



## Baltica 14 (2001) 40-51

### Organic-walled microfossils from the central Baltic Sea, indicators of environmental change and base for ecostratigraphic correlation

Wolfram W. Brenner

#### Abstract

Sediment cores from Bornholm Basin, Gotland Basin and North Central Basin were studied for their organic-walled microfossil assemblages. Absolute abundance and morphometric measurements of these microfossils are used for an ecostratigraphic correlation and interpretation of the environmental changes in the central Baltic Sea basins. Increasing abundance of freshwater phyto- and zooplankton during the final stage of the Ancylus Lake point to a slow eutrophication. Assemblage composition of organic-walled microfossils and changes in processes length of dinoflagellate cyst are used for interpretation of the salinity variation of the Litorina Sea stage. A rapid decrease of absolute dinoflagellate cyst abundance in all three basins occurs at the late Litorina Sea stage. The Post-Litorina Sea stage is marked by a low abundance of dinoflagellate cysts and organic walled microfossils in general. In the uppermost metre of the cores from all three basins a significant increase in the abundance of cladoceran, coccal green algae, and copepod eggs is present, whereas the abundance of dinoflagellate cysts is still low.

□ Baltic Sea, Bornholm Basin, Gotland Basin, North Central Basin, organic walled microfossils, Holocene, paleosalinity, paleoecology, ecostratigraphic correlation.

□ Wolfram Brenner [wbrenner@geomar.de] GEOMAR, Wischhofstr.1-3, 24148 Kiel, Germany.

□ Received 25 June 2001; accepted 9 November 2001.

#### INTRODUCTION

In contrast to the inorganic skeletal elements of calcareous or siliceous microfossils organic-walled microfossils consist of extremely stable biopolymers such as sporopollenin, cutin or chitin. These substances are common in algae, plants and invertebrates remains. Therefore, organic walled microfossils comprise for example spores and pollen (palynomorphs *sensu stricto*) as well as cyanobacteria, dinoflagellate cysts, leaf cuticle, tintinnid cysts, and even eggs and other remains of annelids, crustacean, and insects. Due to the different environmental preferences of the various organisms, ranging from terrestrial and freshwater to marine forms, organic-walled microfossils are an excellent tool for paleoecological studies.

Up to now, most micropalaeontological investigations in the Baltic Sea deal with siliceous microfossils (e.g.: Abelmann 1985; Andrén and Andrén 1999; Miller and Risberg 1990; Witkowski 1994), or pollen (e.g.:

Averdieck 1972; Eriksson 1994; Eronen et al. 1990; Stelle et al. 1994). Only few investigations have been carried out on dinoflagellate cysts in the Baltic Sea and other low salinity environments (Dale 1996; Ellegaard 2000; Matthiessen and Brenner 1995; Matthiessen and Brenner 1996; Matthiessen and Brenner in press; Nehring 1994a; Nehring 1994b; Wall et al. 1973). The present investigation gives a first ecostratigraphic zonation and correlation based on organic walled microfossils in the Central Baltic Sea.

#### MATERIAL AND METHODS

The sediment cores were sampled during a cruise with *R/V Petr Kottsov* in July and August 1997 by using a box core device (Table 1). Due to the high water content, the uppermost sediments were mixed and therefore not useful for investigation. For this reason two cores from the North Central Basin from the same

Table 1. Core sampling localities

Locality	Core no.	Latitude	Longitude	Depth	Used interval
Bornholm Basin	211630-9	55°22,6500N	15°23,8463E	93,57m	39-540cm
Gotland Basin	211660-6	57°17,0283N	20°07,1386E	241,3m	34-681cm
North Central Basin	211670-4	58°49,1843N	20°15,2026E	176,1m	200-670cm
North Central Basin	211670-7	58°49,1622N	20°15,1363E	175,2m	54-200cm

locality are used (Table 1): one with a longer record (211670-4) and another with undisturbed sediments at the top of the core (211670-7).

The sediment cores were sampled continuously with 1 m long U-tubes with a diameter of 2 cm, and cut afterward in 1 cm slices. All samples were freeze-dried. Samples for microfossil investigations were treated with 10% hydrochloric and 40% hydrofluoric acid to remove the carbonates and silicates and extensively washed through a six-micrometer sieve to remove the amorphous organic material. The residues were mounted on microscopical slides with glycerine jelly. Prior to the preparation, a defined quantity of *Lycopodium* spores ( $10^5$  spores per gram dry sediment) was added to the sample, to make the analysis of the absolute abundance of microfossils in the sediment possible.

## ENVIRONMENTAL SIGNIFICANCE OF ORGANIC WALLED MICROFOSSILS

### Dinoflagellate cysts

Dinoflagellates comprise groups of predominantly unicellular, flagellated organisms that possess both photosynthetic (autotroph) and non-photosynthetic (heterotroph) members. Some species are restricted to the marine realm, others tolerate a wide range of salinity, and others are restricted to freshwater. An important factor for interpreting the fossil record of dinoflagellate cysts is, that only a small part of the living dinoflagellate produce cysts, and the cyst building takes place within a few hours or days and reflect therefore the environmental conditions during a small time interval.

(Dale 1996) summarised the basic elements of the dinoflagellate cyst salinity signal, which is based among others on unpublished core top samples from the Baltic and Black Sea as followed:

- Most of the coastal/neritic cyst species tolerate a broad salinity range from normal marine salinity of about 35 psu to reduced marine salinity of about 20 psu. Below 20 psu the species diversity decrease rapidly.

- Environments with salinity below 3 psu are characterised by cyst assemblages restricted to *Operculodinium centrocarpum* (*Protoceratium reticulatum*) and small *Spiniferites*. The salinity interval from 3-10 psu in the Black Sea is characterised

by the presence of *Pyxidinospis psilata* (*Tectatodinium psilatium*), and above 7 psu there is a general increasing abundance of *Lingulodinium machaerophorum* (*Lingulodinium polyedrum* = *Gonyaulax polyedra*).

- The processes length of *O. centrocarpum*, *L. machaerophorum*, and *Spiniferites spp.* is reduced in water with low salinity.

Recent investigations of dinoflagellate cyst assemblages from surface sediments from the western Baltic, Skagerrak, and North Sea suggest a further signal at about 15 psu where the *O. centrocarpum* dominated low salinity assemblage change to a *L. machaerophorum* dominated assemblage (Matthiessen and Brenner, in press). This signal, however, must be carefully used, because *L. machaerophorum* is in addition an indicator for eutrophication, and assemblage changes can be triggered by nutrients (Dale and Fjellsa 1994; Dale 1996). Furthermore, Reid (1974) and Turon (1984) reported, that *L. machaerophorum* is often found in sediments representing cold winters and warm summers, and Bakken and Dale (1986) reported, that it is not found in areas where summer sea-surface temperature is less than 10°C.

The environmental preference of *Ataxiodinium choane* (*Gonyaulax spinifera*) is not well understood, Dale (1983; 1996) regards it as a cold-temperate species and Wall et al. (1977) as an estuarine form. After Edwards and Andrieu (1992) the main distribution of *A. choane* is in areas with a winter surface temperature between 5 and 10°C and a summer surface temperature between 11 and 14°C.

*P. psilata* is an abundant species in the Black Sea with a main distribution at salinity's between 3 and 7 psu (Dale 1996; Wall and Dale 1973; Wall et al. 1973), therefore it is an indicator of low salinity. Dale (1996) and Mudie et al. (2001) have discussed the problem whether *P. psilata* is the end member in an environmental induced morphological graduation from normally long processes through no processes of *O. operculatum* or a separate species. In the Baltic Sea this species is only present in a small interval with high abundance, whereas in other intervals with similar salinity only few or no *P. psilata* could be found, suggesting that *P. psilata* is a separate species. Furthermore, investigations of single laminae (Brenner 2001) show that *P. psilata* occur only in specific laminae in large numbers, whereas in the laminae between

only few specimens are present and that there is no correlation with the abundance of *O. centrocarpum* with short processes. This shows clearly that the occurrence and abundance of *P. psilata* is controlled by additional factors to salinity, which are still unknown.

### Green algae

*Pediastrum boryanum* and *Pediastrum kawraiskyi* dominate the coccale green algae assemblage in the investigated sediments, only few specimens of other *Pediastrum* species, *Botryococcus*, *Scenedesmus* and *Staurastrum* are present. *Pediastrum* spp. is a common algae in nutrient rich, shallow freshwater, often used as indicator for eutrophication and acidification of lakes (e.g. Cronberg 1982a; Cronberg 1982b; Rosén 1981; Willén 1992). Principally, many coccal green algae are able to survive much higher salinity than 10 psu, but higher NaCl concentrations inhibit the cell division and no further breeding is possible (Brenner and Foster 1994; Latala 1991; Setter and Greenway 1979; Soeder and Stengel 1974).

Two species, *P. boryanum* and *P. kawraiskyi*, are known to be more common in coastal brackish water of the Baltic Sea than in the adjacent rivers (e.g. Bandel 1940; Brandes 1939, Brandt 1896; Kell 1985; Kell 1986; Matthiessen and Brenner 1996; Pankow 1990; Schröder 1897). *Pediastrum duplex* and *Pediastrum simplex* are only known from salinity below 5 psu (Kell 1981; Kell 1985, Pankow 1990). Therefore, autochthonous high abundance of *Pediastrum* in the fossil record of brackish water areas is only possible in shallow coastal areas with a salinity below 10 psu, and the assemblage will be dominated by *P. boryanum* and *P. kawraiskyi*. This leads to the assumption, that the high abundance of the latter specimens in the Gotland Basin may be an indicator for transport by currents from the coastal area into the deeper basins rather than high river runoff.

### Cladoceran

Cladoceran are dominant freshwater species. Only few species are present in brackish water or coastal sea area (e.g. Bainbridge 1958; Hofmann 1987; Poggensee and Lenz 1981; Struck et al. 1998). Survival experiments with *Bosmina longispina*, the dominant species in the brackish water of the central Baltic Sea, show best adaptation to a salinity range between 2.5 and 7.5 psu. The animals do not tolerate a salinity of 0.5 psu, and survival rates decrease at higher temperatures with a salinity of 10 psu (Ackefors 1971; Hofmann 1987; Hofmann 2001).

### Copepod eggs

Copepod eggs are described from various recent marine sediments, but a large number, particularly the fossil forms, are still not investigated in detail, neither in ecological preferences nor in taxonomy (e.g. Lindley 1986; Lohmann 1904; Marcus 1990; Van Waveren 1993; Van Waveren 1994).

Notable is the significant low abundance of copepod eggs during the salinity maximum in the Baltic Sea and the increased abundance during the Post-Litorina Sea stage. This phenomenon occurs in all three basins and can not be caused by decreasing salinity, because the same species are abundant in the North Sea (Brenner, unpublished data), and similar forms are found in the Banda Sea (Van Waveren 1994) suggesting that they are indicating higher marine conditions. A selective preservation can be excluded since the few eggs in the Litorina Sea stage are well preserved. Possibly food availability or other environmental factors rather than salinity control the abundance of copepod eggs in brackish water sediments. However, to explain the distribution of copepod eggs further investigations are needed.

### Blue-green algae (cyanobacteria)

Fossil cyanobacteria are well known in Precambrian and Palaeozoic sediments (e.g. Knoll and Golubic 1992; Nyberg and Schopf 1984; Strother et al. 1983; Wicander et al. 1996). From Mesozoic to Holocene sediments, however, only few palaeontological reports on cyanobacteria are published (e.g. Batten and van Geel 1985; Livingstone and Jaworski 1980; Van Geel et al. 1994).

In the Central Baltic Sea (North Central and Gotland Basin) most of the fossil cyanobacteria and their resting stage (akinetes) found in the sediments can be assigned to the genus *Anabena*. In the Bornholm Basin few additional forms are present in the sediment, which can be assigned to the *Rivularia*-group. The lack of "biological characteristics" in fossil cyanobacteria hampers the taxonomic identification of the different species at this stage of the investigation, and the cyanobacterial remains are tentatively assigned to the *Anabena*-group and the *Rivularia*-group. Nevertheless, cyanobacteria are useful indicators of eutrophication (Van Geel et al. 1994; Voss et al. 2001).

### Acritarchs

Hensen (1887) described a row of plankton organisms with unknown affinity as Sternhaarstatoblast (now *Radiosperma*), Barbierbeckenstatoblast (now *Halodinium*) and Röhrenstatoblast (now *Hexasterias*) from the Baltic and North Sea. The reported highest



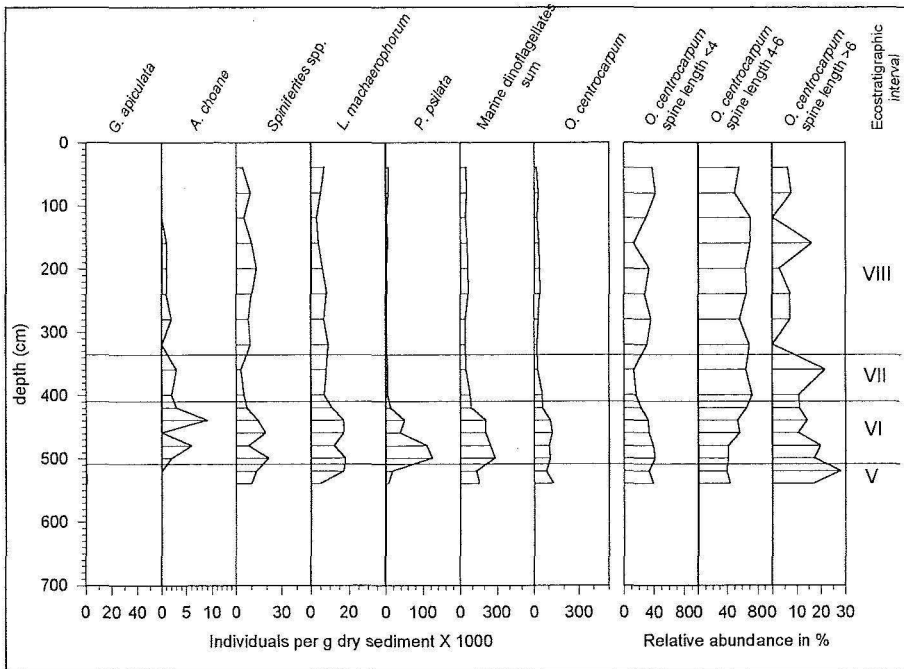


Fig. 2. Distribution of selected dinoflagellate cysts from Bornholm Basin, core 211630-9. Left columns show the absolute abundance of the cysts in the sediment, please note the different scales. The right three columns give the processes length frequency of *O. centrocarpum*, which can be directly used as salinity indicator (see text for details).

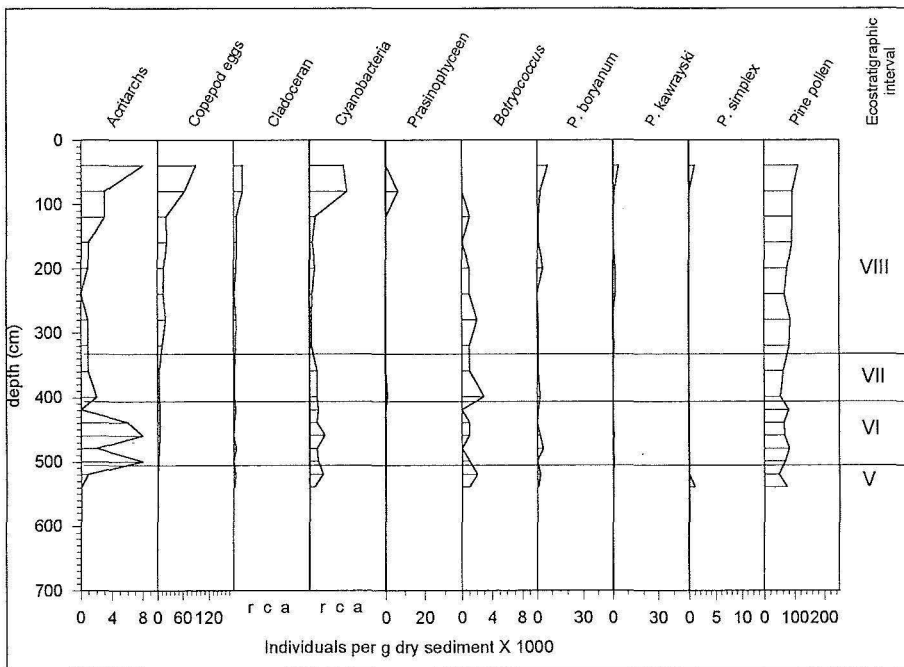


Fig. 1. Absolute abundance of selected organic walled microfossils from Bornholm Basin, core 211630-9, please note the different scales. Cladoceran remains are represented by fragments, and cyanobacteria by colonies of various size. Therefore no absolute values can be given for these two microfossil groups and the abundance is given by r = rare, c = common, and a = abundant.

abundance of *Radiosperma* is in the plankton of central Baltic Sea, leading to the assumption that *Radiosperma* is adapted to lower salinity (e.g. Apstein 1906; Driver 1908; Leegaard 1920; Merkle 1910). However, this organism group is also reported from the seas of Barents and Kara (Meunier 1910), the

no flagellate cysts which are present in lower numbers such as *Spiniferites* spp., *L. machaerophorum*, and *A. choane* do not show a significant preference and can therefore be regarded as opportunistic species.

A significant difference in the distribution of coccal green algae (mainly *Pediastrum* spp.) can be found in

Laptev Sea (Kunz-Pirrung 1997) and even from upwelling areas off Peru (Biebow 1996) and the Guanabara Bay at Rio de Janeiro (Brenner, unpublished data). Therefore, additional factors to salinity may control the occurrence of this enigmatic organism group, which still is of unknown biological affinity.

### Distribution of organic-walled microfossils in the Central Baltic Sea

In general the sediments from the Bornholm Basin (BB, Figs. 1, 2) contain less organic walled microfossils than those from the Gotland Basin (GB; Figs. 3, 4) and North Central Basin (NCB, Figs. 5, 6). The highest absolute abundance of dinoflagellate cyst in the investigated sediments is 283 (BB), 480 (GB) and 474 (NCB)  $\times 10^3$  cysts per gram dry sediment, and in all three cores located at the lower part of the ecostratigraphic interval ESI VI (Figs. 2, 4, 6). This difference between BB and the other basins may be caused by higher sedimentation rates rather than by environmental differences (compare Figs. 1, 3, 5), whereas the distribution of species shows clear environmental differences between all three basins. The highest absolute abundance of *O. centrocarpum* shows a clear preference for the Gotland Basin, whereas *P. psilata* have its distribution maximum at the North Central Basin. The portion of *O. centrocarpum* with short processes generally increases from south to north. Other di-



all three basins. In all investigated samples of the Bornholm Basin only few specimens could be found (Fig. 1), whereas in the Gotland Basin two significant abundance maximum occur (Fig. 3; ESI IX and ESI VI). In the North Central Basin only one abundance maximum in ESI IX can be found (Fig. 5).

### ECOSTRATIGRAPHY AND CORRELATION

During the Holocene no significant evolutionary changes occur, which are useful for biostratigraphic zonation and correlation. For subdivision of stratigraphic useful units, assemblage changes and single abundance maxima of the whole suit of organic walled microfossils as well as changes in spine lengths of *O. centrocarpum*, have been taken into account. In sense of the International Stratigraphic Guide (Salvador 1994) for the subdivision a mixture of assemblage zones, Oppel zones, and acme zones is used and additional elements as morphometric variations of specific dinoflagellate cyst species have been taken into account. Furthermore, the first and last occurrence of the single species do not reflect evolutionary patters, they are only controlled by environmental changes. The main factors influencing the environmental variations of the Baltic Sea are the North Atlantic weather system, the postglacial uplift of Scandinavia and the relative sea level rise (Alheit et al. submitted; Winn et al. 1986; Ekman 1988; Svensson 1991). Such events influence all regions of the Baltic Sea simultaneously, but the effects on the local environment can change signifi-

cantly. Therefore no zonal definitions in sense of the International Stratigraphic Guide (Salvador 1994) can be given for the Holocene of the Baltic Sea, and the term ecostratigraphic intervals (ESI) is used for stratigraphic subdivision.

As a base for the ecostratigraphic framework core 211 660-6 from Gotland Basin was used. Further correlation of the organic walled microfossils with stable isotope and biochemical indicators are given by Voss et al. (2001). For comparison with diatoms the data of Andr n et al. (2000) are used, which are taken from a piston core at the same position taken some hours before the box core during the same cruise.

#### ESI I

This zone is only present in the lowermost sample from Gotland Basin at 681 cm and is marked by an extremely low abundance of organic walled microfossils in the sediment. Nevertheless, the preservation of the few fossils is good, suggesting anoxic or nearly anoxic conditions at the seafloor during sedimentation. Therefore it can be assumed, that no selective solution/destruction of the organic-walled microfossils has occurred. Causes for the low abundance of fossils may be nutrient poor or cloudy surface water, which reduces the photic zone, leading to a low primary productivity, and/or a very high sedimentation rate. The presence of *O. centrocarpum* with short spines, few copepod eggs and *Radiosperma* in this sample point to marine influence (Figs. 3 and 4).

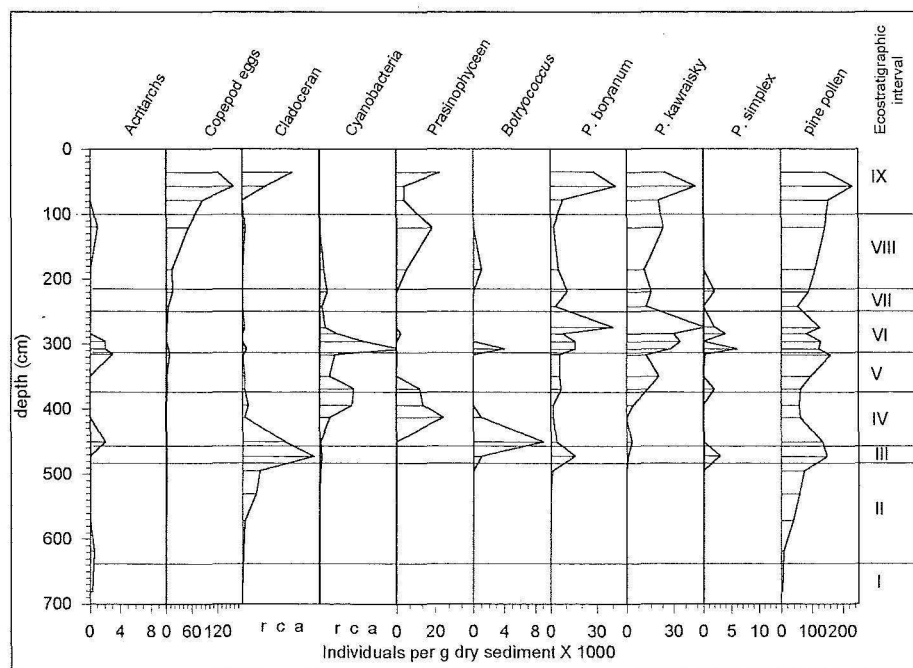


Fig. 3. Absolute abundance of selected organic walled microfossils from Gotland Basin, core 211660-6, please note the different scales. Cladoceran remains are represented by fragments, and cyanobacteria by colonies of various size. Therefore no absolute values can be given for these two microfossil groups and the abundance is given by r = rare, c = common, and a = abundance.

#### ESI II

This interval is marked by the increase in cysts of the freshwater dinoflagellate *Gonyaulax apiculata* with an abundance maximum at the top of this interval, a slow increase of cladoceran and the absence of *Pediastrum* spp. (Figs. 3-6). This suggests a slow but continuous increase in nutrient or an expansion of the photic zone.

In the North central Basin this interval is represented only in the lowermost sample at 669 cm, and its top and base at Gotland Basin are located at 495 cm and 618 cm, correspondingly.

## ESI III

The first occurrence of *Pediastrum* and *Botryococcus* as well as the high abundance of cladoceran and the increase of organic carbon in the sediments points to an eutrophication (Voss et al. 2001). The abundance of *G. apiculata* decrease, and marine dinoflagellate cysts are absent. These patterns can be found in Gotland Basin as well as in North Central Basin. However, in North Central Basin the number of microfossils is smaller than in the Gotland Basin suggesting a lower primary production and/or higher sedimentation rates for the North Central Basin (Figs. 3-6).

Top and base of this interval are located at samples 619 cm and 644 cm from North Central Basin, and at a sample 472 cm from Gotland Basin.

## ESI IV

This zone covers the first Litorina transgression. Decreasing abundance of cladoceran remains, compared with increasing abundance of marine dinoflagellate cysts with a first maximum at the top of this interval, as well as increasing processes length of *O. centrocarpum*, suggest a continuous increase of salinity. The patterns of these events are present in Gotland Basin and North Central Basin (Figs. 3-6).

Top and base of this interval are located at samples 579 cm and 604 cm from North Central Basin, and at 394 cm and 450 cm from Gotland Basin.

## ESI V

The base of this interval is marked by a slow decrease in abundance of marine dinoflagellate cysts and an absence of *Botryococcus*. Within this interval a general increase of dinoflagellate abundance takes place, especially of *L. machaerophorum* reaching its abundance maximum at the top of this interval at Gotland Basin as well as at North Central Basin. In addition, at this top an abundance minimum of *O. centrocarpum* with short processes, suggesting increasing salinity. At the Bornholm basin the abundance maximum continues to the interval above (ESI VI). This may be caused by slightly higher salinity for this basin as it is suggested by the higher abundance of *O. centrocarpum* with longer processes in this basin compared to Gotland Basin and North Central basin (Figs. 1-6).

Top and base of this interval are located at samples 509 cm and 549 cm from North Central Basin, at 316 cm and 369 cm from Gotland Basin, and the top at Bornholm Basin is located at sample 519 cm

## ESI VI

The highest abundance and diversity of dinoflagellate cysts in all three basins mark this interval. Significant for this interval is a high absolute abundance of *P. psilata* (acme zone sensu Salvador 1994). This species is known from the Black Sea where the surface water is warmer than in the Baltic Sea and only from a salinity interval between 3 and 7 psu (Dale 1996; Wall and Dale 1974). Similar conditions regarding salinity are also present in

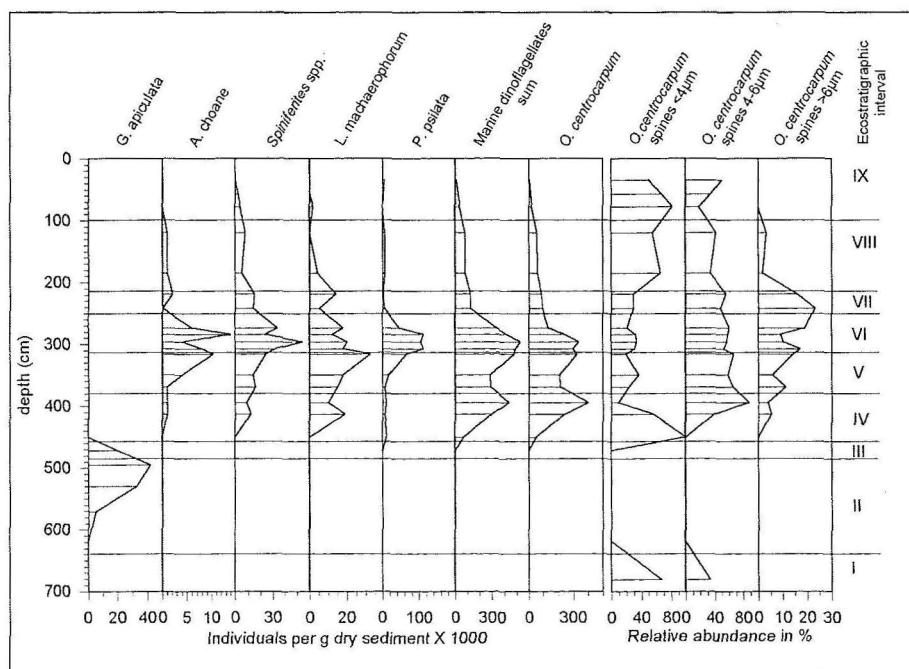


Fig. 4. Distribution of selected dinoflagellate cysts from Gotland Basin, core 211660-6. Left columns show the absolute abundance of the cysts in the sediment, please note the different scales. The right three columns give the processes length frequency of *O. centrocarpum*, which can be directly used as salinity indicator (see text for details).

the interval below but with very low abundance of *P. psilata*, suggesting that other factors than salinity control the blooming of *P. psilata*. Investigations of laminae from the Gotland Basin within this interval suggest, that this species blooms only in few years, whereas in other years the abundance is as low as in the interval below (Brenner 2001). This result suggests that the high abundance of *P. psilata* is rather the accumulation effect of specific environmental conditions favouring blooming of this species than a general high abundance.

Top and base of this interval are located at samples 474 cm and 494 cm from North Central Basin, 274 cm and 307.5 cm from Gotland Basin, and at 439 cm and 499 cm from Bornholm Basin.

ESI VII

The base of this interval is marked by a rapid decrease in absolute abundance of dinoflagellate cysts

and other organic walled microfossils. The *O. centrocarpum* assemblage however, shows a clear shift to forms with longer processes, suggesting a higher salinity in this interval. The rapid decrease in organic-walled microfossil abundance point to a significant environmental change, which is not caused by salinity variation.

Top and base of this interval is located at samples 269 cm and 459 cm from North Central Basin, 219 cm and 242 cm from Gotland Basin, and at 359 cm and 419 cm from Bornholm Basin.

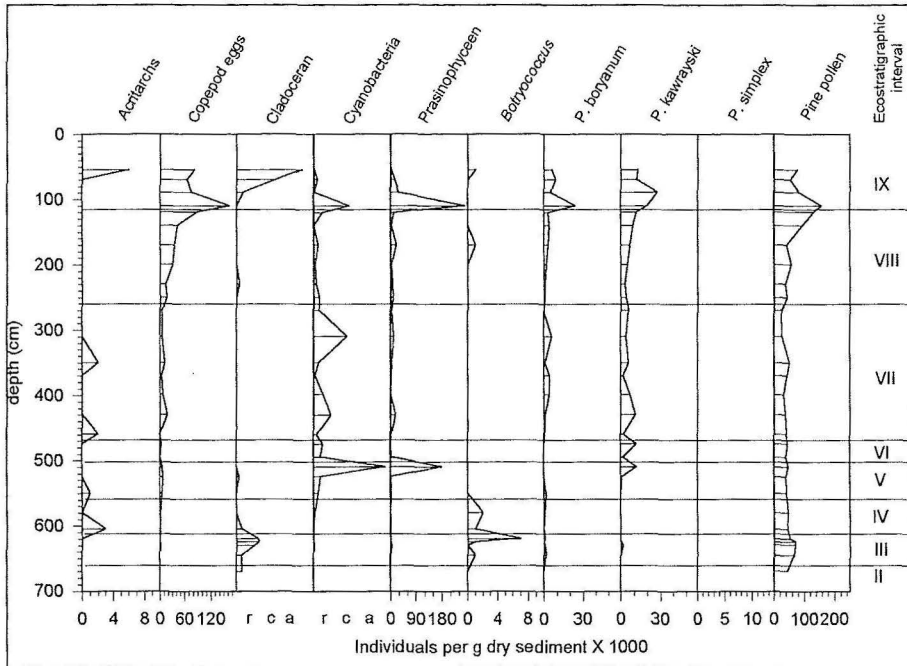


Fig. 5. Absolute abundance of selected organic walled microfossils from North Central Basin, core 211670-4 (depth: 200-670 cm) and core 211670-7 (depth: 54-200 cm), please note the different scales. Cladoceran remains are represented by fragments, and cyanobacteria by colonies of various size. Therefore no absolute values can be given for these two microfossil groups and the abundance is given by r = rare, c = common, and a = abundant.

ESI VIII

No significant changes and a low absolute abundance in the organic-walled microfossil assemblages are present in all three basins. Forms with short processes dominate the *O. centrocarpum* assemblage, suggesting a low salinity without significant changes. This interval seems to be without environmental changes so far reflected by organic-walled microfossils.

Top and base of this interval is located in samples 119 cm and 249 cm from North Central Basin, respectively, and in samples 120 cm and 185 cm from Gotland Basin, as well as the base in sample 319 cm from Bornholm Basin.

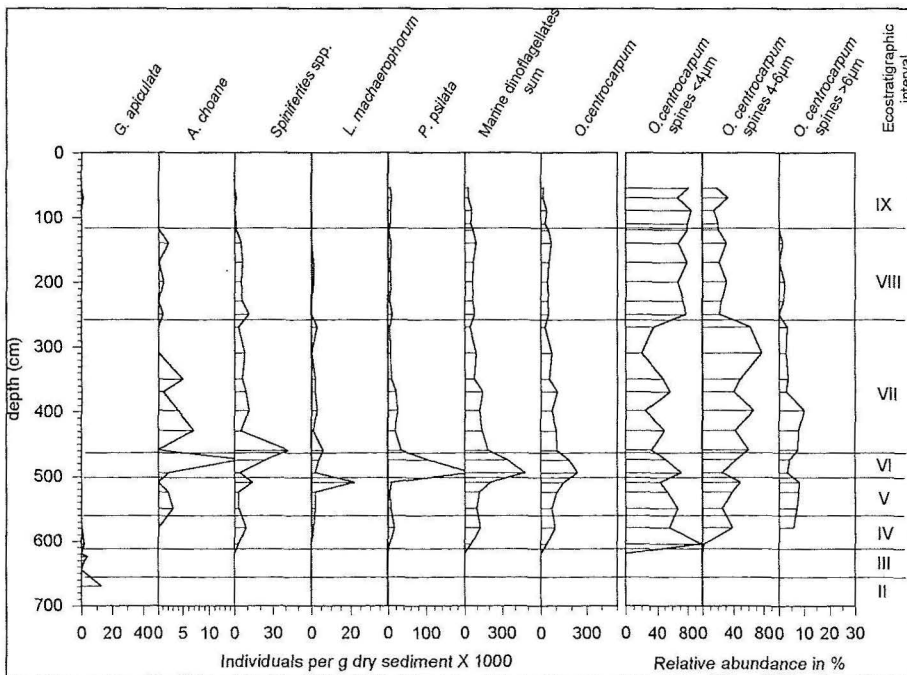


Fig. 6. Distribution of selected dinoflagellate cysts from North Central Basin, core 211670-4 (depth: 200-670 cm) and core 211670-7 (depth: 54-200 cm). Left columns show the absolute abundance of the cysts in the sediment, please note the different scales. The right three columns give the processes length frequency of *O. centrocarpum*, which can be directly used as salinity indicator (see text for details).

ESI IX

A significant change in the microfossil assemblage occurs within the uppermost metre of the sediments in all three Basins. This change is marked by a rapid increase of copepod egg, cladoceran remains, pine pollen, and coccal green algae abundances in the North Central Basin and Gotland Basin, whereas the dinoflagellate cysts show no change. More-



over, a similar increase of copepod eggs can be found in equivalent sediments from Kiel Bay (Brenner and Meemken, unpublished data). This abundance change correlates directly for copepod eggs, coccal green algae, cladoceran remains, pine pollen, and a slight shift to longer processes by *O. centrocarpum* (weak salinity increase), pointing to a complex interaction between terrestrial climate, salinity, nutrient and possibly other factors within the ecosystem. This event correlates directly with an abundance maximum of organic carbon and chlorines (Voss et al. 2001; Kowalewska et al. 1999).

The abundance maxima for copepod eggs, coccal green algae and pine pollen (base of ESI IX) are located in "sample 109 cm" in North Central Basin (core 211 670-7) and "sample 57 cm" in Gotland Basin (core 211 660-6). The topmost sample of core 211 630-9 from Bornholm Basin shows an increase of copepod eggs, cladoceran remains and a slight increase of *Pediastrum* and pine pollen. A similar slight increase can be found in the top of ESI VIII at Gotland and North Central Basin. It is therefore assumed that the abundance maximum is above the topmost sample at 39 cm, and ESI IX is not present in this core.

## DISCUSSION

### Yoldia Sea stage

The marine phase of this stage is possibly represented in the lowermost sample in core 211660-6 (Gotland Basin) and a slightly brackish surface water is suggested by the presence of few specimens of *O. centrocarpum* with short spines (ESI I, Figs. 3, 4). The content of organic-walled microfossils in this sample is low and the interpretation of marine influence should be used carefully. The diatoms of two cores, located close to 211660-6, record a clear brackish Yoldia phase (Andrén et al. 2000; Sohlenius et al. 1996). The transition between the brackish and freshwater phases of the Yoldia stage is visible in the diatom assemblage in a form of a shift to a freshwater flora dominated assemblage (Andrén et al. 2000; Sohlenius et al. 1996). The low content of diatoms as well as organic-walled microfossils makes it difficult to distinguish the final freshwater phase of the Yoldia Sea from the Ancylus Lake, as there is no salinity or nutrient change influencing the microfossil assemblages (Andrén et al. 2000; Sohlenius et al. 1996).

### Ancylus Lake stage

Sediments of the Ancylus stage (ESI II) are present in core 211660-6 (Gotland Basin) and in core 211670-4 (North Central Basin). The lower part of the Ancylus Lake stage is only present in core 211660-6 and is

marked by an extremely low abundance of organic-walled microfossils, nearly 1/2000 compared to the Litorina Sea stage. Although the content of organic carbon in the sediments is low according to Voss et al. (2001), the preservation of microfossils is good, even the chitinous cladoceran remains, which are very sensitive to oxidation, are well preserved. This points to a rapid burial and/or anoxic conditions at the sea floor during deposition. The extremely low content of organic-walled microfossils seems to be a primary feature. Very high sedimentation rates could be an explanation, however, this could also have been caused by a very narrow photic zone as a result of turbid water, low temperatures, and/or low nutrient contents in the surface water. Successive increase of diversity and abundance of organic walled microfossils and especially of the cysts of the freshwater dinoflagellate *G. apiculata* to the top of this stage suggest a continuous increase in nutrient and/or an expansion of the photic zone. In contrast to the organic-walled microfossils, the diatom record of the lower Ancylus Sea stage have there an abundance peak, with a similar assemblage as the final freshwater stage of the Yoldia Sea (Andrén et al. 2000; Sohlenius et al. 1996). Due to the high number of fragmented valves within this peak, Andrén et al. (2000) do not exclude that part of this peak is a product of redeposition from the freshwater Yoldia Sea stage. The increase of diatom diversity leads to the same assumption as for the organic walled microfossils.

### Ancylus-Litorina transitional stage

During this stage (ESI III) a rapid decrease in abundance of the cysts of the freshwater dinoflagellate *G. apiculata* occurs, whereas cladoceran remains and coccal green algae reach their maximum abundance, possibly indicating a rapid increase in nutrients. This event is more intense in the Gotland Basin than in the North Central Basin, indicated by the higher absolute abundance of organic walled microfossils and the first occurrence of dark, organic carbon rich, laminated sediments. Qualitative screening of laminae from core 211660-6 at 454 cm depth shows that a few single lamina contain *O. centrocarpum* with short processes in low abundance (Brenner, unpublished data). These marine dinoflagellate cysts can be found only by careful sampling of single laminae, because in a 1-cm thick slice of sediment the few marine dinoflagellate cysts are masked by a high abundance of all the other non-marine organic-walled microfossils. Nevertheless, the occurrence of marine dinoflagellate cysts in this interval points to sporadically brackish surface water conditions. Simultaneously to this event there is a drop in the absolute abundance of diatoms, which seems to be characteristic in the whole Baltic Proper (e.g. Abelmann 1985;

Andrén et al. 2000; Sohlenius et al. 1996; Thulin et al. 1992).

### Litorina Sea stage

The basal Litorina Sea stage (ESI IV) in the Gotland Basin as well as in the North Central Basin is marked by a continuous increasing abundance of dinoflagellate cysts and increasing processes length of *O. centrocarpum*, indicating a continuous increase in salinity, found as well in the diatom record (Andrén et al. 2000; Sohlenius et al. 1996). After reaching a first saline maximum a slight decrease in salinity is indicated by dinoflagellate cysts followed by an interval with changing, but still high salinity and a further salinity maximum at the top of interval ESI V. The following interval (ESI VI) is marked by a high abundance of *P. psilata*, which is not known from the present Baltic Sea (Dale 1996). A significant environmental change indicated by a rapid and permanent decrease in abundance of dinoflagellate cysts can be found in all three Basins (ESI VII). The processes length of *O. centrocarpum* suggests that the salinity is slightly higher as in the interval below and the rapid decrease of dinoflagellate cyst abundance must be caused by other factors than salinity change, which are till now unknown.

Variation of sedimentation rates at short distances and different sample distribution hamper a detailed correlation of siliceous and organic walled microfossils between cores 211660-1 (Andrén et al. 2000) and 211660-6. However, the assemblage succession of diatom valves at the base of the Litorina Sea stage followed by *Chaetoceros* resting spores and silicoflagellates at the top suggests a general increase of salinity during the Litorina Sea stage as it can be interpreted by the change in processes length of *O. centrocarpum*.

### Post-Litorina Sea stage

The whole post-Litorina Sea stage (ESI II and I) is marked by a permanent low abundance of dinoflagellate cysts, and the processes length of *O. centrocarpum* suggests a lower salinity compared to the Litorina Sea stage. Within the lower part (ESI II) only a slight but continuous increase of copepod egg and cladoceran remains can be found in all three Basins. In the Gotland Basin and the North Central Basin an additional slight increase of coccal green algae occurs. The lower interval (ESI II) corresponds to a poor record of siliceous microfossils in the core 211660-1 (Andrén et al. 2000).

In the uppermost part of this stage a rapid increase in copepod eggs, cladoceran remains, coccal green algae and pine pollen indicates a significant change within the environmental conditions in the two northern ba-

sins (ESI I). This event is further marked by a rapid increase in diatom abundance (Andrén et al. 2000) and a peak in organic carbon and chlorine (Kowalewska et al. 1999; Voss et al. 2001). The abundance of dinoflagellate cysts does not change significantly within this interval, and the processes length of *O. centrocarpum* suggests a rather constant salinity.

The causes for the observed environmental change may therefore be related to changes in nutrient content and/or temperature of the surface water, which do not influence the dinoflagellate assemblage. The significant increase of copepod egg abundance has no analogue in older sediments of the Baltic Sea. The sparse knowledge on copepod eggs, their taxonomy and ecology does not allow an interpretation of this phenomenon and needs further investigation.

Finally it can be stated that the organic walled microfossils provide an excellent tool for palaeoecological investigations, but much more studies with a higher sample resolution are needed to understand the processes and causes for the environmental variations in the Holocene sediments of the Baltic Sea.

### Acknowledgements

This work has been supported by the European Commission through the BASYS Baltic Sea System Studies project (contract number MAS3-CT96-0058). Thanks are due to Prof. J. Thiede, who facilitated this investigation at GEOMAR, Kiel and Prof. A. Rios-Netto for the possibility to finalise the manuscript at LabMicro, Federal Universidade do Rio de Janeiro. Further thanks are due to Prof. M. Kabailienė and an anonymous reviewer for helpful comments on the manuscript.

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