YPRESIAN

Etienne STEURBAUT[1]

(8 figures, 1 table, 1 plate)

1. Royal Belgian Institute of Natural Sciences, Vautierstraat 29, B-1000 Brussel, Belgium & KULeuven, Belgium; E-mail: etienne.steurbaut@naturalsciences.be.

ABSTRACT. The historical Ypresian stage concept or Ypresian Synthem, on which this paper focuses, was introduced by A. Dumont in 1849 (minutes of the meeting published in 1850) to specify marine clays and overlying glauconitic sands occurring in the Ieper area (W Belgium), although without mentioning stratotype or type locality. This concept, which clearly evolved in the course of the 19th and 20th century, fundamentally differs from the GSSP-defined Standard Global Ypresian Stage (GSSP ratified in 2003 at Dababiya, Egypt). The latter ranges from 55.8 (± 0.2) to 48.6 (± 0.2) Ma and represents the lowermost Eocene Standard Stage. Here, we briefly discuss the different geological aspects of the Ypresian *sensu* Dumont, currently equated with the Ieper Group, including its stratigraphy and its sedimentological and palaeontological characteristics. The structural context and palaeogeography of the Belgian Basin during the Ypresian are outlined. The major scientific contributions are thematically listed.

KEYWORDS: Ypresian, historical stage concept, Belgium, geological context, synthesis

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1. Name

Ypresian (English), Ypresiaan (Dutch), Ypresium (German), Ypresien (Dumont, 1850; Anonymous, 1893) ou Yprésien (Leriche, 1905; Anonymous, 1929 and several French speaking authors) (French).

2. Age

In the new geological time scale of Gradstein *et al.* (2004) the GSSP-defined Standard Global Ypresian Stage ranges from 55.8 (± 0.2) to 48.6 (± 0.2) Ma. The base of the Stage is defined by a GSSP ratified in 2003 at Dababiya, Egypt (Dupuis *et al.*, 2003). The top is based on an age estimate of the primary guiding criterion for the Ypresian-Lutetian boundary (lowest occurrence of planktonic foraminiferal taxon *Hantkenina*), as no GSSP for this boundary has been designated yet. This formally defined Ypresian Stage fundamentally differs from the historical stage concept (see below, chapter 5).

3. Author

Dumont, 1850, Rapport sur la carte géologique du Royaume. Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, XVI (1849), 2, 351-373.

In his communication during the meeting of the «Académie Royale» on the 10th of November 1849 André Dumont stated that (quote) "*Le terrain éocène se divise en trois systèmes que je nomme landenien, ypresien et bruxellien. Le système ypresien, que je sépare du landenien parce qu'il semble être plutôt marin que d'eau douce et qu'il prend un grand développement aux collines d'Ypres, dans la Flandre occidentale, offre, vers sa partie inférieure, un puissant massif argileux, et, vers sa partie supérieure, des sables glauconifères à grains ordinairement très-fins, qui, dans certaines localités, contiennent un banc de nummulites*".

4. Historical type area

In the original description of his newly introduced Ypresian stage Dumont (1850, p. 369) did mention neither stratotype nor type locality. He simply referred to the "collines d'Ypres" or Ieper Hills (Ypres has to be officially replaced by its original Flemish name Ieper), as the area where the unit is best developed. However, it remains unclear what is meant by this term. The town of Ieper is situated in W Belgium, at the southern end of a small, NW-SE oriented depression (15 to 20 m above mean sea level or T.A.W.), surrounded from north to south by a series of low hills (between 25 to 45 m T.A.W.). Dumont probably envisaged the elevated zones a few km north and east of Ieper (St.-Jan, Zillebeke, etc.), where clay beds have been quarried for brick and tile making for quite a long time (see Fig. 1). This area is located on topographical

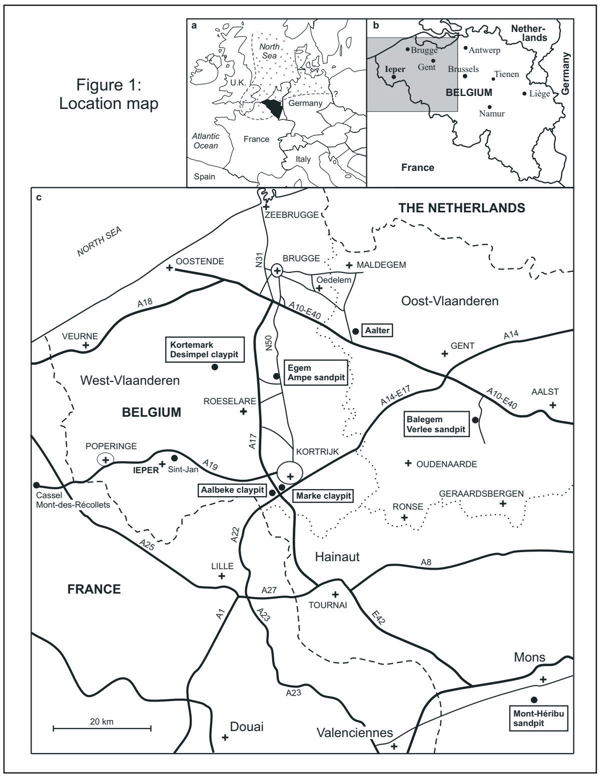

Figure 1. Location of the Ieper area and of the currently accessible Ypresian reference sections (bold face) in Belgium. The position of the Ypresian coastline in NW Europe (North Sea area) is displayed on Fig. 1a.

map Poperinge-Ieper 28/1-2 at 1/25,000, on sheet 81 of the old geological map at 1/40,000 (Rutot, 1897) and on sheet 27-28-36 Proven-Ieper-Ploegsteert of the new geological map at 1/50,000 (Jacobs & De Ceukelaire, 1999). The clay quarry of the "Verenigde Steenbakkerijen van Ieperen" at Sint-Jan, near Ieper (Figs 1 & 2), was designated by Moorkens (1968; confirmed in Willems *et al.*, 1981 and in Willems & Moorkens, 1991) as type locality and stratotype of the Ypresian stage.

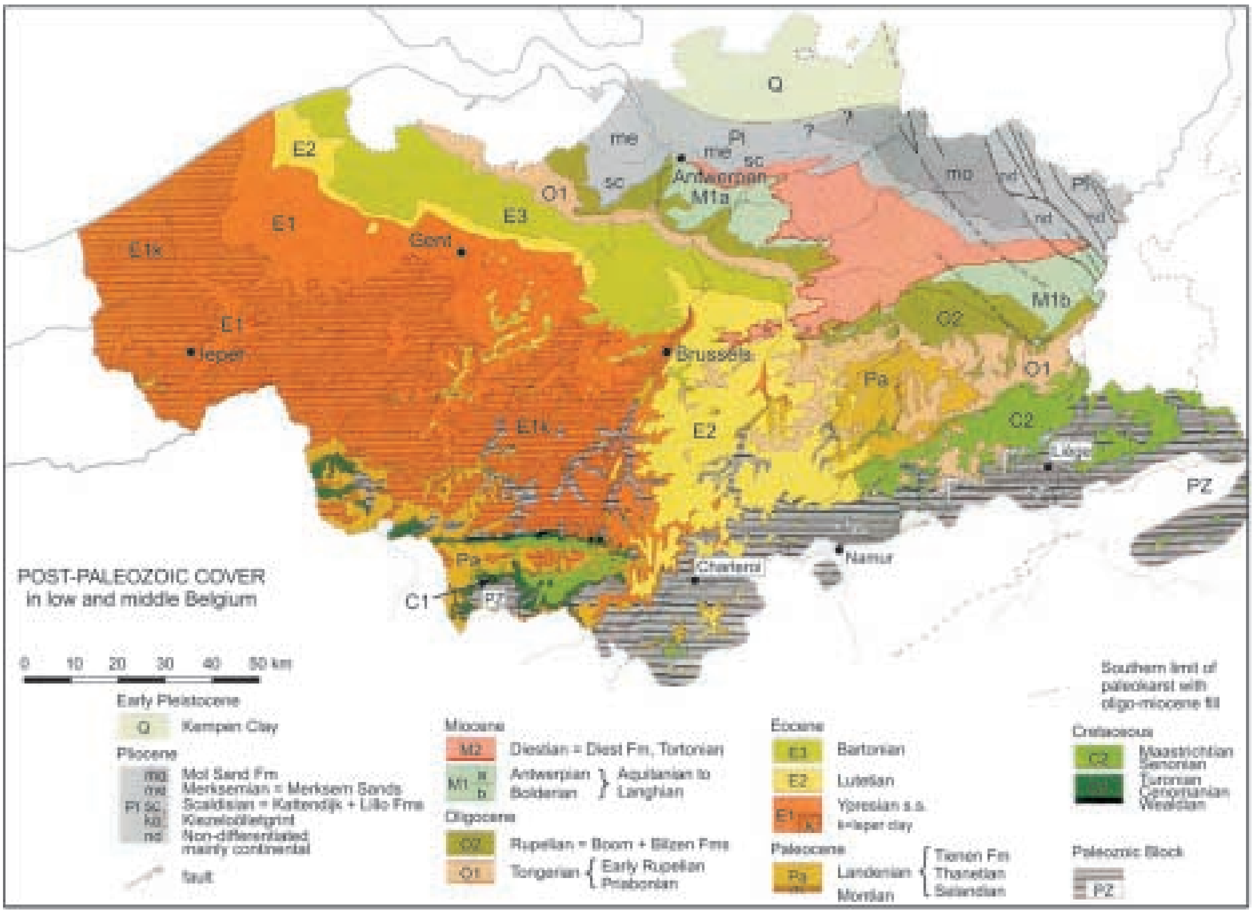

Figure 2. Geological map of north Belgium (Quaternary cover omitted) (after Maréchal, 1992, slightly modified). The Tienen Formation is now included in the Ypresian, according to the newly defined GSSP for the base of the Ypresian Stage.

5. Description

The Ypresian stage (Dumont, 1850) was introduced to specify the marine deposits previously incorporated in the Landenian stage (Dumont, 1839), including a lower thick clayey unit and an upper sandy unit. According to the original definition, the "Ypresian" is sandwiched between the underlying Landenian freshwater deposits and the overlying Bruxellian sand and sandstones (as defined by Dumont in 1839). Whether or not the Aalter Sand Formation has to be included in the Ypresian cannot be ascertained from Dumont's original information (see chapter 6; for details see de Heinzelin & Glibert, 1957, p. 3 and p. 153). As a consequence, the majority of the Belgian geologists currently consider the Ypresian to be an unconformity-bounded unit, corresponding to the total range of the Ieper Group (Fig. 4). It is important to emphasise again that this historical stage concept, for which the term synthem seems to be most appropriate (see Walsh, 2004), is fundamentally different from the formally defined "Ypresian Stage", which is a golden spike-defined Standard Global Chronostratigraphic/Geochronologic unit (Fig. 3). Indeed, since the decision of the Geological Congress at Washington in 1989, approved by the International Subcommission on Paleogene Stratigraphy (Jenkins & Luterbacher, 1992), the Ypresian has been designated to represent the lowermost Eocene Standard Global Stage. The difference between both concepts was clearly illustrated by the work of Steurbaut *et al.* (2003a). They could prove that the base of the negative carbon-isotope excursion, the ratified Paleocene/Eocene boundary criterion or lower boundary criterion of the Ypresian Stage (Dupuis *et al.,* 2003; Magioncalda *et al.*, 2004), is located at the base of the fluvio-lagoonal Tienen Formation. Consequently, this formation, which was traditionally included in the Landenian, has to be incorporated in the formally defined Ypresian Stage (Fig. 3). However, as the present paper relates to a project focussing on Belgian stages, only the historical Ypresian stage concept or Ypresian synthem will be discussed in the following.

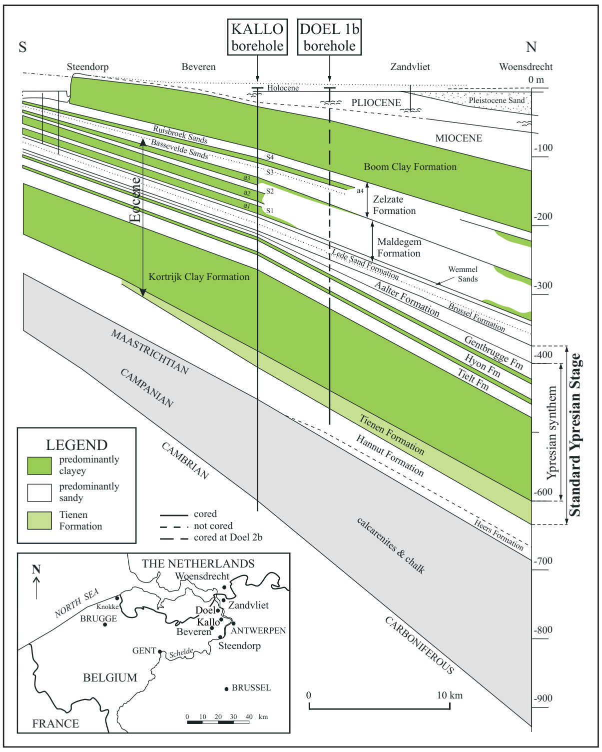

Figure 3. Geological cross-section through the post-Paleozoic of N Belgium with indication of the Ypresian Stage boundaries (after Steurbaut *et al*., 2003a).

6. Historical background

In 1851, shortly after the introduction of the Ypresian, Dumont introduced the term Paniselian stage ("système paniselien") for the clayey-sandy deposits between his formerly defined Ypresian and Brusselian stages (Dumont, 1852b). As this new term was very poorly defined, just figuring in a stratigraphic table, it led, since then, to two different interpretations of the "Ypresian stage concept":

- the Ypresian *sensu stricto* when referring to the two major lithological units defined by Dumont in 1850. In this opinion the Paniselian Stage is considered to be valid (Fig. 4). Its stratigraphic content, however, has been a major point of discussion for over a century. The "Sable glauconifère à *Venericardia planicosta*" (Dumont, 1852a), also known as the Aalter Sands (Nyst, 1842), was not included in the Paniselian by most of the geologists in the second half of the 19th century (Dewalque, 1868, Mourlon, 1880). It was attributed to the Bruxellian, adopting the legend of the first geological map of Belgium (1/160,000; Dumont, 1852a). The term Paniselian was retained in the legend of the subsequent geological map of Belgium (1/40,000) although with a slightly revised interpretation, including a series of strata, from P1m or Merelbeke Clay at the base, to P2 or the Aalter Sands at the top (Anonymous, 1893).
- the Ypresian *sensu lato*, when referring to boundaries mentioned in Dumont's original definition. Here, the Ypresian is considered to include all deposits between the top of the Landenian and the base of the Bruxellian. Consequently, the Paniselian is rejected, falling within the Ypresian. This interpretation, with an "extended" Ypresian and inclusion of the Aalter Sands in the Bruxellian, figured in the first general revision of the legend of the geological map of Belgium (Anonymous, 1929). This second opinion has been adopted in recent national and international compilations on Ypresian or Paleogene stratigraphy (Laga *et al.*, 1980; Willems *et al.*, 1981; Berggren *et al.*, 1985; 1995; Cavelier & Pomerol, 1986; Steurbaut & Nolf, 1986, 1989; Willems & Moorkens, 1991; Maréchal, 1994; Steurbaut, 1998; Laga *et al.*, 2002; Steurbaut *et al.*, 2003b).

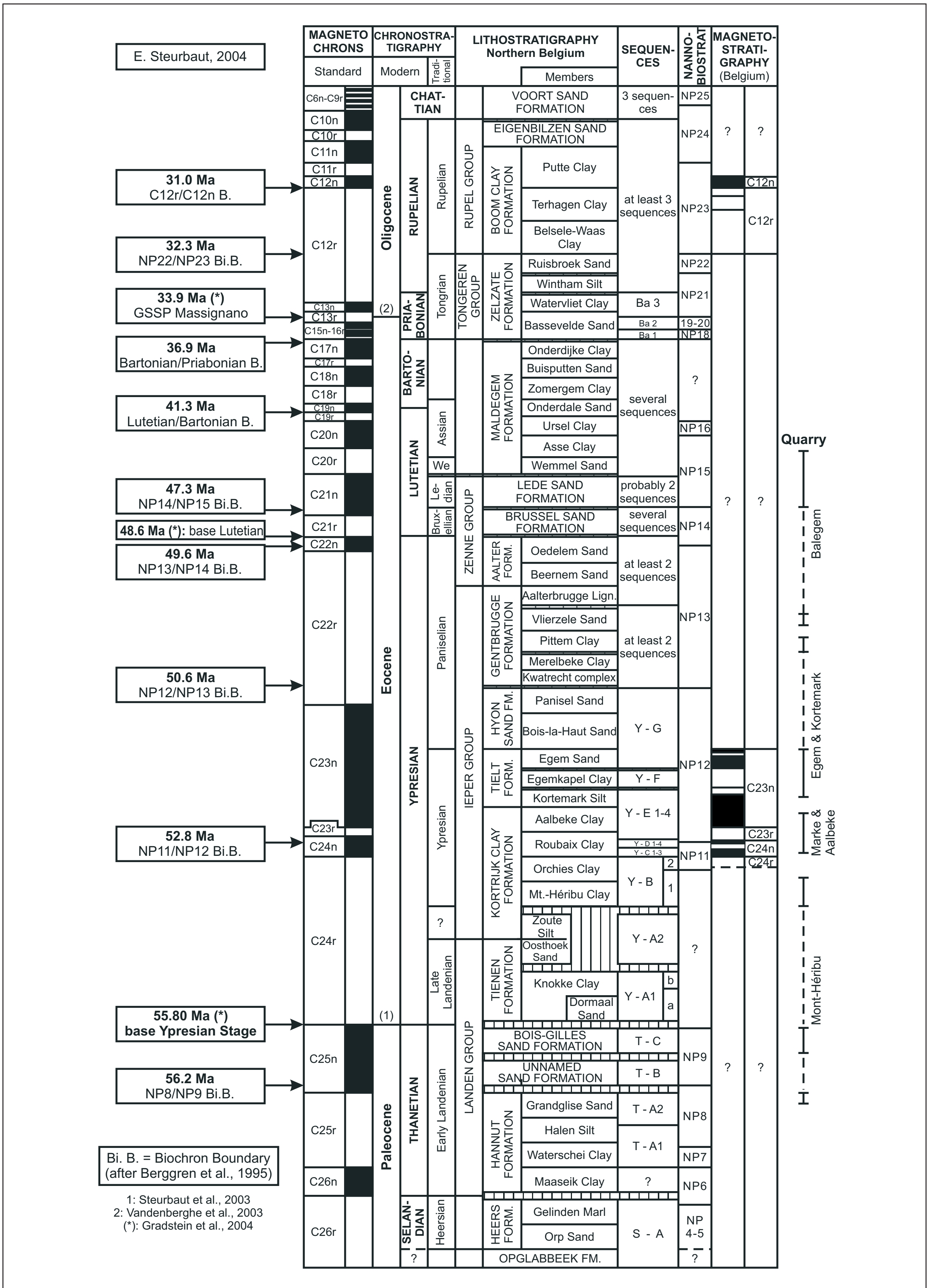

Figure 4. Integrated stratigraphy of the Paleogene of north Belgium with ranges of the currently accessible Ypresian reference sections (We = Wemmelian).

7. Lithology

7.1. Geographic distribution

The Ypresian deposits, currently assembled in the Ieper Group, underlie the whole northern half of the Belgian territory. If the thin Quaternary cover is disregarded they crop out in nearly the entire southern and western sectors of this region (see Fig. 2). They generally rest on Paleocene deposits that are lagoonal in the northwest and continental in the northeast and the southwest (De Geyter, 1981; Steurbaut, 1998; Fairon-Demaret *et al.*, 2003). In the centre of the basin, in the triangle Geraardsbergen-Mons-Genappe southwest of Brussels, they rest directly on Paleozoic deposits (Legrand, 1968, map 11). The thickness of the Ypresian deposits increases northward, from a few metres in the extreme south and southeast to about 150 m in the northern part of the basin, with a maximum recorded thickness in the extreme northwest (Knokke: 182 m). The strata dip gently to the North, but the dip is greater than the inclination of the post-Tertiary erosion surface. Therefore, they are covered by subsequent deposits that become progressively younger northward (see Fig. 3).

7.2. Lithostratigraphic classification

Reviews of the development of the stratigraphic terminology of the Ypresian of Belgium (and northern France) are given by Steurbaut & Nolf (1986) and King (1991). The primary lithological subdivisions of the Eocene established by Dumont (1850, 1852a,b) were formalised into a (nominally chronostratigraphic) letter classification by the Geological Survey of Belgium (e.g. Y for Ypresian, P for Paniselian), each divided further (Ya, Yb etc.) (Anonymous, 1893). This scheme continued in use until the 1980s. A full formal lithostratigraphic classification for the Lower Eocene of Belgium was proposed by Steurbaut & Nolf (1986), based on detailed analysis of calcareous nannofossil biostratigraphy, which required revision of previously accepted correlations. In particular, they demonstrated that the Ypresian 'Yd' sands ("Sands of Mons-en-Pévèle" auctoris), and the overlying stiff clays (Aalbelke Clay) and clayey sand (Panisel Sand) from the southern part of the basin are older and unconnected with their supposed equivalents from northern Belgium, successively the Egem Sands, the Merelbeke Clay and the Vlierzele Sands (see also Steurbaut, 1988a, fig. 1). They divided the Ieper Formation into the Orchies Clay Member, the Roubaix Clay Member, the Aalbeke Clay Member, the Kortemark Silt Member, the Egem Sand Member, the Panisel Sand Member and the Merelbeke Clay Member. The first two of these are formalised versions of the units named by Gosselet (1883) in NW France and applied by Kaasschieter (1961) in Belgium. The Vlierzele Sands of Kaasschieter (op. cit.) were upgraded to formation, including at its base the Pittem Clay Member.

A revised formally defined lithostratigraphic classification of the Late Paleocene and Early Eocene of Belgium was proposed by Steurbaut (1998), based on a series of new formation and member names introduced by Maréchal (1994). In Steurbaut's revision the Ieper Group, Kortrijk Clay Formation and Tielt Formation were formally defined for the first time, and the Members of the Kortrijk Clay Formation were summarised and slightly redefined. The new member names introduced by Maréchal (Saint-Maur Member and Moen Member, replacement names for the Orchies Clay and Roubaix Clay Members) were regarded as informal, due to their lack of formal definition of stratotypes, boundaries, and lithological characteristics, and were not accepted.

7.3. The stratigraphic succession

In recent syntheses on Belgian lithostratigraphy (Laga *et al.*, 2002; Steurbaut *et al.*, 2003b) the Ieper Group, which corresponds to the historical Ypresian Stage concept or the Ypresian synthem, includes, in ascending order, the Kortrijk Clay Formation, the Tielt Formation, the Hyon Sand Formation and the Gentbrugge Formation (see Fig. 4).

The Kortrijk Clay Formation (Lyell, 1852; Steurbaut, 1998) is part of a sheet of neritic marine argillaceous sediments of similar facies, extending through the southern margin of the North Sea Basin, from southern England (London Clay Formation) through northernmost France, Belgium, the Netherlands and west Germany (King, 1981; Vinken, 1988), into the southern North Sea. It grades laterally southwards and eastwards in SW Belgium and northern France into inner neritic sand-dominated sediments, assigned to the Morlanwelz Sand Member and the Mons-en-Pévèle Formation (Steurbaut & Nolf, 1986; King, 1991; Steurbaut & King, 1994). To the north it grades into clays deposited in bathyal environments.

The Kortrijk Clay Formation, which reaches a thickness of approximately 100 m in the north of Belgium, is divided into five successive members. The lower Zoute Silt Member (named Member X by King, 1990; formally renamed by Steurbaut, 1998) is a 4 m thick glauconitic sandy clayey silt, containing wood fragments and degraded volcanic ash particles. It seems to be restricted to the extreme NW of Belgium (only known from Knokke borehole, between 284.1 m and 288 m depth). The basal contact with the underlying Tienen Formation is sharp. It is separated from the overlying Mont-Heribu Clay Member (Cornet, 1874; formally named and described by De Coninck *et al.*, 1983) by a bioturbated surface. This member comprises up to 9 m thick (in Kester borehole) carbonate-free very silty clays with a glauconitic base and diffuse beds of sandy silt and silty clay, more poorly sorted than overlying units. It thins towards the basin centre (less than 1 m at Knokke). The Mont-Héribu Member occurs throughout N Belgium, resting on the Landen Group (except at Knokke, on Zoute Silt), or where it is absent on Paleozoic rocks. Outcrops are restricted to the Mons area (including its stratotype the Mont-Héribu quarry) and southwest of Brussels (Quenast, Lessines). It extends through the southern margin of the North Sea Basin, from southern England (Division A2 of King, 1981) through northernmost France (the "Argiles et Sablons", Dupuis *et al.*, 1998). It passes upwards rather sharply into the ORCHIES CLAY MEMBER (introduced by Gosselet, 1874; redefined by Steurbaut, 1998). The latter is a carbonate free up to 25 m thick very stiff clay, which crops out in Northern France and in the area south and northwest of Mons. The contact with the overlying ROUBAIX CLAY MEMBER (introduced by Gosselet, 1874; formalised by Steurbaut & Nolf, 1986 and redefined by Steurbaut, 1998) is marked by the change from non-calcareous stiff clays to calcareous siltier clays. It is identified only in boreholes, where it can be traced using grain-size data and gamma-ray logs (Steurbaut 1998, figs 4, 10). The Roubaix Clay Member comprises calcareous clays and silts with subordinate very fine sands. The stratotype, originally selected by Steurbaut & Nolf (1986) as the Moen section (Kortrijk – Bossuit canal), was redefined by Steurbaut (1998) through boundary stratotypes, in the Kallo borehole and Kobbe quarry (Aalbeke) respectively. King & Steurbaut (in press) recently reviewed its stratigraphy and paleontology. The Roubaix Clay Member passes laterally into the middle London Clay Formation (Divisions B, C and D) in the London-Hampshire Basins and into the "Argiles des Flandres" in N France. Towards the margin of the North Sea Basin it grades into sand-dominated facies (MORLANWELZ SAND MEMBER, introduced by Mourlon, 1873 and MONS-EN-PÉVÈLE SAND FORMATION, introduced by Ortlieb & Chellonneix, 1870 and redefined by Steurbaut & King, 1994, in Belgium; the Laon Sands, Pierrefonds Sands and Cuise Sands in the Paris Basin: Steurbaut, 1988b). The Roubaix Clay is overlain by non-calcareous (secondarily decalcified) very fine silty clay, named AALBEKE CLAY MEMBER (De Moor & Geets, 1975; defined identically by Steurbaut & Nolf, 1986 and King 1991). Its basal boundary stratotype is defined in the Kobbe quarry, Aalbeke (Steurbaut, 1998). Phosphatic nodules with crab or lobster fragments occur at the junction with the underlying Roubaix Clay. It occurs throughout N Belgium with decreasing thickness towards the east and south (from 20 m at Ieper to about 10 m at Kortrijk and 4 m at Kallo).

The TIELT FORMATION (Maréchal, 1994; Steurbaut, 1998) is a heterogeneous unit of mid-Ypresian age. It is subdivided into three members with different lithologies. Its lower boundary was defined in the Tielt borehole at 71 m depth, its upper boundary in the Egem quarry at the contact of the Egem Sands and the overlying Pittem Clay (Steurbaut, 1998). The three members are recognised throughout N Belgium, although with fluctuating thickness. Some members may be missing towards the south and east. Correlations with southern England and northern France are not well understood up to now. The lower KORTEMARK SILT MEMBER introduced by Steurbaut & Nolf (1986), was redefined by Steurbaut (1998) to include the predominantly silty deposits overlying the Aalbeke Clay, but excluding the topmost silty clay, which was named Egemkapel Clay. It is restricted to the west of the Belgian Basin, with maximum thickness of about 40 m in the outcrop area (Kortemark quarry, Tielt borehole), rapidly thinning towards the east. It is only slightly calcareous in outcrop. Five lithologically distinct intervals are recognised in the type area. The overlying, maximum 5 m thick, EGEMKAPEL CLAY MEMBER (Steurbaut, 1998) occurs throughout N Belgium, although with reduced thickness (~ 1 m) towards the southeast. It is bounded below and above by major omission surfaces. Its base is rich in shark teeth, worm tubes and phosphatic remains, representing a sequence boundary (Y-F of Steurbaut, 1998). The overlying, up to 20 m thick, shallow marine EGEM SAND MEMBER (Laga *et al.*, 1980; Steurbaut & Nolf, 1986) is made up of glauconitic, micaceous fine sand with some thin clay beds and nummulite-rich shell beds, representing the lowstand systems tract of sequence Y-G (Steurbaut, 1998). Steurbaut (1988a, 1998) distinguished 21 beds in its stratotype at Egem (Fig. 8). Jacobs *et al.* (1997) subdivided this member into 6 subunits in the area south of Gent, on the basis of the results of core penetration tests. It is restricted to NW Belgium and seems not to have been deposited south of the line Ieper-Brussels (Fig. 1).

Steurbaut & King (1994) introduced the HYON SAND FORMATION to specify the lower part of the ambiguous and badly defined term Paniselian (Dumont, 1852b), which up to the 1980s was used for glauconitic clayey sand facies occurring throughout the Ypresian (including Aalter Sands). It was subdivided into two members, both identified in its stratotype the Mont-Panisel borehole (Dupuis *et al.*, 1988) and representing the transgressive and highstand systems tract of third order sequence Y-G respectively (Steurbaut, 1998). The Hyon Sand Formation is recorded from outcrops and shallow boreholes in the area Gent-Brussels-Mons-Kortrijk, where its thickness reaches up to 25 m. It has only locally been preserved further northward, being subject to major erosion, preceding the deposition of the overlying Gentbrugge Formation. It rests on different units, depending on its position in the basin (on the Mons-en-Pévèle Sand Formation in its stratotype; on the Aalbeke Clay in the Kortrijk area, etc.). The lower BOIS-LA-HAUT SAND MEMBER (Steurbaut & King, 1994) consists of 3.6 m, carbonate-free, highly bioturbated, glauconitic well-sorted fine to medium fine sand. It is only recorded in its stratotype the Mont-Panisel borehole, covering the Mons-en-Pévèle Sand Formation. The overlying MONT-PANISEL SAND MEMBER (d'Omalius d'Halloy, 1862; Steurbaut & King, 1994), equating the Panisel Sand Member of Steurbaut & Nolf (1986), consists of poorly sorted, prominently glauconitic and highly bioturbated clayey fine sands, which present a slight coarsening upward trend. Locally occur poorly cemented nummulite-bearing sandstones.

The term Gentbrugge Formation (Laga *et al.*, 2002) replaces the term Gent Formation, an incorrectly used name by Maréchal (1994), preoccupied for a unit within the Quaternary of Belgium. It corresponds to the middle part of the obsolete, ambiguously and vaguely defined name "Paniselian" (Dumont, 1852b; Gulinck & Hacquaert, 1954) and to the Vlierzele Formation of Steurbaut & Nolf (1986). Steurbaut & Nolf (in press) have recently subdivided this formation into 5 distinct members. The Gentbrugge Formation is well developed in the Gent area, reaching over 30 m thickness, although not always represented by the entire suite of members. Towards the east it probably passes into parts of the Brussel Sand Formation. The lower Kwatrecht Member (De Moor & Geets, 1974; a controversial term validated by Steurbaut & Nolf, 1986) is a 3 m thick unit, consisting of alternating fine sand and sandy clay beds. It has been identified in the Gent area (De Moor & Geets, 1974) and recently in the Zemst borehole (Steurbaut, pers. com.). The overlying Merelbeke Clay Member (De Moor & Germis, 1971), composed of very fine silty clay to clayey fine silt, is characteristically decalcified, both in outcrop and in subsurface. It contains thin sand lenses with organic material and small pyritic concretions, locally moulds of bivalves and pteropods (King, 1990). It is known from NW Belgium and the Cassel area. In central Belgium it seems not to have been deposited south of the line Ronse-Brussels. The Pittem Clay Member (Geets, 1979) consists of an alternation of thin layers of clayey coarse silt and clayey fine glauconitic sand, locally cemented to thin sandstone and siltstone bands. Its base is always poorly sorted and much coarser. In the type area (Pittem to Egem) this basal unit is locally cemented into a 40 cm thick sandstone, rich in bivalves, phosphatic nodules, shark teeth and coarse-grained glauconite (Hooglede Bed of Fobe, 1997). Its lower junction is considered to represent a sequence boundary. The Pittem Clay generally rests on the Merelbeke Clay, but when the latter is missing on the Egem Sands or the Hyon Sand Formation. The Vlierzele Sand Member (Kaasschieter, 1961) is widespread in NW Belgium, although generally decalcified in outcrop. Exposures of these heterogeneous glauconitic fine to medium-grained sands with thin, but very hard silica-cemented sandstone bands have been frequently observed in the area between Ronse, Gent and Brussels (Fig. 1), although almost never in their full extent. Their stratigraphy was only poorly understood until recently. Fobe (1996) subdivided the Vlierzele Sand unit into 5 subunits, giving member status. However, this new classification is not followed here as it is based on erroneous correlations and misinterpretations. The Vlierzele Sands, representing a tidal sand ridge (Houthuys & Gullentops, 1988) are generally overlain by the Aalter Sand Formation, or when it is missing, e.g. in the area south of Gent, by the Lede Sand Formation. The Aalterbrugge Member was introduced by Hacquaert (1939) (originally termed Aalter-Brug Lignitic Horizon or Aalter-Canal Beds) to specify the whitish glauconitic sands with basal chocolate-coloured lignite-rich lenses and lignitic clay pebbles, exposed during construction works on the Canal Gent-Zeebrugge. These stratotype deposits have only been very shortly exposed. Until recently, the significance of the Aalterbrugge Member, considered to be valid by Steurbaut & Nolf (1986) has remained unclear. New observations along motorway E40 at Wetteren and in the Hijfte borehole (Steurbaut, pers. com.) have allowed identifying glauconitic sands with lignitic clay beds, matching very well Hacquaert's original definition. The contact with the overlying Aalter Sand Formation is sharp.

8. Sedimentology and palaeogeography

During the Ypresian, just after the Initial Eocene Thermal Maximum (Steurbaut *et al.*, 2003a), the current Belgian territory was covered by an epicontinental sea (Fig. 1a), which underwent a series of major sea-level changes. Sea levels were highest during the early Ypresian (Kortrijk Formation). In the extreme NW (Knokke; Laga & Vandenberghe, 1990), at probably more than 200 m depth occurred anoxic muddy sea-bottoms (belt IV, Fig. 5a). Towards the coastline, to the S and SE, sedimentation conditions progressively changed from anoxic upper bathyal to well-oxygenated infralittoral (50 to 100 m depth), with muddy to silty sea-bottoms (belt III). This belt occupied most of the Belgian Basin. A shallow sea covered the area further southward, S of the line Brussels-Lille, up to the north flank of the Ardennes, which formed the coastline. This area represented the foreshore, shoreface and offshore-transition zones, marked by sandy sea-bottoms and strong currents (belt II). This shallow belt extended southward into the Paris Basin (Mégnien, 1980). Further southwards developed an exclusively continental depositional regime (belt I).

During the Late Ypresian, the Early Ypresian subtropical climate continued, although with increasing temperatures, known as the Early Eocene Climatic Optimum (Zachos *et al.*, 2001; Van Simaeys *et al.*, 2003). Sea levels, although subject to substantial changes, were much lower. The coastline shifted 200 to 250 km northward, probably slightly north of the line Mons-Lille (Figs 1 & 5b). The entire Paris Basin permanently emerged (belt I), major parts of the London-Hampshire Basin only temporarily, whereas the Belgian Basin was covered by a shallow sea with very gently dipping sea-bottom (belt II), marked by an alternating sandy-clayey depositional regime.

The Ypresian deposits consist of an alternation of clays and sands, in which several depositional sequences, resulting from the interplay of eustatic sea-level changes and tectonic phenomena can be identified (Steurbaut, 1998; Vandenberghe *et al.*, 1998, 2004). These deposits can be attributed to four lithofacies groups, in which several facies or subfacies can be recognised (Steurbaut & King,

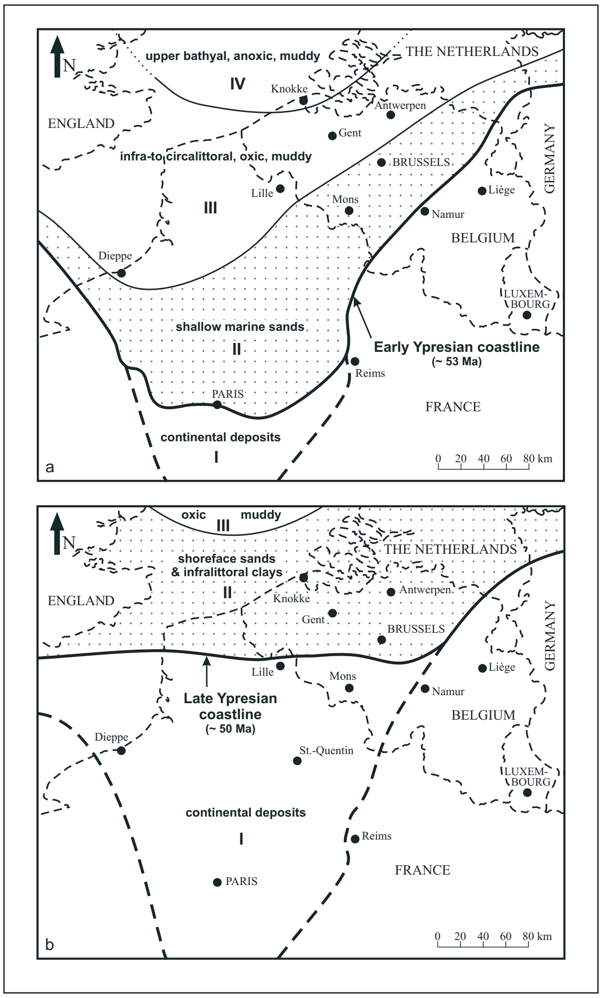

Figure 5. Palaeogeography and facies belts in the southern North Sea Basin during the Ypresian (a: Early Ypresian, b: Late Ypresian).

1994; King & Steurbaut, in press). Apart from grain-size analyses (Geets, 1991), clay-mineralogical investigations (Mercier-Castiaux & Dupuis, 1991) and a petrographic study of a sandstone level in the Roubaix Clay (Fobe, 1991), the sedimentology of the two most fine-grained lithofacies (the stiff clays and the silty clays-clayey silts respectively) has not been studied exhaustively. The stiff clays (e.g. Orchies Clay, Aalbeke Clay, Merelbeke Clay) are non-calcareous, although contain pyritised fossils (such as molluscs, diatoms, pteropods), indicating early diagenetic decalcification. They represent the deepest phase within the successive sequences, reflecting sedimentation on muddy sea-bottoms in an offshore depositional regime. The Merelbeke Clay, with its high quantities of the freshwater algae *Pediastrum* at its top, indicating substantial freshwater influx, might be somewhat more coastal. The silty clays or clayey silts (Roubaix Clay, Kortemark Silt, Egemkapel Clay, Pittem Clay), representing the second group, are much more heterogeneous, containing sand beds, shell beds, sandstones and glauconite levels. They are calcareous in outcrop and subcrop. Some outcrop sections are carbonate-free, due to post-depositional weathering. As a whole this lithofacies group reflects marine offshore conditions, although with a shallowing trend upward in the succession. Some levels within these facies, such as the beds overlying bases of sequences and transgressive surfaces, or shell beds, have been deposited above fair-weather wave base, but do not evidence subaerial exposure. The third and fourth lithofacies include the sandy facies. The sedimentology of these groups is better understood, due to detailed grain-size analyses (Geets, 1991, 2001; Fobe, 1996), petrographic analyses (Fobe, 1993), studies of sedimentary structures (e.g. Egem Sand Member, unpublished master theses by Willems, 1995 and Crepin, 2004; the Vlierzele Sand Member by Houthuys & Gullentops, 1988 and Houthuys, 1990) and heavy minerals (Geets & De Breuck, 1983, Geets, 2001). The third group includes the calcareous sandy silts and very fine sands, clayey or not, and often glauconitic, in which several subfacies can be identified (e.g. bioturbated, laminated/cross laminated, mud-silt interbeds and sandstones). This facies group is dominant in the Morlanwelz Sand Member, Mons-en-Pévèle Sand Formation, Egem Sand Member and Hyon Sand Formation. As a whole they have been deposited in the offshore-transition zone, below mean fair-weather wave base. The thin shell beds or the sharp-bounded cross-laminated units accumulated during storm-generated pulses of erosion and sediment transport, by reworking and sorting of the shallow marine sands (Steurbaut & King, 1994). The fourth lithofacies is made up of fine to medium-grained sands, often bioturbated or cross-laminated. It is well represented in the Vlierzele Sand Member. The latter is interpreted as a longitudinal tidal sand ridge, consisting of a series of stacked storm-generated megaripples (Houthuys & Gullentops, 1988).

9. Palaeontology

The successive units of the Ieper Group have been the subject of detailed micropalaeontological investigations (see Table 1 for references), including calcareous nannofossils (C= calcareous), planktonic and benthic foraminifera (C), nummulites (C), ostracods (C), pteropods (C, sometimes pyritised), calcareous algae (C), calcareous problematica (pseudarcellids and bignotellids, both C), radiolarians, pollen and spores, diatoms, dinoflagellate cysts, sponge spicules and echinoderm spines (C). The stiff clays, included in lithofacies group 1, such as the Orchies Clay or Merelbeke Clay, do not contain calcareous fossils. They can, however, be represented by pyritic moulds. The coarser-grained facies within group 4 (e.g. Vlierzele Sands) are generally devoid of microfossils, because of the coarse grain-size, the often too marginal marine environment or of post-depositional decalcification and/or oxidation. The remainder, the entire gamut of deposits within lithofacies groups 2 and 3, generally contains diversified and fairly rich microfossil associations, which have led to a precise dating of the different units involved (chapter 10).

Lithostratigraphy		Steurbaut & Nolf, 1986, in press Steurbaut, 1988a; King, 1990, 1991 Steurbaut & King, 1994 Maréchal, 1994; Steurbaut, 1998
Biostratigraphy	Calcareous nannofossils	Steurbaut & Nolf, 1986, in press Steurbaut, 1988b, 1990, 1991, 1998 Steurbaut & King, 1994
Biostratigraphy	Foraminifera	Kaasschieter, 1961; Willems, 1983, 1991; Hooyberghs, 1983; King, 1990, 1991; Steurbaut & King,1994
Biostratigraphy	Ostracods	Keij, 1957; Willems, 1975, 1978 King, 1990; Dupuis et al., 1990 Hooyberghs et al., 2002
Biostratigraphy	Micro-problematica	Willems, 1972; King, 1990 Steurbaut & King, 1994
Biostratigraphy	Siliceous microfossils	Willems, 1981; King, 1990; Moorkens et al., 2000; Van Eetvelde et al., 2004
Biostratigraphy	Dinoflagellate cysts	De Coninck, 1976, 1981, 1986, 1991, 1999 a,b; Islam, 1982; De Coninck et al.,1983; Steurbaut et al., 2000, 2003a
Biostratigraphy	Pollen & Spores	Roche, 1982, 1991 Steurbaut et al., 2003a
Palaeontologyy	Macroflora	de Heinzelin & Glibert, 1957 Moorkens & Verhoeve, 1967 Willems & Genot, 1984 Doutrelepont et al., 1997
Palaeontologyy	Molluscs	Briart & Cornet, 1878 Dhondt, 1967; King, 1990
Palaeontologyy	Serpulids, Corals, Bryozoa	King, 1990 Steurbaut & King, 1994
Palaeontologyy	Arthropoda	Van Straelen, 1921 a,b Steurbaut & Nolf, 1986
Palaeontologyy	vertebrates: fishes	Casier, 1946, 1950, 1967; Nolf, 1986; Leriche, 1905, 1906; Herman, 1979; Steurbaut & Nolf, 1991
Palaeontologyy	vertebrates: reptiles	Leriche, 1926; Rage, 1983
Palaeontologyy	vertebrates: mammals	Smith, 2000; Smith & Smith, 2003 Smith et al., 2004
Sedimentology		De Moor & Geets, 1974 Houthuys & Gullentops, 1988 Houthuys, 1990; Geets, 1991, 2001 Steurbaut & King, 1994 Willems, 1995; Crepin, 2004
Petrography		Fobe, 1991, 1993
Clay mineralogy		Mercier-Castiaux & Dupuis, 1991 Steurbaut et al., 2003a
Heavy minerals		Geets & De Breuck,1983; Geets,2001
Geochemistry		Quinif et al., 1982, 1983
Geophysical log correlation		Jacobs et al., 1997 ; De Ceuckelaire & Jacobs, 1998; Steurbaut, 1998 Vandenberghe et al., 1998
Magnetostratigraphy		Ali et al., 1993
Isotope stratigraphy		Steurbaut et al., 2003a
Tectonic features		Demyttenaere & Laga, 1988 Henriet et al., 1991; Verschuren, 1992 Van Vliet-Lanoë et al., 2002
Reflection seismic stratigraphy		Henriet et al., 1989, 1991; De Batist & Henriet, 1995; De Batist et al., 1999
Sequence stratigraphy		Jacobs & De Batist, 1996; Steurbaut, 1998; Vandenberghe et al.,1998, 2004
Chronostratigraphy		Willems et al., 1981; Steurbaut, 1998; Willems, 1982; Steurbaut et al., 1999 Steurbaut et al., 2003b
General handbooks		Maréchal & De Breuck 1979 Robaszynski & Dupuis1983; Maréchal, 1992; Wouters & Vandenberghe,1994

Table 1. Summary of compilation studies on the Ypresian of Belgium.

The richest macrofossil associations were collected from outcrops belonging to lithofacies group 3 (Morlanwelz Sand Member, Mons-en-Pévèle Sand Formation, Egem Sand Member, for references see Table 1). Molluscs dominate the calcareous macrofauna. Except for these in the Egem quarry (Van Nieulande, 2002) and the Marke quarry (King & Steurbaut, in press) they have not been studied in much detail. The calcareous macrofauna also contains to a much lesser degree, corals, serpulids, bryozoa and brachiopods. Rich fish-otolith associations have been collected throughout the Ieper Group, mainly in the sandy facies. The macroflora includes fruits of the palm tree *Nipadites*, reproductive organs of Dasycladacean algae and silicified wood. Arthropods (lobster and crab fragments), generally found in phosphatic nodules, are known from specific levels in the Roubaix Clay Member and at the base of the Aalbeke Clay Member. The vertebrate records mainly relate to shark and ray teeth, which are strongly concentrated in specific levels, such as at sequence boundaries or transgressive surfaces (in the Mons-en-Pévèle Sand Formation, at the base of the Egemkapel Clay and in the basal beds of the Egem Sand Member). Isolated terrestrial mammal teeth very rarely occur in the same levels. Reptile bones have also been mentioned from the Ieper Group. King & Steurbaut (in press) have recently re-investigated the palaeontological content of the upper part of the Kortrijk Formation in detail.

10. Chronostratigraphy

The study of the calcareous nannofossils (Steurbaut & Nolf, 1986; refined in Steurbaut, 1998) has led to exact positioning of the successive units within the Ieper Group and, consequenly, to final resolution of the Ypresian stratigraphy and to its integration in the geomagnetic polarity time scale of Berggren *et al.* (1995). Martini's (1971) standard calcareous nannoplankton zones NP11, NP12 and NP13 have been identified in the Ieper Group. The first interpretable Ypresian nannofossil associations occur in the upper part of the Orchies Clay (lower NP 11). The boundaries between zones NP11-NP12 and NP12-NP13 have been pinpointed within the Roubaix Clay (base unit 22a of King & Steurbaut, in press) and at the base of the Gentbrugge Formation respectively (Figs 4 & 6). The NP13/NP14 boundary falls within the upper part of the Aalter Formation. All these nannoplankton zones have been subdivided into a series of subzones (Steurbaut, 1998; see also Fig. 6), which can be recognised throughout the North Sea Basin (Steurbaut in Schmitz *et al.*, 1996), in California in the west (Steurbaut, 1988b) and in the Crimea and Kazakhstan (Iakovleva *et al.*, 2004) in the east.

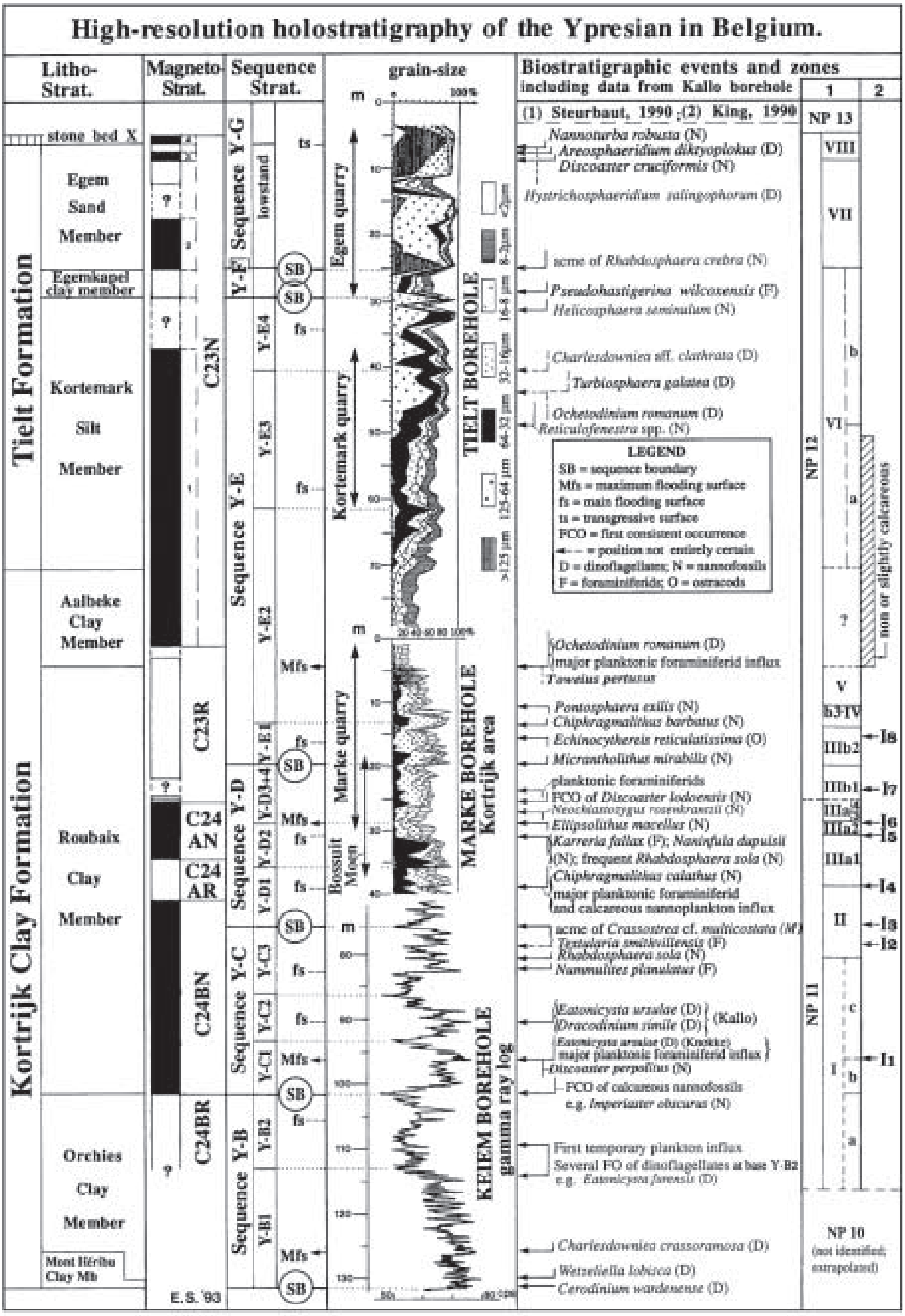

Figure 6. High-resolution holostratigraphy and key-fossils in the Ypresian of Belgium (after Steurbaut, 1998).

Dinoflagellate cysts have contributed much to the positioning of the carbonate-free units (Aalbeke Clay, Merelbeke Clay) within the Ypresian succession. The zonation of De Coninck (1991) has proved to be applicable in the southern North Sea Basin. Planktonic foraminifera suggested attribution of the Ieper Group to zonal interval P6b to P9 of Berggren (Hooyberghs, 1983; Willems & Moorkens, 1991). Several regional assemblage zones have been defined, based on benthic foraminifera, ostracods, diatoms and pollen and spores (for references see Table 1), allowing correlation with the Standard North Sea Basin biozonation of King (1989). These different assemblages have been discussed in detail by Willems & Moorkens (1991); the diatoms were reviewed by Mitlehner (1996).

Ali *et al.* (1993) proved that the middle part of the Ieper Group was laid down during the interval spanning geomagnetic Chrons C24BR to C22R (see also Figs 4 & 6), allowing its calibration with the geomagnetic polarity time scale of Berggren *et al.* (1995). The base of Chron C24BN, currently redefined as C24n.3n, which has an estimated age of 53.3 Ma, has been identified at the base of the Roubaix Clay Member. The base of Chron C23N redefined as C23n.2n and estimated at 51.8 Ma appears to fall within the lower Aalbeke Clay Member.

11. Geochronology

Detailed Rb/Sr analyses on green pellets from a major glauconite level in the middle of the Roubaix Clay Member (unit 20 of King & Steurbaut, in press) revealed low Rb- and high Sr contents and inconsistent D/P ratios, pointing to apparent Rb/Sr ages between 65 Ma and 85 Ma (Keppens, 1981). The incomplete transformation of detrital material, resulting in open lattice glauconite, and probably the inherited radiogenic Sr^{87}, inconsistently caused the high apparent ages. The age of the base of the Standard Ypresian Stage set at 55.8 (± 0.2) Ma was derived through astronomical tuning, scaled from base-Paleocene (Gradstein *et al.*, 2004).

12. Structural environment

The Belgian Basin, a bight-like extension of the southernmost North Sea Basin (Ziegler, 1990, encl. 34), can be classified as an intracratonic basin in a ramp-type margin shelf setting, being surrounded by a series of "old massifs", such as the Welsh-Anglian High in the west, the Armorican Massif in the south and the Ardennes in

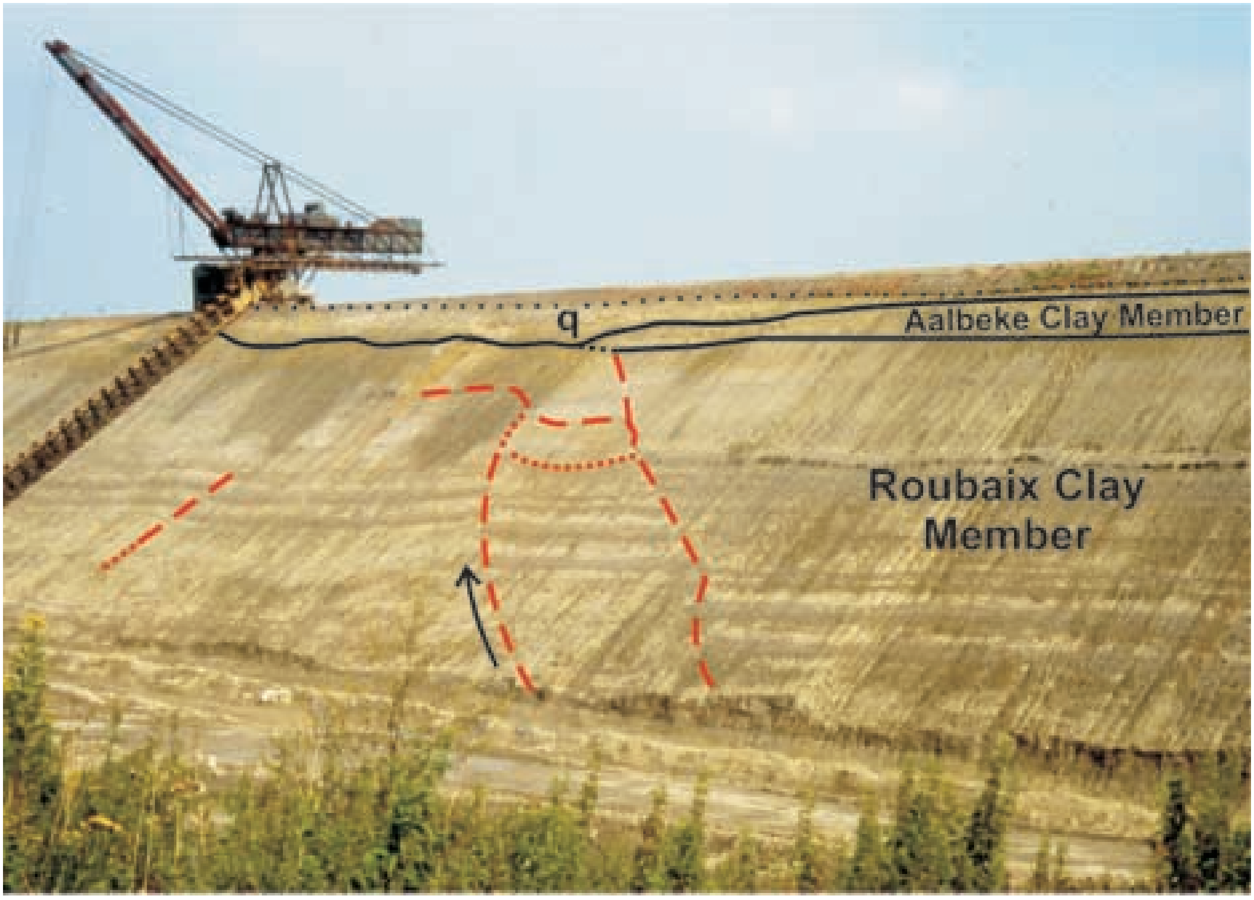

Figure 7. The Marke quarry section exposing the faulted blocks in the middle of the Kortrijk Clay Formation (q = Quaternary cover and dumped material).

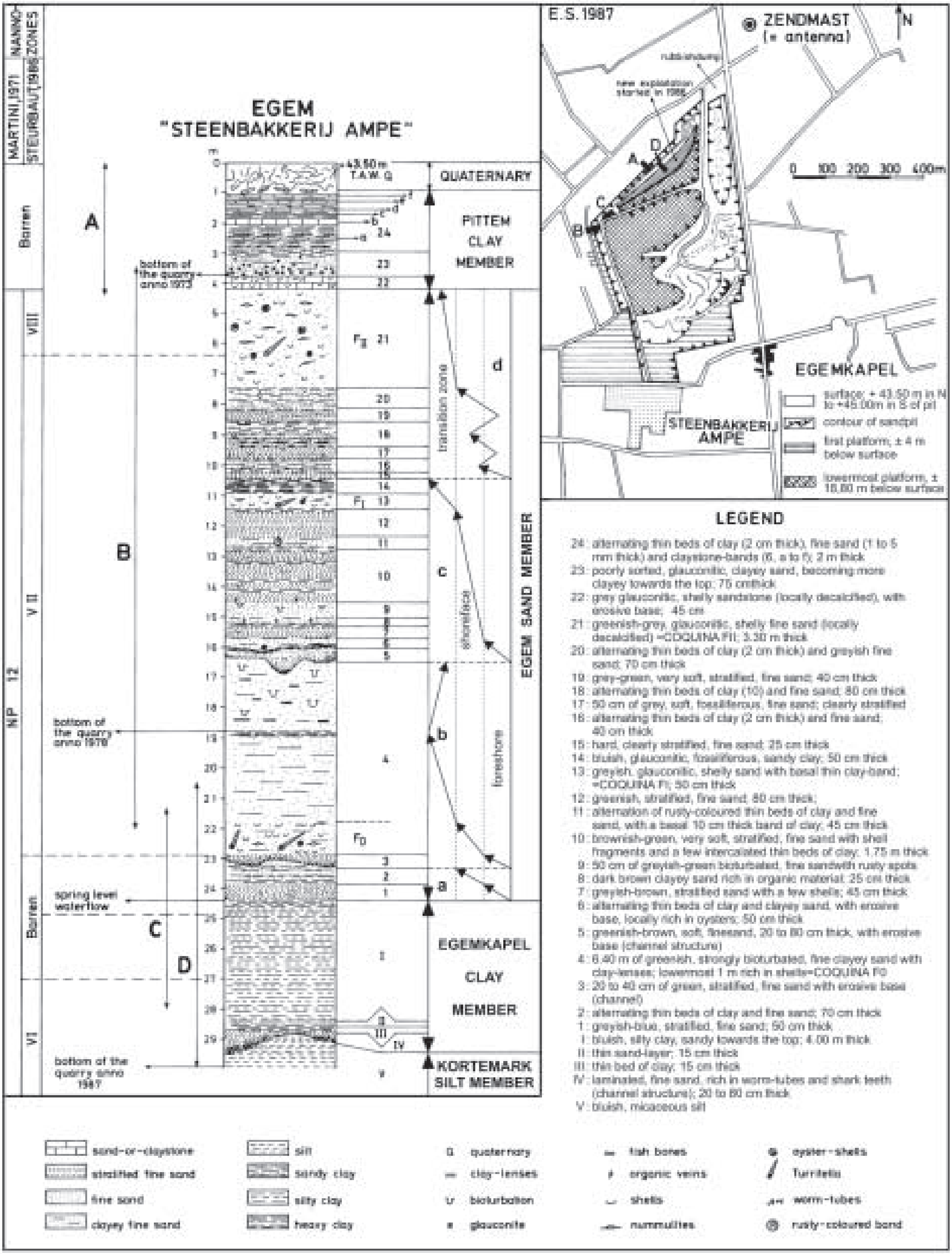

Figure 8. Stratigraphy of the Ypresian deposits in the Egem (Ampe) quarry.

the southeast. Through the North Sea Basin it had a permanent opening towards the North Atlantic Ocean and indirect connections to the Tethys via N Germany and Poland. It was also temporarily connected to the Atlantic Ocean through the Channel. The Belgian Basin developed on top of the London-Brabant Massif, a relatively stable block of Palaeozoic age. This block was not flooded before Late Cretaceous times and continued to shelter the area from strong subsidence throughout the Paleogene and Neogene (Vandenberghe *et al.*, 2004). However, as shown by detailed lithofacies analysis, this block, as well as the Roervalley Graben in East-Belgium, underwent vertical movements as a response to the final phase of the opening of the North Atlantic Ocean and to plate tectonic rearrangements in the Alpine realm (Demyttenaere & Laga, 1988, De Batist & Versteeg, 1999). Small-scale vertical deformations, restricted to the thick clay mass of the Kortrijk Clay Formation, have been frequently observed in offshore (Henriet *et al.*, 1991) and onshore seismic profiles (De Batist & Versteeg, 1999) and in outcrop sections (Steurbaut & Nolf, 1986; Verschuren, 1992; see Fig. 7). The Kortrijk Clay Formation seems to consist of numerous 50 to 100 m wide faulted blocks, with throws ranging from a few m up to 10 m. The fault systems, sometimes extremely complex, developed as the result of instability during compaction, caused by density inversion in self-sealing clay bodies (Henriet *et al.*, 1991).

13. Reference sections and major contributions

The most crucial, currently accessible reference sections are displayed on Figures 1 and 4. Important compilation works are grouped in Table 1.

14. Acknowledgements

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Plate 1

CALCAREOUS NANNOFOSSILS FROM THE KALLO BOREHOLE.

Figure 1. *Tribrachiatus orthostylus* Shamrai, 1963; Egem Sand Member, 242.6 m depth.
Figure 2. *Chiphragmalithus armatus* Perch-Nielsen, 1971; Egem Sand Member, 242.6 m depth.
Figure 3. *Discoaster cruciformis* Martini, 1958; Egem Sand Member, 245.0 m depth.
Figure 4. *Nannoturba robusta* Müller, 1979; Pittem Clay Member, 234 m depth.

KORTEMARK (Desimpel) CLAY QUARRY

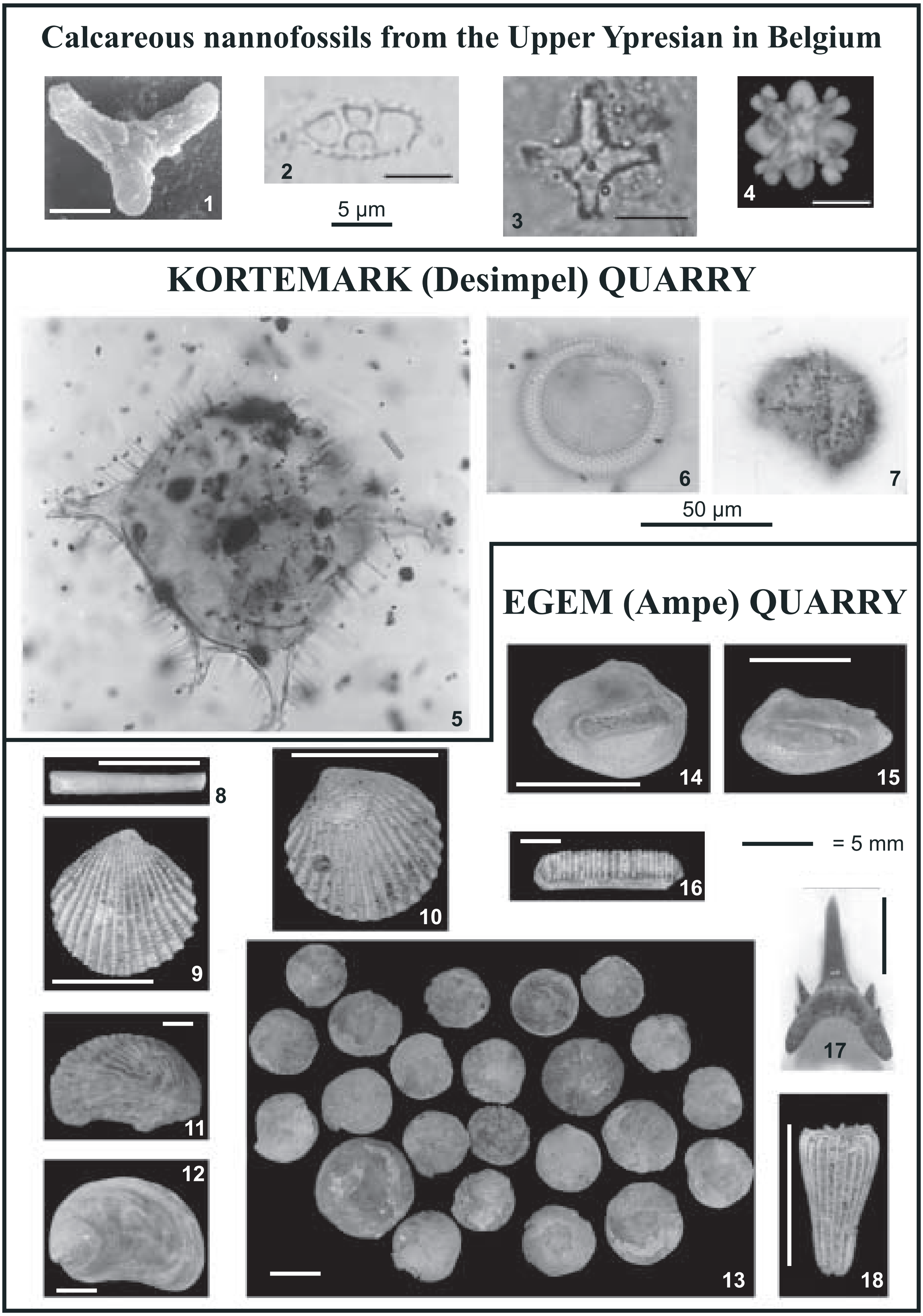
Organic-walled phytoplankton from the Kortemark Silt Member, De Coninck's dinoflagellate zone 7. Figs 5 & 7 = dinoflagellates from 17.50 m below top of pit I (see Steurbaut, 1998, fig. 6); Fig. 6 = Prasinophyceae from 10 m below top of pit I. Negatives Archief R.U.G., Laboratorium voor Paleontologie, Krijgslaan 281, Gent, Belgium.

Figure 5. *Wetzeliella articulata* (Wetzel) Eisenack, 1938
Figure 6. *Crassosphaera* aff. *concinna* Cookson & Manum, 1960
Figure 7. *Ochetodinium romanum* Damassa, 1979

EGEM (Ampe) SAND QUARRY

Macrofossils from bed 13 (Fl) of the Egem Sand Member, at c. 11 m below the top of the quarry.
Numbers refer to the collections of the "Koninklijk Belgisch lnstituut voor Natuurwetenschappen", Brussel, Belgium.

Figure 8. *Ditrupa* sp.; worm-tube (IST 5978)
Figures 9-10. *Venericardia sulcata aizyensis* (Deshayes, 1858) (IST 5979) (IST 5980)
Figures 11-12. *Turkostrea multicostata* (Deshayes, 1832) (IST 5981) (IST 5982)
Figure 13. *Nummulites planulatus* (Bruguière, 1792) (IST 5983 - IST 6004)
Figure 14. *Paraconger papointi* (Priem, 1906); fish otolith (P. 5052)
Figure 15. "genus Neobythitinorum" *subregularis* (Schubert, 1916); fish otolith (P. 5053)
Figure 16. *Myliobatis* sp.; ray tooth (P. 5054)
Figure 17. *Odontaspis winkleri* Leriche, 1905; shark tooth (P. 5055)
Figure 18. *Turbinolia paniselensis* Glibert, 1974; coral (IST 6005)


Calcareous nannofossils from the Upper Ypresian in Belgium
1
2
5 µm
3
4
KORTEMARK (Desimpel) QUARRY
5
6
7
50 µm
EGEM (Ampe) QUARRY
8
9
10
11
12
13
14
15
16
= 5 mm
17
18