Dinoflagellate cysts of the shallow marine Neogene succession in the Kalmthout well, northern Belgium

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Louwye, S. & Laga, P.: Dinoflagellate cysts of the shallow marine Neogene succession in the Kalmthout well, northern Belgium. *Bulletin of the Geological Society of Denmark*, Vol. 45, pp. 73–86. Copenhagen, 1998-09-25.

The dinoflagellate cyst associations from the Neogene succession in the Kalmthout well allow a correlation with biozonations and key dinocyst events from the North Sea area and the eastcoast of the USA. The recovered cyst assemblages suggest that an Early Miocene (late Aquitanian – early Burdigalian) age can be attributed to the Berchem Formation, while the Diest Formation is of Late Miocene (late Tortonian – Messinian) age. The age of the Kattendijk Formation remains unclear. The Lillo Formation in the Kalmthout well is of Pliocene age and possibly not younger than early Late Pliocene.

Keywords: Dinoflagellates, Neogene, Southern North Sea, Belgium.

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Neogene sediments in Belgium are only found in the area north of Antwerp and the Campine area (Fig. 1). The deposition took place along the southernmost rim of the North Sea Basin in nearshore environments. The lithologies are dominated by medium- to coarse-grained sands, often very glauconitic and intercalated with shell beds. Decalcification can locally be important. The occurrence of gravel layers in the Neogene sequence points to a discontinuous sedimentation, which started in the Early Miocene after a long period of non-deposition caused by Late Oligocene tectonic uplift (Vandenberghe et al. in press). According to these authors, the combined effect of tectonic uplift of Northern Belgium with fluctuating sea levels caused the Neogene units to be incomplete, at least in the base of the succession. The generally monotonous, uniform lithology and the patchy distribution of the units hamper a correlation on a regional scale.

The Neogene succession of Northern Belgium have been the subject of marine microfossil biostratigraphical studies since 1970. Planktonic foraminiferal associations from outcrops and boreholes in the Antwerp area were described by De Meuter & Laga (1970) and Hooyberghs & De Meuter (1972). Six benthic foraminiferal assemblage zones for the Miocene and Pliocene succession of the Antwerp area were defined by De Meuter & Laga (1976). A correlation between the benthic foraminiferal biostratigraphy of the nearshore Neogene deposits of the Antwerpen area with the deeper marine Neogene of The Netherlands is given by Doppert et al. (1979). Nuyts (1990) commented upon the distribution of benthic foraminifera in Pliocene deposits at Kallo near Antwerpen. More recently, Hooyberghs (1996) has dealt with the planktonic foraminiferal associations and the stratigraphical position of the early Miocene Edegem Sands (Berchem Formation). All these micropalaeontological studies led to but restricted chronostratigraphical interpretations for the Belgian Neogene. Correlation with the international standard biozonations is difficult due to the boreal character of the foraminiferal associations in the Antwerp area. No biostratigraphical data on calcareous nannofossils or dinoflagellate cysts have been published so far. This paper describes the dinoflagellate cyst associations from the Neogene formations in the Kalmthout well. The Neogene succession in the Kalmthout well is considered to be a reference section for the Antwerp area.

Lithostratigraphy and lithology

De Meuter & Laga (1976) redefined and formalised the lithostratigraphic framework of the Neogene sediments based on observations of large temporary out-

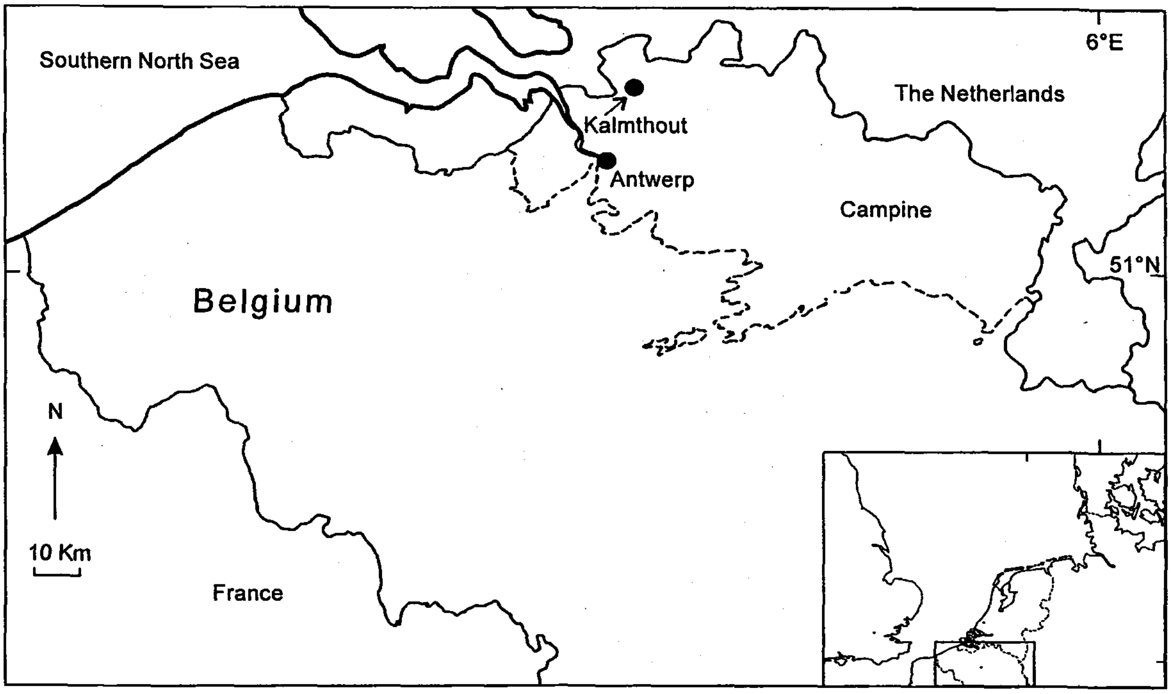

Fig. 1. Location of the Kalmthout well. Dashed line = southern limit of Neogene deposits in northern Belgium (modified after Tavernier & De Heinzelin 1963).

crops in the Antwerp area (Fig. 2). The cored Kalmthout well (no. 6E-110 of the Geological Survey of Belgium) is located north of Antwerp near the border with The Netherlands (Fig. 1). Marine Neogene sediments are present between 52.7 m and 137 m depth (Fig. 3). The Berchem Formation rests unconformable on the Oligocene Boom Formation and consists of glauconitic medium-grained sands with phosphate nodules and marine shell beds. De Meuter & Laga (1976) redefined three members (Edegem Sands, Kiel Sands and Antwerp Sands) in the type area around Antwerp. This formation is interpreted as a discontinuous unit characterised by short hiatuses (Wouters & Vandenberghe 1994). The unconformity between the Berchem Formation and the overlying Diest Formation is marked by a gravel intercalation at 112 m. The Diest Formation is 35 m thick and consists of coarse-grained non-calcareous glauconitic sands and scattered fragments of marine shells. The sediments of this formation are considered to be gully deposits. According to Wouters and Vandenberghe (1994), the gully formed during Middle Miocene times and is the result of strongly eroding tidal currents parallel to the coast. The infilling of the gully is thought to be of Late Miocene age. The Kattendijk Formation lies unconformably on the Diest Formation and is found between 77 m and 75 m. The lithology consists of medium- to coarse-grained glauconitic sands with numerous *Ditrupa*. The Lillo Formation comprises the upper part of the Neogene sequence between 75 m and 52.7 m and consists of fine- to medium-grained sand with clay intercalations, shell layers and scattered shells. The members of the Lillo Formation (Fig. 2) were not identified in the Kalmthout well. The Lillo Formation is considered to have been deposited in a very shallow marine environment.

Lithostratigraphy	Series
Antwerp area	
Lillo Formation Zandvliet Sands Merksem Sands Kruisschans Sands	Upper Pliocene
Oorderen Sands Luchtbal Sands Kattendijk Formation	Lower
Diest Formation Deurne Sands	Upper Miocene
Berchem Formation	Middle Miocene
Antwerpen Sands Kiel Sands Edegem Sands (Burcht gravel)	Lower Miocene

Fig. 2. Lithostratigraphy of the Neogene of the Antwerp area, northern Belgium (after De Meuter & Laga 1976).

Table 1. Distribution and frequency (%) of dinocyst taxa in the Kalmthout well. Reworked cysts are marked with an asterisk. Kt = Kattendijk.

Formations	Berchem					Diest								Kt	Lillo				
Depth in m below surface	136,6	130,5	126,4	124	118	112	110,5	107,5	101,5	92,5	87	82	78	76	73,3	70,7	68,1	64	62,6
Acanthaulax spp. indet.																		0,7	1,7
Achilleodinium biformoides			0,8					0,8				0,5							
Achomosphaera alcicornu alcicornu				0,7				1,3	1,1		6,1	1,7							
Achomosphaera andalousiensis andalousiensis Pl. 2, Fig. 3						8,7	11,6	7,1	1,9			1,4	0,4	1,5	1,5	15,4	0,4	0,7	0,6
Achomosphaera andalousiensis suttonensis																7,5			
Achomosphaera crassipellis	1,7	0,9	0,8																
Achomosphaera ramulifera ramulifera			0,3		0,7		2,3	0,4					0,4						
Achomosphaera sp. A	0,3																		
Achomosphaera sp. B																0,4		0,3	
Achomosphaera sp. Head 1996																	1,2	0,7	
Achomosphaera sp. Head 1997																0,4		0,7	
Achomosphaera spp. indet.	0,3					1,5	4,7	1,3	1,1	1,6	0,5	0,5	0,4	0,5	0,4	0,4	0,8		1,1
*Adnatosphaeridium multispinosum**			0,3																
*Adnatosphaeridium robustum**												0,5						0,3	
Algidasphaeridium? sp. A														0,5	1,2				
Amiculosphaera umbracula Pl. 2, Fig. 1												0,5	0,4	4,4	3,8	2,6	0,8	1,7	
*Apectodinium homomorphum**																	1,2	0,3	2,8
Apteodinium australiense Pl. 1, Fig. 1	7,4	2,8	3,6	0,7	1,5	0,5		0,4		1,6		0,5	0,4						
Apteodinium cf. *granulatum**		0,4																	
Apteodinium spiridoides Pl. 1, Figs 4–5		0,4	1,1	22,4	5,2										0,4				
Apteodinium tectatum	1,3	0,9	0,6	1,0					0,4										
Apteodinium spp. indet.	0,3	0,1																	
Areoligera cf. *semicirculata**			0,3																
Areoligera sp. A*		0,1																	
Areoligera spp. indet.*																			1,1
*Ascostomocystis potane**		0,1								1,6									
Ataxiodinium zevenboomii Pl. 1, Figs 10–11														1,0	0,8	4,5		1,4	
Ataxiodinium sp. A													0,4						
Ataxiodinium sp. B													0,4						
cf. *Ataxiodinium* sp. indet.					0,4														
Barssidinium graminosum									1,9	4,3	7,1	1,0		1,0					
Barssidinium wrennii Pl. 1, Fig. 3									0,7	5,3		6,5	2,0	12,2	3,8	3,8	5,9	2,4	1,5
Barssidinium sp. A															0,4				
Barssidinium sp. B			0,3																
Batiacasphaera cf. *granospina**		0,1																	
Batiacasphaera hirsuta		0,3	0,3		0,7			0,4			0,5								
Batiacasphaera cf. *hirsuta*				0,7	1,1														
Batiacasphaera micropapillata	1,7	1,6	0,6	1,6	3,0				0,7	1,6	1,2	1,3	0,8						
Batiacasphaera minuta Pl. 2, Fig. 6	0,7	5,7	2,0	14,8	14,7									4,4					
Batiacasphaera sphaerica	0,3	0,1		1,0		1,2					2,6			0,5					
Batiacasphaera sp. A		0,1																	
Batiacasphaera sp. B		0,4						0,4											
Batiacasphaera spp. indet.					0,4						0,5						0,8	0,3	
Bitectatodinium raedwaldii Pl. 2, Figs 11–12												1,7	2,0		1,9	5,7	3,1		
Bitectatodinium serratum Pl. 2, Fig. 8												1,4			1,5				
Bitectatodinium tepikiense																2,2	0,8		
Bitectatodinium sp. A															3,8	1,1	7,6	2,8	1,1
Brigantedinium cariacoense														0,5	0,8				
cf. *Brigantedinium* sp. Head *et al.* 1989													0,8						
Caligodinium amiculum Pl. 1, Fig. 13			0,3																
Caligodinium cf. *pychnum*		0,1																	
Caligodinium sp. A		0,3																	
Cerebrocysta? cf. *namocensis*															0,4				

Depth in m below surface	136,6	130,5	126,4	124	118	112	110,5	107,5	101,5	92,5	87	82	78	76	73,3	70,7	68,1	64	62,6
Cerebrocysta sp. A		0,1																	
*Charlesdowniea edwardsii**																		0,3	
*Charlesdowniea limitata**			0,3								0,5								
Chiropteridium galea	0,3	0,1	0,6	1,0	0,4							0,2							
Chiropteridium lobospinosum		0,1	1,5					0,4											
Cleistosphaeridium sp. A		0,1	0,3	0,3															
Cordosphaeridium cantharellus		0,7	0,8									0,2			0,4		0,4		
*Cordosphaeridium funiculatum**			0,3																
Cordosphaeridium gracile				0,3					0,7									0,3	3,3
Cordosphaeridium inodes inodes							2,3	0,8										0,7	
Cordosphaeridium minimum sensu Benedek & Sarjeant 1981		0,5	0,6	0,3								0,2							
*Corrudinium incompositum**												0,7							
Corrudinium? labradorii												1,7	2,0						
Cousteaudinium aubryae				2,6	3,4														
Cribroperidinium tenuitabulatum	0,3	0,1	0,3						0,4										
Cyclopsiella granosa		0,1	0,8	0,3		2,5			0,7										
Cyclopsiella sp. cf. *C. granosa*		0,3																	
Cyclopsiella? trematophora	1,7	0,1	2,2	0,7		1,5			0,7				4,0	2,0	2,4	0,4		0,3	0,6
Cyclopsiella aff. *vieta*		0,1									1,5								
Cyclopsiella? sp. A		0,3	0,3																
Cyclopsiella? sp. B	0,3	0,3																	
Cyclopsiella sp. indet.										1,6									
Cyst D													4,8		2,7				
Cyst E																		0,3	2,3
Dapsilidinium pseudocolligerum	0,7	3,2	4,5	1,6	3,4	1,2		1,7	0,4		1,2	1,7			0,4				
Deflandrea cf. *heteroplycta sensu* Biffi & Manum 1988*			0,3																
Deflandrea phosphoritica phosphoritica	0,3	0,1						0,4											1,1
*Deflandrea spinulosa**	0,7	0,4	1,1								0,5	0,2							
Dinopterygium cladoides sensu Morgenroth 1966	0,7	0,4	1,1	0,7															
Dinopterygium spp. indet.										1,6	0,5								
Distatodinium paradoxum Pl. 2, Fig. 2	2,1	2,3	1,5	0,3	0,7														
*Eatonicysta ursulae ursulae**																		0,3	
Elytrocysta cf. *breva**	0,7	0,3	0,3																
*Endoscrinium campanula campanula**			0,3																
*Enneadocysta pectiniformis**	0,3	0,5	0,6					0,4	0,7			0,5			0,8				
Enneadocysta sp. A*			0,3									0,2							
Erymnodinium cf. *delectabilis*	0,7	0,4	1,5		0,7														
cf. *Erymnodinium* sp.													0,4						
Exochosphaeridium insigne	3,7	0,9	1,7	0,3	1,5														
Filisphaera filifera															0,4		0,4		
Filisphaera microornata									0,4			0,2							
Florentinia sp. A*		0,1																	
Florentinia sp. B*		0,1																	
Forma D Wrenn & Kokinos 1986																		0,3	
cf. *Forma* D Wrenn & Kokinos 1986				0,7															
Fromea sp. A		1,5	0,6	1,0					0,4										
Geonettia? sp. Head 1997																		0,3	
*Gerdiocysta conopeum**		0,3																	
Glaphyrocysta laciniiformis sensu Brosius 1962*		0,1																	
*Glaphyrocysta microfenestrata**											0,5								
*Glaphyrocysta semitectata**														0,5					
Habibacysta tectata				0,3			2,3	0,4	4,9	3,2	6,1	0,2			1,2				
Habibacysta? sp. Head 1994												0,5					0,4		
Habibacysta sp. B								1,3	0,4		0,5								
Heteraulacacysta sp. A Costa & Downie 1966			0,8						1,1	2,1	2,5	0,5			0,8		14,9	3,5	28,7
Histiocysta sp. A*		0,1																	
Histiocysta sp. B*		0,3																	

Depth in m below surface	136,6	130,5	126,4	124	118	112	110,5	107,5	101,5	92,5	87	82	78	76	73,3	70,7	68,1	64	62,6
*Homotryblium floripes floripes**		0,4	0,8																
*Homotryblium oceanicum**		0,3																	
*Homotryblium pallidum pallidum**	1,3	0,5	1,5	1,6		0,5		0,8										0,7	
*Homotryblium plectilum**			0,3					0,4											
Homotryblium vallum		0,3									0,5								
Hystrichokolpoma cinctum cinctum									0,4		0,5								
Hystrichokolpoma rigaudiae rigaudiae	0,7	1,5	0,8	0,3	0,7	0,5			0,4			0,5			0,8			0,3	
*Hystrichosphaeridium tubiferum tubiferum**						0,5													
*Hystrichosphaeridium sp. indet.**																			0,6
Hystrichosphaeropsis obscura	0,3	0,8	0,3	1,3	1,9														
*Hystrichostrogylon coninckii**		0,1																	
*Impagidinium maculatum**			0,3			1,2	7,0	1,7	3,0	2,1	8,7								
Impagidinium aff. maculatum sensu De Coninck 1968*		0,1																	
Impagidinium strialatum											0,5								
Impagidinium sp. F Wrenn & Kokinos 1986															0,4				
Impletosphaeridium sp. A			0,3																
Invertocysta lacrymosa					0,4				0,4	1,6	1,2	1,7					0,4		
Invertocysta tabulata		0,1	0,3																
Invertocysta spp. indet.												0,5							
*Kallosphaeridium capulatum**		0,3	0,3																
?*Kallosphaeridium capulatum**												0,5							
Kallosphaeridium sp. indet.*			0,3																
Labyrinthodinium sp. A		0,1																	
?*Labyrinthodinium* sp. indet.		0,1																	
Lejeunecysta catoma														0,5					
Lejeunecysta hyalina											0,5								
Lejeunecysta aff. *lata**										1,6									
Lejeunecysta sp. A		0,9	0,8		0,4														
Lejeunecysta sp. B								0,4											
Lejeunecysta spp. indet.				0,7		0,5													
Lingulodinium machaerophorum machaerophorum	3,4	3,5	4,5	2,0	3,4	3,6	4,7	1,3	2,2	5,3	1,2	1,7	1,2		0,4	0,4		12,8	1,7
cf. *Lingulodinium machaerophorum machaerophorum*		0,1																	
Lingulodinium multivirgatum			0,3		0,4														
*Lingulodinium xanthium**		0,1																	
Lingulodinium sp. A	0,3	0,8	0,3	2,6	0,7	0,5													
Melitasphaeridium choanophorum	1,7	1,7	1,1	1,0	3,7	14,3			0,7	1,6	3,6	1,4			0,8				0,6
Membranophoridium aspinatum	0,3		0,6																
*Membranophoridium connectum**		0,4																	
*Membranophoridium intermedium**				0,3							0,5								
*Microdinium reticulatum**	1,7	1,7	0,6	1,6	0,4	0,5		2,9		1,6	1,2	0,5	0,4						
*Microdinium setosum**			0,3																
Nematosphaeropsis lemniscata									0,7			0,2						0,7	
Operculodinium centrocarpum	1,3	2,3	2,5	2,3	1,9			2,5	36,7	1,6	2,6	6,5						0,7	
Operculodinium centrocarpum sensu Wall & Dale 1966																9,7	2,0	21,5	12,8
O. sp. cf. *Operculodinium centrocarpum*														3,4	5,8				
*Operculodinium divergens**		0,1																	0,6
Operculodinium? eirikianum Pl. 2, Fig. 5						5,6		4,2	5,6	1,6	1,2	6,8	1,6	11,2	2,7				
Operculodinium giganteum													0,4						
Operculodinium israelianum		0,8	0,8		0,7			0,4	0,4	3,2	2,5	1,0	44,8	3,9	7,7	11,1	3,6	6,9	14,4
Operculodinium janduchenei													0,4			0,4		0,3	
Operculodinium longispinigerum	1,7	0,4	0,8	1,6	1,5			0,4											
*Operculodinium microtriainum**		0,3	0,8															0,3	0,6
Operculodinium pontis? Zevenboom 1995ms									0,4	1,6		33,9	3,2	3,4	12,4				
Operculodinium piaseckii	0,3			0,7	1,5														
Operculodinium placitum	0,3	0,1	0,3																
Operculodinium tegillatum																		0,3	
*Operculodinium uncinispinosum**	0,3																		

Depth in m below surface	136,6	130,5	126,4	124	118	112	110,5	107,5	101,5	92,5	87	82	78	76	73,3	70,7	68,1	64	62,6
Operculodinium sp. II Manum 1976					0,4														
Operculodinium? sp. 1			0,3																
Operculodinium sp. 3 de Verteuil & Norris 1996	2,1	0,4	0,6	0,3															
Operculodinium sp. A		0,1																	
Operculodinium sp. indet.			0,3																
Palaeocystodinium golzowense		0,7	0,3	0,3	0,4														
Paralecaniella indentata		2,0	0,8	0,7	1,1	4,6	2,3	8,8	0,4	6,4	7,1	0,5	1,4	1,7	1,2			0,3	
Paucisphaeridium? sp. A			0,3																
Paucisphaeridium? sp. B		0,4	0,3																
Paucisphaeridium? sp. C						0,5							0,4						
Pentadinium laticinctum laticinctum	0,7	0,3	0,3	0,3	0,4							0,2	0,4						
Pentadinium? sp. 1												0,7							
Pentadinium sp. indet.			0,3																
*Perisseiasphaeridium pannosum**		0,4																	
Phthanoperidinium sp. indet.			0,3																
Polysphaeridium zoharyi zoharyi				0,3															
Polysphaeridium? sp. Head 1997													0,8						
Polysphaeridium sp. A									0,4										
Protoperidinium sp. A								5,9		8,5	4,6		0,4	3,9	6,5				
Pterodinium sp. indet.		0,1																	
Pyxidiella sp. A		0,1																	
Pyxidinopsis cf. *pastelliformis*	0,7																		
Pyxidinopsis tuberculata		1,3	0,8	1,3	0,7			0,4											
Pyxidinopsis sp. A				3,9															
Reticulatosphaera actinocoronata Pl. 2, Fig. 7	0,7	1,2	1,5	0,3	2,2	3,6	2,3	3,3	1,5	3,2	3,6	0,2	0,4						0,6
Reticulatosphaera sp. A			0,3																
*Rhombodinium longimanum**			0,3																
Riculacysta perforata			0,3																
Samlandia chlamydophora			0,3																
*Samlandia reticulifera**					0,4														
Selenopemphix armageddonensis Pl. 1, Fig. 7						1,2					1,2								
Selenopemphix? *armageddonensis*								0,4											
Selenopemphix brevispinosa brevispinosa Pl. 1, Fig. 6						2,5		0,4	0,4	4,3			2,0						
Selenopemphix coronata											1,2								
Selenopemphix dionaeacysta Pl. 1, Fig. 8						1,5		3,8		14,9	1,5		0,4						
Selenopemphix nephroides														0,5	1,9				
Selenopemphix quanta														1,0					
Selenopemphix? sp. 2 Head 1993		0,1	0,3									0,2	0,4		0,4		1,2	0,3	1,1
Selenopemphix sp. A						0,5		4,2		4,3				1,0					
Selenopemphix spp. indet.								1,3											
Spiniferites bentorii bentorii												0,2							
Spiniferites bulloideus		0,3						0,4		2,1		3,1	0,4					0,7	
Spiniferites cf. *elongatus*													0,8					0,3	
Spiniferites hyperacanthus	0,7	0,1	0,8		1,1	0,5			0,7	1,6		0,7	0,4	0,5	0,4	0,9		2,8	0,6
Spiniferites membranaceus							2,3	1,3	0,4		0,5	0,7						0,3	
Spiniferites mirabilis	0,3	0,5	0,6			0,5	2,3		0,4		1,2	0,2	0,4	2,0	1,2	1,8	0,4	0,3	
*Spiniferites ramosus granomembranaceus**												0,2							
Spiniferites ramosus granosus	2,3		2,8			0,5	2,3		0,7		1,2				0,4				
Spiniferites ramosus ramosus	4,3	0,4	2,8	3,6	5,6	12,8	2,9	7,5	4,1	3,2	5,6	2,2	0,8	3,4	1,2	2,2	1,2	8,3	0,6
Spiniferites sp. B Wrenn & Kokinos 1986													0,4					2,8	
Spiniferites spp. indet.	12,4	34,4	2,7	6,3	13,5	25,5	18,6	23,1	18,0	12,8	3,6	8,9	3,6	24,4	26,9	2,3	7,8	2,5	9,4
Stoveracysta? sp. indet.		0,1																	
Sumatradinium druggii Pl. 1, Fig. 9			0,6	1,6	0,7														
Sumatradinium hamulatum Pl. 2, Figs 9–10		0,3																	
Sumatradinium hispidum									0,4										
Sumatradinium aff. *hispidum*		0,1																	
Sumatradinium soucouyantae Pl. 1, Fig. 2	1,3	1,5	1,7	0,7	1,9														

Depth in m below surface	136,6	130,5	126,4	124	118	112	110,5	107,5	101,5	92,5	87	82	78	76	73,3	70,7	68,1	64	62,6
Systematophora placacantha Pl. 1, Fig. 12	35,6	6,2	5,9	9,2	12,7			2,9	0,4			0,5	0,4						
Systematophora sp. indet.												0,2							
Tanyosphaeridium sp. indet.			0,3																
Tectatodinium pellitum	1,7	0,7	1,7	1,3	2,2	3,6	14,0	4,6	0,7		2,6	1,3	2,4	0,5	0,4	0,4		0,3	
Thalassiphora delicata												0,2							
Thalassiphora pelagica	0,3	0,7	1,1	0,3					0,7										
Thalassiphora sp. cf. *T. pelagica*		0,1																	
Thalassiphora sp. A		0,1																	
Trinovantedinium capitatum													1,6	0,5					
Trinovantedinium glorianum											3,6		1,6	0,5					
Trinovantedinium aff. *variabile*			0,3																
Trinovantedinium sp. A			0,3																
Tuberculodinium vancampoae Pl. 2, Fig. 4	0,7	0,7	0,8		1,1				0,7			0,2						0,3	
*Turbiosphaera galatea**		0,1																	
*Wetzeliella articulata**								0,4			1,2								
*Wetzeliella eocaenica**												0,2							
*Wetzeliella symmetrica incisa**		0,3																	
*Wetzeliella symmetrica symmetrica**	0,3	0,5	0,3	0,3													0,4	0,7	0,6
Wetzeliella spp. indet.*								0,4	0,4									0,3	1,7
Number of specimens	298	753	357	304	267	196	43	239	267	94	196	414	250	205	260	227	255	288	181

Material and methods

Twenty-three core samples distributed over the marine Neogene sequence were prepared for palynological analysis using standard maceration techniques. The preservation of the dinoflagellate cysts ranges from moderate to good and 243 species were recorded. Table 1 gives in alphabetical order the percentage of the species recorded in the investigated section (see also Pl. 1–2). Four samples were not rich enough to count a minimum of 200 specimens. Reworked dinocysts are marked with an asterisk. Reworking is never important, but most apparent in the Berchem and Lillo Formations. A full account dealing with dinocyst taxonomy is in preparation. We followed Lentin & Williams (1993) for the nomenclature of the dinocysts. Two barren samples (114 m and 116 m) are located at the top of the Berchem Formation and another two at the top of the Lillo Formation (58 m and 54.5 m).

The recovered associations allow a comparison and interregional correlation with contiguous areas. We referred to zonations, dinocyst events and other studies from northwest Europe (Costa & Manum, 1988; Powell, 1992), northern Germany (Lund et al. 1993), England (Head 1993, 1996, 1997), The Netherlands (Herngreen, 1987) and the Norwegian Sea (Manum et al., 1989). The comprehensive biozonation of Powell (1992) was calibrated with earlier biozonations from the British Isles and northwest Europe. A comparison with the eastcoast of the USA (de Verteuil & Norris, 1996) is also proposed. The dinocyst associations and biostratigraphy are discussed per formation.

Dinoflagellate cyst associations and correlation

Berchem Formation (136.6 to 118 m)

The basal two samples contain species with a known highest occurrence (HO) in the Lower Miocene, such as *Caligodinium amiculum, Cordosphaeridium cantharellus, Cribroperidinium tenuitabulatum, Deflandrea phosphoritica phosphoritica, Dinopterygium cladoides* sensu Morgenroth (1966), *Homotryblium vallum* and *Sumatradinium hamulatum*. A break in the dinocyst associations is noted between samples 118 and 112 m (Fig. 3). The following stratigraphically significant species have their HO in the top of the Berchem Formation: *Apteodinium spiridoides, Chiropteridium galea, Cousteaudinium aubryae, Exochosphaeridium insigne, Lingulodinium multivirgatum, Operculodinium longispinigerum, Operculodinium piaseckii, Palaeocystodinium golzowense, Sumatradinium druggii* and *Sumatradinium soucouyantae*. It is not clear whether *Chiropteridium galea, D. phosphoritica phosphoritica* and *H. vallum* are reworked or not in the Berchem Formation. de Verteuil & Norris (1966) give an overview of the occurrences of these

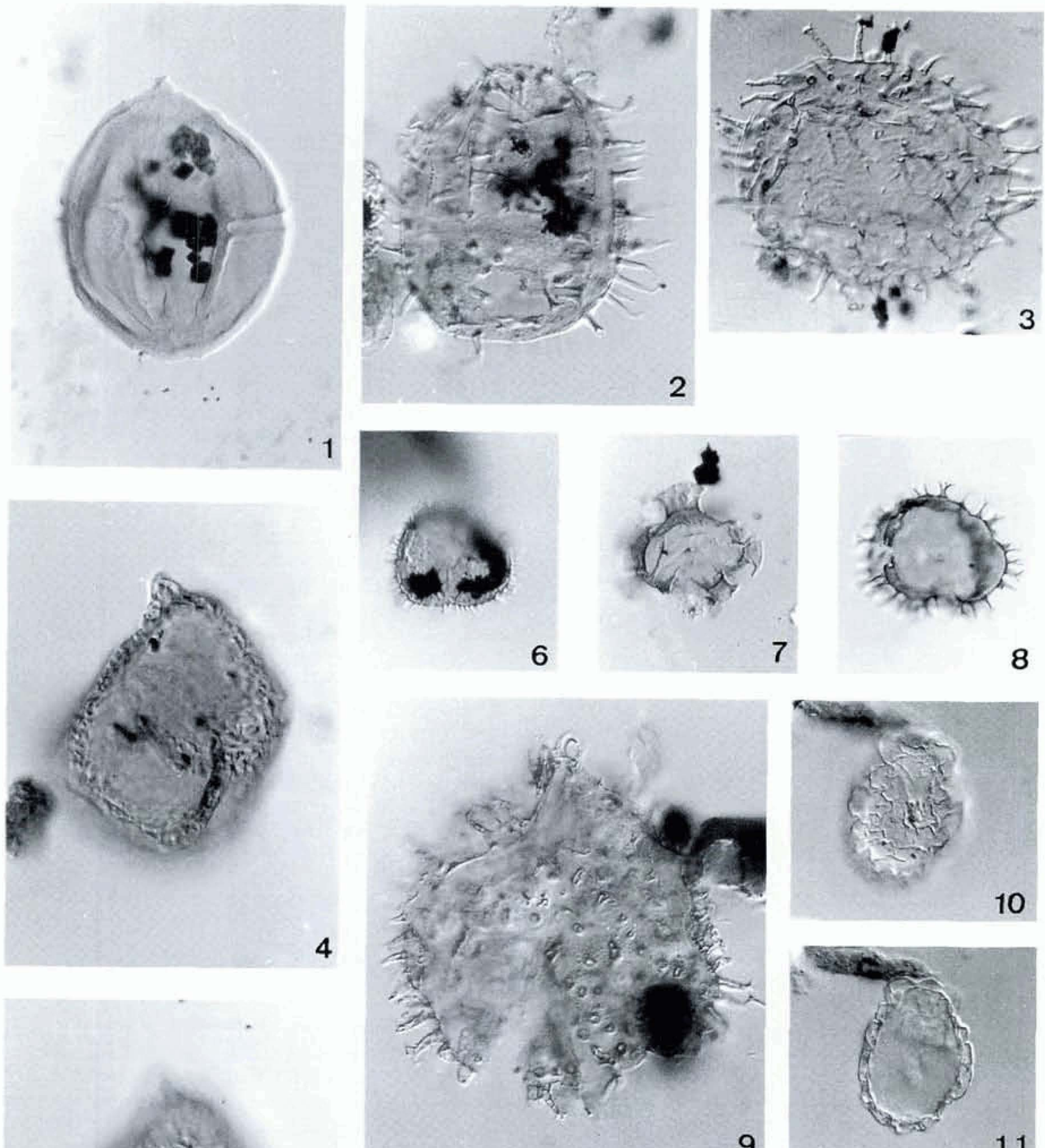

Plate 1. Fig. 1. *Apteodinium australiense*, sample 126.4, 500 ×. Fig. 2. *Sumatradinium soucouyantae*, sample 126.4, 500 ×. Fig. 3. *Barssidinium wrennii*, sample 101.5, 500 ×. Figs 4–5. *Apteodinium spiridoides*, sample 126.4, 500 ×. Fig. 6. *Selenopemphix brevispinosa brevispinosa*, sample 112, 500 ×. Fig. 7. *Selenopemphix armageddonensis*, sample 87, 500 ×. Fig. 8. *Selenopemphix dionaeacysta*, sample 107.5, 500 ×. Fig. 9. *Sumatradinium druggii*, sample 126.4, 500 ×. Figs 10–11. *Ataxiodinium zevenboomii*, sample 70.7, 500 ×. Fig. 12. *Systematophora placacantha*, sample 126.4, 500 ×. Fig. 13. *Caligodinium amiculum*, sample 126.4, 500 ×.

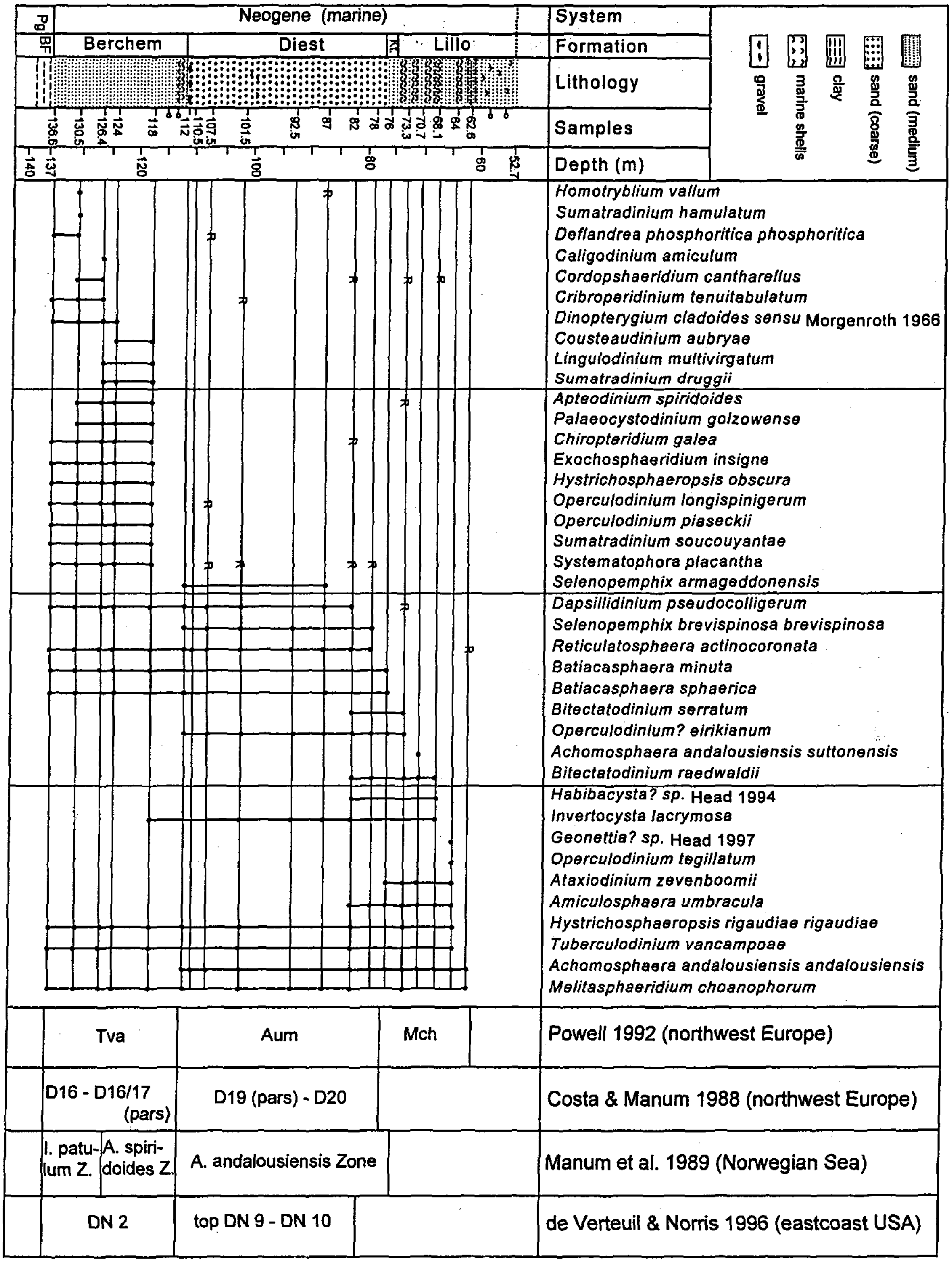

Fig. 3. Stratigraphy, lithology, distribution of selected dinoflagellate cysts in the Kalmthout well and comparison with other biozonations (R: probably reworked; Kt: Kattendijk; Pg: Paleogene; BF: Boom Formation).

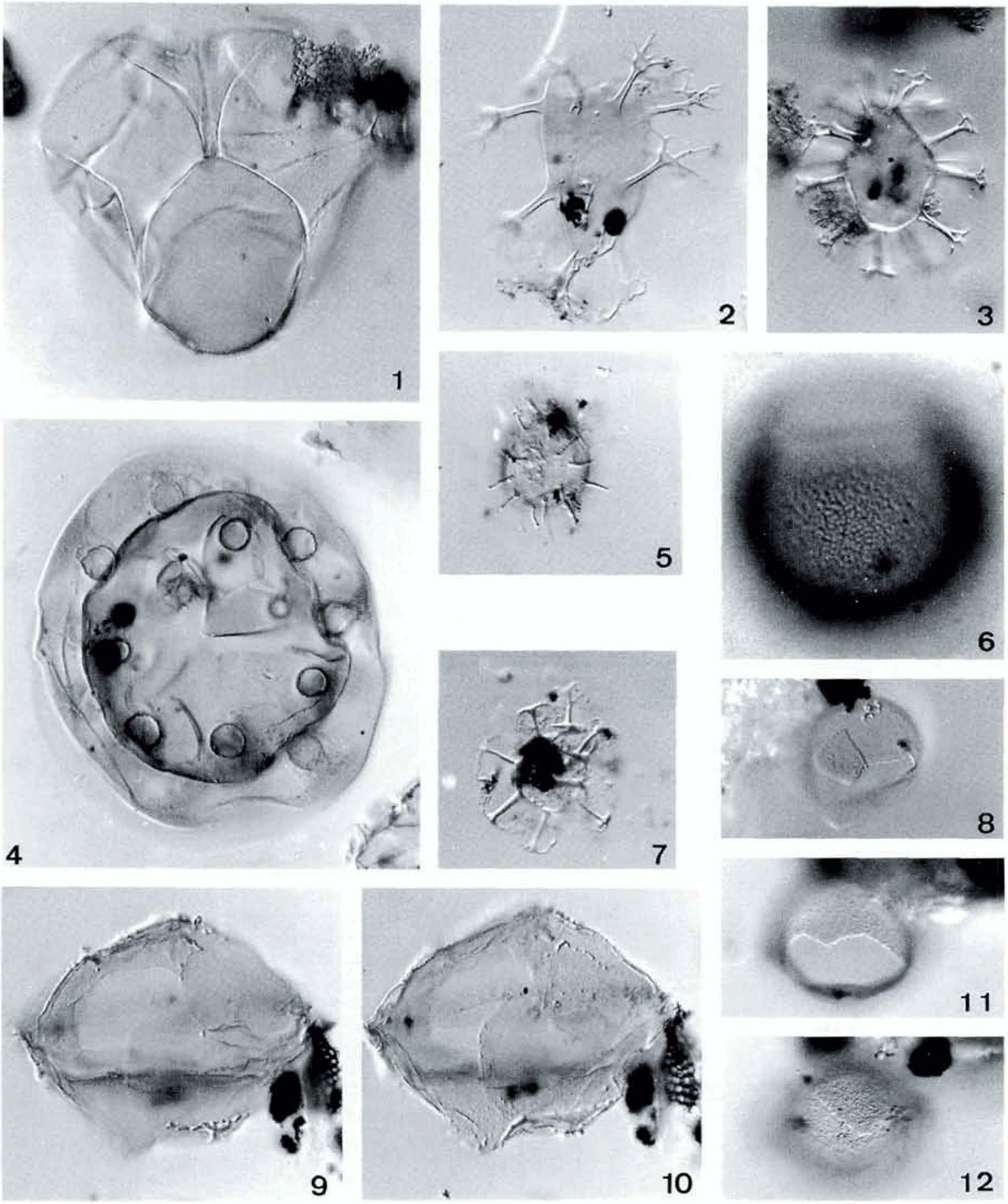

Plate 2. Fig. 1. *Amiculosphaera umbracula*, sample 70.7, 500 ×. Fig. 2. *Distatodinium paradoxum*, sample 126.4, 500 ×. Fig. 3. *Achomosphaera andalousiensis andalousiensis,* sample 112, 500 ×. Fig. 4. *Tuberculodinium vancampoae,* sample 126.4, 500 ×. Fig. 5. *Operculodinium*? *eirikianum*, sample 101.5, 500 ×. Fig. 6. *Batiacasphaera minuta*, sample 126.4, 1400 ×. Fig. 7. *Reticulatosphaera actinocoronata*, sample 101.5, 500 ×. Fig. 8. *Bitectatodinium serratum,* sample 82, 500 ×. Figs 9–10. *Sumatradinium hamulatum,* sample 130.5, 500 ×. Figs 11–12. *Bitectatodinium raedwaldii,* sample 82, 500 ×.

species in Lower Miocene strata from several localities. An indirect argument for possible reworking is the occasional occurrence in the Berchem Formation of other pre-Neogene species, such as *Homotryblium pallidum, Homotryblium plectilum* and *Chiropteridium lobospinosum.*

The Berchem Formation can be placed within the *Tuberculodinium vancampoae* (Tva) Interval Biozone of Powell (1992) (Fig. 3). The lower boundary of this zone is marked by the first appearance of the nominate species, which has its lowest occurrence (LO) in 136.6 m at the base of the formation. The upper boundary of this zone is defined by the first occurrence of *Labyrinthodinium truncatum truncatum*, a species absent in the Kalmthout well. *A. spiridoides* and *C. cantharellus* disappear resp. within and at the upper boundary of the Tva Biozone. No diagnostic species of the above lying *Labyrinthodinium truncatum truncatum* (LTr) Interval Biozone are recorded. Powell (1992) calibrated his biozonation with the biozonation of Costa & Manum (1988) and correlates the Tva Interval Biozone with Biozone D16 and biozonal unit D16/17 (pars).

The lower part of the Berchem Formation (136.6 to 126.4 m) falls within the *Impagidinium patulum* Zone of Manum et al. (1989), even though the nominate species which defines the lower boundary of the zone, is absent. The HO of *C. cantharellus* marks the upper boundary of this zone and the lower boundary of the next *Apteodinium spiridoides* Zone. The upper part of the Berchem Formation can placed within the *Apteodinium spiridoides* Zone, although the upper boundary cannot be recognised because of the absence of *L. truncatum truncatum.*

The associations allow to place the Berchem Formation in de Verteuil & Norris' (1996) *Sumatradinium soucouyantae* Zone DN2, if *C. galea, D. phosphoritica phosphoritica, H. vallum* are regarded as reworked. *S. druggii* co-occurs with characteristic species of the Zone DN2, where in the type locality (eastcoast of the USA) its LO is at the lower boundary of the overlying *Cousteaudinium aubryae* Zone DN3. The absence in the Berchem Formation of other species such as *Cerebrocysta poulsenii, Impagidinium arachnion, L. truncatum truncatum* and *Labyrinthodinium truncatum modicum* exclude the presence of Zones DN3 and DN4.

Diest Formation (112 to 78 m)

Few species have their HO near or at the top of the Diest Formation, such as *Dapsilidinium pseudocolligerum* and *Reticulatosphaera actinocoronata.* Stratigraphical important species appearing in the base of the Diest Formation are *Achomosphaera andalousiensis andalousiensis* and *Operculodinium? eirikianum. Hystrichosphaeropsis obscura, Palaeocystodinium golzowense* and *Systematophora placacantha* are species with a known HO in the Middle or Upper Miocene; they disappear at the top of the Berchem Formation and were not encountered in the Diest Formation. Stratigraphical important species with a restricted range and a LO in the Middle or Upper Miocene, such as *Cannosphaeropsis passio* (= *Cannosphaeropsis utinensis* sensu Brown & Downie 1985), *C. poulsenii* (= Gen. et sp. nov. of Piasecki 1980), *Gramocysta verricula, Labyrinthodinium truncatum truncatum* and *Unipontedinium aquaductum* are not found in the Diest and Berchem Formations in the Kalmthout well. The ranges of *Selenopemphix armageddonensis* and *Selenopemphix brevispinosa brevispinosa* are limited to the Diest Formation. No other stratigraphically important species with a HO or LO in this formation are noted.

The Diest Formation falls within the *Amiculosphaera umbracula* (Aum) Interval Biozone of Powell (1992), based on diagnostic indices, such as *Amiculosphaera umbracula, Reticulatosphaera actinocoronata* and *Selenopemphix brevispinosa brevispinosa* (= *Selenopemphix* sp. A sensu Brown & Downie 1985) and the absence of others, such as *Apteodinium tectatum, Gerlachidinium aechmophorum, G. verricula, P. golzowense, S. placacantha* and *U. aquaductum.* The upper part of the Aum Interval biozone (above the HO of *R. actinocoronata*) is most probably not present in the Diest Formation. The nominate species of the Aum Interval Biozone has its LO in sample 82 and is poorly represented in the Diest Formation. Its absence in the lower samples could be environmentally controlled, since this formation was deposited in a nearshore environment. According to Head (1996), *A. umbracula* has an oceanic to outer neritic preference. The Aum Interval Biozone is calibrated by Powell (1992) with Biozones D19 (pars) and D20 of Costa & Manum (1988).

The Diest Formation can be correlated with the *Achomosphaera andalousiensis* Zone of Manum et al. (1989), based on the LO of the nominate species. The upper boundary of this zone is not defined. *R. actinocoronata* has its HO within this zone according to Manum et al. (1989).

The presence of *A. andalousiensis andalousiensis, D. pseudocolligerum, O.? eirikianum* and *S. brevispinosa brevispinosa* and the HO's of *H. obscura, Operculodinium piaseckii, P. golzowense, Sumatradinium soucouyantae, Sumatradinium druggii* place the Diest Formation within the upper part of de Verteuil & Norris' (1996) *Hystrichosphaeropsis obscura* Zone DN9 and in the *Selenopemphix armageddonensis* Zone DN10.

A correlation of the Diest Formation with deposits of the regional Miocene Gram and Sylt stages in the Nieder Ochtenhausen well (Lund et al. 1993) is based on the occurrences of *S. brevispinosa brevispinosa* and *R. actinocoronata* (Fig. 4). The absence of *H. obscura* in the Diest Formation hampers a more detailed correlation.

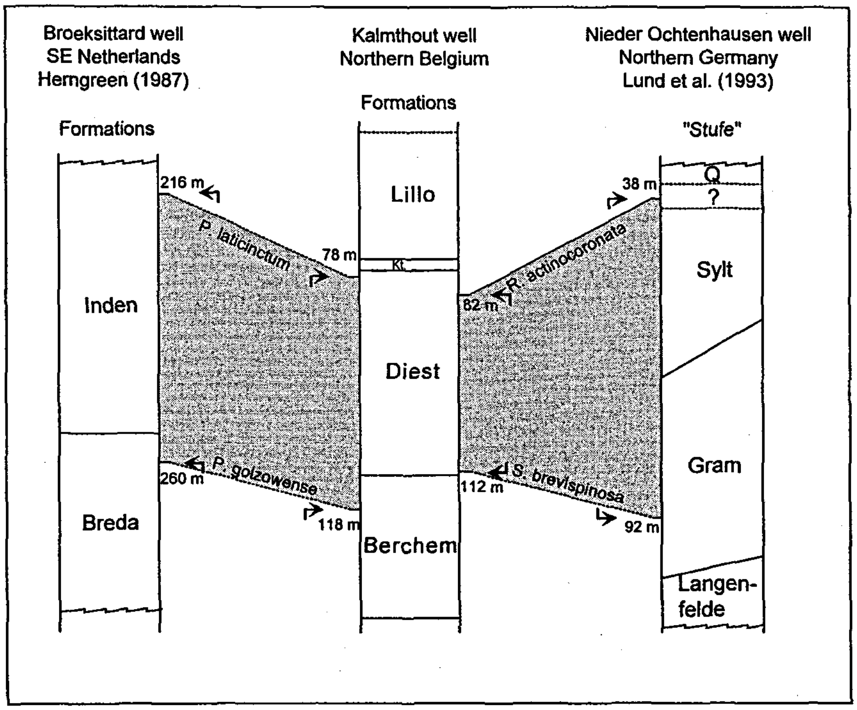

Fig. 4. Correlation of the Neogene Formations in the Kalmthout well with the Neogene Formations in the Broeksittard well (SE Netherlands) and the Nieder Ochtenhausen well (northern Germany) (Kt.: Kattendijk; Q: Quaternary).

The occurrences of *P. golzowense* and *Pentadinium laticinctum laticinctum* in the Broeksittard well in SE Netherlands (Herngreen 1987) correlate tentatively the deposits of the Diest Formation partly with the Breda Formation and the Inden Formationin the Ruhr Valley Graben (Fig. 4).

Kattendijk Formation (76 m)

Batiacasphaera sphaerica is the only species with a HO in the Kattendijk Formation. The joint occurrence with *Achomosphaera andalousiensis andalousiensis* places the Kattendijk Formation also in the *Achomosphaera andalousiensis* Zone of Manum et al. (1989). The HO of *Reticulatosphaera actinocoronata* at 78 m suggest that the Kattendijk Formation may be correlated with the *Melitasphaeridium choanophorum* (Mch) Interval Biozone of Powell (1992).

Lillo Formation (73.3 to 62.6 m)

The Lillo Formation is characterised by the HO of *Ataxiodinium zevenboomii, Bitectatodinium raedwaldii, Bitectatodinium serratum, Habibacysta*? sp. Head (1994), *Hystrichokolpoma rigaudiae rigaudiae* and *Invertocysta lacrymosa*. The range of three stratigraphical important species is restricted to the Lillo Formation (*Achomosphaera andalousiensis suttonensis, Geonettia*? sp. Head (1997) and *Operculodinium tegillatum*).

The Lillo Formation falls within the *Melitasphaeridium choanophorum* (Mch) Interval Biozone of Powell (1992), even though the species defining the lower and upper zonal boundaries are not recognised (resp. *Spiniferites* cf. *pseudofurcatus* and *Spiniferites elongatus*). The diagnostic species of this zone with a HO in the Lillo Formation are *H. rigaudiae rigaudiae, I. lacrymosa* and *M. choanophorum.*

Age of the formations in the Kalmthout well

An early Miocene age can be proposed for the Berchem Formation (Powell 1992, Costa & Manum 1988 and Manum et al. 1989). The correlation with the DN2 Zone of de Verteuil & Norris (1996) indicates a late Aquitanian to early Burdigalian age for the formation (Fig. 5).

The correlation of the Diest Formation with the Aum Interval Biozone of Powell (1992) points to a Tortonian – Messinian age, while a correlation with the upper part of de Verteuil & Norris' (1996) DN9 Zone and with the succeeding DN10 Zone indicates a late Tortonian – Messinian age.

A comparison with the zonation of Manum et al. (1989) indicates a possible Late Miocene age for the

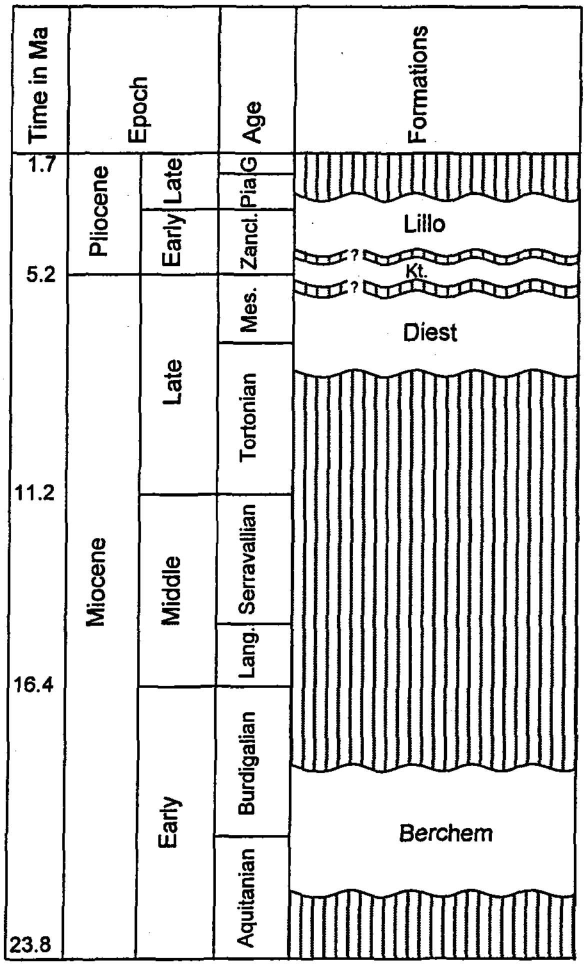

Fig. 5. Age of the Neogene Formations from the Kalmthout well. Time scale after Berggren et al. (1995) (Kt.: Kattendijk). The question marks indicate the uncertain position of the Kattendijk Formation.

Kattendijk Formation. The assignment of the Kattendijk and Lillo Formations to the Mch Interval Biozone of Powell (1992) indicates thus a Pliocene age.

Head (1993, 1996, 1997) has described the dinoflagellate cyst associations of several Pliocene deposits in outcrops and boreholes in East Anglia and gave a detailed overview of the ranges of the stratigraphically important species found there in the Lillo Formation (see above). The ranges allow to attribute to the sequence below 64 m an age not younger than the early late Pliocene (early Piacenzian). A younger age for 62.6 m cannot be excluded. If the presence of *A. zevenboomii* (as "Ataxiodinium elongatum" in Zevenboom 1995 MS) in the Late Miocene of The Netherlands proves indeed to be doubtful, then a Pliocene age (Zanclean to Piacenzian) can be attributed to the Kattendijk Formation and Lillo Formation.

Acknowledgements

We are indebted to J. De Coninck for stimulating discussions on dinoflagellate cyst taxonomy and morphology. J. Powell, S. Piasecki, J. Samuelsson and J. Vernieres are thanked for their constructive reviews of the manuscript.

Dansk sammendrag

Neogene dinoflagellat selskaber i Kalmthout boringen i det nordlige Belgien beskrives på basis af 23 prøver fra Berchem, Diest, Kattendijk og Lillo Formationerne. Disse selskaber kan korreleres med dinoflagellat zonationer og vigtige dinoflagellat events kendt fra Nordsøen og østkysten af USA. På grundlag af dinoflagellat selskaberne kan Berchem Formationen henføres til Nedre Miocæn (Øvre Aquitanien-Nedre Burdigalien), mens Diest Formationen er fra Øvre Miocæn (Øvre Tortonien-Messinien). Alderen af Kattendijk Formationen er usikker. Lillo Formationen i Kalmthout boringen er af Pliocæn alder and sandsynligvis ikke yngre end tidlig Sen Pliocæn.

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