

# Palynological dating of the Oligocene – Miocene successions in the Lille Bælt area, Denmark

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A new geological model for the succession outcropping in the Lille Bælt area, Denmark, is proposed. The model is based on dinoflagellate cyst stratigraphy on the three sections at Hindsgavl, Hagenør and Rønshoved combined with earlier biostratigraphic studies and sequence stratigraphic correlation of outcrops and borings.

Our results indicate that there have been two periods with lagoonal and nearshore marine deposition in the Lille Bælt area separated by a hiatus of at least 3.5 million years. The first period occurred in Late Oligocene or earliest Early Miocene (early Aquitanian) time and is represented by the deposits at Hindsgavl. The second period occurred in Early Miocene (early to mid-Burdigalian) time and is represented by the deposits at Hagenør and Rønshoved.

The deposits at Hindsgavl are time equivalent with the lagoonal upper part of the Vejle Fjord Formation and the overlying nearshore marine sand at Hvidbjerg. The deposits at Hagenør and Rønshoved correlate with the lower part of the offshore marine Arnum Formation and thus represent part of the coastline during the early to mid-Burdigalian.

**Key words:** Palynology, sequence stratigraphy, Late Oligocene, Early Miocene, Hagenør, Hindsgavl, Rønshoved, Lille Bælt, Denmark.

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In the Late Oligocene, the eastern coastline of the North Sea Basin ran through East Jylland. The coastline migrated repeatedly from northeast to southwest Jylland and back again during the Miocene due to successive sea-level changes (Rasmussen 1961, Rasmussen 1996). This resulted in deposition of interfingering lagoonal, near-shore and offshore marine sediments. To establish a stratigraphic framework for this complicated succession, biostratigraphy, log-correlation, sedimentological facies analysis and seismic interpretation are combined within a sequence stratigraphic framework.

In the Lille Bælt and Vejle Fjord areas Upper Oligocene – Lower Miocene deposits crop out in a number of coastal sections. Our palynological study focusses on three localities in the Lille Bælt area, Hindsgavl, Hagenør and Rønshoved (Fig. 1). The deposits at those and other localities in the Lille Bælt area were by Friis et al. (1998) referred to as “the southern complex” of the Vejle Fjord Formation (Larsen & Dinesen 1959) while deposits outcropping in the Vejle Fjord area were referred to as “the northern complex”. Friis et al. interpreted “the southern complex” as a

continuous series of transgressive barrier complexes within an overall regressive succession. The “northern complex” were interpreted as deposited during one continuous transgression. The stratigraphic relationship between “the southern” and “the northern complex” was not unravelled in their study.

In contrast to Friis et al. (1998), Rasmussen (1998) proposed a subdivision of the succession outcropping at Lille Bælt, into two sequences, separated by a distinct sequence boundary. This sequence boundary can be seen in wells and outcrops in proximal areas as a conglomeratic, probably reworked, fluvial horizon, whereas on seismic data in more distal parts it is indicated by a detached delta front outbuilding south-westwards.

Prior to our study, it has not been possible to date and correlate these sections in detail due in part to dissolution of the molluscs and foraminifers and in part to their relatively low stratigraphic resolution. In an attempt to refine the stratigraphic resolution, we sampled material for dinoflagellate cyst stratigraphy from marine influxes within the succession.



Fig. 1. Location of the outcrops studied at Hindsgavl, Hagenør and Rønshoved, and of related key sections and boreholes. The Early Miocene coastline is indicated on the inserted map (after Jordt, Faleide, Bjørlykke & Ibrahim 1995; Rasmussen 1996).

## Geological setting

During Early Paleogene, Danian, times cool water calcareous sediments prevailed in northwest Europe (Surlyk 1997). In later Paleogene time the depositional environment in the North Sea area was dominated by marine, fine-grained, siliciclastic deposits. This dramatic change in facies probably resulted from major changes in palaeogeography. Clastic deposition of fine-grained clayey sediments commenced in the Selandian and dominated throughout the Eocene. In Early Eocene time, the clayey deposits became interbedded with volcanic ash layers marking the onset of the opening of the North Atlantic Ocean. Uplift of Fennoscandia in the Late Eocene, and a general lowering of sea-level during the Oligocene, formed a major hiatus in the Lille Bælt area; This separates the fine-grained, older deposits from more coarse-grained, Upper Oligocene and Miocene deposits (Dinesen et al. 1977, Heilmann-Clausen et al. 1985).

In the Late Oligocene-Miocene, the coastline was

oriented in a northwest-southeastern direction in the present day Jylland. The position of the coastline varied due to a series of major transgressive and regressive cycles and the resulting deposits comprise a series of interfingering back-barrier, nearshore marine and offshore marine sediments (Rasmussen 1961). The marine units are represented by the Klintinghoved, Vejle Fjord, Arnum, Hodde and Gram formations, while the terrestrial units comprise the Ribe and Odderup formations (Fig. 2) (Sorgenfrei 1958, Larsen & Dinesen 1959, Rasmussen 1961). The Vejle Fjord Formation was subdivided into the Brejning Clay, the Vejle Fjord Clay and the Vejle Fjord Sand (Larsen & Dinesen 1959).

The Miocene – Pliocene succession forms a successive infill of the North Sea Basin by distinct progradation of the shoreline towards the southwest (Hinsby et al. 1999). The major source area for these sediments was created in the latest Eocene by uplift of the Fennoscandian Shield (Michelsen & Nielsen 1993). Further uplift in the Neogene enhanced erosion, thus in-

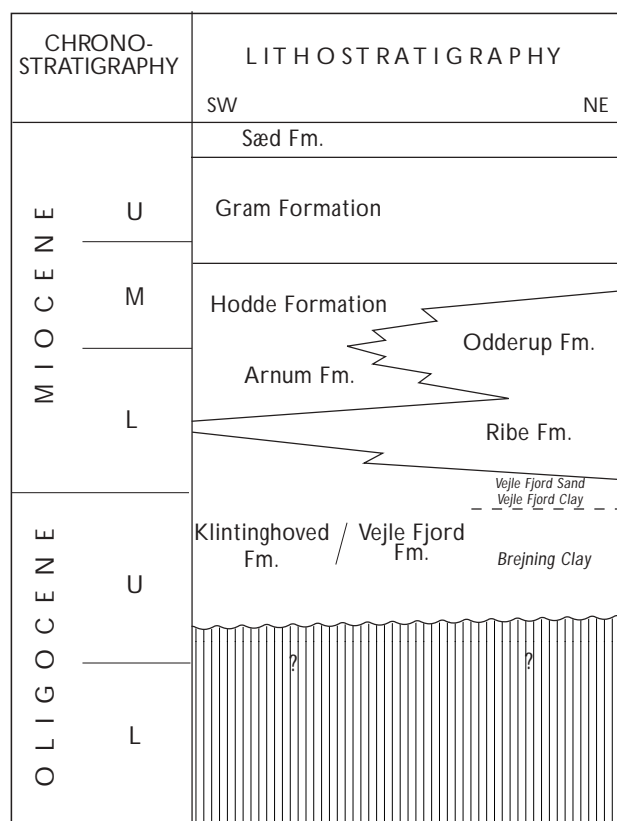


Fig. 2. Lithostratigraphy of South Denmark. Modified from Buchardt-Larsen and Heilmann-Clausen (1988).

creasing deposition in the basin (Jensen & Schmidt 1993, Japsen 1993).

## Earlier biostratigraphic studies

The Hindsgavl section represents the Vejle Fjord Clay and the Vejle Fjord Sand Members which conformably overlie the Brejning Clay (Fig. 2). The latter was referred to the Upper Oligocene (Chattian B) on the basis of mollusks by Schnetler & Beyer (1987, 1990). Foraminifer analysis of the Brejning Clay supported a Late Oligocene age (Larsen & Dinesen 1959, Dinesen 1965, Ulleberg 1987). The Vejle Fjord Clay was referred to the Upper Oligocene or Lower Miocene on the basis of mollusks (Eriksen 1937, Rasmussen 1961). A more recent, preliminary, palynological study of the Vejle Fjord Clay at the type section for the Vejle Fjord Formation, Skansebakke, indicated a Late Oligocene or earliest Early Miocene (Aquitania) age (Dybckjær et al. 1999). The sand at Hvidbjerg was also referred to the Late Oligocene or earliest Early Miocene (Aquitania) by Dybckjær et al. (1999). The Vejle Fjord Sand and the Ribe Formation have not been dated

previously, the former because of the poor preservation of the forams and molluscs, the latter because it is non-marine. The marine Arnum Formation was referred to the Middle Miocene by Sorgenfrei (1958) and Rasmussen (1966), based on molluscs; however, Laursen & Kristoffersen (1999), Laursen et al. (1998) and Michelsen et al. (1998) consider it to be Early Miocene (Burdigalian), the former based on foraminifera, the latter two based on foraminifera and dinoflagellate cysts.

## Methods

A total of 14 samples were collected, 8 from the Hindsgavl section, 3 from the Hagenør section and 3 from the Rønshoved section (Fig. 3). The low number of samples, especially from Hagenør and Rønshoved, reflect the small thickness of the sections. Furthermore, the samples were taken to represent changes in facies and horizons interpreted as marine influxes. The samples have been treated using standard palynological preparation techniques, including treatment with HCl, HF, brief oxygenation with fuming HNO<sub>3</sub> and sieving on 20µm filters (Poulsen et al. 1990). Relative abundances of dinoflagellate cyst species were based on counts of at least 200 specimens from each sample. However, this was not possible in some samples from marginal marine sediments (Fig. 4).

## Results

The results from each section are presented separately in the following. A range chart combining the results from the three localities is presented in Figure 4 and the recorded dinoflagellate cyst species are illustrated on Plates 1–3. The systematics used herein are in accordance with Williams et al. (1998a). The recovered species are listed alphabetically after genus below. The palynological slides are stored at the Geological Survey of Denmark and Greenland.

### Hindsgavl

The dominant palynomorphs in the lower 6 samples (Fig. 3) are terrestrial taxa, especially non-saccate and bisaccate pollen and there are few dinoflagellate cysts. A distinct change occurs in samples 7 and 8, in which dinoflagellate cysts predominate. This sudden change is interpreted to reflect a marine flooding. In spite of

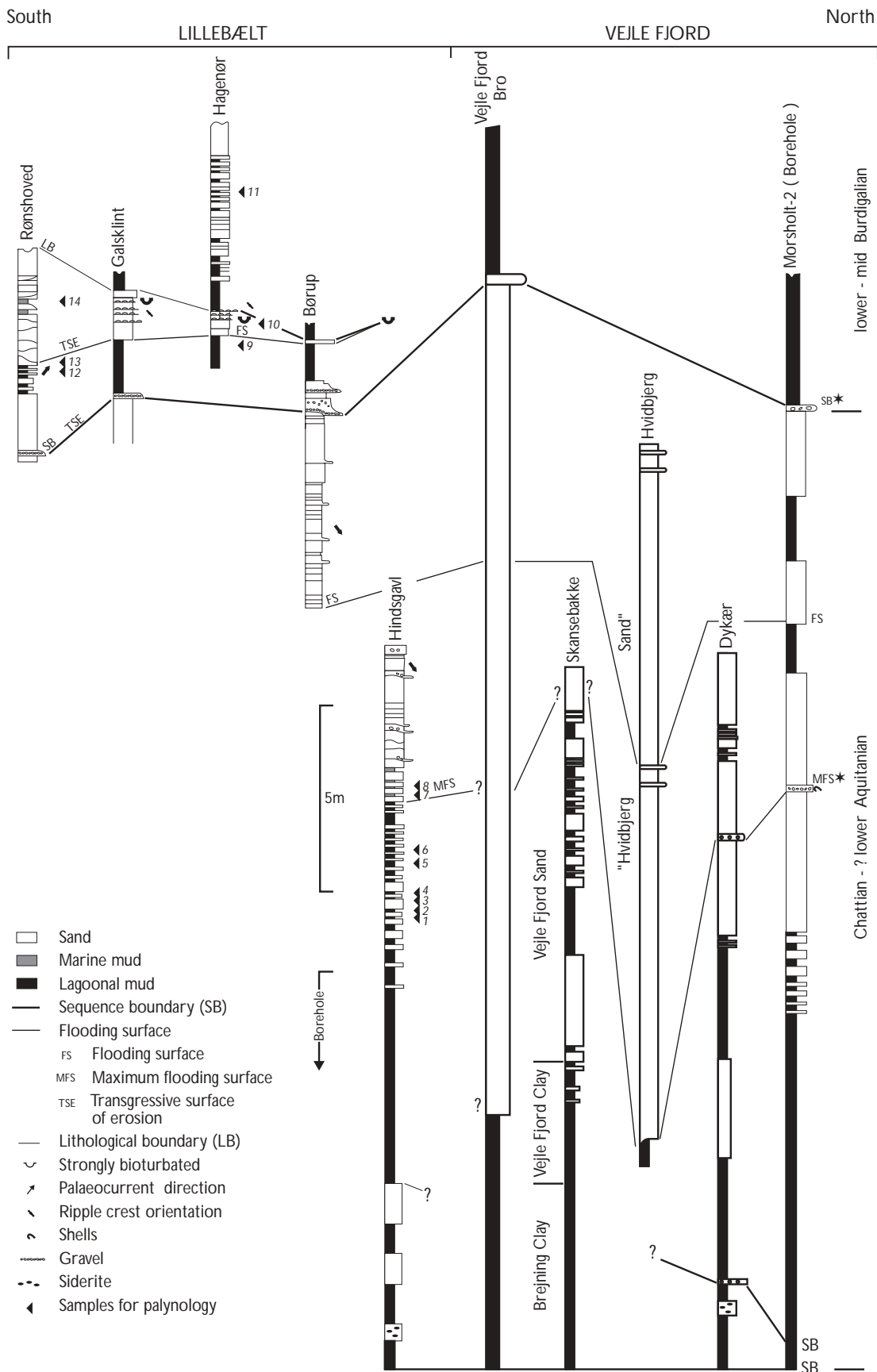


Fig. 3. Correlation of the three sections studied and key sections and boreholes from East Jylland. The location of samples for palynology is indicated by arrows. Note the abrupt change from lagoonal to marine mudstone in the upper part of the Hindsgavl and Rønshoved sections. The asterisks mark the maximum flooding surface and the sequence boundary discussed in the text.



the variation in abundances, the dinoflagellate cyst assemblages from the 8 samples are very similar and are therefore treated as one assemblage in the following, representing the whole profile.

The assemblage is strongly dominated by *Homotryblium tenuispinosum* (constituting 43–59% of the dinoflagellate cyst assemblage). *Homotryblium plectilum*, *Glaphyrocysta* sp. cf. *G. ? vicina*, *Lingulodinium machaerophorum* and *Systematophora placacantha* are common (comprising more than 5% of the dinoflagellate cyst assemblage). *Distatodinium craterum* occurs commonly only in samples 4 and 5. Less common species of stratigraphic importance are *Apteodinium spiridoides*, *Chiropteridium galea*, *Wetzeliiella* spp., *Membranophoridium aspinatum*, *Deflandrea phosphoritica* and *Homotryblium vallum*.

**Discussion.** – *Homotryblium tenuispinosum* is often abundant in the Lower Eocene of the Danish area (Nielsen et al. 1986, their Fig. 6, as *H. pallidum*), in the North Sea (e.g. Bujak & Mudge 1994) and in the Lower Eocene and Upper Oligocene of North Germany [Köthe 1990 (zones D9 and D14nb as *H. pallidum*), 1996]. *H. plectilum* is common to abundant in the Upper Eocene – lowermost Oligocene and in the Upper Oligocene in North Germany (Köthe 1990, zones D14nb and D15) and in the Upper Oligocene of the Central North Sea (Gradstein et al. 1992) and the Norwegian Sea (Manum et al. 1989). Stratigraphical use of abundant *H. tenuispinosum* and *H. plectilum* should, however, be taken with caution as this genus probably is related to lagoonal depositional settings (Brinkhuis 1992). *H. tenuispinosum* ranges from the uppermost Paleocene – Middle Miocene and *H. plectilum* ranges from the Middle Eocene – Upper Miocene (Köthe 1990, Williams et al. 1999).

The occurrence of *Apteodinium spiridoides* and *Chiropteridium galea* indicates an age not older than the Oligocene (Köthe 1990, 1996, Powell 1992, Stover & Hardenbol 1994, Williams et al. 1998).

The presence of *Chiropteridium galea*, *Deflandrea phosphoritica*, *Membranophoridium aspinatum* and *Homotryblium vallum* indicate an age not younger than the earliest Early Miocene (Aquitania). In North Germany the last common occurrence of *Chiropteridium* spp. was recorded in the lower part of the Upper Oligocene while it occurred sporadically in the upper part of the Upper Oligocene (Köthe 1990).

*C. galea*, *D. phosphoritica*, *H. vallum* and *M. aspinatum* have been recorded sporadically in the lowermost Miocene in the North Atlantic (Stover 1977). The former three species have their last occurrences in the lower part of the Aquitania in the eastern USA (de Verteuil & Norris 1996) and in the Mediterranean (Williams et al. 1998b).

**Conclusion.** – The dinoflagellate cyst assemblage from the Hindsø section indicates a Late Oligocene or earliest Early Miocene (early Aquitania) age. This corresponds closely with the age of the Vejle Fjord Clay as Late Oligocene or Early Miocene based on molluscs (Eriksen 1937, Rasmussen 1961), and of the underlying Brejning Clay as Late Oligocene, based on mollusks (Schnetler & Beyer 1987, 1990) and foraminifers (Larsen & Dinesen 1959, Dinesen 1965, Ulleberg 1987).

## Hagenør

The three samples from the Hagenør section contain very different palynomorph assemblages. The lowermost sample, 9, (Fig. 3) is dominated by terrestrial taxa, especially non-saccate pollen, with only a few marine palynomorphs. Most of the dinoflagellate cysts are torn or otherwise physically degraded; therefore only a few are identified to the species level (Fig. 4). Sample no. 10 is clearly more marine with a relatively rich dinoflagellate cyst assemblage, while terrestrial palynomorphs, especially bisaccate pollen, are dominant in sample no. 11. This sample also has high numbers of acritarchs, prasinophycean and freshwater algae, with only occasional dinoflagellate cysts, possibly indicating a brackish water environment. The three samples are considered together in the following as representing the whole profile due to the very poor recordings of dinoflagellate cysts from samples 9 and 11.

The dinoflagellate cyst assemblage is distinctly different from the assemblage of the Hindsø section. It is strongly dominated by specimens of the *Spiniferites ramosus* group. Taxa occurring commonly (representing more than 5% of the dinoflagellate cyst assemblage) are *Systematophora placacantha*, *Lingulodinium machaerophorum*, *Dapsilodinium pseudocolligerum* and *Cometodinium* spp. Furthermore, the acritarch species *Cyclopsiella lusatica* (senior synonym of *C. granosa* according to Strauss & Lund 1992, p. 174) is common in sample no. 10. *Chiropteridium galea* and *Homotryblium tenuispinosum* were not recorded while *H. plectilum* was recorded sporadically. The stratigraphically important dinoflagellate cyst *Hystrichosphaeropsis obscura* was recorded in a clay-layer located in between samples no. 10 and 11, about 1.5 m above sample 10 of the present study. Dr. J. J. Lund kindly made the authors aware of this and made a slide containing this species available.

**Discussion.** – The occurrence of *Hystrichosphaeropsis obscura* indicates an age not older than Burdigalian. The absence of the genus *Chiropteridium* in the samples



from the Hagenør section is compatible with a possible Burdigalian age, while the presence of *Cyclopsiella lusatica* indicates a latest Oligocene or younger age.

*Hystriosphæroides obscura* has its first occurrence the Early Miocene according to a long number of references (e.g. Costa & Manum 1988, Heilmann-Clausen & Costa 1989, Manum et al. 1989, Powell 1992, de Verteuil & Norris 1996). Recent multidisciplinary studies from the northwest and central parts of Italy have refined the first occurrence of *H. obscura* to the lower part of the Burdigalian (Zevenboom et al. 1994; Montanari et al. 1997, Coccioni et al. 1997).

Specimens referred to *Hystriosphæroides obscura* have also been recorded from the Lower Oligocene Boom Clay Formation in Belgium (Stover & Hardenbol 1994). However, the specimen illustrated by these authors does not have an apical horn which is one of the descriptive criteria for *H. obscura*. Furthermore, the endophragm seems to be smooth and the specimen seems to have a well-developed tabulation and be rather small (ca. 75 µm). The specimens recorded from the Boom Clay Formation may belong to *Hystriosphæroides rectangularis* Bujak et al. (1980) which occurs regularly in the Lower Oligocene of Belgium (Jan De Coninck pers. comm. 1999) or they could be specimens of *H. minimus* Zevenboom (1995). *Hystriosphæroides rectangularis* differs from *H. obscura* in lacking an apical horn, in having a smooth to chagrinated endophragm, and in being somewhat smaller (49–80 µm in total length while *H. obscura* varies between 70 and 95 µm). *Hystriosphæroides minimus* is also described as being smaller than *H. obscura* (70–75 µm) and with a smaller apical pericoel and a smooth endophragm (Zevenboom 1995).

*C. lusatica* has its first occurrence in the uppermost Oligocene. *Cyclopsiella*, referred to the *C. elliptica* group, was abundant in an Upper Oligocene sample from the Würsterheide well, northwestern Germany (Heilmann-Clausen & Costa 1989). These specimens are conspecific with *C. lusatica* (Matsuoka & Head 1992). A sporadic first occurrence of this species (as *Ascostomocystis* sp. 1 of Manum 1976) in the uppermost Chattian, a consistent occurrence from the Oligocene/Miocene boundary up to the uppermost Burdigalian, and a sporadic occurrence in the Langhian and lower part of the Serravallian was indicated by Powell (1992). It has further been recorded from the Lower Miocene in the Norwegian Sea, in the DSDP site 338 (as *Ascostomocystis* sp. 1, sp. nov.) (Manum 1976) and in the ODP site 643 (as *Ascostomosystis granosa*) (Manum et al. 1989). In northwest Italy, in the Lemme-Carrosio section, *Cyclopsiella lusatica* first appear in the late Aquitanian (Zevenboom 1996), while it has a first occurrence in the late Burdigalian in the section at Santa Croce di Arcevia, northeast Apennines, Italy

(Coccioni et al. 1997). In Japan it has its first appearance in the late Early Miocene (Matsuoka 1983; Matsuoka et al. 1987), while it was recorded close to the Lower - Middle Miocene boundary in ODP Site 645, Baffin Bay (Head et al. 1989).

The occurrence of *Tityrosphaeridium cantharellus*, *Distatodinium craterum* and *Thalassiphora pelagica* indicate an age not younger than the mid-Burdigalian. The last occurrence of *T. cantharellus* occur in the middle part of the Burdigalian in the eastern part of the USA (de Verteuil & Norris 1996), in the Mediterranean and in the North Atlantic (Williams et al. 1998b). Both *D. craterum* and *T. cantharellus* have last occurrences in the uppermost Burdigalian according to Powell (1992).

*Thalassiphora pelagica* was recorded consistently in the Hindsgavl section in the present study, but only one specimen was recorded from the Hagenør profile. Powell (1992) indicated sporadic occurrences of *T. pelagica* within the Aquitanian with the last occurrence in the uppermost part of that stage, for the British Isles. In the NE Apennines, Italy, *T. pelagica* is common in the lower Burdigalian and sporadic in the middle Burdigalian, where it has its last occurrence (Coccioni et al. 1997).

**Conclusion.** – The dinoflagellate cyst assemblage indicates an Early Miocene, possibly early or mid-Burdigalian age for the previously undated Hagenør section. This is based on the presence of *Hystriosphæroides obscura*, *Cyclopsiella lusatica*, *Distatodinium craterum*, *Tityrosphaeridium cantharellus* and *Thalassiphora pelagica* and the absence of *Chiropteridium galea*.

## Rønshoved

The palynomorph assemblages in the three samples from Rønshoved (nos. 12–14, Fig. 3) indicate a gradually increasing marine influence, with much higher relative abundances of dinoflagellate cysts in sample 14, relative to the two lower samples. Among the terrestrial taxa, non-saccate pollen dominates in samples no. 12 and 13 while saccate pollen dominates in sample 14.

The dinoflagellate cyst assemblage in the section compare well with that in Hagenør, except for the absence of *Cyclopsiella lusatica* and *Polysphaeridium zoharyi*. The assemblage from Rønshoved differs from that in the Hindsgavl section in the dominance of *Systematophora placacantha*, which constitutes 60% of the dinoflagellate cyst assemblage in sample 14. The *Spiniferites ramosus* group and *Lingulodinium machaerophorum* are common while *Cometodinium* spp. is common only in sample 13. Other stratigraphically use-

ful species are *Hystrichosphaeropsis obscura*, *Tityrosphaeridium cantharellus* and *Thalassiphora pelagica*. *Chiropteridium* is absent and *Homotryblum* occurs only sporadically.

**Discussion.** – The presence of *Hystrichosphaeropsis obscura*, *Tityrosphaeridium cantharellus* and *Thalassiphora pelagica* indicate an early to mid- Burdigalian (late Early Miocene) age for the Rønshoved section. As discussed above *Hystrichosphaeropsis obscura* appear in the Early Miocene, in the early Burdigalian. Furthermore, the absence of *Chiropteridium* supports an age younger than Oligocene and possibly younger than Aquitanian (see discussion for the Hindsgavl section regarding the last occurrence of this genus). The occurrences of *Tityrosphaeridium cantharellus* and *Thalassiphora pelagica* indicate an age not younger than mid- Burdigalian (see discussion above).

A dinoflagellate cyst assemblage dominated by *Systematophora placacantha*, with frequent *Lingulodinium machaerophorum*, *Apteodinium australiense* and *Spiniferites ramosus* group, and with occurrences of *Hystrichosphaeropsis obscura*, *Thalassiphora pelagica* and *Tityrosphaeridium cantharellus*, was recorded in a sample at 5800 ft from the Danish North Sea well Karl-1 (Poulsen 1995). The dinoflagellate assemblages in this sample, which was dated as Aquitanian-Burdigalian on the basis of foraminifers, are very similar to those of the Rønshoved section.

**Conclusion.** – The succession at Rønshoved has not been dated previously. Our results indicate an Early Miocene, possibly early or mid- Burdigalian age, based on the presence of *Hystrichosphaeropsis obscura*, *Tityrodinium cantharellus* and *Thalassiphora pelagica* and the absence of *Chiropteridium galea*.

## Stratigraphy

A tentative correlation of the investigated sections and other related key sections and boreholes in the Lille Bælt and Vejle Fjord area is presented in Figure 3. The location of sections and wells is presented in Figure 1. The model is based on palynology, earlier biostratigraphic studies (see above) and correlation of key stratigraphy horizons as determined from the sequence stratigraphy. Two of these horizons will be discussed in the following; a maximum flooding surface (MFS) and a sequence boundary (SB) (both marked by an asterisk in Fig. 3).

In the succession at Hindsgavl a maximum flooding surface is interpreted to occur between samples 6 and 7 (Fig. 3). The distinct change in palynofacies from

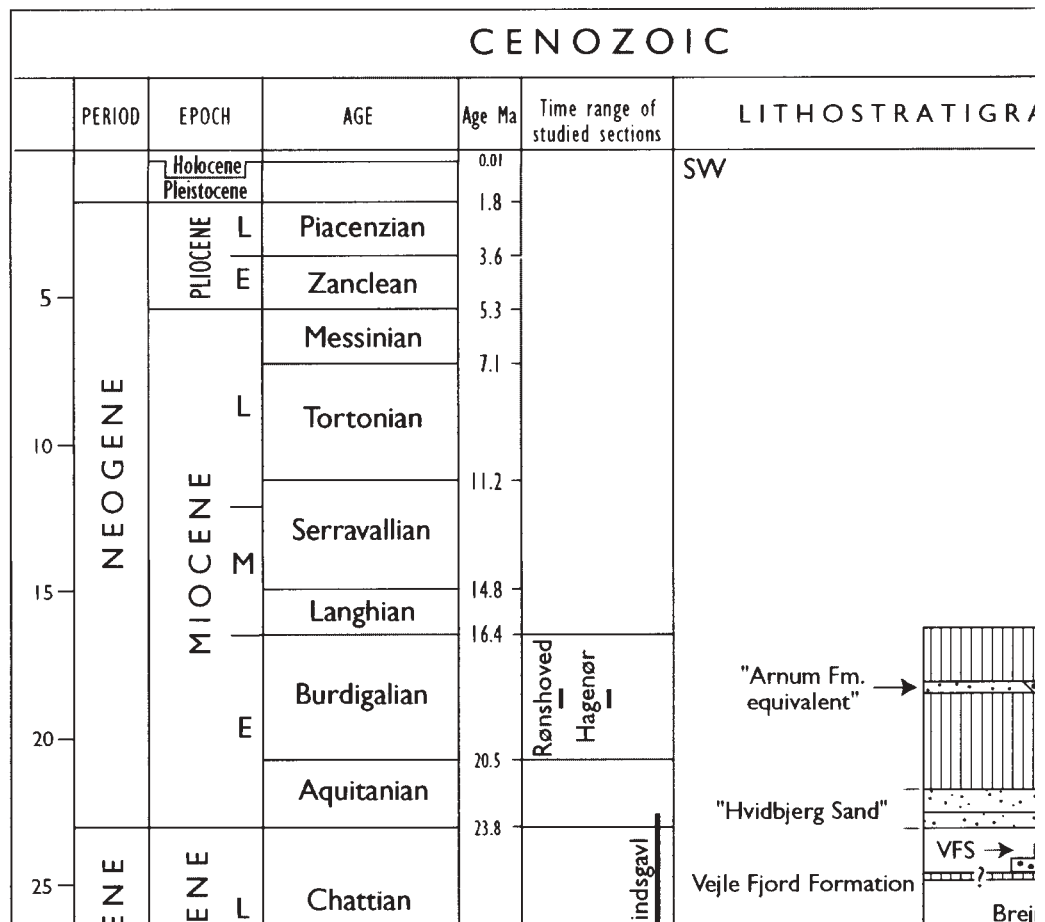
samples 1–6, which are dominated by terrestrial palynomorphs (spores, pollen and freshwater algae), to samples 7–8, which are dominated by marine dinoflagellate cysts, strongly indicates an increased marine influence. A regional flooding of the area is supported by a change from backbarrier to shoreface deposits at a number of outcrops in the Vejle Fjord area (e.g. Hvidbjerg, Dykær) and referred to as the change from the Vejle Fjord Formation to the sand at Hvidbjerg (Mikkelsen 1983, Rasmussen & Dybkjær 1999). Dinoflagellate cyst stratigraphy support the correlations of the Hindsgavl section with the sections Hvidbjerg and Dykær in the Vejle Fjord area (Dybkjær et al. 1999; Dybkjær unpublished). In the Morsholt-2 borehole a distinct maximum flooding surface overlain by a pebble layer with abundant shell fragments occur at the same level and showing the same heavy mineral association as the sand at Hvidbjerg (Rasmussen 1987).

A sequence boundary is proposed at a distinct lithological change from fine-grained sand to a pebble layer (pebbles up to 3 cm in diameter) seen at e.g. Rønshoved, Børup, Vejle Fjord Bro, and in the Morsholt-2 borehole. The regionally distributed pebble layer is interpreted as reworked fluvial deposits, the base of which now forms a ravinement surface associated with the sequence boundary (Rasmussen 1998). In the southern part of Jutland this surface (base of the sequence SJOM 2 of Rasmussen 1996) is overlain by a detached lowstand delta indicating a marked basinal displacement of the coastline (see further Rasmussen 1998). The deposits overlying this sequence boundary have been included in the latest Aquitanian in the Borg-1 well, based on foraminifers (Laursen & Kristoffersen 1999) and in a number of North Sea wells, based on foraminifers and dinoflagellate cyst stratigraphy (Bidstrup 1995).

The palynological ages presented in this paper strongly support the stratigraphic model proposed by Rasmussen (1998) and outlined above. The succession at Hindsgavl, referred to the Vejle Fjord Formation, and the sand at Hvidbjerg are both of Late Oligocene or earliest Early Miocene (early Aquitanian) age, while the successions at Hagenør and Rønshoved represent younger deposits, possibly of early to mid- Burdigalian (late Early Miocene) age (Fig. 5). There is a time-gap of approximately 3.5 m.a. between the last occurrence of *Chiropteridium galea* recorded from the Hindsgavl section (samples 1, 2, 5 and 8) and the first occurrence of *Hystrichosphaeropsis obscura* recorded from both the Hagenør (between samples 10 and 11) and Rønshoved sections (sample 14) (Williams et al. 1998b; Williams & Manum 1999). These datings indicate that at least 3.5 million years separate the succession at Hindsgavl and those at Hagenør and Rønshoved. The



Fig. 5. Scheme showing the distribution in time of the studied sections. The datings of the studied sections are based on the occurrence of stratigraphically important dinoflagellate cyst species. The relation of the ranges of these dinoflagellates to the time scale is based on Williams et al. (1998b). The time scale is according to Gradstein & Ogg (1996). VFS: Vejle Fjord Sand. VFC: Vejle Fjord Clay.



differences between the palynomorph assemblages from Hagenør and Rønshoved, with *Cyclopsiella lusatica* and *Polysphaeridium zoharyi* as common elements at Hagenør, are probably due to different depositional environments of two time equivalent successions, with the Hagenør profile being the most nearshore.

## Consequences for the lithostratigraphic subdivision

The stratigraphic model has some implications for the lithostratigraphy in the study area and regionally. The lithostratigraphic subdivision of the Upper Oligocene - Lower Miocene succession in Jylland has been revised a number of times (e.g. Rasmussen 1961, Buchardt-Larsen & Heilmann-Clausen 1988, Michelsen et al. 1998) and there is still some confusion concerning the definitions, ages and the interrelationship between the formations, e.g. the age of the Vejle Fjord Formation and its relation to the Ribe, Klintinghoved and Arnum formations.

The lower part of the section at Hindsgavl is referred to the Vejle Fjord Clay and Sand Members (Fig. 5) and probably correlates with the Skansebakke section (the type section for the Vejle Fjord Formation), whereas the upper part is equivalent to the sand at Hvidbjerg. The successions at Hagenør and Rønshoved should not be referred to the Vejle Fjord Formation as there is a major hiatus between these deposits and the type Vejle Fjord Formation. The hiatus probably represents the period in which the Ribe Formation was deposited in southwestern Jylland. The Arnum Formation was dated as Burdigalian (Laursen & Kristoffersen 1999, Laursen et al. 1998, Michelsen et al. 1998). The datings of the Rønshoved and Hagenør sections presented here indicate that these deposits probably are time equivalents with the lower part of the Arnum Formation.

## Conclusions

- Dinoflagellate cyst stratigraphy is a useful tool for evaluating the complex Oligocene-Miocene succession in Jylland.
- There have been two separate periods with lagoonal and nearshore marine deposits in the Lille Bælt area separated by a hiatus of at least 3.5 million years.
- The first period occurred in the Late Oligocene or the earliest Early Miocene (early Aquitanian) and is represented by the deposits at Hindsgavl, which are coeval with the Vejle Fjord Formation and the overlying sand at Hvidbjerg.
- The second period occurred in the late Early Miocene (early to mid-Burdigalian) and is represented by the deposits at Hagenør and Rønshoved. These sections are correlated with the lower part of the Arnum Formation and represent part of the coastline during the early to mid-Burdigalian.

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## Dansk sammendrag

Tre daglokaliteter i Lille Bælt-området, Hindsgavl, Hagenør og Rønshoved, er blevet dateret ved hjælp af palynologi (dinoflagellat cyster). Lagserien ved Hindsgavl er af Sen Oligocæn (Chattian) eller tidligste Tidlig Miocæn (tidlig Aquitanien) alder, mens lagserierne ved Hagenør og Rønshoved er af Tidlig Miocæn (tidlig til midt-Burdigalien) alder. En stratigrafisk model er opstillet, baseret på de nye palynologiske resultater kombineret med tidligere biostratigrafiske undersøgelser, samt sekvensstratigrafiske korrelationer af borer og daglokaliteter. Modellen indikerer, at der har været to perioder med la-

gune og kystnære marine aflejringer i Lille Bælt-området, adskilt af en hiatus på mindst 3.5 millioner år. Den første periode var i Sen Oligocæn eller tidligste Tidlig Miocæn (tidlig Aquitanien) og er repræsenteret af aflejringerne blottet ved Hindsgavl. Disse aflejringer er tidsækvivalente med Vejle Fjord Formationen og det overlejrende sand ved Hvidbjerg. Den anden periode var i Tidlig Miocæn (tidlig til midt-Burdigalien) og er repræsenteret af aflejringerne blottet ved Hagenør og Rønshoved. Disse aflejringer er tids-ekvivalente med den nedre del af Arnum Formationen og repræsenterer den daværende kystlinie.

## Species list

### Dinoflagellate cysts

- Apteodinium australiense* (Deflandre & Cookson 1955) Williams 1978  
*Apteodinium spiridoides* Benedek 1972  
*Batiacasphaera* spp. Drugg 1970  
*Chiropteridium galea* (Maier 1959) Sarjeant 1983  
*Cometodinium* spp. Deflandre & Courteville 1939  
*Cribrroperidium tenuitabulatum* (Gerlach 1961) Helenes 1984  
*Dapsilidinium pseudocolligerum* (Stover 1977) Bujak et al. 1980  
*Deflandrea phosphoritica* Eisenack 1938  
*Distatodinium craterum* Eaton 1976  
*Distatodinium paradoxum* (Brosius 1963) Eaton 1976  
*Eatonicysta ursulae* (Morgenroth 1966) Stover & Evitt 1978  
*Glaphyrocysta* spp. Stover & Evitt 1978  
*Glaphyrocysta* sp. cf. *G. vicina* (Eaton 1976) Stover & Evitt 1978  
*Homotryblum caliculus* Bujak in Bujak et al. 1980  
*Homotryblum plectilum* Drugg & Loeblich Jr. 1967  
*Homotryblum tenuispinosum* Davey & Williams 1966  
*Homotryblum vallum* Stover 1977  
*Hystrichokolpoma cinctum* Klumpp 1953  
*Hystrichokolpoma rigaudiae* Deflandre & Cookson 1955  
*Hystrichokolpoma* sp. cf. *H. salacia* Eaton 1976  
*Hystrichokolpoma* spp. Klumpp 1953  
*Hystrichosphaeropsis obscura* Habib 1972  
*Lingulodinium machaerophorum* (Deflandre & Cookson 1955) Wall 1967  
*Melitasphaeridium choanophorum* (Deflandre & Cookson 1955) Harland & Hill 1979.  
*Membranophoridium aspinatum* Gerlach 1961  
*Operculodinium* spp. Wall 1967  
*Palaeocystodinium golzowense* Alberti 1961  
*Pentadinium laticinctum* Gerlach 1961  
*Polysphaeridium zoharyi* (Rossignol 1961) Bujak et al. 1980  
*Reticulatosphaera actinocoronata* (Benedek 1972) Bujak & Mat-suoka 1986  
*Selenopemphix nephroides* Benedek 1972  
*Spiniferites pseudofurcatus* (Klumpp 1953) Sarjeant 1970  
*Spiniferites* spp. Mantell 1854  
*Systematophora placacantha* (Deflandre & Cookson 1955) Davey, Downie, Sarjeant & Williams 1969  
*Thalassiphora pelagica* (Eisenack 1954) Eisenack & Gocht 1960  
*Tityrosphaeridium cantharellus* (Brosius 1963) Sarjeant 1981  
*Wetzeliella* spp. Eisenack 1938

## Acritarchs

*Cyclopsiella lusatica* (Krutzsch 1970) Strauss & Lund 1992

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## Plate 1

(the bars for scale are 20 µm)

- Fig. 1: *Chiropteridium galea* (Maier 1959) Sarjeant 1983. Hindsgavl, sample 8.  
Fig. 2: *Chiropteridium galea* (Maier 1959) Sarjeant 1983. Hindsgavl, sample 1.  
Fig. 3: *Deflandrea phosphoritica* Eisenack 1938. Hindsgavl, sample 6.  
Fig. 4: *Homotryblium tenuispinosum* Davey & Williams 1966. Hindsgavl, sample 8.  
Fig. 5: *Homotryblium plectilum* Drugg & Loeblich Jr. 1967. Hindsgavl, sample 5.  
Fig. 6: *Homotryblium vallum* Stover 1977. Hindsgavl, sample 7.  
Fig. 7: *Homotryblium caliculum* Bujak in Bujak et al. 1980. Hindsgavl, sample 8.  
Fig. 8: *Glaphyrocysta* cf. *vicina* (Eaton 1976) Stover & Evitt 1978. Hindsgavl, sample 8.  
Fig. 9: *Membranophoridium aspinatum* Gerlach 1961. Hindsgavl, sample 8.  
Fig. 10: *Lingulodinium machaerophorum* (Deflandre & Cookson 1955) Wall 1967. Hindsgavl, sample 8.  
Figure 11: *Lingulodinium machaerophorum* (Deflandre & Cookson 1955) Wall 1967, variant with short processes. Hindsgavl, sample 8.  
Fig. 12: *Pentadinium laticinctum* Gerlach 1961. Hindsgavl, sample 8.  
Fig. 13: *Apteodinium australiense* (Deflandre & Cookson 1955) Williams 1978. Rønshoved, sample 14.  
Fig. 14: *Apteodinium spiridoides* Benedek 1972. Hindsgavl, sample 8.  
Fig. 15: *Cribrorperidinium tenuitubulatum* (Gerlach 1961) Helenes 1984. Hindsgavl, sample 8.

## Plate 2

- Fig. 1: *Distatodinium craterum* Eaton 1976. Hindsgavl, sample 7.  
Fig. 2: *Areosphaeridium dictyoplokum* (Klumpp 1953) Eaton 1971. Hindsgavl, sample 8. Presumed reworked.  
Fig. 3: *Tityrosphaeridium cantharellus* (Brosius 1963) Sarjeant 1981. Rønshoved, sample 14.  
Fig. 4: *Dapsilidinium pseudocolligerum* (Stover 1977) Bujak et al. 1980. Hagenør, sample 10.  
Fig. 5: *Operculodinium* sp. 1. Hagenør, sample 10.  
Fig. 6: *Spiniferites ramosus* group (Ehrenberg 1838) Mantell 1854. Hagenør, sample 10.  
Fig. 7: *Polysphaeridium zoharyi* (Rossignol 1962) Bujak et al. 1980. Hagenør, sample 10.  
Fig. 8: *Systematophora placacantha* (Deflandre & Cookson 1955) Davey et al. 1969. Hindsgavl, sample 8.  
Fig. 9: *Thalassiphora pelagica* (Eisenack 1954) Eisenack & Gocht 1960. Hindsgavl, sample 8.  
Fig. 10: *Eatonicysta* sp. 1.  
Fig. 11: *Hystrichosphaeropsis obscura* Habib 1972. Rønshoved, sample 14.  
Fig. 12: *Hystrichosphaeropsis obscura* Habib 1972. Rønshoved, sample 14.  
Fig. 13: *Hystrichokolpoma rigaudiae* Deflandre & Cookson 1955. Hagenør, sample 10.  
Fig. 14: *Hystrichokolpoma* sp. cf. *H. salacia* Eaton 1976. Rønshoved, sample 14.  
Fig. 15: *Eatonicysta ursulae* (Morgenroth 1966) Stover & Evitt 1978. Hindsgavl, sample 8. Presumed reworked.

## Plate 3

- Fig. 1: *Cometodinium* sp. 1. Hagenør, sample 10.  
Fig. 2: *Reticulatosphaera actinocoronata* (Benedek 1972) Bujak & Matsuoka 1986. Hagenør, sample 10.  
Fig. 3: Gen. et sp. indet. A. Hagenør, sample 11.  
Fig. 4: *Cyclopsiella lusatica* (Krutzsch 1970) Strauss & Lund 1992. Hagenør, sample 10.  
Fig. 5: *Cyclopsiella lusatica* (Krutzsch 1970) Strauss & Lund 1992. Hagenør, sample 10.  
Fig. 6: *Batiacasphaera* sp. 1. Rønshoved, sample 14.  
Fig. 7: *Melitasphaeridium choanophorum* (Deflandre & Cookson 1955) Harland & Hill 1979.  
Fig. 8: Gen. et sp. indet. B. Hindsgavl, sample 7.  
Fig. 9: Gen. et sp. indet. B. Hindsgavl, sample 7.  
Fig. 10: *Mougeotia laetevirens* (Braun) Wittrock 1877. Hagenør, sample 10.  
Fig. 11: *Mougeotia laetevirens* (Braun) Wittrock 1877. Hagenør, sample 10.  
Fig. 12: *Mougeotia laetevirens* (Braun) Wittrock 1877. Hagenør, sample 11.  
Fig. 13: *Acanthomorpha* spp. Rønshoved, sample 14.  
Fig. 14: *Pediastrum* spp. Hagenør, sample 10.  
Fig. 15: *Botryococcus braunii* Kützing 1849. Hagenør, sample 11.

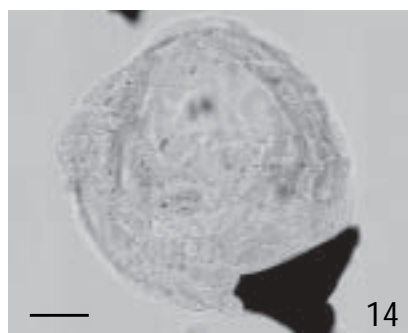
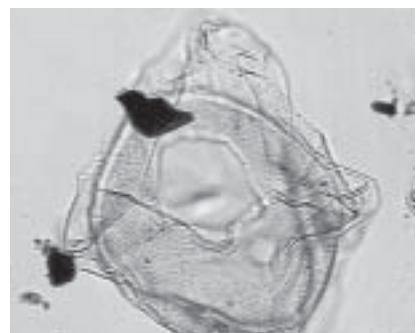
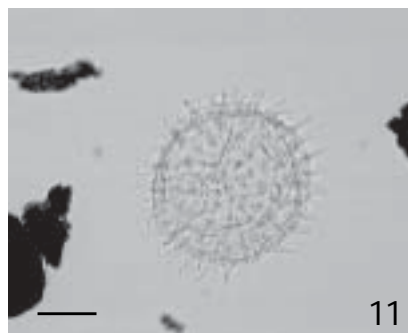
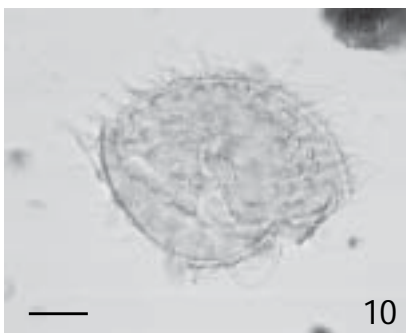
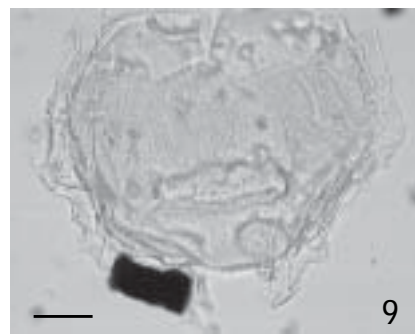
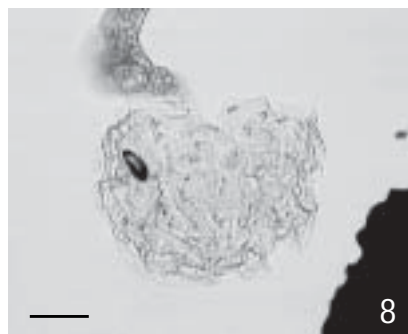
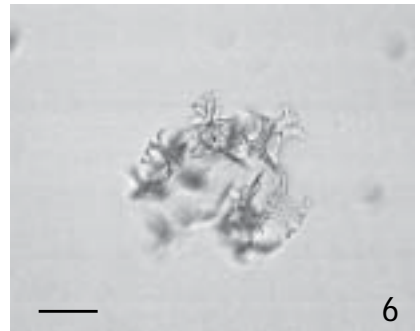
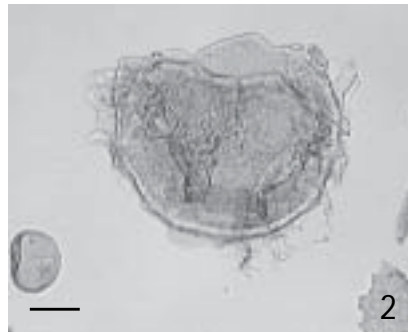
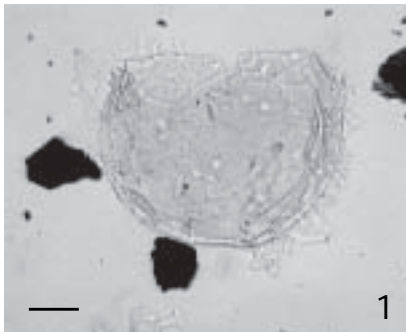


Plate 2

