GEOLOGICA CARPATHICA, FEBRUARY 2012, 63, 1, 49–70 doi: 10.2478/v10096-012-0004-8

Oligocene dinoflagellate cysts from the North Alpine Foreland Basin: new data from the Eggerding Formation (Austria)

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(Manuscript received January 25, 2011; accepted in revised form June 9, 2011)

Abstract: In spite of detailed geological and geophysical investigations, information available on palynostratigraphy for the successions deposited in the Austrian part of the North Alpine Foreland Basin (NAFB) is scanty. For the first time, relatively diverse and well preserved Oligocene dinocyst assemblages, comprising 53 genera and 138 species, are presented from the organic-rich sediments of the Eggerding Formation. These assemblages contribute to the biostratigraphy of the Oligocene deposits within the NAFB. Dinocysts such as *Chiropteridium lobospinosum*, *Membranophoridium aspinatum*, *Cordosphaeridium* spp., *Enneadocysta* spp., *Deflandrea* spp., *Spiniferites/Achomosphaera* group, *Hystrichokolpoma* spp., *Apteodinium* spp., *Glaphyrocysta/Areoligera* complex and *Wetzeliella* spp. represent the main palynological elements. The occurrence of *Chiropteridium* spp., *Tuberculodinium vancampoae*, *Distatodinium biffii* and *Wetzeliella gochtii* is of particular importance for regional correlations within the Lower Oligocene sediments. A comparison with age-controlled assemblages from the North Sea Basin, Carpathian and circum-Mediterranean regions substantiate the attribution to the Rupelian. Lack or sporadic occurrence of the oceanic taxa (e.g. *Nematosphaeropsis* and *Impagidinium*) and dominance of *Glaphyrocysta/Areoligera* indicate an inner-neritic marine setting during the deposition of the studied intervals. Although, it is difficult to reconstruct precisely the climatic conditions based on the recorded dinocysts, warm? sea surface water is suggested. A variation in salinities is interpreted based on the abundances of *Homotryblium* spp. The abundance of Peridiniaceae taxa (e.g. *Lejeunecysta*, *Wetzeliella*, and *Deflandrea*) indicates nutrient-rich surface water.

Key words: Oligocene, Austria, North Alpine Foreland Basin, Eggerding Formation, paleoenvironment, dinocysts.

Introduction

The amount of geological and geochemical data from the Oligocene–Miocene successions of the North Alpine Foreland Basin (NAFB), northern Austria, has increased over the last decades, as a number of wells have been drilled for hydrocarbon exploration (e.g. Wagner 1998; Sachsenhofer & Schulz 2006). The Oligocene organic-rich sediments were deposited during the early stages of the Paratethys separation and are one of the most important sources of hydrocarbons within the Paratethys Realm (Popov et al. 2004). The Oligocene sediments are represented by four formations: Schöneck, Dynow, Eggerding and Zupfing (Fig. 1).

Three boreholes penetrated the Oligocene sediments of northern Austria (Sachsenhofer et al. 2010) and proved to be rich in dinoflagellate cysts (hereinafter referred to as dinocysts). However, although macro and micropaleontological studies have been carried out extensively (Cicha et al. 1971; Harzhauser & Mandic 2002; Scherbacher et al. 2002; and references therein), the systematic investigation of the dinocysts has been almost ignored so far except for the pioniering study of Hochuli (1978) on the Oligocene-Lower Miocene palynomorphs of the NAFB, mostly focused on miospores. The present study of dinocysts was therefore undertaken in order to provide additional data for the refining of the stratigraphic framework of the Oligocene deposits in the NAFB, Austria.

In Central Europe, especially in the Carpathian Flysch, there are several studies which dealt with the Paleogene dinocysts and some of them are dedicated to the Oligocene. Gedl (1995) discussed the age and depositional environment of the Ostrysz Formation (Oligocene) of the Polish Inner Carpathians based on dinocysts. Gedl (2000a,b) investigated Oligocene sediments in the Podhale Paleogene, Inner Carpathians, Poland and detected identical dinocyst assemblages as in the Eggerding Formation. He used dinocysts and palynofacies analysis to establish the biostratigraphy and to reconstruct its paleoenvironment. Gedl (2004a) investigated the dinocysts at the Eocene/Oligocene boundary at Leluchów, Poland. Gedl & Leszczyński (2005) examined the deep-marine Upper Eocene-Lower Oligocene turbiditic and hemipeligic sediments exposed at Folusz, Polish part of the Western Carpathians. They proposed a Rupelian age for the investigated sediments from Magura Beds. Soták et al. (2007) in an integrated micropaleontological study of the Pucov section, Podtatranská Group used foraminifera, calcareous nannoplankton and dinocysts to detect the Eocene/Oligocene and Rupelian/Chattian boundaries. Recently, Barski & Bojanowski (2010) used dinocysts from the Oligocene flysch deposits of the Western Carpathians as a tool to investigate the occurrence of the carbonate concretions. Soták (2010) discussed the climatic changes across the Eocene/Oligocene boundary in the Central-Carpathian Paleogene Basin using several biota including dinocysts.

Several studies dealing with the Oligocene dinocyst stratigraphy of adjacent areas have been published from the North Sea (e.g. Dybkjær 2004; Schiøler 2005; Dybkjær &

Rasmussen 2007), Germany (e.g. Köthe 1990, 2003; van Simaeys et al. 2005; Köthe & Piesker 2007), and the circum-Mediterranean area (e.g. El Beialy 1990; Brinkhuis & Biffi 1993; Brinkhuis 1994; Torricelli & Biffii 2001; Bati & Sancay 2007; Pross et al. 2010).

In this study, 1) the distribution of dinocysts of the Oligocene sediments in the NAFB, northern Austria is documented, 2) the dinocyst assemblages from the NAFB (NP23–NP24) and comparison with the coeval assemblages of adjacent areas is discussed, 3) the paleoecological significance of the dinocyst assemblages is elucidated.

Geological setting and stratigraphy

The NAFB, a foreland basin, extends along the northern margin of the Alps from Geneva to Vienna (Wagner 1998). It has developed since Eocene times in response to loading of the southern margin of the European plate after the Alpine orogeny (e.g. Genser et al. 2007). In the Austrian sector, the basin is delineated to the North by the outcropping basement of the Bohemian Massif, whereas the southern part of the basin is overthrusted by the Alpine nappes.

In the NAFB, sedimentation took place from Late Eocene through Miocene time (Fig. 1). The oldest sediments marking the initial evolution of the NAFB are of Late Eocene age (Priabonian), shallow marine sediments onlapped northward onto fluvial and limnic deposits (Wagner 1980). During the Rupelian, the NAFB deepened and widened abruptly (Sissingh 1997). Major changes in sedimentary facies and marine fauna are associated with the initial separation of the Paratethys and the Mediterranean Sea (Bruch 1998). Detailed descriptions of the geodynamics, sedimentology, tectonics and facies development in the investigated part of the NAFB are given by Wagner (1996, 1998).

The Early Oligocene succession in the NAFB (Austria) comprises from bottom to top: Schöneck Formation, Dynow Formation, Eggerding Formation and Zupfing Formation (Wagner 1998). The depositional environment and hydrocarbon source potential of the Schöneck, Dynow, Eggerding and lower part of Zupfing Formations were discussed in detail by Schulz et al. (2002, 2004, 2005), Sachsenhofer & Schulz (2006) and Sachsenhofer et al. (2010).

The Schöneck Formation (formerly "Lattorf Fischschiefer"; nannoplankton Zones NP19–20 to the lower part of NP23), is a typically 10–20 m thick succession consisting of organic-

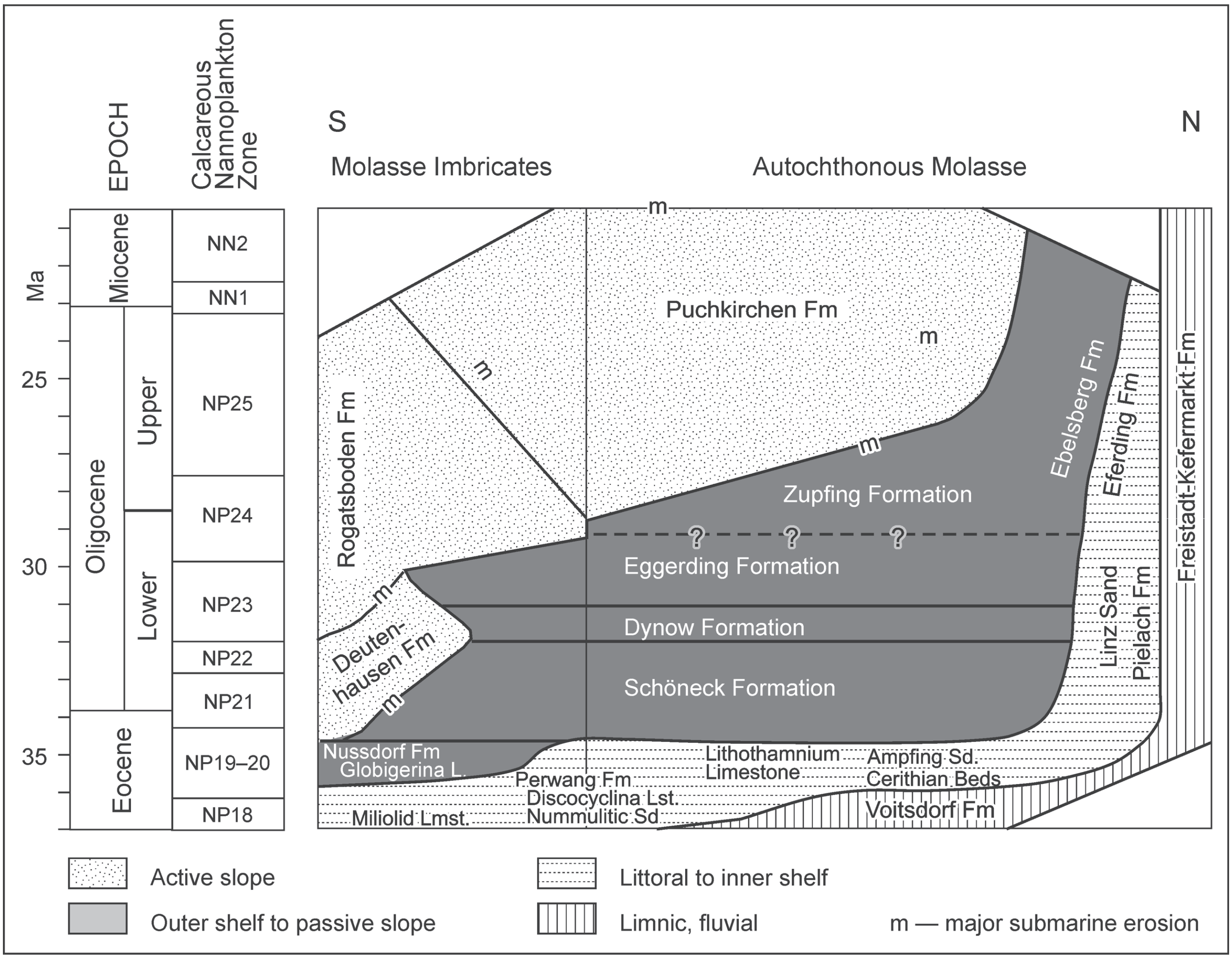


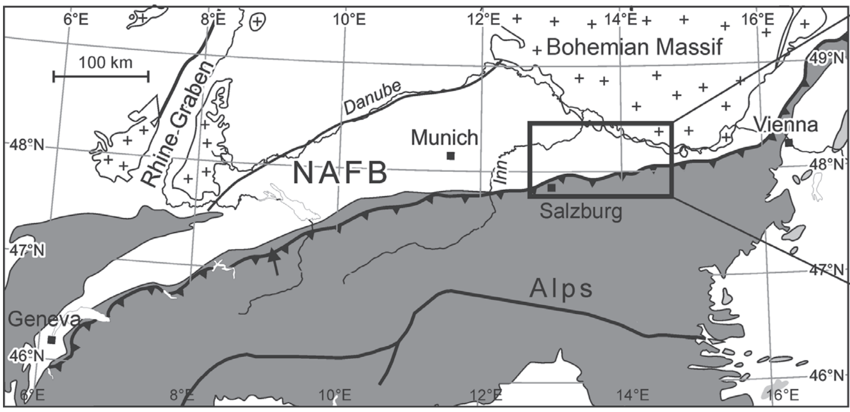
Fig. 1. Stratigraphic chart of the Paleogene rocks in the NAFB, Austria (adopted from Wagner 1998; Time Scale of Berggren et al. 1995).

rich marls and shales. Water depth during the deposition of the Schöneck Formation increased from 400 m to 600 m (Dohmann 1991).

The Dynow Formation (formerly "Heller Mergelkalk"; nannoplankton Zone NP23), is about 5–15 m thick. It is composed of light-coloured marlstones rich in coccolithophorides (Wagner 1998). The contact between the Dynow and Eggerding formations in the area of study is erosive (Sachsenhofer et al. 2010).

The Eggerding Formation (formerly "Banded Marl"; NP23–NP24 nannoplankton Zones) is about 40 m thick but it is represented in the Eggerding borehole by a 14 m thick section (Sachsenhofer et al. 2010). The lateral thickness variation is documented by Sachsenhofer & Schulz (2006) and attributed to sub-aquatic erosion during the late stages of the deposition of the Eggerding Formation. It is composed mainly of dark grey laminated pelites with abundant sand layers representing a near-shore environment.

The Zupfing Formation (formerly "Rupelian Marl"), up to 450 m thick, consists mainly of dark grey hemipelagites and distal turbidites. It is intercalated with slumps, slides and turbidites derived from the northern slope. Limestone layers



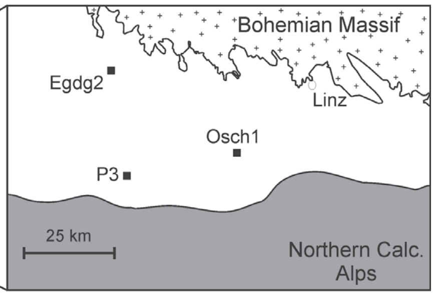


Fig. 2. Sketch of the North Alpine Foreland Basin. The rectangle marks the area of study. Egdg2 — Eggerding 2, P3 — Puchkirchen 3, and Osch1 — Oberschauersherg 1.

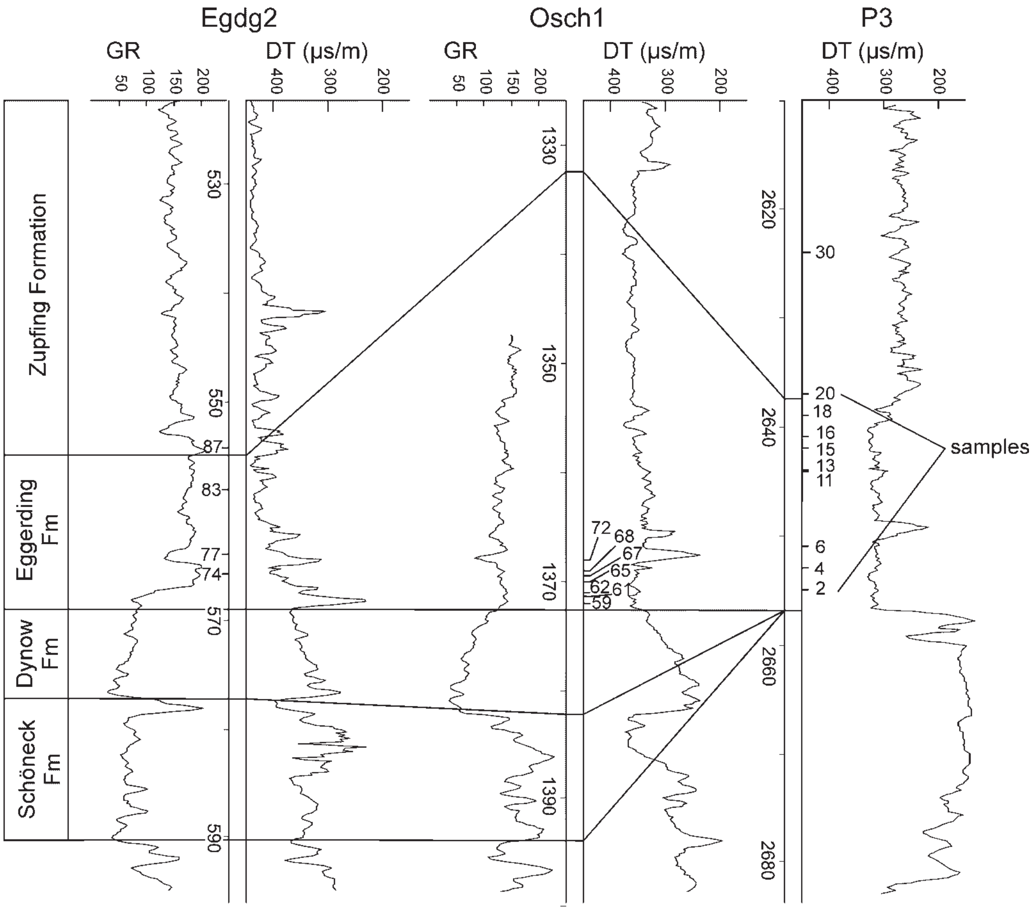


Fig. 3. Logs of the investigated wells showing sample positions. Gamma Ray (GR) and Sonic log (DT) (adopted from Sachsenhofer et al. 2010).

with nannofossils (nannoblooms) occur in the lower part of the section. This formation is present only in the subsurface (Wanger 1998).

Material

Twenty-one core samples representing the studied intervals from the Eggerding Formation and the lowermost part of the Zupfing Formation, obtained from the Puchkirchen 3 (P3), Eggerding 2 (Egdg2) and Oberschauersberg 1 (Osch1) wells are used in this study (Fig. 2).

In the Eggerding 2 well, the Eggerding Formation is about 14 m thick. The lowermost 1.45 m is composed of sandstone with clasts up to 10 cm of the Dynow Formation, near its base. Pelitic rocks intercalating with sandstone beds overlay the basal sandstone. Remains of land plants and fish occur frequently (Sachsenhofer et al. 2010). Four samples have been palynologically investigated from this well; their position is shown in Fig. 3.

In the Oberschauersberg Well, the Eggerding Formation is about 40 m thick and seven samples have been selected for this study from the lowermost part. The lower part of the Eggerding Formation contains dark grey laminated shaly marlstone with white bands of nannoplankton. Fish remains occur in many samples. The position of the samples is shown in Fig. 3.

The Eggerding Formation in the Puchkirchen 3 well is about 20 m thick and composed mainly of dark grey, partly laminated, marly shales. Fish scales are frequently observed. The lowermost 30 cm contain clasts of "Lithothamnium Limestone", up to 7 cm in diameter. Ten samples from this well were investigated for dinocysts and their position is shown in Fig. 3.

Methods

20 g of each sample have been prepared following the standard procedures (e.g. Green 2001). The carbonates and silicates were dissolved with HCl and HF, respectively. The residue was treated for 1 minute in an ultrasonic bath to disaggregate the AOM clusters before sieving at 20 μm. A slight oxidation with diluted HNO_3 was applied to all samples. The residue is stained with Safranin "O". Two to four slides from each sample were prepared using glycerine jelly as mounting medium, and sealed by nailvarnish. The slides were studied both qualitatively and quantitatively. The quantitative analysis included a counting of the first 300—or more—dinocysts (determinable and undeterminable) whenever possible. Freshwater algae and acritarchs recorded during this process were also counted. Examination and light-photomicrographs were taken using a Carl-Zeiss (Axioplan 2) light microscope. For photographed taxa England Finder coordinates are provided.

Mounts for SEM studies were made by air drying water suspended residues (re-sieved at 30 μm) on glass coverslips that were mounted on an aluminium stub with a thin-doubled side sticky tape. Stubs were coated with Platinum. Observa-

Series	**Oligocene**			
Stage	**Rupelian**			
Calcareous nannoplankton	**NP23**			
Formation	**Eggerding Fm.**			
Samples	Egdg2-74	Egdg2-77	Egdg2-83	Egdg2-87
Apteodinium spp.	1	11	6	74
Caligodinium amiculum	1	1		
Chiropteridium galea	1	20		
Cordosphaeridium cantharellus	31	9	25	3
Distatodinium ellipticum	1	5		
Glaphyrocysta-Areoligera complex	4	63	40	162
Lejeunecysta spp.	4	3	1	1
Round brown cysts	15	2	3	6
Selenopemphix nephroides	1	1		
Thalassiphora spp.	1	2		7
Wetzeliella spp.	1		31	33
Chiropteridium lobospinosum		9		
Cleistosphaeridium spp.		14	5	
Cyclonephelium spp.		5	5	
Dapsilidinium spp.		6	7	
Deflandrea phosphoritica complex		15	33	14
Enneadocysta pectiniformis		4		
Hemiplacophora semilunifera		5		6
Heteraulacacysta porosa		4		
Homotryblium spp.		59	5	6
Hystrichokolpoma cinctum		1	1	
Impagidinium spp.		3	1	2
Lejeunecysta fallax		6	1	
Leptodinium italicum		1	1	2
Membranophoridium aspinatum		12		
Operculodinium spp.		15	23	1
Pentadinium goniferum		3		
Polysphaeridium zoharyi		4	2	1
Rhombodinium draco		3	5	3
Selenopemphix armata		4		
Spiniferites pseudofurcatus		1	4	
Spiniferites/Achomosphaera spp.		67	87	3
Wetzeliella articulata		48		8
Wetzeliella asymmetrica		5	2	
Wetzeliella gochtii		5		6
Achilleodinium biformoides		1		1
Hystrichokolpoma rigaudiae		2	1	3
Lingulodinium machaerophorum		2	1	
Batiacasphaera spp.		2		
Cordosphaeridium spp.		1	2	2
Cribroperidinium giuseppei		2		
Cribroperidinium tenuitabulatum		1		
Deflandrea spp.		1	4	1
Distatodinium spp.		5		
Enneadocysta deconinckii		2		
Enneadocysta harrisii		2		
Hystrichostrogylon membraniphorum		1		
Lingulodinium spp.		4		
Palaeocystodinium powellii		2		
Reticulatosphaera actinocoronata		2		
Adnatosphaeridium spp.			2	
Heteraulacacysta campanula			1	
Hystrichokolpoma truncata			1	
Leptodinium membranigerum				1
Indet. dinoflagellate cysts	2	5	7	10
Total dinocysts counted	63	451	307	356
Other palynolorphs				
Tasmanites spp.		2		
Foraminiferal test linings		2		
Cyclopsiella spp.		2	2	
Pediastrum spp.		150		

Fig. 4. Stratigraphic distributions of dinoflagellate cysts and other palynomorphs, Egdg2 well, NAFB, Austria.

Series	**Oligocene**						
Stage	**Rupelian**						
Calcareous nannoplankton	**NP23**						
Formation	**Eggerding Fm.**						
Samples	Osch1-59	Osch1-61	Osch1-62	Osch1-65	Osch1-67	Osch1-68	Osch1-72
Chiropteridium lobospinosum	1			9	1		1
Diphyes colligerum	1				3		5
Adnatosphaeridium multispinosum	1				3		
Batiacasphaera sphaerica	1				3		
Hystrichokolpoma cinctum	1						1
Cordosphaeridium cantharellus	2	4		11	73	19	87
Achilleodinium biformoides	2			1	2		2
Membranophoridium aspinatum	2			4	2	2	
Apteodinium spp.	2			11	7		8
Homotryblium spp.	3		1	2	5		2
Polysphaeridium zoharyi	3			2	2	1	1
Batiacasphaera micropapillata	3				1		
Hystrichokolpoma rigaudiae	4				1		2
Hystrichokolpoma truncata	4				6		1
Stoveracysta spp.	5		4		11		2
Hystrichokolpoma sp. cf. *H. salacia*	6						
Cyclonephelium spp.	8	1		1			2
Impagidinium spp.	8				4		
Batiacasphaera explanata	34	6	16	3	49	8	3
Hystrichokolpoma spp.	71	1		1	13		39
Glaphyrocysta/Areoligera complex	153	4	3	43	51		15
Selenopemphix nephroides		1	1	4	2		
Round brown cysts		1			1		
Deflandrea phosphoritica			1	17	17		4
Fibrocysta axialis			2		3		
Hemiplacophora semilunifera			2		6		1
Lingulodinium pycnospinosum				1	1	2	
Distatodinium ellipticum				1	1		
Distatodinium paradoxum				1	1		
Spiniferites pseudofurcatus				1	2		1
Cribroperidinium giuseppei				1	2		10
Cribroperidinium tenuitabulatum				1			4
Apteodinium spiridoides				1			
Lingulodinium machaerophorum				2	3	2	
Wetzeliella articulata				2	9		3
Enneadocysta pectiniformis				3	4		3
Wetzeliella gochtii				3	5		2
Spiniferites/Achomosphaera spp.				5	3		5
Pentadinium laticinctum/taeniagerum				9	4		1
Chiropteridium galea				13	3		1
Wetzeliella spp.				14	9		6
Lejeunecysta spp.				26			
Reticulatosphaera actinocoronata					1		1
Adnatosphaeridium robustum					1		
Cordosphaeridium inodes					1		
Deflandrea scabrata					1		
Distatodinium craterum					1		
Enneadocysta arcuata					1		
Enneadocysta harrisii					1		
Leptodinium membranigerum					1		
Thalassiphora spp.					2		1
Operculodinium spp.					2		2
Wetzeliella asymmetrica					2		2
Apteodinium maculatum subsp. *grande*					2		
Cleistosphaeridium spp.					3		4
Enneadocysta deconinckii					3		
Leptodinium italicum					7		
Distatodinium scariosum					2		
Charlesdowniea columna							1
Dapsilidinium spp.							1
Heteraulacacysta porosa							1
Palaeocystodinium golzowense							1
Rhombodinium draco							1
Rhombodinium pustulosum							2
Tuberculodinium vancampoae							2
Hystrichokolpoma sp. A							35
Indet. dinoflagellate cysts	8				14		14

Series	**Oligocene**						
Stage	**Rupelian**						
Calcareous nannoplankton	**NP23**						
Formation	**Eggerding Fm.**						
Samples	Osch1-59	Osch1-61	Osch1-62	Osch1-65	Osch1-67	Osch1-68	Osch1-72
Total dinocyst counting	323	18	30	193	358	34	281
Other palynomorphs							
Tasmanites spp.				3	1		6
Foraminiferal test lining						1	
Cyclopsiella spp.	2						
Pediastrum spp.	30						4

◄ ▲

Fig. 5. Stratigraphic distributions of dinoflagellate cysts and other palynomorphs, Osch1 well, NAFB, Austria.

tions and photographs were made using DSM 982 Gemini SEM, operating at a working voltage of 10 kv. All slides, SEM stubs and residues are housed in the paleontological collection of the Institute of Earth Sciences, Graz University, Austria. The identified dinocyst nomenclature generally follows Dinoflaj 2 available at "http://dinoflaj.smu.ca/wiki/Main_Page" (Fensome et al. 2008), where the taxonomic references are cited. Images of the most important dinocysts are illustrated in Figs. 10–17. A list of the recorded species is given in Appendix 1.

Results

All samples contain fair to well-preserved palynological assemblages consisting of dinocysts, acritarchs, bisaccate pollen, other pollen grains, spores, microforaminiferal test linings and freshwater algae. This study concentrates mostly on dinocysts as they provide more information to assess the age of the investigated samples. Although bisaccate pollen is abundant and spores occur sporadically, no attempt has been made to identify their taxonomy. In addition, most samples are dominated by organic debris which is mostly composed of amorphous organic matter (AOM) and terrestrial elements (opaque and translucent phytoclasts). More details about palynofacies and its implications is published in Sachsenhofer et al. (2010). The results of the studied wells are reported in occurrence-charts (Figs. 4–6) with numbers representing specimens counted for each taxon/category. Several age-diagnostic dinocyst species are encountered and their biostratigraphic significance is discussed accordingly. The results of each well will be presented in the following sections.

Eggerding 2 (Egdg2) well

Out of four samples analysed, three are productive and yielded well preserved dinocyst assemblages. The qualitative and quantitative composition of the recorded assemblages is presented in Figures 4 and 7. The assemblage shows a relatively high diversity, as 71 taxa were identified. The *Glaphyrocysta/Areoligera* complex (including *Glaphyrocysta*, *Areoligera* and *Cyclonephelium* taxa) represents the dominant group (6.0–45.0 %). *Cordosphaeridium* spp. (1.4–9.0 %);

Epoch	Oligocene									
Stage	**Rupelian**								**Chattian**	
Calcareous nannoplanktons	**NP23**								**NP24**	
Formation	**Eggerding Fm.**								**Zupfing Fm.**	
Samples	P3-2	P3-4	P3-6	P3-11	P3-13	P3-15	P3-16	P3-18	P3-20	P3-30
Rhombodinium draco	72	3	1				1	2		23
Deflandrea phosphoritica	63	104	27	106	1	11	36	25	6	2
Homotryblium spp.	37		9	5	3	1	60	24	5	7
Spiniferites/Achomosphaera spp.	28	9	30	3	4	6	19	38	62	38
Glaphyrocysta/Areoligera complex	15	57	3	35	70	11	13	96	9	11
Cordosphaeridium cantharellus	14	12	14	15	3	4	28	15	4	11
Operculodinium spp.	12	1	5				1		3	3
Cleistosphaeridium spp.	8	1	4	2	1	6	9	10	14	9
Chiropteridium galea	8			1		3	12	6	1	
Wetzeliella articulata	6	11	6	11	1	4	9	5		
Cordosphaeridium minimum	6			1						
Wetzeliella asymmetrica	5	6	1	9	2	6	2	3		
Hystrichokolpoma truncata	4					1				
Wetzeliella spp.	6	29	27	65	17	3	30	11	13	
Wetzeliella gochtii	3	4	3	5	3	5	4	4		
Lingulodinium machaerophorum	3		1			2		3	3	16
Thalassiphora spp.	3					2	7	3		3
Lejeunecysta spp.	2	12	73	5	108	26	1	5	5	5
Membranophoridium aspinatum	2	11	1	7	2	1	13	11		7
Distatodinium craterum	2	1				2				
Adnatosphaeridium multispinosum	2		3					23	7	
Apteodinium spp.	2					28	5	4	1	
Adnatosphaeridium robustum	2								2	
Cordosphaeridium fibrospinosum	2									
Lejeunecysta fallax	1	8	5	3	18	6	2	2	1	
Distatodinium ellipticum	1	6	1					4	2	23
Polysphaeridium zoharyi	1	3	3	1		4	1	5	12	5
Round brown cysts	1	1	4		24	1	3		6	14
Distatodinium paradoxum	1	1	3	1	1					35
Batiacasphaera explanata	1		26	1	3					
Lejeunecysta communis	1		1	2	6	3	6		2	3
Enneadocysta pectiniformis	1		1				1	1		1
Leptodinium italicum	1		3	5			5			
Melitasphaeridium spp.	1		1							
Hystrichokolpoma spp.	1			2		1			6	
Heteraulacacysta porosa	1					1			1	5
Spinidinium spp.	1					1				
Operculodinium microtriainum	1						1	2		
Pentadinium goniferum	1						1		1	
Deflandrea leptodermata	1									
Dracodinium sp.	1									
Wetzeliella cf. *W. ovalis*	1									
Lejeunecysta diversiforma		1	6		11	1			1	
Araneosphaera stephanophorum		2	6	2	4					
Impletosphaeridium insolitum		9								
Pentadinium laticinctum/taeniagerum			1				3	8	1	
Operculodinium centrocarpum			1					1	1	
Selenopemphix armata			1						2	
Caligodinium pychnum			1							1
Selenopemphix brevispinosa			2		3					3
Reticulatosphaera actinocoronata			3						3	12
Selenopemphix nephroides			8	1	5	2			2	13
Chiropteridium lobospinosum				1		1		3		3
Heteraulacacysta campanula				1						1
Cyclonephelium paucispinum				1						
Deflandrea scabrata				1						
Achilleodinium biformoides					1		1	2		
Impagidinium spp.					1			13		
Deflandrea heterophlycta						1	1			
Caligodinium amiculum						1				2
Batiacasphaera sphaerica						1				
Cordosphaeridium gracile						1				
Lejeunecysta hyalina						2			1	1

Fig. 6. Stratigraphic distributions of dinoflagellate cysts and orther palynomorphs, P3 well, NAFB, Austria. *Continued on the next page.*

Spiniferites/Achomosphaera complex (including all identified and unidentified taxa of both genera) (1.0–28.0 %), *Apteodinium* (1.5–20.8 %), *Wetzeliella* (10.7–13.4%) and *Deflandrea* (3.0–10.5 %) are fairly represented. Low percentages of *Operculodinium* (0.2–7.5 %), *Cleistosphaeridium* (1.6–3.0 %), *Dapsilidinium* (1.3–2.3 %), *Hystrichokolpoma* (0.6–1.0 %), *Rhombodinium draco* (0.0–1.6 %), *Homotryblium* (1.6–13.0 %) and *Chiropteridium* (1.5–6.4 %), have also been recorded. Many other taxa occur sporadically (Fig. 7).

Oberschauersberg 1 (Osch1) well

Seven samples were investigated and all of them yielded dinocysts. 67 taxa were identified and are quantitatively represented in Fig. 5. The recorded assemblages are similar to those from the Eggerding 2 well. Some taxa are abundantly recorded in all samples, including *Deflandrea* (1.4–8.8 %), *Wetzeliella* (4.6–10.0 %), *Hystrichokolpoma* (0.5–28.0 %), *Glaphyrocysta/Areoligera* complex (5.0–47.0 %) and *Cordosphaeridium* (0.6–31.0 %). Some other taxa are persistently encountered, for example, *Apteodinium* (0.6–3.0 %), *Homotryblium* (0.7–1.4 %), *Pentadinium* (0.0–4.6 %), *Polysphaeridium* (0.3–1.0 %), *Spiniferites/Achomosphaera* complex (1.4–3.0 %) and *Stoveracysta* (0.7–3.0 %) (Fig. 8).

Puchkirchen 3 (P3) well

84 taxa were identified from this well, reflecting the highest diversity of dinocysts among the studied wells (Fig. 6). *Apteodinium* (0–17.0 %), *Cordosphaeridium* (1–10.0 %), *Deflandrea* (0.3–35.1 %), *Glaphyrocysta/Areoligera* complex (1.0–26.0 %), *Spiniferites/Achomosphaera* (1.3–31.0 %) and *Homotryblium* (1.0–20.0 %) and *Wetzeliella* (0.0–30.0 %) are the most abundant taxa. Figure 9 shows many more taxa but with low percentages, for example, *Cleistosphaeridium*, *Hystrichokolpoma*, *Impagidinium*, *Lingulodinium*, *Operculodinium*, *Polysphaeridium*, and *Thalassiphora*.

Epoch	Oligocene									
Stage	Rupelian								Chattian	
Calcareous nannoplanktons	NP23								NP24	
Formation	Eggerding Fm.								Zupfing Fm.	
Samples	P3-2	P3-4	P3-6	P3-11	P3-13	P3-15	P3-16	P3-18	P3-20	P3-30
Hemiplacophora semilunifera						3				
Hystrichokolpoma cinctum							1	3	1	
Hystrichokolpoma rigaudiae							1	5	2	1
Apteodinium emslandense							1			
Gerlachindinium aechmoorum							1			
Wetzeliella spinosa							1			
Spiniferites pseudofurcatus							3		5	2
Dapsilidinium spp.							4	1	6	2
Apteodinium spiridoides							5		3	
Heterosphaeridium heteracanthum								1	1	
Cribroperidinium giuseppei								1		2
Diphyes colligerum								1		
Deflandrea pachyceros								2		
Pentadinium lophophorum								2		
Palaeocystodinium powellii									1	4
Distatodinium biffii									1	1
Hystrichostrogylon membraniphorum									2	
Nematosphaeropsis labyrinthus									2	
Hystrichokolpoma pusillum										1
Lejeunecysta sp. 3 of Biffi & Grignani, 1983										2
Rottnestia borussica										2
Indet. dinoflagellate cysts	29	8	17	10	8	6	14	22	14	22
Total dinocysts counted	354	300	302	302	300	158	306	367	215	296
Other palynomorphs										
Palaeostomocystis sp.										1
Fungal spore	1	1	2			2				5
Tasmanites spp.	2	75		47	17	5	11		2	
Foraminiferal test linning					1	3			8	
Cyclopsiella spp.	1					1			2	
Pterospermella spp.							6			

Fig. 6. *Continued.*

Wetzeliella gochtii is one of the stratigraphic markers for the Oligocene and its first occurrence is commonly used to recognize the Lower Oligocene (Eldrett et al. 2004 and references therein). Brinkhuis (1992) detected its lowest occurrence in northern Italy within the *Reticulatosphaera actinocoronata* Interval Zone calibrated with the middle part of NP21 Zone (Lower Rupelian). Powell (1992) indicated that the first occurrence datum of *W. gochtii* marks the base of dinocyst biozone Wgo (Lower Rupelian), which corresponds to the base of calcareous nannofossil Biozone NP22. The same event was documented from the southern North Sea Basin (van Simaeys et al. 2005). The lowest occurrence of *W. gochtii* delineates the Eocene/Oligocene boundary in Leluchów, Carpathians Mountains, Poland (Gedl 2004a). Torricelli & Biffi (2001) stated that the *W. gochtii* occurred in the Lower Oligocene Numidian Flysch in Oued El Guastal and El Gassaa sections in Tunisia. Globally, the range of *W. gochtii* has been documented from the Early Rupelian to mid-Chattian — lower part of subzone C of Zone D15 (Gradstein et al. 2004). In summary, according to Pross et al. (2010) *W. gochtii* has a stratigraphic range from 33.1 Ma to 26.4 Ma (NP22–NP25; Rupelian–Lower Chattian).

Stoveracysta is encountered only in the Osch1 well (*S. conerae*, *S. ornata*, *Stoveracysta* sp. 1 of Brinkhuis & Biffi 1993, *Stoveracysta* sp. 2 of Brinkhuis & Biffi 1993). Pross et al. (2010) recorded the two informally described *Stoveracysta* species of Brinkhuis & Biffi (1993) from the Contessa Barbetti Road section and correlate their last occurrences to Chron C12n, i.e. 30.8 Ma (NP23; mid-Rupelian).

Distatodinium biffii is found in two samples (P3-20 and P3-30) from the Zupfing Formation. This could imply a ?Late Rupelian-Early Chattian age of the Zupfing Formation (e.g. van Simaeys et al. 2005). Avoiding the taxonomic problem, due to the few recorded specimens, Pross et al. (2010) calibrate the first occurrences of *D. biffii* (s.l. and s.s.) from Umbria-Marche section in Central Italy to NP24.

Only two specimens of *Tuberculodinium vancampoae* have been recorded from the uppermost studied part of the Osch1 well (sample 72). According to Brinkhuis & Biffi (1993) the first appearance of *T. vancampoae* can be used as a confirmatory event for the detection of the *Reticulatosphaera actinocoronata* Interval Zone of Early Oligocene age at Monte Cagnero (central Italy). The same event has been used by Torricelli & Biffi (2001) to recognize the Rupelian age of the Tabarka section of the Numidian Succession, Tunisia.

Age assignments

Age based on dinocysts

However, earlier studies indicated that the Eggerding Formation and the lower part of the Zupfing Formation were deposited during NP23–NP24 (e.g. Sachsenhofer et al. 2010) the recorded dinocyst assemblages represent additional data to the biostratigraphy of the NAFB (Figs. 4–6). In general, the samples examined are dominated by dinocysts and other palynomorphs (Figs. 10–17). Qualitatively, there is no considerable change in the dinocysts throughout the investigated samples from the three wells. In order to comment on the age of the studied samples based on dinocysts, a correlation with chronostratigraphically calibrated dinocyst events in the adjacent areas will be discussed herein.

Together with a persistent population of long-ranging cosmopolitan representatives of *Glaphyrocysta*, *Areoligera*, *Spiniferites*, *Operculodinium*, *Hystrichokolpoma* and *Cleistosphaeridium* some other taxa are particularly useful for age assignment. The age of some marker taxa are discussed in the following paragraphs taking into consideration their first and last occurrences in relation to the nannoplankton stratigraphy. Most of these marker taxa are recorded from the three wells, thus the suggested age could be applied for the studied intervals.

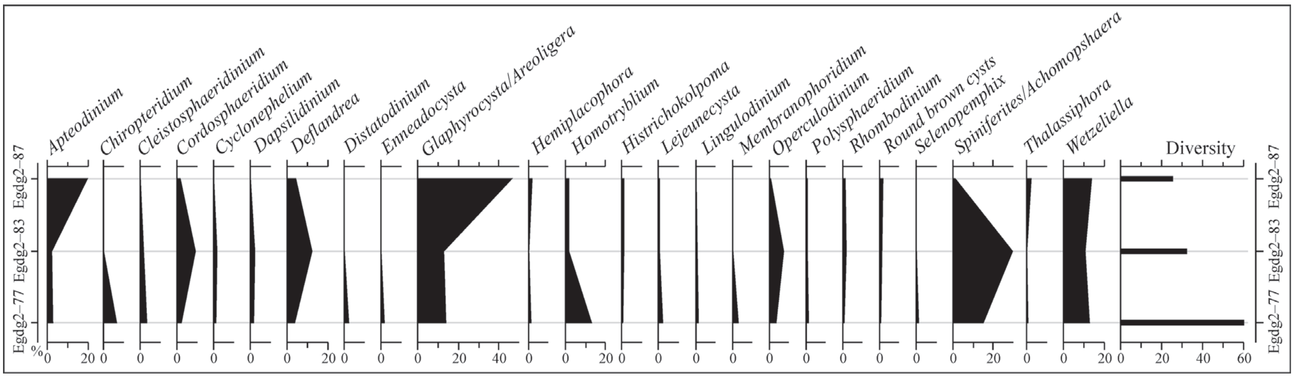


Fig. 7. Abundance of dinoflagellate cysts in Egdg2 well. "Sample 74 is excluded due to low recovery".

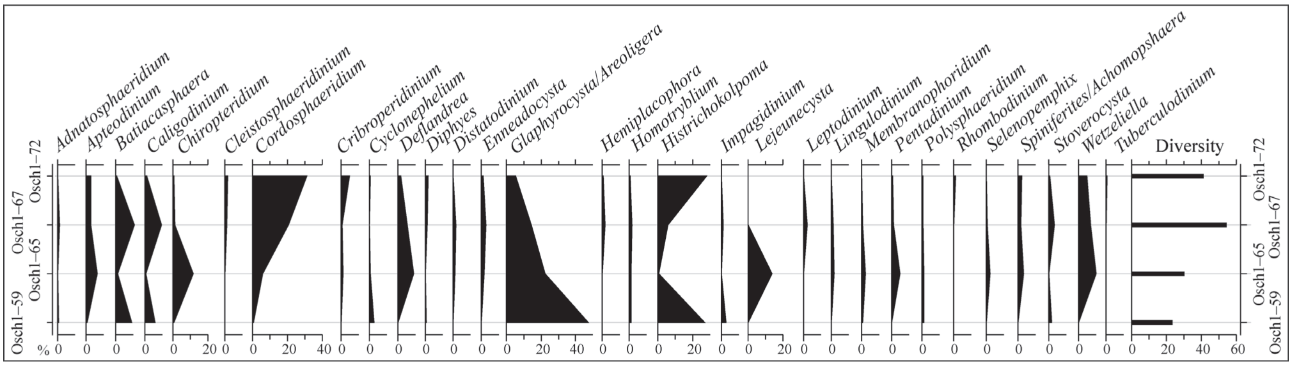


Fig. 8. Abundance of dinoflagellate cysts in Osch1 well. "Samples 61, 62 and 68 are excluded due to low recovery".

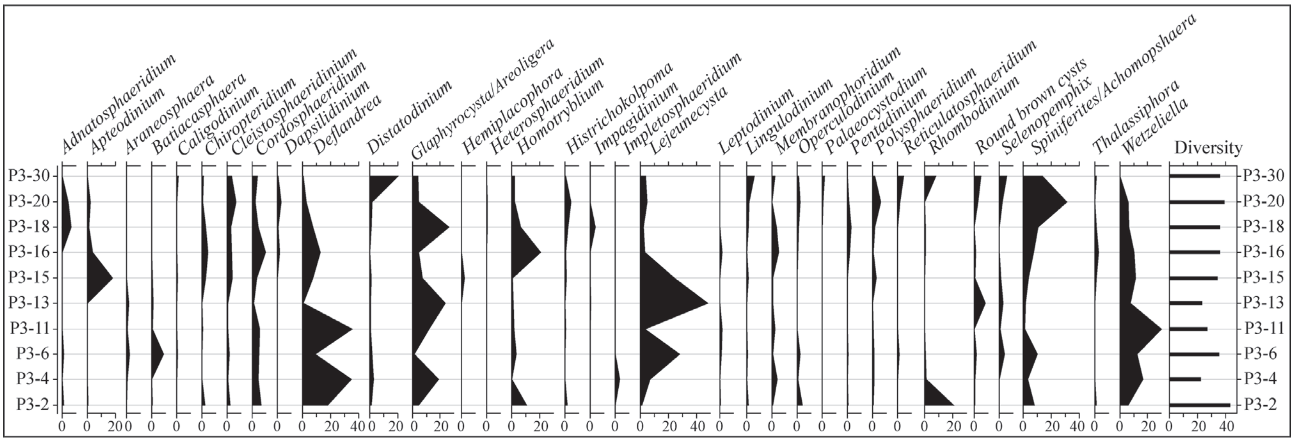


Fig. 9. Abundance of dinoflagellate cysts in P3 well.

Rhombodinium draco is well represented in Well P3 (two peaks at P3-2 and P3-30) and sporadically recorded from the Egdg2 and Osch1 wells. According to Köthe (1990), van Simaeys et al. (2004, 2005) and Schiøler et al. (2007) the Rupelian-Chattian boundary may be approximated by the last occurrences of *R. draco*, middle part of NP24. Hence, the investigated interval in the three wells is not younger than Rupelian.

According to Stover & Hardenbol (1994) *Fibrocysta axialis* has its last occurrence in the Rupelian. It is recorded within the Lower Oligocene dinocyst Interval Zone (Cin) of central Italy (Brinkhuis & Biffi 1993). Three records are confirmed from western Germany (Bodenheim, Bosenheim and Frei-Laubersheim) and dated as Rupelian (dinocyst Zone D17na) (Köthe & Piesker 2007).

The last appearance of *Enneadocysta pectiniformis* is dated as Late Rupelian for the Northern Hemisphere mid-latitudes (Williams et al. 2004). Schiøler et al. (2007) delineated its last occurrence in the uppermost Rupelian (lowermost part of planktonic foraminiferal Zone NSP9c) from the Danish North Sea. Van Simaeys et al. (2004) in their studies of the Rupelian-Chattian transition in the type region (boreholes in Belgium and Germany) indicate that the last occurrence of

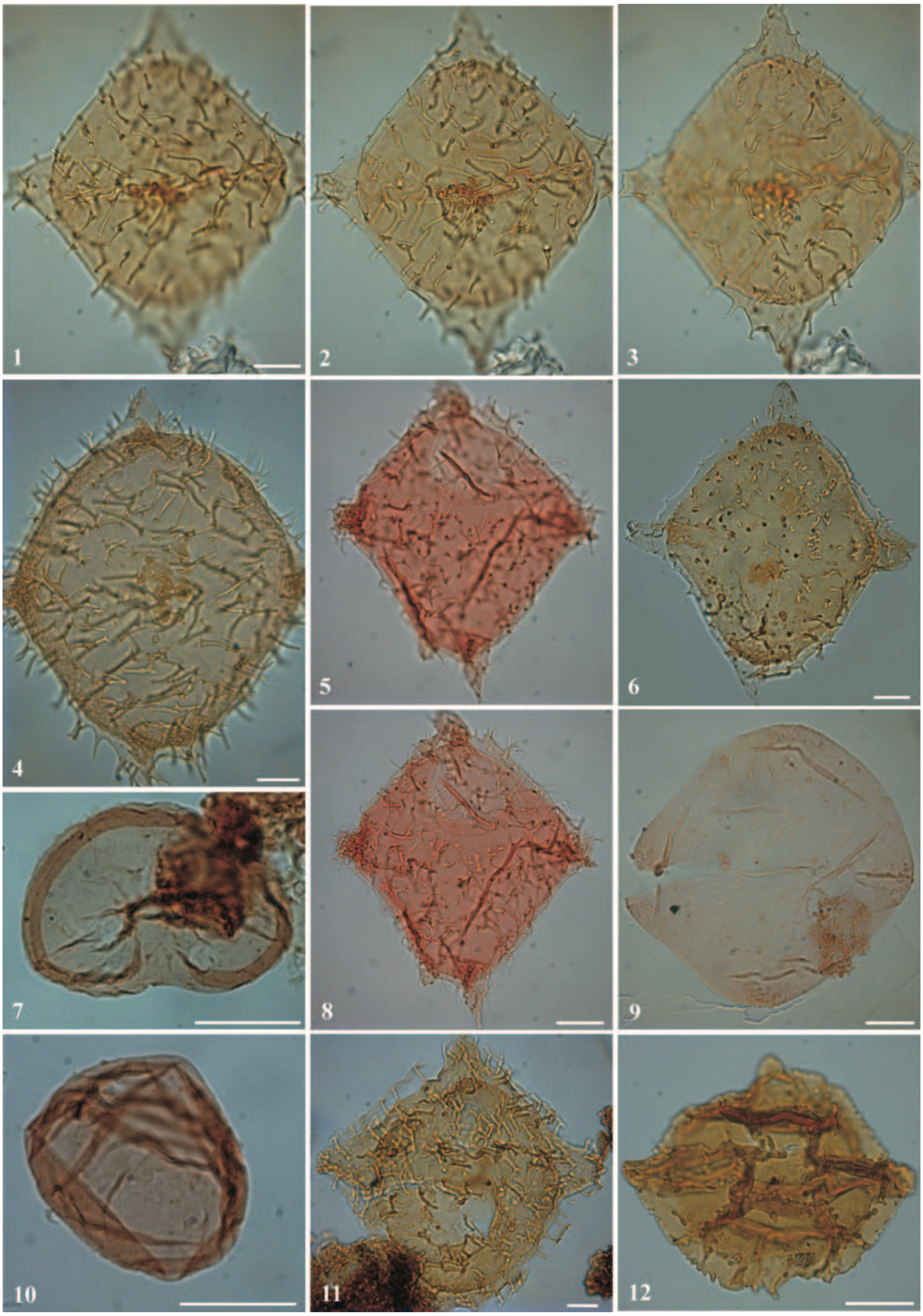


Fig. 10. Dinocysts from the NAFB, Austria. All images are in bright field illumination. The sample number, slide number & England Finder (EF) reference are given for each specimen. Scale bars indicate 20 μm (applicable also for Figs. 11, 12, 13): **1–3** — *Wetzeliella symmetrica* Weiler, 1956; sample Egdg2-77, slide X, EF B62-1. **4** — *Wetzeliella gochtii* Costa & Downie, 1976; sample Egdg2-87, slide X. **5, 8** — *Wetzeliella articulata* Eisenack, 1938; successive foci, sample Egdg2-83, slide X, EF X60-1. **6** — *Wetzeliella spinula* (Bujak) Lentin & Vozzhennikova, 1989; sample Egdg2-87, slide X, EF X26. **7** — *Selenopemphix nephroides* Benedek, 1972; emend. Benedek & Sarjeant, 1981; sample Egdg2-77, slide E, EF W56. **9** — Internal body of ?*Rhombodinium draco* Gocht, 1955; sample Egdg2-77, slide C, EF Q36-3. **10** — Round brown cyst; sample Egdg2-77, slide Z; **11** — *Charlesdowniea columna* (Michoux) Lentin & Vozzhennikova, 1990; sample Osch1-72, slide E, EF R32. **12** — *Wetzeliella echinosuturata* Wilson, 1967; sample Osch1-67, slide X, EF U66.

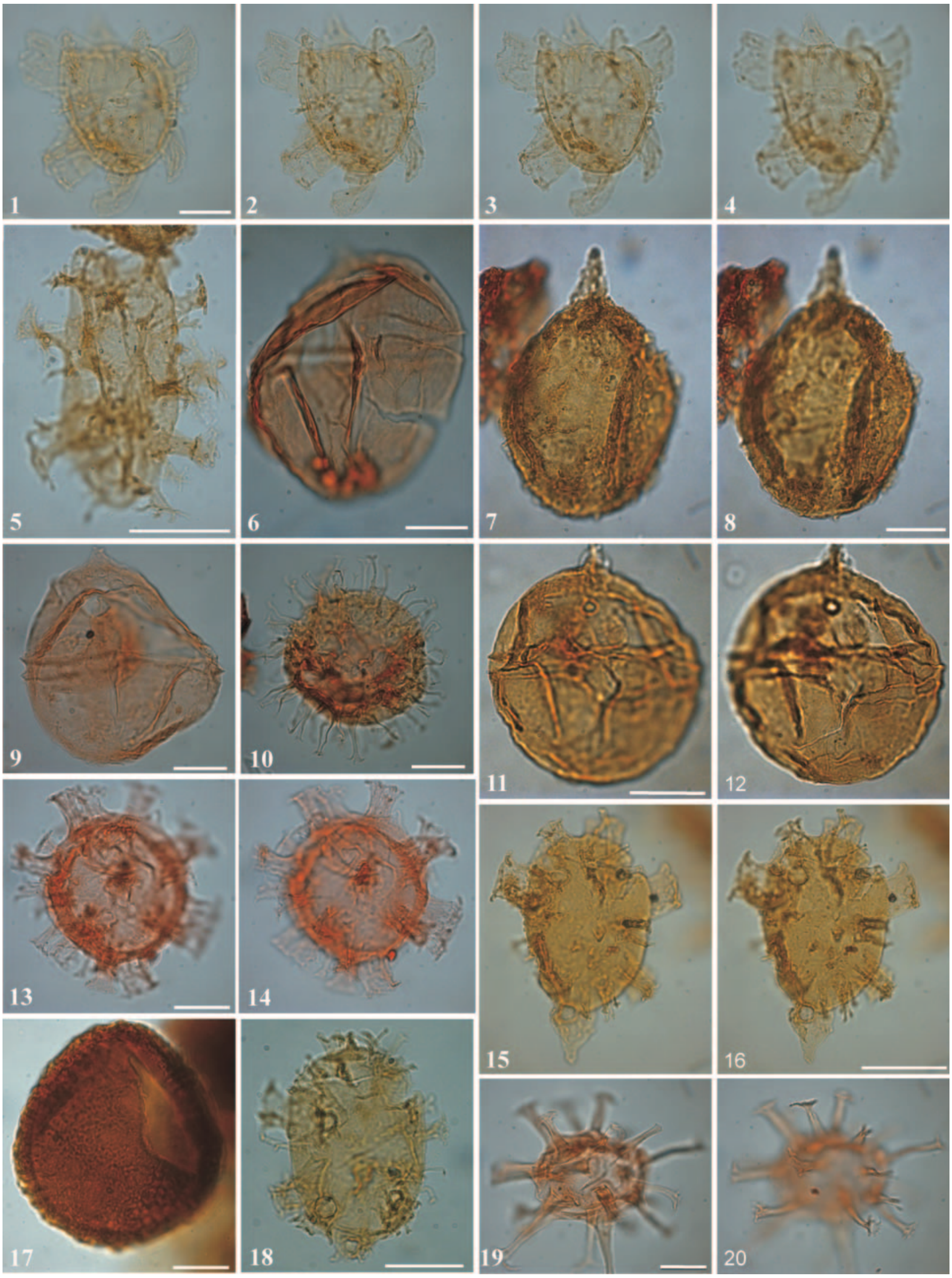


Fig. 11. 1–4 — *Hystrichokolpoma* sp.; sample Osch1-67, slide C, EF O71-4. **5** — *Distatodinium scariosum* Liengjarern et al., 1980; sample Osch1-6, slide R, EF N73-3. **6** — *Cribroperidinium tenuitabulatum* (Gerlach) Helenes, 1984; sample Egdg2-77, slide X, EF K45-2. **7, 8** — *Apteodinium emslandense* (Gerlach) Stover & Evitt, 1978; emend. Benedek & Sarjeant, 1981; sample P3-16, slide X, EF M37. **9** — *Apteodinium spiridoides* Benedek, 1972; sample Egdg2-77, slide X, EF W55-4. **10** — *Cleistosphaeridium ancyreum* (Cookson & Eisenack) Eaton et al., 2001; sample Egdg2-77, slide X, EF G76-2. **11, 12** — *Cribroperidinium giuseppei* (Morgenroth) Helenes, 1984; sample Osch1-72, slide X, EF D53. **13, 14** — *Cordosphaeridium fibrospinosum* Davey & Williams, 1966; sample Egdg2-83, slide X, EF A53-3. **15, 16** — *Hystrichokolpoma* sp.; sample Osch1-59, slide E, EF J32. **17** — *Tectatodinium pellitum* Wall, 1967 emend. Head, 1994; sample Osch1-67, slide R, EF 35-2. **18** — *Hystrichokolpoma* sp.; sample Osch1-72, slide E, EF J32. **19, 20** — *Homotryblium tenuispinosum* Davey & Williams, 1966; sample Egdg2-83, slide X, EF 38-1.

E. pectiniformis defines the top of the dinocyst Zone D14na of Rupelian age contemporaneously with the first occurrences of *Saturnodinium pansum*, not recorded in the current study. Pross et al. (2010), in their integrated study of the dinocyst events for the Oligocene in the Western Tethys, recorded discrepancies for the last occurrences of *E. pectiniformis*, but all are within the Upper Rupelian–Lower Chattian (NP24).

The first occurrence of *Chiropteridium lobospinosum* has been recorded from many sites in northern and western Germany corresponding to Lower Rupelian, dinocyst D13na of Köthe & Piesker (2007). According to Pross et al. (2010) the first common occurrence of *Chiropteridium* spp. (*C. lobospinosum*) has Rupelian age (NP24).

The co-occurrences of *Wetzeliella symmetrica*, *Wetzeliella articulata* and *Areoligera semicirculata* in such assemblages indicate a Rupelian age (see Wilpshaar et al. 1996; Torricelli & Biffi 2001; Williams et al. 2004; Köthe & Piesker 2007; Pross et al. 2010).

On the basis of the co-occurrence of the discussed taxa, a Rupelian age is suggested for the studied intervals of the Eggerding Formation from the three wells. This is consistent with the age suggested by Sachsenhofer et al. (2010) based on calcareous nannoplankton (NP23) and partly dinocysts.

Regional and global comparison

A comparison with the published data suggests that dinocysts are potentially meaningful for recognizing and correlating the Oligocene of the NAFB, northern Austria with other regions. Several biostratigraphical studies based on dinocysts have been carried out Oligocene sediments in different regions of the Mediterranean, Western Europe and Carpathians (e.g. Biffi & Manum 1988; Gedl 1995, 2000a,b; van Simaeys et al. 2004, 2005). Some dinocyst biozonations of the Oligocene have been proposed by Brinkhuis & Biffi (1993), Brinkhuis (1994), Gedl (2000a,b), Bati & Sancay (2007), and Pross et al. (2010), such schemes are considered in the current study.

Gedl (2000a,b) proposed four Interval Biozones for the Oligocene of the Podhale, Inner Carpathians, Poland, namely *C. lobospinosum*, *Wetzeliella* sp. A, *D. biffii* and *Glaphyrocysta* sp. A. Based on the recorded dinocysts from the NAFB and Podhale, the investigated interval is identical to *C. lobospinosum*, *Wetzeliella* sp. A, biozones. The *C. lobospinosum* Interval Zone is defined from the first occurrence (FO) of *C. lobospinosum* to the FO of *Wetzeliella* sp. A. Many associated taxa of this zone have been recorded in the current study, including *H. cinctum*, *W. symmetrica*, *W. gochtii*, *R. draco*, *D. phosphoritica*, *Caligodinium amiculum*, *R. actinocoronata* and many other taxa. The *Wetzeliella* sp. A Interval Zone is defined from its FO to the FO of *D. biffii*. *Wetzeliella* sp. A is not defined clearly in the current study, so it may be included in *Wetzeliella* spp. But this zone is characterized by the first occurrence of *Caligodinium* sp. A which is identified herein as Gen. et sp. indet. (Fig. 13.5–7; Fig. 16.10,11). This species is only recorded from the Osch1 well which could mean that the Osch1 samples are younger than those from the other wells.

In general, the recorded assemblage from the three wells is equivalent to the *Reticulatosphaera actinocoronata* (Rac) Interval Zone, Lower Oligocene of Brinkhuis & Biffi (1993) from central Italy. This zone is defined from the last occurrence of *Areosphaeridium diktyoplokum*, which is not recorded in the current samples, to the last occurrence of *Glaphyrocysta semitecta*. Many taxa, namely, *Distatodinium tenerum*, *W. gochtii*, *T. vancampoae* and *C. amiculum* have their FOs in this zone and are recorded in the NAFB assemblage.

Bati & Sancay (2007) define the *Wetzeliella gochtii* Interval Zone (P-Rp2; Rupelian, uppermost NP23 to lowermost NP24) from Ebulbahar and Keleresdere sections, Eastern Anatolia, Turkey. They used the lower occurrence of *W. gochtii* to define their zone which include many other taxa, also recorded in the current study, for example, *T. vancampoae*, *D. biffii*, *M. aspinatum* and *D. phosphoritica*.

Pross et al. (2010) in their refinement of the magnetostratigraphic calibration of dinocyst events for the Oligocene of Western Tethys (several sections in central Italy) discussed the first and last occurrences of many Oligocene taxa. Many of their taxa have been recorded in the studied samples including *W. gochtii*, *G. semitecta*, *H. pusillum*, *Stoveracysta* spp., *D. biffii*, *E. pectiniformis*, *W. symmetrica* and *C. lobospinosum*. A combination of the first and last occurrences of these taxa ranging from NP22 to NP24 supports the suggested age of the studied interval from the NAFB, Austria.

Depositional environment

Over the last decades, many studies indicate that the distribution of dinocysts in Recent sediments is controlled by the interplay between position relative to shore, water temperature, salinity, depth, light, nutrients and productivity (e.g. Wall et al. 1977; Dale 1996; Marret & Zonneveld 2003). The (paleo)ecological preferences of some Oligocene taxa, grouped according to their morphological similarities, are discussed in detail in earlier studies (e.g. Brinkhuis 1994; Gedl 2005; Sluijs et al. 2005).

The Eggerding Formation is characterized by dark grey hemipelagites and distal turbidities. Such sediments are deposited in a near-shore marine environment, which could represent favourable marine conditions for many cyst-forming dinoflagellates. Many of the recorded taxa in the investigated samples have been found in a similar setting in the Upper Eocene–Lower Oligocene hemipelagites at Folusz, Polish Carpathians (Gedl 2005, for more details).

Although, there is no considerable qualitative change in the dinocyst assemblages throughout the three wells, there are notable quantitative changes for some taxa. In the following paragraphs the prevailing paleoenvironmental conditions during the deposition of the NAFB Oligocene sediments in each well are discussed based on the co-occurrence of the dinocysts.

Egdg2 well

The absolute dinocyst abundance of three samples from the Egdg2 well is illustrated in Fig. 7. A near-shore paleoenvironment during the deposition of this interval could be pre-

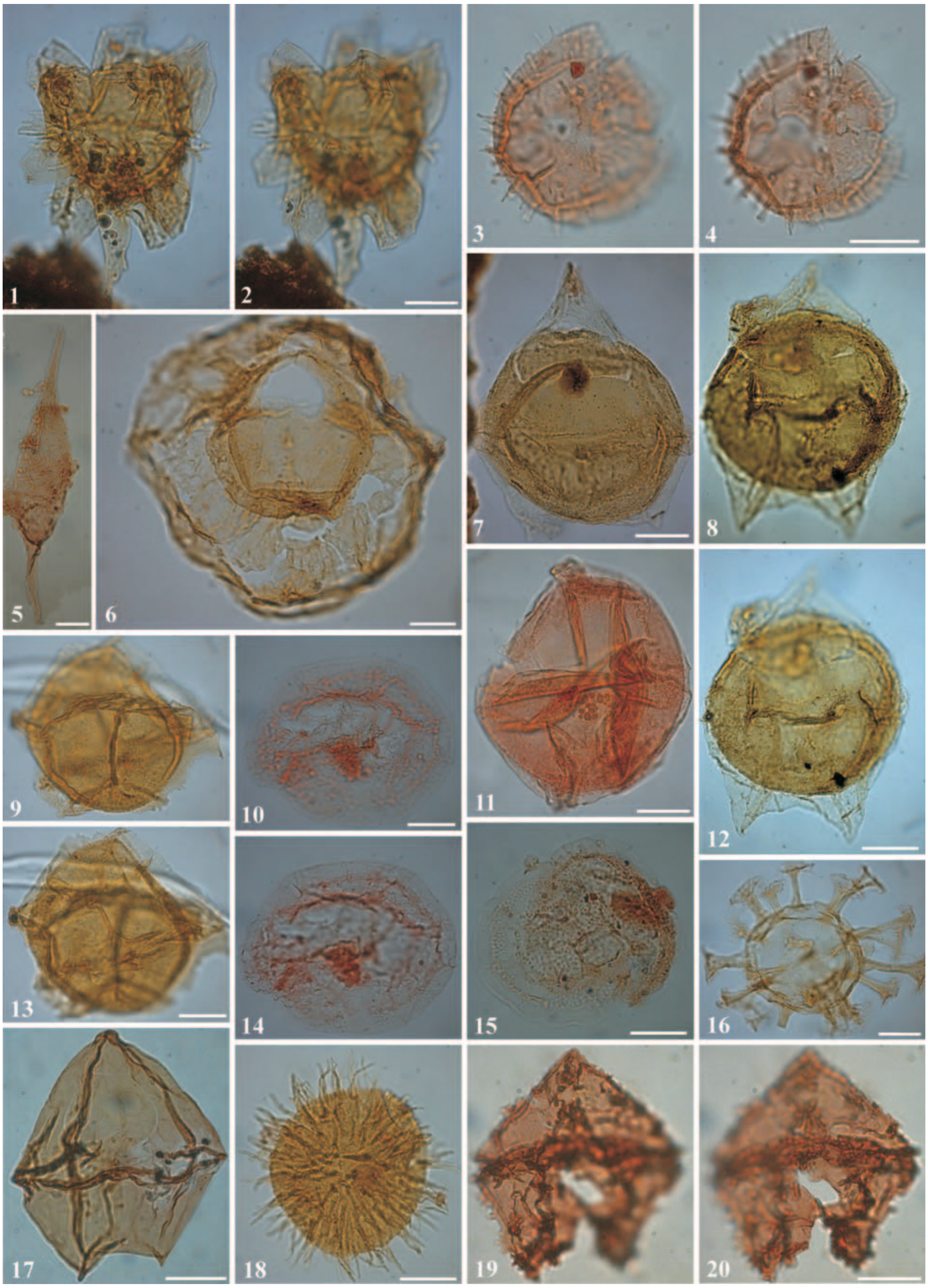


Fig. 12. 1, 2 — *Hystrichokolpoma cinctum* Klump, 1953: sample P3-18, slide X, EF N69. **3, 4** — *Operculodinium centrocarpum* (Deflandre & Cookson) Wall, 1967; sample Egdg2-77, slide Z, EF Y63. **5** — *Palaeocystodinium golzowense* Alberti, 1961; sample Egdg2-77, slide C, EF M52-4. **6** — *Thalassiphora patula* (Williams & Downie, 1966) Stover & Evitt, 1978; sample Osch1-67; slide X, EF T45. **7** — *Deflandrea phosphoritica* Eisenack, 1938; sample Osch1-67, slide X, EF D70. **8, 12** — *Deflandrea scabrata* Wilson, 1988; sample P3-11, slide A, EF 65-2. **9, 13** — *Pentadinium laticinctum* Gerlach, 1961; emend. Benedek et al., 1982; sample Osch1-67, slide X, EF F68. **10, 14** — *Heteraulacacysta campanula* Drugg & Loeblich, 1967; sample Egdg2-83, slide X, EF F73-1. **11** — *Deflandrea leptodermata* Cookson & Eisenack, 1965; sample Egdg2-83, slide X, EF X48. **15** — *Heteraulacacysta porosa* Bujak, 1980; sample Egdg2-77, slide C, EF C43-4. **16** — *Cordosphaeridium cantharellus* (Brosius) Gocht, 1969; sample Osch1-67, slide X, EF U65-4. **17** — *Lejeunecysta fallax* (Morgenroth) Artzner & Dörhöfer, 1978; emend. Biffi & Grignani, 1983; sample Egdg2-77, slide C, EF Y63. **18** — *Lingulodinium pycnospinosum* (Benedek) Stover & Evitt, 1978; emend. Benedek & Sarjeant, 1981; sample Osch1-67, slide X, EF W32. **19, 20** — *Gerlachidium aechmophorum* (Benedek, 1972) emend. Benedek & Sarjeant, 1981; sample P3-16, slide X, EF M40.

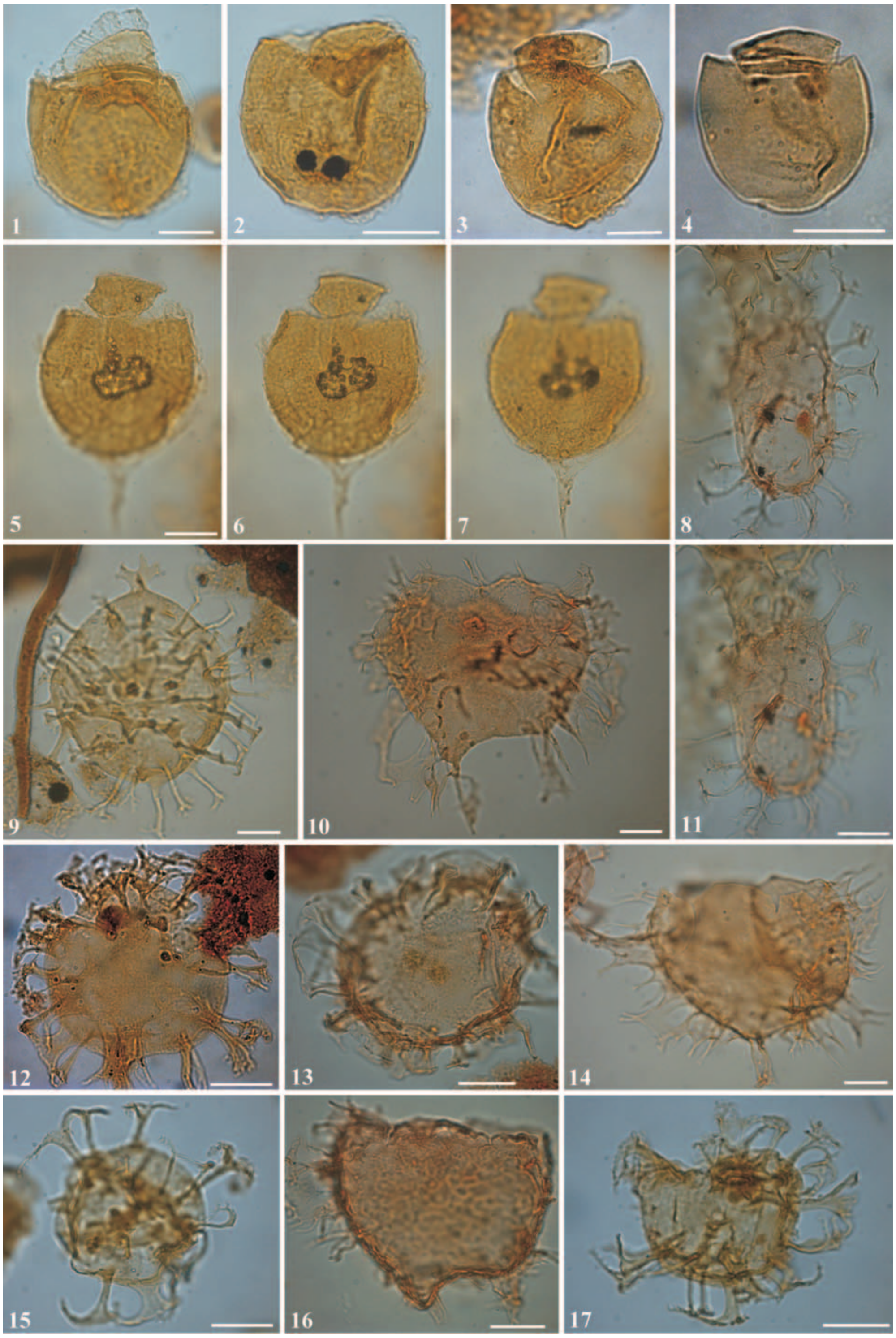


Fig. 13. **1** — *Stoveracysta* sp. 1 of Brinkhuis & Biffi, 1993; sample Osch1-67, slide XX, EF L53. **2** — *Stoveracysta* sp. 2 of Brinkhuis & Biffi, 1993; sample Osch1-67, slide XX, EF H49. **3** — *Batiacasphaera explanata* (Bujak) Islam, 1983; sample Osch1-68, slide X, EF C42. **4** — *Batiacasphaera explanata* (Bujak, in Bujak et al., 1980) Islam, 1983; sample Osch1-72, slide X, EF D39. **5–7** — Genus et species indet.; sample Osch1-59, slide XX, EF B40. **8, 11** — *Distatodinium ellipticum* (Cookson) Eaton, 1976; sample Egdg2-77, slide X, EF S64-1. **9** — *Fibrocysta axialis* (Eisenack) Stover & Evitt, 1978; sample Osch1-62, slide E, EF G40. **10** — *Chiropteridium lobospinosum* (Gocht) Gocht, 1960; sample Egdg2-77, slide X, EF S46-2. **12** — *Glaphyrocysta ordinata* (Williams & Downie) Stover & Evitt, 1978; sample Osch1-65, slide X, EF B37. **13** — *Glaphyrocysta retiintexta* (Cookson) Stover & Evitt, 1978; sample Egdg2-77, slide X, EF Y66-2. **14** — *Chiropteridium galea* (Maier) emend. Sarjeant, 1983; sample Egdg2-77, slide X, EF F72-2. **15** — *Enneadocysta pectiniformis* (Gerlach) emend. Stover & Williams, 1995; sample Osch1-67, slide X, EF B48. **16** — *Chiropteridium lobospinosum* (Gocht) Gocht, 1960; sample Egdg2-77, slide C, EF F30-2. **17** — *Enneadocysta pectiniformis* (Gerlach) emend. Stover & Williams, 1995; sample Osch1-67, slide X, EF S45.

dicted from the abundance of *Glaphyrocysta/Areoligera* spp. (Brinkhuis 1994). The Peridiniaceae taxa as *Wetzeliella* and *Deflandrea* show a considerable abundance. Their occurrence refers to rich-nutrient environments (Brinkhuis et al. 1992). *Spiniferites/Achomosphaera* spp. are regarded as representing a wide range of depositional settings (e.g. Dale 1996). Their high percentages are recorded when the heterotrophic taxa (especially, *Wetzeliella*) are at a minimum (sample Egdg2-83). This indicates oligotrophic surface water (Vink et al. 2000).

In sample Egdg2-77, *Homotryblium* shows a considerable abundance but it is depleted in the other samples (Fig. 7). *Homotryblium* is broadly considered to be characteristic of restricted conditions with abnormal salinity (Brinkhuis 1994). Pross & Schmiedl (2002) proposed temporary high-salinity conditions during the deposition of the Lower Oligocene sediments of the Mainz Embayment based on a dinocyst assemblage dominated by *Homotryblium tenuispinosum*. The same conclusion was suggested by Köthe (1990, 2009) where intervals of high *Homotryblium* abundances in the Oligocene of northwest and central Germany indicate high-salinity conditions. It is worthy noting that the acme of *Homotryblium* is associated with abundance of the brackish-water algae *Pediastrum* (Fig. 4) which implies that *Homotryblium* forming-cyst can tolerate a wide range of salinities (Sluijs et al. 2005). Thus, salinities are verified during the deposition of the lower part of the Eggerding Formation based on the variation of *Homotryblium* and $\delta^{18}O$ (Sachsenhofer et al. 2010). In addition, the occurrence of *Thalassiphora pelagica* is distinguished when *Homotryblium* is depleted. Pross & Schmiedl (2002) interpreted alternation of *Homotryblium* and *T. pelagica*, as an indication of alternations between high- and low-salinity conditions, respectively. Williams & Bujak (1977) have suggested that elevated abundances of *Homotryblium* spp. may be associated with warm climatic conditions. In addition, Sachsenhofer et al. (2010) concluded on the basis of palynofacies analysis that the Eggerding Formation was deposited in an anoxic environment. The occurrence of *Thalassiphora*, a genus found in oxygen-depleted environments (Pross 2001), confirms this hypothesis.

Osch1 well

Due to low recovery of dinocysts in the three samples of the Osch1 well, only the absolute abundance of four samples is presented in Figure 8. The low abundance of *Spiniferites/Achomosphaera* in this well is notable while the high abundance of *Hystrichokolpoma* spp. is recognizable. *Hystrichokolpoma* may occur in a wide range of marine environments and has a global distribution (Brinkhuis 1994). Van Mourik et al. (2001) and Rasmussen et al. (2003) considered *Hystrichokolpoma* as an open marine indicator. There is also an inverse correlation between *Cordosphaeridium*, mostly *C. cantharellus*, and *Glaphyrocysta/Areoligera* spp. The latter is accepted as representing a shallow-water environment while *Cordosphaeridium* is associated with open marine water masses (Brinkhuis 1994; Rasmussen et al. 2003). In sample Osch1-65, there is an acme of heterotrophic taxa (*Lejeunecysta*, *Deflandrea* and *Wetzeliella*) which indicate elevated nutrient-rich environment (Pross & Schmiedl 2002).

It is widely accepted that the Early Oligocene is a period of cold climatic conditions. This is mostly reflected by the abundance of the cold water dinocyst *Svalbardella cooksoniae*. Śliwińska & Heilmann-Clausen (2011) revealed that *S. cooksoniae* is present in the narrow interval of Chron 12r, close to the NP21/NP22 boundary in many high and mid latitude Northern Hemisphere sections, ranging from the Greenland Sea in the North to Italy in the South. *S. cooksoniae* is not recorded in the studied samples which mean that the studied interval may be younger than this event. On the other hand, *Glaphyrocysta/Areoligera* spp. dominated all studied samples. According to Köthe (1990) its abundance indicates warm climatic conditions. The elevated abundances of *Homotryblium* spp. as in Egdg2-77 and P3-16 may be associated with warm conditions (Brinkhuis 1994). *Diphyes colligerum* is sporadically recorded from the studied samples, its occurrence suggests warm-water conditions (van Mourik et al. 2001; Gedl 2004b). However, the warm climatic conditions still doubtful based on the encountered dinocyst assemblage.

It is worth to mention that the occurrences of *Impagidinium* (0.7 to 3.5 %) and outer neritic to oceanic indicators, and *Stoveracysta* (e.g. Wall et al. 1977; Clowes 1985; Brinkhuis & Biffi 1993) are approximately contemporaneous (Fig. 8), which could indicate a short invasion of open marine water.

P3 well

The absolute abundance of dinocysts in P3 well is presented in Fig. 9. At a glance, *Deflandrea* spp. and other (proto)peridinioid (heterotrophic) as Wetzelielloideae (e.g. *Wetzeliella*) and Congruentidioideae (e.g. *Lejeunecysta*) are abundant in the lower and middle part of the investigated interval. Their co-occurrence indicates nutrient-rich near-shore environments (e.g. Pross & Schmiedl 2002) but some studies attribute the abundance of *Deflandrea* to nutrient availability rather than distance to the shoreline (e.g. Brinkhuis 1994; Gedl 2005). In the upper part, the autotrophic taxa such as *Spiniferites/Achomosphaera*, *Homotryblium* and *Distatodinium* show relatively high abundances. Thus the abundance of the autotrophic taxa in samples P3-15 to P3-30 could indicate depletion in the nutrient supply. Additionally, the co-occurrence of *Homotryblium* spp. and *Polysphaeridium zoharyi*, a near-shore and high salinity indicator, indicates a change, probably, to a more saline environment (Brinkhuis 1994; Gedl 1995; Dybkjær 2004; Sluijs et al. 2005). The occurrence of the inner to outer neritic genus *Adnatosphaeridium* spp. matches *Spiniferites/Achomosphaera* in the upper part of this well (Fig. 9) (Brinkhuis & Biffi 1993).

Additional evidence of the near-shore environments are the abundance of *Glaphyrocysta-Areoligera* complex (e.g. *Areoligera*, *Cyclonephelium*, *Glaphyrocysta*) (e.g. Brinkhuis & Zachariasse 1988) and the considerable occurrence of *Membranophoridium aspinatum* (Gedl 2005). Normal marine shallow water could be indicated by the presence of *Impletosphaeridium* in the lower part of the well (Islam 1984) (Fig. 9). This conclusion is also supported by the rare occurrence of the open marine genus *Impagidinium* and *Leptodinium*.

Summarily, the studied interval of the P3 well was deposited, in general, under a shallow-water environment which is more nutrient-rich in the lower part (samples 2 to 16) than the upper part.

Conclusions

The following conclusions are drawn from the data discussed about the Eggerding Formation of the North Alpine Foreland Basin (NAFB) in Austria:

1. 138 species belonging to 53 genera of dinocysts have been identified and documented from the Lower Oligocene of the NAFB, Austria (Appendix 1). Such high diversity of dinocysts encourages further studies of the Oligocene sediments in the NAFB which could enhance the biostratigraphic resolution and paleoenvironmental interpretation as well.
2. Many Oligocene marker dinocysts are recorded, but the occurrence of *Chiropteridium* spp. (*C. lobospinosum*), *Fibrocysta axialis*, *Tuberculodinium vancampoae* and *Wetzeliella gochtii* indicate a Rupelian age of the studied interval of the Eggerding Formation. The occurrence of *Distatodinium biffii* in the Zupfing Formation, probably indicates the Lower Chattian.
3. A marine inner-neritic setting could be suggested on the basis of the encountered dinocysts. The dominance of AOM, phytoclasts reflect the influence of the terrestrial freshwater discharge on the area of deposition.
4. A doubtful warm climatic conditions is suggested.
5. The variable occurrences of *Homotryblium*, *P. zoharyi* and pediastrum suggest changes in sea surface salinities during the deposition on the studied interval.
6. The co-occurrence (proto)peridinioid (heterotrophic) taxa indicates nutrient-rich surface water during the deposition of the Lower Oligocene in the NAFB.

Taxonomic notes

The species presented herein are listed in Appendix (1) and some of them including marker taxa are illustrated in Figs. 10–17. Remarks or comments are given for some taxa and a brief description is provided for dinocysts that are presented in open or informal nomenclature. Taxa are presented alphabetically following Fensome et al. (1993).

Division: **Dinoflagellata** (Bütschli 1885) Fensome et al., 1993
Class: **Dinophyceae** Pascher, 1914
Subclass: **Peridiniphycidae** Fensome et al., 1993
Order: **Gonyaulacales** Taylor, 1980
Genus: ***Batiacasphaera*** Drugg, 1970

Batiacasphaera explanata (Bujak in Bujak et al., 1980) Islam, 1983
Fig. 13.3,4; Fig. 17.2,3

Chytroeisphaeridia explanata Bujak et al., 1980, pl. 13, figs. 13–14
Batiacasphaera explanata (Bujak in Bujak et al. 1980) Islam, 1983, p. 235
Batiacasphaera? sp. 1 Schiøler, 2005, Pl. 7, fig. 12

Remarks: Bujak in Bujak et al. (1980) described *Batiacasphaera* (*Chytroeisphaeridia*) *explanata* from the Eocene of Southern England. In his original description he attributed a smooth to chagrinate autocyst with spherical to ovoidal shape and apical archaeopyle to this new species. Recently, Schiøler (2005: Pl. 7, fig. 12) attributed a similar morphotype from the base of the Oligocene of North Sea but a little bit longer than broader to *Batiacasphaera*? sp. 1. It may be possible that the current material and that of Schiøler are conspecific with Bujak's, if the length/width ratio is not an important feature (Schiøler, personal communications). Thus, all similar morphotypes recorded from the studied samples are attributed to *B. explanata*.

Genus: *Hystrichokolpoma* Klump, 1953 emend. Foucher, 2004

Type species: *Hystrichokolpoma cinctum* Klumpp, 1953.

Hystrichokolpoma sp. cf. *H. salacium* Eaton, 1976
Fig. 14.3

Hystrichokolpoma salacia Eaton, 1976, p. 271–272, pl. 11, figs. 1–3, text-figs.16A–B

Remarks: The recorded specimens are questionably attributed to *H. salacium* because the SEM investigation shows processes with thicker striations. Some processes include small or weakly developed tubuli.

Hystrichokolpoma spp.
Fig. 11.1–4,15,16,18; Fig. 14.6–8

Remarks: A group of different morphotypes attributed to *Hystrichokolpoma* based on the presence of two types of processes (large and cylindrical in the post and pre-paracingular area and small in the paracingular and parasulcal areas).

Genus et sp. indet.
Fig. 13.5-7; Fig. 16.10,11

Caligodinium? sp. A, Gedl 2000, p. 231, Fig. 11h, n, o, q, r

Remarks: A holocavate cyst, proximochorate, subspherical to ovoidal in shape, autophragm granular and ornamented by penitabular rods of equal height supporting an ectophragm across the intratabular area. Apical (rarely seen) and antapical horns are prolonged from the ectophragm. Sutural ridges probably delineating a gonyaulacacean tabulation. The archeopyle is apical and operculum is free.

Comparison: Genus et sp. indet. and *Gardodinium* Alberti 1961; emend. Harding 1996 are similar in having a thin ectophragm, but the former differs in lacking the apical boss in the endocyst and the rods supporting ectophragm are penitabular rather than covering the intratabular areas. It differs from *Stoveracysta* by having an ectophragm rather than an autophragm cyst (Clowes 1985). It differs from *Alisocysta*, *Schematophora* and *Eisenackia* in the intratabular areas covered by ectophragm. The attribution of similar morphotypes from the Oligocene sediment of Podhale as *Caligodinium* sp. A (Gedl 2000) is rejected due to the holocavate nature.

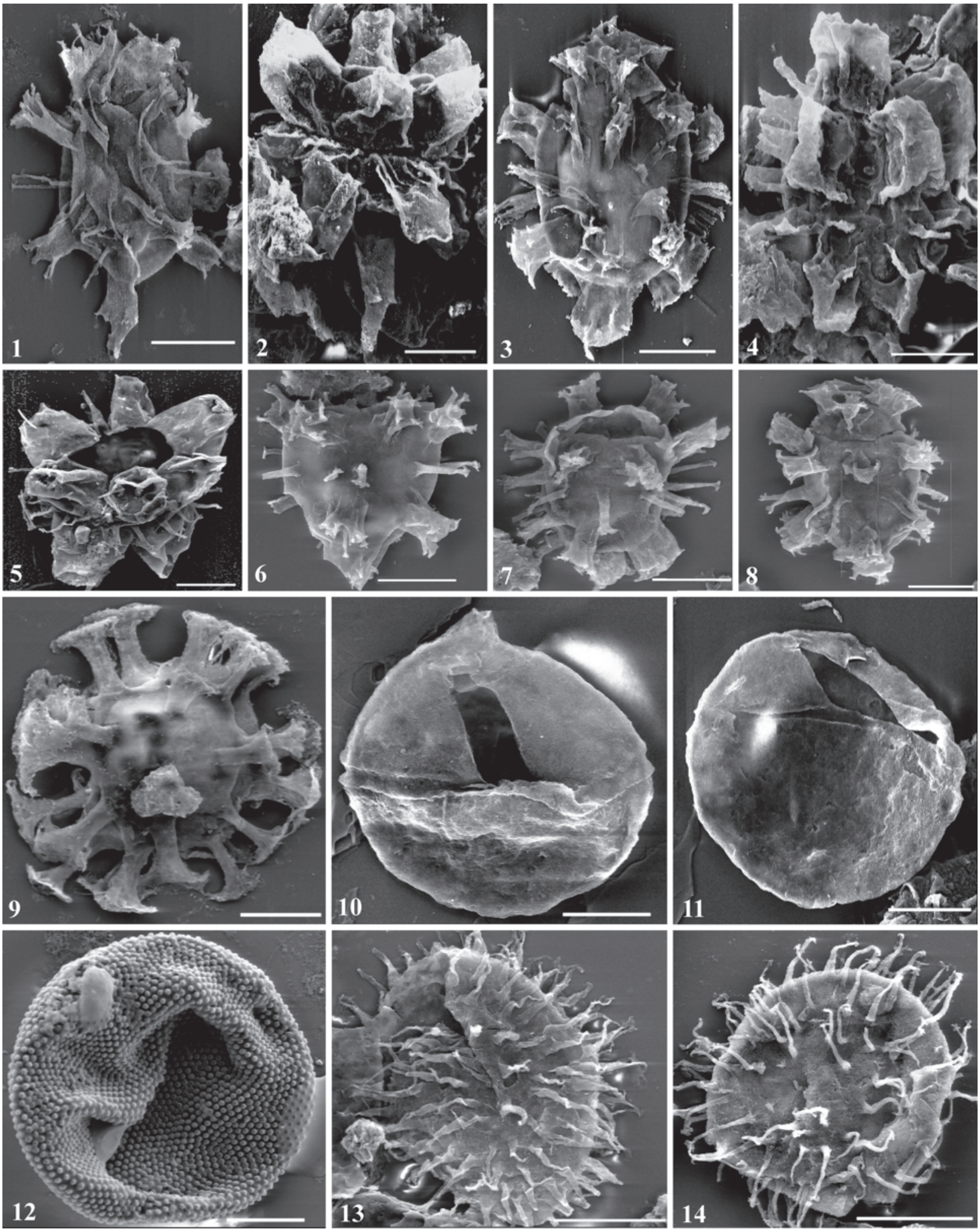


Fig. 14. Dinocysts from the NAFB, Austria. All are scanning electron micrographs. The sample number is given for each specimen. Scale bars indicate 20 μm (applicable also for Figs. 15, 16, 17): **1** — *Hystrichokolpoma rigaudiae* Deflandre & Cookson, 1955; sample Egdg2-87. **2** — *Hystrichokolpoma cinctum* Klumpp, 1953: sample P3-20. **3** — *Hystrichokolpoma* sp.; sample Osch1-67. **4** — *Achilleodinium biformoides* (Eisenack) Eaton, 1976; P3-18. **5** — *Hystrichokolpoma truncata* Biffi & Manum, 1988; sample P3-2. **6, 8** — *Hystrichokolpoma* sp.; sample Osch1-59. **7** — *Hystrichokolpoma* cf. *H. salacium* Eaton, 1976; sample Osch1-59. **9** — *Cordosphaeridium cantharellus* (Brosius) Gocht, 1969; sample Osch1-67. **10** — *Apteodinium australiense* (Deflandre & Cookson) Williams, 1978; sample Egdg2-77. **11** — *Apteodinium* sp., sample Egdg2-77. **12** — *Tasmanites* sp.; sample Egdg2-67. **13** — *Lingulodinium machaerophorum* (Deflandre & Cookson, 1955) Wall, 1967; sample P3-18. **14** — *Operculodinium centrocarpum* (Deflandre & Cookson) Wall, 1967; sample P3-18.

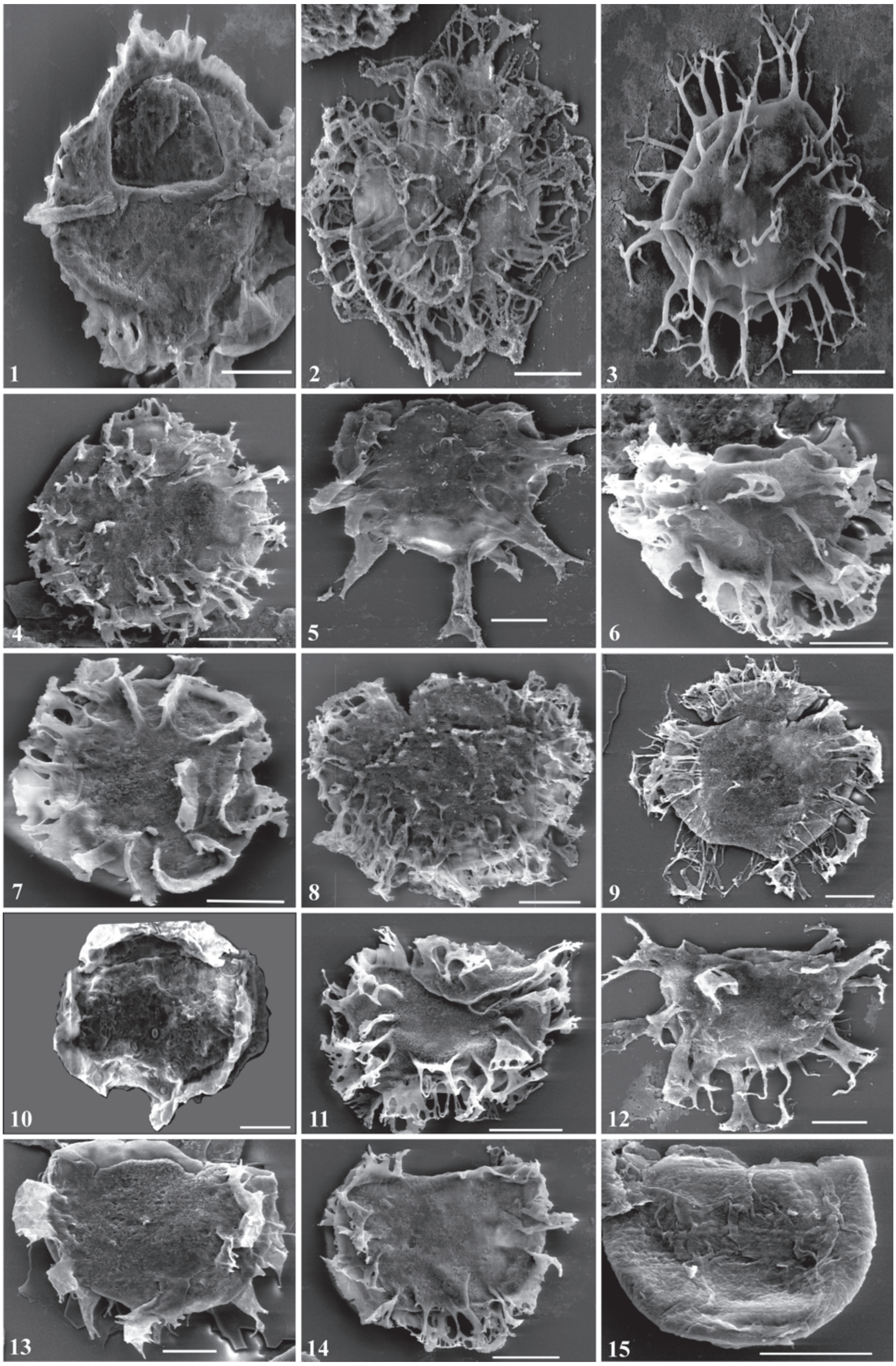


Fig. 15. **1** — *Thalassiphora patula* (Williams & Downie) Stover & Evitt, 1978; sample Egdg2-87. **2** — *Adnatosphaeridium robustum* (Morgenroth) De Coninck, 1975; sample Osch1-67. **3** — *Achomosphaera ramulifera* (Deflandre) Evitt, 1963; sample P3-2. **4** — *Cyclonephelium paucispinum* Davey, 1969; sample Osch1-59. **5** — *Chiropteridium lobospinosum* (Gocht) Gocht, 1960; sample Osch1-67. **6** — *Glaphyrocysta semitecta* (Bujak in Bujak et al., 1980) Lentin & Williams, 1981; sample Egdg2-77. **7** — *Hemiplacophora semilunifera* Cookson & Eisenack, 1965; sample egdg2-87. **8** — *Glaphyrocysta exuberans* (Deflandre & Cookson, 1955) Stover & Evitt, 1978; emend. Sarjeant, 1986; sample Osch1-67. **9** — *Glaphyrocysta texta* (Bujak, 1976) Stover & Evitt, 1978 ; sample Egdg2-67. **10** — *Membranophoridium aspinatum* Gerlach, 1961; sample P3-16. **11** — *Areoligera coronata* (Wetzel) Lejeune-Carpentier, 1938; sample Egdg2-77. **12** — *Areoligera semicirculata* (Morgenroth) Stover & Evitt, 1978; sample P3-18. **13** — *Chiropteridium galea* (Maier) emend. Sarjeant, 1983; sample Egdg2-77. **14** — *Glaphyrocysta dentata* Matsuoka, 1984; sample Egdg2-87. **15** — *Stoveracysta conerae* Biffi & Manum, 1988; sample Osch1-67.

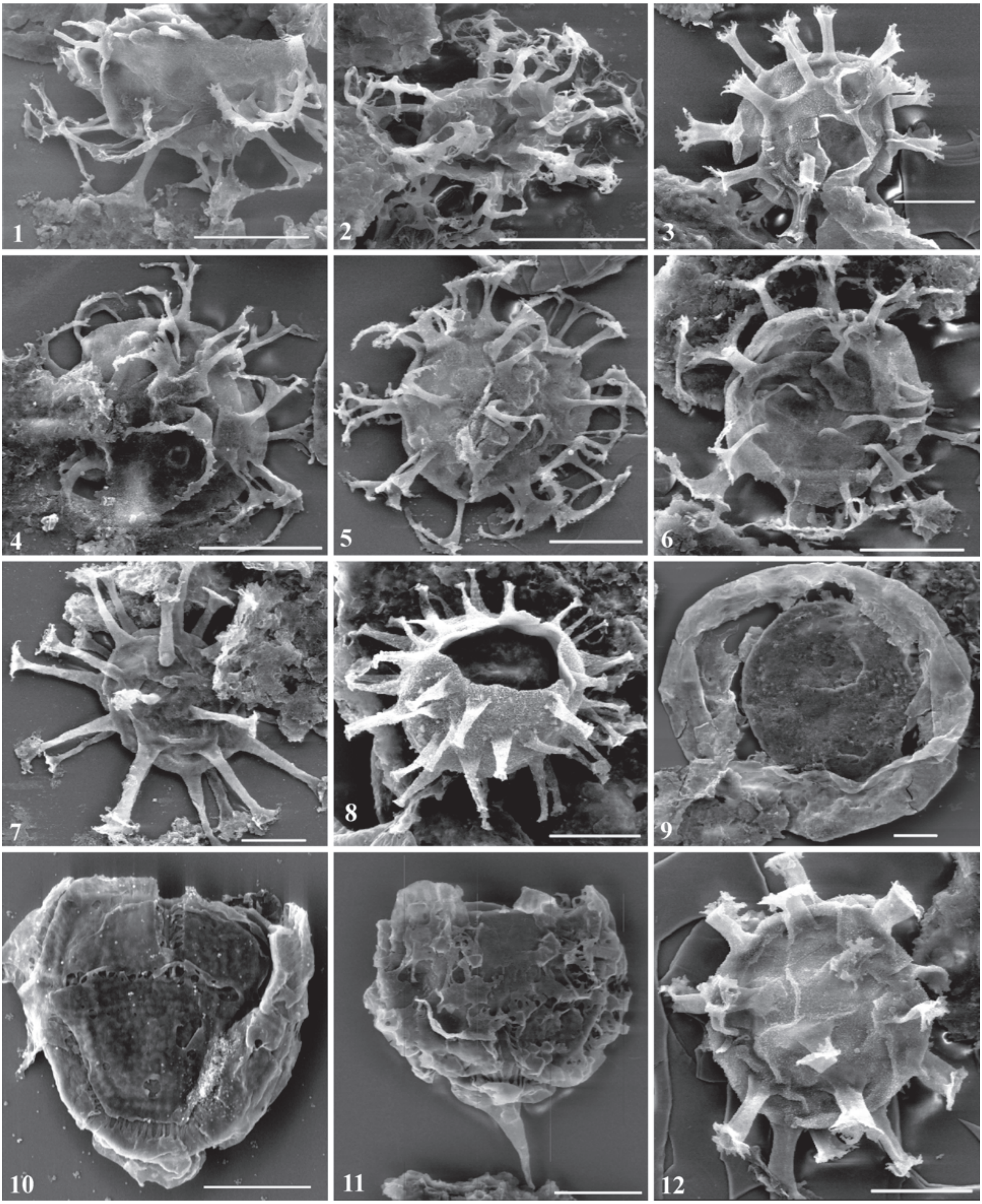


Fig. 16. **1** — *Enneadocysta deconinckii* Stover & Williams, 1995; sample Osch1-67. **2** — *Reticulatosphaera actinocoronata* (Benedek) emend. Bujak & Matsuoka, 1986; sample P3-20. **3** — *Homotryblium oceanicum* Eaton, 1976; sample Egdg2-77. **4** — *Enneadocysta arcuata* (Eaton) emend. Stover & Williams, 1995; sample Osch1-67. **5** — *Enneadocysta deconinckii* Stover & Williams, 1995; sample Osch1-67. **6** — *Enneadocysta harrisii* Stover & Williams, 1995; sample Egdg2-77. **7** — *Homotryblium tenuispinosum* Davey & Williams, 1966; sample P3-30. **8** — *Dapsilidinium pseudocolligerum* (Stover) Bujak et al., 1980; sample Egdg2-77. **9** — *Thalassiphora pelagica* (Eisenack) Eisenack & Gocht, 1960; emend. Benedek & Gocht, 1981; sample Egdg2-87. **10** — Genus et sp. indet.; sample Osch1-67. **11** — Genus et sp. indet.; sample Osch1-59. **12** — *Homotryblium abbreviatum* Eaton, 1976; sample Egdg2-77.

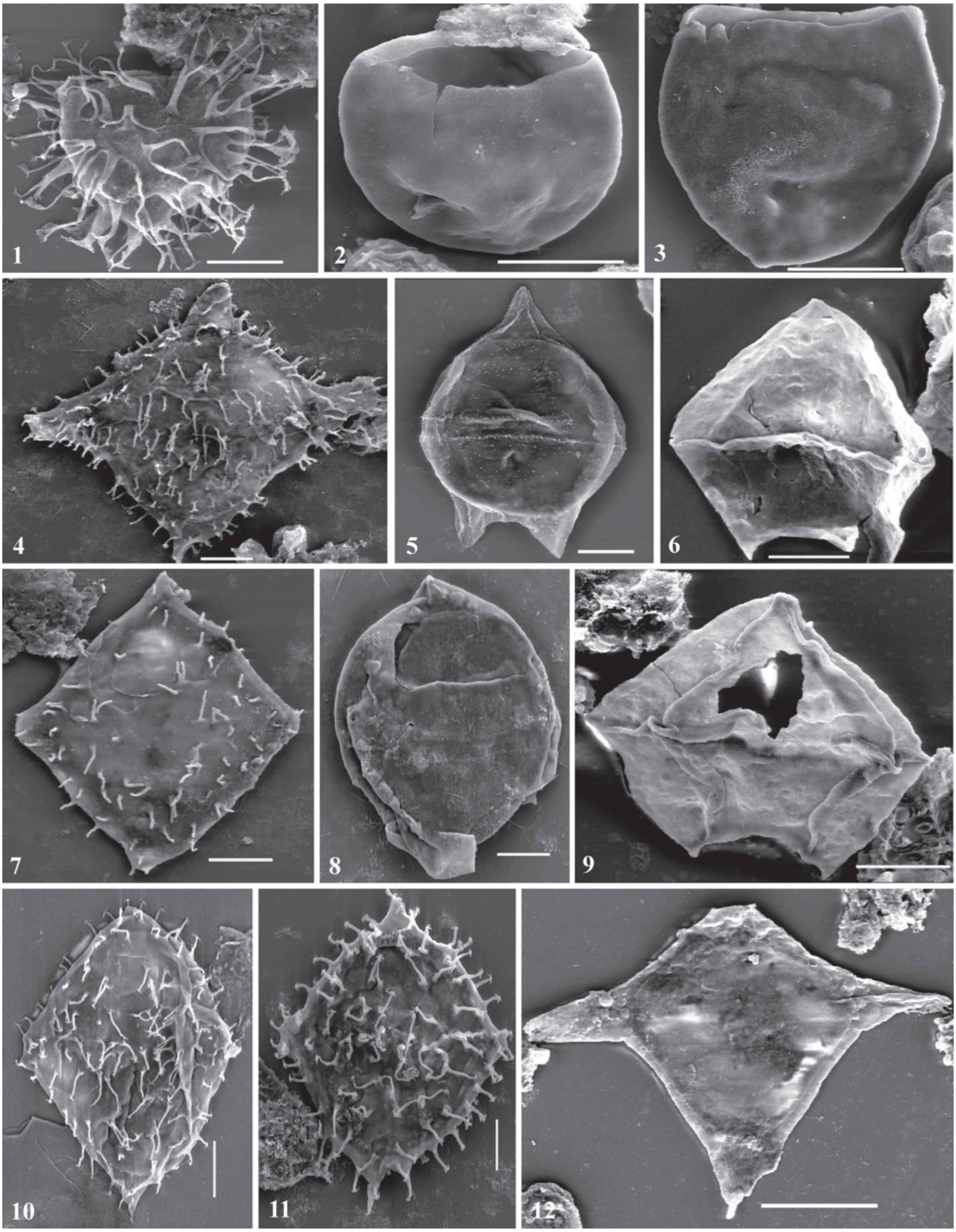


Fig. 17. **1** — *Cleistosphaeridium ancyreum* (Deflandre & Cookson) Eaton et al., 2001; sample Osch1-72. **2–3** — *Batiacasphaera explanata* (Bujak) Islam, 1983; sample Osch1-67. **4** — *Wetzeliella articulata* Eisenack, 1938; sample P3-2. **5** — *Deflandrea phosphoritica* Eisenack, 1938; sample Egdg2-87. **6** — *Lejeunecysta communis* Biffi & Grignani, 1983; sample Egdg2-77. **7** — *Wetzeliella gochtii* Costa & Downie, 1976; sample Egdg2-87. **8** — *Deflandrea leptodermata* Cookson & Eisenack, 1965; sample P3-2. **9** — *Lejeunecysta fallax* (Morgenroth) Artzner & Dörhöfer, 1978; emend. Biffi & Grignani, 1983; sample P3-18. **10** — *Wetzeliella ovalis* Eisenack, 1954; sample Egdg2-77. **11** — *Wetzeliella gochtii* Costa & Downie, 1976; sample P3-15. **12** — *Rhombodinium draco* Gocht, 1955; sample P3-30.

Acknowledgment: Reinhard Sachsenhofer (Leoben) and Rohöl-Aufsuchung AG (RAG) are thanked for the well data and samples. I am deeply indebted to Drs. W. Piller (Graz) and S. Torricelli (Milan) for their helpful comments on the early version. I gratefully acknowledge the constructive reviews of P. Gedl (Kraków) and the two anonymous reviewers. This work is supported by the ÖWA and FWF (Project No. 21414-B16).

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Appendix 1

List of the identified dinocyst from the NAFB, Austria (for full taxonomic references see Fensome et al. 2008).

Achilleodinium biformoides (Eisenack, 1954) Eaton, 1976
Achomosphaera alcicornu (Eisenack, 1954) Davey & Williams, 1966
Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963
Adnatosphaeridium multispinosum Williams & Downie, 1966
Adnatosphaeridium robustum (Morgenroth, 1966) De Coninck, 1975
Apteodinium australiense (Deflandre & Cookson, 1955) Williams, 1978
Apteodinium emslandense (Gerlach 1961) Stover & Evitt, 1978; emend. Benedek & Sarjeant, 1981
Apteodinium maculatum ssp. *grande* (Cookson & Hughes, 1964) Below, 1981
Apteodinium spiridoides Benedek, 1972
Apteodinium? *vescum* Matsuoka, 1983
Araneosphaera stephanophora (Benedek, 1972) emend. Benedek & Sarjeant, 1981
Areoligera coronata (O. Wetzel, 1933) Lejeune-Carpentier, 1938
Batiacasphaera explanata (Bujak in Bujak et al., 1980) Islam, 1983
Batiacasphaera micropapillata Stover, 1977
Batiacasphaera sphaerica Stover, 1977
Caligodinium amiculum Drugg, 1970
Caligodinium pychnum Biffi & Manum, 1988
Charlesdowniea columna (Michoux, 1988) Lentin & Vozzhennikova, 1990
Chiropteridium galea (Maier, 1959) Sarjeant, 1983
Chiropteridium lobospinosum Gocht, 1960

Chiropteridium spp.
Cleistosphaeridium ancyreum (Cookson & Eisenack, 1965) Eaton et al., 2001
Cleistosphaeridium placacanthum (Deflandre & Cookson, 1955) Eaton et al., 2001
Cordosphaeridium cantharellus (Brosius, 1963) Gocht, 1969
Cordosphaeridium fibrospinosum Davey & Williams, 1966
Cordosphaeridium gracile (Eisenack, 1954) Davey & Williams, 1966
Cordosphaeridium inodes (Klumpp, 1953) Eisenack, 1963 emend. Sarjeant, 1981
Cordosphaeridium minimum (Morgenroth, 1966) Benedek, 1972
Cribroperidinium giuseppei (Morgenroth, 1966)
Cribroperidinium tenuitabulatum (Gerlach, 1961) Helenes, 1984
Cyclonephelium compactum Deflandre & Cookson, 1955
Cyclonephelium paucimarginatum Cookson & Eisenack ,1962
Cyclonephelium paucispinum Davey, 1969
Cyclonephelium vannophorum Davey, 1969
Dapsilidinium pseudocolligerum (Stover, 1977) Bujak et al., 1980
Dapsilidinium simplex Bujak et al., 1980
Dapsilidinium spp.
Deflandrea heterophlycta Deflandre & Cookson, 1955
Deflandrea leptodermata Cookson & Eisenack, 1965
Deflandrea? pachyceros Deflandre & Cookson, 1955
Deflandrea phosphoritica Eisenack, 1938
Deflandrea phosphoritica var. *spinulosa* Alberti, 1959
Deflandrea scabrata Wilson, 1988
Deflandrea truncata Stover, 1974
Diphyes colligerum (Deflandre & Cookson, 1955) Cookson, 1965 emend. Goodman & Witmer, 1985
Distatodinium biffii Brinkhuis Powell & Zevenboom, 1992
Distatodinium craterum Eaton, 1976
Distatodinium ellipticum (Cookson, 1965) Eaton, 1976
Distatodinium paradoxum (Brosius, 1963) Eaton, 1976
Distatodinium scariosum Liengjarern et al., 1980
Distatodinium tenerum (Benedek, 1972) Eaton, 1976; emend. Benedek & Sarjeant, 1981
Dracodinium sp.
Enneadocysta deconinckii Stover & Williams, 1995
Enneadocysta harrisii Stover & Williams, 1995
Enneadocysta arcuata (Eaton, 1971) Stover & Williams, 1995
Enneadocysta pectiniformis (Gerlach, 1961) Stover & Williams, 1995
Fibrocysta axialis (Eisenack, 1965) Stover & Evitt, 1978
Gerlachidium aechmophorum (Benedek, 1972) Benedek & Sarjeant, 1981
Glaphyrocysta espiritosantensis (Regali et al., 1974) Arai in Fauconnier & Masure, 2004
Glaphyrocysta exuberans (Deflandre & Cookson, 1955) Stover & Evitt, 1978; emend. Sarjeant, 1986
Glaphyrocysta intricata (Eaton, 1971) Stover & Evitt, 1978
Glaphyrocysta microfenestrata (Bujak, 1976) Stover & Evitt, 1978
Glaphyrocysta ordinata (Williams & Downie, 1966) Stover & Evitt, 1978
Glaphyrocysta retiintexta (Cookson, 1965) Stover & Evitt, 1978
Glaphyrocysta semitecta (Bujak, 1980) Lentin & Williams, 1981
Glaphyrocysta texta (Bujak, 1976) Stover & Evitt, 1978
Glaphyrocysta wilsonii Kirsch, 1991
Glalphyrocysta dentata Matsuoka, 1984
Hemiplacophora semilunifera Cookson & Eisenack, 1965
Heteraulacacysta campanula Drugg & Loeblich Jr., 1967
Heteraulacacysta porosa Bujak in Bujak et al., 1980
Heterosphaeridium heteracanthum (Deflandre & Cookson, 1955) Eisenack & Kjellström, 1972
Homotryblium aculeatum Williams, 1978
Homotryblium floripes (Deflandrea & Cookson, 1955) Stover, 1975
Homotryblium oceanicum Eaton, 1976
Homotryblium pallidum Davey & Williams, 1966
Homotryblium abbreviatum Eaton, 1976
Homotryblium plectilum Drugg & Loeblich Jr., 1967
Homotryblium tenuispinosum Davey & Williams, 1966
Homotryblium spp.
Homotryblium vallum Stover, 1977
Hystrichokolpoma truncata Biffi & Manum, 1988
Hystrichokolpoma cinctum Klumpp, 1953
Hystrichokolpoma pusillum Biffi & Manum, 1988
Hystrichokolpoma rigaudiae Deflandre & Cookson, 1955
Hystrichokolpoma salacia Eaton, 1976
Hystrichokolpoma sp. A
Hystrichokolpoma torquatum Damassa, 1979
Hystrichostrogylon membraniphorum Agelopoulos, 1964
Impagidinium brevisulcatum Michoux, 1985
Impagidinium dispertitum (Cookson & Eisenack, 1965) Stover & Evitt, 1978
Impagidinium maculatum sensu Schioler, 2005
Impagidinium pallidum Bujak, 1984
Impletosphaeridium insolitum Eaton, 1976
Lejeunecysta communis Biffi & Grignani, 1983
Lejeunecysta diversiforma (Bradford, 1977) Artzner & Dörhöfer, 1978
Lejeunecysta fallax (Morgenroth, 1966) Artzner & Dörhöfer, 1978 emend. Biffi & Grignani, 1983
Lejeunecysta hyalina (Gerlach, 1961) Artzner & Dörhöfer, 1978
Lejeunecysta sp. 3 of Biffi & Grignani, 1983
Lejeunecysta tenella (Morgenroth, 1966) Wilson & Clowes, 1980
Leptodinium italicum Biffi & Manum, 1988
Leptodinium membranigerum Gerlach, 1961
Lingulodinium brevispinosum Matsuoka & Bujak, 1988
Lingulodinium machaerophorum (Deflandre & Cookson, 1955) Wall, 1967
Lingulodinium pycnospinosum (Benedek, 1972) Stover & Evitt, 1978
Melitasphaeridium spp.
Membranophoridium aspinatum Gerlach, 1961
Nematosphaeropsis labyrinthus (Ostenfeld, 1903) Reid, 1974
Operculodinium centrocarpum (Deflandre & Cookson, 1955) Wall, 1967
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983
Operculodinium spp.
Operculodinium tiara (Klumpp, 1953) Stover & Evitt, 1978
Palaeocystodinium golzowense Alberti, 1961
Palaeocystodinium powellii (Strauss et al., 2001)
Pentadinium goniferum Edwards, 1982
Pentadinium laticinctum Gerlach, 1961
Pentadinium taenigerum Gerlach, 1961
Polysphaeridium zoharyi (Rossignol, 1962) Bujak et al., 1980
Pyxidinopsis fairhavenensis de Verteuil & Norris, 1996
Reticulatosphaera actinocoronata (Benedek, 1972) Bujak & Matsuoka, 1986
Rhombodinium draco Gocht, 1955
Rhombodinium pustulosum Chateauneuf, 1980
Rottnestia borussica (Eisenack, 1954) Cookson & Eisenack, 1961
Selenopemphix armata Bujak, 1980
Selenopemphix brevispinosa Head et al., 1989
Selenopemphix nephroides Benedek, 1972
Spinidinium sp.
Spiniferites crassivariabilis Strauss et al., 2001
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970 emend. Sarjeant, 1981
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854
Stoveracysta conerae Biffi & Manum, 1988
Stoveracysta ornata (Cookson & Eisenack, 1965) Clowes, 1985
Tectatodinium pellitum Wall, 1967
Thalassiphora patula (Williams & Downie, 1966) Stover & Evitt, 1978
Thalassiphora pelagica (Eisenack, 1954) Eisenack & Gocht, 1960
Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967
Wetzeliella articulata Eisenack, 1938
Wetzeliella ovalis Eisenack, 1954
Wetzeliella echinosuturata Wilson, 1967
Wetzeliella gochtii Costa & Downie, 1976
Wetzeliella spinulosa Wilson, 1988
Wetzeliella symmetrica Weiler, 1956