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Dinoflagellate Cysts at the Karpatian/Badenian Boundary of Wagna (Styrian Basin, Austria)

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5 Text-Figures, 2 Plates

Steiermark
Steirisches Becken
Paratethys
Karpatium
Badenium
Dinoflagellaten

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Contents

Dinoflagellaten-Zysten von der Karpatium/Badenium-Grenze bei Wagna (Steirisches Becken, Österreich)

Zusammenfassung

Von der Lokalität Wagna (Karpatium/Badenium, Unter/Mittel-Miozän) werden erstmals Dinoflagellaten-Zysten beschrieben. Die erfassten Vergesellschaftungen beinhalten 38 Taxa and liefern neue biostratigraphische und paläoökologische Informationen. Die Karpatium/Badenium-Grenze wird in allen drei studierten Profilen durch das Erstauftreten von *Operculodinium*? *borgerholtense* und *Batiacasphaera sphaerica* markiert. Generell ist die Dinozysten-Diversität in allen Proben relativ gering, trotzdem ist ein deutlicher Rückgang direkt unterhalb der Karpatium/Badenium-Grenze auffällig. Das stimmt mit den Foraminiferen-Daten überein und ebenso mit dem Meeresspiegel-Rückgang 3. Ordnung an dieser Grenze. Im Gegensatz zu kalkigen planktischen Foraminiferen scheinen Dinozysten mit ihren organischen Kammerwänden von höheren Nährstoffgehalten, die durch verstärkte vulkanische Aktivität im Karpatium hervorgerufen wurden, nicht beeinflusst worden zu sein.

Abstract

From the locality Wagna (Karpatian/Badenian, Early/Middle Miocene) dinoflagellate cysts are described for the first time. The detected assemblages include 38 taxa and provide new biostratigraphic as well as paleoenvironmental information. The Karpatian/Badenian boundary is clearly marked in all three studied sections by the first occurrences of *Operculodinium*? *borgerholtense* and *Batiacasphaera sphaerica* with the onset of the Badenian. Generally, dinocyst diversity is relatively low in all studied samples but a distinctive decline just below the Karpatian/Badenian boundary is recorded. This is in accordance with foraminiferal data and coincides with the 3rd order sea-level fall at the Karpatian/Badenian (Early/Middle Miocene) boundary. In contrast to calcareous planktic foraminifers, organic-walled dinocysts seem not to be affected by higher nutrient levels, which may have been induced by increased volcanic activities during the Karpatian.

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1. Introduction

The brickyard of Wagna is the best available surface outcrop in the Central Paratethys for the Karpatian/Badenian (Early/Middle Miocene) boundary. This outcrop is well studied in terms of foraminifers and calcareous nannoplankton (Rögl et al., 2002; Spezzaferri et al., 2002, 2004) as well as for magnetostratigraphy (Stingl & Scholger, 2005) and stable isotope distribution (Latal & Piller, 2003).

Dinoflagellate cysts (dinocysts) have not been described in detail so far, neither from Wagna in particular nor from Miocene strata of the Styrian Basin in general. Only two short reports have been published (Soliman & Piller, 2004, 2005). However, from the entire Central Paratethys Miocene dinocyst assemblages are known from few studies only, e.g., Baltes (1967, 1969), Hochuli (1978) and Jiménez-Moreno et al. (in print) for the Early and Middle Miocene and Süto-Szentai (1994, 1995, 2002, 2003) for the Late Miocene.

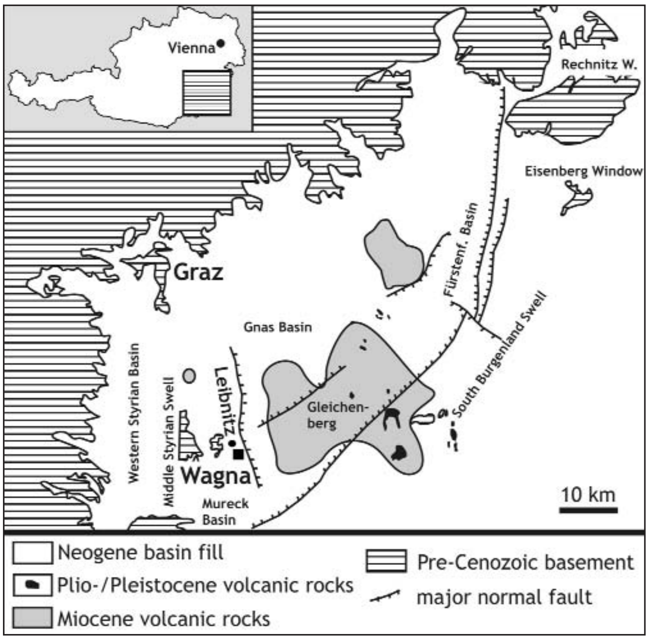
This is in clear contrast to the knowledge of time equivalent assemblages from the Atlantic Ocean, northern Europe, and the Mediterranean Sea, from where dinocysts have been extensively documented (e.g., for the North Atlantic by Head et al. (1989a,b), Manum et al. (1989), de Verteuil & Norris (1996); for northern Europe by Piasecki (1980), Strauss et al. (2001), Dybkjær & Rasmussen (2000), Dybkjær (2004), Munsterman & Brinkhuis (2004); for the Mediterranean by Powell (1986), Biffi & Manum (1988), El beialy (1988), Zevenboom (1995), Torricelli & Biffi (2001), El beialy & Ali (2002), Soliman (2006).

The present study examines the upper Lower Miocene and lower Middle Miocene dinocysts in the brickyard Wagna (Text-Fig. 1) and provides new information on their stratigraphic distribution at the Karpatian/Badenian boundary as well as on their potential for paleoenvironmental reconstruction.

2. Geological Setting

The outcrop Wagna is located approximately 20 km south of Graz near Leibnitz (Text-Fig. 1). Geologically, it belongs to the Styrian Basin which is part of the Neogene Pannonian Basin system. The evolution of the Styrian Basin was described in detail by Ebner & Sachsenhofer (1991, 1995) and Sachsenhofer (1996).

The sediments in the abandoned brickyard of Wagna represent two units. The lower part belongs to the Kreuzkrumpel Formation and is made up mainly of grey shales with intercalated siltstones, which are informally termed "Steirischer Schlier". The upper part is dominated by marls and sands with interlayered coral and red algal limestones belonging to the Weissenegg Formation. Between these lithostratigraphic units a major unconformity occurs, known as "Styrian unconformity", which is related to the "Styrian Tectonic Phase" of Stille (1924). In interaction with a global sea level change this tectonic activity caused a major erosional hiatus between the two lithological units, which is coeval with the Karpatian/Badenian (= Early/Middle Miocene) boundary. These tectonic movements, accompanied by volcanic activity, were not a single event but a long term process represented by an angular disconformity already below the Karpatian/Badenian boundary and another unconformity at the boundary (Rögl et al., 2002; Latal & Piller, 2003). The erosional phase is indicated by reworked pebbles in a silty fine sand recognized as "Geröllmergel" (Kollmann, 1965; Friebe, 1990; Latal & Piller, 2003). Biostratigraphically, the major part of the outcrop belongs to calcareous nannoplankton zone NN4, only in the upper part of section 3 NN5 is also represented (Rögl et al., 2002; Spezzaferri et al., 2002, 2004; Latal & Piller, 2003).



Text-Fig. 1.
Simplified geologic overview map of the Styrian Basin and location of the studied outcrop.

3. Materials and Methods

The outcrop was logged in three sections which overlap laterally. In all 3 sections the Karpatian/Badenian boundary is represented (Text-Figs. 2–4). The sections were already described in detail by Latal & Piller (2003) and Spezzaferri et al. (2004). In the current study a total of 37 samples were examined in detail for organic-walled dinoflagellate cysts and acritarchs. These samples and the sample numbers are identical with those studied by Spezzaferri et al. (2002, 2004), Rögl et al. (2002), and Latal & Piller (2003).

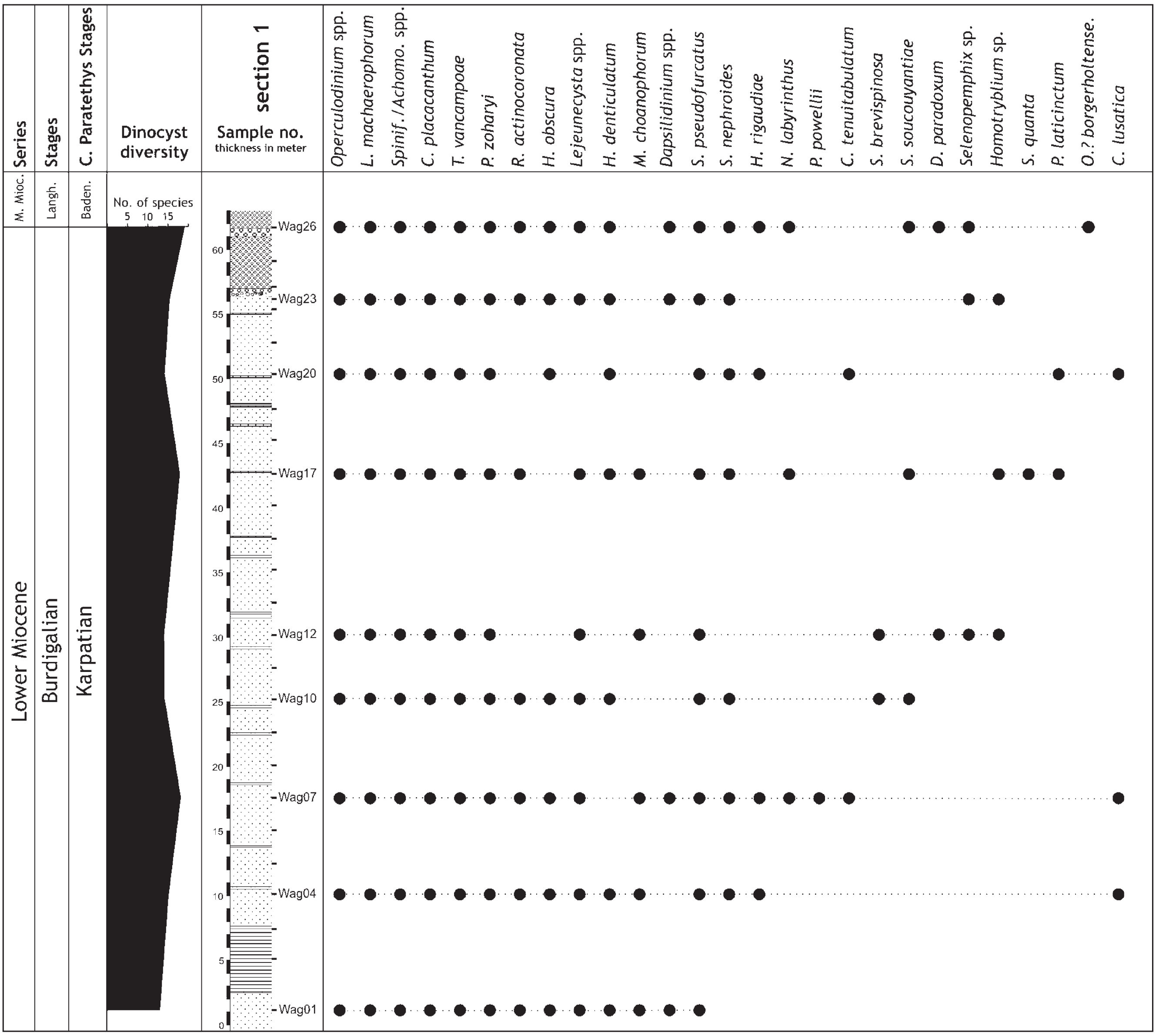
For studying dinocysts, 20 to 30 grams of dry rock sample were processed following the standard palynological procedure (Wood et al., 1996) including 30 % hydrochloric acid (HCl), 40 % hydrofluoric acid (HF), ultrasonic treatment for 10–15 seconds, and sieving over a 20 μm nylon mesh. Neither oxidation nor alkali treatment were applied to the residues. Two microscope slides were made from each sample using glycerine jelly as a mounting medium. Dinocysts were counted and photographed from both slides using a Zeiss Axioplan 2 microscope fitted with a Leica DFC 320 digital camera. Dinocyst nomenclature generally follows that of Fensome & Williams (2004).

The rock samples, palynological residues and slides are stored in the collection of the Institute of Earth Sciences, Geology and Paleontology, University of Graz, Austria.

4. Results and Discussion

Dinoflagellate cysts are recorded from all studied samples, however, preservation varies from poor to good and diversity is generally low with a total number of 38 in situ taxa (in alphabetical order):

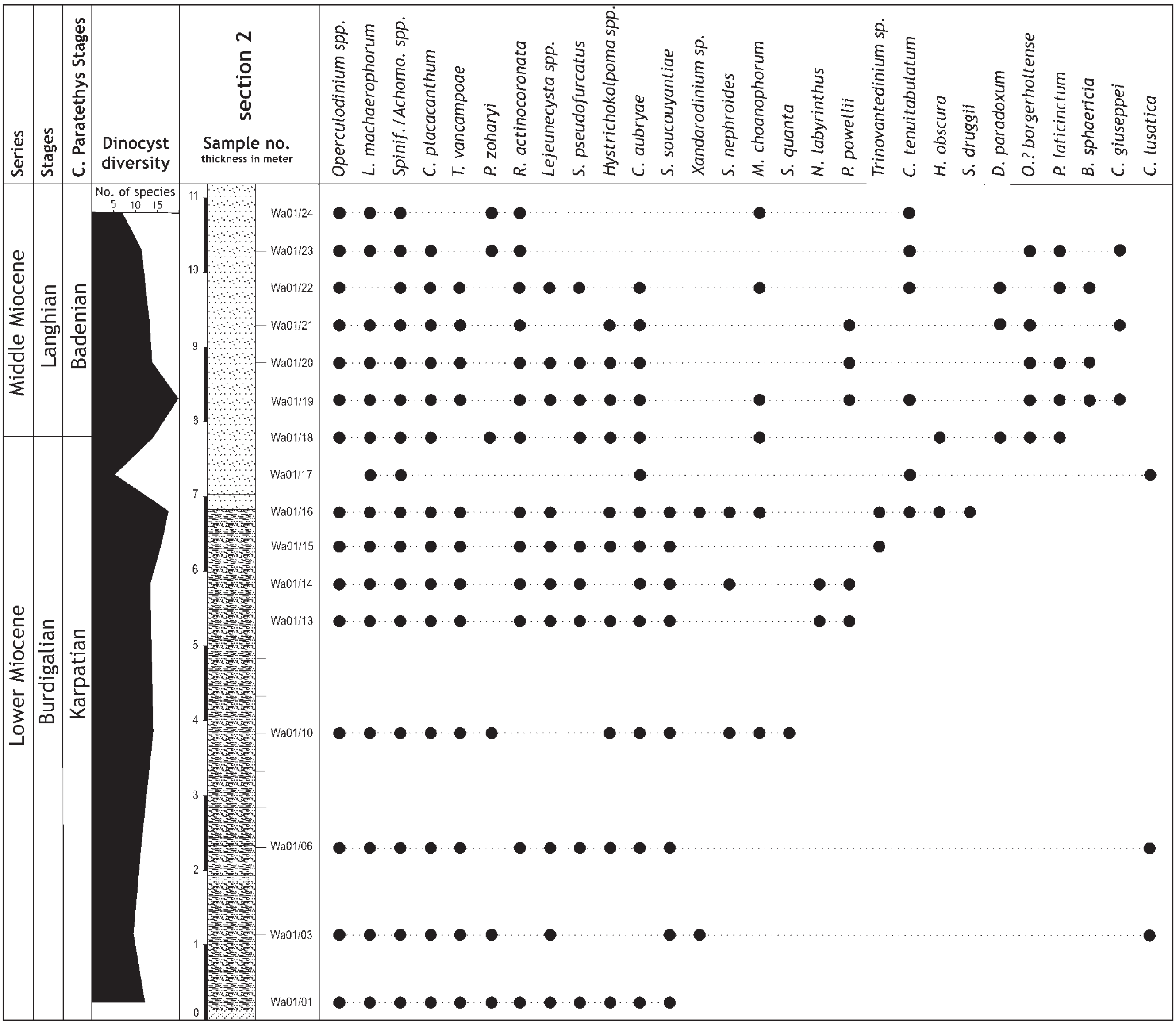
1. *Apteodinium tectatum* Piasecki, 1980.
2. *Batiacasphaera sphaerica* Stover, 1977.
3. *Cleistosphaeridium ancyreum* (Cookson & Eisenack) Eaton et al., 2001.
4. *Cleistosphaeridium placacanthum* (Deflandre & Cookson) Eaton et al., 2001.



Text-Fig. 2.
Stratigraphic distribution of selected dinoflagellate cysts and associated palynomorphs in section 1.
For explanation of lithology compare LATAL & PILLER (2003) and SPEZZAFERRI et al. (2004).

5. *Cousteaudinium aubryae* DE VERTEUIL & NORRIS, 1996.
6. *Cribroperidinium giuseppei* (MORGENROTH) HELENES, 1984.
7. *Cribroperidinium tenuitabulatum* (GREAT) HELENES, 1984.
8. *Dapsilidinium pastielsii* (DAVEY & WILLIAMS) BUJAK et al., 1980.
9. *Dapsilidinium pseudocolligerum* (STOVER) BUJAK et al., 1980.
10. *Distatodinium paradoxum* (BROSIUS) EATON 1976.
11. *Hystrichokolpoma denticulatum* MATSUOKA, 1974.
12. *Hystrichokolpoma rigaudiae* DEFLANDRE & COOKSON, 1955.
13. *Hystrichosphaeropsis obscura* HABIB, 1972.
14. *Lejeunecysta communis* BIFFI & GRIGNANI, 1983.
15. *Lejeunecysta convexa* MATSUOKA & BUJAK, 1988.
16. *Lejeunecysta diversiforma* (BRADFORD) ARTZNER & DÖRHÖFER, 1978.
17. *Lejeunecysta fallax* (MORGENROTH) ARTZNER & DÖRHÖFER, 1978 emend. BIFFI & GRIGNANI, 1983.
18. *Lejeunecysta globosa* BIFFI & GRIGNANI, 1983.
19. *Lingulodinium machaerophorum* (DEFLANDRE & COOKSON) WALL, 1967.
20. *Melitasphaeridium choanophorum* (DEFLANDRE & COOKSON) HARLAND & HILL, 1979.
21. *Nematosphaeropsis labyrinthus* (OSTENFELD) REID, 1974.
22. *Operculodinium ? borgerholtense* LOUWYE, 2001, emend. herein.
23. *Palaeocystodinium powellii* STRAUSS et al., 2001.
24. *Pentadinium laticinctum* GERLACH, 1961 emend. BENEDEK et al., 1982.
25. *Polysphaeridium zoharyi* (ROSSIGNOL) BUJAK, DOWNIE, EATON & WILLIAMS, 1980
26. *Reticulatosphaera actinocoronata* (BENEDEK) BENEDEK & MATSUOKA, 1986
27. *Selenopemphix bothrion* HARLAND & PUDSEY, 2002.
28. *Selenopemphix brevispinosa* HEAD, NORRIS & MUDIE, 1989.
29. *Selenopemphix nephroides* BENEDEK emend. BUJAK in BUJAK et al., 1980
30. *Selenopemphix quanta* (BRADFORD) MATSUOKA, 1985.
31. *Spiniferites pseudofurcatus* (KLUMPP) SARJEANT, 1970 emend. SARJEANT, 1981.
32. *Spiniferites solidago* DE VERTEUIL & NORRIS, 1996.
33. *Sumatradinium druggii* LENTIN, FENSOME & WILLIAMS, 1994.
34. *Sumatradinium soucouyantiae* DE VERTEUIL & NORRIS, 1992.
35. *Trinovantedinium* sp. cf. *T. applanatum* (BRADFORD) BUJAK & DAVIES, 1983.
36. *Tuberculodinium vancampoae* (ROSSIGNOL) WALL, 1967.
37. *Xandarodinium* sp.
38. Dinocyst VI of MANUM (1976), sensu SCHIØLER, 2005.

The distribution of the most abundant taxa is shown in Text-Figures 2–4. Dinocyst microphotographs are shown in Plates 1 and 2. Pollen and spores were observed in all three sections but not studied.



Text-Fig. 3.
Stratigraphic distribution of selected dinoflagellate cysts and associated palynomorphs in section 2.
For explanation of lithology compare LATAL & PILLER (2003) and SPEZZAFERRI et al. (2004).

4.1. Biostratigraphy

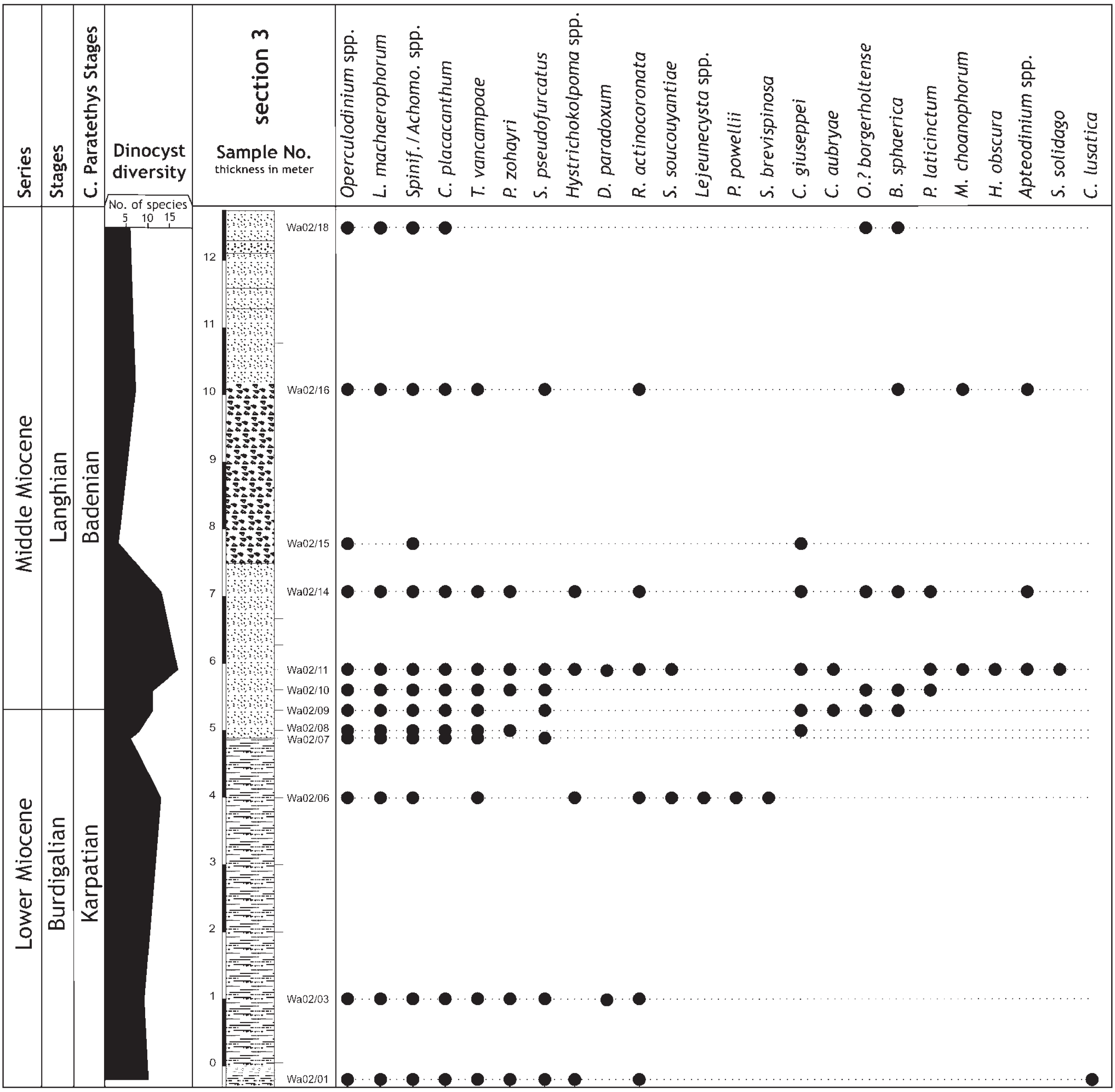
The studied sections are well dated by means of planktic and benthic foraminifers and calcareous nannoplankton (e.g., RÖGL et al., 2002; SPEZZAFERRI et al., 2002, 2004; CORIC, 2002; Text-Fig. 5). Dinoflagellate cyst distribution provides additional biostratigraphic information.

Karpatian

The Karpatian part of the studied sections is characterized by the common occurrence of *Operculodinium centrocarpum, Lingulodinium machaerophorum, Reticulatosphaera actinocoronata*, and *Spiniferites* spp. undiff. These taxa are present in almost all samples. Sporadic occurrences are detected for *Melitasphaeridium choanophorum, Spiniferites pseudofurcatus, Cribroperidinium tenuitabulatum, Hystrichokolpoma rigaudiae, Dapsilidinium* spp., and *Pentadinium laticinctum*. In addition to the above mentioned species a group of characteristic Early Miocene species, as *Sumatradinium soucouyantiae, Cousteaudinium aubryae, Hystrichosphaeropsis obscura, Cleistosphaeridium placacanthum, Tuberculodinium vancampoae, Palaeocystodinium powellii*, and *Hystrichokolpoma denticulatum*, was also recognized. The acritarch species *Cyclopsiella lusatica* occurs in some samples (Text-Figs. 2–4).

Outside the Central Paratethys *Hystrichosphaeropsis obscura* (Pl. 1, Figs. 14, 18) indicates Burdigalian age according to many authors (e.g., HAQ et al., 1987; MANUM et al., 1989; POWELL, 1992; STOVER et al., 1996; HARDENBOL et al., 1998; DYBKJÆR, 2004). *S. soucouyantiae* (Pl. 1, Fig. 16), which occurs in all studied sections of Wagna (section 1: sample 10; section 2: sample 1; section 3: sample 6), is restricted to the Early Miocene (DE VERTEUIL & NORRIS, 1996; HARDENBOL et al., 1998; WILLIAMS et al., 2004; GRADSTEIN et al., 2004).

Cousteaudinium aubryae (Pl. 2, Figs. 20, 21) is persistently recorded from section 2 and sporadically from section 3; no record comes from section 1. In Cortemilia section (Italy) the lowest occurrence (LO) of *C. aubryae* (described as *Thalassiphora gonoperforata*) defines the Tgo Interval Zone (uppermost Burdigalian) of ZEVENBOOM (1995). In the eastern United States, however, the LO of this species is dated as mid-Aquitanian (base of dinocyst zone DN2) and is correlated with the lower part of nannoplankton zone NN2 (DE VERTEUIL & NORRIS, 1996). In the southern North Sea Basin its LO is also detected at the base of dinocyst zone M2 and dated as mid-Aquitanian (MUNSTERMAN & BRINKHUIS, 2004). WILLIAMS et al. (2004) argue for a heterochronous occurrence of this species with a mid-Aquitanian LO



Text-Fig. 4.
Stratigraphic distribution of selected dinoflagellate cysts and associated palynomorphs in section 3.
For explanation of lithology compare LATAL & PILLER (2003) and SPEZZAFERRI et al. (2004).

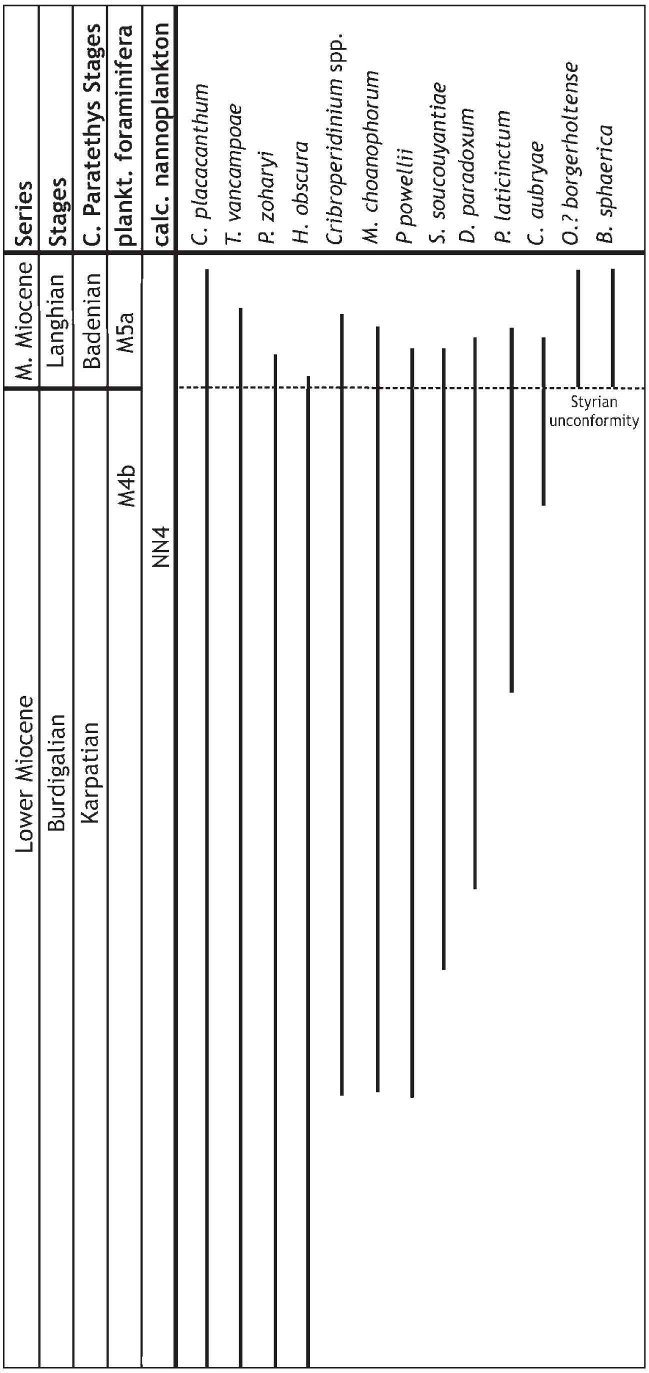
for mid latitudes in the northern hemisphere and an upper Burdigalian LO for equatorial regions.

The absence of some of the early to middle Early Miocene marker taxa (e.g., *Exochosphaeridium insigne, Cordosphaeridium cantharellus*) from the studied sections is in accordance with the Karpatian age (late Burdigalian). In the eastern Alpine Foreland Basin of Austria (section Strass-Eberschwang) the highest occurrence (HO) of these species defines the top of the *E. insigne* Assemblage Biozone (Ein), which is middle Ottnangian in age and correlated to calcareous nannoplankton Zone NN3 (JIMÉNEZ-MORENO et al., in press).

Badenian

The Badenian sediments are represented by 1 sample in section 1, 6 samples in section 2 and 6 samples in section 3. The dinocyst assemblage of the Karpatian part of the sections is generally also recorded in the Lower Badenian part. In addition, *Operculodinium* ? *borgerholtense* (Pl. 1, Figs. 6–12) and *Batiacasphaera sphaerica* (Pl. 1, Figs. 1–5) have their LO immediately above the Karpatian/Badenian boundary. The uppermost occurrences of the two lower Middle Miocene marker species, *Distatodinium paradoxum* (Pl. 1, Figs. 13, 17) and *C. aubryae*, are recorded in sections 2 and 3 (Text-Figs. 3, 4).

The HO of *D. paradoxum* and *C. aubryae* is reported from the top of dinocyst zone DN4 in the eastern USA correlated with lowermost NN5 (lower Langhian) (DE VERTEUIL & NORRIS, 1996). The highest occurrence of both species was documented in the lowermost Middle Miocene at the top of Cpl dinocyst zone of well Nieder Ochtenhausen (STRAUSS et al., 2001) and at the top of dinocyst zone DN4 of northern Germany (KÖTHE, 2003). In the southern North Sea area the HO of *C. aubryae* defined the dinocyst zone SNSM6 (MUNSTERMAN & BRINKHUIS, 2004).



Text-Fig. 5.
Summarized stratigraphic ranges of selected dinoflagellate cysts and acritarchs in the Wagna outcrop.

The most characteristic bioevent of the Badenian in the studied samples is the first occurrence of *O. ? borgerholtense*. This species is not abundant but persistently recorded. In the Retznei outcrop (Badenian), few kilometers south of Wagna, this species is very abundant and shows high intraspecific variability in its morphologic features (personal observation). The exact stratigraphic range of this species is unknown yet, but it is well documented form the Middle Miocene of the North Sea, Gulf of Suez, and Central Paratethys basins (LOUWYE, 2001; SOLIMAN, 2006; JIMÉNEZ-MORENO et al., in print; personal observations).

The LO of *B. sphaerica* is also recorded in the Badenian of sections 2 and 3. This species was first described from the Lower Miocene *Globorotalia kugleri* Zone of the Blake Plateau, offshore North Carolina (STOVER, 1977). It is, however, also recorded from the Aquitanian (Ebu Zone) of the Santa Croce di Arcevia Section in Italy (ZEVENBOOM, 1995), the Burdigalian stratotype area, Bordeaux, France (LONDEIX & JAN DU CHÊNE, 1998), the uppermost Upper Burdigalian – Lower Langhian of the Zonderschot Sands, northern Belgium (LOUWYE, 2000), and the middle Ottnangian (Burdigalian) of the Strass-Eberschwang section, Austria (JIMÉNEZ-MORENO et al., in print).

Thus, the LO of *B. sphaerica* in Wagna is younger than all other known records.

Karpatian/Badenian Boundary

In the Styrian Basin the Karpatian/Badenian boundary is represented by the "Styrian unconformity" (Text-Fig. 5), which is related to the "Styrian Tectonic Phase" (STILLE, 1924; LATAL & PILLER, 2003). In the brickyard of Wagna SPEZZAFERRI et al. (2002, 2004) attributed the "Steirischer Schlier", which represents the sediments below the unconformity, to the middle Karpatian based on the presence of *Uvigerina graciliformis, Pappina primiformis*, a typical small sized planktic foraminiferal assemblage, and the rare occurrence of *Globigerinoides bisphericus* (planktic foraminiferal zone M4b). The portion above the unconformity is assigned to the Lower Badenian based on foraminifers (*Globigerinoides trilobus, Praeorbulina glomerosa circularis*) and correlated with planktic foraminiferal zone M5a (Text-Fig. 5). Sedimentological features and an incomplete evolutionary lineage from *Globigerinoides bisphericus* to *Praeorbulina* species, however, clearly indicate a gap in sedimentation. In terms of calcareous nannoplankton all samples of the 3 sections studied belong to zone NN4 based on the co-occurrence of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta*. The latter increases in abundance just below the unconformity (RÖGL et al., 2002).

With regard to the dinocyst assemblages the boundary is marked by the lowest occurrences (LO) of *O. ? borgerholtense* and *B. sphaerica*. Both species are not recorded below the unconformity but occur persistently above, especially *O. ? borgerholtense* (Text-Fig. 5).

4.2. Paleoenvironmental Interpretation

Generally, the recorded dinoflagellate cyst assemblages (Text-Figs. 2–4) reflect a neritic environment for the studied area. The sporadic occurrences of *N. labyrinthus* in the "Steirischer Schlier" (Karpatian) of sections 1 and 2 indicate that these beds were deposited in a deep water environment. DALE (1996) pointed out that the presence of even a few specimens of these cysts is a reliable indication of deep waters. In the Badenian parts of the sections *N. labyrinthus* is completely missing. For the same part of section 1 SPEZZAFERRI et al. (2004) suggested a paleodepth from 250 m to 300 m based on benthic agglutinated and calcareous foraminifers.

A significant number of thermophile species, as *T. vancampoae, L. machaerophorum, S. nephroides, P. zoharyi*, and *M. choanophorum*, indicates subtropical conditions for all studied samples (e.g., EDWARDS & ANDRLE, 1992; HEAD & WESTPHAL, 1999; MARRET & ZONNEVELD, 2003). Temperate to cool-water species, as *Impagidinium pallidum* BUJAK, 1984 and *Spiniferites elongatus* REID, 1974, were not recognized. No distinct change between the Karpatian and Badenian parts of the sections was detected. For the Karpatian this contrasts with the results of SPEZZAFERRI et al. (2002), in which the foraminiferal ratios point to cool climatic conditions. This interpretation is, however, already in contrast to the coeval sediments of the Molasse Basin (Laa an der Thaya, Göllersdorf) where warm climatic conditions are indicated by foraminiferal assemblages. Since the two basins (Molasse Basin and Styrian Basin) are only a few hundred kilometers apart one plausible explanation could be the increased volcanic activity in the Styrian Basin that caused higher nutrient concentrations. The latter may have provoked a small and poorly diversified planktic foraminiferal assemblage veiling the original climate signal (SPEZZAFERRI et al., 2004). The organic walled dinoflagellate cyst assemblages seem to be less affected by this volcanically induced nutrification. The only hint to a nutrient enrichment in the Karpatian part of the sections is the higher abundance and diversification of heterotrophic protoperidinioid dinoflagellate cysts, as *Lejeunecysta* spp., *Selenopemphix* spp., and *Trinovantedinium* spp. (e.g., WALL et al., 1977; BUJAK, 1984; POWELL et al., 1990; LEWIS et al., 1990; SOLIMAN, 2006).

Generally, dinocyst diversity is relatively low in all the studied samples, however, a decline is noted just below the Karpatian/Badenian boundary (Text-Figs. 3, 4). This decline clearly coincides with a drastic change in foraminiferal assemblages with an increasing number of shallow-water taxa, as *Ammonia, Nonion, Elphidiella, Elphidium*, and small globigerinids as referred by RÖGL et al. (2002) and SPEZZAFERRI et al. (2002, 2004). On the base of this foraminiferal change a decreasing water depth from ca. 240 m to 50 m was calculated (SPEZZAFERRI et al., 2004). This shallowing of the depositional environment may be also the reason for the decreasing dinocyst diversity and is in accordance with the sea-level low stand at the Karpatian/Badenian boundary (FRIEBE, 1993; EBNER & SACHSENHOFER, 1995), which can be correlated with the TB 2.3 sequence boundary of HAQ et al. (1988) and Lan-1 by VAKARCS et al. (1998) (LATAL & PILLER, 2003).

5. Taxonomic Note

Operculodinium ? *borgerholtense* LOUWYE, 2001

Plate 1, Figs. 6–12

2001 *Operculodinium* ? *borgerholtense* LOUWYE, p. 126–127, Figs. 4.1–4.12.

Discussion: In their emendation of the genus *Operculodinium* MATSUOKA et al. (1997) did not state the presence of granules and/or small rods as a surface ornamentation as well as spinules and/or small granules on the process shaft. *O.* ? *borgerholtense* is distinguished from “typical” species of this genus by its prismatic luxuria (low granules and/or small rods) and in that shafts of the processes have spinules or granules. However, the latter can also be smooth in some specimens. The antapical plate with fused low and high ornamentation is clearly seen in many specimens but may depend on the specimen’s orientation (Pl. 1, Fig. 12). These characteristic morphologic features distinguish this species from other *Operculodinium* species and require its emendation.

Previous records: Middle Miocene (Antwerp Sands, Berchem Formation) of northern Belgium (LOUWYE, 2001); uppermost Lower Miocene–Middle Miocene, Gulf of Suez, Egypt (SOLIMAN, 2006); Middle Miocene (Badenian-Sarmatian) of the Central Paratethys (JIMÉNEZ-MORENO et al., in print); Middle Miocene of the Styrian Basin, Retznei section (personal observation); Middle Miocene of the North Sea and North Atlantic basins (personal communications by M.J. HEAD and S. LOUWYE).

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Plate 1

Dinoflagellate cysts from the Wagna outcrop.

Figs. 1, 5: *Batiacasphaera sphaerica*.
Sample W01-22, E. F. Ref. B8, low and high focus of indet. orientation.

Figs. 2–4: *Batiacasphaera sphaerica*.
Sample W01-19, slide A, E. F. Ref. X15-1, high focus showing surface ornamentation, mid-focus and low focus showing apical archeopyle.

Figs. 6–8: *Operculodinium* ? *borgerholtense*.
Sample W01-19, slide A, E. F. Ref. M56, different foci.

Figs. 9–10: *Operculodinium* ? *borgerholtense*.
Sample W01-19, slide A, E. F. Ref. K17, dorsal view showing 2P archeopyle.

Figs. 11–12: *Operculodinium* ? *borgerholtense*.
Sample W02-18, slide B, E. F. Ref. A28-3, oblique antapical view showing antapical plate.

Figs. 13,17: *Distatodinium paradoxum*.
Sample W01-17, slide A, E. F. Ref. R22, note characteristic distal ends of processes.

Figs. 14,18: *Hystrichosphaeropsis obscura*.
Sample W01-17, slide A, E. F. Ref. Y25-2, ventral view of ventral surface.

Fig. 15: *Sumatradinium druggii*.
Sample W01-16, slide A, E. F. Ref. U34-4, note annular thickenings at the processes shafts.

Fig. 16: *Sumatradinium soucouyantiae*.
Sample Wa2-10, E. F. Ref. X54-1, specimen in dorsal view.

Fig. 19: *Palaeocystodinium powellii*.
Sample W02-6, slide A, E. F. Ref. H46.

Fig. 20: *Palaeocystodinium powellii*.
Sample W02-6, slide A, E. F. Ref. F66.

Figs. 21–22: Dinocyst VI of Manum (1976), sensu Schiøler, 2005.
Sample W01-22, slide A, E. F. Ref. P6, different foci of uncertain position.

Scale bar 20 µm.
E. F. Ref. = England Finder Reference.

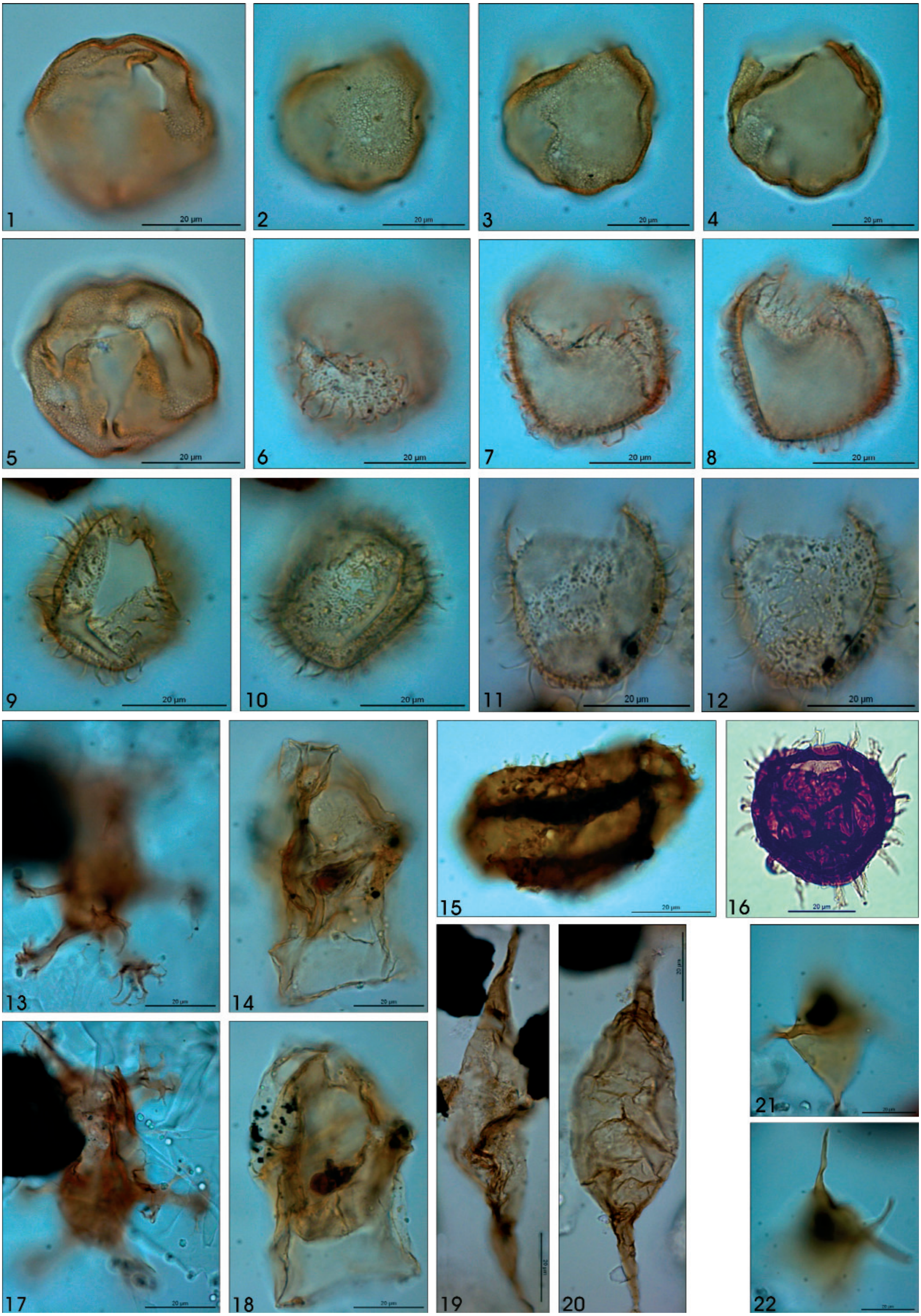
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Plate 2

Dinoflagellate cysts from the Wagna outcrop.

Figs. 1–2: *Cribroperidinium tenuitabulatum*.
Sample W02-11, slide A, E. F. Ref. N45-1, mid and high foci of a lateral view showing the apical horn and surface ornamentation.

Figs. 3, 7: *Cleistosphaeridium placacanthum*.
Sample W02-10, slide A, E. F. Ref. N63, indet. orientation, different foci showing the developed base sutures and distal ends of processes.

Figs. 4, 8: *Lingulodinium machaerophorum*.
Sample W01-13, slide A, E. F. Ref. T23, low and high foci, note granular surface ornamentation.

Figs. 5, 6: *Melitasphaeridium choanophorum*.
Sample W02-11, slide A, E. F. Ref. F53-3, different foci of uncertain orientation.

Figs. 9–10: *Pentadinium laticinctum*.
Sample W02-11, slide A, E. F. Ref. H65-3, different foci.

Figs. 11: *Reticulatosphaera actinocoronata*.
Sample W02-14, slide A, E. F. Ref. V48-1, mid-focus.

Figs. 12–13: *Cyclopsiella lusatica*.
Sample W01-19, slide A, E. F. Ref. S18-3, low and high focus, note the pylome is near the periphery.

Figs. 14,19: *Pyxidinopsis* sp.
Sample W01-22, slide A, E. F. Ref. Y28-4.

Figs. 15–16: *Nematosphaeropsis labyrinthus*.
Sample W01-13, slide A, E. F. Ref. K38-3, different foci.

Figs. 17–18: *Spiniferites solidago*.
Sample W02-11, slide A, E. F. Ref. T59, dorsal view, different foci, note mid-shaft vacuoles and apical boss.

Figs. 20–21: *Cousteaudinium aubryae*.
Sample W02-9, slide A, E. F. Ref. F34, dorsal view of dorsal surface showing archeopyle sutures.

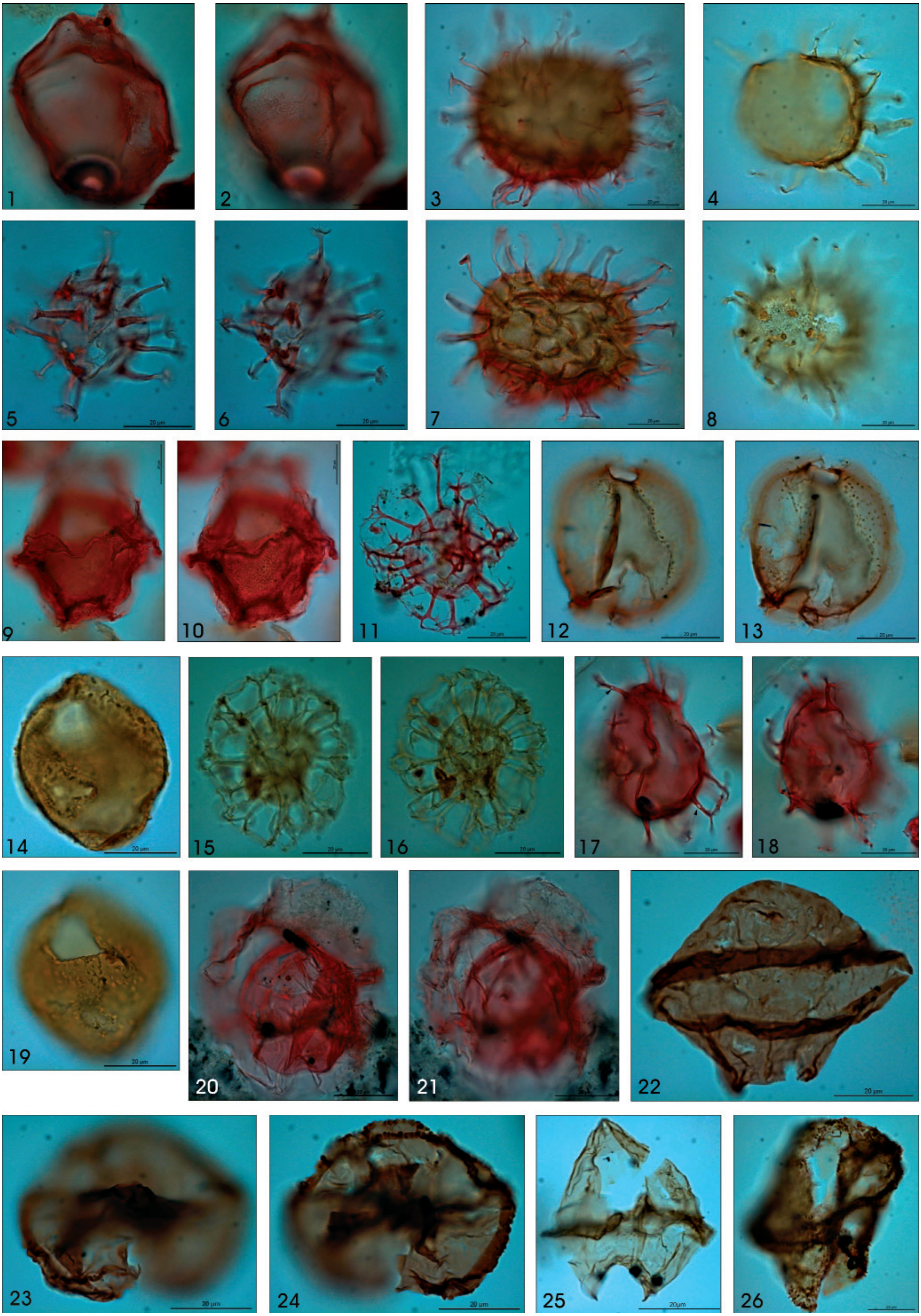
Fig. 22: *Lejeunecysta diversiforma*.
Sample Wa2-23, E. F. Ref. J50, mid-focus.

Figs. 23–24: *Selenopemphix bothrion*.
Sample Wa3-23, E. F. Ref. L31, low and high foci.

Fig. 25: *Lejeunecysta fallax*.
Sample W01-20, slide A, E. F. Ref. D8-3.

Fig. 26: *Trinovantedinium* sp. cf. *T. applanatum*.
Sample W01-15, slide A, E. F. Ref. S36-4, lateral view.

Scale bar 20 μm.
E. F. Ref. = England Finder Reference.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