



Oligocene dinoflagellate cyst biostratigraphy of the southern North Sea Basin

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Received 20 February 2004; accepted 9 December 2004

Abstract

The Rupelian (Lower Oligocene) and Chattian (Upper Oligocene) stratotype sections are both defined on the basis of the southern North Sea Basin sedimentary successions. The characterisation of biotic events occurring within the stratotypes (and equivalents) is vital for the recognition of these stages outside the North Sea Basin. Although the restricted marine setting of the North Sea Basin during most of the Paleogene clearly hampers ‘traditional’ calcareous microfossil calibration, organic-walled dinoflagellate cysts (dinocysts) are increasingly successful in the stratigraphic analysis and calibration of the marginal-marine North Sea Basin successions. Here we present a high-resolution Oligocene dinocyst biostratigraphic zonation scheme for the southern North Sea Basin based on previously published and new dinocyst studies from Belgium, northern Germany and The Netherlands. Eight (southern) North Sea Oligocene (NSO) dinocyst zones (biozones) and four subzones are here defined. Their application on a regional and inter-regional scale is discussed. The stratigraphic important Late Oligocene dinocyst taxon *Triphragmadinium demaniae* gen. and sp. nov. is formally described.

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Keywords: Oligocene; dinoflagellate cysts; biostratigraphy; North Sea Basin

1. Introduction

The Paleogene successions of the North Sea Basin (Fig. 1) rank among the best-documented passive margin systems worldwide, e.g., in terms of facies

history, biostratigraphy and sequence stratigraphy. Yet, despite the fact that local biostratigraphies achieve very high resolution and accurate regional correlations, chronostratigraphic calibration of the successions to ‘international’ time scales (e.g., Berggren et al., 1995) remains problematic. This is due to: (1) the marginal marine, siliciclastic nature of most deposits, leading to the near absence of age-indicative planktonic calcareous microfossils; (2) the effect of

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Fig. 1. Paleogeographic reconstruction of the mid-Oligocene North Sea Basin, showing the location of the Rupelian (R) and Chattian (C) unit-stratotypes (modified after Ziegler, 1990; Verbeek et al., 2002 and Sissingh, 2003).

weak paleomagnetic signals; and (3) the widespread occurrence of tectonically and/or eustatically induced unconformities. Moreover, many of the Late Eocene and Oligocene biostratigraphic calibration problems arise from the additional effects of global climatic cooling (e.g., Zachos et al., 2001; DeConto and Pollard, 2003). Changing surface temperatures had a severe impact on the biotic communities; species migrated towards lower (warmer) latitudes, resulting in the notoriously diachronous nature of many biotic events at this time (e.g., Wei and Wise, 1990; Brinkhuis and Visscher, 1995; Prothero et al., 2003). In addition, and as a result, many of the biotic events used in various ‘standard’ Oligocene zonation schemes are not recorded at middle and high latitudes, or occur diachronously. Other correlation and calibration problems arise from the apparently restricted marine setting of the North Sea Basin during the Oligocene. The semi-enclosed basin only had two narrow outlets: a northern connection with the North Atlantic and temporary southern connections with the para-Tethys (Fig. 1). This aspect clearly enhanced an endemic flora and fauna. While noting the calibration problems, dinocysts are increasingly successful in the stratigraphic analysis and calibration of the marginal-marine Paleogene and Neogene North Sea Basin successions (Powell, 1992; Bujak and Mudge, 1994;

Stover and Hardenbol, 1994; Powell et al., 1996; Louwey et al., 1999, 2000; Dybkjær and Rasmussen, 2000; Eldrett et al., 2004). Many of the dinocyst events are now recognised outside the North Sea Basin, indicating their potential for inter-regional chronostratigraphic correlations. In order to explore this potential further, we here provide an updated, detailed dinocyst zonation scheme for the southern North Sea Basin Oligocene successions by integrating previously published information with results from recent studies of outcrops and boreholes in Belgium, The Netherlands, and northern Germany.

2. Material and methods

The southern North Sea Basin Oligocene successions are important in that they contain the Rupelian (Lower Oligocene) and Chattian (Upper Oligocene) stratotype sections. The stiff clays outcropping along the Rupel River in NW Belgium constitute the type-Rupelian, while the Doberg section in northern Germany comprises the type-Chattian (Fig. 1). Despite the many (micro)paleontological studies on the type- and paratype sections (for an overview see Van Simaey et al., 2004), until a decade ago, dinocyst biostratigraphy suffered from poor resolution (e.g.,

Benedek, 1972, 1975). Only quite recently, knowledge of dinocyst biostratigraphy from Oligocene sections in Belgium, Germany, and The Netherlands significantly increased (e.g., Köthe, 1990; Stover and Hardenbol, 1994; De Coninck, 1995, 1999, 2001; Vandenberghe et al., 2003; Van Simaey et al., 2004). However, until now, no attempt was made to combine existing data into a relatively high-resolution Oligocene dinocyst biostratigraphic zonation scheme for the southern North Sea Basin.

New data on the distribution of Oligocene dinocysts were generated through palynological analysis of apparently continuous Chattian sections from the Roer Valley Graben (SE The Netherlands); the Groote Heide (Table 1) and the Broekhuizenborst boreholes were sampled with a 6-m sample interval. In addition, we analysed Chattian samples from the Mol Belchim, Retie and Wijshagen boreholes in NE Belgium, the Ekeren and Essen boreholes in NW Belgium, and samples from the Gartow borehole in northern Germany (Table 2). Standard procedures as described in Van Simaey et al. (2004) were used for the preparation of the samples and for the qualitative and quantitative analyses of the dinocyst assemblages. For the location of the sections studied, see Fig. 2.

The boreholes have been correlated with each other, and with the various outcrop sections, as well as other previously analysed sections, on the basis of geophysical well log correlation and available bio- and magnetostratigraphy. All these data have subsequently been integrated into a composite section (Fig. 3). The *Asterigerina* Horizon, defining the base of the Chattian in the North Sea Basin (for discussion see Van Simaey et al., 2004) is designated as reference level 0; the lithostratigraphic units in Belgium are after Laga et al. (2001).

3. A southern North Sea Oligocene (NSO) dinoflagellate cyst zonation

All the new borehole samples contain rich assemblages of well-preserved palynomorphs. In general, the assemblages are dominated by dinocysts and bisaccate pollen, except for some uppermost Rupelian samples in the Weelde and Mol-1 boreholes, which yield high numbers of small, spherical acritarchs (Plate III, 5–7). The most diversified Rupelian dinocyst assemblage

consists of 58 taxa; the most diversified Chattian sample contains 61 taxa. Most assemblages are characterised by high numbers of *Spiniferites* spp., *Dapsilidinium* spp., and *Cleistosphaeridium* spp. (see Eaton et al., 2001). In some samples, either *Homotryblidium* spp. or the acritarch *Paralecianiella* spp. are dominant. Typical ‘oceanic’ taxa (e.g., *Nematosphaeropsis* and *Impagidinium* spp.) are very rare throughout the section, reflecting the shallow marine setting of the southern North Sea Basin at this time. Cysts of the heterotrophic protoperidinoids appear only in relatively low percentages. The stratigraphic dinocyst distribution patterns in all successions have been analysed and compared with the previous studies in detail. This resulted in the recognition of over 30 dinocyst events that may be used for regional and possible inter-regional correlation. The most consistent and characteristic dinocyst events have been selected to establish eight dinocyst zones and four subzones, defined below. The definitions of the zones and subzones are based on the first occurrence (FO) and last occurrence (LO) of one or more taxa of dinocysts (Fig. 3).

3.1. North Sea Oligocene-1 zone (NSO-1)

Definition: The interval from the FO of *Thalassiphora reticulata* to the LO of *Areosphaeridium diktyoplokum*.

Characteristics: The LO of *Thalassiphora reticulata* is in the upper part of this zone; throughout its range, *T. reticulata* is relatively rare (less than 1% of the total dinocyst assemblage). The LO of *Rhombodinium perforatum* and *Cerebrocysta bartonensis* coincides with the LO of *Areosphaeridium diktyoplokum*.

Calibration: The NSO-1 zone can be correlated with the upper part of NP21 (Vandenberghe et al., 2003). The last occurrence of *Areosphaeridium diktyoplokum* in the Norwegian–Greenland Sea is calibrated to the basal part of magnetochron C13n with age assignment of 33.4 Ma (Eldrett et al., 2004). In Northern Hemisphere mid latitudes, the LO of *A. diktyoplokum* occurs at 33.3 Ma (Brinkhuis and Visscher, 1995; Williams et al., 2004).

Chronostratigraphic age: Latest Eocene to earliest Oligocene.

Type section: Kallo borehole, from –110.5 to –109.5 m (De Coninck, 1999).

<i>Lingulodinium</i> spp.	4		3	14	8	6	10	2	7	5	18	10	13	3	8	8	5	7	1	11	
<i>Melitasphaeridium choanophorum</i>	1		1																		
<i>Membranilarnacia? picena</i>	1		1		1				1												
<i>Operculodinium xanthium</i>																					
<i>Palaeocystodinium</i> spp.					1	1			1	1	1	1	1			1	1	2			
<i>Paralecaniella</i> spp.	10	3		2	6	1	1	3	1	3		6	2	1						1	
<i>Pentadinium</i> spp.						3	1	4	2	2		4		1		3		1	4	1	
<i>Pentadinium imaginatum</i>						1			1			1			1	1	1		1		
<i>Pentadinium lophophorum</i>																					
<i>Phthanoperidinium filigranum</i>																					
<i>Polysphaeridium</i> spp.							1			1		1	1								
<i>Reticulosphaera actinocoronata</i>		1		2	2	3	6		1	3	7	5	3	1	5	3			2	6	
<i>Rhombodinium draco</i>																					
<i>Saturnodinium pansum</i>																					
<i>Selenopemphix</i> spp.												1									
<i>Spiniferites</i> spp.	24	45	5	29	61	39	46	46	52	29	50	54	66	29	52	43	26	34	30	24	63
<i>Svalbardella cooksoniae</i>																					
<i>Tectatodinium</i> spp.		1				1		1	2	1	1	1	2	1	1					1	
<i>Thalassiphora pelagica</i>	1	1		1	1	2	2	2	4	1			2	1							
<i>Tityrosphaeridium cantharellus</i>	3	1		2	4	2		7							2			1		2	
<i>Triphragmadinium demaniae</i>												1	2								
<i>Tuberculodinium vancampoeae</i>						2															
<i>Wetzeliiella</i> spp.		2		1	1															1	
Other taxa	1	3	1	3	8	21	34	18	26	19	16	4	10	10	7	5	3	5	13	9	20
Total counted	127	108	11	72	135	130	147	136	124	117	127	108	143	95	122	95	96	70	120	91	127

Numbers represent absolute counts, x=rare occurrence, not included into counts.

<i>Lingulodinium</i> spp.	9	1	7	9	14	12	6	7	3	1	2	5	4	3	4	3	3	3	3	2	29
<i>Melitasphaeridium choanophorum</i>																					
<i>Membranilarnacia? picena</i>																					
<i>Operculodinium xanthium</i>													2				3	3	2	2	
<i>Palaeocystodinium</i> spp.	3	1	3	1	1	1	5	3	1	2	3	1	1	1	2						1
<i>Paralecaniella</i> spp.			1	1					1	1		1								1	
<i>Pentadinium</i> spp.				1	1		1	2	1	2	1	2	1	1	5	2	2	2	1	1	1
<i>Pentadinium imaginatum</i>				1	1	1	1	1				1	1								
<i>Pentadinium lophophorum</i>																	1	1	2	2	
<i>Phthanoperidinium filigranum</i>																					2
<i>Polysphaeridium</i> spp.	1		1			1								1		1					
<i>Reticulosphaera actinocoronata</i>	8	2	8	6	1	6	2	4	2	2	3	2	1	2	2	8	3	2	1	1	9
<i>Rhombodinium draco</i>										1	1	1	17	1	3	1	2	1	1	1	
<i>Saturnodinium pansum</i>			2	2	1	3	1	2	4			3	1	1		1			1		
<i>Selenopemphix</i> spp.			1												1						
<i>Spiniferites</i> spp.	39	27	36	40	27	35	41	38	14	11	30	43	26	29	17	36	37	15	17	19	40
<i>Svalbardella cooksoniae</i>				1		1	1														
<i>Tectatodinium</i> spp.	1	1		1				1	1	1	1				1	5	1		1		
<i>Thalassiphora pelagica</i>			1	1	1		1	1	1	1	1	2	1	1	2	1	7	4	6	3	1
<i>Tityrosphaeridium cantharellus</i>	1	1	1	3	4	2	1	3	3	1	1	5	1	3	1	1	3	1	1	2	3
<i>Triphragmadinium demaniae</i>																					
<i>Tuberculodinium vancampoeae</i>															1						
<i>Wetzeliiella</i> spp.		2	1	2	2	4	10	20	12	1	4	2	6	4	3	9	11	4	22	12	29
Other taxa	11	8	8	5	14	8	3	7	9	4	9	5	12	9	2	14	12	7	5	6	11
Total counted	119	63	104	147	103	122	160	163	128	50	88	104	105	91	87	124	127	76	97	87	182

Table 2
Quantitative dinocyst distribution of selected species within samples from the Gartow borehole

Sample depth	Gohy 215.00	Gohy 218.60	Gohy 221.00	Gohy 230.00	Gohy 236.00	Gohy 242.20	Gohy 253.80	Gohy 258.00	Gohy 260.70	Gohy 264.80	Gohy 265.00	Gohy 268.00	Gohy 270.00	Gohy 272.20	Gohy 274.00	Gohy 276.30	Gohy 277.00	Gohy 280.60	Gohy 290.60	Gohy 298.20	
<i>Achilleodinium</i> <i>biformoides</i>											1			x	3	1	x	x	x	x	
<i>Adnatosphaeridium</i> <i>multispinosum</i>						x				x	x		x	x		x	x	3	1	x	
<i>Apteodinium</i> <i>australiense</i>		19	3	2	22		x	1	x			6	3	2	7	3	1	7	1	6	x
<i>Apteodinium</i> <i>spiridoides</i>								8													
<i>Areoligera</i> <i>semicirculata</i>			x			x		x	x	x	6	13	3	8	2	2	x	14	1	1	
<i>Artemisiocysta</i> <i>cladodichotoma</i>		1	2	9	3		6	4	7	2	x	1	x	x							
<i>Caligodinium</i> <i>amiculum</i>	1	1	x	x	x	1	x	x		1	x		x	x	x	1	x	x		1	
<i>Chiropteridium</i> spp.	3	9	3		x	1	4	1	11	7	25	24	14	4	17	23	6	12	9	24	
<i>Cleistosphaeridium</i> spp.	6	32	36	57	71	55	21	34	27	19	29	20	28	17	56	27	18	18	30	28	
<i>Cribrorperidium</i> spp.							2					4	1	8	2	1	4	2	1	21	1
<i>Cyclopsiella</i> <i>elliptica</i>		1		1				x		x			x		1						
<i>Cyclopsiella</i> <i>granosa</i>		1		x	x	x	x	1													
<i>Cymatiosphaera</i> <i>bujakii</i>			1	1				2	1	2	3		1	4		1				1	
<i>Dapsilidinium</i> spp.	1	7	21	11	8	9	17	19	26	24	22	25	27	19	21	15	24	25	24	37	
<i>Deflandrea</i> <i>phosphoritica</i> complex									x	x	22	x	15	3	3	2	6	1	2	4	
<i>Dinopterygium</i> <i>cladoides</i>						3		1		2	1	1	2	1	x	2	5	2	6	1	
<i>Distatodinium</i> <i>biffii</i>			1	6	2	11	1	x		x	1	x	x	2	x	1	1	x			
<i>Distatodinium</i> <i>paradoxum</i>	2	6	8	8	1	10	5	12	7	6	10	7	1	5	5	11	25	15	10	4	
<i>Filisphaera</i> <i>filifera</i>	1	2			1																
<i>Gerlachidium</i> <i>aechmophorum</i>	x	1		5	x	1	7	4	2	6	x	1	1	x							
<i>Glaphyrocysta</i> spp.			x	x	1	6	x	6	x	x	x	1		1		x	x			x	
<i>Glaphyrocysta</i> <i>semitecta</i>			x					x	6	1	x	x	1								

<i>Homotryblium</i> spp.	x		3	4		90	2	3	5	3	1	1	2	2	2	6	7	6	6	21
<i>Hystrichokolpoma cinctum</i>	x	2	x	x	x	2	1			x	1	x	1	x	1	5	2	x	6	1
<i>Hystrichokolpoma pusillum</i>								1	cf	cf						cf			x	x
<i>Hystrichokolpoma rigaudiae</i>	12	8	54	8	3	3	11	9	7	4	10	11	13	9	13	10	12	2	19	5
<i>Impagidinium</i> spp.		1	4	3	x	x	4	3	4		x	1	x	x	x			x		
<i>Lejeunecysta hyalina</i>		2	x	3	x	x	6	4	6	1	3	1	x	x			x	x	1	x
<i>Lejeunecysta tenella</i>		4	2	2	x	1		x	1	3		1								
<i>Lingulodinium</i> spp.	2	13	13	21	11	12	10	11	7	10	11	6	4	8	13	17	11	34	10	18
<i>Membranophorum aspinatum</i>					x	2	5	x	1				2	2	4	4		3		
<i>Operculodinium xanthium</i>																x	x	3	6	x
<i>Palaeocystodinium golzowense</i>	x	1	7	3	x	1	1	2	2	4	3	5	3	5	6	1	3	x	x	
<i>Paralecaniella indentata</i>	11	9	1	15	2	6	9		10	12	5	8	6	10	x	6	1	3	2	
<i>Pentadinium imaginatum</i>			x	5	x	2	x			x	2	3	x	x	x					
<i>Pentadinium laticinctum</i>		1	x	5	x	4	1	1	x	2	x	1	1	x	1	x	x	x	2	x
<i>Pentadinium lophophorum</i>																			x	x
<i>Polysphaeridium zoharyi</i>														1	2	2		1	1	
<i>Reticulosphaera actinocoronata</i>			16	8	2	6	8	13	16	9	10	5	7	3	3	3	7	8	13	6
<i>Rhombodinium draco</i>											4			x	1	8	3	x	5	x
<i>Saturnodinium pansum</i>										4	4	9	5	2	3	x	2	1	x	1
<i>Selenopemphix armata</i>							x			1				x	x					
<i>Selenopemphix nephroides</i>	1		1	1			1	3	4	4	2	3	2	x			1			x
<i>Spiniferites-Achomosphaera</i> complex	34	92	123	108	53	70	133	126	152	156	126	132	116	75	120	79	122	116	142	120
<i>Tectatodinium pellitum</i>				2	x	1	1	1	x	x	1	1	2	x	x	2	1	1	2	1
<i>Thalassiphora pelagica</i>	x	3	x	4		1	x	x	1	5	7	12	9	3	4	36	14	16	15	10
<i>Tityrosphaeridium cantharellus</i>	3	3		3	5	5	3	2	2	2	2	3	7	5	15	6	5	17	13	6
<i>Triphragmadinium demaniae</i>			2	4	1															
<i>Tuberculodinium vancampoe</i>										x				x	x		1	1	x	x
<i>Wetziella articulata</i>							x				x	x	3	2		1	x	2	x	
<i>Wetziella gochtii</i>						x		x	x	x	x	x	9	2	1	1	x	x	1	x
<i>Wetziella symmetrica</i>							x				1	x	1	x		x		x	x	x
Other taxa	3	16	24	24	40	37	72	45	30	26	29	24	40	27	16	22	42	30	29	19
Total	80	235	325	323	226	340	331	317	335	316	352	324	336	229	317	301	328	335	383	310

Numbers represent absolute counts, x=rare occurrence, not included into counts.

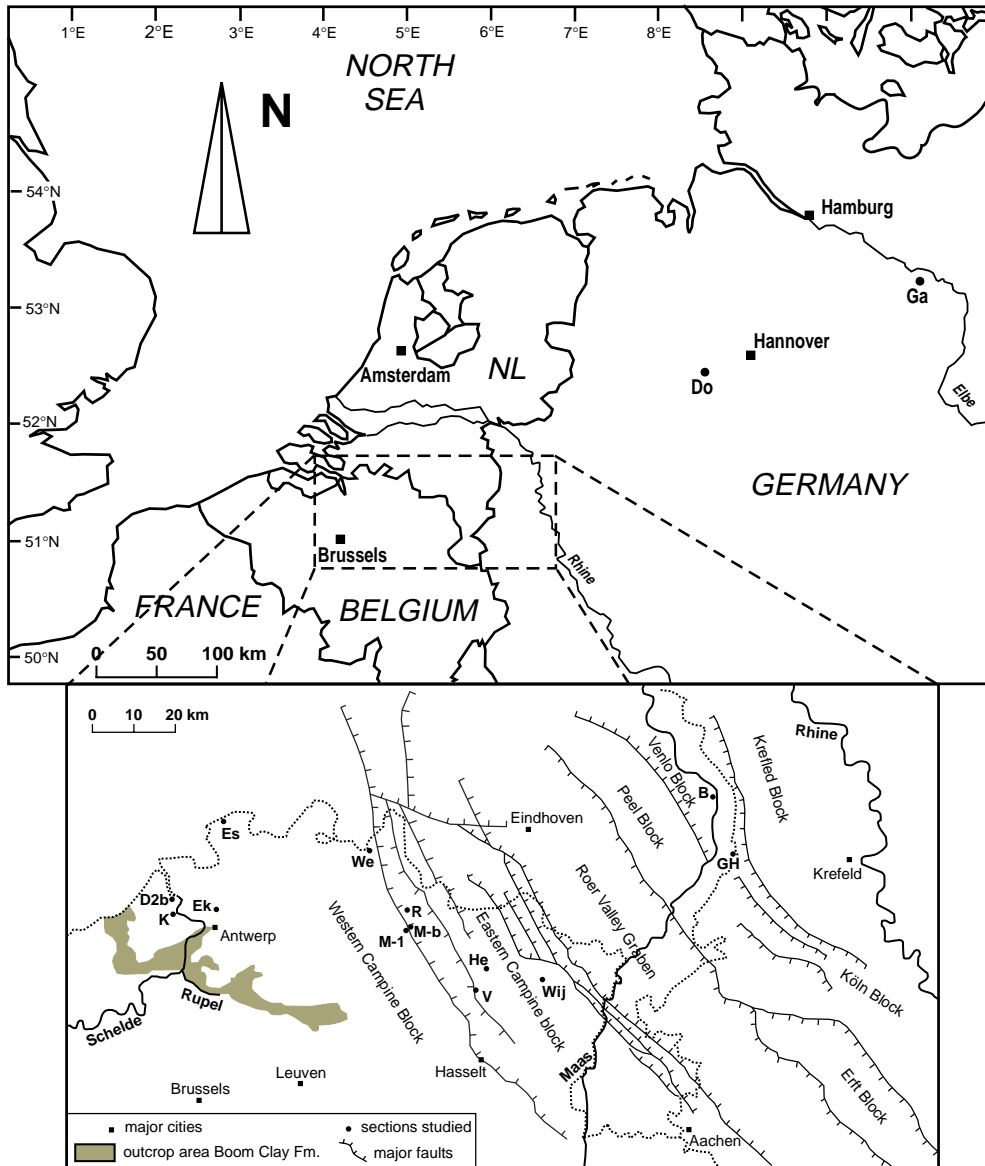


Fig. 2. Location of the studied sections. The wells investigated in this study are Mol-belchim (M-b), Wijshagen (Wij), Ekeren (Ek), Essen (Es), Retie (R), Grootte Heide (GH), Broekhuizenvorst (B), and Gartow (Ga). Van Simaey et al. (2004) studied the dinocysts from the Weelde (We), Hechtel (He), Voort (V), Mol-1 (M-1), and Doberg (Do) sections. Stover and Hardenbol (1994) studied the dinocysts from the outcrop area of the Boom Clay Formation, while De Coninck (1995, 1999) and Vandenberghe et al. (2003), respectively, investigated the dinocyst assemblages from the Kallo (K) and Doel 2-b (D2b) boreholes.

Remarks: This zone is recognised in the upper part of the Bassevelde Member (Zelzate Formation), the Watervliet Member (Zelzate Formation), and the stratotype of the Wintham Silt (Zelzate Formation)

in NW Belgium (De Coninck, 1999; Vandenberghe et al., 2003) and in both the Grimertingen and Neerreen Members (Sint-Huibrechts-Hern Formation) in NE Belgium (De Coninck, 2001).

3.2. North Sea Oligocene-2 zone (NSO-2)

Definition: The interval between the LO of *Areosphaeridium diktyoplokum* and the FO of *Chiropteridium* spp.

Characteristics: The FO of the *Wetziella gochtii*–*Wetziella symmetrica* complex occurs in the basal part of this zone. Slightly higher, still in the lower part of this zone, *Gerdiocysta conopeum* and *Areoligera semicirculata* consistently occur and single occurrences of *Svalbardella* sp. are recorded (De Coninck, 1999). Higher-up in the NSO-2 zone, *Glaphyrocysta semitecta* and *Charlesdownia clathrata* occur for the last time.

Calibration: The NSO-2 zone correlates with the lower and middle part of NP22 (Vandenberghe et al., 2003). In the Norwegian–Greenland Sea, the FO of both *Wetziella gochtii* and *Chiropteridium* spp. is associated with the NP21/NP22 transition and is calibrated to magnetochron C13n (Eldrett et al., 2004). The FO of *W. gochtii* in Northern Hemisphere mid latitudes occurs at 32.8 Ma (Williams et al., 2004), while the last occurrence of *Glaphyrocysta semitecta* in the central Mediterranean is calibrated to the lower part of magnetochron C12r, with an age-assessment of 32.5 Ma (Wilpshaar et al., 1996).

Chronostratigraphic age: Early Oligocene, earliest Rupelian.

Type section: Doel 2b borehole, from –140.0 to –121.0 m (Vandenberghe et al., 2003).

Remarks: This zone is recognised through most of the Ruisbroek Member (Zelzate Formation) in NW Belgium (De Coninck, 1995, 1999).

3.3. North Sea Oligocene-3 zone (NSO-3)

Definition: The interval from the FO of *Chiropteridium* spp. to the LO of *Phthanoperidinium* spp. (including *Phthanoperidinium comatum*, *Phthanoperidinium filigranum*, and *Phthanoperidinium amoenum*).

Characteristics: Throughout this zone both *Phthanoperidinium comatum* and *Phthanoperidinium filigranum* are abundant. *Spiniferites* sp. 1 *sensu* Manum et al., 1989 (see Plate II,4,5 herein) occurs in a narrow interval between septaria-levels S30 and S40 (Lund, 2002).

Calibration: The NSO-3 zone can be correlated with the uppermost NP22 and the lower part of NP23 (Vandenberghe et al., 2003). A comparison between ODP Holes 985A and 643A suggests that the FO of *Spiniferites* sp. 1 occurs at 31.6 Ma while the LO is dated at 31.3 (Williams and Manum, 1999). In a level slightly above septaria-horizon S-40, the magnetochron C12r/C12n reversal, at 30.9 Ma, is recognised (Vandenberghe et al., 2003).

Chronostratigraphic age: Early Oligocene, early Rupelian.

Type section: Weelde borehole, from –390 to –341 m (Van Simaey et al., 2004).

Remarks: From its base to top, this zone is recognised in the following lithostratigraphic units: The uppermost part of the Ruisbroek Member (Zelzate Formation), the Belsele–Waas Member (Boom Formation), the Terhagen Member (Boom Formation), and the basal part of the Putte Member (Boom Formation) in northern Belgium (Stover and Hardenbol, 1994; Vandenberghe et al., 2003; Van Simaey et al., 2004).

3.4. North Sea Oligocene-4 zone (NSO-4)

Definition: The interval between the LO of *Phthanoperidinium* spp. and the FO of *Distatodinium biffii*.

Characteristics: This zone is subdivided into two subzones.

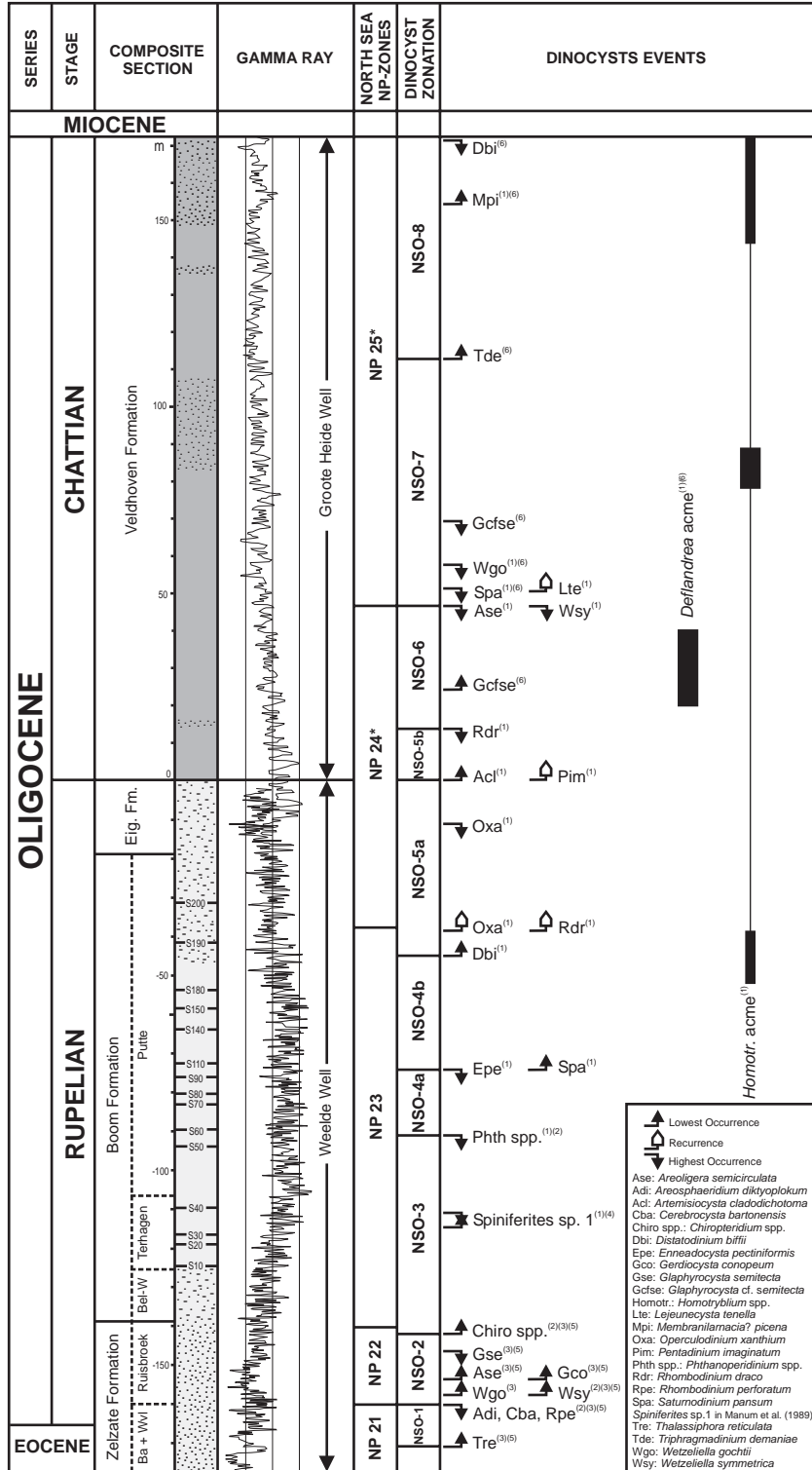
Chronostratigraphic age: Early Oligocene, mid Rupelian.

3.4.1. North Sea Oligocene-4a subzone (NSO-4a)

Definition: The interval between the LO of *Phthanoperidinium* spp. and the FO of *Saturnodinium pansum*.

Characteristics: The last common occurrence of *Enneadocysta pectiniformis* (>1% of the total dinocyst assemblage) occurs at the top of this subzone. Isolated (reworked?) records of *E. pectiniformis* are recorded throughout the upper Rupelian (Van Simaey et al., 2004).

Calibration: The NSO-4a subzone correlates to the middle part of NP23 (Van Simaey et al., 2004). According to Williams et al. (2004), the FO of *Saturnodinium pansum* and the LO of *Enneadocysta*



pectiniformis in Northern Hemisphere middle latitudes occur, respectively, at 29.4 and 29.3 Ma.

Chronostratigraphic age: Early Oligocene, mid Rupelian.

Type section: Weelde borehole, from –341 to –318 m (Van Simaey et al., 2004).

Remarks: This subzone is recognised in the lower part of the Putte Member (Boom Formation) in northern Belgium (Van Simaey et al., 2004).

3.4.2. North Sea Oligocene-4b subzone (NSO-4b)

Definition: The interval between the FO of *Saturnodinium pansum* and the FO of *Distatodinium biffii*.

Characteristics: The last common occurrence of *Enneadocysta pectiniformis* (>1% of the total dinocyst assemblage) virtually coincides with the FO of *Saturnodinium pansum* and hence can also be used to recognise the base of this subzone.

Calibration: The NSO-4b subzone can be correlated with the upper part of NP23. New data from well-calibrated central Italian sections show that the first occurrence of *Distatodinium biffii* occurs in the uppermost part of magnetochron C9r and has an estimated age of 27.9 Ma (Van Simaey, 2004).

Chronostratigraphic age: Early Oligocene, mid-Rupelian.

Type section: Weelde borehole, from –318 to –288 m (Van Simaey et al., 2004).

Remarks: This subzone is recognised in the upper part of the Putte Member (Boom Formation) in northern Belgium (Van Simaey et al., 2004).

3.5. North Sea Oligocene-5 zone (NSO-5)

Definition: The interval from the FO of *Distatodinium biffii* to the LO of *Rhombodinium draco*.

Characteristics: This zone is subdivided into two subzones.

Chronostratigraphic age: Early to Late Oligocene transition, late Rupelian to earliest Chattian.

3.5.1. North Sea Oligocene-5a subzone (NSO-5a)

Definition: The interval comprising the range of *Distatodinium biffii* below the FO of *Artemisiocysta cladodichotoma*.

Characteristics: The LO of *Operculodinium xanthium* is in the upper part of this subzone. Samples from the Western Campine Block contain high amounts (>50% of total aquatic palynomorphs) of small, spherical acritarchs (Plate III,5–7).

Calibration: The base of this subzone virtually coincides with the base of the alternative North Sea NP24* (Van Simaey et al., 2004). The LO of the benthic foraminifer *Rotaliatina bulimoides* is in the basal part of NSO-5a (Van Simaey et al., 2004).

Chronostratigraphic age: Early Oligocene, latest Rupelian.

Type section: Weelde borehole, from –288 to –242 m (Van Simaey et al., 2004).

Remarks: Both *Rhombodinium draco* and *Operculodinium xanthium* have an inconsistent range throughout the lower Rupelian and were not recorded by Stover and Hardenbol (1994) above septaria-level S-80. New data from several upper Rupelian boreholes (Van Simaey et al., 2004; this study) reveal that these species consistently re-occur above septaria-level S-190, here at the base of NSO-5a (see Fig. 3). Subzone NSO-5a is recognised in the silty upper part of the Boom Formation (the “transitional layers” in Vandenberghe et al., 2001) and the Eigenbilzen Formation; both in northern Belgium (Van Simaey et al., 2004).

3.5.2. North Sea Oligocene-5b subzone (NSO-5b)

Definition: Interval from the FO of *Artemisiocysta cladodichotoma* to the LO of *Rhombodinium draco*.

Characteristics: NSO-5b assemblages from the Western Campine Block contain high percentages of

Fig. 3. Composite diagram showing the dinoflagellate cyst zonation for the Oligocene southern North Sea Basin. The composite section was constructed by using the most complete Rupelian and Chattian profiles, respectively, in the Weelde and Groote Heide boreholes. The North Sea NP-zones are after Steurbaut (1992) and Van Simaey et al. (2004); the dinoflagellate cysts events are after (1) Van Simaey et al. (2004), (2) Stover and Hardenbol (1994), (3) Vandenberghe et al. (2003), (4) Lund (2002), (5) De Coninck (1999), and are completed with new data (6). The different septaria horizons in the Boom Formation are indicated from S10 to S200. Eig. Fm.: Eigenbilzen Formation; Ba+Wvl: Bassevelde Member and Watervliet Member; Bel-W: Belsele Waas Member.

Paralecianiella spp. Closely associated with the base of this subzone is the re-occurrence of *Pentadinium imaginatum*.

Calibration: The base of NSO-5b coincides with the onset of the benthic foraminifer *Asterigerina guerichi*-bloom. This event, together with the first occurrence of benthic foraminifera *Nonion roemeri* and the re-occurrence of *Protelphidium subnodosum* defines the base of the Chattian (for discussion see Van Simaey et al., 2004).

Chronostratigraphic age: Late Oligocene, earliest Chattian.

Type section: Weelde borehole, from –242 to –240.5 m (Van Simaey et al., 2004).

Remarks: This subzone is recognised in the Voort Formation (Belgium), the Veldhoven Formation (The Netherlands) and in the Eochatt-successions of the Gartow borehole (northern Germany, this study).

3.6. North Sea Oligocene-6 zone (NSO-6)

Definition: The interval comprising the range of *Areoligera semicirculata* and *Wetzeliella symmetrica* above the LO of *Rhombodinium draco*.

Characteristics: Within NSO-6 there is an acme of *Deflandrea* spp.; above the acme this genus is very rare. In this zone *Glaphyrocysta* cf. *semitecta* (Plate I, 1–4) appears for the first time and reworked specimens of *Svalbardella* spp. occur.

Calibration: The top of NSO-6 coincides with the alternative North Sea NP24*/NP25* transition (Van Simaey et al., 2004).

Chronostratigraphic age: Late Oligocene, early Chattian.

Type section: Groote Heide borehole, from –632 to –599 m (this study).

Remarks: In boreholes on the Western Campine Block, the NSO-6/NSO-7 zone transition corresponds with an intraformational gravel bed (ca. 5 cm thick), consisting of coarse quartz grains and fine gravel (less than 1 cm in diameter). *Areoligera semicirculata* and *Wetzeliella symmetrica* both have their highest occurrence just below this bed, and hence an intra-Chattian hiatus can be assumed in this area. In the Roer Valley Graben (i.e. the Groote Heide and Broekhuizenvorst boreholes) no gravel layer occurs and the uniform clay deposits reflect continuous sedimentation. The zone is recognised in the Voort Formation (Belgium), the Veldhoven Formation (The Netherlands) and in the Eochatt-successions of the Gartow borehole (northern Germany, this study).

3.7. North Sea Oligocene-7 zone (NSO-7)

Definition: Interval between the LO of *Areoligera semicirculata* and *Wetzeliella symmetrica*, and the FO of *Triphragmadinium demaniae* (Plate I, 1–5).

Plate I (see page 119).

Triphragmadinium demaniae gen. and sp. nov. (Bar=50 µm).

- 1–5. Same specimen. Holotype. Sample/slide: Gartow, –221 m, S-199-1–30 µm [Y43].
 1. High focus on periphragm, showing irregular circular claustra.
 - 2–3. Slightly differing high foci on pericyst and endocyst.
 4. Optical section.
 5. Detail of holotype in optical section, showing the funnel-like, periphragmal invagination (PINV), and the distinct mesophragm (MP), expressing the paracingulum (CI).
 6. Paratype. Sample/slide: Gartow, –221 m, S-199-1-30 µm [G56/3]. Specimen showing apical archeopyle (Type tA).
-

Plate II (see page 120).

Triphragmadinium demaniae gen. and sp. nov. (Bar=50 µm).

- 1–3. Same specimen. Paratype. Sample/slide: Weelde, –229 m, S-209-1-30 µm [M59/1]. Slightly differing optical sections, the arrows point towards the funnel-like, sickle-shaped periphragmal invagination (PINV) at the antapical region.
- 6–8. Same specimen. Paratype. Sample/slide: Weelde, –229 m, S-209-2-30 µm [Y51].
 6. High focus on the anterior part of the cyst, showing archeopyle.
 - 7–8. Slightly differing low foci on the distally closed, antapical process, arising from the funnel-like invagination of the periphragm. *Spiniferites* sp. 1 *sensu* Manum et al., 1989 (Bar=50 µm).
- 4–5. Same specimen. Sample/slide: Viborg borehole, CHC-1059-F-4 [H47/4]. Slightly differing optical sections showing archeopyle margin and rigid, long processes.

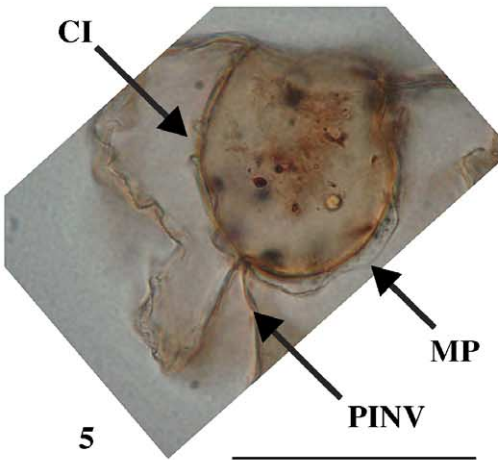
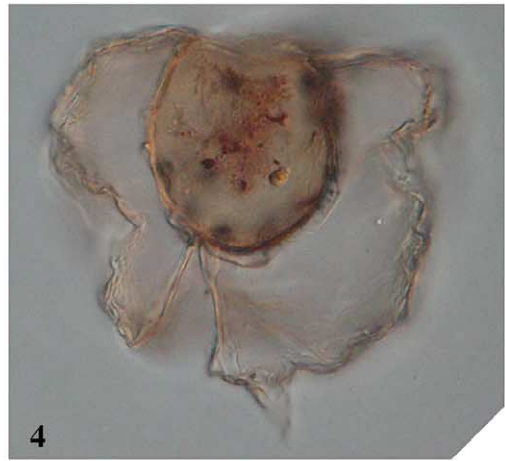
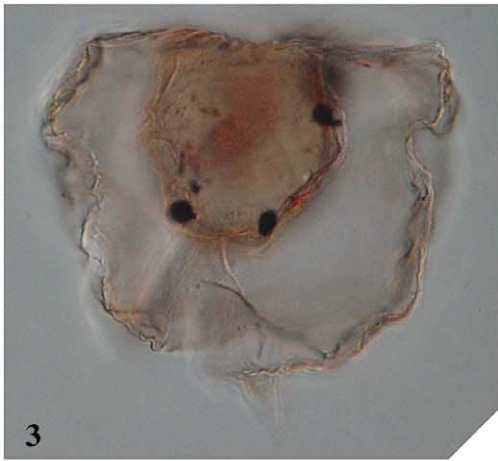
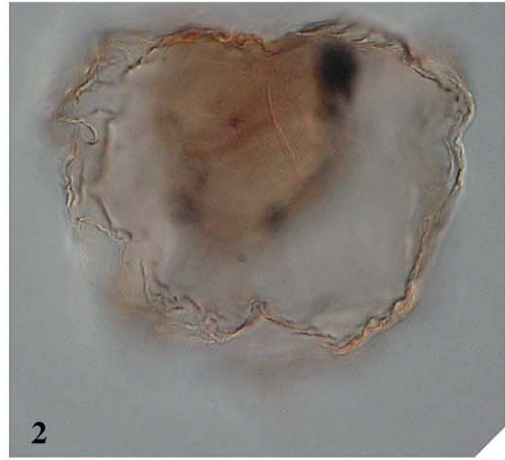
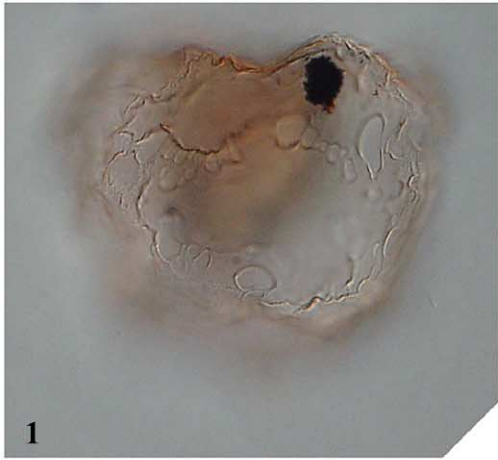


Plate I.

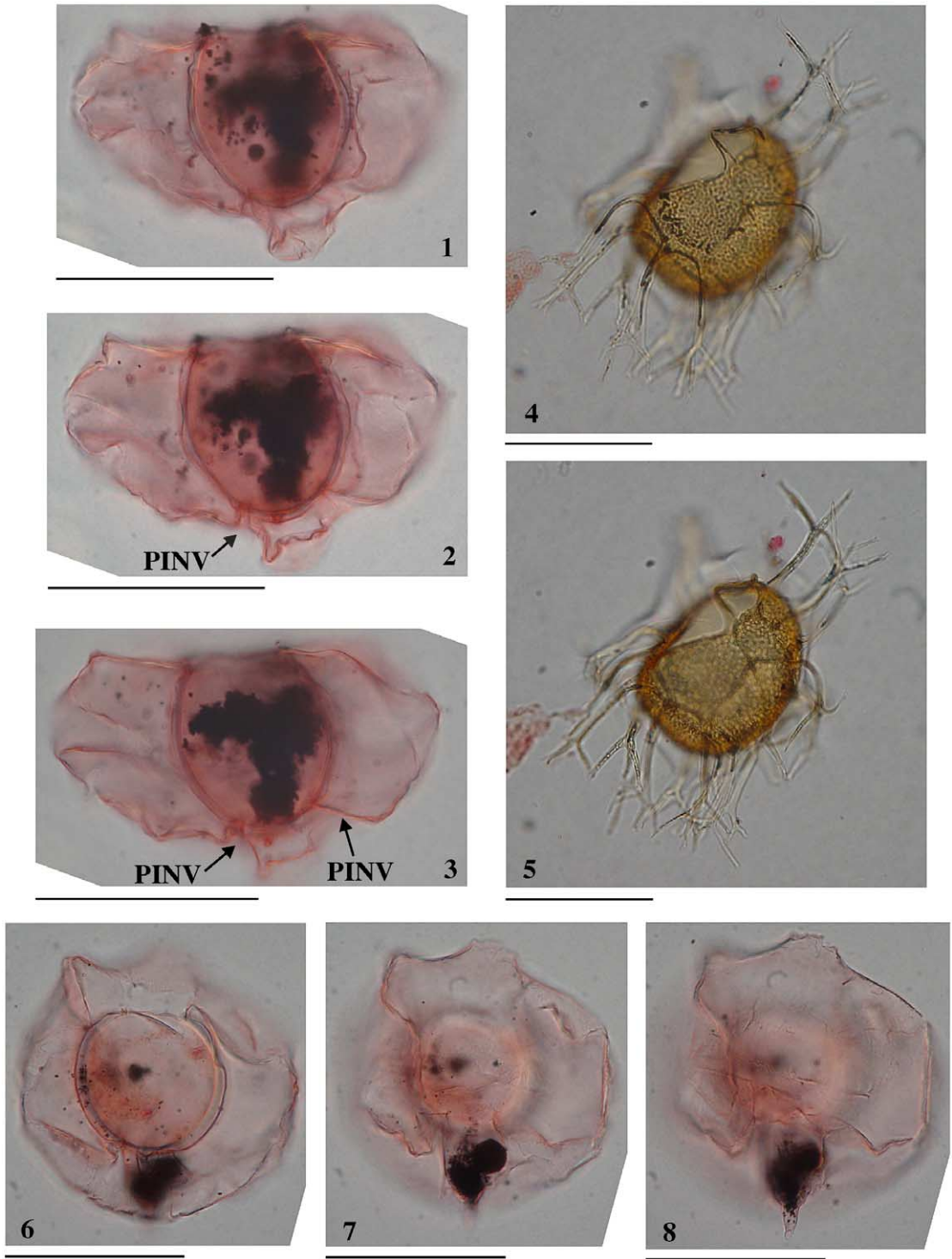


Plate II (Caption on page 118).

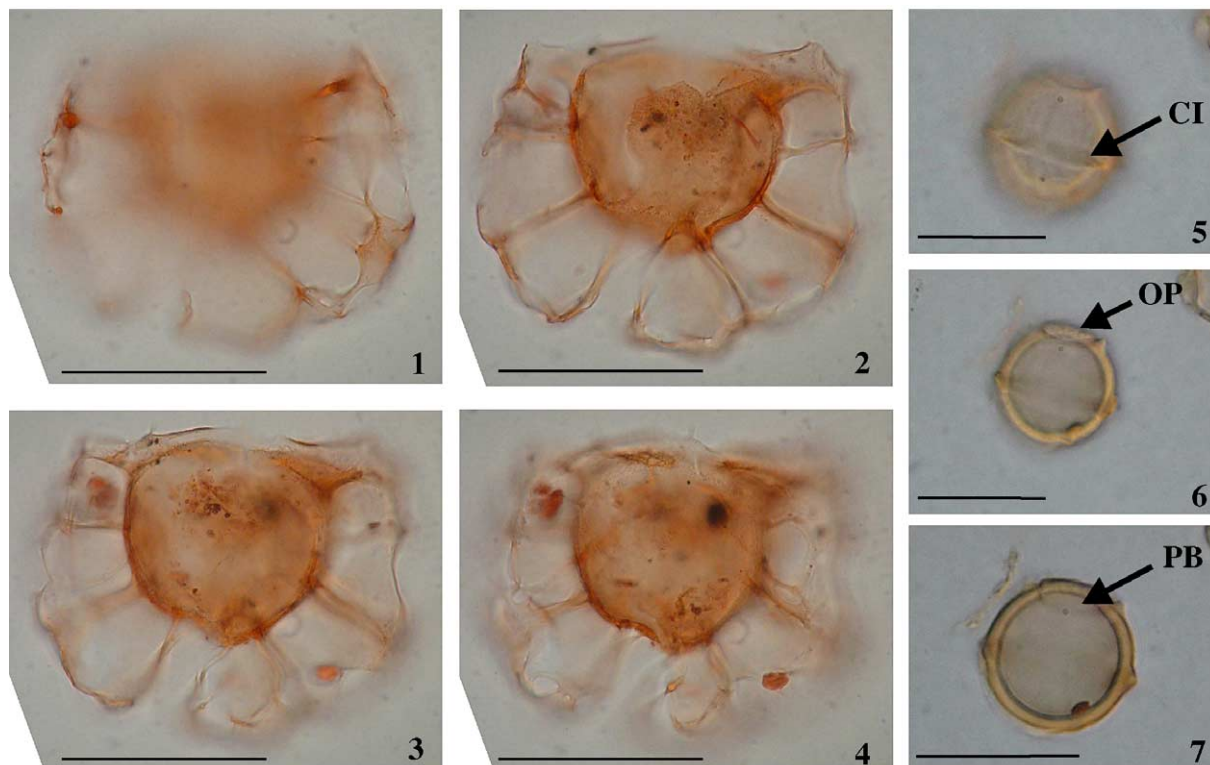


Plate III.

Glaphyrocysta cf. *semitecta* (Bujak, 1980) Lentin and Williams, 1981 (Bar=50 µm).

1–4. Same specimen. Sample/slide: Hechtel, –225 m, S-149-1-30 µm [W50/3].

1–2. Differing high foci, ventral view.

3–4. Differing low foci, dorsal view.

Spherical acritarch sp. 1 (Bar=20 µm).

5–7. Same specimen. Sample/slide: Weelde, –244 m, S-95-2-15 µm [M42/1].

5–6. Differing high foci, showing paracingulum? (CI) and attached operculum (OP).

7. Optical section, showing pylome-boundary (PB).

Characteristics: The LO of *Saturnodinium pansum* and *Wetzelia gochtii* occur in the basal part of this zone. The LO of *Glaphyrocysta* cf. *semitecta* is also recognised in this zone. In the Roer Valley graben, the upper part of NSO-7 is characterised by an abundance of *Homotryblum* spp (Table 1).

Calibration: This zone is equated with the lower part of the alternative North Sea NP25* (Van Simaey et al., 2004).

Chronostratigraphic age: Late Oligocene, mid Chattian.

Type section: Groote Heide borehole, from –599 to –532 m (this study).

Remarks: In boreholes on the Western Campine Block, a second intraformational gravel bed occurs at the NSO-7/NSO-8 zonal transition; hence a second intra-Chattian hiatus can be assumed in this area. The NSO-7 zone is part of the Voort Formation (Belgium), the Veldhoven Formation (The Netherlands), and the upper part of the Eochatt-successions in the Gartow borehole (northern Germany, this study).

3.8. North Sea Oligocene-8 zone (NSO-8)

Definition: Interval from the FO of *Triphragmadinium demaniae* to the LO of *Distatodinium biffii*.

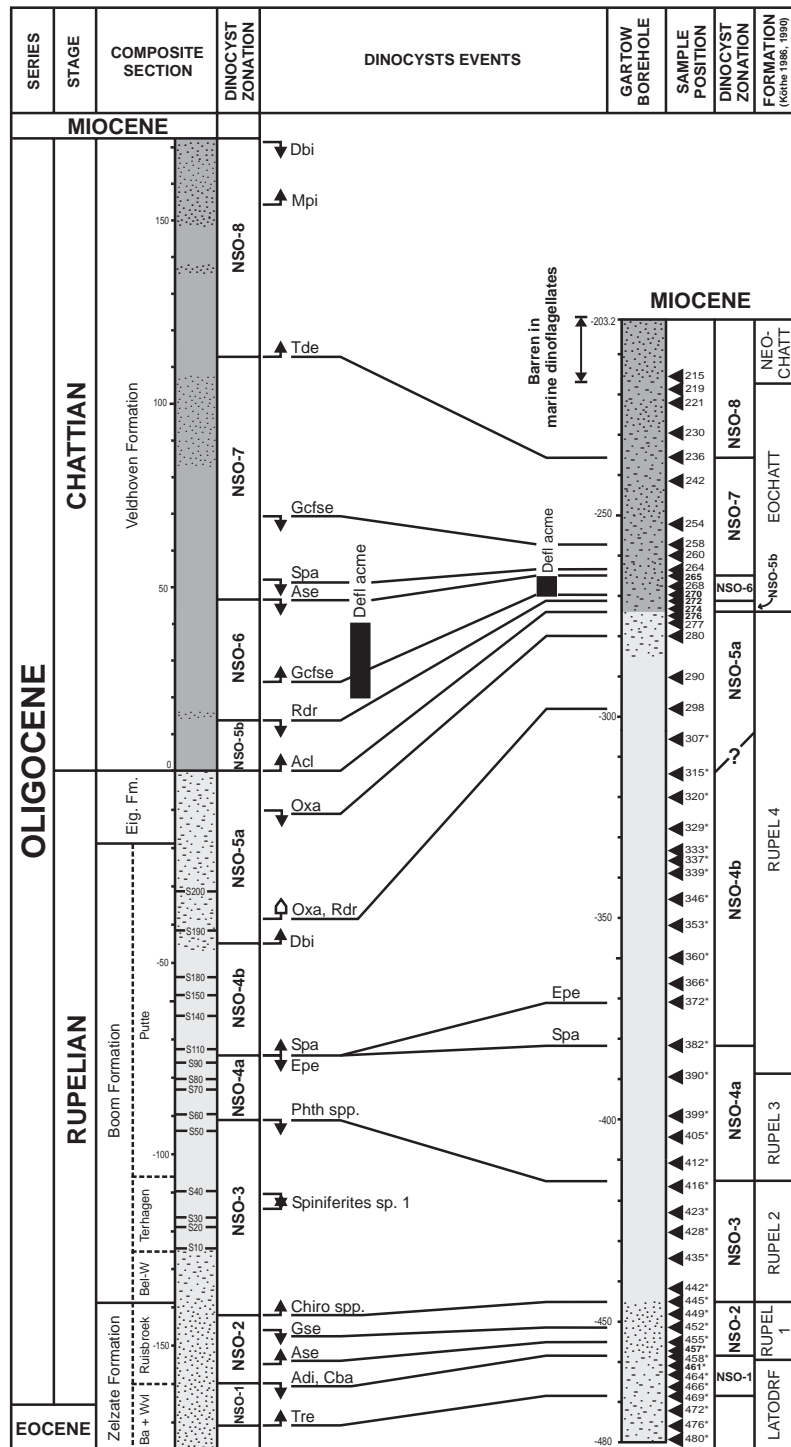


Fig. 4. Dinoflagellate cyst correlation between the composite diagram of the Oligocene southern North Sea sections and the Gartow borehole in northern Germany. Samples from the Gartow borehole indicated with an asterisk were analysed by Köthe (1990); samples without asterisk were analysed in this study.

Characteristics: The FO of *Membranilarnacia? picena* occurs in the upper part of this zone.

Calibration: The LO *Distatodinium biffii* occurs at 24.2 Ma in low latitudes (Williams et al., 2004).

Chronostratigraphic age: Late Oligocene, late Chattian.

Type section: Groote Heide borehole, from –532 to –479 m (this study).

Remarks: This zone is recognised in the upper part of both the Voort Formation (Belgium) and the Veldhoven Formation (The Netherlands). The NSO-8 is furthermore recognised in the uppermost part of the Eochatt-successions in the Gartow borehole; the restricted to non-marine overlying Neochatt succession is probably correlative with the upper part of this zone (Fig. 4).

4. Discussion

The validity of the proposed zonation within the North Sea Basin is difficult to assess in the view of the few other related studies available. However, a one-to-one correlation of the different bio-events with the Gartow borehole (Fig. 4) in northern Germany, together with unpublished evidence from Denmark (SVS), shows that the NSO-zonation is applicable to the marginal-marine Oligocene sections from onshore NW Europe. The southern North Sea Oligocene dinocyst zonation could further be applied to a limited number of side-wall core samples from a thick (>1000 m) Oligocene section in the central North Sea Basin (Mona-1 borehole, SVS, personal observations).

The North Sea Oligocene (NSO) dinocyst zonation proposed here differs from Köthe's D-zonation (1990) mainly in the mid and Late Oligocene; the two lowermost zones (NSO-1 and NSO-2) are identical to respectively Köthe's D12nc and D13 (Fig. 5). The boundary between Köthe's D14na and D14nb is defined by the first occurrence of *Apteodinium spiridoides*. However, as *A. spiridoides* is not common, Köthe (1990) suggests that the LO of *Enneadocysta pectiniformis* is close to this boundary and may also be used to recognise the D14na/D14nb boundary. Indeed, *A. spiridoides* is rare throughout the Oligocene and the distribution pattern of this species is scattered (Stover and

Hardenbol, 1994; Van Simaey et al., 2004). Moreover, the FO of *A. spiridoides* is well below the last common occurrence of *E. pectiniformis* (De Coninck, 1999) and hence the former is not a good marker. The last common occurrence of *E. pectiniformis* virtually coincides with the FO of *Saturnodinium pansum*; both bio-events are associated with the NSO-4a/NSO-4b boundary (Fig. 5).

The LO of *Rhombodinium draco* defines the top of both Köthe's D14nb and the NSO-5b zone defined here. This event occurs within the *Asterigerina* bloom and hence is a little younger than the base of the Late Oligocene or the Rupelian–Chattian boundary in the stratotype area (see Figs. 3 and 4). The overlying D15 zone of Köthe represents the interval between the LO of *R. draco* and the FO of *Tuberculodinium vancampoeae* (Köthe, 1990). However, *T. vancampoeae* is already encountered in the earliest Oligocene (De Coninck, 1999), in a level that can be attributed to NSO-3. A better bio-event to define the uppermost Chattian sequence is the LO of *Distatodinium biffii*. This event defines the top of NSO-8 (Fig. 5).

From the Wursterheide research well, northern Germany, Heilmann-Clausen and Costa (1989) record an Upper Oligocene to Lower Miocene dinocyst assemblage. The interval between 348.0 and 346.8 m is characterised by the occurrence of *Pentadinium imaginatum*, *Rhombodinium draco*, *Saturnodinium pansum*, *Wetzeliella gochtii*, and *Wetzeliella symmetrica*; this assemblage can hence be attributed to NSO-5b. In the overlying sample, 341.8–342.0 m, both *S. pansum* and *W. gochtii* are present, while no *R. draco* is recorded. This dinocyst association favours correlation with NSO-6. Detailed correlation of the interval between 340.0 and 330.8 m to the NSO zonation is difficult due to the limited amount of data and the few recorded biostratigraphic marker species. The presence of *Artemisiocysta cladodichotoma* and *Lejeunecysta tenella*, and the absence of *S. pansum* and *W. gochtii*, favours attribution to NSO-7 or younger (Miocene?) zones.

As demonstrated by Stover and Hardenbol (1994), Brinkhuis and Visscher (1995), and Vandenberghe et al. (2003), dinocyst biostratigraphy provides relatively good correlation potential in the Lower Oligocene between the restricted, marginal-marine settings of the southern North Sea Basin and the pelagic successions from the central Mediterranean. In central Italy, the

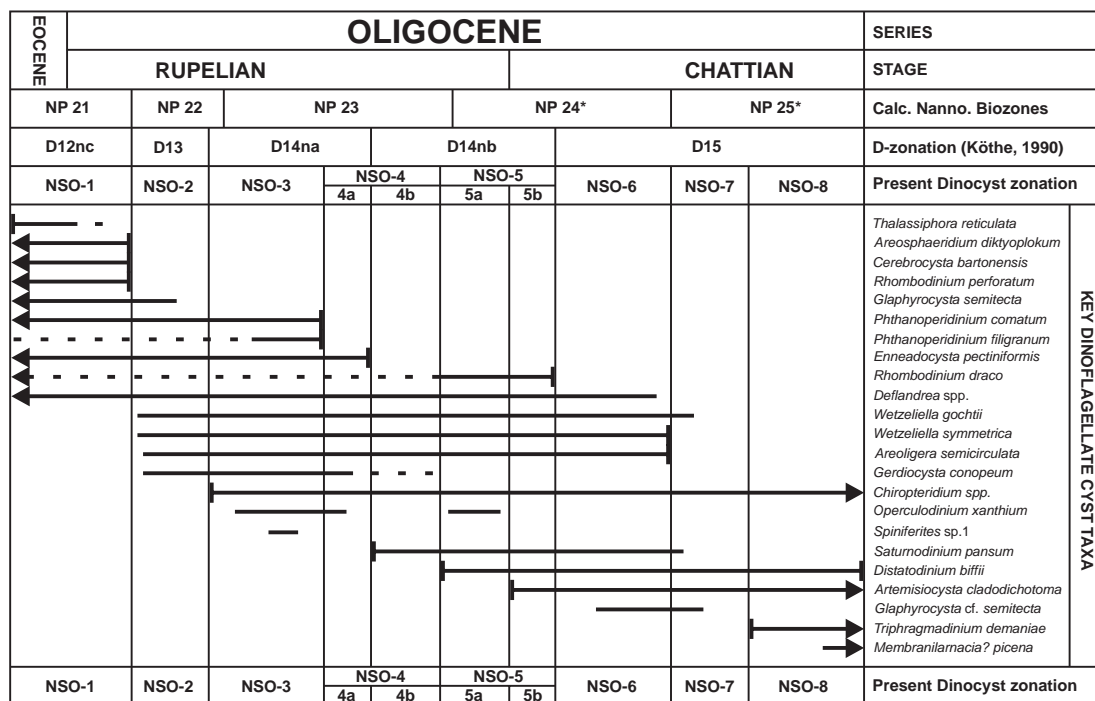


Fig. 5. Range chart of the dinoflagellate cysts used in the present North Sea Oligocene zonation scheme. The proposed NSO-zones are compared with the modified dinoflagellate zones (D-zones) after Köthe (1990). The calcareous nannoplankton zones are after Steurbaut (1992) and Van Simaey et al. (2004).

Reticulosphaera actinocoronata (Rac) Interval Zone is defined as the interval above the LO of *Areosphaeridium diktyoplokum* to the LO of *Glaphrocysta semitecta* (Brinkhuis and Biffi, 1993). According to the authors (Brinkhuis and Biffi, 1993) *Wetzelella gochtii* first occurs within this zone. These dinocyst events occur in the same chronologic order in the southern North Sea Basin. The top of the Rac Interval Zone is calibrated to the lower part of magnetochron C12r, with an age-assessment of 32.5 Ma (Wilpshaar et al., 1996). In the central Mediterranean, the LO of *Enneadocysta pectiniformis* is calibrated to the top of magnetochron C11n.1n, well below the first occurrence of *Distatodinium biffii* (Wilpshaar et al., 1996); these dinocyst events occur in the same chronologic order in the southern North Sea Basin. Some dinocyst events, however, have a peculiar range: In the southern North Sea Basin, *Membranilarnacia? picena* first occurs in NSO-8, below the LO of *D. biffii*; in the central Mediterranean, however, the FO of *M. picena* is calibrated to

the base of magnetochron C6AAr (Wilpshaar et al., 1996), clearly above the LO of *D. biffii*.

5. Concluding remarks

New data on the distribution of Oligocene dinocysts in the southern North Sea Basin, combined with previously published results, has led to the establishment of a high resolution (southern) North Sea Oligocene (NSO) dinoflagellate cyst zonation scheme. Eight zones and four subzones are recognised in several boreholes and outcrop sections in northern Belgium, SE The Netherlands, and northern Germany and are calibrated to existing biostratigraphic information. The events used in this zonation scheme are applicable on a regional scale and the significance of some of these events on an inter-regional scale is discussed. This dinocyst zonation scheme contributes to the characterisation and understanding of the poorly known Rupelian and Chattian unit-stratotypes.

Acknowledgements

The authors thank G.L. Eaton and A.J. Powell for their constructive reviews, which led to substantial improvements of the manuscript. S. Louwye, K. Dybkjær, S. Piaseki, and C. Heilmann-Clausen are thanked for their enthusiastic help and discussions concerning the new dinocyst *Triphragmadinium demaniae* gen. and sp. nov. Particular thanks are due to S. Louwye for providing the Essen, Retie and Mol belchim samples, C. Heilmann-Clausen for loaning his Oligocene slides from the Viborg borehole and to A. Köthe for her hospitality and cooperation during the Gartow borehole sample-session. SVS acknowledges support from the University of Leuven (Special Faculty Section nr. 12692 Grant).

Appendix A. Taxonomic notes

Glaphyrocysta cf. *semitecta* (Bujak, 1980) Lentin and Williams, 1981.

Plate III, 1–4.

Remarks: *Glaphyrocysta* cf. *semitecta* is similar to the holotype in having fibrous processes arising from the central body periphery, supporting a membrane which is present around the dorsal side and absent from most of the ventral side. However, unlike the holotype, the psilate membrane in *G.* cf. *semitecta* is not highly perforated, showing only very few irregularly distributed circular claustra.

Spiniferites sp.1 *sensu* Manum et al., 1989.

Plate II, 4–5.

Remarks: This species is also known as *Pseudospiniferites manumii* (Lund, 2002). The central body of this remarkable large spiniferitid form is 80–120 µm in diameter with rigid processes ~40 µm long and distal trifurcations up to 10 µm long. The cyst body is thick walled and usually dark brown in colour.

Evidence from the central Norwegian Sea (ODP site 643 in Manum et al., 1989 and ODP site 985 in Williams and Manum, 1999) and the central and southern North Sea (Lund, 2002) reveals that *Spiniferites* sp.1 has a restricted stratigraphic range of approximately 400 Ka in the early Oligocene. However, the range of this species in Northern Hemisphere high latitudes is remarkably longer

compared to Northern Hemisphere mid latitudes: first order dinocyst magnetobiostratigraphic calibrations from the northern ODP site 913 (~75°N) show that the range of *Spiniferites* sp.1 expands between magnetochron C13n (~33.2 Ma) and the base of C12n (~30.9 Ma) (Eldrett et al., 2004). Based on the extended range of *Spiniferites* sp.1 in Arctic waters, we suggest that this species originates from high latitudes, favouring cold surface water masses. The unusual large size of this spiniferitid form reflects gigantism, a feature related to cool climates (Lentin and Williams, 1980; Gedl, 2000), and hence supporting the high latitude origin of *Spiniferites* sp.1 *sensu* Manum et al. (1989).

Genus *Triphragmadinium* Van Simaey et al., **gen. nov.**

Type: Holotype of *Triphragmadinium demaniae* gen. and sp. nov.: (Plate I, 1–5).

Etymology: Latin *tri-*, three, + Greek *phragma*, wall: the name refers to the three wall layers of this dinoflagellate cyst.

Diagnosis: Proximate cavate gonyaulacacean dinoflagellate cyst with three distinct wall layers and an apical archeopyle; the endocyst is suturocavate and comprises an inner endophragm and outer mesophragm. The pericyst comprises the periphragm and is in contact with the endocyst at the margins of the apical archeopyle.

Description: Cyst proximate, subspherical to “box-shaped”, with three wall layers. The endocyst (endophragm and mesophragm) is suturocavate: the mesophragm is generally in contact with the endophragm but separates from the latter along the paracingulum and along the paraplate boundaries. The pericyst (periphragm) is in contact with the endocyst at the archeopyle margins and at the antapical region of the dinocyst. The archeopyle is apical and the operculum is free.

Remarks: Multilayered walls are uncommon in dinoflagellate cysts and no forms with an apical archeopyle and three wall layers have been described. Both *Cepadinium* Duxbury, 1983 and *Lasagniella* Brinkhuis et al., 2000 have three or more wall layers, but these cysts have intercalary archeopyles and are regarded as peridiniacean dinoflagellate cysts.

***Triphragmadinium demaniae* sp. nov.**

Holotype: Plate I,1–5, sample/slide: Gartow, –221 m, S-199-1-30 μm (Y-43).

Paratype: Plate II,1–3, sample/slide: Weelde, –229 m, S-209-1-30 μm (M-59/1); Plate II,6–8, sample/slide: Weelde, –229 m, S-209-2-30 μm (Y-51); Plate I,6, sample/slide: Gartow, –221 m, S-199-1-30 μm (G-56/3).

Type occurrence: Gartow borehole, –221 m, northern Germany (sheet TK 2934 (Lenzen), R: 44 62 824, H: 58 77 250), Chattian Sand Formation, upper Eochatt, Late Oligocene.

Etymology: Named for Ellen De Man of the Royal Belgian Institute of Natural Sciences, in recognition of her micropaleontological studies of the Belgian Oligocene.

Diagnosis: A species of *Triphragmadinium* in which the periphragm is in contact with the endocyst both at the apical archeopyle margins and along parts of the antapical paraplate 1'' boundaries.

Description: Cysts comprising endocyst and pericyst that are typically in contact only at the margins of the apical archeopyle and by a funnel-like, sickle-shaped invagination of the periphragm at the posterior end (Plate I,5). Endocyst is subspherical to spherical and consists of two phragma: the inner endophragm is smooth and ca. 1–2 μm thick; the outer mesophragm is thin (<0.5 μm) and in general contact with the endophragm but separates from the latter along the paracingulum and along the paraplate boundaries (Plate I,5). This suturocavate structure, formed by an outfold of the mesophragm, demarcates the paraplate boundaries and allows the paracingulum to be easily recognised. The pericyst is subspherical to “box-shaped”, formed from a smooth to scabrate periphragm, which is typically perforated showing irregular circular claustra. The position of the funnel-like, sickle-shaped invagination suggests that the periphragm is in contact with the endocyst along parts of the antapical paraplate 1'''' boundaries (Plate II,2–3). A pronounced, hollow, tubular, antapical process arises from the funnel-like invagination of the periphragm. No other processes or columellae were observed. This antapical process is distally closed (Plate II,7–8). The archeopyle is apical (Type tA), and exhibits a zigzag suture; the operculum is free. The width of the pericoel is fairly constant among specimens,

being ca. 50% to 60% of the endocyst length. The width of the pericoel at the antapex is variable but never exceeds more than 50% of the endocyst length.

Dimensions: Many specimens are obliquely compressed and hence are difficult to measure. In those cases we measured only the maximum endocyst and pericyst diameter. Fourteen specimens were measured. Maximum endocyst diameter 40(48)55 μm , holotype 50 μm ; maximum pericyst diameter 85(90)95 μm , holotype 95 μm . The height of the suturocavate structures between endophragm and mesophragm is ca. ~4 μm .

Comparison: *Triphragmadinium demaniae* is most similar to fully inflated specimens of *Cousteaudinium aubryae* De Verteuil and Norris, 1996. However, *Triphragmadinium demaniae* comprises three phragma and the funnel-like, sickle-shaped invagination of the periphragm at the posterior end, indicating the antapical paraplate 1'''' boundaries. All other cavate Paleogene and Neogene taxa, including species of *Amiculosphaera*, *Invertocysta*, *Saturnodinium*, and *Thalassiphora*, are quite distinct from *Triphragmadinium demaniae*, most obviously in having a precingular archeopyle.

Stratigraphic occurrence: Latest Chattian. Evidence from Gartow borehole, 236–221 m, northern Germany; Weelde borehole, 229 m, NE Belgium; Mol Belchim borehole, 160 m, NE Belgium; Retie borehole, 153.3 m, NW Belgium; Ekeren borehole, 33.3 m, NW Belgium; Groote Heide borehole, 532–523, SE The Netherlands.

Other records: Specimens from the Lower Miocene of the Norwegian Sea illustrated by Manum et al. (1989) as Dinocyst 5, may be conspecific with *Triphragmadinium demaniae*, although this cannot be confirmed from the available information. The pronounced antapical horn (Manum et al., 1989, plate 8,15) and the zigzag apical archeopyle sutures (Manum et al., 1989, plate 8,14) of Dinocyst 5 favour an attribution to the genus *Triphragmadinium* rather than to *Cousteaudinium* as suggested by De Verteuil and Norris (1996, p. 114).

Remarks: *Triphragmadinium demaniae* occurs in deposits thought to be marginal marine, judging from the associated high concentrations of *Paralecaniella indentata* and *Homotryblum* spp.

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