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New insights on the Late Paleocene – Early Eocene dinoflagellate cyst zonation for the Paris and Dieppe basins

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Abstract – The Anglo-Belgo-Paris Basin, historical cradle of the Paleogene stratigraphy since the 19th century, is known by the presence of very specific so-called "Sparnacian" deposits (very diverse and laterally highly variable, predominantly lagoonal to terrestrial facies), which encompass the short stratigraphic interval of the Paleocene-Eocene Thermal Maximum (PETM). Due to the insufficient nature of the paleontological record, the "Sparnacian" succession of the Paris and Dieppe-Hampshire basins still needs to be robustly chronostratigraphically correlated with other Paleogene records worldwide. In order to refine the stratigraphy of the Thanetian-Lower Ypresian succession in northern France a number of cores and outcrop sections have been investigated palynologically. As a result, an updated version of the dinoflagellate cyst zonation for the Paris and Dieppe basins is proposed and contains six new or revised biozones for this stratigraphical interval: *Alisocysta margarita*, *Apectodinium hyperacanthum*, *Apectodinium*-acme, *Biconidinium longissimum*-acme, *Dracodinium astra*, and *Axiodinium lunare*/*Stenodinium meckelfeldense*. Based on combined bio-, litho- and chemostratigraphic data, it appears that the dinocyst assemblages, corresponding to the PETM event interval ("Sparnacian" deposits, Soissonnais and upper Mortemer formations), are characterized by an acme of *Apectodinium* spp. (70–98%) in both basins, sometimes alternating with an acme of a few gonyaulacoid groups in the Dieppe Basin. Dinocyst assemblages from the PETM interval contain a significant number of atypical, longer specimens of *Apectodinium parvum*, which could represent an ecological onshore substitute for *Axiodinium augustum* in the Paris and Dieppe-Hampshire basins. The establishment of a new *Biconidinium longissimum*-acme Zone suggests that the stratigraphic hiatus previously inferred within this sequence in the Paris Basin does not exist.

Keywords: dinoflagellate cysts / Late Paleocene / Early Eocene / "Sparnacian" / zonation / Paris and Dieppe-Hampshire basins

Résumé – Nouveau regard sur la zonation de kystes de Dinoflagellés du Paléocène supérieur – Éocène basal des bassins de Paris et Dieppe. Le Bassin anglo-belgo-parisien, berceau historique de la stratigraphie du Paléogène depuis le XIX^{e} siècle, est connu pour la présence de dépôts très spécifiques, nommés sparnaciens (faciès très divers, majoritairement continentaux et lagunaires, avec de nombreuses variations latérales), qui contiennent le court intervalle stratigraphique du Maximum Thermique de la limite Paléocène-Éocène (*Paleocene-Eocene Thermal Maximum* ou PETM en anglais). En raison de l'enregistrement paléontologique insuffisant, la succession sparnacienne des bassins de Paris et de Dieppe-Hampshire nécessite toujours une corrélation robuste avec les autres enregistrements mondiaux. Afin d'affiner la stratigraphie de la succession du Thanétien-Yprésien inférieur du Nord de la France, une série de forages et d'affleurements a été étudiée sur le plan de la palynologie. Il en résulte une version mise à jour de la zonation des kystes de Dinoflagellés pour les bassins de Paris et de Dieppe, qui contient six biozones nouvelles ou révisées pour cet intervalle stratigraphique : *Alisocysta margarita*, *Apectodinium hyperacanthum*, *Apectodinium*-acme, *Biconidinium longissimum*-acme, *Dracodinium astra*, et *Axiodinium lunare*/*Stenodinium meckelfeldense*. Fondée sur l'intégration de

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données bio-, litho- et chemostratigraphiques, il y apparaît que les assemblages de dinokystes correspondant à l'intervalle du PETM (dépôts sparnaciens de la Formation du Soissonnais et du sommet de la Formation de Mortemer), sont caractérisés par un acmé d'*Apectodinium* spp. (70–98 %) dans les deux bassins, alternant parfois avec un acmé de quelques groupes de gonyaulacoïdes dans le bassin de Dieppe. Les assemblages de dinokystes de l'intervalle du PETM contiennent un nombre significatif de spécimens atypiques, plus longs, d'*Apectodinium parvum*, qui pourraient représenter un substitut écologique côtier de l'espèce *Axiodinium augustum* dans les bassins de Paris et de Dieppe-Hampshire. L'établissement de la nouvelle zone d'acmé à *Biconidinium longissimum* suggère l'absence d'un important hiatus stratigraphique auparavant interprété pour le bassin de Paris.

Mots clés : kystes de Dinoflagellés / Paléocène supérieur / Éocène inférieur / "Sparnacian" / Bassin parisien / Bassin de Dieppe-Hampshire

1 Introduction

The Paris Basin is where the Paleocene Epoch and the "Sparnacian Stage" were originally defined and introduced in the 19th century (Dollfus, 1880; Schimper, 1874). Until the end of the 20th century, the Upper Paleocene-Lower Eocene succession considered here included three different lithologies, easily distinguishable. Marine glauconiferous sandy units, broadly referred to the Paleocene "Sables de Bracheux" and the Eocene "Sables de Cuise", bracket a poorly understood lithologic body composed by terrestrial and brackish clays, limestones, sands and lignites (mostly containing organic matter) and widely referred to as "Argiles à Lignites" (Aubry *et al.*, 2005, p. 65). This lithologic complex of littoral to terrestrial deposits with particular facies and faunas, sandwiched between marine Thanetian and "Cuisian" sands, was considered in the 19th century sufficiently distinctive as to erect a new, Sparnacian stage by Dollfus (1880). As was highlighted by Aubry *et al.* (2005, p. 65), whereas the chronostratigraphic connotation of the "Sparnacian Stage" has been controversial since its initial definition, modern studies of the Late Paleocene-Early Eocene interval have revealed that the so-called Sparnacian deposits encompass a remarkable and short (~200 kyr; Dickens, 2000) episode in Cenozoic history, the Paleocene-Eocene Thermal Maximum (PETM). Nevertheless, the "Sparnacian" deposits, diachronous across the Paris and Dieppe basins and represented by diverse and laterally highly variable, predominantly lagoonal and non-marine facies, are still insufficiently documented and chronostratigraphic correlation with other Paleogene records worldwide needs to be updated.

Based on extensive fieldwork and integration of litho- and biostratigraphy in the Paris and Dieppe basins (Aubry *et al.*, 2005), M.-P. Aubry, M. Thiry, Ch. Dupuis and W. Berggren introduced a formal lithostratigraphic framework for the Paleocene-Lower Eocene succession in northern France. Since 2005, the Paleocene-Lower Eocene succession in the Paris and Dieppe (French part of the Dieppe-Hampshire) basins has comprised four distinct groups of lithostratigraphic units (from bottom to top, Fig. 1):

- the Vigny Group – the Lower Paleocene marine limestones ("Calcaire de Vigny", "Calcaire de Meudon", etc.) and terrestrial marls ("Marnes de Meudon") in the Paris Basin, unconformably overlying the Campanian Chalk;
- the Vesles Group – marine glauconitic sandy units of Thanetian age (Moulin Compensé, Châlons-sur-Vesles and Bracheux formations), expanded from Dieppe to Paris and Reims;
- the Mont Bernon Group (Mortemer, Vaugirard, Soissonnais and Epernay formations), broadly extended across the Paris and Dieppe basins, was introduced by Aubry *et al.* (2005) to formalize the so-called "Sparnacian" clays and lignite-bearing clays with intercalated lacustrine limestone and marls, littoral sands and brackish clays including coquinas. These sediments are diachronous across the Paris Basin and embrace the P/E boundary and Early Eocene;
- the Montagne de Laon Group (marine calcareous sandy Mont-Notre-Dame, Cuise and Laon formations) of younger Ypresian age.

As was underlined by Aubry *et al.* (2005, p. 88), correlations within the Mont Bernon Group are problematic even within distances of a few tens of kilometers as a consequence (1) of abrupt lateral and vertical facies variations and especially (2) because these abrupt changes in facies result in an irregular distribution of biostratigraphic markers. Thus, calcareous nannoplankton is virtually absent in the Mont Bernon Group sediments; it is known only from the underlying Thanetian deposits (NP8–9 zones interval) and from the overlying Varengeville Fm (NP11 Zone). Consequently, the "Sparnacian" sediments are only provisionally attributed to the upper NP9–lower NP10 zones interval.

For over 50 years, since the two important papers of Châteauneuf and Gruas-Cavagnetto (1978) and Costa *et al.* (1978) appeared, dinoflagellate cyst stratigraphy has played an important part in clarifying the correlations between the Upper Paleocene-Lower Eocene succession in northern France and the other parts of the former North Sea Basin. However, until now the dinocyst data from the Paris and Dieppe basins have been sparse, mostly focused on paleoenvironmental reconstructions and only a limited amount of data is useful for robust stratigraphic interpretations. As a result, Aubry *et al.* (2005, p. 88) concluded that the Mont Bernon Group ("Sparnacian" deposits) cannot be described in terms of biozonal succession, and biozonal boundaries have not been delineated in any of its formations due to the sporadic distribution of fossil groups in highly variable lithologies, reflecting deposition in unstable marginal environments.

Focusing on producing a new high-resolution study of the Mont Bernon Group and its relationship with the PETM and its associated carbon isotope excursion (CIE), a number of old and new Paleocene-Lower Eocene BRGM boreholes and key-outcrops have been investigated palynologically and

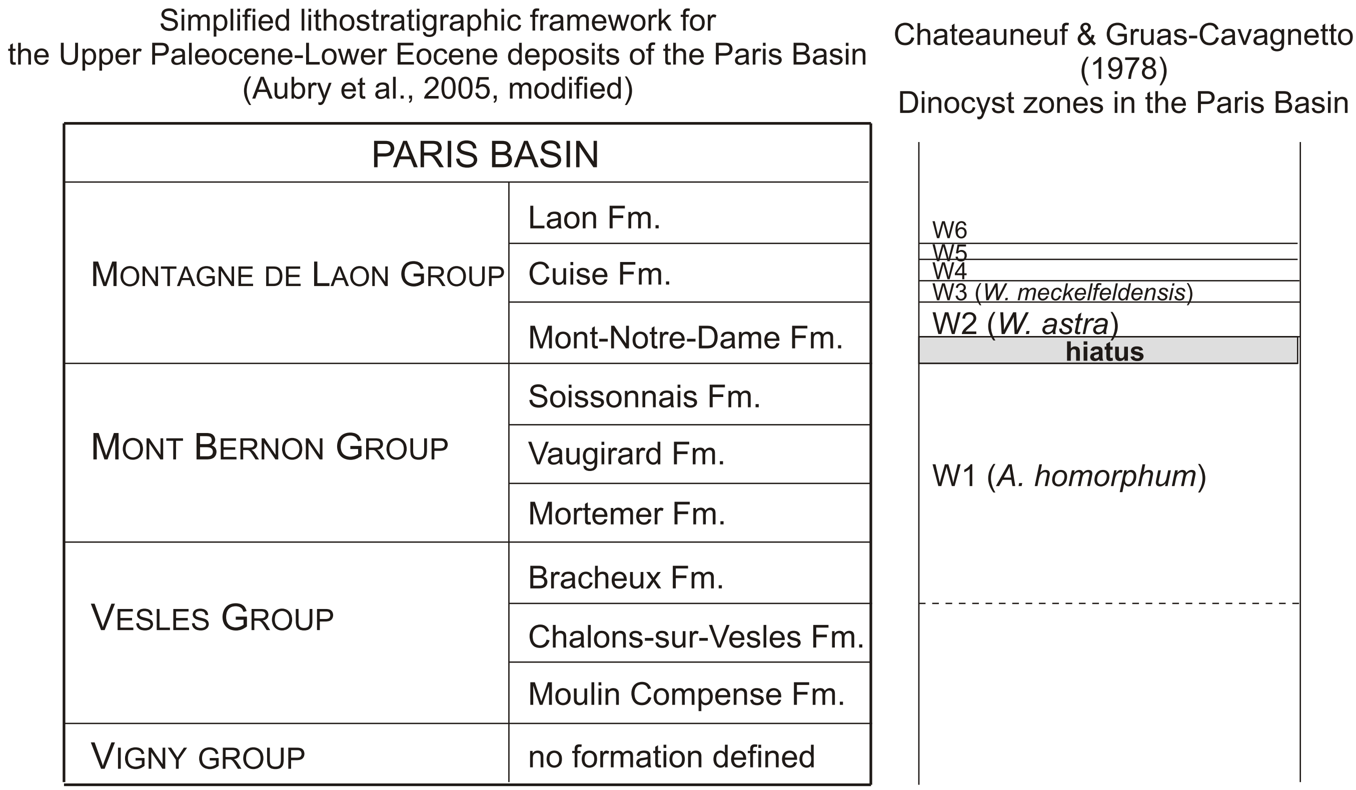

Fig. 1. Simplified lithostratigraphic framework for the Upper Paleocene-Lower Eocene deposits of the Paris Basin (modified from Aubry *et al.*, 2005), combined with the previous Paris Basin dinoflagellate cyst zonation of Châteauneuf and Gruas-Cavagnetto (1978).

chemostratigraphically over the last 13 years as a part of the BRGM PaleoScene and "Paléosurface éocène-PETM" research projects (included in the "Référentiel géologique de la France" (RGF) Program), resulting in a significant amount of new dinocyst records. The purpose of the present paper is to refine the high-resolution stratigraphic framework for the Upper Paleocene-Lower Eocene succession in the Paris and Dieppe basins by introducing an updated dinoflagellate cyst zonation, based on our new palynological data.

2 Previous studies

In the last century dinoflagellate cysts have been studied from the Paleogene sediments in northern France by J.J. Châteauneuf and C. Gruas-Cavagnetto (Bignot *et al.*, 1981; Châteauneuf, 1968, 1971, 1976, 1980; Châteauneuf and Fauconnier, 1977; Châteauneuf and Gruas-Cavagnetto, 1968, 1978; Châteauneuf and Trauth, 1972; Gruas-Cavagnetto, 1968, 1970, 1974, 1976a, 1976b, 1976c, 1978; Gruas and Bignot, 1985; Gruas-Cavagnetto *et al.*, 1980) and recorded from the most part of the lagoonal and marine Paleogene formations from the Sables de Bracheux up to the Sables de Fontainebleau. According to Châteauneuf and Gruas-Cavagnetto (1978), the Paleogene of the Paris Basin can be divided into 14 dinoflagellate zones (W1–W14, Late Paleocene-Early Oligocene) based on the subfamily Wetzelielloideae (Fig. 2). Together with the similar zonations of Costa and Downie (1976) for the Late Paleocene-Early Oligocene of southern North Sea Basin and of Caro (1973) for the Paleocene-Early Eocene of Spanish Pyrenees, the Paris Basin dinoflagellate zonation represented the first important step in the development of the Paleogene dinoflagellate cyst biostratigraphy.

Dinoflagellate studies from the so-called "Sparnacian" sediments in the Paris and Dieppe basins started in the 1960s. As a result, a number of key-outcrops and cores have been investigated with quite different sampling spacing: Guitrancourt Quarry, Le Meux and Vieux Moulin localities (Gruas-Cavagnetto, 1968); Sinceny core (Gruas-Cavagnetto, 1968); Montjavoult, Le Tillet and Ludes cores (Châteauneuf and Gruas-Cavagnetto, 1968); Les Hogues core (Châteauneuf, 1971); Mont Chenot outcrops (Gruas-Cavagnetto, 1974); Cuise-la-Motte and La Defense cores (Gruas-Cavagnetto, 1976a, 1976b); Châlons-sur-Vesles outcrops (Gruas-Cavagnetto, 1976c); Montagne de Reims outcrops (Gruas-Cavagnetto *et al.*, 1980); Soissons outcrops (Bignot *et al.*, 1981); Saint-Valery-sur-Somme outcrops and core (Dupuis *et al.*, 1982); Sotteville-sur-Mer cliff section (Gruas and Bignot, 1985); and the Cap d'Ailly cliff section (Dupuis *et al.*, 1998a, 1998b).

According to Schuler *et al.* (1992), the lowermost association, recognized in the Paris Basin within the Tuffeau de la Fère and Sables de Bracheux, was not defined as a zone and only presumably attributed to the European D4 Zone, and contained species *Alisocysta circumtabulata*, *Deflandrea oebisfeldensis* and *Hafniasphaera septata*. In the Thanetian-Early Ypresian interval of the Paris Basin Châteauneuf and Gruas-Cavagnetto (1978) have established three main dinoflagellate zones (Fig. 1):

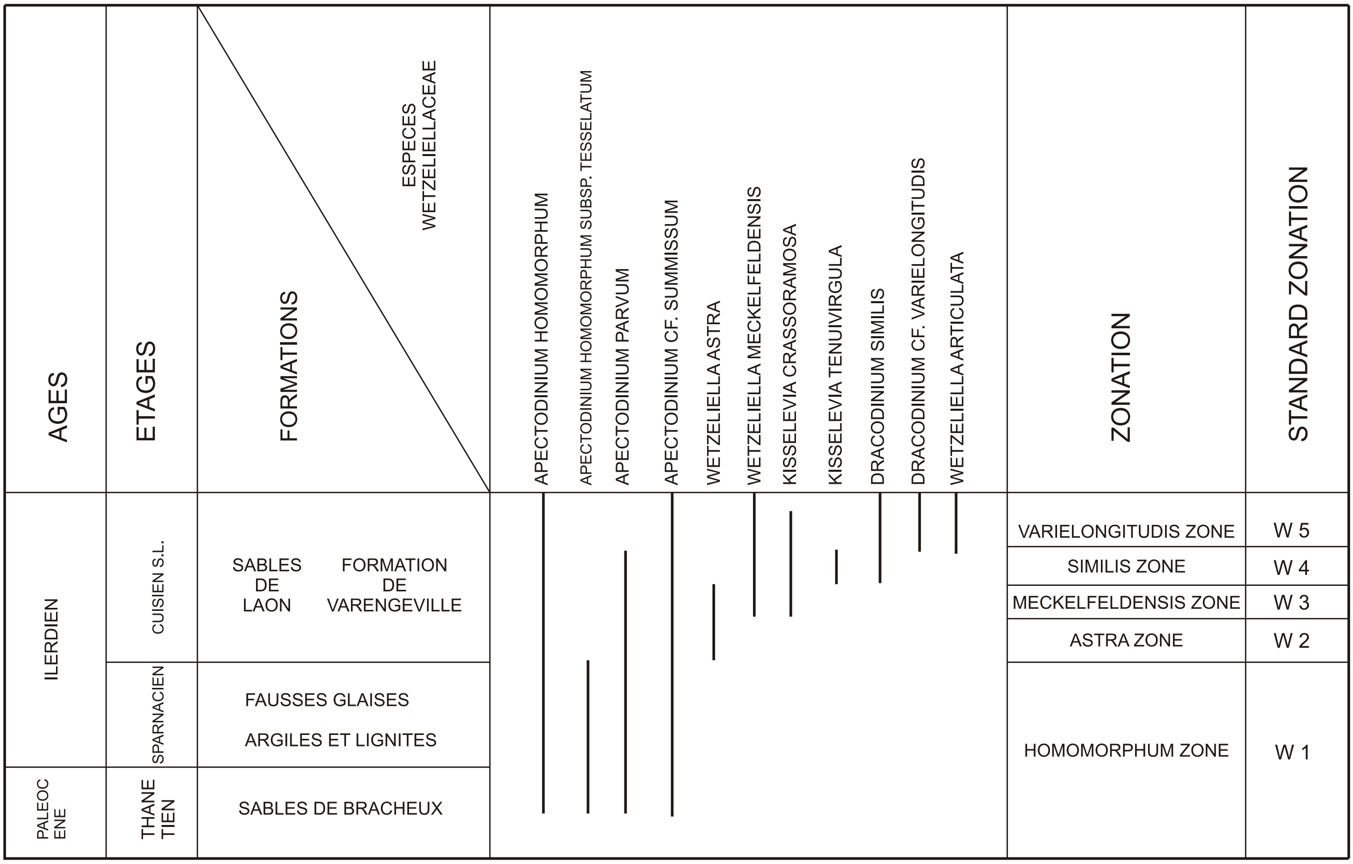

Fig. 2. Paleocene-Early Eocene part of the previous dinoflagellate cyst zonation for the Paris Basin as published originally by Châteauneuf and Gruas-Cavagnetto (1978).

- W1 (*Apectodinium homomorphum*) Zone from the lowermost (LO) occurrence of *Apectodinium* spp. to the LO of *Wetzeliella astra*;
- W2 (*Wetzeliella astra*) Zone from the LO of *W. astra* to the LO of *Wetzeliella meckelfeldensis*;
- W3 (*Wetzeliella meckelfeldensis*) Zone from the LO of *W. meckelfeldensis* to the LO of *Dracodinium simile*.

Based on the study of the key-sections, Châteauneuf and Gruas-Cavagnetto (1978) then concluded that the bulk of the "Sparnacian" deposits, including the Sables de Sinceny, Argiles à Lignites du Soissonnais and Fausses Glaises du Vexin (=Soissonnais Fm) correspond to the W1 Zone, while the Fausses Glaises de Paris (=Epernay Fm) and Sables d'Auteuil belong to the W3 Zone. Furthermore, Châteauneuf and Gruas-Cavagnetto (1978) noted that the Soissonnais Formation revealed dinocyst assemblages extremely rich in *Apectodinium* spp. (up to 80–90%).

It can be noted that, while dinoflagellate *Wetzeliella astra* (W2) and *Wetzeliella meckelfeldensis* (W3) zones are still used as references and are present in different dinoflagellate zonations for the North Sea Basin, eastern Peri-Tethys and Western Siberia, the *Apectodinium homomorphum* Zone in terms of Costa and Downie (1976) and Châteauneuf and Gruas-Cavagnetto (1978) is now subdivided into three successive zones (Iakovleva, 2017; Iakovleva and Aleksandrova, 2013; Köthe, 2012; Mudge and Bujak, 1996; Powell, 1992): *Apectodinium hyperacanthum*, *Apectodinium* (=*Axiodinium*) *augustum* and *Glaphyrocysta ordinata*/*Deflandrea oebisfeldensis*. The *A. augustum* Zone, established between the lowermost and highest occurrences of the nominative taxon, is characterized by the oldest acme of *Apectodinium* spp., occurring ~at the Paleocene-Eocene boundary defined by the CIE. As was rightly noted by Aubry *et al.* (2005, p.89), it is problematic to delineate the *A. augustum* Zone in the Paris Basin because the nominative species has not been recorded here. The similar virtual absence of *Apectodinium augustum* in the adjacent London Basin was explained by its restriction to more offshore marine conditions (Powell *et al.*, 1996). As a result, Powell *et al.* (1996) proposed to use the beginning of the *Apectodinium*-acme (>35% of dinocyst assemblage) to recognize the base of the *A. augustum* Zone. However, in 2005, Aubry *et al.* noticed (p. 89) that (1) the *Apectodinium*-acme was not unique to the Paleocene-Eocene boundary, (2) dinocyst counts were not available for all localities in the Paris Basin where *Apectodinium* species were recorded, (3) dinocyst assemblages were often rare and of low diversity in the shallow marine deposits of the Mont Bernon Group.

With regard to younger lowermost Eocene sediments, Aubry *et al.* (2005) concluded that there may be an indication of a stratigraphic gap in northern France based on the similarity of the Paris and London basins, the absence of *Leiosphaeridia*-acme or *Deflandrea oebisfeldensis*-abundance in the dinocyst-bearing deposits of the Paris Basin, which are known from the

Harwich Formation in the North Sea and southern England and characterize the *Glaphyrocysta ordinata* Zone (Mudge and Bujak, 1996; Powell *et al.*, 1996).

3 Material and methods

Our updated version of dinoflagellate cyst zonation of the Late Paleocene-Early Eocene interval for northern France is based on the study of ~600 palynological samples, investigated during the last 13 years under the scope of the BRGM PaleoScene and "Paléosurface éocène-PETM" research projects from more than 35 new or already well-known Paleocene-Lower Eocene key localities and boreholes (Fig. 3). More precisely they are (i) the cores Siège-Madame and Phare d'Ailly and outcrops Cap d'Ailly, Blanc Pâtis, Vasterival, Sotteville-sur-Mer and Criel on the Normandy coast (Dieppe Basin); (ii) the cores Therdonne, Le Tillet, Sinceny, Noyon, Cuise-la-Motte, Try, Venteuil, Montmacq, Porquericourt and outcrops Lihons, Clairoix, Rivecourt, Holnon, Laon, and Brimont for the Paris Basin; (iii) and the core Bois-de-Ville and outcrops Wizernes, Flines-lez-Râches and Boiry-Notre-Dame for the Belgian Basin, and the cores Avesnois-007 (Locquignol), Avesnois-031 (Viesly), and Vertain for the transitional zone between the Paris and Belgian basins. Additionally, for interregional correlation purposes, we use our unpublished dinocyst data from the BGS (British Geological Survey) cores from the London and Hampshire basins: the London Jubilee Line 404T, Shamblehurst Lane, Shotley Gate and Stanford-Le-Hope; and, finally from the BGS 81/46A core drilled in the British sector of the North Sea Basin. See the List of locations of the principal studied sections in Supplementary Material. Our study is also the first attempt to make a first-order calibration between dinocyst and isotopic data from the Late Paleocene-Early Eocene interval in the shallow marine to lagoonal settings of the Paris and Dieppe basins.

In the scope of our research, dinoflagellate cysts have been investigated from the following lithostratigraphic units (from base to top):

- the Vesles Group: (a) the Châlons-sur-Vesles Fm (6 m thick) – white and yellow, fine, glauconitic sand with abundant molluscan shells; it comprises the "Sables de Dieppe", "Sables de Châlons-sur-Vesles", "Sables de Montjavoult", "Sables du Tillet" and corresponds to nannoplankton NP8 Zone (Aubry, 1983, 1986; Dupuis and Steurbaut, 1987; Steurbaut, 1998); (b) the Bracheux Fm (4.5–30 m) – coarse, glauconitic, calcareous sand; it includes the "Sables de Bracheux" and "Sables de Criel" and corresponds to nannoplankton NP9a Subzone (Aubry, 1983, 1986; Aubry *et al.*, 2005; Bignot *et al.*, 1994; Dupuis and Steurbaut, 1987; Steurbaut, 1998);
- the Mont Bernon Group: (a) the Mortemer Fm (~3–15 m), which consists of mainly terrestrial limestones and marls ("Calcaire d'Ailly", "Marnes à Rognons", etc. members), rich in ostracods and charophytes (part of the *Peckichara disermas* Zone, Riveline, 1986); (b) the Vaugirard Fm is composed of clays ("Argiles Plastiques" in Cuvier and Brongniart, 1811), and includes the Limay, Provins, Meudon and other members, it corresponds to the charophyte *Peckichara disermas* Zone; (c) the Soissonnais Fm (~8–12 m) is quite diverse lithologically and includes dark clays, silts, sands, shelly laminae or beds and lignite beds ("Argiles du Soissonnais à Lignites" of Brongniart, 1829) deposited in lacustrine, swamp and shallow-marine conditions. Regionally the Soissonnais Fm is divided in a number of members, including the "Sables et Argiles à Ostracodes et Mollusques" (SAOM) in Bignot (1965) and Craquelins members in the Dieppe Basin, and the Vauxbuin, Vexin and others in the Paris Basin; (d) the Epernay Fm (exposed only in the eastern part of the Paris Basin, up to 20 m thick) includes clays, sands and lignites;
- the Montagne de Laon Group deposits (mostly calcareous and glauconitic sands) are widely exposed in the Paris Basin and are divided successively into the Mont-Notre-Dame (Sinceny, "Sables de Laon", "Sables d'Aizy" members), Cuise and Laon Fms. The Varengeville Formation in the Dieppe Basin is preliminary related to the Montagne de Laon Group, while it clearly differs lithologically and is mostly composed of clays (Aubry *et al.*, 2005). The upper Varengeville Fm ("Argiles et Sablons" Member) and "Sables d'Aizy" Member are attributed to the nannoplankton NP11 Zone, while the "Sables de Cuise" Member questionably corresponds to the lower NP12 Zone (Aubry, 1983, 1986). The Montagne de Laon Group is overlain by the "Glauconie Grossière" of Lutetian age (Aubry *et al.*, 2005).

According to recently obtained high-resolution geochemical data (Garel, 2013; Iakovleva *et al.*, 2014a, 2014b; Quesnel *et al.*, 2009, 2011, 2014; Smith *et al.*, 2011, 2014; Storme 2013; Storme *et al.*, 2012), it appears that the onset of the CIE corresponding to the PETM, is clearly delineated within the Mortemer Fm, which was deposited in mostly terrestrial environments (marsh, pond, lake, fluvial channels, flood plain etc.). The CIE continues until the top of the littoral-lagoonal Soissonnais Fm (Muirancourt and Vauxbuin members in the Paris Basin and the SAOM and Craquelins members in the Dieppe Basin). Within the CIE-event interval the $\delta^{13}C_{or}$ values vary between −25 and −32‰ PDB (Pee Dee Belemnite) with the most negative $\delta^{13}C_{or}$ values between −27 and −32‰ depending on the localities and depositional environments, while the $\delta^{13}C_{or}$ values below and above the CIE extend from −22 to 24‰. The lowermost unit (postdating the PETM) of the Mont Notre Dame Fm (Sinceny Member) in the Paris Basin is characterized by very homogeneous $\delta^{13}C_{org}$ values between −24 and −25‰ PDB (Quesnel *et al.*, 2011).

In the present work we use the terms LO (lowermost occurrence), HO (highest occurrence) and acme to designate significant dinocyst "events" (datums). Dinoflagellate cyst taxonomy follows Williams *et al.* (2017). Recently, for the subfamily Wetzelielloideae, a new systematics, introducing a number of new genera, was proposed by Williams *et al.* (2015). Because the species of Wetzelielloideae were the nominative taxa in the first Paris Basin dinoflagellate zonation of Châteauneuf and Gruas-Cavagnetto (1978), we mention below the old generic names in parentheses to simplify the understanding of the emendated species names.

The chronostratigraphic age is according to Ogg *et al.* (2016).

Palynomorphs were concentrated using standard palynological techniques of the British Geological Survey (Riding and Kyffin-Hughes, 2004) and Liège University (Belgium, Roche *et al.*, 2008). These are: (1) dissolution of carbonates

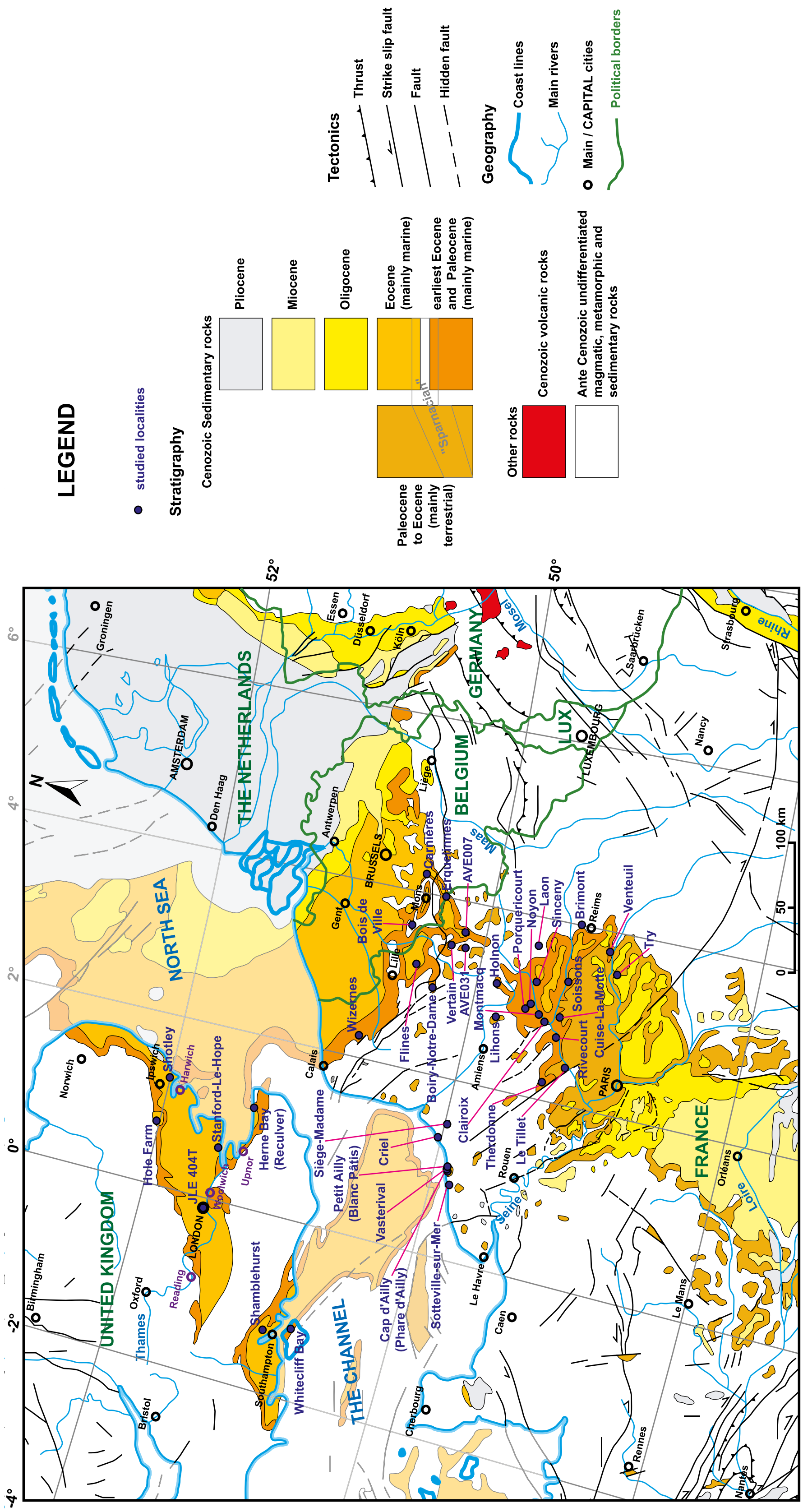

Fig. 3. Simplified geological map showing the distribution of Cenozoic sedimentary rocks in the SE part of the former North Sea Basin with location of studied sections (modified after IGME, 2005 and Quesnel *et al.*, 2009).

and silicates by HCl and HF acid digestion; (2) sieving between 106 and 10 µm; (3) neutralization with distilled water and centrifugation; then mounting of the remaining residues on the slides. A slight acetolysis was performed for the samples richer in amorphous organic matter.

Palynological material from the Paris, Dieppe and London basins, containing the dinoflagellate cyst zonal assemblages, is stored in the BRGM, Orléans, France. The raw palynological data (containing ~200 taxa of dinoflagellate cysts, acritarchs and prasinophytes) from the BRGM and BGS sections are available in Supplementary Material.

4 Results

Stratigraphic distribution of the key dinocyst events from studied sections in northern France and adjacent areas has enabled the development of a precise dinoflagellate zonation scheme for the Late Paleocene-Early Eocene of the Paris and Dieppe basins. Based on our palynological counting and on a number of noticeable lithostratigraphic features in the Dieppe and Paris basins, we present here a new updated biozonation with the lithostratigraphic logs for each basin (Fig. 4). The most typical dinoflagellate cysts are shown on Plates 1, 2 and 3.

It should be noted that the Moulin Compensé Formation (6–7 m thick), the lowermost Upper Paleocene unit in northern France, has a restricted geographical distribution. It is composed of glauconitic, clayey, calcareous silts or sands and assigned to the nannoplankton NP6–7 zones (Aubry *et al.*, 2005; Janin and Bignot, 1993; Steurbaut, 1998), but was not seen in the sections we have studied. As a result, the characteristics of the dinocyst assemblage from the lowermost Thanetian sediments in this region remains unclear.

4.1 The *Alisocysta margarita* Zone (Paris Basin)

Definition: interval from the LO of *Deflandrea denticulata* to the LO of *Apectodinium homomorphum*.

Diagnostic events: besides *D. denticulata*, the species *Alisocysta* sp.2 *sensu* Heilmann-Clausen (1985) occurs also at the base of this zone. The species *Biconidinium longissimum* occurs, while *Alisocysta margarita* and *Tanyosphaeridium xanthiopyxides* disappear within this interval. Characteristic species of this zone are *Phthanoperidinium crenulatum*, *Conneximura fimbriata*, *Melitasphaeridium pseudorecurvatum*, *Hystrichosphaeridium tubiferum*, *Trigonopyxidia ginella*, *Palaeotetradinium minusculum*, *Palaeocystodinium lidiae*, *Glaphyrocysta divaricata*, *Glaphyrocysta pastielsii*, as well as abundant *Areoligera gippingensis*-group (*A. coronata*, *A. gippingensis*, *A. medusettiformis*, *A. senonensis*).

Reference section: Châlons-sur-Vesles Fm (31.12–25.19 m depth), Noyon core, Oise Department (former Picardy, now Hauts-de-France Region).

Calibration: the *Alisocysta margarita* Zone corresponds to the NP8 nannoplankton Zone interval (Dupuis and Steurbaut, 1987).

Chronostratigraphic Age: Thanetian (~58.5–56.5 Ma).

The *Alisocysta margarita* Zone is also established in the Paris Basin within the Châlons-sur-Vesles Fm from the presently unexposed base of the Rivecourt section (Sables de Châlons-sur-Vesles Member); in the transitional zone between the Paris and Belgian basins within the Wizernes Tuffeau Member in the Wizernes and Boiry-Notre-Dame sections and within the Grandglise Member in the Flines-lez-Râches section.

The *A. margarita* Zone, established in the Paris Basin, corresponds to the homonymous zone in southern England (Powell *et al.*, 1996) and is equivalent to the Viborg 4-lowermost Viborg 5 zones in Denmark (Heilmann-Clausen, 1985). According to our unpublished data from the south of England, the *A. margarita* Zone interval is also recognized within the Thanet Sand Fm in the BGS London Jubilee Line 404T and Stanford-Le-Hope cores.

4.2 The *Apectodinium hyperacanthum* Zone (Paris and Dieppe basins)

Definition: interval from the LO of *Apectodinium homomorphum* to the LO of the acme of *Apectodinium* spp.

Diagnostic events: the species *Apectodinium quinquelatum*, *A. summissum*, *A. parvum* occur at the base of this zone, while *Apectodinium paniculatum*, *A. folliculum* and *A. hyperacanthum* occur first within this zonal interval.

Reference section in the Paris Basin: Châlons-sur-Vesles Fm (uppermost Le Tillet Sand Member) – Bracheux Fm (184.35–166.0 m depth), Le Tillet core, Oise Department (former Picardy, now Hauts-de-France Region).

Reference section in the Dieppe Basin: Bracheux Fm (Criel Sand Member) (27.2–18.9 m depth), Siège-Madame core, Seine-Maritime Department, Normandy Region.

The *A. hyperacanthum* Zone is also established in the Paris Basin in the Clairoix locality, although this part of the section is now obscured at the base of the cliff (glauconitic sand of the Bracheux Fm), in the Noyon core (uppermost Châlons-sur-Vesles Fm), Cuise-la-Motte core (uppermost Le Tillet Sand Member of the Châlons-sur-Vesles Fm and Sables de Bracheux Member of the Bracheux Fm), Try core. In the transitional zone between the Paris and Belgian basins this zone is established in the Brimont outcrop section (in a silty very fine sand, unascribed to any formal lithostratigraphic unit yet), Vertain core (Vertain Crag Member), AVE-007 and AVE-031 cores (Vervins Member, Clary Clay Member and Viesly Crag Member of the Hainaut-Valenciennois Formation) and in the Boiry-Notre-Dame outcrop section.

Calibration: the *A. hyperacanthum* Zone interval corresponds to the NP9 nannoplankton Zone (Steurbaut, 1998).

Chronostratigraphic Age: Late Thanetian (~56.5–55.8 Ma).

The *Apectodinium hyperacanthum* Zone from the Paris and Dieppe basins corresponds to its homologous in southern England (Powell *et al.*, 1996) and in the central part of the North Sea (AI, unpublished data from the BGS 81/46A core), to the Viborg-5 Zone in Denmark (Heilmann-Clausen, 1985) and the P6a Subzone in the North Sea (Bujak and Mudge, 1994).

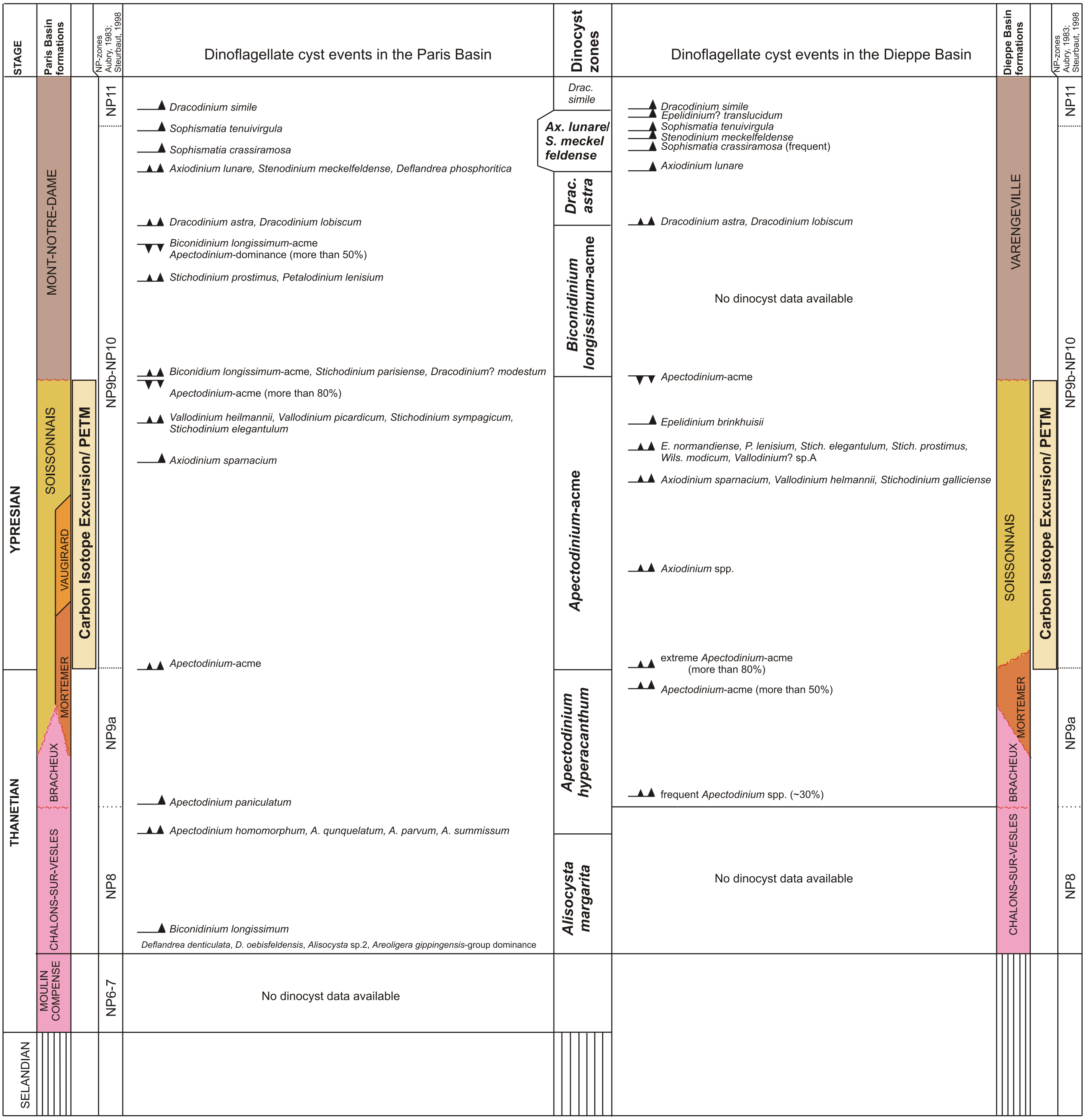

Fig. 4. New proposed Late Paleocene-Earliest Eocene dinoflagellate cyst zonation for the Paris and Dieppe basins.

4.3 The *Apectodinium*-acme Zone (Paris Basin)

Definition: interval from the LO of the acme of *Apectodinium* spp. (minimum 75% of total dinoflagellate cyst assemblage) to the LO of *Biconidinium longissimum*-acme.

Diagnostic events: the base of this zone is characterized by the occurrence of *Apectodinium parvum* specimens that are different from typical forms by the larger size of cyst and more developed apical, lateral and antapical horns. The species *Axiodinium sparnacium*, *Vallodinium heilmannii*, *Vallodinium picardicum*, *Stichodinium sympagicum* and *Stichodinium elegantulum* occur first within this zone interval (Vauxbuin Member, Soissonnais Fm).

Reference section: Soissonnais Fm (Muirancourt and Vauxbuin Members, 154.93–61 m depth), Le Tillet core, Oise Department (former Picardy, now Hauts-de-France Region).

The *Apectodinium*-acme Zone is also established in the Paris Basin in the Therdonne core (Bourguillemont Sand

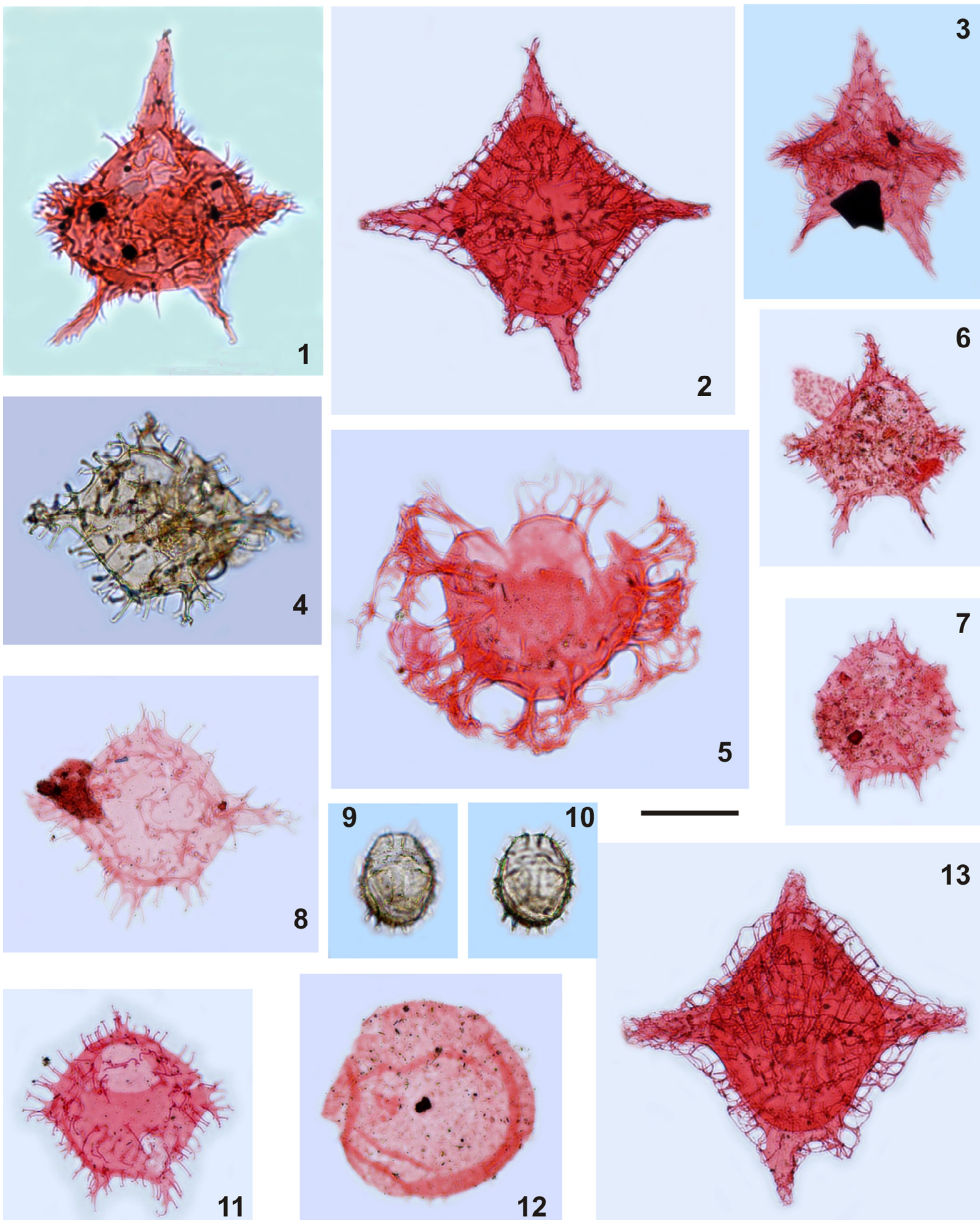

Plate 1. 1: *Apectodinium parvum*; Le Tillet core, 148.6 m depth; slide MPA 62334-4; 2: *Sophismatia crassoramosa-tenuivirgula*; Siège-Madame core, 3.5 m depth; slide MPA 62290-7; 3: *Apectodinium parvum*; Sinceny core, 9.1 m depth; slide MPA 61460-3; 4: *Dracodinium astra*; Flines-lez-Râches section, sample FLA-2.99 m; slide MPA 60007-3; 5: *Glaphyrocysta* aff. *ordinata*; Siège-Madame core, 9.6 m depth; slide MPA 62299-5; 6: *Apectodinium parvum*; Try core, 6.2 m depth; slide MPA 62326-3; 7: *Apectodinium homomorphum*; Try core, 6.2 m depth; slide MPA 62326-3; 8: *Apectodinium paniculatum*; Siège-Madame core, 9.6 m depth; slide MPA 62299-4; 9, 10: *Alisocysta* sp. 2 *sensu* Heilmann-Clausen (1985); Rivecourt section, sample RIVE 2-0; slide MPA 59942-3; 11: *Apectodinium quinquelatum*; Siège-Madame core, 3.5 m depth; slide MPA 62290-5; 12: Gonyaulacoid C; Siège-Madame core, 7.8 m depth; slide MPA 62297-3; 13: *Sophismatia tenuivirgula*; Siège-Madame core, 3.5 m depth; slide MPA 62290-7.

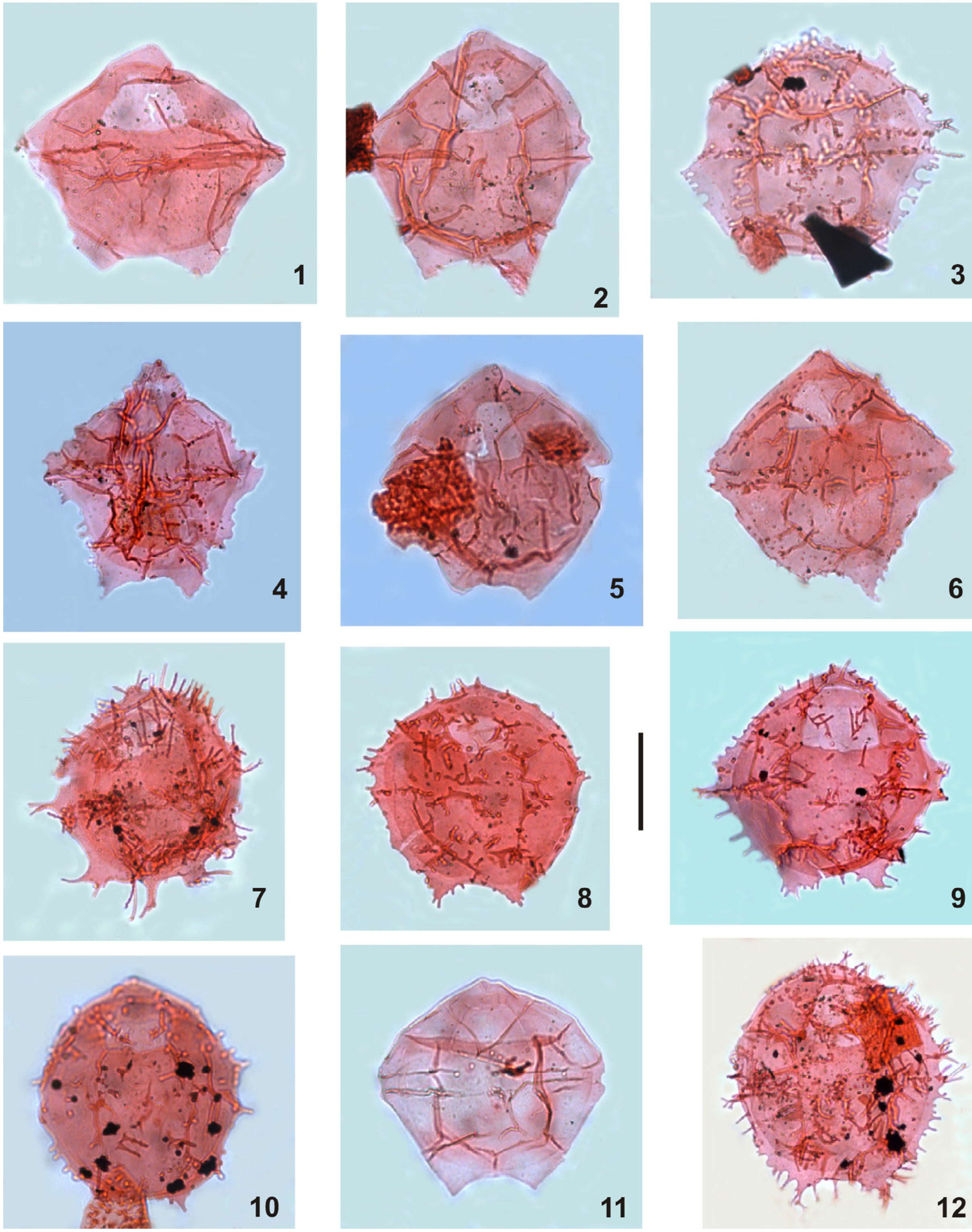

Plate 2. 1: *Petalodinium lenisium*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 2: *Vallodinium heilmannii*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 3: *Stichodinium galliciense*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 4: *Wilsonidium modicum*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 5: *Epelidinium normandiense*; Siège-Madame core, 13.0 m depth; slide MPA 62304-3; 6: *Stichodinium prostimus*; Siège-Madame core, 13.0 m depth; slide MPA 62304-3; 7: *Axiodinium sparnacium*; Sinceny core, 7.0 m depth; slide MPA 61459-5; 8: *Stichodinium sympagicum*; Le Tillet core, 144.8 m depth; slide MPA 62331-4; 9: *Stichodinium parisiense*; Le Tillet core, 144.8 m depth; slide MPA 62331-5; 10: *Dracodinium*? *modestum*; Le Tillet core, 148.6 m depth; slide MPA 62334-4; 11: *Stichodinium elegantulum*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 12: *Vallodinium picardicum*; Le Tillet core, 144.8 m depth; slide MPA 62331-4.

Member, uppermost Mortemer Fm); in the Porquericourt core and in the Laon outcrop (Vauxbuin Member, Soissonnais Fm); within the interval of the Soissonnais Fm in the Sinceny core; in the Try and Venteuil cores within the uppermost Mortemer Fm and in the Soissonnais Fm (Vauxbuin Member); in the Flines-lez-Râches outcrop section (uppermost Flines-lez-Râches Member); within the Santerre Formation (Holnon Member) in the Lihons and Holnon outcrop sections.

Calibration: according to isotopic data from the Le Tillet, Try, Flines-lez-Râches, Therdonne, Sinceny, Holnon, Lihons, Laon and Porquericourt, the base of the acme of *Apectodinium* spp. corresponds to the global CIE, associated with the PETM event. The upper zonal boundary coincides with the end of the CIE.

Chronostratigraphic Age: Earliest Eocene (~55.8–55.6 Ma).

4.4 The *Apectodinium*-acme zone (Dieppe Basin)

Definition: interval from the LO of the acme of *Apectodinium* spp. (80–98% of total dinoflagellate cyst assemblage) to the HO of the acme of *Apectodinium* spp.

Diagnostic events: as in the Paris Basin, atypical specimens of *Apectodinium parvum* occur at the base of this zone in the Dieppe Basin. The species *Axiodinium sparnacium*, *Epelidinium brinkhuisii*, *Epelidinium normandiense*, *Petalodinium lenisium*, *Stichodinium elegantulum*, *Stichodinium galliciense*, *Stichodinium prostimus*, *Vallodinium heilmannii*, *Vallodinium* sp. A, and *Wilsonidium modicum* occur within this zone interval. The acme of *Kenleyia* (up to 100%) and *Lingulodinium*-groups as well as those of gonyaulacoids of uncertain systematic affinity (probably goniodomaceans, see Plate 1, fig. 12; Plate 3, figs. 9, 14, 16, 17) are observed at the base and within the lower half of this zone.

Reference section: Soissonnais Fm (Ailly and Craquelins members, 8.5–20.0 m), Cap d'Ailly cliff section, Normandy.

The *Apectodinium*-acme Zone is also established in the Dieppe Basin within the uppermost Mortemer Fm (Siège-Madame Member) and Soissonnais Fm (SAOM, Sotteville and Craquelins members) in the Siège-Madame core and Sotteville-sur-Mer section and core; in the Vasterival (Phare d'Ailly and Craquelins Members), Blanc Pâtis (SAOM Member) and Criel (SAOM Member) outcrop sections.

Calibration: according to isotopic data from the Sotteville-sur-Mer, Ailly, Cap d'Ailly, Blanc Pâtis, Criel and Siège-Madame sections, the base of the acme of *Apectodinium* spp. corresponds to the global CIE, associated with the PETM event. The upper zonal boundary coincides with the end of the CIE.

Chronostratigraphic Age: Earliest Eocene (~55.8–55.6 Ma).

The *Apectodinium*-acme Zone from the Paris and Dieppe basins nearly corresponds to the *Apectodinium augustum* Zone in southern England (without nominate taxon, Powell *et al.*, 1996) and northern Belgium (Steurbaut *et al.*, 2003), to the Viborg-6 Zone in Denmark (Heilmann-Clausen, 1985), and to the P6b Subzone in the North Sea (Mudge and Bujak, 1996). According to our unpublished data from the south of England, the *Apectodinium*-acme Zone interval may be recognized within the Lambeth Group in the BGS London Jubilee Line 404T key-core. Thus, within the Lower Woolwich Beds *Apectodinium*-acme attains 50–75%, while Gonyaulacoid A (Plate 3, fig. 16), known from the Dieppe Basin, represents 35% of the dinoflagellate cyst assemblage; the Upper Reading Beds are characterized by the *Apectodinium*-acme (95–97%); finally, within the Upper Woolwich Beds *Apectodinium* spp. represents 70% and Gonyauacoid A – 25% of the assemblage.

4.5 The *Biconidinium longissimum*-acme Zone (Paris Basin)

Definition: interval from the LO of the acme of *Biconidinium longissimum* (20–48% of total assemblage) to the LO of *Dracodinium astra*.

Diagnostic events: the species *Stichodinium parisiense* and *Dracodinium*? *modestum* occur first at the base of this zone, while the species *Stichodinium prostimus* and *Petalodinium lenisium* occur within this zone interval. The last manifestation of the *Apectodinium*-acme (up to 50%) is observed at the base of this zone.

Reference section: Mont-Notre-Dame Fm (Sinceny Member, 148.6–142.2 m depth), Le Tillet core, Oise Department (former Picardy, now Hauts-de-France Region).

The *Biconidinium longissimum*-acme Zone is also established within the Sinceny Member of the Mont-Notre-Dame Fm in the Therdonne, Sinceny and Cuise-la-Motte cores and in the Laon outcrop section.

Calibration: the *Biconidinium longissimum*-acme Zone corresponds indirectly to part of the NP10 Zone interval.

Chronostratigraphic Age: Earliest Eocene (~55.6–55.0 Ma).

The *Biconidinium longissimum*-acme Zone, established in the Paris Basin, is the chronostratigraphic analogue of the *Glaphyrocysta ordinata* Zone in southern England (Powell *et al.*, 1996), the *Deflandrea oebisfeldensis* Zone from the NW European compilation dinocyst scale (Powell, 1992) and of the Viborg-7 Zone in the Danish Basin (Heilmann-Clausen, 1985).

4.6 The *Dracodinium astra* Zone (Paris and Dieppe basins)

Definition: interval from the LO of *Dracodinium astra* to the LOs of *Axiodinium lunare* and *Stenodinium meckelfeldense*.

Diagnostic events: the species *Dracodinium lobiscum* occurs at the base of this zone. The species *Cleistosphaeridium polypetellum*, *Homotryblium tasmaniense* and *Homotryblium tenuispinosum* occur within the interval of this zone.

Reference section in the Paris Basin: Mont-Notre-Dame Fm (Sables de Laon Member, 140.0–137.0 m depth), Le Tillet core, Oise Department (former Picardy, now Hauts-de-France Region).

This zone is also established in the Paris Basin in the Venteuil Member (Mont-Notre-Dame Fm) in the Venteuil core.

Reference section in the Dieppe Basin: Varengeville Fm (Sables Fauves Member, samples 8.9–6.0 m depth), Siège-Madame core, Seine-Maritime, Normandy.

It is also established in the Dieppe Basin within the Sables Fauves Member in the Cap d'Ailly cliff section.

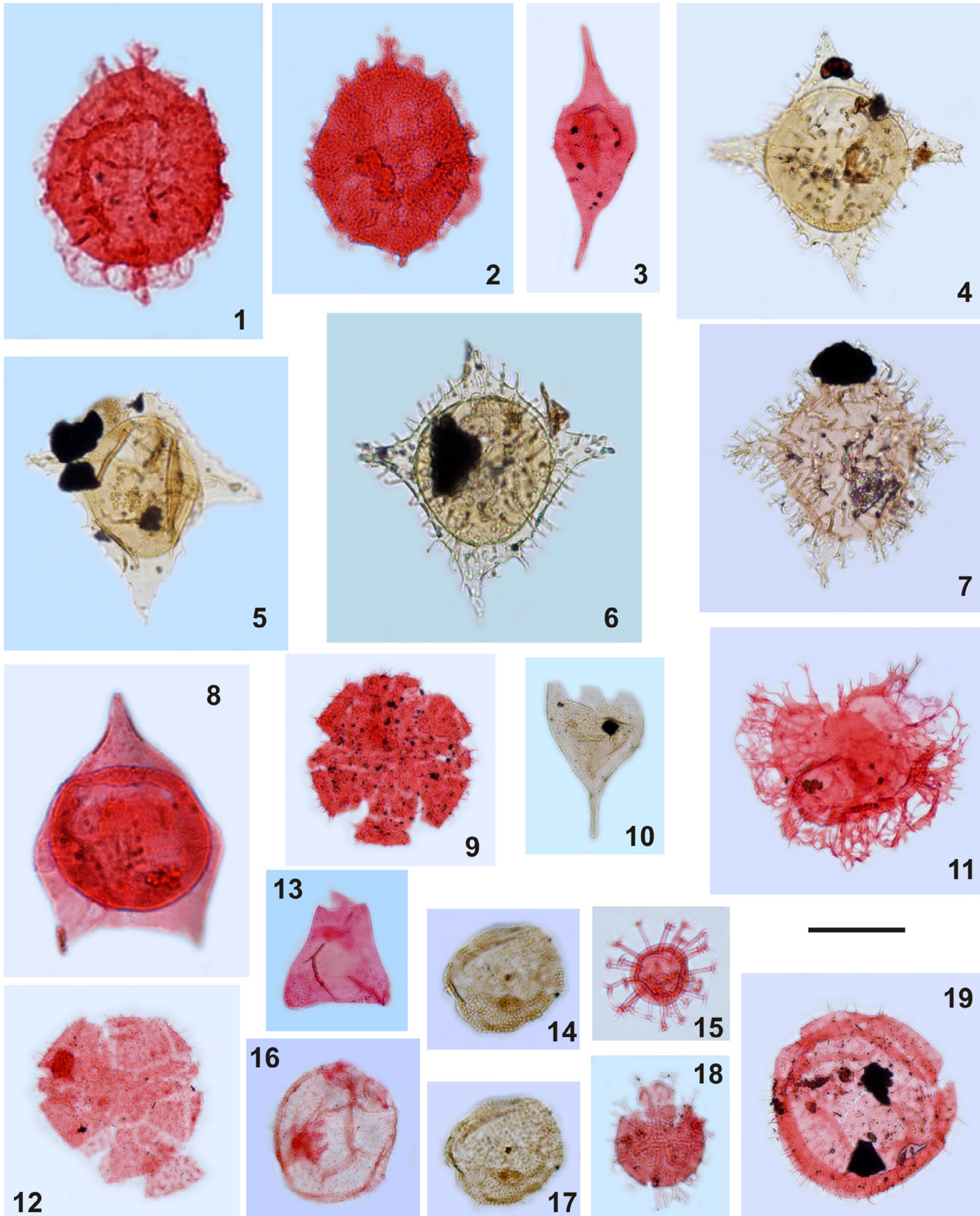

Plate 3. 1: *Kenleyia*-complex; Siège-Madame core, 18.4 m depth; slide MPA 62307-3; 2: *Kenleyia*-complex; Siège-Madame core, 18.4 m depth; slide MPA 62307-3; 3: *Biconidinium longissimum*; Le Tillet core, 144.8 m depth; slide MPA 62331-4; 4: *Axiodinium lunare*; Cap d'Ailly cliff section, 35 m height; slide 61781; 5: *Stenodinium meckelfeldense*; Cap d'Ailly cliff section, 38 m height; slide 61788; 6: *Axiodinium lunare*; Cuise-la-Motte core, 82.5 m depth; slide 59969-2; 7: *Dracodinium astra-lobiscum*; Siège-Madame core, 8.9 m depth; slide MPA 59999; 8: *Deflandrea phosphoritica*; Siège-Madame core, 3.5 m depth; slide MPA 62290-7; 9: Gonyaulacoid B; Try core, 6.7 m depth; slide MPA 62339-2; 10: *Biconidinium longissimum*; Sinceny core, 6.2 m depth; slide MPA 59804-3; 11: *Glaphyrocysta* aff. *ordinata*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 12: Gonyaulacoid B; Try core, 6.0 m depth; slide MPA 62335-3; 13: *Trigonopyxidia ginella*; Siège-Madame core, 13.0 m depth; slide MPA 62304-2; 14 and 17: Gonyaulacoid A; Vasterival section, 2 m height; slide MPA 59922-3; 15: *Melitasphaeridium pseudorecurvatum*; Siège-Madame core, 9.6 m depth; slide MPA 62299-6; 16: Gonyaulacoid A; Criel cliff section, 9.7 m height; slide MPA 59959-3. 18: *Alisocysta* sp. 2 *sensu* Heilmann-Clausen (1985); Erquelinnes section; sample ERQ 1.59–1.63 m; slide MPA 59955-4; 19: Gonyaulacoid C; Siège-Madame core, 7.8 m depth; slide MPA 62298-4.

Calibration: the *Dracodinium astra* Zone corresponds indirectly to the mid part of the NP10 Zone interval.

Chronostratigraphic Age: Early Eocene (Early Ypresian s.s.) (~55.0–54.8 Ma).

It must be noted that the *Wetzeliella* (now *Dracodinium*) *astra* Zone was first established in the Paris Basin by Châteauneuf and Gruas-Cavagnetto (1978) in the lower part of the Sables de Laon Member between the LO of *Dracodinium* (=*Wetzeliella*) *astra* and LO of *Stenodinium* (=*Wetzeliella*) *meckelfeldense*. The present version of the *Dr. astra* Zone differs by the use of species *Axiodinium* (=*Wetzeliella*) *lunare* as a second (or sometimes only) marker for the upper zonal limit definition.

The *Dracodinium astra* Zone is known from different parts of the North Sea Basin: in southern England (Powell *et al.*, 1996) and in the central part of the North Sea (Balder Formation; AI, pers. data). It corresponds to the D6a Subzone of the German sector of the North Sea (Köthe, 2012). According to our unpublished data from the south of England, the *Dracodinium astra* Zone interval is also recognized within the lower London Clay Fm in the BGS London Jubilee Line 404T and Shamblehurst-Lane cores.

4.7 The *Axiodinium lunare/Stenodinium meckelfeldense* Zone (Paris and Dieppe basins)

Definition: interval from the LOs of *Axiodinium lunare* and *Stenodinium meckelfeldense* to the LO of *Dracodinium simile*.

Diagnostic events: the species *Deflandrea phosphoritica*, *Sophismatia crassoramosa*, *Sophismatia tenuivirgula*, *Axiodinium prearticulatum*, *Heteraulacacysta everriculata* occur within this zone interval in the Paris and Dieppe basins.

Reference section in the Paris Basin: Mont-Notre-Dame Fm (Sables d'Aizy Member, 137.0–133.0 m depth), Le Tillet core, Oise Department (former Picardy, now Hauts-de-France Region).

This zone is also established within the Sables d'Aizy Member of the Mont-Notre-Dame Fm in the Therdonne and Cuise-la-Motte cores, within the Epernay Fm in the Venteuil core, within the Orchies Member in the Flines-lez-Râches outcrop section from the transitional area between the Paris and Belgian basins, and within the Flandres Fm in the Bois-de-Ville core in southern Belgium.

Reference section in the Dieppe Basin: Varengeville Fm (Argiles et Sablons Member, 5.5–3.0 m depth), Siège-Madame core, Seine-Maritime, Normandy.

In the Dieppe Basin this zone is also established in the Cap d'Ailly cliff section.

Calibration: the *Axiodinium lunare/Stenodinium meckelfeldense* Zone corresponds to the upper part of the NP10 Zone interval.

Chronostratigraphic Age: Early Ypresian s.s. (~54.8–53.4 Ma).

The *Wetzeliella meckelfeldensis* Zone was originally established in northern France by Châteauneuf and Gruas-Cavagnetto (1978) in the lower Sables d'Aizy Member between the LO of *Wetzeliella meckelfeldensis* (now *Stenodinium meckelfeldense*) and the LO of *Dracodinium simile*. Based on our new dinocyst data from the Paris and Dieppe basins, we suggest the use of the LO of *Axiodinium lunare* (synchronous to the LO of *S. meckelfeldense*) as the second (or even often only) marker to define the lower zonal boundary.

The *Stenodinium* (=*Wetzeliella*) *meckelfeldense* Zone is known from different parts of the former North Sea Basin: in the Belgian Basin (De Coninck, 1991), in the central part of the North Sea (Balder Fm, AI, pers. data), in the lower London Clay Fm in southern England (Shamblehurst-Lane BGS core, unpublished). It corresponds to the D6a Subzone of the German part of the North Sea (Köthe, 2012) and to the E2a Subzone of the North Sea zonation of Bujak and Mudge (1994).

5 Discussion

5.1 The Paleocene interval and hiatuses

Thanetian sands are often considered as a unique glauconitic sandy unit in the Paris and Dieppe basins (see for example Rouvillois, 1960). It is not the place here to discuss extensively the twofold division of these so-called "Thanetian glauconitic sands", this will be done elsewhere arguing on lithological, sedimentological, paleontological and other criteria and new data. Nevertheless, it is necessary to put forwards evidence that supports such a two-fold division. The southwestern extension of the Paleogene strata north of the Seine valley provides such an opportunity as this region shows the maximum extent of these two transgressive sandy units, which crop out separately and have been paleontologically identified. The "Sable de Dieppe" Member that correlates with the Sables de Châlons-sur-Vesles Fm and belongs to the NP8 Zone rests directly on the Cretaceous chalk (Dupuis and Steurbaut, 1987). Near Beauvais, the well-known "Sable de Bracheux" that records the NP9a Zone, lies directly on the Cretaceous chalk without any sandy intercalation of NP8 age (Aubry, 1983). In addition, each sand unit can be easily equated with the two equivalent but distinct formations from southeast UK, the Thanet Fm and the Upnor Fm that are separated by a surface representing a major drop in sea level (Knox, 1996). The fine-grained unit that forms laterally the base of the sequence of the Dieppe – Châlons-sur-Vesles sands, is only present in the north and the east of the Paris Basin, it is not younger than the NP6–7 zones and it is distinct from the Selandian, which belongs only to the NP6 zone (Schmitz *et al.*, 2011). Consequently, there is a significant hiatus between the Early Paleocene represented by the Vigny Group and the Upper Paleocene Vesles Group in the Paris Basin.

Our new data confirm the absence of any Selandian deposits in the Paris and Dieppe basins and no units dating from the lower part of the Early Thanetian (NP6 to NP7 Zones) has been obtained here either. Instead, the upper part of the Lower Thanetian and the Upper Thanetian (NP8 and NP9a) are revealed in a number of reference sections in northern France.

The major part of the Châlons-sur-Vesles Fm in the Paris Basin corresponds to the *Alisocysta margarita* Zone interval and clearly correlates with the Thanet Sand Fm in southern England, the Wizernes "Tuffeau" and Grandglise Sand members in the transitional zone between the Paris and Belgian basins. Such widespread distribution of the upper part of the Lower Thanetian deposits from the London to the Paris and Belgian basins indicates an important transgressive phase in the development of the North Sea Basin after one or a few long regressive episode(s) and/or hiatus(es) during the whole Selandian and locally also during the early part of the Early Thanetian.

The Upper Thanetian sediments of Bracheux and lowermost Mortemer formations contain the dinoflagellate cyst assemblage, corresponding to the *Apectodinium hyperacanthum* Zone interval and are generally characterized by up to 30% (and even up to 50% in the Dieppe Basin) of *Apectodinium* spp. Lithologically varied Upper Thanetian sediments are widely distributed over the Paris and Dieppe basins, in transitional zone between the Paris and Belgian basins (Vervins, Viesly Crag and Vertain Crag members of the Hainaut-Valenciennois Fm) and in southern England (Upnor Fm), suggesting a new significant transgression during the Late Thanetian in the North Sea Basin, as suggested by Steurbaut (1998) and Aubry *et al.* (2005), and as known in other regions of western Eurasia like eastern Peri-Tethys and West Siberia (Iakovleva and Aleksandrova, 2014) as well.

5.2 The PETM event

As was mentioned above, the onset of the CIE associated with the PETM event, starts within the Mortemer Fm, which was deposited in an almost entirely terrestrial environment and continues through the whole Soissonnais Fm (terrestrial and lagoonal depositional environments). The CIE interval in these littoral-lagoonal facies is characterized by an acme of *Apectodinium* spp. (70–98%). The Mortemer Fm, mostly accumulated in terrestrial depositional environments rich in carbonates, and as such rarely yielded dinoflagellate cyst assemblages that can be counted quantitatively. Nevertheless, our data from the Therdonne core and section show that the beginning of the *Apectodinium*-acme almost coincides with the CIE onset within the Mortemer Fm.

The Soissonnais Fm, also corresponding to the CIE event and composed of alternating clay, silt and lignite lithofacies including coquina beds or laminae, is characterized, in its lagoonal part, by dinocyst assemblages dominated by *Apectodinium* (70–98%). Nevertheless, it should be noted that while the Soissonnais Fm in the Paris Basin (*cf.* Sinceny core, etc.) is characterized exclusively by the *Apectodinium*-acme, in the Dieppe Basin (Cap d'Ailly cliff section and Phare d'Ailly and Siège-Madame cores) the same formation revealed in its lower half an alternation of the *Apectodinium*-acme (presumably heterotrophic dinoflagellates) and the acmes of autotrophic groups: *Kenleyia*, *Lingulodinium* and other gonyaulacoids of uncertain systematic affinity (Gonyaulacoids A, B, C; Plate 1, fig. 12; Plate 3, figs. 9, 12, 14, 16, 17) in the lowermost SAOM Member. This alternation of extreme acmes is supported by our data from the Woolwich Formation in southern England (from the London Jubilee Line 404T core, BGS collection), where we recognized not only the same *Apectodinium*-acme, but the acme (35%) of Gonyaulacoid A as well. This noticeable alternation of almost monospecific dinoflagellate cyst assemblages may indicate prominent changes in nutrient availability and may be explained by exceptionally specific environments during the so-called Sparnacian times in the Dieppe-Hampshire and London basins.

The upper part of the "Sparnacian" deposits (Craquelins Member in the Dieppe Basin; Vauxbuin Member in the Paris Basin) is characterized by a relative decrease in *Apectodinium* abundance and increase in *Spiniferites*- and *Areoligera*-groups as well as by the occurrence of a number of species of Wetzelielloideae (Iakovleva, 2017), suggesting a relative sea-level rise at the end of the PETM.

As mentioned by Gruas-Cavagnetto (1976c), dinoflagellate cyst assemblages from the Dieppe-Hampshire and Paris basins' "Sparnacian" do not contain the key-species *Axiodinium* (=*Apectodinium*) *augustum* (nominate species of the *A. augustum* Zone mostly corresponding to the PETM interval worldwide). It is also the case at Schöningen in Germany (Methner *et al.*, 2019), whereas it is present in northern Belgian Tienen Formation and is coeval there with the CIE and *Apectodinium*-acme interval (Steurbaut *et al.*, 2003). As previously noted, Powell *et al.* (1996) explained the absence of *Axiodinium augustum* in the Anglo-Paris Basin by its restriction to more offshore conditions. According to our new data from northern France, the species *Axiodinium augustum* is virtually absent from the Laon outcrop section, although a few specimens were seen in unfavourable orientations on the microscope slide which might be identified as this species. However, instead of *Axiodinium augustum* a significant number of specimens of *Apectodinium parvum*, which are longer both in overall length and in the length of the apical and antapical horns (compared to the holotype) were observed here (Plate 1, fig. 1). We presume that this atypical morphotype of *Apectodinium parvum* could represent an ecological onshore substitute of *Axiodinium augustum*. Additionally, the uppermost part of the PETM interval within the "Sparnacian" deposits (Craquelins Member in Dieppe Basin, Vauxbuin Member in Paris Basin) is characterized by the appearance of several wetzelielloidean species: *Axiodinium sparnacium*, *Epelidinium brinkhuisii*, *Epelidinium normandiense*, *Petalodinium lenisium*, *Stichodinium elegantulum*, *Stichodinium galliciense*, *Stichodinium sympagicum*, *Stichodinium prostimus*, *Vallodinium heilmannii*, *Vallodinium picardicum*, and *Wilsonidium modicum*.

5.3 The Early Eocene record, postdating the PETM

Until now, it was considered that there was no evidence for dinocyst assemblages assignable to the *Glaphyrocysta ordinata* or its equivalent *Deflandrea oebisfeldensis* Zone in the Paris and Dieppe basins (Aubry *et al.*, 2005): there was no northern France record of the *Leiosphaeridia*-acme, *D. oebisfeldensis*-abundance or *Glaphyrocysta*/*Areoligera*-dominance documented from the Harwich Fm in southern England (Powell *et al.*, 1996) and in the North Sea (Mudge and Bujak, 1996). Based on our new data it appears that the lowermost unit (postdating the PETM) of the Mont-Notre-Dame Fm in the Paris Basin (Sinceny Member, introduced by Quesnel *et al.*, 2011) corresponds to a littoral depositional environment, with homogeneous $\delta^{13}C_{or}$ values between –24–25‰ PDB and contains a distinctive dinoflagellate cyst assemblage, characterized by the *Biconidinium longissimum*-acme combined at its base with still abundant *Apectodinium* spp. (up to 50%). The *Biconidinium longissimum*-acme event is unknown from the adjacent Belgian, Hampshire and London basins and possibly reflects a local and extremely specific environment during this time in the Paris Basin (with specific nutrient availability and reduced salinity). We suggest that the interval of the new *Biconidinium longissimum*-acme Zone corresponds to the lowermost Ypresian *Glaphyrocysta ordinata*/or *Deflandrea oebisfeldensis* Zone, indicating a more continuous sedimentation during the Early Eocene in the Paris Basin and, then, the absence or much less importance of the stratigraphical hiatus previously hypothesized by Aubry *et al.* (2005). It may be noted that, according to our data, in southern England the dinoflagellate cyst assemblages of the *Glaphyrocysta ordinata*/*Deflandrea oebisfeldensis* Zone recognized within the Harwich Fm in different localities often have significant differences even within short distances. Indeed the dinoflagellate cyst assemblages from the lower Harwich Fm (Orwell Unit) may be characterized by poor associations dominated by *Spiniferites*-, *Lingulodinium*-groups and *Apectodinium* spp. (Hole Farm Quarry, BGS core 81/46A) or, alternatively, by a *Palaeotetradinium minusculum*-acme (60%, BGS Shotley Gate core). The upper Harwich Fm (Wrabness Unit), in its turn, is either characterized by depleted dinocyst associations containing up to 15% of *Deflandrea oebisfeldensis* (BGS Shotley Gate core) or by those with a *Deflandrea oebisfeldensis*-acme (70–40%, Hole Farm Quarry).

When comparing the Paris and Dieppe basin successions, it can be noted that in the sections from the Pays de Caux and Vimeu (Cap d'Ailly cliff section, Siège-Madame core) the lowermost part of the Varengeville Fm is represented by the "Sables Fauves" Member (Dupuis and Steurbaut, 1987). The lower part of the "Sables Fauves" appears to be an unfavorable facies for palynomorph preservation and does not contain any dinoflagellate cyst in the Cap d'Ailly section or the Phare d'Ailly core. Nevertheless, it is possible that the "Sables Fauves" Member is stratigraphically equivalent to the Sinceny Member in the Paris Basin, the Zoute Silt Member in Belgium (data from De Coninck in Steurbaut, 1998) and the Harwich Fm including the Oldhaven Sand Member in southern England, at least below the LO of *Dracodinium astra*.

Overlying the Sinceny Member in the Paris Basin and the Sables Fauves Member in the Dieppe Basin respectively, the Sables de Laon Member (Mont-Notre-Dame Fm), the Argiles et Sablons Member (Varengeville Fm) as well as the lowermost London Clay Fm in the London Basin and the Mont-Héribu Clay in the Belgian Basin are characterized by the LOs of *Dracodinium astra* and *Dracodinium lobiscum*, indicating their Early Ypresian s.s. age. The next units of these formations contain, sequentially, the LOs of the younger key-species *Axiodinium lunare*, *Stenodinium meckelfeldense*, *Sophismatia crassoramosa*, *Sophismatia tenuivirgula*, *Dracodinium simile*, *Dracodinium varielongitudum* and *Charlesdowniea coleothrypta*.

6 Conclusions

Thanks to a new high-resolution palynological study, an updated version of the Late Paleocene-Early Eocene dinoflagellate cyst zonation for the Paris and Dieppe basins is proposed and contains six new or revised zones: *Alisocysta margarita*, *Apectodinium hyperacanthum*, *Apectodinium*-acme, *Biconidinium longissimum*-acme, *Dracodinium astra*, *Axiodinium lunare*/*Stenodinium meckelfeldense*. Based on combined bio-, litho- and chemostratigraphic data, the peculiarities of dinoflagellate cyst assemblages from the so-called "Sparnacian" deposits in northern France have been recognized: thus, the dinoflagellate cyst assemblages corresponding to the PETM event interval are characterized by an acme of *Apectodinium* spp., sometimes alternating with an acme of few gonyaulacoid groups in the Dieppe Basin. Dinoflagellate cyst assemblages from the PETM interval contain a significant number of atypical, longer specimens of *Apectodinium parvum*, which could represent an ecological onshore equivalent of species *Axiodinium augustum* in the Paris and Dieppe-Hampshire basins. The establishment of a new *Biconidinium longissimum*-acme Zone suggests that the stratigraphic hiatus (~55.6–55.0 Ma) previously inferred in the Paris Basin, does not exist.

Supplementary Material

Supplement 1. Raw palynological data from the studied sections considered in the present work. Raw data are the property of the BRGM and cannot be used without a special permission of the authors and the BRGM.
Supplement 2. List of locations of the studied sections.

The Supplementary Material is available at https://www.bsgf.fr/10.1051/bsgf/2021035/olm.

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References

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

Aubry M-P. 1986. Paleogene calcareous nannoplankton biostratigraphy of Northwestern Europe. *Palaeogeography Palaeoclimatology Palaeoecology* 55: 267–334.

Aubry M-P, Thiry M, Dupuis C, Berggren WA. 2005. The Sparnacian deposits of the Paris Basin: A lithostratigraphic classification. *Stratigraphy* 2(1): 65–100.

Bignot G. 1965. Le gisement éocène du cap d'Ailly (près de Dieppe, Seine-Maritime). *Bulletin de la Société géologique de France*, série 7 7: 273–283.

Bignot G, Gruas-Cavagnetto C, Guernet C, Perreau M, Renard M, Riveline J, *et al.* 1981. Le Sparnacien de Soissons (Aisne, France) : étude sédimentologique et paléontologique. *Bulletin d'Information de l'AGBP* 18: 3–19.

Bignot G, Janin M-C., Guernet C. 1994. Mise en évidence de la zone de nannofossiles calcaires NP9 dans le Thanétien de Rollot (Bassin de Paris). *Bulletin d'Information de l'AGBP* 31(4): 25–28.

Brongniart A. 1829. Tableau des terrains qui composent l'écorce du globe, ou essai sur la structure de la partie connue de la Terre. Paris: F.G. Levrault.

Bujak JP, Mudge D. 1994. A high-resolution North Sea Eocene dinocyst zonation. *Journal of the Geological Society of London* 151: 449–462.

Caro Y. 1973. Contribution à la connaissance des dinoflagellés du Paléocène-Éocène inférieur des Pyrrénnées espagnoles. *Revista Española de Micropaleontologìa* (3): 329–372.

Châteauneuf J-J. 1968. Étude palynologique et planctologique du Paléogène de Cormeilles-en-Paris : résultats stratigraphiques. *C R Acad Sci Paris* 267: 938–941.

Châteauneuf J-J. 1971. Étude palynologique de l'Éocène inférieur du sondage des Hogues. *Bulletin du BRGM*, section 1 1: 16–19.

Châteauneuf J-J. 1976. Upper Eocene and Oligocene Dinophyceae of the Paris Basin (France). In: 4th ICP Conference, Lucknow, India 1970, vol. 2, pp. 47–58.

Châteauneuf J-J. 1980. Palynostratigraphie et paléclimatologie de l'Éocène supérieur et de l'Oligocène du Bassin de Paris (France). *Mémoires du BRGM* 116: 360 p.

Châteauneuf J-J, Fauconnier D. 1977. Étude palynologique des sondages du lac Léman. In: C R 10e Congr Intern INQUA, Birmingham, pp. 371–412.

Châteauneuf J-J, Gruas-Cavagnetto C. 1968. Étude palynologique du Paléogène de quatre sondages du bassin parisien (Chaignes, Montjavoult, Le Tillet, Ludes). *Mémoires du BRGM* 59: 113–162.

Châteauneuf J-J, Gruas-Cavagnetto C. 1978. Les zones de Wetzeliellaceae (Dinophyceae) du bassin de Paris. Comparaison et corrélations avec les zones du Paléogène des bassins du nord-ouest de l'Europe. *Bulletin du BRGM* (deuxième série), section IV 2: 59–93.

Châteauneuf J-J, Trauth N. 1972. Palynologie, composants minéralogiques majeurs et phase argileuse des Marnes bleues d'Argenteuil. Contribution à la reconstitution du milieu de dêpot. *Mémoires du BRGM* 77: 329–336.

Costa LI, Downie C. 1976. The distribution of the dinoflagellate Wetzeliella in the Paleogene of North-Western Europe. *Palaeontology* 19: 591–614.

Costa LI, Dennison C, Downie C. 1978. The Paleocene/Eocene boundary in the Anglo-Paris Basin. *Journal of the Geological Society of London* 135: 261–264.

Cuvier G, Brongniart A. 1811. Essai sur la géographie minéralogique des environs de Paris, avec une carte géognostique, et des coupes de terrain. Paris: Baudouin, Imprimerie de l'Institut Impérial de France.

De Coninck J. 1991. Ypresian organic-walled phytoplankton in the Belgian Basin and adjacent areas. The Ypresian stratotype. *Bulletin de la Société belge de géologie* 97: 287–319.

Dickens GR. 2000. Methane oxidation during the late Palaeocene thermal maximum. *Bulletin de la Société géologique de France* 171: 37–49.

Dollfus GF. 1880. Essai sur l'extension des terrains tertiaires dans le bassin anglo-parisien. *Bulletin de la Société géologique de Normandie* 6: 584–605.

Dupuis C, Steurbaut E. 1987. Altérites, sables marins (NP8, NP9) et fluviatiles, silicifications et stromatolites dans le Paléocène supérieur entre Criel et le Cap d'Ailly (Haute-Normandie). *Annales de la Société géologique du Nord* 105: 233–242.

Dupuis C, Gruas-Cavagnetto C, Mercier M, Perreau M, Riveline J, Roche E. 1982. Données paléontologiques, stratigraphiques et paléogéographiques nouvelles sur le Tertiaire de Saint-Valery-sur-Somme (France). *Bulletin d'Information de l'AGBP* 19(4): 31–46.

Dupuis C, Steurbaut E, De Coninck J, Riveline J. 1998a. Stop 3–The Western Argiles à Lignite facies. In Thiry M, Dupuis C, eds.The Palaeocene/Eocene boundary in Paris Basin: the Sparnacian deposits. Field Trip Guide. Mémoire des Sciences de la Terre 34. École des Mines de Paris, pp. 60–71.

Dupuis C, Steurbaut E, De Coninck J, Riveline J, Sinha A. 1998b. The Paleocene-Eocene boundary of the Chanel coast (NW Paris Basin), main events and stratigraphical interpretation. *Strata*, série 1 9: 45–47.

Gruas-Cavagnetto C. 1968. Étude palynologique des divers gisements de Sparnacien du Bassin de Paris. *Mémoires de la Société géologique de France*, nouvelle série 57(2): 144 p.

Gruas-Cavagnetto C. 1970. Dinophyceae, Acritarcha et pollens de la Formation de Varengeville (Cuisien, Seine maritime). *Revue de micropaléontologie* 15: 63–74.

Gruas-Cavagnetto C. 1974. Associations sporopolleniques et microplanctoniques de l'Éocène et de l'Oligocène inférieur du Bassin de Paris. *Paléobiologie continentale* 5(2): 3–20.

Gruas-Cavagnetto C. 1976a. Les marqueurs stratigraphiques (Dinoflagellés) de l'Éocène du Bassin de Paris et de la Manche orientale. *Revue de micropaléontologie* 18(4): 221–228.

Gruas-Cavagnetto C. 1976b. Étude palynologique du sondage de la Défence (Paris). *Revue de micropaléontologie* 19(1): 27–46.

Gruas-Cavagnetto C. 1976c. Étude paléontologique du sondage de Cuise-la-Motte (Oise). *Bulletin d'Information de l'AGBP* 13: 11–23.

Gruas-Cavagnetto C. 1978. Étude playnologique de l'Éocène du bassin Anglo-Parisien. *Mémoires de la Société géologique de France* 131: 1–64.

Gruas C, Bignot G. 1985. La transgression cuisienne en Haute-Normandie à Sotteville-sur-Mer (76-France) et le diachronisme des facies sparnaciens. *Révue de paléobiologie* 4(1): 117–132.

Gruas-Cavagnetto C, Laurain M, Meyer R. 1980. Paysage végétal et position stratigraphique du sommet des lignites du Soissonnais dans la Montagne de Reims (Yprésien, Bassin de Paris). *Géobios* 13: 947–952.

Heilmann-Clausen C. 1985. Dinoflagellate stratigraphy of the uppermost Danian to Ypresian in the Viborg 1 borehole, central Jylland, Denmark. *Danmarks Geologiske Undersogelse*, serie A 7: 69 p.

Iakovleva AI. 2017. Detailization of Eocene dinocyst zonation for Eastern Peritethys. *Bulletin of Moscow Society of Naturalists, Geological Series* 92(2): 32–48 (in Russian).

Iakovleva AI, Aleksandrova GN. 2013. To the question to updating the Paleocene-Eocene dinocyst zonation of Western Siberia. *Bulletin of Moscow Society of Naturalists, Geological Series* 88 (1): 59–82 (in Russian).

Iakovleva AI, Aleksandrova GN. 2014. Paleoenvironmental reconstructions of Lulinvor time (Eocene) in the south West Siberian marine Basin by palynological data. *Bulletin of Moscow Society of Naturalists, Geological Series* 89(3): 33–52 (in Russian).

Iakovleva AI, Quesnel F, Dupuis C, Storme J-Y, Breillat N, Magioncalda R, *et al.* 2014a. New integrated high-resolution dinoflagellate cyst stratigraphy and chemostratigraphy from the Paris and Dieppe-Hampshire Basins for the "Sparnacian". In Rocha R, Kullberg JC, Finney S, eds. STRATI 2013, First International Congress On Stratigraphy. Switzerland: Springer International Publ, pp. 107–111.

Iakovleva AI, Quesnel F, Fléhoc C, Dupuis C. 2014b. Rejuvenating the Paris Basin stratigraphy using lost drillings: the $\delta^{13}C_{or}$ calibration of Upper Thanetian to Lower Ypresian dinocyst events succession. *Rendiconti Online Societa Geologica Italiana* 7: 117–118.

Janin M-C, Bignot G. 1993. Nouvelle subdivision biostratigraphique du Thanétien du Bassin de Paris, fondée sur les nannofossiles calcaires. *C R Acad Sci Paris*, série 2 317: 927–934.

Knox RWO'B. 1996. Correlation of the early Paleogene in northwest Europe: an overview. In Knox RWO'B, Corfield RM, Dunay RE, eds. Correlation of the Early Paleogene in North-west Europe. *Geological Society, London, Special Publications* 101: 1–11.

Köthe A. 2012. A revised Cenozoic dinoflagellate cyst and calcareous nannoplankton zonation for the German sector of the southeastern North Sea Basin. *Newsletters on Stratigraphy* 45(3): 189–220.

Methner K, Lenz O, Riegel W, Wilde V, Mulch A. 2019. Palaeoenvironmental response of mid-latitudinal wetlands to PETM climate change (Schöningen lignite deposits, Germany). *Clim Past Discuss*. https://doi.org/10.5194/cp-2019-20.

Mudge DC, Bujak JP. 1996. Palaeocene biostratigraphy and sequence stratigraphy of the UK central North Sea. *Mar Petrol Geol* 13: 295–312.

Ogg JG, Ogg G, Gradstein FM. 2016. A Concise Geologic Time Scale. Amsterdam: Elsevier.

Powell AJ. 1992. A Stratigraphic Index of Dinoflagellate cysts. *British Micropaleontological Society Publication Series*.

Powell AJ, Brinkhuis H, Bujak JP. 1996. Upper Paleocene-Lower Eocene dinoflagellate sequence biostratigraphy of southeast England. In: Knox RWO'B, Corfield R, Dunay RE, eds. Correlation of the Early Paleogene in Northwest Europe. *Geol Soc Lond Spec Publ* 101: 145–183.

Quesnel F, Dupuis C, Yans J, Ricordel-Prognon C, Rad S, Storme J-Y, *et al.* 2009. In: Crouch C, Strong P, Hollis C, eds. Climatic and Biotic Events of the Paleogene (CBEP 2009), extended abstracts from an international conference in Wellington, New Zealand, 12–15 January 2009. *GNS Science Miscellaneous Series* 18: 102–106.

Quesnel F, Storme J-Y, Iakovleva AI, Roche E, Breillat N, Andre M, *et al.* 2011. Unraveling the PETM record in the "Sparnacian" of NW Europe: new data from Sinceny, Paris Basin, France. In: Egger H, ed. Climate and Biota of the Early Paleogene, Conference Program and Abstracts, 5–8 June 2011, Salzburg, Austria. *Berichte Der Geologische Budesanstalt* 85: 135.

Quesnel F, Storme J-Y, Roche E, Iakovleva AI, Missiae P, Smith T, *et al.* 2014. An unexpected record of the PETM in terrestrial and organic sediments of Avesnois, between the Paris and Belgian basins, NW Europe. *Rendiconti Online Societa Geologica Italiana* 7: 183–184.

Riding JB, Kyffin-Hughes JE. 2004. A review of the laboratory preparation of palynomorphs with a description of an effective non-acid technique. *Revista Brasileira Paleontologia* 7: 13–44.

Riveline J. 1986. Les charophytes du Paléogène et du Miocène inférieur d'Europe occidentale. *Cahiers de micropaléontologie*: 227 p.

Roche E, Dupuis C, Stambouli-Essassi S, Russo-Ermoli E, De Putter T, Nicaise D, *et al.* 2008. Phytostratigraphie et paléoenvironnements du Néogène de l'Entre-Sambre-et-Meuse et du Condroz (Belgique). Évolution paléoclimatique du subtropical humide au tempéré froid. *Geo-Eco-Trop* 32: 101–130.

Rouvillois A. 1960. Le Thanétien du Bassin de Paris (étude hydrogéologique et micropaléontologique). *Mémoire du Muséum d'Histoire Naturelle de Paris*, nouvelle série, série C, Sciences de la Terre, tome VIII.

Schimper WP. 1874. Traité de Paléontologie végétale ou la flore du monde primitif dans ses rapports avec les formations géologiques. Paris: J.B. Baillière et Fils.

Schmitz B, Pujalte V, Molina E, Monechi S, Orue-Etxebarria X, Speijer RP, *et al.* 2011. The Global Stratotype Sections and Points for the bases of the Selandian (Middle Paleocene) and Thanetian (Upper Paleocene) stages at Zumaia, Spain. *Episodes* 34(4): 220–243.

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* 7: 29–92.

Smith T, Dupuis C, Folie A, Quesnel F, Storme J-Y, Iacumin P, *et al.* 2011. A new terrestrial vertebrate site just after the Paleocene-Eocene boundary in the Mortemer Formation of Upper Normandy, France. *Comptes rendus Palevol* 10: 11–20.

Smith T, Quesnel F, De Plöeg G, De Franceschi D, Métais G, De Bast E, *et al.* 2014. First Clarkforkian Equivalent Land Mammal Age in the Latest Paleocene Basal Sparnacian Facies of Europe: Fauna, Flora, Paleoenvironment and (Bio)stratigraphy. *PLoS One* 9(1): E86229. https://doi.org/10.1371/Journal.Pone.0086229.

Steurbaut E. 1998. High-resolution holostratigraphy of Middle Paleocene to early Eocene strata in Belgium and adjacent seas. *Palaeontographica A* 247: 91–156.

Steurbaut E, Magioncalda R, Dupuis C, Van Simaeys S, Roche E, Roche M. 2003. Palynology, paleoenvironments, and organic carbon isotope evolution in lagoonal Paleocene-Eocene boundary settings in North Belgium. In: Wing SL, Gingerich PD, Schmitz B, Thomas E, eds. Causes and Consequences of Global Warm Climates in the Early Paleogene. Boulder, Colorado. *Geological Society of America Special Paper* 369: 291–317.

Storme J-Y. 2013. Organic Carbon and Nitrogen Isotopes of the Palaeocene-early Eocene: Implications on Stratigraphy, Paleoenvironment and Paleoclimatology. Namur, Belgium: Namur University.

Storme J-Y, Dupuis C, Schnyder J, Quesnel F, Garel S, Iakovleva AI, *et al.* 2012. Cycles of humid-dry climate conditions around the P/E boundary: Vasterival section (NW France). *Terra Nova* 24: 114–122.

Williams GL, Damassa SP, Fensome RA, Guerstein GR. 2015. *Wetzeliella* and its allies – the "hole" story: a taxonomic revision of the Paleogene dinoflagellate subfamily Wetzelielloideae. *Palynology* 3: 1–41.

Williams GL, Fensome RA, MacRae RA. 2017. The Lentin and Williams index of fossil dinoflagellates 2017 edition. American Association of Stratigraphic Palynologists Contributions Series, No. 48.

Appendix. List of dinoflagellate cyst species

Alisocysta margarita Harland, 1979
Alisocysta sp. 2 *sensu* Heilmann-Clausen, 1985
Apectodinium folliculum Islam, 1983
Apectodinium homomorphum (Deflandre and Cookson, 1955) Lentin and Williams, 1977
Apectodinium hyperacanthum (Cookson and Eisenack, 1965) Lentin and Williams, 1977
Apectodinium paniculatum (Costa and Downie, 1976) Lentin and Williams, 1977
Apectodinium parvum (Alberti, 1961) Lentin and Williams, 1977
Apectodinium quinquelatum (Williams and Downie, 1966) Costa and Downie, 1979

Apectodinium summissum (Harland, 1979) Lentin and Williams, 1981
Areoligera coronata (Wetzel, 1933) Lejeune-Carpentier, 1938
Areoligera gippingensis Jolley, 1992
Areoligera medusettiformis (Wetzel, 1933) Lejeune-Carpentier, 1938
Areoligera senonensis Lejeune-Carpentier, 1938
Axiodinium lunare (Gocht, 1969) Williams *et al.*, 2015
Axiodinium prearticulatum Fensome *et al.*, 2009
Axiodinium sparnacium Iakovleva, 2016
Biconidinium longissimum Islam, 1983
Cleistosphaeridium polypetellum (Davey *et al.*, 1966) Islam, 1993
Conneximura fimbriata (Morgenroth, 1968) May, 1980
Deflandrea denticulata Alberti, 1959
Deflandrea phosphoritica Eisenack, 1938
Dracodinium astra (Costa *et al.*, 1978) Williams *et al.*, 2015
Dracodinium lobiscum (Williams and Downie, 1966) Williams *et al.*, 2015
Dracodinium? *modestum* Iakovleva, 2016
Epelidinium brinkhuisii Iakovleva, 2016
Epelidinium normandiense Iakovleva, 2016
Glaphyrocysta divaricata (Williams and Downie, 1966) Stover and Evitt, 1978
Glaphyrocysta pastielsii (Deflandre and Cookson, 1955) Stover and Evitt, 1978
Heteraulacacysta everriculata Islam, 1983
Homotryblium tasmaniense Cookson and Eisenack, 1967
Homotryblium tenuispinosum Davey and Williams, 1966
Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Davey and Williams, 1973
Melitosphaeridium pseudorecurvatum (Morgenroth, 1966) Bujak *et al.*, 1980
Palaeocystodinium lidiae (Gorka, 1963) Davey, 1969
Palaeotetradinium minusculum (Alberti, 1961) Stover and Evitt, 1978
Petalodinium lenisium Iakovleva, 2016
Phthanoperidinium crenulatum (De Coninck, 1975) Lentin and Williams, 1977
Sophismatia crassoramosa (Williams and Downie, 1966) Williams *et al.*, 2015
Sophismatia tenuivirgula (Williams and Downie, 1966b) Williams *et al.*, 2015
Stenodinium meckelfeldense (Gocht, 1969) Williams *et al.*, 2015
Stichodinium elegantulum Iakovleva, 2016
Stichodinium galliciense Iakovleva, 2016
Stichodinium parisiense Iakovleva, 2016
Stichodinium prostimus Iakovleva, 2016
Stichodinium sympagicum Iakovleva, 2016
Tanyosphaeridium xanthiopyxides (Wetzel, 1933) Stover and Evitt, 1978
Trigonopyxidia ginella (Cookson and Eisenack, 1960) Downie and Sarjeant, 1965
Vallodinium heilmannii Iakovleva, 2016
Vallodinium picardicum Iakovleva, 2016
Vallodinium sp. A *sensu* Iakovleva, 2016
Wilsonidium modicum Iakovleva, 2016

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