Palynology, 2014
Vol. 38, No. 1, 38–50, http://dx.doi.org/10.1080/01916122.2013.793626

New acritarchs from the late Cenozoic of the southern North Sea Basin and the North Atlantic realm

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Biostratigraphical investigations of Miocene deposits from the southern North Sea Basin, the Oligocene and Miocene of the Bahamas, and the lower Pliocene of northern Iceland revealed the presence of new acritarch species. *Halodinium eirikssonii* n. sp. is recovered from the lower Pliocene *Serripes* Zone of the Tjörnes beds in northern Iceland, where its range is well constrained through magnetostratigraphy and biostratigraphy using dinoflagellate cysts. *Leiosphaeridia spongiosa* n. sp. is recovered from lower to upper Miocene deposits of the southern North Sea Basin and from upper Oligocene and Miocene deposits of the Bahamas. *Palaeostomocystis orbiculata* n. sp. appears to be restricted to the middle Miocene of the North Sea Basin.

Keywords: acritarchs; Cenozoic; Atlantic Ocean; North Sea Basin; taxonomy; biostratigraphy

1. Introduction

Acritarchs often constitute a distinct component of Neogene and Quaternary palynomorph assemblages. Small acritarchs are especially easily overlooked, and when observed, they are frequently classified under open nomenclature. Small acritarchs, however, have recently received more attention and several studies have already proved their usefulness as biostratigraphical tools (e.g. De Schepper & Head 2008, 2009) and palaeoecological proxies (Matsuoka & Head 1992; Head 1993).

Here we report three new acritarch species recorded during palynological investigations of late Cenozoic marine to marginal marine deposits of the Atlantic realm (northern Iceland and the Bahamas) and the southern North Sea Basin (northern Belgium). The depositional environment of these sites differs significantly, and most probably limits – at first sight – to a certain degree the potential of the new acritarch species as palaeoenvironmental proxies. The sediments from the Bahamas were deposited on a shallow carbonate platform in a warm temperate to subtropical climate (Head & Westphal 1999), while the deposits from northern Iceland originate from a cold temperate marginal marine to intertidal environment (Verhoeven et al. 2011). The Miocene sediments of northern Belgium were deposited in a temperate environment at the southern rim of a shallow marine siliciclastic sea (Louwye 2005).

2. Geological background

2.1. Northern Iceland

The lower Pliocene Tjörnes beds crop out in the Tjörnes Peninsula in northern Iceland (Figure 1). The beds represent a marginal marine depositional succession consisting of sandstones and siltstones alternating with terrestrial deposits such as lignites (Einarsson et al. 1967). Lava flows are present but do not constitute a substantial part of the sequence. The Tjörnes beds rest unconformably on the Tortonian Kaldakvísl lavas and are overlain by the upper Pliocene Höskuldsvík lavas (Einarsson et al. 1967) (Figure 2). The Tjörnes beds have a thickness of *circa* 525 m and were the subject of many palaeontological, palaeomagnetic and radiometric studies. Previous palaeontological studies focused on amongst others marine molluscs (Bárdarson 1925; Strauch 1972; Norton 1975, 1977; Gladenkov et al. 1980; McCoy 2007, Símonarson & Eiríksson 2008; Símonarson & Leifsdóttir 2008) and ostracods (Cronin 1991). The three mollusc biozones defined by Bárdarson (1925) are still used today as a practical division of the Tjörnes beds; these are the *Tapes* Zone, the *Mactra* Zone and the *Serripes* Zone (Figure 2).

Verhoeven et al. (2011, 2013) and Verhoeven and Louwye (2013) studied the marine and terrestrial palynomorphs in 68 samples for a refinement of the age model and a reconstruction of the palaeoenvironment

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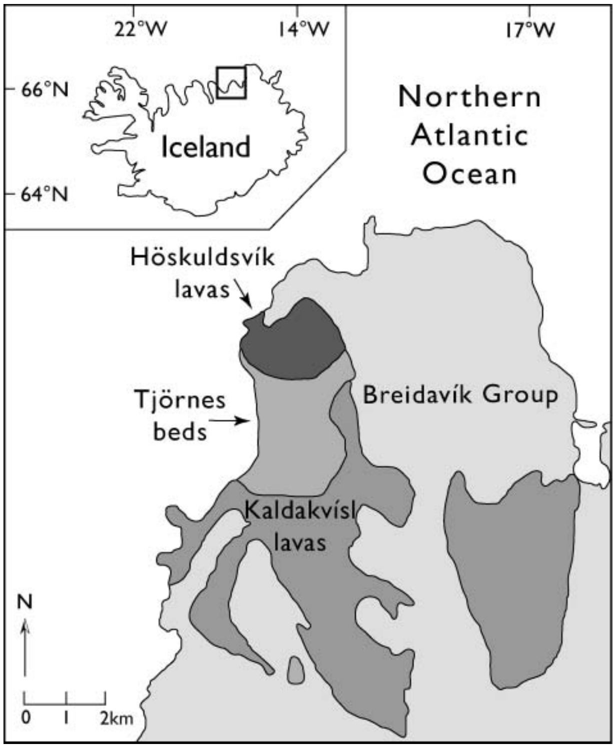


Figure 1. A simplified geological map of the Tjörnes peninsula showing Breidavík group, Höskuldsvík lavas, Kaldakvísl lavas and Tjörnes beds (after Verhoeven et al. 2011). Inset: Iceland and the location of the Tjörnes Peninsula.

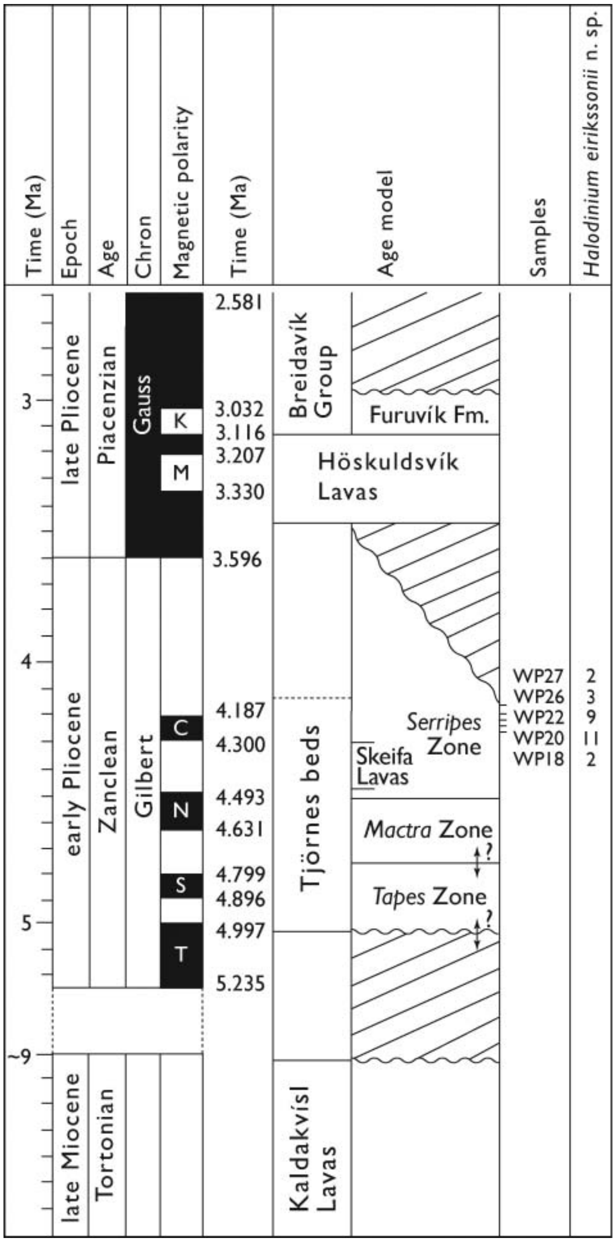


Figure 2. Late Miocene and Pleistocene stratigraphy of the Tjörnes sequence. Stratigraphical interpretation after Verhoeven et al. (2011). Raw counts are given for *Halodinium eirikssonii* n. sp. K: Kaena, M: Mammoth, C: Cochiti, N: Nunivak, S: Sidufjall, T: Thvera.

and the depositional history. The stratigraphical assessment of the Tjörnes beds by Verhoeven et al. (2011) is based on the presence of typical post-Miocene dinoflagellate cyst taxa and the highest occurrence (HO) of the dinoflagellate cysts *Batiacasphaera minuta* and *Operculodinium tegillatum* near the top of the sequence in the *Serripes* Zone. According to De Schepper and Head (2008), *Batiacasphaera minuta* and *Operculodinium tegillatum* have a HO in Deep Sea Drilling Project (DSDP) Hole 610A (eastern North Atlantic) at 3.83 Ma and at 3.71 Ma, respectively. The dinoflagellate cyst biostratigraphy in combination with the palaeomagnetic data further refined the age of the upper boundary of the Tjörnes beds to 4.0 Ma. The Tjörnes beds thus have a Zanclean age. Pollen analysis on the same samples used for the dinoflagellate cyst analysis, indicates summers of 8 °C warmer than today during deposition of the Tapes Zone, and at least 5 °C warmer during the remainder of the Tjörnes beds (Verhoeven et al. 2013). The early Pliocene vegetation of northern Iceland compares well to the flora of the present-day western European temperate climate. The dinoflagellate cyst assemblages of the Tjörnes beds allow a correlation with the lower Pliocene Kattendijk Formation in northern Belgium (southern North Sea Basin), and the lower Pliocene Ramsholt Member of the Coralline Crag (East Anglia, UK) (Head 1997; Louwye et al. 2004; De Schepper et al. 2009).

2.2. *Southern North Sea Basin*

The lower–middle Miocene Berchem Formation in northern Belgium is a fine-grained to medium-grained sandy sequence, rich in glauconite and characterised by numerous shelly intervals. Local decalcification occurs. The formation rests on the stiff clays of the Rupelian Boom Formation (lower Oligocene) or Chattian sands (upper Oligocene), and is overlain unconformably by the upper Miocene Diest Formation, the lower Pliocene Kattendijk Formation or Quaternary sands (Louwye 2005). The formation is divided into four members: the Edegem Sands, the Kiel Sands, the Antwerp Sands and a local facies, the Zonderschot Sands (De Meuter & Laga 1976). The biostratigraphy of the Berchem Formation remained unclear for many decades because of the patchy distribution of the deposits, the uniform sandy character with varying glauconite content and the local decalcification that hampered routine biostratigraphical analysis with calcareous microfossils. Organic-walled palynomorphs (dinoflagellate cysts, acritarchs, phycoma of green algae) are not prone to decalcification and proved an excellent tool for the elucidation of the stratigraphy of these shallow marine deposits (Louwye et al. 2000; Louwye 2005; Lambert & Louwye 2006). Palynological analysis with dinoflagellate cysts indicated deposition of the Berchem Formation in an inner neritic environment (Louwye 2005).

Fossil marine mammal bones were discovered in 2008 in a temporary outcrop near the Posthofbrug in the community of Berchem near Antwerp (Figure 3). The decalcified medium-grained Kiel Sands were exposed in the lower part of the outcrop (Figure 4). No macrofossils were recovered from this unit, although distinct traces of bioturbation were observed. The superjacent fine-grained to medium-grained sands are rich in glauconite and hold large numbers of broken shell fragments, and were lithostratigraphically interpreted to belong to the Antwerpen Sands Member of the Berchem Formation (Louwye et al. 2010). The marine mammal fossils were observed within the Antwerpen Sands Member and are near the lower boundary with the Kiel Sands Member (Figure 4). No magnetostratigraphy or radiometric dating are available, and only a relative dating with dinoflagellate cysts was carried out by Louwye et al. (2010).

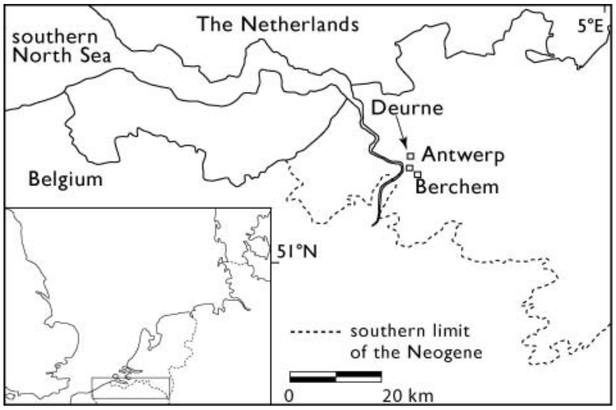


Figure 3. A simplified map of northern Belgium showing the southernmost distribution of Neogene deposits. Inset: southern North Sea Basin.

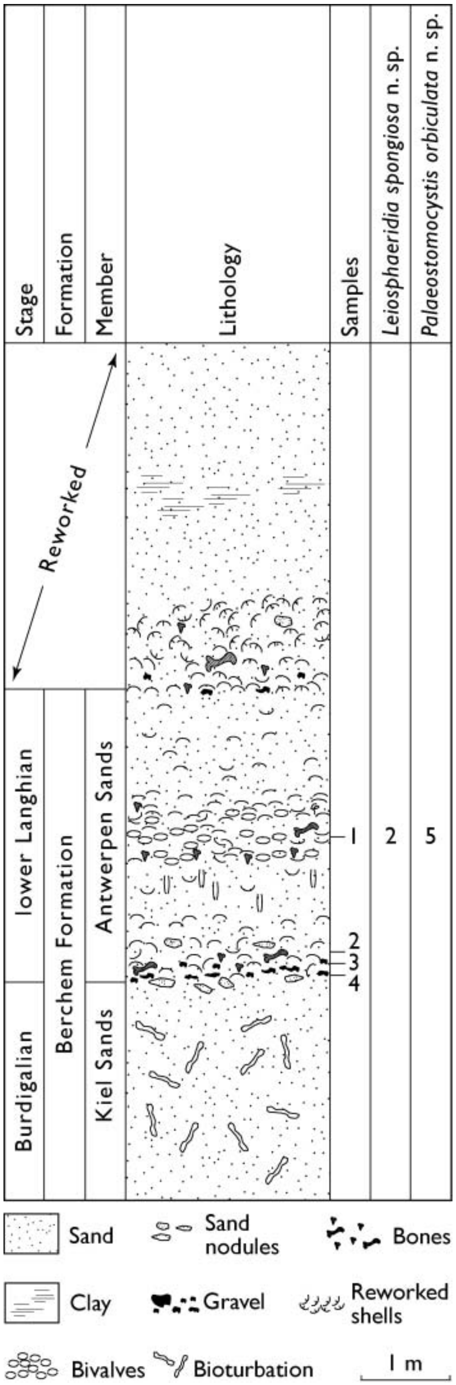


Figure 4. Lithostratigraphy and lithology of the Antwerpen Sands Member (Berchem Formation) in the temporary Posthofbrug outcrop in Berchem near Antwerp. Raw counts are given for *Leiosphaeridia spongiosa* n. sp. and *Palaeostomocystis orbiculata* n. sp.

Samples PHB1 to PHB4 (Figure 4) are characterised by the co-occurrences of the dinoflagellate cysts *Cousteaudinium aubryae*, *Distatodinium paradoxum* and *Labyrinthodinium truncatum*, and belong to the *Labyrinthodinium truncatum* Zone of Dybkjær and Piasecki (2010). This zone is defined as the interval from the lowest occurrence (LO) of *Labyrinthodinium truncatum* to the LO of *Unipontedinium aquaeductus*. The latter species was not recorded. *Cousteaudinium aubryae* has its highest occurrence within this zone. The *Labyrinthodinium truncatum* Zone has an early Langhian age and was deposited between 15.97 Ma (the first appearance of *Labyrinthodinium truncatum* near the Burdigalian–Langhian boundary according to Hilgen et al. 2012) and 14.8 Ma (first appearance of *Unipontedinium aquaeductus* at 14.8 Ma according to Powell & Brinkhuis 2005). Dybkjær and Piasecki (2010) equate their zone with the *Distatodinium paradoxum* DN4 biozone of de Verteuil and Norris (1996), the SNSM5 biozone of Munsterman and Brinkhuis (2004), and the D17b biozone of Powell and Brinkhuis (2005), since they are based on the same bioevents.

The upper Miocene Diest Formation occurs in northern Belgium and is defined as a glauconitic, mostly medium-grained to coarse-grained sandy unit (De Meuter & Laga 1976). The majority of the sequence is largely decalcified and has in consequence a very poor calcareous fossil content. The Deurne Sands Member is a local facies found at the base of the Diest Formation in the community of Deurne near Antwerp (Figure 3). It consists lithologically of glauconitic, very fine-grained to fine-grained sand which is rich in calcareous microfossils and macrofossils. The Deurne Sands Member rests unconformably on the middle Miocene Antwerpen Sands Member (the upper member of the Berchem Formation), and is overlain by the lower Pliocene Kattendijk Formation. Louwye (2002) recorded a rich and well-preserved assemblage of marine organic-walled palynomorphs (dinoflagellate cysts, acritarchs and phycoma of green algae) from the Deurne Sands Member in a temporary outcrop in Deurne (Figure 5). The assemblage is characterised by the joint occurrence of *Amiculosphaera umbraculum*, *Cleistosphaeridium placacanthum*, *Cordosphaeridium minimum*, *Labyrinthodinium truncatum* and *Palaeocystodinium* spp. The Deurne Sands Member correlates with the *Amiculosphaera umbraculum* Zone of Dybkjær and Piasecki (2010) that is defined from the LO of the index species to the LO of *Barssidinium evangelineae*; the latter species was not recorded by Louwye (2002). The *Amiculosphaera umbraculum* Zone has an early Tortonian age (11.4 Ma to 8.8 Ma). Dybkjær and Piasecki (2010) correlate the *Amiculosphaera umbraculum* Zone with the upper part of the *Palaeocystodinium golzowense* DN8 biozone of de Verteuil and Norris (1996), the upper part of the SNSM12-13 biozone of Munsterman and Brinkhuis (2004) and with the entire D19 biozone of Powell and Brinkhuis (2005).

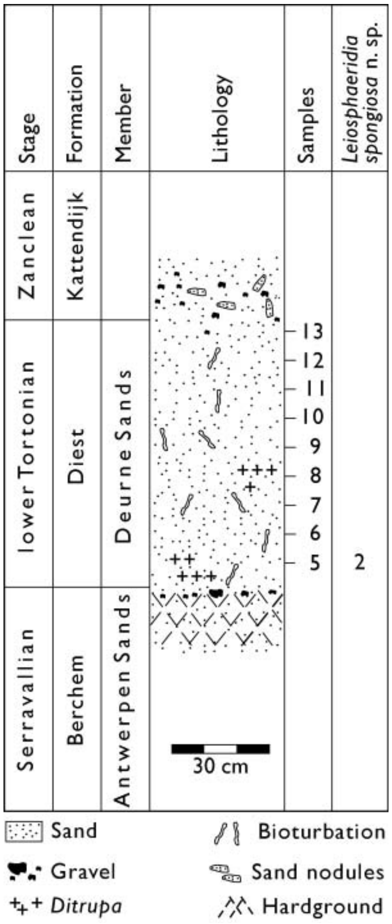


Figure 5. Lithostratigraphy and lithology of the Deurne Sands Member (Diest Formation) in the temporary Borgerhout Rivierenhof VIIB.R. outcrop near Antwerp (see De Meuter & Laga 1976, and Louwye 2002 for detailed location). *Leiosphaeridia spongiosa* n. sp. was only recorded in basal sample no. 5. The raw count is given.

2.3. *Bahamas*

Ocean Drilling Program (ODP) Leg 166, Hole 1007C (24° 30.254' N, 79° 19.348' W) was drilled in 1996 on the distal slope of the western Great Bahama Bank at a water depth of 647 m (Figure 6). A relatively complete upper Oligocene to upper Miocene succession with a total thickness of 933.4 m was recovered. One of the goals of the drilling was to test ideas about how Miocene sea level changes might be recorded in the peri-platform areas of a carbonate ramp (Shipboard Scientific Party 1997).

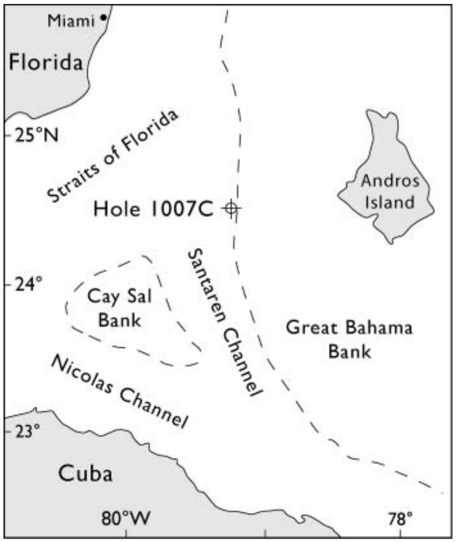


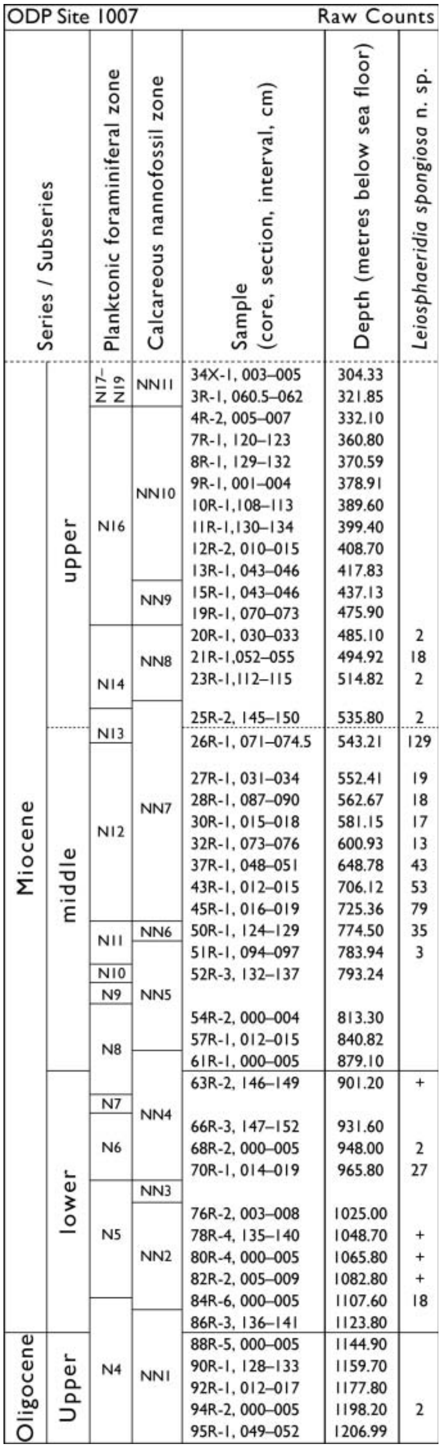
Figure 6. The location of Ocean Drilling Program (ODP) Hole 1007C.

The lithology at this site consists of light pelagic wackestones and nannofossil chalks cyclically alternating with dark neritic wackestones and packstones at metre and centimetre scales. Locally coarse-grained turbidites and slumps are present (Shipboard Scientific Party 1997). The origin of these rhythmic sequences has been attributed to differential shedding of neritic particles into the basin driven by sea-level changes in precession (Betzler et al. 2000; Reuning et al. 2002). However, the hypothesised differential exporting of aragonitic particles alone cannot explain the couplets, and so differential diagenesis is believed to be responsible at some level for the observed petrophysical contrasts in the lithologies (Melim et al. 2002).

A total of 74 samples from the Oligocene and Miocene interval were palynologically analysed for a biostratigraphical study and the reconstruction of the palaeoenvironment (Figure 7).

3. Material and methods

All the samples were prepared using standard palynological preparation techniques involving demineralisation with hydrochloric acid (HCl) and hydrofluoric acid (HF) for the removal of carbonates and silicates, respectively, and recommendations by Mertens et al. (2009, 2012) were followed except for the mesh size. No oxidation or alkali treatment was applied. A short ultrasonic treatment of *circa* 15 seconds was applied. Residues were sieved on a 16-μm nylon screen. Slides were strew-mounted with glycerine jelly and the cover slip was sealed with nail polish. Photomicrographs were taken with a Zeiss AxioImager A1 optical microscope equipped with differential interference contrast and a Zeiss MR5c digital camera. All images are true and are not reversed. Confocal microscopy was performed using a C1 confocal microscope (Nikon Belux, Brussels, Belgium). No staining was necessary since the



ODP Site 1007 Raw Counts

Series / Subseries		Planktonic foraminiferal zone	Calcareous nannofossil zone	Sample (core, section, interval, cm)	Depth (metres below sea floor)	*Leiosphaeridia spongiosa* n. sp.
Miocene	upper	N17–N19	NN11	34X-1, 003–005	304.33	
				3R-1, 060.5–062	321.85	
		N16	NN10	4R-2, 005–007	332.10	
				7R-1, 120–123	360.80	
				8R-1, 129–132	370.59	
				9R-1, 001–004	378.91	
				10R-1,108–113	389.60	
				11R-1,130–134	399.40	
				12R-2, 010–015	408.70	
				13R-1, 043–046	417.83	
			NN9	15R-1, 043–046	437.13	
				19R-1, 070–073	475.90	
		N14	NN8	20R-1, 030–033	485.10	2
				21R-1,052–055	494.92	18
				23R-1,112–115	514.82	2
			NN7	25R-2, 145–150	535.80	2
	middle	N13		26R-1, 071–074.5	543.21	129
		N12		27R-1, 031–034	552.41	19
				28R-1, 087–090	562.67	18
				30R-1, 015–018	581.15	17
				32R-1, 073–076	600.93	13
				37R-1, 048–051	648.78	43
				43R-1, 012–015	706.12	53
				45R-1, 016–019	725.36	79
		N11	NN6	50R-1, 124–129	774.50	35
			NN5	51R-1, 094–097	783.94	3
		N10		52R-3, 132–137	793.24	
		N9				
		N8		54R-2, 000–004	813.30	
				57R-1, 012–015	840.82	
			NN4	61R-1, 000–005	879.10	
	lower			63R-2, 146–149	901.20	+
		N7				
		N6		66R-3, 147–152	931.60	
				68R-2, 000–005	948.00	2
				70R-1, 014–019	965.80	27
		N5	NN3			
			NN2	76R-2, 003–008	1025.00	
				78R-4, 135–140	1048.70	+
				80R-4, 000–005	1065.80	+
				82R-2, 005–009	1082.80	+
		N4		84R-6, 000–005	1107.60	18
			NN1	86R-3, 136–141	1123.80	
Oligocene	Upper			88R-5, 000–005	1144.90	
				90R-1, 128–133	1159.70	
				92R-1, 012–017	1177.80	
				94R-2, 000–005	1198.20	2
				95R-1, 049–052	1206.99	

Figure 7. Chronostratigraphy and biostratigraphy of the Miocene section studied in Ocean Drilling Program (ODP) Hole 1007C. Raw counts are given for *Leiosphaeridia spongiosa* n. sp.

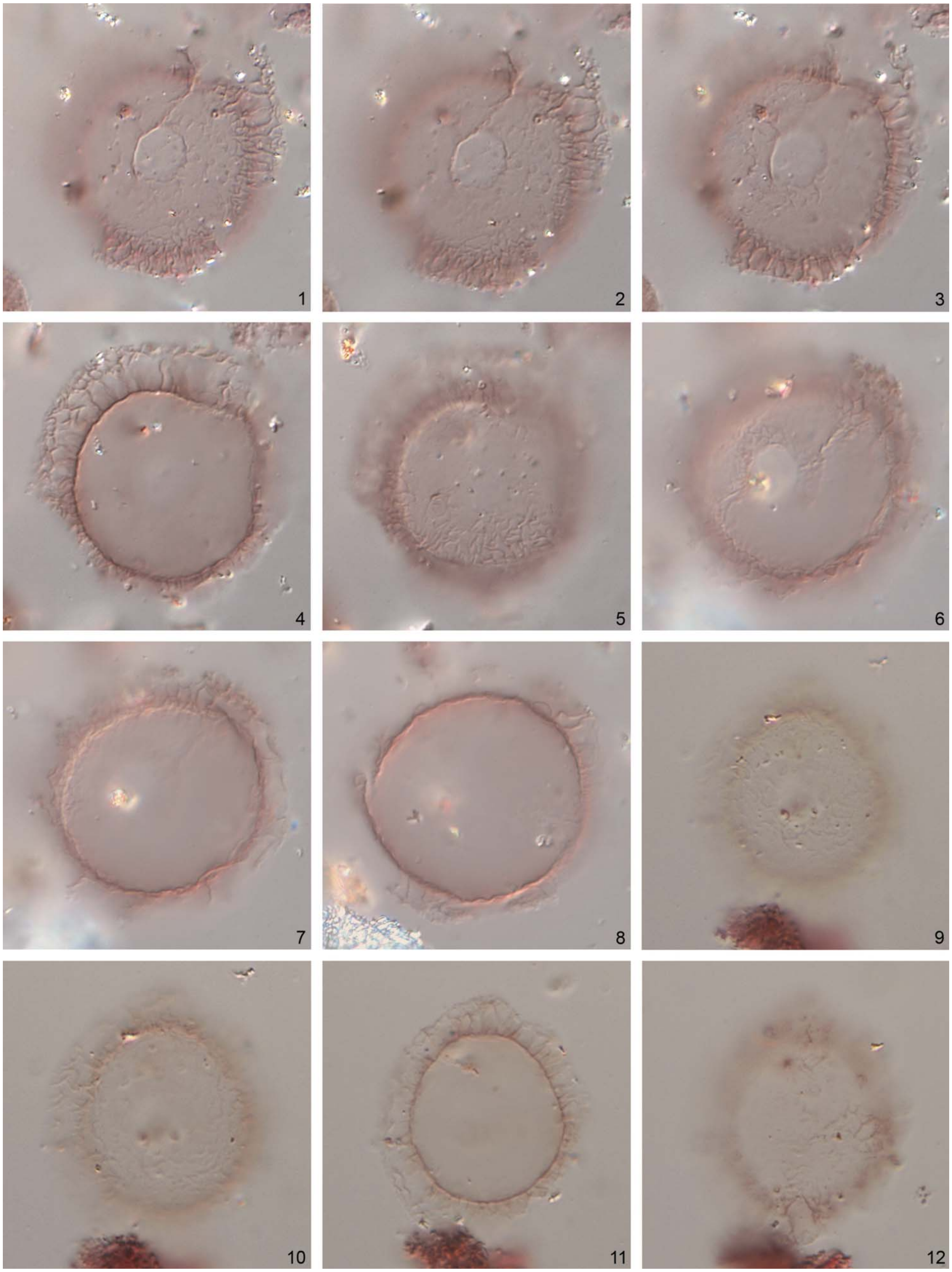


Plate 1. Photomicrographs of *Halodinium eirikssonii* n. sp., all specimens from the Serripes zone of the Tjörnes beds, northern Iceland. EF: England Finder coordinates. Figures 1–5. Holotype, slide WP20, EF: Y55, slightly differing foci varying from high focus (Figure 1) to low focus (Figure 5). Maximum diameter central body: 27.4 μm. Figures 6–8: Slide WP20, EF: W62, slightly differing foci varying from high focus (Figure 6) to low focus (Figure 8). Maximum diameter central body: 27.2 μm. Figures. 9–12: Slide WP26, EF: S40/4, slightly differing foci varying from high focus (Figure 9) to low focus (Figure 12). Maximum diameter central body: 23.4 μm.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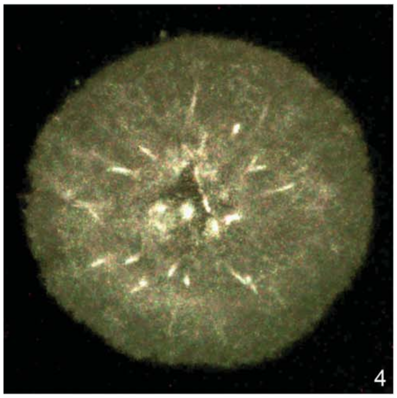
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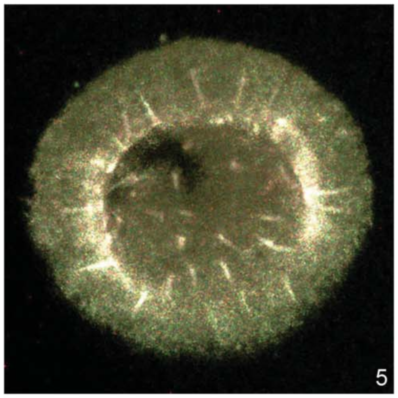
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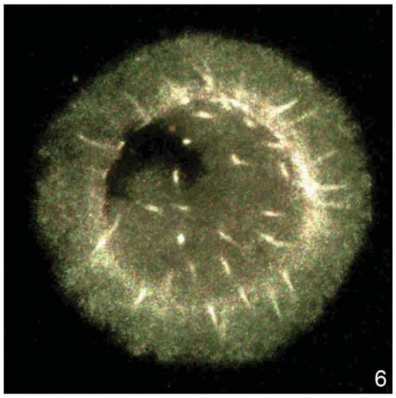
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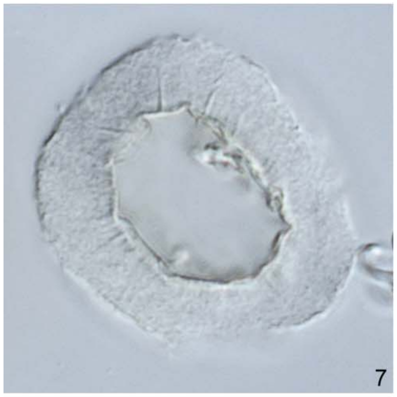
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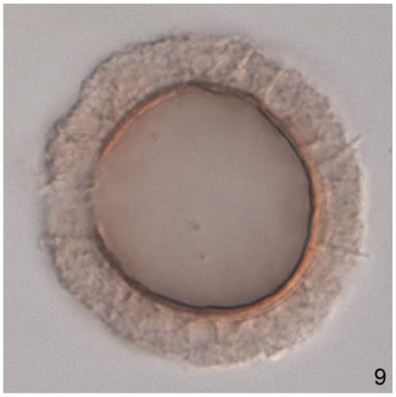
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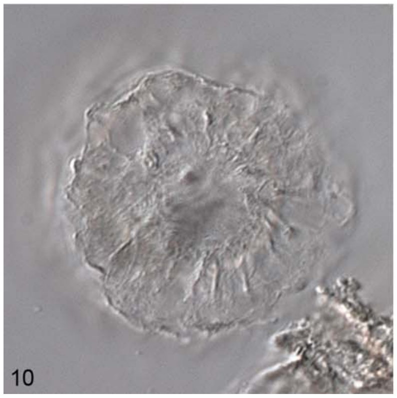
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grains were sufficiently autofluorescent. Autofluorescence was excited with the 488 nm wavelength of an argon (Ar)-ion laser. Z-stacks were taken with a step size of 0.35 µs with a Pixel dwell time of 7.92 µs. The objective used was a 60×/1.40/0.13 Plan-Apochromat lens with oil immersion. After correcting the z-axis for differences in refractive index between the immersion oil and glycerine jelly (a correction factor of 78% was used), images were rendered with Volume Graphics VGStudioMax software. The nomenclature of the dinoflagellate cysts mentioned in the text follows Dinoflaj2 (Fensome et al. 2008).

4. Systematic palynology

Group ACRITARCHA Evitt, 1963

Genus *Halodinium* Bujak 1984

Halodinium eirikssonii n. sp.
Plate 1, figures 1–12

Synonymy. Acritarch sp. 1 in Verhoeven and Louwye (2013), pl. 4, figs. M–P.

Holotype. Plate 1, Figures 1–5, slide WP 20, England Finder coordinate: Y52.

Stratigraphical horizon and type locality. *Serripes* Zone, Tjörnes beds. Locality: Tjörnes peninsula, northern Iceland (Figure 1).

Repository. Collection of the ‘Institut Royal des Sciences Naturelles’ (Brussels, Belgium), catalogue number IRScN b6558.

Derivatio nominis. Named in honour of Dr. Jón Eiríksson for his contributions to the geology of the Tjörnes beds in northern Iceland.

Diagnosis. Small, polar compressed palynomorph with circular to subcircular outline. The scabrate to smooth outer wall is appressed to the inner wall over the greater part of the cyst body. The outer wall has a rugulate surface consisting of occasionally anastomosing wrinkle-like ridges. At the periphery of the cyst, the outer wall forms a collar-like ambital flange consisting of irregular septate or foldlike structures. The pylome is circular without operculum.

Description. The discoidal central body has a circular to subcircular outline in polar view. The diameter of the central body is relatively constant and is between 23.9 and 27.4 µm. The wall is composed of two layers. The inner layer is smooth, while the thinner outer layer is scabrate to smooth. Both layers are appressed over the greater part of the polar region. Linear or irregular wrinkle-like ridges ornament the outer surface and interconnect occasionally to form an irregular pattern. Near the margin of the central body, in polar view, irregular, interconnecting septa or fold-like structures arise from the outer layer, forming an ambital flange. The ambital flange is often torn because of the thin and membranous nature of the septa. The height of the septa varies on a single specimen. The circular pylome is centrally positioned in polar view. The slightly thickened margin of the pylome is smooth or weakly indented. The diameter of the pylome is variable (between 4.6 and 8.8 µm). An operculum is never observed. The pale specimens barely absorb the stain Safranin-O, and are, as a consequence, difficult to observe under transmitted light microscopy. Furthermore, the cyst is thin-walled and is often observed folded, wrinkled or torn.

Dimensions. Holotype: maximum diameter central body: 27.4 µm; maximum diameter pylome: 8.8 µm; width ambital flange: 6.8 µm. Range: maximum diameter central body: 23.9–27.4 µm (mean: 26.5 µm); maximum diameter pylome: 4.6–8.8 µm (mean: 6.6 µm); average width ambital flange: 1.6–6.8 µm (mean: 4.1 µm). Number of specimens measured: five.

Comparison. The light and translucent ambital flange of *Halodinium scopaeum* Head 1993 surrounds the central body entirely and is approximately of constant width. It is furthermore thin and smooth or faintly scabrate (Head 1993, p. 47), and contrasts with the complex ambital flange of *Halodinium eirikssonii* n. sp. The central body maximum diameter of *Halodinium scopaeum* Head 1993 ranges between 21 and 24 µm, and is comparable to those of *Halodinium eirikssonii* n. sp. (23.9–27.4 µm). Both *Halodinium major* Bujak 1984 and *Halodinium minor* Bujak 1984 have much larger diameters of the central body (104–116 µm and 46–63 µm, respectively) and possess an unornamented,

Plate 2. Figures 1–3, 7–12: photomicrographs of *Leiosphaeridia spongiosa* n. sp. Figures 4–6: confocal laser microscopy images of *Leiosphaeridia spongiosa* n. sp. EF: England Finder coordinates. Figures 1–3: Holotype, Posthofbrug outcrop, slide PHB1/1–358, EF: P45/4, slightly differing foci ranging from high focus (Figure 1) to low focus (Figure 3). Maximum total diameter: 33.7 µm. Figures 4–6: Holotype, Posthofbrug outcrop, slide PHB1/1–358, EF: P45/4, slightly differing foci ranging from high focus (Figure 4) to low focus (Figure 6). Maximum diameter central body: 33.7 µm. Figure 7: Posthofbrug outcrop, slide PHB1/1–358, EF: N20/1, median focus. Maximum diameter central body: 31.5 µm. Figures 8–9: Borgerhout Rivierenhof outcrop, slide VII BR5–1, EF: F55/1, high focus (Figure 8), median focus (Figure 9). Maximum diameter central body: 27.7 µm. Figures 10–11: Ocean Drilling Program (ODP) Hole 1007C, Core70R, Section 1, Interval 014–019 cm, 985.60 m below sea floor. Slide 1, 10 µm. EF: G53-3, high focus (Figure 10), median focus (Figure 11). Maximum diameter central body: 18 µm. Figure 12: ODP Hole 1007C, Core 70R, Section 1, Interval 014–019 cm, 985.60 m below sea floor. Slide 2, 10 µm, EF: H46, median focus. Maximum diameter central body: 16 µm.


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thin and pale ambital flange. Species of the genus *Cyclopsiella* Drugg & Loeblich 1967 have a subapical pylome and often possess an equatorial thickening of line or folding across the main body (Head et al. (1989).

Stratigraphical occurrence. A total of 27 specimens were recorded from five samples in the middle part of the lower Pliocene dinoflagellate cyst biozone DAZ3 of the Tjörnes beds in northern Iceland (Verhoeven & Louwye 2013) (Figure 3). Biozone DAZ3 encompasses the Bárdarson beds 17 to 22 of the *Serripes* mollusc Zone. The new species is not encountered in the time equivalent deposits of northern Belgium and the UK. Species of *Halodinium* have been recorded in Pliocene to Recent deposits in the northern hemisphere (see Head 1993 for an overview of the stratigraphical occurrences).

Biological affinity. Unknown for the genus (see Head 1993 for a discussion).

Palaeoecology. *Halodinium eirikssonii* n. sp. is recorded in the intertidal to nearshore deposits of the lower Pliocene dinoflagellate cyst zone DZ3 of the Tjörnes beds (Verhoeven et al. 2011; Verhoeven and Louwye, 2013). The new species occurs together with high numbers of heterotrophic dinoflagellate cysts and the acritarch *Halodinium scopaeum* Head 1993. The latter species was for the first time recorded in the nutrient-rich, shallow marine deposits of the lower Pleistocene St. Erth Beds in southwestern England (Head 1993). The latter author gave a detailed overview of the palaeoecology of the genus *Halodinium* – based on published records – and concluded that representatives of the genus thrive in transitional environments as testified by their presence in shallow marine (intertidal to nearshore) and estuarine environments. Noteworthy is the presence of high numbers of *Halodinium major* in Recent intertidal and nearshore deposits of Arctic estuaries (Mudie 1992).

Genus *Leiosphaeridia* Eisenack 1958 emend. Turner 1984

Leiosphaeridia spongiosa n. sp.
Plate 2, figures 1–12

Synonymy. Algal cyst type 2 Head 1997, Louwye 2002, p. 64, fig. 5/3–4.
Small spiny acritarchs (undifferentiated), Louwye et al. 2010, Table 1.

Holotype. Plate 2, figures 1–6, PHB1/1–358 (England Finder co-ordinate: P45/4).

Stratigraphical horizon and type locality. Antwerpen Sands Member, Berchem Formation, southern North Sea Basin. Locality: Berchem, Belgium.

Repository. Collection of the 'Institut Royal des Sciences Naturelles' (Brussels, Belgium), catalogue number IRScN b6559.

Derivatio nominis. From *spongia* (via Latin from Greek): sponge. In reference to the spongelike nature of the cyst.

Diagnosis. Small acritarch possessing a spherical, single-walled central body covered with solid, acuminate spines. The majority of the spines are entirely embedded in a spongy outer layer. Occasionally a few spines protrude minimally out of the outer layer. The surface of the outer layer is foveolate.

Description. Small acritarch with a spherical to subspherical central body consisting of a thin, smooth layer (thickness *circa* $< 0.5\ \mu$m). The central body is covered with solid, acuminate spines that taper gradually over their length. The width of the spines at their base is less than 1 μm. The spines are entirely embedded or covered by a spongy to cancellous outer layer of even thickness (approximately 6 to 7 μm). The length of the spines is usually a few μm less than the thickness of the spongy layer. A few spines equal the length of the spongy layer or protrude very slightly over a few μm. The distribution of the spines is difficult to observe, but so far no clear pattern could be observed. The spacing of the spines appears to be even (*circa* 3 to 5 μm between two spines). No connection between the spines was observed. The surface of the outer, spongy layer is foveolate. An angular and irregular theropylic split was observed on one specimen and could be visualised with confocal microscopy (Plate 2, figures 5–6). The autofluorescence of the spongy layer is less intense, and of a different spectral range than the autofluorescence of the central body and its spines. Together with the fact that the spines sometimes protrude outside of the spongy layer, this could suggest that this outer spongy layer is not part of the actual cyst, but kerogen that has remained attached. However, we have not observed specimens without a spongy layer, and therefore at this time we consider the spongy layer an integral part of the cyst.

Dimensions. Holotype: maximum diameter: 33.7 μm; minimum diameter: 31.3 μm; maximum diameter central

◀

Plate 3. Photomicrographs of *Palaeostomocystis orbiculata* n. sp., all specimens from the Posthofbrug outcrop near Antwerp. EF: England Finder coordinates. Figures 1–4: Holotype, Slide PHB1/1–358, EF: Q21/1, slightly differing foci ranging from high focus (Figure 1) to low focus (Figure 4). Maximum diameter central body: 36.8 μm. Figures 5–7: Slide PHB1/2–358, EF: U25/4, slightly differing foci ranging from high focus (Figure 5) to low focus (Figure 7). Maximum diameter central body: 42.2 μm. Figures 8–9: Slide PHB1/1–358, EF: L20/4, slightly differing foci ranging from high focus (Figure 8) to low focus (Figure 9). Maximum diameter central body: 43.1 μm. Figures 10–12: Slide PHB1/1–358, EF: B27/4, slightly differing foci ranging from high focus (Figure 10) to low focus (Figure 12). Maximum diameter central body: 41 μm.

body: 19.3 μm; minimum diameter central body: 18 μm. Range: maximum diameter: 19–34 μm (mean: 26.9 μm); minimum diameter: 19–34 μm (mean: 25.8 μm); maximum diameter central body: 14–24 μm (mean: 17.9 μm); minimum diameter central body: 13–24 μm (mean: 16.8 μm). Number of specimens measured: 25.

Comparison. *Leiosphaeridia rockhallensis* Head and Norris 2003, previously recorded and described as Algal cyst type 2 Head 1997 from the lower Pliocene of eastern England, differs in the overall smaller size (range maximum diameter 17–23 μm, with a mean of 18.9 μm), the smaller width of the outer spongy layer (1.4–3.2 μm versus *circa* 7 μm for our holotype), and the absence of solid spines.

Stratigraphical occurrence. *Leiosphaeridia spongiosa* n. sp. was recorded from the lower Langhian Antwerpen Sands Member of the Berchem Formation in the Posthofbrug outcrop near Antwerp (Figure 4). The species was also recorded by Louwye (2002) in low numbers (two specimens during a routine count of 302 specimens) from the base of the lower Tortonian Deurne Sands Member of the Diest Formation in the Borgerhout Rivierenhof outcrop near Antwerp (Figure 5). The species was erroneously identified as Algal cyst type 2 Head 1997 (now *Leiosphaeridia rockhallensis* Head & Norris 2003). *Leiosphaeridia spongiosa* n. sp. ranges in Hole 1007C from the upper Oligocene into the base of the upper Miocene (planktonic foraminiferal zone NN1 to NN8), and occurs in high numbers in the middle Miocene (Figure 7). Its presence was also noted outside the systematic counts.

The stratigraphical range of *Leiosphaeridia spongiosa* n. sp. is thus restricted to the Upper Oligocene and Miocene.

Biological affinity. Unknown.

Genus *Palaeostomocystis* Deflandre 1937

Palaeostomocystis orbiculata n. sp.
Plate 3, figures 1–12

Holotype. Plate 3; figures 1–4, slide PHB1(358), England Finder co-ordinate: Q21/1

Stratigraphical horizon and type locality. Antwerpen Sands Member, Berchem Formation, southern North Sea Basin. Locality: Berchem, Belgium.

Repository. Collection of the 'Institut Royal des Sciences Naturelles' (Brussels, Belgium), catalogue number IRScN b6560.

Derivatio nominis. From '*orbiculata*' (Latin, adjective): having a circular shape. With reference to the outline of the cyst.

Diagnosis. Single-layered, spherical to subspherical acritarch with a circular pylome possessing a thickened rim. The thick wall is slightly granular and ornamented with low ridges forming an irregular net-like structure with lumina of varying size and distribution. Operculum free.

Description. Small-sized to medium-sized, proximate acritarch with a circular to subcircular ambitus in polar view. The cyst body is spherical to subspherical and a slight polar compression is occasionally observed. The thick wall is single layered, and smooth to slightly granular. The outer surface is ornamented with low, anastomosing ridges. The ridges form an often incomplete net-like structure with lumina of strongly varying size (Plate 3, figure 8). The distribution of these lumina is very irregular over the cyst body, and no clear pattern could be discerned. The pylome is circular or nearly circular, and has a slightly thickened rim. An operculum was never observed in place. The acritarch is commonly observed in polar view.

Dimensions. Holotype: maximum diameter central body: 36.8 μm; maximum diameter pylome: 18.6 μm. Range: maximum diameter central body: 34.5–43.1 μm (mean: 39.6 μm); maximum diameter pylome: 17.6–22,4 μm (mean: 20.1 μm). Number of specimens measured: five.

Comparison. *Palaeostomocystis orbiculata* n. sp. differs from all other species of the genus by its characteristic circular to subcircular ambitus, its robust appearance, the irregular reticulum and the circular pylome.

Stratigraphical occurrence. *Palaeostomocystis orbiculata* n. sp. is recorded from the lower Langhian Antwerpen Sands Member of the Berchem Formation near the Posthofbrug outcrop (Figure 4). It is the sole record of the species.

Comparison. *Palaeostomocystis globosa* Louwye 1999, also defined from the Diest Formation in northern Belgium, has the same dimensions but possesses a larger pylome (12–38 μm) and a discretely ornamented wall. The general image and the shape of the pylome of *Palaeostomocystis subtilitheca* Roncaglia 2004a are somewhat similar to those of the new species. The overall vesicle length of *Palaeostomocystis subtilitheca* is, however, larger (45–55 μm), and the species has a thin, smooth or finely ornamented wall. *Palaeostomocystis orbiculata* n. sp. differs from all other species of the genus by its characteristic circular to subcircular ambitus, its robust appearance, the irregular net-like ornamentation and the circular pylome.

Biological affinity. This is uncertain. Roncaglia (2004a) suggested affinities with tintinnid cysts for *Palaeostomocystis subtilitheca*, and Warny (2009) made similar suggestions.

Palaeoecology. *Palaeostomocystis orbiculata* n. sp. has been recorded in this study from the shallow marine Antwerpen Sands Member of the Berchem Formation. Roncaglia (2004b) recorded relatively high numbers of *Palaeostomocystis subtilitheca*, together with *Beringiella fritilla* Bujak 1984 (which she also considered to belong to the genus *Palaeostomocystis*) and *Halodinium minor* Bujak 1984 from a Holocene, temperate–cold to warm sea surface temperature environment in the Skálafjord of the Faroe Islands, for which they are considered characteristic. Depositional depth in the fjord was *circa* 70 m.

5. Conclusions

Three previously undescribed acritarchs are recognised as new: *Halodinium eirikssonii* n. sp., *Leiosphaeridia spongiosa* n. sp. and *Palaeostomocystis orbiculata* n. sp. The geographical distribution of *Halodinium eirikssonii* n. sp. is restricted to the high latitudes (northern Iceland), and might be suggestive of colder water affinities. The species thrived in marginal marine environments. The stratigraphical range of this species appears to be the lower Pliocene.

Leiosphaeridia spongiosa n. sp. was recorded from the Miocene of the Bahama Platform and from the lower Langhian to lower Tortonian of the southern North Sea Basin. The geographical distribution implies a broad temperature tolerance in coastal to oceanic environments. *Palaeostomocystis orbiculata* n. sp. is apparently a rare species that is only known from lower Langhian, shallow marine deposits of the southern North Sea Basin.

Acknowledgements

Ms. Sabine Van Cauwenberghe is kindly thanked for the palynological preparation of the samples. M. Bosselaers and Dr. O. Lambert provided the samples from the Posthofbrug outcrop. The research was carried out by the first author within the framework of an assistantship at the Palaeontology Research Unit of Ghent University. The palynological analysis of the Posthofbrug sediments was carried out within the framework of a research project funded by the Fund for Scientific Research, Flanders. M. P-R. conducted the research during his graduate studies at Brock University, supported by a NSERC Discovery Grant to M.J. Head K.N.M. is a postdoctoral fellow of the Fund for Scientific Research, Flanders. K.V. studied the palynology of the Tjörnes section during an assistantship at Ghent University. K. Dybkjaer and S. De Schepper are kindly thanked for their meticulous review of the manuscript and their constructive and stimulating comments.

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