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STRATIGRAPHY OF AN EARLY–MIDDLE MIOCENE SEQUENCE NEAR ANTWERP IN NORTHERN BELGIUM (SOUTHERN NORTH SEA BASIN)

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(5 figures, 2 tables & 3 plates)

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ABSTRACT. The lithostratigraphy and biostratigraphy of a temporary outcrop in the Antwerp area is described. The deposits can be attributed to the Kiel Sands and the Antwerpen Sands members, both belonging to the Lower and Middle Miocene Berchem Formation. Invertebrate and vertebrate macrofossils are abundantly present. The molluscan fauna compares well to former findings in the Antwerpen Sands Member. It can be concluded that the studied sequence is continuously present in the Antwerp area, and thickens in a northward direction. The study of the marine mammal fauna shows that eurhinodelphinids are the most common fossil odontocete (toothed-bearing cetaceans) in the Antwerpen Sands Member, associated here with kentriodontine, physeteroid, squalodontid, mysticete (baleen whales) and pinniped (seals) fragmentary remains. Both the molluscan fauna and the organic-walled palynomorphs indicate for the Antwerpen Sands Member deposition in a neritic, energetic environment, which shallowed upwards. The dinoflagellate cysts indicate that the Antwerpen Sands Member was deposited during late Burdigalian to Langhian times.

KEYWORDS: Antwerpen Sands, Mollusca, Odontoceti, Mysticeti, Pinnipedia, dinoflagellate cysts.

1. Introduction

The Miocene of the Antwerp area in northern Belgium (Fig.1) is particularly rich in vertebrate remains. The marine mammal fauna was described for the first time by Van Beneden (1865, 1869, 1876, 1877-1886, Odontoceti, Mysticeti and Pinnipedia), du Bus (1867, 1872) and Abel (1901, 1902, 1905, Odontoceti), and was based on material originating from temporary outcrops during the constructions of the fortresses around the city of Antwerp during the second half of the nineteenth century. The precise stratigraphic context is therefore largely unknown, since geologically untrained military collected the fossils. Later, shark teeth were described by Leriche (1926, 1951), and otoliths by Huyghebaert & Nolf (1979) and Nolf & Smith (1983).

During the last decade, one of the authors (Lambert, 2004, 2005a,b,c, 2006, 2008; Lambert & Post,

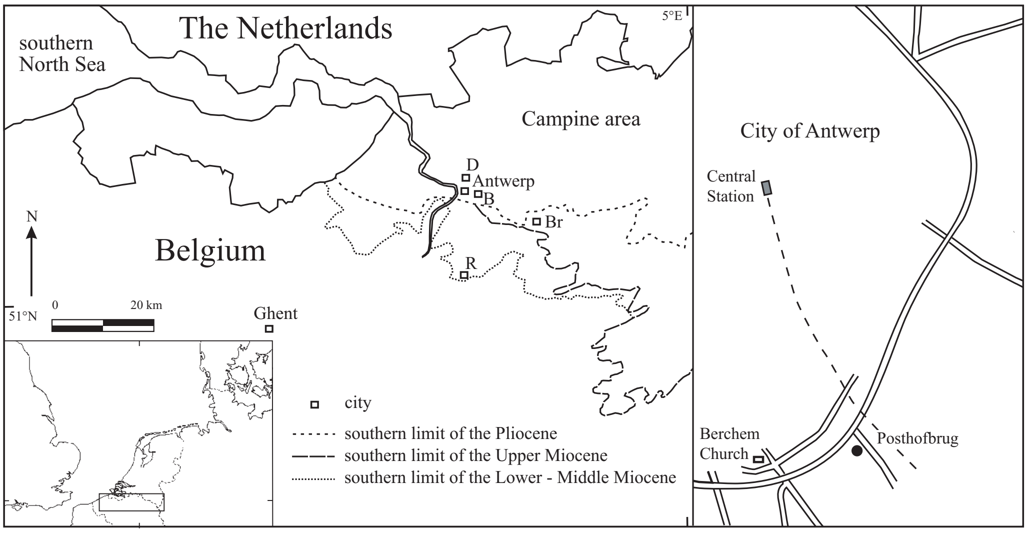

Figure 1: Location of the study area near Antwerp in northern Belgium. The temporary outcrop was located near the site “Posthofbrug” (N 51° 11’ 38” – E 4° 26’ 04”). B: Borgerhout, Br: Broechem, D: Deurne, R: Rumst and Terhagen.

2005; Lambert & Louwye, 2006), started a revision of the cetacean fauna, partly based on newly collected material and new reconstructions of the old material. For the study of teeth of Chondrichtyes by Leriche (1926, 1951) a similar problem arose: much material was collected in basal gravels of mixed Miocene and Pliocene age, which rendered the distinction between the Miocene and Pliocene faunae nearly impossible. Only the study of otoliths by Huyghebaert & Nolf (1979) and Nolf & Smith (1983) relied on material of known stratigraphic origin.

A temporary outcrop of the Kiel Sands and Antwerpen Sands members of the Miocene Berchem Formation became recently available and yielded a fauna rich in marine invertebrates (Mollusca) and remains of marine mammals. The goal of this study was to determine the relative age of the sequence through a palynological analysis with dinoflagellate cysts, and to assess for the first time the stratigraphic position of the marine mammal fauna.

2. Stratigraphy of the Posthofbrug outcrop

2.1. Introduction

The Posthofbrug outcrop is located southeast of the city of Antwerp near the railway station of the suburb Berchem (Fig. 1). The exposed sediments belong to the Kiel Sands and Antwerpen Sands members of the Lower to Middle Miocene Berchem Formation. The Berchem Formation was formally defined by De Meuter & Laga (1976) and consists lithologically of fine-grained to medium-grained sand, often slightly clayey and rich in glauconite. Shells occur dispersed or in massive layers. The formation has a basal gravel of rounded pebbles. According to the latter authors, the Berchem Formation is geographically restricted to the type area and the area north and east of Antwerp. The Berchem Formation is divided in three members in the type area (Fig. 2): the Edegem Sands, the Kiel Sands and the Antwerpen Sands (De Meuter & Laga, 1976). The two latter members are encountered in the studied outcrop. The Kiel Sands Member is defined as a glauconitic, medium-grained to coarse-grained sandy unit devoid of fossils. Louwye et al. (2000) attribute a Burdigalian age to the Kiel Sands Member. The Antwerpen Sands Member consists lithologically of very glauconitic, medium-grained sand, often clayey and with variable shell layers. According to Louwye et al. (2000), the Antwerpen Sands Member was deposited sometime between the latest Burdigalian and middle Serravallian. The Berchem Formation is in the Antwerp area unconformably overlain by the Late Miocene Diest Formation, more specifically the Deurne Sands Member, or by Quaternary deposits. East and north of the city of Antwerp, the formation is covered by the Late Miocene Diest Formation or the Pliocene Kattendijk Formation (Louwye, 2005).

Series	Lithostratigraphy
Upper Miocene	Diest Formation Deurne Sands
Middle - Lower Miocene	Berchem Formation Antwerpen Sands Kiel Sands Edegem Sands

Figure 2: Lithostratigraphy of the Neogene in the Antwerp area, after De Meuter & Laga (1976) and Louwye & Laga (2008).

2.2. Lithology of the Posthofbrug outcrop

More than nine meters of glauconitic, fine-grained to medium-grained sediments were exposed, and nine lithological units were observed (Fig. 3). The lowermost unit 1 belongs to the Kiel Sands Member, while units 2 to 6 represent the Antwerpen Sands Member. The uppermost three units are of Quaternary age.

The lowermost unit 1 consists of 340 cm light greyish, glauconitic sand. No macrofossils were observed, only sparse trace fossils were present.

Unit 2 consists of 25 cm dark grey to black, slightly clayey sand with large *Glycymeris baldii* valves without preferred orientation. The upper part holds *Turritella eryna* (d'Orbigny, 1852) (Pl. 1A), and is often separated from the lower part by about 5 cm of non-fossiliferous sand. Elongated phosphate concretions are present in the lower part. Both parts contain *Patinopecten brummeli* (Nyst, 1864). All shells are more or less eroded and decalcified. At the base and at the top, flat, fragile light grey sandstones with trace fossils occur (Pl. 1B).

The lithology of unit 3 consists of 30 cm dark grey to black, slightly clayey sand. Occasional *Glycymeris* valves are present.

Unit 4 holds 27 cm of glauconitic, greyish fine-grained sand with dispersed shells, especially *Panopea kazakovae* Glibert & Van de Poel, 1965 in life position and *Glossus lunulatus lunulatus* (Nyst, 1835) were observed.

Unit 5 is a crag deposit with a thickness of 75 cm. In the upper part single valves of *Glycymeris baldii* Glibert & Van de Poel, 1965 occur, all oriented with the convex side up. Bivalved specimens dominate in the basal part. All shells are to a certain degree decalcified.

Unit 6 consists of 85 cm glauconitic, greyish, medium-grained sand with dispersed shells, mainly *Glycymeris baldii*.

Unit 7 is a 30 cm thick, red to orange coloured crag with a clayey, fine-grained sandy matrix. Pliocene shells occur at the top, while in the base grey sandstones, possibly from the Upper Miocene Deurne Sand Member, occur. Dark coloured grey nodules containing shells occur within the unit. The nodules are comparable to those from Broechem (Marquet, 1980) (Fig. 1). Eroded bones and shark teeth are present. Intervals of glauconitic, greyish sand with Glycymerididae, reworked from the underlying

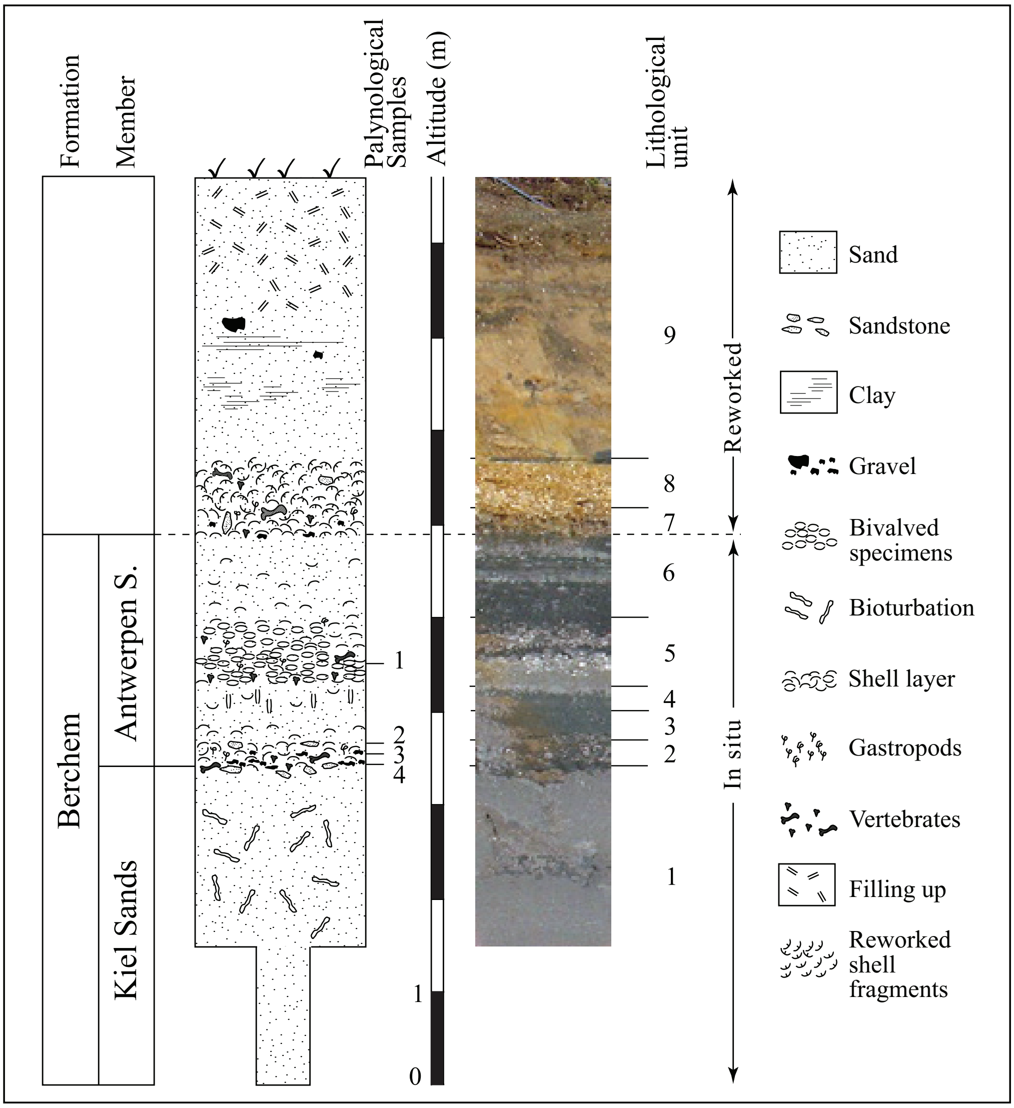

Figure 3: Lithology and lithostratigraphical interpretation of the exposed deposits at the Posthofbrug site. Altitude (in m) refers to the Belgian Ordnance Level (TAW).

unit 6, occur. The sediments of this unit are obviously reworked, possibly during Pleistocene times, and hold elements from the Middle Miocene (Antwerpen Sands Member), the Upper Miocene (Deurne Sands Member) and the Pliocene.

Unit 8 consists of 50 cm red to orange sand with strongly eroded Pliocene shells. Unit 8 is probably of Pleistocene age.

Unit 9 consists of circa 300 cm of red to orange loam without fossils. Brick fragments are encountered in the upper 2 m.

2.3. Remarks

The phosphate nodules in unit 2 are mostly irregular, and have an elongated shape. A few phosphate nodules show ichnofossils (Pl. 1C), and occasionally some contain fish remains (Pl. 1D), such as partly encased shark teeth. The shells in unit 2 are internally phosphatised. Only casts of gastropods were found since they usually lose their shell. The random position of the shell material in unit 2 points to deposition in a current-dominated environment.

Units 2 and 3 yielded the bulk of the collected mammalian and shark fauna. It is probable that most of the genuine Miocene vertebrate material from older studies (Van Beneden, 1877-1886) originated from this horizon, except for the fossils found in the upper gravel of the Upper Miocene Deurne Sands member in Borgerhout and Deurne (pers.obs. R. Marquet). This gravel contains large amounts of vertebrates and was identified by Van Beneden (1877-1886) as «Sable à Héterocètes».

Units 4 and 5 were probably formed during one depositional event. *Panopea* species live deep infaunal, while *Glycymeris* species burrow just below the surface. On the sea bottom, slightly displaced *Glycymeris* can occur. The molluscan fauna in the units considered was rather poor due to decalcification, but at other localities it is the most diverse fauna of the Antwerpen Sands Member. Vertebrate remains are rare, except for fish otoliths and fish bones.

The shell beds and *Glycymeris* concentrations between units 5 and 7 were already observed by Marquet (1991) to the north and centre of the city of Antwerp. Unit 7 contains many reworked bones and shark teeth of Miocene or Pliocene age. Van Beneden (1877-1886) assumed that these fossils originated from the “crag rouge”, and stressed their uncertain age.

3. Methods

Bulk samples from unit 2 were collected for the paleontological study of molluscs, shark teeth, otoliths and fish bones. The sediments were sieved on a screen with a 0.5 mm mesh size. Circa 10 kg of dried residue larger than 0.5 mm was examined. Cetacean material was hand picked by raking along the section and carefully digging out the bones. The invertebrate and mammal material will be deposited at the Royal Belgian Institute of Natural Sciences.

Three samples (PHB1, PHB3, PHB4) from the Antwerpen Sands Member were palynologically analysed (Fig. 3). About thirty grams of sediment were chemically treated following standard palynological maceration techniques using hydrochloric acid and hydrofluoric acid for the dissolution of carbonates and silicates, respectively. The organic residues were filtered on a 10 µm nylon mesh for the recovery of the small-sized palynomorphs such as acritarchs and pollen, and mounted with glycerine jelly. The slides were scanned under a 400x magnification on a Zeiss AxioImager light microscope until a minimum of 250 marine organic-walled palynomorphs, mainly dinoflagellate cysts, were identified and counted. The rest of the slide was then scanned for rare and well-preserved specimens for microphotography.

4. Palynology

4.1. Biostratigraphy

A total of 55 dinoflagellate cysts, five acritarch species and one prasinophyte species were recovered (Table 1). The assemblage is well preserved and the diversity is high. The reworking is relatively low, and only a few reworked specimens were recorded during the systematic count. Terrestrial palynomorphs, mainly bisaccate pollen, are present but never in high numbers.

The dinoflagellate cyst assemblage is characterised by many species with a long stratigraphic range from the pre-Miocene into the Pliocene. The dating of the studied samples relies on a few species with a well-documented stratigraphic record.

Labyrinthodinium truncatum (Pl. 2E, F) is recorded in every sample, and this species has a well-calibrated occurence in the northern hemisphere. According to Williams et al. (2004), *Labyrinthodinium truncatum* has a first appearance (FA) at 16.5 Ma. De Verteuil & Norris (1996) place the FA of this species in the base of Chron C5Cn, which corresponds to an age of circa 16.7 Ma according to the astronomically tuned Neogene time scale (Lourens et al., 2004). Louwye et al. (2008) recorded the FA of *Labyrinthodinium truncatum* in the Porcupine Basin in the base of Subchron C5Cn.2n at 16.5 Ma.

Distatodinium paradoxum (Pl. 2G–H) is also recorded in each sample. This species has a last appearance (LA) at 15.16 Ma in the base of Chron C5Bn according to de Verteuil & Norris (1996). Louwye et al. (2008) place the LA of *Distatodinium paradoxum* around 15.2 Ma in the upper part of Chron C5Br.

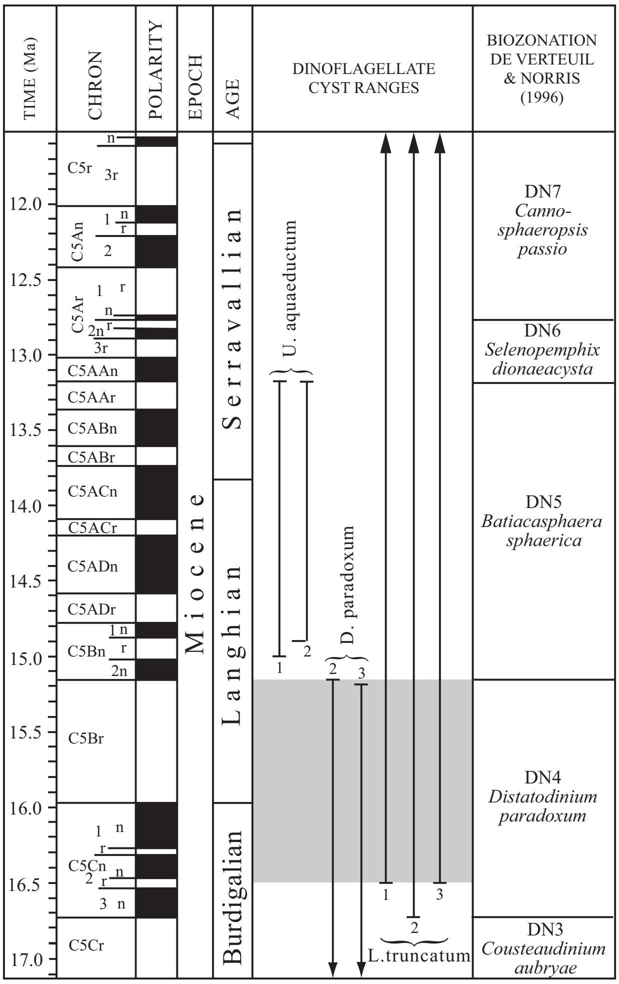

Figure 4: Stratigraphic position and age of the Posthofbrug outcrop, based on dinoflagellate cyst analysis. Shaded area represents the stratigraphic position of the Antwerpen Sands Member at the Posthofbrug site. 1. Williams *et al*. (2004), 2. De Verteuil & Norris (1996), 3. Louwye *et al*. (2008).

The absence of *Unipontedinium aquaeductum* is noteworthy. This robust species is regularly recorded in the Middle Miocene deposits of the North Sea Basin and the North Atlantic Ocean (Louwye et al, 2000; Louwye et al. 2008), although its presence is never continuous in the sequences. *Unipontedinium aquaeductum* has according to Williams et al. (2004) a FA at 15 Ma in the northern hemisphere. De Verteuil & Norris (1996) place the FA within Chron C5Bn at circa 14.9 Ma.

The Miocene biozonation of de Verteuil & Norris (1996) was defined in the shallow marine deposits of the US Atlantic Coastal Plain (Virginia and Maryland), and can readily be applied to our dataset. The *Distatodinium paradoxum* Biozone DN4 is defined as the interval from the lowest occurrence of *Labyrinthodinium truncatum* to the highest occurence of *Distatodinium paradoxum*. Both species are continuously recorded in this study, and the deposits can thus be attributed to the *Distatodinium paradoxum* Biozone DN4. *Palaeocystodinium golzowense* (Pl. 2I–J) is a common element in the dinoflagellate cyst assemblage of Biozone DN4. De Verteuil & Norris (1996)

Samples	PHB1		PHB3		PHB4	
Dinoflagellate cysts	n	%	n	%	n	%
Apteodinium spiridoides			9	3,46	3	1,14
Apteodinium tectatum	+		4	1,54	1	0,38
Barssidinium pliocenicum					+	
Batiacasphaera deheinzelinii	1	0,38	2	0,77	+	
Batiacasphaera hirsuta					+	
Batiacasphaera micropapillata					+	
Batiacasphaera minuta	5	1,92	9	3,46	6	2,28
Batiacasphaera sphaerica	+		1	0,38		
Brigantedinium sp. cf. *B. cariacoense*			+			
Cerebrocysta poulsenii	+					
Cleistosphaeridium placacanthum	42	16,15	27	10,38	26	9,89
Cordosphaeridium minimum sensu Benedek & Sarjeant 1981	+		+		+	
Cousteaudinium aubryae aubryae	3	1,15	1	0,38	+	
Dapsilidinium pseudocolligerum	3	1,15	6	2,31	3	1,14
Distatodinium paradoxum	3	1,15	1	0,38	1	0,38
Filisphaera microornata			+			
Heteraulacacysta sp. A Costa & Downie 1979	2	0,77	3	1,15	4	1,52
Homotryblium pallidum	+		2	0,77		
Hystrichokolpoma rigaudiae rigaudiae	+		1	0,38	1	0,38
Hystrichosphaeropsis obscura			+		+	
Impletosphaeridium sp. ind.	+		1	0,38		
Invertocysta tabulata			1	0,38		
Labyrinthodinium truncatum modicum	+		+		+	
Labyrinthodinium truncatum truncatum			+		+	
Lejeunecysta catomus	+					
Lejeunecysta marieae	+		1	0,38		
Lejeunecysta sp. ind.	1	0,38				
Lingulodinium machaerophorum machaerophorum	6	2,31	8	3,08	9	3,42
Melitasphaeridium choanophorum	2	0,77	8	3,08	5	1,90
Operculodinium? *borgerholtense*	+		2	0,77	1	0,38
Operculodinium centrocarpum centrocarpum	5	1,92	11	4,23	9	3,42
Operculodinium longispinigerum	+				+	
Operculodinium piaseckii	+		1	0,38	1	0,38
Operculodinium sp. ind.	1	0,38				
Organic membrane of calcareous cyst	2	0,77				
Palaeocystodinium golzowense	6	2,31	1	0,38	4	1,52
Pentadinium laticinctum laticinctum	+				+	
Pyxidiniopsis brabantiana			+		1	0,38
Pyxidinopsis fairhavenensis			1	0,38		
Quinquecuspis concreta	2	0,77	1	0,38	1	0,38
Round brown cysts			+		3	1,14
Reticulatosphaera actinocoronata	+		5	1,92	3	1,14
Selenopemphix brevispinosa	6	2,31	1	0,38	1	0,38
Selenopemphix nephroides	+		+		+	
Selenopemphix quanta			+		1	0,38
Spiniferites spp. ind.	49	18,85	131	50,38	168	63,88
Sumatradinium druggii	+		1	0,38	+	
Sumatradinium hamulatum			+			
Sumatradinium soucouyantiae	+		1	0,38	2	0,76
Tectatodinium pellitum	1	0,38	1	0,38	+	
Trinovantedinium ferugnomatum	1	0,38	1	0,38		
Trinovantedinium glorianum			2	0,77	+	
Trinovantedinium henrietii	+		1	0,38		
Trinovantedinium sp. A					+	
Tuberculodinium vancampoae	+		3	1,15	2	0,76
Acritarcha						
Cyclopsiella? *granosa*/*elliptica*	20	7,69	+		+	
Cyclopsiella? *trematophora*					1	0,38
Nannobarbophora gedlii	1	0,38	+		+	
Paralecaniella indentata	96	36,92	3	1,15	4	1,52
Small spiny acritarchs	2	0,77	8	3,08	2	0,76
Chlorophyta						
Tasmanites					+	
Total in situ organic-walled palynomorphs	260		260		263	
Terrestrial palynomorphs						
Bisaccate pollen	12		18		13	
Quercus pollen			6			
Reworked marine palynomorphs	2		1		1	

Table 1: Distribution of dinoflagellate cysts and other organic-walled palynomorphs in the Posthofbrug outcrop. Raw numbers and percentages are given.

postulate a latest Burdigalian to Langhian age for the DN4 Zone. The superjacent *Batiacasphaera sphaerica* Biozone DN5 holds the interval from the highest occurrence of *Distatodinium paradoxum* to the highest occurrence of *Cleistosphaeridium placacanthum*. *Habibacysta tectata* occurs for the first time within this zone. The latter species is not recorded in this study. Furthermore, the range of *Unipontedinium aquaeductum* is restricted to the Biozone DN5.

Based on the FA of *Labyrinthodinium truncatum* and the LA of *Distatodinium paradoxum*, the relative age of the sequence can be constrained between circa 16.7 Ma and 15.1 Ma (Fig. 4). The sequence was thus deposited some time during late Burdigalian to (early) Langhian times. The absence of the stratigraphic markers *Unipontedinium aquaeductum* and *Habibacysta tectata* corroborates the relative dating.

4.2. Palaeoecological considerations

Dinoflagellate cyst genera with oceanic affinities such as *Impagidinium* and *Nematosphaeropsis* (Dale, 1996) are absent in the recovered assemblages. The dinoflagellate cyst assemblages from samples PHB3 and PHB4 are dominated by *Spiniferites* spp., a genus characteristic for neritic environments.

Two acritarch species with specific environmental affinities, *Cyclopsiella granosa*/*elliptica* and *Paralecaniella indentata*, are present in high numbers in the uppermost sample PHB1 (Table 1). Species of the genus *Cyclopsiella* are characterised by an oval to subelliptical outline and a subpolar pylome (Pl. 2A–B). Ornamentation is present on the apertural side, while the antapertural side is unornamented. *Cyclopsiella* species often occur clustered in the palynological slides, and every specimen within these clusters has the apertural side upwards. According to Matsuoka & Head (1992), the characteristics point to an encrusted or attached way of life. According to M. Smelror (pers. comm.), high numbers or acmes of *Cyclopsiella* species are characteristic for prograding shoreface or intertidal environments.

Paralecaniella indentata (Pl. 2C–D) is the most abundant organic-walled palynomorph in sample PHB1. Louwye & Laga (2008) recorded high to very high (45%) numbers of *Paralecaniella indentata* in the latest Burdigalian to Langhian Houthalen Sands Member (Bolderberg Formation) in the eastern part of the Campine area. The Houthalen Sands Member is deposited in a marginal marine environment at the southern border of the North Sea Basin. Louwye & Laga (2008) give an elaborate overview of the published records on the palaeoecology of *Paralecaniella indentata*. Kurita & Matsuoka (1994) recorded *Paralecaniella indentata* in a low-diversity assemblage of organic-walled palynomorphs from Middle Eocene to Early Oligocene deposits in northern Japan. The assemblage developed in a paleoenvironment characterised by saline, stratified waters in shallow embayments. Kurita (2004) recorded more than 30% *Paralecaniella indentata* in Late Eocene to Early Oligocene deposits from Japan, but gives no palaeoecological interpretation. Zaporozhets et al. (2006) report high numbers of the euryhaline species *Trinovantedinium boreale*, together with the acritarch species *Paralecaniella indentata* and *Micrhystridium* spp. from a shallow, low-salinity depositional environment of Eocene to Oligocene age from western Kamchatka. According to Brinkhuis & Schiøler (1996), high relative abundances of *Paralecaniella indentata* may indicate restricted marine influence or may reflect increased transport from such settings. Usually, *Paralecaniella indentata* is associated with high energy conditions during which clay particles remain suspended and heavier elements such as *Paralecaniella indentata* settle. Schiøler et al. (1997) record in a quantitative palynological study of the Lanaye member (Upper Maastrichtian, The Netherlands) a marked transition from a dinoflagellate cyst dominated assemblage to a *Paralecaniella indentata* dominated assemblage. The sudden transition is indicative of a change from an open marine to a marginal marine depositional environment.

In summary, the high relative abundances of *Cylopsiella granosa/elliptica* and *Paralecaniella indentata* in the uppermost sample PHB1 indicate deposition in a high energy, nearshore environment, probably with a reduced salinity. A general shallowing upward trend from favourable, open neritic conditions to a high energy, shallow marine environment is recognised.

5. The invertebrate fauna of lithological unit 2

5.1. Composition of the fauna

Only the invertebrate fauna of unit 2 is discussed here, since this fauna differs considerably from the one described by Glibert (1945, 1952). Three coral species (identified after the publication of Chevalier, 1964), one bryozoan (after Lagaaij, 1952), three crustacean (balanid after Darwin, 1854 and Collins, pers. comm. 2008), one amphineuran, two scaphopods, 36 bivalves, 14 gastropods (after Glibert, 1945, 1952 and Janssen, 1984) and one echinoderm (after Cotteau, 1880) were identified (Table 2). Furthermore, unidentified foraminifers and ostracods occur abundantly. The diversity and preservation of the collected molluscan fauna is poor in comparison to the fauna from the upper part of the Antwerpen Sands Member in other localities (Antwerp Ring Highway, Metro Station Schijnpoort, Ploegstraat, see Marquet, 1991, fig. 1). The scarcity is probably caused by the poor preservation of the material. Gastropods are found mainly as phosphatic casts, and this renders the identification of some taxa impossible. Turrid and fasciolarid species usually constitute a large part of the molluscan faunal diversity, and these species are especially difficult to determine when phosphatised. Despite the poor preservation, a species new for the Miocene of Antwerp was found. A list of the fauna from the phosphoritic nodules level in unit 2 is presented in Table 2.

Trace fossils		
Unidentified type on phosphorite		1 specimen
Corallia		
Eupsammidae	*Eupsammia praelonga* (Michelotti, 1838)	1 specimen
Flabellidae	*Flabellum* cf. *tuberculatum* Keferstein, 1859	rare
Caryophillidae	*Ceratocyathus granulatus* (Goldfuss, 1826)	rare
Bryozoa		
Cupuladriidae	*Cupuladria* cf. *haidingeri* (Reuss, 1826)	common
Amphineura		
Hanleyidae	*Hanleya multigranosa* (Reuss, 1868)	1 specimen
Scaphopoda		
Siphonodentaliidae	*Gadila benoisti houthaelensis* (Goddeeris, 1977)	fragments
Dentaliidae	*Dentalium* sp.	fragments
Bivalvia		
Nuculidae	*Nuculoma h. haesendoncki* (Nyst & Westendorp, 1839)	fragments
Limopsidae	*Limopsis* (*P.*) *anomale* (Eichwald, 1830)	common
	Limopsis (*L.*) *lamellata* (Lehmann, 1885)	rare
Glycymerididae	*Glycymeris* (*Chevronia*) *baldii* Glibert & Van de Poel, 1965	very common
Mytilidae	*Arcoperna sericea* (Bronn, 1831)	cast
Pteriidae	*Pinctada phalaenacea* (Lamarck, 1819)	fragments
Pectinidae	*Korobkovia woodi* (Nyst, 1861)	rare
Pectinidae	*Pecten praebenedictus* Tournouër in Dollfus & Dautzenberg, 1920	fragments
Pectinidae	*Patinopecten brummeli* (Nyst, 1864)	common
Pectinidae	*Mimachlamys angelonii* (Di Stefani & Pantanelli, 1880)	common
Pectinidae	*Hinnitis ercolaniana* (Cocconi, 1878)	fragments
Pectinidae	*Pseudamussium lilli* (Pusch, 1837)	rare
Gryphaeidae	*Neopycnodente navicularis* (Brocchi, 1814)	common
Lucinidae	*Lucinoma borealis praecedens* (Von Koenen, 1868)	rare
Galeommatidae	*Spaniorinus cimbricus* (Kautsky, 1925)	rare
Carditidae	*Cyclocardia* sp.	rare
Carditidae	*Glans* (*C.*) *ronchetti* Glibert & Van de Poel, 1970	rare
Condylocardiidae	*Erycinella chavani* (Glibert, 1945)	rare
Astartidae	*Astarte radiata* Nyst & Westendorp, 1839	common
Astartidae	*Astarte goldfussi* Hinsch, 1952	rare
Astartidae	*Goodallia angulata* (Lehmann, 1885)	rare
Astartidae	*Goodallia waeli waeli* (Glibert, 1945)	rare
Astartidae	*Goodallia laevigata* (Speyer, 1866)	rare
Astartidae	*Digitaria beyschlageri* Kautsky, 1925	rare
Cardiidae	*Laevicardium* (*H.*) *subturgidum* (d'Orbigny, 1852)	rare
Mactridae	*Spisula* aff. *subtruncata* (auct. non Da Costa, 1778)	common
Semelidae	*Abra antwerpiensis* Glibert, 1945	rare
Arcticidae	*Arctica islandica islandica* (Linnaeus, 1758)	common
Glossidae	*Glossus l. lunulatus* (Nyst, 1835)	rare
Veneridae	*Venus* (*Ventricoloidea*) *m. multilamella* Lamarck, 1818	common
Veneridae	*Gouldia minima* (Montagu, 1803)	rare
Veneridae	*Mancasinodia nysti (*d'Orbigny, 1852)	fragments
Corbulidae	*Corbula* (*Varicorbula*) *gibba gibba* (Olivi, 1792)	common
Hiatellidae	*Hiatella* (*Hiatella*) *arctica* (Linnaeus, 1758) rare	
Hiatellidae	*Panopea* (*P.*) *kazakovae* Glibert & Van de Poel, 1966	fragments
Hiatellidae	*Cyrtodaria angusta* (Nyst & Westendorp, 1839)	fragments
Gastropoda		
Fissurellidae	*Diodora subcostaria* (d'Orbigny, 1852)	1 specimen
Turbinidae	*Astraea belgica* Glibert, 1952	opercula
Turritellidae	*Turritella eryna* (d'Orbigny, 1852)	fragments
Xenophoridae	*Xenophora d. deshayesi* Michelotti, 1847	casts
Aporrhaidae	*Aporrhais dingdenensis* Marquet, Grigis & Landau, 2002	casts
Naticidae	Unidentified	casts
Naticidae	*Sinum deshayesi* (Michelotti, 1857)	casts
Cassidae	*Semicassis b. bicoronata* (Beyrich, 1854)	casts
Ficidae	*Ficus c. condita* (Brongniart, 1823)	casts
Muricidae	*Haustellum inornatum* (Beyrich, 1854)	casts
Olividae	*Baryspira obsoleta* (Brochi, 1814)	common
Mitridae	Unidentified	casts
Volutidae	*Scaphella bolli* (Koch, 1863)	casts
Turrid gastropods	Unidentified	casts
Conidae	*Conus antediluvianus* Bruguière, 1792	casts
Crustacea		
Balanidae	*Megabalanus tintinnabulum* (Linnaeus, 1767)	common
Crab claws	Unidentified	rare
Crab carapace	Unidentified	1 cast
Echinodermata		
Cidaridae	"*Cidaris belgica*" Cotteau, 1880	common

Table 2: Invertebrate fossils from unit 2, the phosphorite level of the Antwerpen Sands Member, Berchem Formation.

5.2. Remarks

Specimens of *Glycymeris baldii* become unusually large in unit 2 and they are relatively flatter than conspecific material from higher levels. However, the hinge characteristics are the same. Glibert & Van de Poel (1965) considered this Miocene taxon as a subspecies of the Early Oligocene *Glycymeris lunulata* (Nyst, 1836). However, *Glycymeris lunulata*, which is found only in the Grimmertingen Sands Member of the Oligocene Rupel Formation, clearly differs by its smaller and thinner shell, its relatively longer and straight hinge line and its more symmetric outline. Therefore, a close relation between both species seems highly improbable and the Miocene taxon is considered here as a separate species.

The occurrence of *Pecten praebenedictus* in the Miocene of the Antwerp area is published here for the first time. It occurs in all localities in which a unit 2 fauna was observed, but the species is rare (Antwerp Ring Highway, Metro Station Schijnpoort, Ploegstraat, see Marquet, 1991, fig. 1). The species is characterised by its large shell, very tumid right valve and concave left valve. The number of radial ribs is about 15, and the ribs are rectangular in cross section and broader than the intercostal spaces. No secondary ornament or spines are present. A specimen better preserved than those of the Posthofbrug section is figured in Pl. 1E–F.

The occurrence of *Patinopecten brummeli* is also restricted to unit 2. It is absent from younger Miocene deposits but it is present in the Miocene basal gravel overlying the Oligocene Boom Formation in the claypits at Rumst and Terhagen, where it forms a major part of the molluscan fauna (pers. obs., R. Marquet).

5.3. Mollusc biostratigraphy

The Glossidae are a useful biostratigraphic tool for the Neogene of northern Belgium and following stratigraphic distribution was observed by Herman & Marquet (2007):

Edegem Sands Member: *Glossus lunulatus crassus* (Nyst & Westendorp, 1839) and *Glossus burdigalensis cypriniformis* (Nyst in Dewalque, 1868);

Houthalen and Kiel Sands members: only *Glossus burdigalensis cypriniformis* (Nyst in Dewalque, 1868);

Antwerpen Sands Member: *Glossus lunulatus lunulatus* (Nyst, 1835);

Deurne Sands Member: *Glossus olearii* (Semper, 1861);

Kattendijk Formation and Luchtbal Sands Member (Pliocene): *Glossus humanus* (Linnaeus, 1758).

Glossus lunulatus lunulatus was recorded only in unit 2, together with *Patinopecten brummeli.* These findings differentiate unit 2 from the Rumst basal gravel, where the latter species is present together with *Glossus burdigalensis cypriniformis* (Herman & Marquet, 2007).

Turritella eryna is in the Antwerp area restricted to unit 2, and occurs in the Bolderberg Formation in the Campine area. In the higher levels of the Antwerpen Sands Member it is replaced by *Turritella subangulata subacutangula* (Brocchi, 1814). This species occurs also earlier, in the Edegem Sands Member, but together with another turritellid, *Protoma schwarzbachi* Strauch, 1967. The reappearance of *Turritella subangulata subacutangula* could be related to water depth, with *Turritella eryna* being typical for deeper water and *Turritella subangulata subacutangula* for shallow environments. These findings corroborate the palaeoenvironmental observations with dinoflagellate cysts.

Based on the occurrence of holoplanctonic mollusca, Janssen (2001) supposed a Langhian age for at least part of the Antwerpen Sand Member, although typical short ranging species were only found in the older Edegem Sands and Kiel Sands members and the younger Deurne Sands Member. However, no holoplanctonic mollusca were collected in the Posthofbrug section.

6. The vertebrate fauna of unit 2

6.1. Chondrichthyes

Units 2 and 5 of the Posthofbrug section yielded many species of shark teeth. A very diverse fauna of shark and ray teeth (22 species) was already described from a nearby section close to the church of Berchem (De Ceuster, 1987) (Fig. 1). Levels 2 to 4 described by De Ceuster (1987) correspond to unit 2 at the Posthofbrug outcrop. The material was abundant and very well preserved. Only one level higher in the section, just above the level with *Panopea* in life position, also contained a more or less rich fauna of chondrichthyes, with 10 species, but in low numbers of specimens.

6.2. Reptilia

A fragmentary left scapula belonging to a cheloniid turtle was found (Pl. 3A). This bone displays strong similarities with the recent cheloniids *Caretta caretta* and *Chelonia mydas*.

6.3 Mammalia

An overview of the composition of the marine mammal fauna collected from unit 2 is given in Fig. 5. Three skull fragments, several isolated teeth, two right periotics, one left humerus, and two caudal vertebrae belong to the extinct long-snouted dolphin family Eurhinodelphinidae. The most complete skull fragment includes both frontals and maxillae on the cranium, fragments of the premaxillae, and the right nasal (Pl. 3B). Lacking the apomorphies of *Xiphiacetus cristatus* (du Bus, 1872) and having dimensions and general morphology in the range of *Xiphiacetus bossi* (Kellogg, 1925), it is referred to the latter, a species also known from the east coast of the USA (Lambert, 2005b). A fragment of the right frontal and maxilla at the level of the vertex and supraorbital process and a more robust portion of the left supraorbital process and vertex are similarly referred to *Xiphiacetus bossi*. The two periotics with a rounded pars cochlearis are too small to be referred to the largest eurhinodelphinid from Antwerp, *Eurhinodelphis cocheteuxi* du Bus, 1867. The humerus (Pl. 3E), lacking the humeral head, is distinctly smaller

- Cetacea
  - Odontoceti
    - Odontoceti indet.
    - Eurhinodelphinidae
      - Eurhinodelphinidae indet.
      - Xiphiacetus bossi
    - Kentriodontidae
      - Kentriodontidae indet.
      - aff. Delphinodon
      - aff. Kentriodon
    - Physeteroidea
      - Physeteroidea indet.
    - Squalodontidae
      - Squalodon sp.
  - Mysticeti
    - Pelocetidae ("Calvert cetotheres")
      - Pelocetidae indet.

- Pinnipedia
  - Pinnipedia indet.
  - Phocidae aff. Prophoca

Figure 5: Composition of the marine mammal fauna from unit 2, Antwerpen Sands Member.

than humeri of *Eurhinodelphis cocheteuxi*. One of the caudal vertebrae bears thick exostoses, possibly due to age-related vertebral spondylosis (Pl. 3F).

A delphinoid (Delphinoidea, small to moderate-size dolphins) right periotic (Pl. 3D) with a total length of 34 mm shares similarities with periotics referred to the kentriodontine *Kampholophos serrulus* Rensberger, 1969, the lophocetine *Lophocetus pappus* Kellogg, 1931, and the ?kentriodontine *Liolithax kernensis* Kellogg, 1931. This ear bone is nearly identical to a specimen from the late Early to early Middle Miocene of the east coast of the USA attributed by Whitmore & Kaltenbach (2008) to aff. *Lophocetus pappus*.

A partial left tympanic bulla belongs to a small kentriodontid, possibly from the genus *Kentriodon* Kellogg, 1927. A 31 mm long isolated tooth bears a large denticle on the posterior keel of the crown, followed distally by tiny crenulations, and a series of smaller denticles and protuberances on the lingual surface of the crown (Pl. 3K). Several kentriodontines bear such denticles; the most similar species is *Delphinodon dividum* True, 1912, from the Middle Miocene of the east coast of the USA.

One thoracic vertebra (Pl. 3M) is tentatively identified as belonging to a medium size sperm whale (Physeteroidea). The physeteroid species *Eudelphis mortezelensis* du Bus, 1872, *Placoziphius duboisi* Van Beneden, 1869, and more recently *Orycterocetus crocodilinus* Cope, 1868 are identified in levels of the Berchem Formation in the area of Antwerp (Lambert, 2008).

The triangular crown of an isolated squalodontid (Squalodontidae, extinct heterodont dolphins) tooth (Pl. 3L) bears crenelations on the anterior and posterior carinae, at least two denticles on the posterior carina, and crista rugosa on the lingual and labial surfaces, covered by a few enamel papillae. The cristae density is around 9. This tooth, identified as the 6th or 7th left lower or right upper buccal tooth (cheek tooth), is referred to *Squalodon* sp., sharing similarities with the teeth of *Squalodon antwerpiensis papillatus* Rothausen, 1968.

Two almost identical isolated mysticete (Mysticeti, baleen whales) periotics, belonging to juveniles, have been found (Pl. 3N). In addition to similarities in the general shape of the pars cochlearis, they resemble the periotic of *Idiocetus laxatus* and *Parietobalaena palmeri* (Pelocetidae in Steeman, 2007; the so-called "Calvert cetotheres") in the following characteristics: the periotic body is short; the internal auditory meatus is narrow and circular; the endolymphatic foramen and the endocranial foramen of the facialis nerve are both slit-like; the three together form an equilateral triangle. A smooth and slightly concave depression dorsal to this triangle resembles the condition in Balaenidae. The stylomastoid fossa is strong, short, and dorsally roofed, separated from the tensor timpany fossa by a thin septum. The anterior process is short. However, these periotics differ from the two species mentioned above in having a prominent groove for the tensor tympani muscle anteroventral to the pars cochlearis, widening and deepening anteromedially, and in the anterior process being dorsally rounded and anteriorly obtuse. The section at the base of the posterior process is also smaller and ventrodorsally thinner.

An isolated pinniped (Pinnipedia, seals and walruses) canine 42 mm long is likely the left c1 (Pl. 3O). The crown is considerably worn by the opposite upper teeth C1 and I3.

The femoral head of a pinniped femur (Pl. 3Q) has a preserved maximum diameter of 32 mm, matching the size of the acetabulum on the innominate of the phocid *Prophoca rousseaui* (Van Beneden, 1876) described from the Berchem Formation in the area of Antwerp. A well preserved left innominate (Pl. 3P), only lacking the posterior end of the ischium and pubis and the anterior crest of the ilium, is more slender than the innominate of *Prophoca rousseaui* cited above. Apart from this, it displays a similar general morphology, with a moderate size ischiatic spine, high edges of the acetabular fossa, a wide acetabular notch, and a developed iliopectineal eminence. The preserved anterior portion of the ischium and pubis is flatter than in the specimen referred to *Prophoca rousseaui*, but considering the sexual dimorphism observed at the level of the innominate in pinnipeds these differences probably have a low diagnostic value.

7. Conclusions

The biostratigraphical analysis with dinoflagellate cysts attributes a late Burdigalian to Langhian age to the Antwerpen Sands Member in the Posthofbrug outcrop.

Deposition of the sequence took place some time between 16.5 Ma and 15.1 Ma. Both the dinoflagellate cyst assemblage and the gastropods from the Antwerpen Sands Member in the Posthofbrug outcrop indicate an upward shallowing of the depositional environment. The invertebrate fauna was compared with those published by Marquet (1991), and it can be concluded that the units in the Posthofbrug outcrop are continuously present throughout the Antwerp region. The Antwerpen Sands Member however becomes thicker to the north (Marquet, 1991), since a number of beds have been preserved stratigraphically above those discussed in the present paper.

The examination of the isolated vertebrate remains from unit 2 confirms that long-snouted eurhinodelphinids were the most common odontocetes in this part of the Berchem Formation. With their long neck made of unfused cervical vertebrae and their elongated snout, eurhinodelphinids are generally considered as slow-swimming shallow water dwellers, feeding on the bottom of coastal to estuarine areas (Lambert, 2005b). In this unit, they were co-existing with at least two or three kentriodontids, a species of *Squalodon*, and at least one sperm whale. In contrast, only one mysticete taxon, a possibly new cetotheriid s.l., is identified in that layer. A pinniped innominate further supports the presence of one of the oldest phocids in Langhian deposits from the southern margin of the North Sea Basin.

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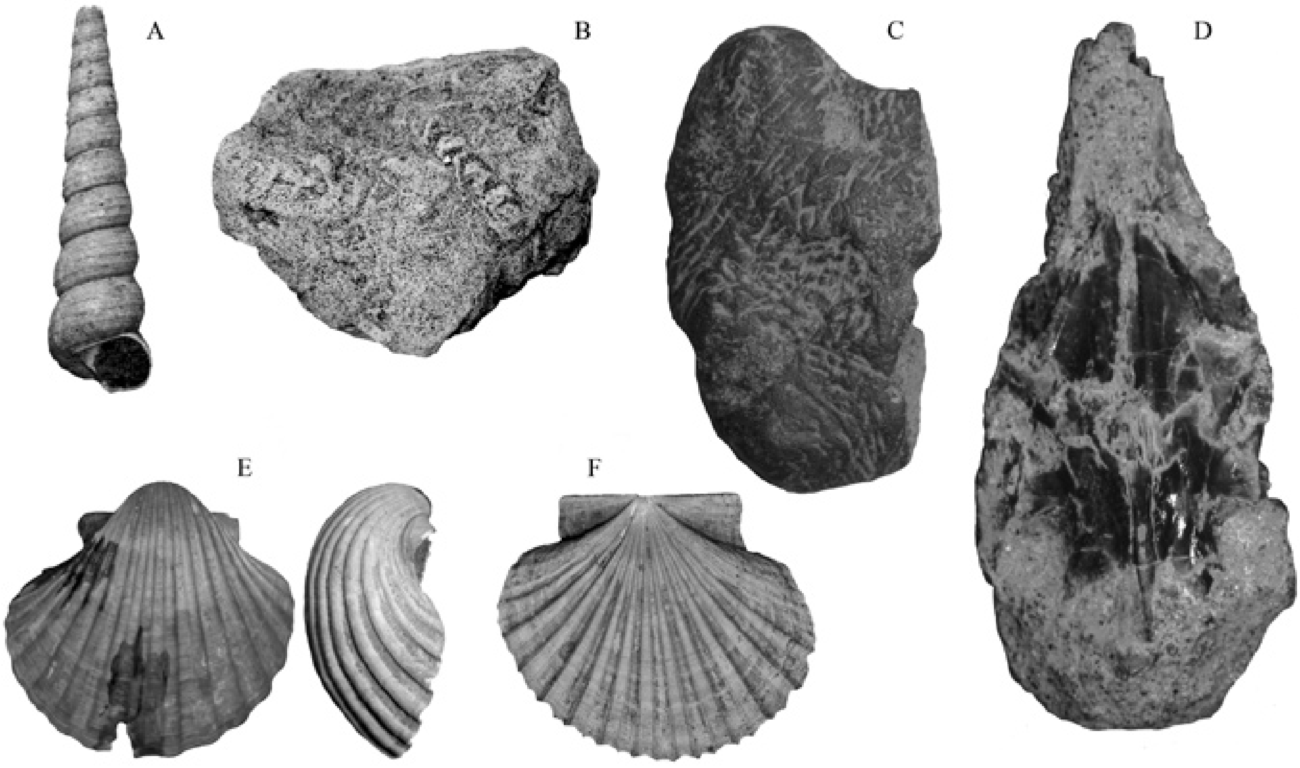

Plate 1: Trace fossils and invertebrates. A. *Turritella eryna* (d'Orbigny, 1852). 53 x 14 mm. Antwerp, Metro station Schijnpoort. B. Sandstone with trace fossils. 54 x 65 mm. Posthofbrug section. C. Phosphorite with trace fossils. 46 x 26 mm. Posthofbrug section. D. Fish skull bones in phosphorite. 29.5 x 13 mm. Posthofbrug section. E-F. *Pecten praebenedictus* Tournouër *in* Dollfus & Dautzenberg, 1920. a. 87 x 91 x 42 mm, b. 88 x 72 x 5 mm. Ploegstraat, Antwerp.

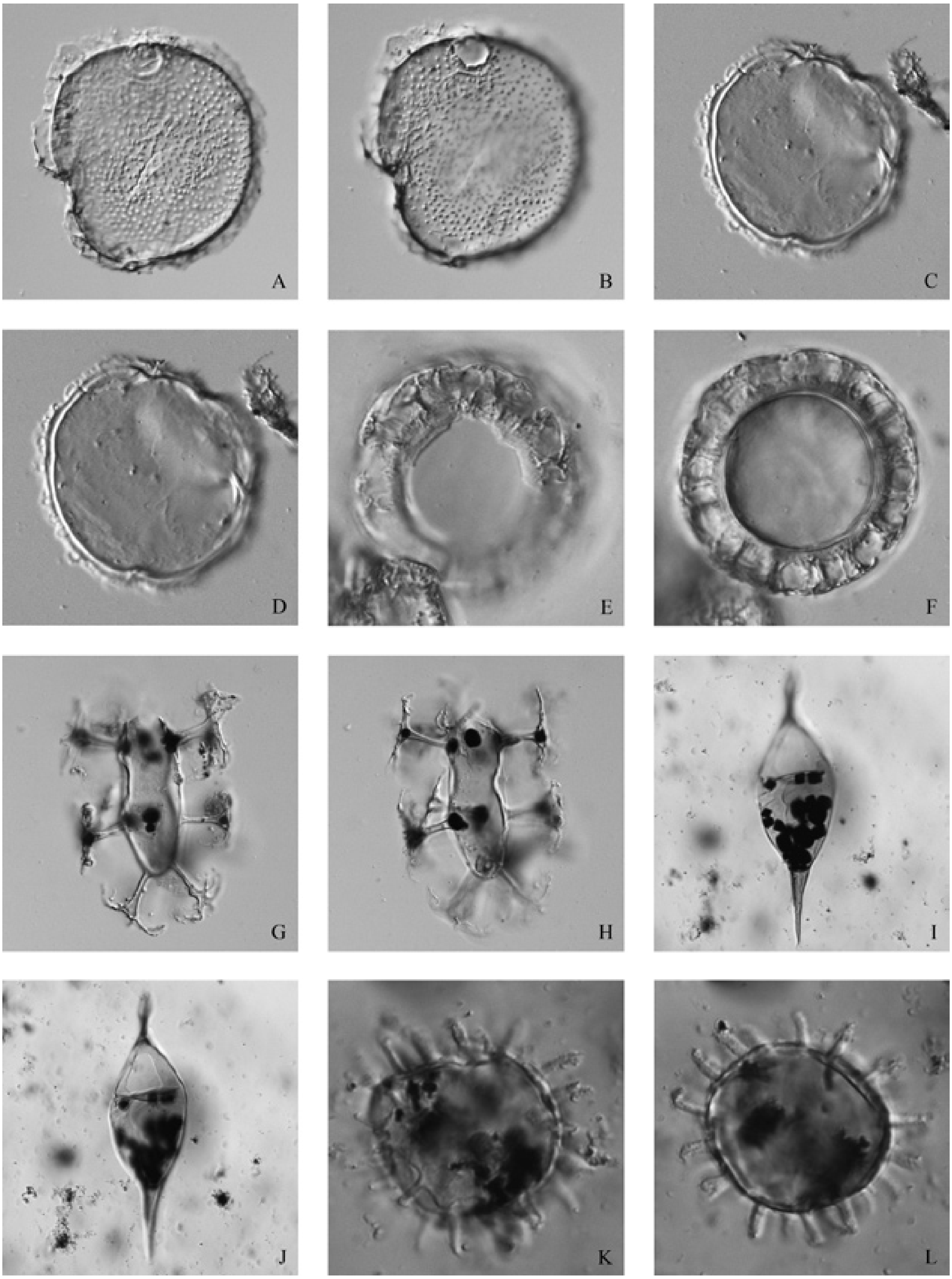

Plate 2: Dinoflagellate cysts and acritarchs from the Posthogbrug site. All photomicrographs are taken in bright field. Various magnifications. A–B *Cyclopsiella granosa/elliptica*. A.High focus on apertural side, maximum length excluding rim: 63,5 µm, sample PHB1-362, G41/1. B. Same specimens, slightly lower focus. C–D. *Paralecaniella indentata*. C. High focus, maximum length excluding rim: 57,9 µm, sample PHB1-362, G25/4. D. Same specimen, slightly lower focus. E–F. *Labyrinthodinium truncatum truncatum*. E. High focus, maximum diameter central body: 32,5 µm, sample PHB4-362, D36/4. F. Same specimen, optical section. G–H. *Distatodinium paradoxum*. G. High focus, length central body:61,5 µm, sample PHB1-362, G41/1. H. Same specimen, slightly differing high focus. I–J. *Palaeocystodinium golzowense*. I. High focus, maximum length: 114,3 µm, sample PHB3-362, E35/2. J. Same specimen, slightly differing high focus on archeopyle. K–L. *Nannobarbophora gedlii*. K. High focus, maximum diameter central body: 25 µm, sample PHB3-362, C37/3. L. Same specimen, optical section.

Plate 3: Various vertebrate remains from unit 2 at Posthofbrug. A. Left scapula of a cheloniid turtle in posterior view. B. Cranium fragment of *Xiphiacetus bossi* in dorsal view. C. Fragment of the vertex of *X. bossi* in dorsal view. D. Right periotic of Eurhinodelphinidae indet. in ventral (D_1), medial (D_2), dorsal (D_3), and lateral view (D_4). E. Left humerus of Eurhinodelphinidae indet. in posterior (E_1) and lateral view (E_2). F. Caudal vertebra of aff. Eurhinodelphinidae in anterior (F1) and ventral view (F2), displaying thick exostoses. G. Caudal vertebra of Eurhinodelphinidae indet. in dorsal view. H_1-H_2. Isolated tooth of Eurhinodelphinidae indet. I. Right periotic of Delphinoidea indet. in ventral (I_1), medial (I_2), dorsal (I_3), and lateral view (I_4). J. Fragment of left tympanic bulla, aff. *Kentriodon* in medial view. K. Isolated tooth, aff. *Delphinodon* in lingual view (K_1) and detail of the crown (K_2). L. Crown of a cheek tooth of *Squalodon* sp. in lingual (L_1) and proximal view (L_2). M. Thoracic vertebra of Physeteroidea indet. in left lateral (M_1) and anterior view (M_2). N. Left periotic of Cetotheriidae s.l. in ventral (N_1), medial (N_2), and dorsal view (N_3). O_1-O_2. Isolated left lower canine of Pinnipedia indet. P. Left innominate, aff. *Prophoca* in lateral view. Q_1-Q_2. Femoral head of a pinniped femur, aff. *Prophoca*. Scale bars for A, B, C, E, F, G, M, P equal 30 mm and for D, H, I, J, K, L, N, O, Q equal 10 mm.