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Dinoflagellate cysts and Ammonoids from Upper Cretaceous sediments of the Pemberger Formation (Krappfeld, Carinthia, Austria)

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(With 3 plates, 2 figures, 1 table)

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Abstract

Dinoflagellate cysts (dinocysts) and acritarchs are described for the first time from the Pemberger Formation of the Gosau Group (Krappfeld, Carinthia, Austria). The dinoflagellate cyst assemblage is quite diverse and well preserved and compositionally similar to those described from Upper Cretaceous strata in northern Italy, Germany and the Czech Republic. Many stratigraphically significant taxa are documented, among them *Alisogymnium nucleases*, *Cannosphaeropsis utinensis*, *Florentinia mayii*, *Isabelidinium cooksoniae* and *Xenascus ceratioides*. They support a Campanian to Maastrichtian age. Ammonoids observed in this study are instead rare within the investigated section: although several taxa were previously described to occur in this area, only *Pachydiscus* (*Pachydiscus*) *haldemsis* and some indeterminable fragments were found in the present study.

Key words: Dinoflagellata, Ammonoidea, biostratigraphy, Upper Cretaceous.

Zusammenfassung

Zysten von Dinoflagellaten (Dinozysten) und Arcritarchen werden zum ersten Mal aus der Pemberger-Formation der Gosau-Gruppe (Krappfeld, Kärnten, Österreich) beschrieben. Die beschriebene Vergesellschaftung von Dinoflagellaten-Zysten ist relativ divers und gut erhalten und in ihrer Zusammensetzung sehr ähnlich der Vergesellschaftung aus gleichaltrigen Ablagerungen von Nord-Italien, Deutschland und der Tschechischen Republik. Viele stratigraphisch signifikante Formen sind dokumentiert. Darunter finden sich Arten wie *Alisogymnium nucleases*, *Cannosphaeropsis utinensis*, *Florentinia mayii*, *Isabelidinium cooksoniae* und *Xenascus ceratioides*. Der Fossilbefund lässt auf ein Campanium bis Maastrichtium Alter schließen. Was die Makrofossilien betrifft, so konnten nur wenige Ammoniten aus dem bearbeiteten Intervall geborgen werden. Obwohl schon einige Arten aus diesem Gebiet beschrieben worden sind, wurden nur Vertreter der Art *Pachydiscus (Pachydiscus) haldemsis* sowie einige unbestimmbare Ammonitenreste entdeckt.

Schlüsselwörter: Dinoflagellata, Ammonoidea, Biostratigraphie, Oberkreide.

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Introduction

Upper Cretaceous sediments of the Krappfeld in Carinthia (Austria) yield diverse dinoflagellate cysts, benthic foraminifera (SCHREIBER 1979, 1980) and some ammonoids. Earlier investigations on the micro- and macrofauna were done by THIEDIG & WIEDMANN (1976). Based on foraminifera, SCHREIBER (1980) suggested an early Maastrichtian age for these deposits belonging to the Krappfeld Group (Krappfeld Gruppe, VAN HINTE 1963). Same early Maastrichtian age was suggested for the unit by THIEDIG & WIEDMANN (1976), who dated the sequence by ammonites. These authors collected *Pseudokossmaticeras brandti*, *Pseudokossmaticeras tercense*, *Pseudokossmaticeras galicianum* and *Pachydiscus carinthiacus*. The proposed age then unfortunately was based on the incorrect use of the range of *P. brandti* which finally resulted in assigning the investigated unit to early Maastrichtian age (HANCOCK & KENNEDY 1993). Recent studies show that the ammonoid fauna (including species like *Pseudokossmaticeras tercense* (SEUNES, 1892)) indicate a Late Campanian age of the upper part of the Cretaceous at the Krappfeld. This age is largely confirmed by the micro- and macrofossils of our investigations because some of the fossil remnants hint at Late Campanian age. The rare ammonoid fauna is accompanied by lamellaptychi, belemnites, bivalves, serpulids, fish remains, trace fossils and plant debris.

This study provides new taxonomic and biostratigraphic data on dinoflagellate cysts and ammonoids from the Pemberger Formation at the Krappfeld that confirm a Campanian to Maastrichtian age for this unit. The dinoflagellate biostratigraphy is correlated with other micro- and macrofossil zonations (SUMMESBERGER et al. 1999) of the studied section and with dinoflagellate zonation schemes of Germany (KIRSCH 1991), northern Italy (RONCAGLIA and CORRADINI 1997a) and the Mediterranean area (HOEK et al. 1996).

Previous Dinoflagellate Cyst Studies

Few studies have been published on Late Cretaceous dinoflagellate cysts of Austria. KIRSCH (1991) studied 6 samples from the Waidach section near Salzburg and suggested a Late Maastrichtian age. PAVLISHINA et al. (2004) carried out a palynological study on Upper Cretaceous sediments (upper Turonian-Maastrichtian) from many sections in the Northern Calcareous Alps, focusing on sporomorphs and dinoflagellate cysts. WAGREICH et al. (2006), in an integrated study with foraminifera and calcareous nannoplankton, contributed a short note on the late Albian to early Cenomanian dinoflagellate cysts of the lower red shale interval in the Rhenodanubian Flysch (Upper Austria).

Although Austria lacks literature on Late Cretaceous dinoflagellate cysts, extensive studies from other European sections are available (e.g. ALBERTI 1961; CLARKE & VERDIER 1967; KJELLSTRÖM 1973; CORRADINI 1973; HANSEN 1977; ROBASZYNSKI et al. 1985; KIRSCH 1991; MARHEINECKE 1992; SIEGL-FARKAS & WAGREICH 1996; SIEGL-FARKAS 1997; RONCAGLIA & CORRADINI 1997a, b; TORRICELLI & AMORE 2003; SKUPIEN & MOHAMED 2008). Notable studies from the circum-Mediterranean include those of SONCINI & RAUSCHER (1990), EL BEIALY (1995), HOEK et al. (1996) and MAHMOUD & SCHRANK (2007).

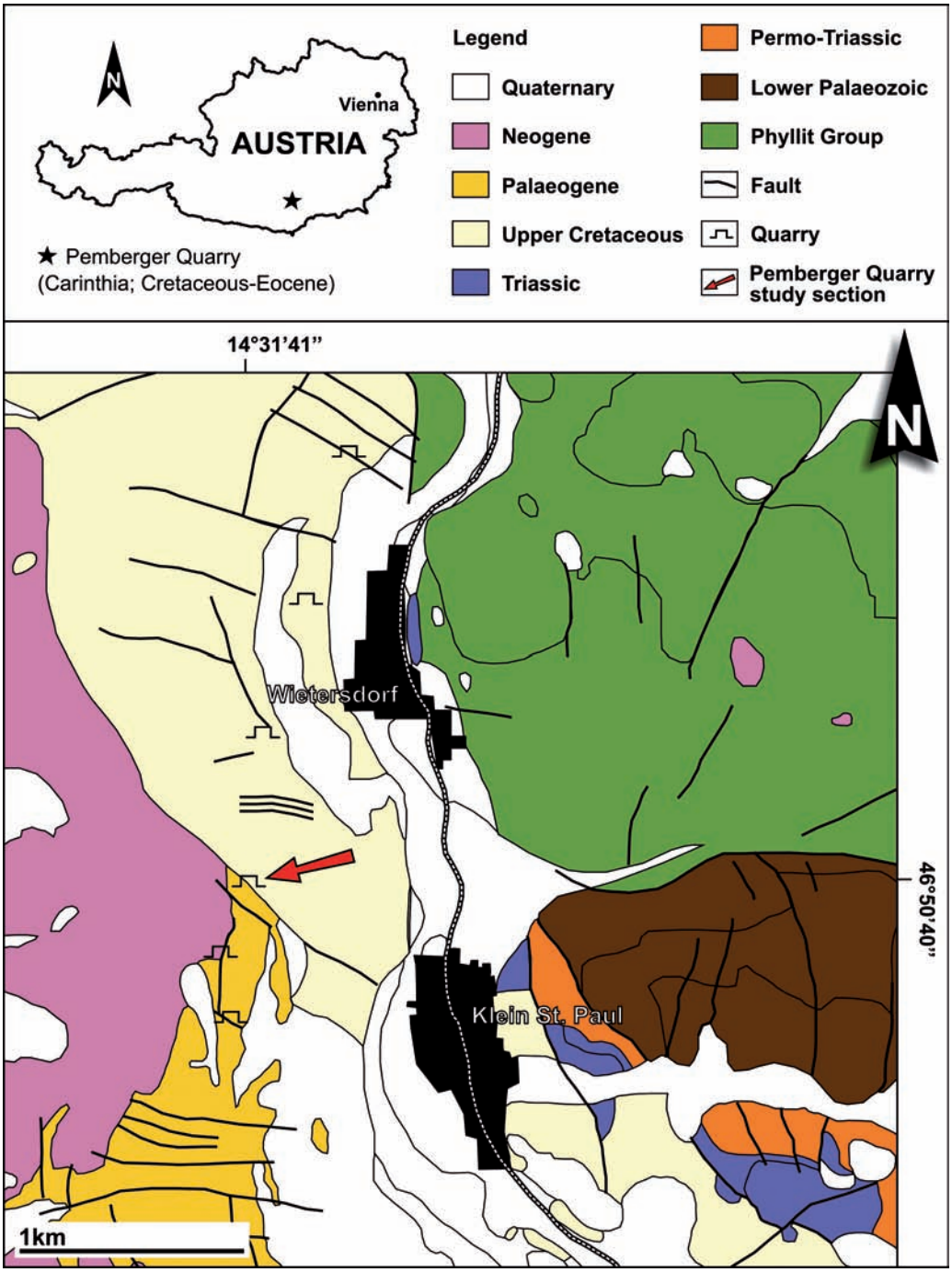

Fig. 1: Geological map of the Krappfeld area and sampling location.

Study Area

In general, the investigated deposits belong to the Gosau Group and crop out on a surface of about 100 km². These deposits are composed of flyschoid limestone and marl with a thickness up to 1500 m within the Krappfeld area (compare TIEDIG & WIEDMANN 1976). The Krappfeld Subgroup is incorporated into the Gosau Group, with the Pemberger Formation spanning part of the Upper Cretaceous.

The observed section within the Pemberger Quarry (fig. 1) is about 5.5 m thick and consists mainly of marl and marly limestones. Bed 24 consists of a lithoclastic breccia. The thickness of single beds is variable; usually, beds are about 10-15 cm thick and separated by thin interbeds, but at the base and top of the section, bed thickness increases to 50-80 cm. Lithologically, the beds consist of marly limestone with higher calcareous content than the interbeds; this makes them more resistent to weathering. A detailed log is provided in figure 2.

Materials and Methods

For dinoflagellate cyst analyses, nine samples were collected. Small bulk samples were processed in the Separation Laboratory of the Institute of Earth Sciences, University of Graz, following standard palynological preparation procedures (e.g. WOOD et al. 1996). About 20-25 g of each sample was finely crushed and dissolved in cold hydrochloric acid (35%) and cold hydrofluoric acid (40%). Neutralization after HCl and HF was achieved by repeated decanting. A slight oxidation by diluted HNO_3 was initiated for some samples for 45 to 60 seconds, followed by washing with diluted NaOH. The remaining residue was sieved through 20 micron nylon mesh and stained with Saffranin "O". Two slides from each sample were prepared using glycerine jelly and then sealed with nail varnish for light microscopy. One SEM stub from each sample was prepared too. Residues, slides and SEM stubs are housed at the Institute of Earth Sciences, University of Graz, with labels PE-01 to PE-26 (e.g. PE-01 equates to Pemberger Quarry-bed 01).

Systematic Part

Palynofloral characteristics

All the studied samples were productive and yielded well-preserved dinocysts. The total record consisted of about 74 dinocyst taxa along with three acritarch genera (*Tarsisphaeridium*, *Paralecaniella*, ? *Cyclopsiella*) and microforaminiferal test linings (compare listing in Appendix A). Terrestrial palynomorphs are rare throughout the section. Range charts of stratigraphically significant species taxa were plotted against the lithological log of the studied section (fig. 2). There was no major change in the dinocyst assemblage throughout the studied samples. Selected taxa are illustrated on plates 1 and 2. The dinoflagellate cyst taxa listed in the present paper are fully referenced in FENSOME et al. (2008).

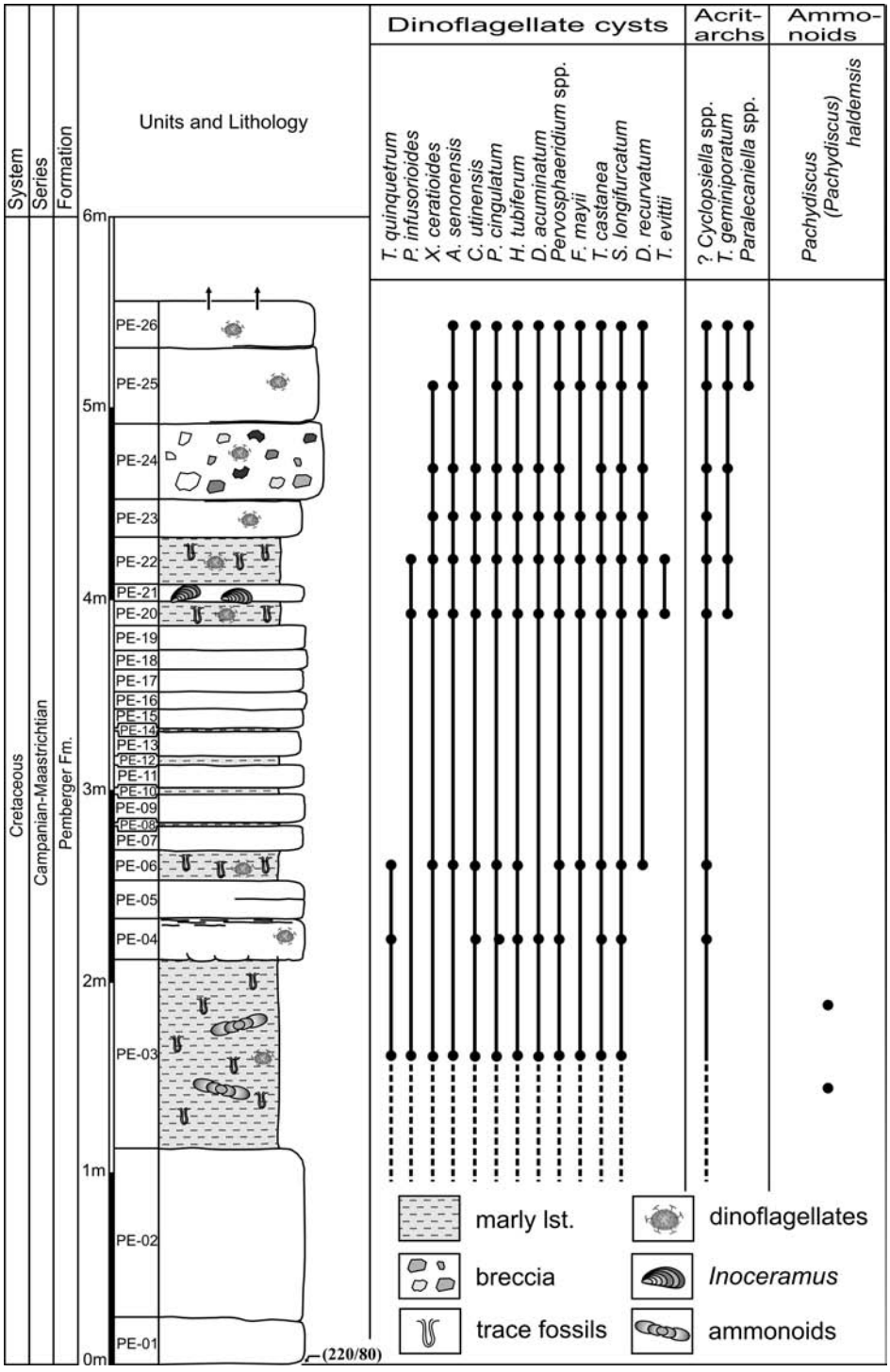

Fig. 2: Range chart of stratigraphically relevant species of palynomorphs and ammonoids.

Age assignment based on dinoflagellate cysts

Although only few samples were studied, the dinocyst assemblage is diverse and age diagnostic as many marker taxa suggesting a Late Cretaceous age have been recorded. No formal or informal zonation is proposed due to insufficient material. The recorded dinoflagellate cyst assemblage has been dated by comparison with assemblages documented from adjacent areas (ROBASZYNSKI et al. 1985; KIRSCH 1991; RONCAGLIA & CORRADINI 1997a) and especially by correlation with lowest and highest occurrences of dinocyst taxa calibrated by WILLIAMS et al. (2004).

Florentinia mayii KIRSCH, 1991 (pl. 2, fig. 4) was described from the lower Maastrichtian of Moos-Graben, Germany. However, WILLIAMS et al. (2004) calibrated its first occurrence in the northern hemisphere in the early Middle Campanian (79.0 Ma) and the last occurrence in the latest Campanian (71.86 Ma). Since this species was recorded in all of the studied samples, they cannot be older than Middle Campanian.

According to KIRSCH (1991), *Cannosphaeropsis utinensis* WETZEL, 1933 (pl. 1, fig. 3) ranges from the lower Campanian to lower Maastrichtian, yet its earliest occurrence could be as far back as the upper Santonian according to FOUCHER (1976), HARDENBOL et al. (1998: chart 5) and PRINCE et al. (1999). Furthermore, MAY (1980) suggested a latest Campanian to earliest Maastrichtian age. A record from the Campanian to lower Maastrichtian of the northern Apennines, Italy, is reported by RONCAGLIA & CORRADINI (1997a) and RONCAGLIA (2002). Closer to the study area, its highest occurrence was recorded from the upper Campanian in Hungary (SIEGL-FARKAS & WAGREICH 1996; SIEGL-FARKAS 1997).

The presence of *Xenascus ceratioides* (DEFLANDRE, 1937) LENTIN & WILLIAMS, 1973 (pl. 2, figs 2, 3), *Trichodinium castanea* (DEFLANDRE, 1935) CLARKE & VERDIER, 1967, *Surculosphaeridium*? *longifurcatum* (FIRTION, 1952) DAVEY et al., 1966 and *Palaeohystrichophora infusorioides* DEFLANDRE, 1935 (pl. 1, fig. 11) indicates a Campanian to (?) earliest Maastrichtian age (MAY 1980; TOCHER 1987; MAHMOUD & SCHRANK 2007).

Hystrichosphaeridium tubiferum (EHRENBERG, 1838) DEFLANDRE, 1937b (pl. 1 fig. 8) is a long-ranging species, a common constituent of the Late Cretaceous assemblages, and geographically widespread. Occurrences of this taxon have been recorded from the upper Turonian to Campanian of the Paris Basin (FOUCHER 1975); Campanian to Maastrichtian of the Atlantic coastal plain of New Jersey and Delaware (AURISANO 1989); ?Upper Campanian to Maastrichtian of Germany (KIRSCH 1991; MARHEINECKE 1992).

The presence of *Glaphyrocysta expansa* (CORRADINI, 1973) RONCAGLIA & CORRADINI, 1997 strongly indicates an Early Maastrichtian age (RONCAGLIA & CORRADINI 1997a). This short-ranging species was documented across the Lower/Middle Maastrichtian boundary in the northern Apennines, Italy. Its lowest occurrence delineates the *G. expansa* subzone (RONCAGLIA & CORRADINI 1997a). *Pervosphaeridium intervelum* KIRSCH, 1991 (pl. 1, fig. 13) was described from the Lower to Middle Campanian of Germany (KIRSCH 1991). It ranges from Upper Santonian (PRINCE et al. 1999) to Maastrichtian (SCHIØLER et al. 1997).

In addition to the key taxa discussed above, there are other notable taxa. Two specimens of *Apteodinium deflandrei* (pl. 2, fig. 7) were obtained from sample PE-20. This species was recorded in the Upper Campanian from the Tercis Quarry (France) by SCHIØLER &

WILSON (2001). According to WILLIAMS et al. (2004), its highest occurrence is within the lower Maastrichtian in the northern hemisphere (68.8 Ma). A Campanian-Maastrichtian age of the investigated sediments is also supported by the presence of *Dinogymnium acuminatum* EVITT et al. (1967), which is a well-known and widely distributed Late Cretaceous fossil (SCHRANK 1984, 1987; SONCINI & RAUSCHER 1990; PAVLISHINA et al. 2004).

Ammonoid taxa

Conventions: NHMW (Museum of Natural History Vienna, Austria); PIB (Institut für Paläontologie, Rheinische Friedrich-Wilhelms-Universität, Bonn, Germany); D (Diameter); Wh (Whorl height); U (Diameter of Umbilicus).

Class Cephalopoda CUVIER, 1797

Order Ammonoidea ZITTEL, 1884

Suborder Ammonitina HYATT, 1889

Superfamily Desmoceratoidea ZITTEL, 1895

Family Pachydiscidae SPATH, 1922

Genus *Pachydiscus* ZITTEL, 1884

Type species: *Ammonites neubergicus* HAUER, 1858, p. 12, pl. 2, fig. 1-3, by subsequent designation of DE GROSSOUVRE 1894.

Pachydiscus (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867)

Plate 3, figs 1, 2

1867 *Ammonites haldemsis* SCHLÜTER, p. 19, pl. 3, fig. 1.
1872 *Ammonites haldemsis* SCHLÜTER, p. 70.
1894 *Pachydiscus koeneni* DE GROSSOUVRE, p. 178.
1984 *Pachydiscus* (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867) – KENNEDY & SUMMESBERGER, p. 158, pl. 4, fig. 1-5, pl. 5, fig. 1, pl. 6, fig. 2; pl. 7, fig. 1-11; pl. 13, fig. 1. With synonymy.
1997 *Pachydiscus* (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867) – KENNEDY & KAPLAN, p. 40, pl. 4, fig. 5-8; pl. 5, fig. 4; pl. 6, fig. 1,2; pl. 7, fig. 2,3; pl. 8,9; pl. 10, fig. 5,8.
1998 *Pachydiscus* (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867) – KENNEDY & JAGT, p. 158, pl. 1, fig. 2-4.
2004 *Pachydiscus* (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867) – JAGT et al., p. 575, pl. 1, fig. 9.

Lectotype is the original of SCHLÜTER (1867, p. 3, fig. 1) subsequently designated and refigured by KENNEDY & SUMMESBERGER (1984: p. 158, pl. 7, figs 3, 4).

M a t e r i a l : Two individuals, NHMW 2008z0276/0001 and NHMW 2008z0276/0002 from the Late Cretaceous Gosau Group of the Krappfeld in Carinthia, Austria.

D e s c r i p t i o n : Two flattened, corroded and fragmented internal moulds. Measurements are exaggerated by post mortem compaction. No shell remains are preserved, fragments of sutures are visible but undecipherable. Both individuals are adult macroconchs and have parts of the body chamber preserved. The whorl section cannot be restored, whorls covering about two thirds of the preceding one. Between 25 and 30 bullae per volution give rise to strong primary ribs. Intercalatories appear in irregular distances in the outer third of the flanks. At the venter about 40 ribs per volution can be counted. Ribs are about 4 mm broad and spaced irregularly about 5 mm apart. They cross the flank in a slight flexuous curve or with a shallow concavity, sweeping finally over the venter with a shallow adapertural curvature.

	D	Wh	Wh%	U	U%
NHMW/08/276/1	160	70	43.7%	40	25%
NHMW/08/276/2	131	61.5	47%	38.4	29%
PiB 50b	147	67	45.5%	38	26.2%

Tab. 1: Measurements of the Wietersdorf specimens in comparison to the lectotype of *Pachydiscus koeneni* De Grossouvre, 1894 (PIB 50b).

D i s c u s s i o n : Both individuals are interpreted to be specifically identical and macroconchs of *Pachydiscus (Pachydiscus) haldemsis* (Schlüter, 1867), which were originally described as *Pachydiscus koeneni* De Grossouvre, 1894 (Kennedy & Summesberger 1984, p. 158). The co-occurring *Pachydiscus carinthiacus* Thiedig & Wiedmann 1976 (pl. 2, fig. 4) is a fragment of an adult volution which shows a distinct change in ornament from delicate and narrow standing ribs to coarse and distant ones. Co-occurring taxa of *Pseudokossmaticeras* differ by their smaller whorl height, *P. brandti* (Redtenbacher, 1873) also by its wider umbilicus (38%) and much fewer and coarser ribs (25 primaries on the last whorl of the lectotype). *Pseudokossmaticeras galicianum* (Favre, 1869) differs by its much finer ribbing.

O c c u r r e n c e : *Pachydiscus* (*Pachydiscus*) *haldemsis* (Schlüter, 1867) is a widely distributed Late Campanian species. It occurs in the Northern Temperate Realm. In Austria it is described from the Late Campanian of Gams (Styria, Austria) by Summesberger et al. (1999) and from the Gschliefgraben (Kennedy & Summesberger 1984). Co-occurrence with *Pseudokossmaticeras brandti* (Redtenbacher, 1873) (Thiedig & Wiedmann 1976) in the "Krappfeld Gosau" endorses its stratigraphical position. The former use of *P. brandti* to indicate Lower Maastrichtian (Thiedig & Wiedmann 1976: 23-24) is outdated (Hancock & Kennedy 1993, p. 156). Co-occurrence with the Maastrichtian *Pachydiscus neubergicus* (Hauer) (Thiedig & Wiedmann, 1976: 23) is based upon a doubtful juvenile specimen: *Pachydiscus* sp. juv. aff. *neubergicus* (Hauer; Thiedig & Wiedmann, 1976, fig. 2A) and an earlier described adult *Pachydiscus neubergicus* (Hauer) of 10 cm diameter (Redlich 1900).

Conclusions

Dinoflagellate cysts from the Upper Cretaceous of Carinthia (Austria) are described for the first time. The encountered palynomorphs are well preserved and diversified. The identified palynofloral assemblage includes 77 species belonging to 40 genera of dinoflagellates and 3 genera of acritarchs. However, the sporomorphs (pollen and spores) are already documented but no attempt has been done, neither to identify them nor to use them as biostratigraphic tool, for dating the section. An Early Maastrichtian age was proposed for the Pemberger Formation based on foraminifera (SCHREIBER 1979, 1980) and ammonoids (THIEDIG & WIEDMANN 1976). According to this study Campanian-Early Maastrichtian age is suggested for at least the upper part of the Pemberger Formation based on the occurrence of dinoflagellate cysts like *Alisogymnium nucleases*, *Cannosphaeropsis utinensis*, *Florentinia mayii*, *Isabelidinium cooksoniae* and *Xenascus ceratioides*. Additionally, the occurrence of the newly found ammonoid taxon *Pachydiscus (Pachydiscus) haldemsis* supports the age proposed by the microflora, as it is an indicator for Late Campanian age.

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Appendix

List of dinocyst species recorded

Plate and figure numbers are provided when the taxon is illustrated. Taxonomy follows FENSOME et al. (2008) and references therein.

1. *Achomosphaera ramulifera* (DEFLANDRE, 1937b) EVITT, 1963 (pl. 1, fig. 1)
2. *Actinotheca aphroditae* COOKSON & EISENACK, 1960a
3. *Alisogymnium eucleases* (COOKSON & EISENACK, 1970a) LENTIN & VOZZHENNIKOVA, 1990
4. *Apteodinium* cf. *reticulatum* SINGH, 1971 (pl. 1, fig. 6)
5. *Apteodinium deflandrei* (CLARKE & VERDIER, 1967) LUCAS-CLARK, 1987 (pl. 2, fig. 7)
6. *Areoligera coronata* (WETZEL, 1933b) LEJEUNE-CARPENTIER, 1938
7. *Areoligera flandriensis* SLIMANI, 1994
8. *Areoligera guembelii* KIRSCH, 1991
9. *Areoligera senonensis* LEJEUNE-CARPENTIER, 1938
10. *Areoligera volata* DRUGG, 1967
11. *Balcattia cirrifera* COOKSON & EISENACK, 1974
12. *Batiacasphaera compta* DRUGG, 1970
13. *Biconidinium reductum* (MAY, 1980) KIRSCH, 1991
14. *Cannosphaeropsis utinensis* WETZEL, 1933 (pl. 1, fig. 3)
15. *Codoniella campanulata* (COOKSON & EISENACK, 1960a) DOWNIE & SARJEANT, 1965
16. *Coronifera oceanica* COOKSON & EISENACK, 1958 (pl. 1, fig. 4)
17. *Cometodinium*? *whitei* (DEFLANDRE & COURTEVILLE, 1939) STOVER & EVITT, 1978; emend. MONTEIL, 1991a
18. *Cordosphaeridium fibrospinosum* DAVEY & WILLIAMS, 1966b
19. *Cribroperidinium edwardsii* (COOKSON & EISENACK, 1958) DAVEY, 1969a
20. *Cribroperidinium*? *pyrum* (DRUGG, 1967) STOVER & EVITT, 1978
21. *Cyclonephelium crassimarginatum* COOKSON & EISENACK, 1974
22. *Dinogymnium acuminatum* EVITT et al., 1967 (pl. 1, fig. 2)
23. *Dinogymnium albertii* CLARKE & VERDIER, 1967
24. *Dinogymnium curvatum* (VOZZHENNIKOVA, 1967) LENTIN & WILLIAMS, 1973
25. *Dinogymnium westralium* (COOKSON & EISENACK, 1958) EVITT et al., 1967
26. *Diphyes recurvatum* MAY, 1980 (pl. 1, fig. 5)
27. *Downiesphaeridium multispinosum* (SINGH, 1964) ISLAM, 1993
28. *Exochosphaeridium bifidum* (CLARKE & VERDIER, 1967) CLARKE et al., 1968 (pl. 1, fig. 7)
29. *Exochosphaeridium phragmites* DAVEY et al., 1966
30. *Florentinia aculeata* KIRSCH, 1991 (pl. 1, fig. 9)

31. *Florentinia mantellii* (Davey & Williams, 1966b) Davey & Verdier, 1973
32. *Florentinia mayii* Kirsch, 1991 (pl. 2, fig. 4)
33. *Glaphyrocysta espiritosantensis* (Regali et al., 1974) Arai in Fauconnier & Masure, 2004
34. *Glaphyrocysta expansa* (Corradini, 1973) Roncaglia & Corradini, 1997
35. *Glaphyrocysta ordinata* (Williams & Downie, 1966c) Stover & Evitt, 1978 (pl. 1, fig. 10)
36. *Glaphyrocysta semitecta* (Bujak in Bujak et al., 1980) Lentin & Williams, 1981
37. *Hystrichosphaeridium recurvatum* (White 1842) Lejeune-Carpentier, 1940
38. *Hystrichosphaeridium salpingophorum* (Deflandre, 1935) Deflandre, 1937b; emend. Davey & Williams, 1966b
39. *Hystrichosphaeridium tubiferum* (Ehrenberg, 1838) Deflandre, 1937b; emend. Davey & Williams, 1966b (pl. 1, fig. 8)
40. *Hystrichosphaeropsis ovum* Deflandre, 1935
41. *Isabelidinium cooksoniae* (Alberti, 1959b) Lentin & Williams, 1977a (pl. 2, fig. 1)
42. *Manumiella*? *cretacea* (Cookson, 1956) Bujak & Davies, 1983 (pl. 2, fig. 8)
43. *Nelsoniella aceras* Cookson & Eisenack, 1960a
44. *Operculodinium centrocarpum* (Deflandre & Cookson, 1955) Wall, 1967
45. *Palaeohystrichophora infusorioides* Deflandre, 1935 (pl. 1, fig. 11)
46. *Pervosphaeridium intervelum* Kirsch, 1991 (pl. 1, fig. 12)
47. *Pervosphaeridium pseudohystrichodinium* (Deflandre, 1937) Yun, 1981
48. *Phelodinium exilicornutum* Smith, 1992
49. *Phelodinium pentagonale* (Corradini, 1973) Stover & Evitt, 1978
50. *Phelodinium tricuspe* (Wetzel, 1933a) Stover & Evitt, 1978
51. *Pterodinium cingulatum* (Wetzel, 1933) Below, 1981 (pl. 1, fig. 12)
52. *Pterodinium crassimuratum* (Davey & Williams, 1966a) Thurow et al., 1988
53. *Raetiaedinium truncigerum* (Deflandre, 1937b) Kirsch, 1991
54. *Spinidinium echinoideum* (Cookson & Eisenack, 1960a) Lentin & Williams, 1976 (pl. 2, fig. 9)
55. *Spinidinium eggeri* Kirsch, 1991
56. *Spiniferites cooksoniae* Lentin & Williams, 1977b
57. *Spiniferites katatonos* Corradini, 1973
58. *Spiniferites multibrevis* (Davey & Williams, 1966a) Below, 1982c
59. *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854
60. *Spiniferites ramosus* subsp. *granosus* (Davey & Williams, 1966) Lentin & Williams, 1973
61. *Spiniferites scabrosus* (Clarke & Verdier, 1967) Lentin & Williams, 1975
62. *Surculosphaeridium basifurcatum* Yun, 1981
63. *Surculosphaeridium belowii* Yun, 1981
64. *Surculosphaeridium cassospinum* Yun, 1981 (pl. 2, figs 11, 12)
65. *Surculosphaeridium longifurcatum* (Firtion, 1952) Davey et al., 1966
66. *Tanyosphaeridium xanthiopyxides* (Wetzel, 1933b) Stover & Evitt, 1978; emend. Sarjeant, 1985b
67. *Trabeculidium quinquetrum* Duxbury, 1980 (pl. 2, figs 13-15)
68. *Trichodinium castanea* (Deflandre, 1935) Clarke & Verdier, 1967
69. *Trithyrodinium evittii* Drugg, 1967 (pl. 2, figs 5, 6)

70. *Trithyrodinium suspectum* (MANUM & COOKSON, 1964) DAVEY, 1969b
71. *Xenascus australensis* COOKSON & EISENACK, 1969
72. *Xenascus ceratioides* (DEFLANDRE, 1937b) LENTIN & WILLIAMS, 1973 (pl. 2, figs 2, 3)
73. *Xenascus gochtii* (CORRADINI, 1973) STOVER & EVITT, 1978
74. *Xenascus sarjeantii* (CORRADINI, 1973) STOVER & EVITT, 1978

Acritarchs

1. *Tarsisphaeridium geminiporatum* RIEGEL, 1974 (pl. 2, fig. 10)
2. *Paralecaniella* spp.
3. ? *Cyclopsiella* spp.

Plate 1

All are SEM microphotographs. The species names are followed by sample number. Scale bars equal 20 µm.

Fig. 1: *Achomosphaera ramulifera* (DEFLANDRE, 1937b) EVITT, 1963; sample PE-23; dorsal view.

Fig. 2: *Dinogymnium acuminatum* EVITT et al., 1967; sample PE-26; ventral view.

Fig. 3: *Cannosphaeropsis utinensis* WETZEL, 1933; sample PE-06; uncertain orientation.

Fig. 4: *Coronifera oceanica* COOKSON & EISENACK, 1958; sample PE-26; ? ventral view.

Fig. 5: *Diphyes recurvatum* MAY, 1980; sample PE-06; ? ventral view.

Fig. 6: *Apteodinium* cf. *reticulatum* SINGH, 1971; sample PE-23; dorsal view.

Fig. 7: *Exochosphaeridium bifidum* (CLARKE & VERDIER, 1967) CLARKE et al., 1968; sample PE-23; ? apical view.

Fig. 8: *Hystrichosphaeridium tubiferum* (EHRENBERG, 1838) DEFLANDRE, 1937; emend. DAVEY & WILLIAMS, 1966; sample PE-25; apical view.

Fig. 9: *Florentinia aculeata* KIRSCH, 1991; sample PE-26; oblique dorsal view.

Fig. 10: *Glaphyrocysta ordinata* (WILLIAMS & DOWNIE, 1966c) STOVER & EVITT, 1978; sample PE-25; ventral view.

Fig. 11: *Palaeohystrichophora infusorioides* DEFLANDRE, 1935; sample PE-20; lateral view.

Fig. 12: *Pterodinium cingulatum* (WETZEL, 1933) BELOW, 1981a; sample PE-24; antapical view.

Fig. 13: *Pervosphaeridium intervelum* KIRSCH, 1991; sample PE-22; uncertain orientation.

Fig. 14: *Xenascus gochtii* (CORRADINI, 1973) STOVER & EVITT, 1978; sample PE-06; apical view.

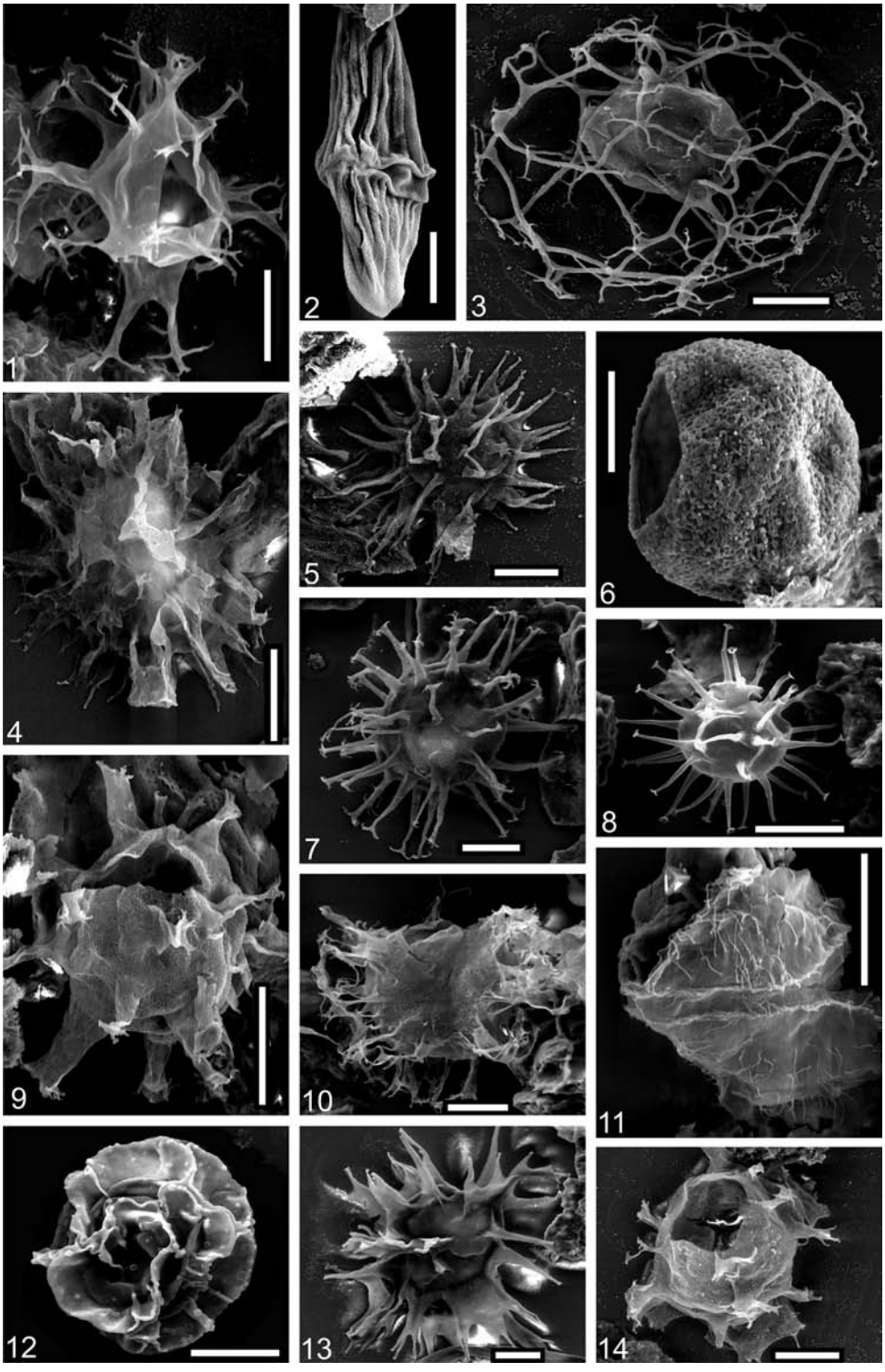

Plate 2

All are bright field microphotographs. The species names are followed by sample number, slide number and England Finder reference. Scale bars equal 20 µm.

Fig. 1: *Isabelidinium cooksoniae* (Alberti, 1959b) Lentin & Williams, 1977a; sample PE-06, slide A, K54, dorsal view.

Figs. 2, 3: *Xenascus ceratioides* (Deflandre, 1937b) Lentin & Williams, 1973; sample PE-22, slide B, S24/3, successive foci.

Fig. 4: *Florentinia mayii* Kirsch, 1991; sample PE-20, slide A, D51, dorsal view.

Figs. 5, 6: *Trithyrodinium evittii* Drugg, 1967; sample PE-20, slide A, G26, dorsal view.

Fig. 7: *Apteodinium deflandrei* (Clarke & Verdier, 1967) Lucas-Clark, 1987; sample PE-20, slide A, N28/3, ? ventral view.

Fig. 8: *Manumiella*? *cretacea* (Cookson, 1956) Bujak & Davies, 1983; sample PE-24, slide A, U55/4, dorsal view.

Fig. 9: *Spinidinium echinoideum* (Cookson & Eisenack, 1960a) Lentin & Williams, 1976; sample PE-20, slide A, C29/3, ventral view?

Fig. 10: *Tarsisphaeridium geminiporatum* Riegel, 1974; sample PE-22, slide A, O48, uncertain orientation.

Figs. 11, 12: *Surculosphaeridium cassospinum* Yun, 1981; sample PE-03, slide A, E34/4, successive foci.

Figs. 13-15: *Trabeculidium quinquetrum* Duxbury, 1980; sample PE-04, slide B, O70/1, successive foci.

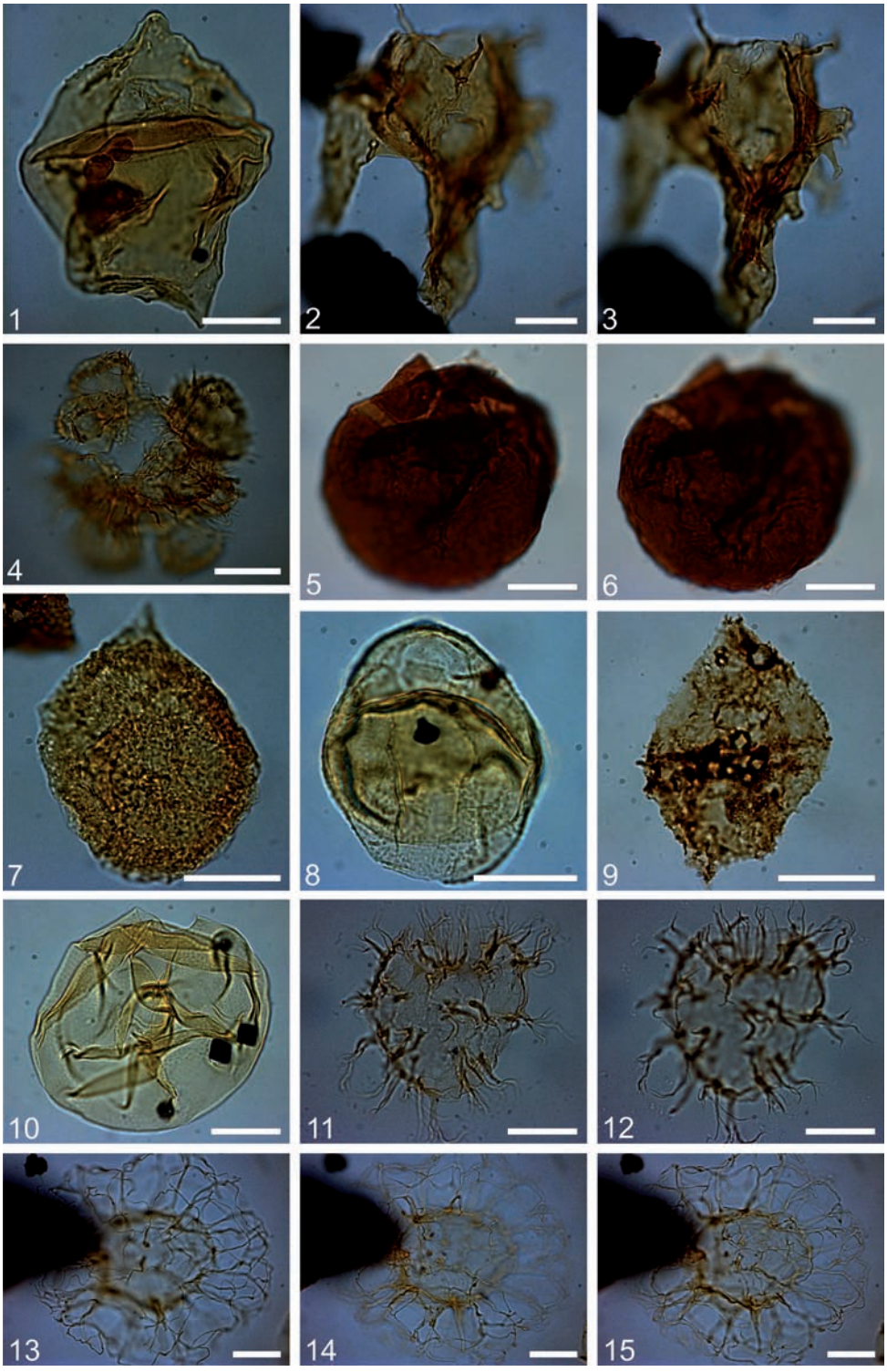

Plate 3

Fig. 1, 2: *Pachydiscus* (*Pachydiscus*) *haldemsis* (SCHLÜTER, 1867); sample PE-03; lateral view, NHMW 2008z0276/0001-2.