — Ypresian, *in* Dejonghe L. (ed.), Current status of chronostratigraphic units named from Belgium and adjacent areas. *Geologica Belgica* 9 (1-2): 73-93. https://popups.uliege.be/1374-8505/index.php?id=1101

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.

Steurbaut E. 2015. — Het Vroeg-Eoceen, *in* Borremans M. (ed.), *Geologie van Vlaanderen, Cenozoicum: Paleogeen en Neogeen*. Uitgeverij Academia Press Gent, 3.3: 125-135.

Steurbaut E. & King C. 1994. — Integrated stratigraphy of the Mont-Panisel borehole section (151E340), Ypresian (Early Eocene) of the Mons Basin, SW Belgium. *Bulletin de la Société belge de Géologie* 102 (1-2) (1993): 175-20.

Steurbaut E. & Nolf D. 1986. — Revision of Ypresian stratigraphy of Belgium and Northern France. *Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie* 23 (4): 115-172.

Steurbaut E. & Nolf D. 1989. — The stratotype of the Aalter Sands (Eocene of NW Belgium): stratigraphy and calcareous nannoplankton. *Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie* 26 (1): 11-28.

Steurbaut E. & Sztrákos K. 2008. — Danian/Selandian boundary criteria and North Sea Basin-Tethys correlations based on calcareous nannofossil and foraminiferal trends in SW France. *Marine Micropaleontology* 67 (1-2): 1-29. https://doi.org/10.1016/j.marmicro.2007.08.004

Steurbaut E., King C., Matthijs J., Noiret C., Yans J. & Van Simaeys S. 2015. — The Zemst borehole, first record of the EECO in the North Sea Basin and implications for Belgian Ypresian-Lutetian stratigraphy. *Geologica Belgica* 18 (2-4): 147-159. https://popups.uliege.be/1374-8505/index.php?id=5045

Steurbaut E., De Ceukelaire M., Lanckacker T., Matthijs J., Stassen P., Van Baelen H. & Vandenberghe N. 2016a. — An update of the lithostratigraphy of the Ieper Group (National Commission for Stratigraphy of Belgium: 76 p. https://ncs.naturalsciences.be/paleogene-neogene/update-lithostratigraphy-ieper-group

Steurbaut E., De Coninck, J. & Van Simaeys S. 2016b. — Micropalaeontological dating of the Prémontré mammal fauna MP10, Prémontré Sands, EECO, early late Ypresian, Paris Basin). *Geologica Belgica* 19 (3-4): 273-280. https://doi.org/10.20341/gb.2016.006

Stradner H. 1961. — Vorkommen von Nannofossilien im Mesozoikum und Alttertiär. *Erdöl-Zeitschrift* 77 (3): 77-88.

Stradner H. 1962. — Über neue und wenig bekannte Nannofossilien zum Kreide und Alttertiär. *Verhandlungen der Geologischen Bundesanstalt* 2: 363-377.

Takayama T. 1972. — A note on the distribution of *Braarudosphaera bigelowii* (Gran et Braarud) Deflandre in the bottom sediments of Sendai Bay, Japan. *Transactions and Proceedings of the Paleontological Society of Japan*, N. S., 87: 429-435. https://doi.org/10.14825/prpsj1951.1972.87_429

Tori F. & Monechi S. 2013. — Lutetian calcareous nannofossil events in the Agost section (Spain): Implications toward a revision of the Middle Eocene biomagnetostratigraphy. *Lethaia* 46: 293-307. https://doi.org/10.1111/let.12008

Tracey S., Todd J. A., Le Renard J., King C. & Goodchild M. 1996. — Distribution of Mollusca in units S1 to S9 of the Selsey Formation (middle Lutetian), Selsey Peninsula, West Sussex. *Tertiary Research* 16 (1-4): 97-139.

Troelsen J. C. & Quadros L. P. 1971. — Three species of Braarudosphaeraceae from Brasil. *Boletim Paranaense de Geociências* 28-29: 211-217.

Vandenberghe N., Laga P., Steurbaut E., Hardenbol J. & Vail P. R. 1998. — Tertiary Sequence Stratigraphy at the southern border of the North Sea Basin in Belgium, *in* de Graciansky P.-C., Hardenbol J., Jacquin T. & Vail P. R. (eds), *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. SEPM (Society for Sedimentary Geology) Special Publication 60: 119-154. https://doi.org/10.2110/pec.98.02.0119

Van den Broeck E. 1902. — À propos de l'origine des *Nummulites laevigata* du gravier de base du Laekenien. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie* 16: 580-587. https://www.biodiversitylibrary.org/page/45040556

Van Waterschoot van der Gracht W., Tesch P. & Halet F. 1913. — Coupe géologique des terrains traversés jusqu'à ce jour par le grand sondage de Woensdrecht (Pays-Bas). *Bulletin de la Société belge de Géologie, Paléontologie et d'Hydrologie*, Procès-Verbaux, 27: 124. https://www.biodiversitylibrary.org/page/45184622

Varol O. 1989. — Eocene calcareous Nannofossils from Sile (Northwest Turkey). *Revista Española de of Micropalaeontologia* 21 (2): 273-320.

Varol O. 1992. — *Sullivania* a new genus of Palaeogene coccoliths. *Journal of Micropalaeontology* 11 (2): 141-149. https://doi.org/10.1144/jm.11.2.141

Varol O. 1998. — *Palaeogene, in* Bown P. R. (ed.), *Calcareous Nannofossil Biostratigraphy*. Kluwer Academic Publishers: 200-224 (British Micropalaeontological Society Publications Series; 7).

Verbeek J., Steurbaut E. & Moorkens T. 1988. — Belgium, *in* Vinken R. (ed.), The Northwest European Tertiary Basin, I.G.C.P. Project 124. *Geologisches Jahrbuch A* 100: 267-273.

Vincent E. & Lefèvre T. 1872. — Note sur la faune laekenienne de Laeken, de Jette et de Wemmel. *Annales de la Société royale malacologique de Belgique* 7: 49-79.

Wei W. & Wise S. W. Jr 1989a. — Paleogene Calcareous Nannofossil Magnetobiochronology: results from South Atlantic DSDP Site 516. *Marine Micropaleontology* 14: 119-152. https://doi.org/10.1016/0377-8398(89)90034-0

Wei W. & Wise S. W. Jr 1989b. — *Discoaster praebifax* n. sp.: a possible ancestor of *Discoaster bifax* Bukry (Coccolithophoridae). *Journal of Paleontology* 63 (1): 10-14. https://doi.org/10.1017/S0022336000040890

Wei W. & Wise S. W. Jr 1990. — Biogeographic gradients of middle Eocene-Oligocene calcareous nannoplankton in the South Atlantic Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology* 79: 29-61. https://doi.org/10.1016/0031-0182(90)90104-F

Wesselingh F. P., Janse A. C., Vervoenen M. & van Nieulande F. A. D. 2013. — New records of giant campanilid gastropods (Mollusca) from the southern North Sea Basin: implications for Eocene and Quaternary palaeogeography. *Netherlands Journal of Geosciences (Geologie en Mijnbouw)* 92 (2-3): 159-164. https://doi.org/10.1017/S0016774600000093

Wouters L. & Vandenberghe N. 1994. — *Geologie van de Kempen – Een synthese*. Nationale Instelling voor Radioactief Afval en Verrijkte Splijtstoffen, Brussel, 208 p.

Wrigley A. 1940. — The English Eocene *Campanile*. *Proceedings of the Malacological Society* 24: 97-112. https://doi.org/10.1093/oxfordjournals.mollus.a064397

Young J. R. & Bown P. R. 1997. — Cenozoic calcareous nannoplankton classification. *Journal of Nannoplankton Research* 19 (1): 36-47.

Submitted on 2 October 2018;
accepted on 20 January 2020;
published on 25 May 2021.

Appendix 1. — Alphebetic list of localities and sections mentioned in the present study.

Belgium

Aalter (Aa)	Type-locality of the Aalter Sand Formation including several outcrops and shallow auger boreholes (Steurbaut & Nolf 1989); GPS coordinates: between 51°05'12.28"N, 3°27'15.17"E and 51°05'17.20"N, 3°28'03.56"E (Fig. 13).
Assenede (As)	Borehole drilled at Hollekensdijk on behalf of the Belgian Geological Survey (25E-123) (Steurbaut 1986: 61); GPS coordinates: 51°14'42.47"N, 3°45'46.36"E.
Balegem (Ba)	Outcrop along road N42, type-locality of the Lede Sand Formation (Jacobs & Sevens 1994); GPS coordinates: 50°55'00.06"N, 3°48'46.28"E.
Diegem	Temporary exposure along the Brussels Ring R0 at the Zaventem interchange with A201 (Hooyberghs 1986); GPS coordinates: 50°53'27.09"N, 4°27'14.38"E.
Egem (Eg)	Large quarry along road N50, type-locality of the Egem Sand Member and the Egemkapel Clay Member (Steurbaut 1998); GPS coordinates: between 51°00'40.29"N, 3°13'50.74"E and 51°00'49.93"N, 3°13'40.38"E.
Gent, Blandijnberg	Temporary outcrops seen at different times at the occasion of construction works at the Blandijnberg, 1 km south of Gent city centre (Delvaux 1886; Hacquaert 1936); GPS coordinates: between 51°02'44.92"N, 3°43'27.03"E and 51°02'37.96"N, 3°43'32.81"E.
Gobertange (Go)	Type locality of the 'Calcaires et sables de Gobertange' (Damblon & Steurbaut 2000); GPS coordinates: 50°43'59.53"N, 4°50'37.24"E (Fig. 13).
Hijfte (Hi)	Borehole drilled at Hijfte (community of Lochristi) on behalf of the Belgian Geological Survey (40E-373); GPS coordinates: 51°06'43.94"N, 3°48'48.58"E (Fig. 13).
Isnes	Small quarry 1 km north of the village centre, now flooded (Hooyberghs 1986); GPS coordinates: 50°30'59.11"N, 4°44'32.52"E.
Kallo (Ka)	Borehole drilled in 1969 at 'Fort la Perle' on behalf of the Geological Survey of Belgium (27E-148) (Steurbaut 1991); GPS coordinates: 51°16'14.25"N, 4°17'38.22"E.
Kester	Borehole drilled in 1988 at Kesterheide on behalf of the Geological Survey of Belgium (101W-79) (Steurbaut in prep.); GPS coordinates: 50°46'31.07"N, 4°06'17.77"E.
Knokke (Kn)	Borehole drilled in 1980 at Hazegraspolder, 4.2 km east of the Knokke village centre, on behalf of the Geological Survey of Belgium (11E-138) (Laga & Vandenberghe 1990); GPS coordinates: 51°20'33.75"N, 3°20'47.26"E.
Leuven (Le)	Borehole drilled in 1991 at the Stella Artois Factory on behalf of the Geological Survey of Belgium (89E-401); GPS coordinates: 50°53'24.36"N, 4°42'33.69"E (Fig. 13).
Merksplas	Borehole drilled in 1987 at the hamlet of Meergoor, municipality of Beerse, 3 km SW of Merksplas village centre on behalf of the Geological Survey of Belgium (17W-280) (Steurbaut *et al.* 2016a, p. 66); GPS coordinates: 51°20'25.74"N, 4°49'42.10"E.
Mol (Mo)	Borehole drilled in 1975 at ca 5 km northwest of the Mol village centre on behalf of the Geological Survey of Belgium (31W-237); GPS coordinates: 51°12'46.59"N, 5°03'41.33"E (Fig. 13).
Mont-Panisel	Borehole drilled close to the top of the Mont-Panisel Hill near Mons on behalf of the Belgian Geological Survey (151E-340) (Steurbaut & King 1994); GPS coordinates: 50°26'17.87"N, 3°58'44.63"E.
Mont Saint-Aubert	Two boreholes drilled at 1 m from each other, about 0.4 km east of the church at the top of the Mont Saint-Aubert Hill and 6 km north of Tournai, as support for the making of the geological maps of Wallonie; GPS coordinates: 50°39'18.70"N, 3°24'17.51"E.
Nederokkerzeel	The Imbrechts sand pit was sampled by Hooyberghs in 1978 (in Gerits *et al.* 1981) and by Herman in 2000 (in Herman *et al.* 2001); GPS coordinates: 50°55'15.83"N, 4°32'48.23"E.
Neerijse	Quarry in the Ganzemansstraat, 1 km west of the village centre (Hooyberghs 1992); GPS coordinates: 50°49'05.09"N, 4°36'41.35"E.
Oedelem (Oe)	Borehole drilled along the Egyptestraat on behalf of the Belgian Geological Survey (23E-88) (Steurbaut 2011); GPS coordinates: 51°11'11.63"N, 3°19'48.35"E (Fig. 12).
Oosterzele	Outcrop of the base of the Lede Sand Formation at the hamlet of Scheurbroek along road N42 (Smith *et al.* 2004); GPS coordinates: 50°55'03.77"N, 3°49'09.45"E.

APPENDIX 2. — Continuation.

Rodeberg Borehole drilled in 1968 at the Leistermolen on the Rodeberg hill, 1.6 km south of the Westouter village centre, on behalf of the Geological Survey of Belgium (95W-150); GPS coordinates: 50°47'02.38"N, 2°45'24.29"E.

Rotselaar (Ro) Borehole drilled in 1980 close to the hamlet of Wakkerzeel about 1.9 km west of the Rotselaar village centre, on behalf of the 'Nationalaaatschappij der Waterlopen' (74E-122); GPS coordinates: 50°57'15.55"N, 4°41'06.27"E (Fig. 13).

SEWB Offshore borehole drilled 2 km north of Blankenberge on behalf of the Belgian Geological Survey (10E/0082) (Steurbaut 2011); GPS coordinates: 51°19'50.40"N, 03°07'34.10"E (Fig. 12).

Sint-Stevens-Woluwe Large sandpit just north of the 'Cliniques Uni--versitaires Saint-Luc' at the most southeast point of the village (Hooyberghs 1992); GPS coordinates: 50°51'15.09"N, 4°27'12.30"E.

Vilvoorde Borehole drilled in 2017 in the Gustaaf Levistraat 45, 1.25 km east of the village centre, on behalf of the 'Databank Ondergrond Vlaanderen (DOV)' (1439-BB17-0115); GPS coordinates: 50°55'28.95"N, 4°26'32.42"E.

Vlakte van de Raan (Ra) Offshore borehole drilled in 1988 about 17.5 km north of the Port of Zeebrugge on behalf of the Geological Survey of Belgium (999A/0015) (Steurbaut 2011: 254); GPS coordinates: 51°29'08"N, 03°09'50"E (Fig. 12).

Vossem 10 m deep sandpit, about 0.6 km east of the village centre (Nolf 1974: 41); GPS coordinates: 50°50'01.96"N, 4°34'08.96"E.

Wetteren Outcrop along the north side of Motorway E40, close to the exit Wetteren, accessible during the construction works for a new pedestrian/bicycle bridge over the E40; GPS coordinates: 50°58'36.83"N, 3°49'48.37"E.

Zaventem Cutting for the railway connection to the airport, dug out in the mid-1990s (Herman *et al.* 2001); GPS coordinates: *c.* 50°50'01.96"N, 4°34'08.96"E.

Zeebrugge Borehole Zeebrugge 19.6, located on the municipality of Heist-aan-Zee, is one of many boreholes drilled for the geotechnical mapping of the port area of Zeebrugge in the late 1970s (Depret & Willems 1983); GPS coordinates: 51°19'35.69"N, 3°14'01.09"E.

Zemst (Ze) Borehole drilled in 2001 on behalf of the Belgian Geological Survey (73E-359) (Steurbaut *et al.* 2015); GPS coordinates: 50°59'54.52"N, 4°26'46.50"E.

FRANCE

Cassel Hill Borehole drilled in 1966 at the 'Place Général Plumer" (later on renamed Place D.-J. Vandamme, after one of Napoleon's generals) in the Cassel city centre on top of the highest and the most western member of the Flemish Hills, northern France (see Fig. 1) (Blondeau *et al.* 1972); GPS coordinates: *c.* 50°48'09.18"N, 2°28'57.24"E (Fig. 12).

Chaumont-en-Vexin Large quarry at the intersection of road RD153 Cergy-Paris and road RD566 Liancourt-Saint-Pierre, also known as the Darcy site, exposing the 'Cuisian'-Lutetian transition (Ott d'Estevou *et al.* 2014); section sampled in 2015-2016 by X. Devleeschouwer & V. Scaut (Université Libre de Bruxelles); GPS coordinates: *c.* 49°15'33.59"N, 1°52'44.20"E.

Fleury-la-Rivière Subsurface gallerie in the east of the Paris Basin (20 km southwest of Reims), exposing the "Tuffeau de Damery" of Lutetian age (Courville 2012); GPS coordinates: 49°06'02.14"N, 3°52'54.40"E.

Gisors Outcrop at the hamlet of Boisgeloup, 3 km south of Gisors and about 28 km southwest of Beauvais, exposing the Ypresian-Lutetian transition in the Paris Basin (Steurbaut 1988); GPS coordinates: 49°15'20.10"N, 1°47'11.91"E.

Le Grand Aléré Small sand quarries 1 km southeast of the "Le Grand Alléré" village centre, exposing the Ypresian-Lutetian transition in the Paris Basin, probably all filled in now (Aubry, 1983: 216); GPS coordinates: *c.* 49°12'32.54"N, 2°01'42.49"E.

Margival Outcrop exposing the Ypresian-Lutetian transition in the Paris Basin, about 8.5 km northeast of Soissons (Bignot *et al.* 1980); GPS coordinates: 49°25'51.47"N, 3°24'02.89"E.

Prémontré Temporary exposure of the Ypresian-Lutetian transition in the Paris Basin, accessible during construction works on the Psychiatic Hospital of Prémontré, 20 km northeast of Soissons (Dégremont *et al.* 1985, Steurbaut *et al.* 2016b); GPS coordinates: *c.* 49°32'48.99"N, 3°24'21.43"E.

Appendix 2. — Continuation.

Saint-Géours d'Auribat — Large quarry in the Aquitaine Basin, 18 km east of Dax, exposing large parts of the Donzacq Marl of Lutetian age (Lin *et al.* 2017); GPS coordinates: 43°45'09.36"N, 0°50'24.2"W.

Saint-Vaast-lès-Mello — Stratotype of the historical Lutetian Stage in the Paris Basin, 29 km southeast of Beauvais (Blondeau & Renard 1980, p. B-15/3; Blondeau 1981: 171); GPS coordinates: 49°16'25.36"N, 2°24'15.37"E.

Other European Locations

Agost — Large outcrop along hill slope, 1 km north of the village of Agost, about 17 km west of Alicante, exposing the the Ypresian-Lutetian transition in the Betic Cordillera (Larrasoaña *et al.* 2008; Tori & Monechi 2013); GPS coordinates: *c.* 38°27'18.44"N, 0°38'42.92"W.

Bottacione — Road section along the SR 298 about 1 km north of Gubbio in the Province of Umbria, exposing the Ypresian-Lutetian transition (Monechi & Thierstein 1985; Galeotti *et al.* 2017); GPS coordinates: 43°21'50.72"N, 12°34'59.93"E.

Gorrondatxe — GSSP for the base of the Lutetian Stage, coastal section about 14.5 km north of Bilbao city centre, northern Spain (Molina *et al.* 2011); GPS coordinates: 43°22'46.95"N, 3°00'52.22"W.

Rotterdam — Borehole E-55 drilled in 1955 by the Nederlandse Aardolie Maatschappij (N.A.M.) in the centre of the city of Rotterdam (southwest Netherlands) (details in Janssen 2010); GPS coordinates: *c.* 51°54'29"N, 4°28'20"E.

Smirra — Small abandoned quarry near the village of Smirra in the Marche region, 5 km north of the town of Cagli and 16 km south of Urbino, exposing the Ypresian-Lutetian transition (Franceschi *et al.* 2015); GPS coordinates: 43°35'09.40"N, 12°40'37.30"E.

Whitecliff Bay — Coastal section 0.8 km southeast of the hamlet of Hillway on the east coast of the Isle of Wight, southern England, exposing the Ypresian-Lutetian transition (Eaton 1976; King 2016: 391); GPS coordinates: between 50°40'06.95"N, 1°05'49.62"W and 50°40'26.57"N, 1°05'18.86"W.

Woensdrecht — Borehole n° 17 of the "Rijks Opsporing voor delfstoffen" of the Netherlands drilled in 1912 in southern Brabant (southern Netherlands), approximately 1.3 km northwest of Woensdrecht village centre, 25 km north of Antwerp city centre (Halet 1913; van Waterschoot van der Gracht *et al.* 1913; Kaasschieter 1961: 109); GPS coordinates: *c.* 51°26'19.84"N, 4°17'35.50"E (Fig. 13).

West Asia

Aktulagay — Outcrop section in west Kazakhstan, about 35 km north of the Embi River, key site for northern mid-latitude Early Eocene stratigraphy (King *et al.* 2013); GPS coordinates: 47°32'32.32"N, 55°09'13.70"E.