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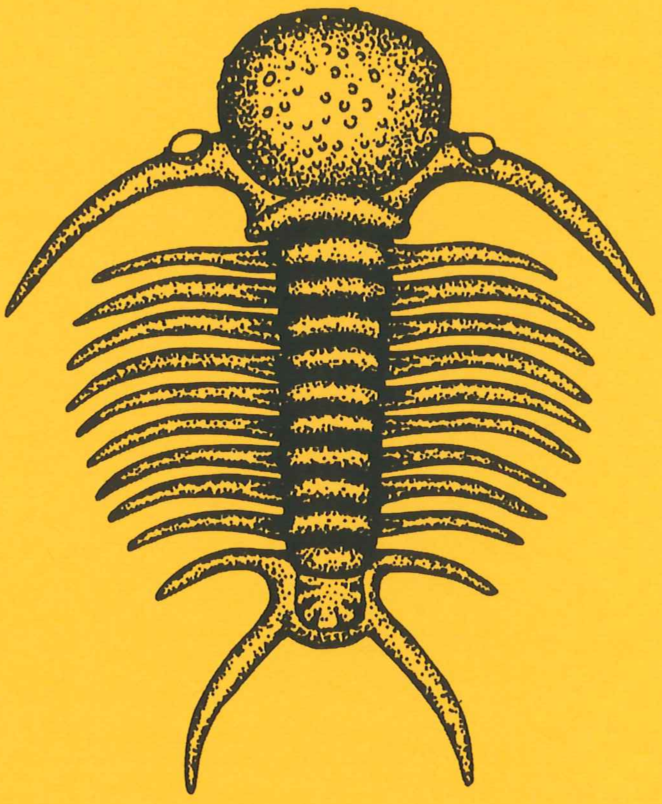

A Light Microscopy and Scanning Electron Microscopy study of coccoliths from two bore holes along the City Tunnel Line in Malmö, Sweden

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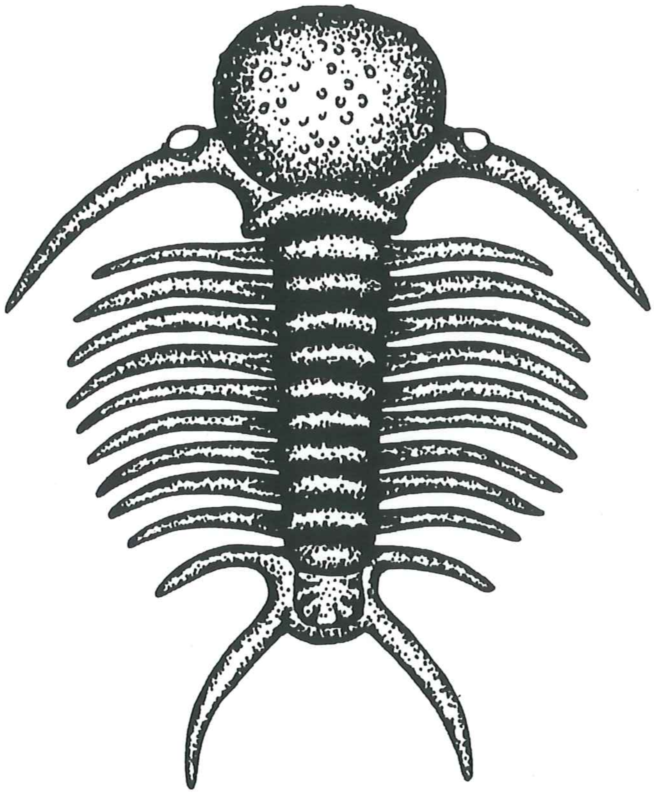

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Abstract: Samples from the Danian were prepared for study of coccoliths, on one hand with Light Microscopy, on the other hand with Scanning Electron Microscopy to test the different advantages and disadvantages of these methods. Light Microscopy studies can be used for quantitative investigations and Scanning Electron Microscopy studies for quantitative and qualitative investigations of coccoliths. Scanning Electron Microscopy is preferred in several respects. Smaller details can be studied as the resolution is considerably higher and the specimen can be tilted, rotated and studied from different angles. The sample preparations for both methods are quick, easy and fairly cheap. It takes about the same time to investigate coccoliths with either technique. Light Microscopy studies are less costly than Scanning Electron Microscopy studies. The material for this study is from two bore holes; one hammer drilled hole and one cored hole. Both bore holes are from the same stratigraphical interval and area, located along the City Tunnel Line in Malmö. This study indicates that hammer drilling can be used in coccolith biostratigraphy, though the hammer drilling method has a higher contamination risk compared to core drilling.
Keywords: Light Microscopy, Scanning Electron Microscopy, coccoliths, stratigraphy, hammer drilling, core drilling, Danian, Tertiary, City Tunnel Line, Malmö, Sweden.

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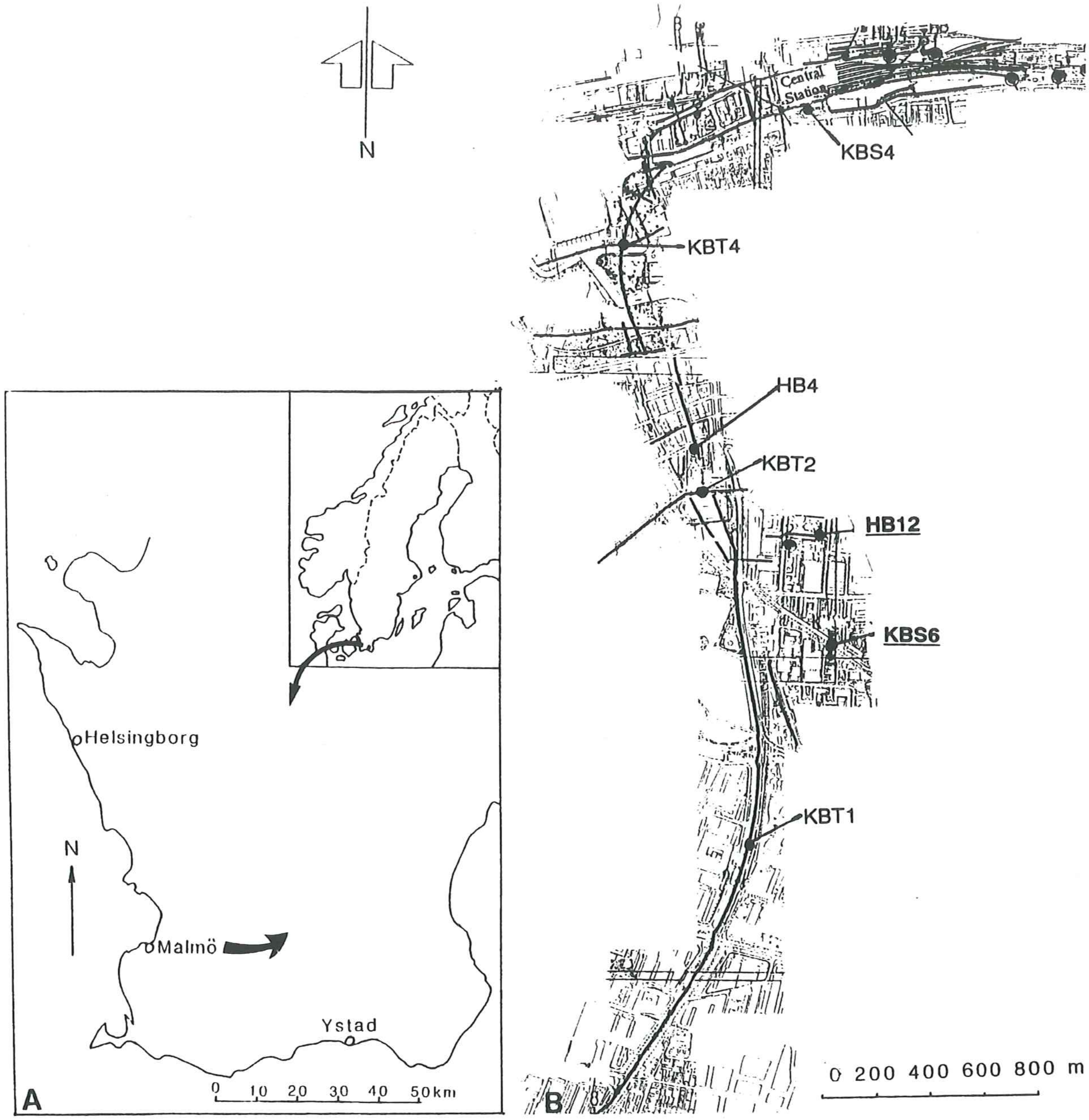


Fig. 1. **A**. Map showing the location of Malmö, Sweden. **B**. The City Tunnel Line in Malmö with location of the bore holes. HB12 and KBS6 are investigated here.

The primary purpose of this investigation is to compare the use of Light Microscopy and Scanning Electron Microscopy when establishing a biostratigraphic division of the Danian limestone on the basis of coccolith, nannoplankton. The second purpose is to discuss if samples from a hammer drilled hole can be used in such biostratigraphy. The bore holes are located along the City Tunnel Line in the southern part of Malmö, Sweden (Figs. 1 and 2A). The hammer drilled hole (HB12) was correlated with a core drilled hole (KBS6). The drill core was also investigated in this study. The initiative for this study came from VBB Viak in Malmö, Sweden, and the material came from SVEDAB in Malmö, Sweden.

Geological setting

The occurrence and stratigraphy of the Maastrichtian and Danian in Sweden are chiefly known through publications by Brotzen (1940, 1944, 1948 and 1959).

The Danian limestone in the southern part of the Öresund area can be divided into two units. The lower unit is the Bryozoan Limestone. It is greyish-white and generally 50 to 60 m thick. It consists of bryozoans and other fossilised organisms, mixed with a fine-grained lime ooze. The

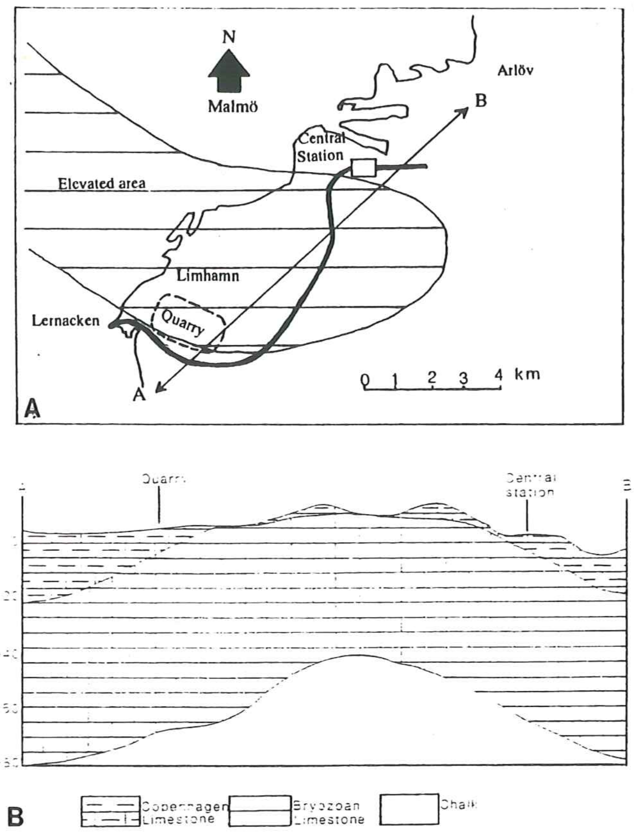


Fig. 2. **A**. Sketch over the City Tunnel Line and the elevated structure in Malmö, Sweden (after SVEDAB 1995). **B**. Sketch of the elevated structure and the general stratigraphy along the City Tunnel Line (after SVEDAB 1995). The position of the section is shown in Fig. 2A (line A to B).

upper unit is called the Copenhagen Limestone and reaches a total thickness of about 40 m (Thomsen 1995*b*). Copenhagen Limestone is used as a collective name for a limestone which consists of carbonate sand, carbonate silt and carbonate ooze in a varied mixture (Larsen et al. 1991). This limestone is more fine-grained due to lower content of bryozoans. Danian limestone covers the Cretaceous in the entire southwest part of Scania, except for a narrow sector along the Romeleåsen fault.

The limestone investigated in this study comprises the upper part of the Bryozoan Limestone and the lower part of the Copenhagen Limestone. In both units hard and soft rocks alternate due to silicification and cementation. The limestones also contain nodules of a dark, compact chert.

The biozones of the Danian limestone are roughly parallel with the lithological boundaries. Variation in thickness of the zones may be due to irregular bedding in the Bryozoan Limestone, related to mounds. Thus, the biostratigraphic evidence supports the general geological model of the area with a large elevated area, situated between the central part of Malmö and Limhamn (Fig. 2). The investigated bore holes are apparently situated on the top of and northern flank of this structure. The fact that the largest hiatus between the Bryozoan Limestone and the Copenhagen Limestone is found in the previously examined bore hole KBT1 on the top of the elevated area suggests that the structure existed prior to the deposition of the Copenhagen Limestone (Figs. 2 and 3; Thomsen 1995*b*; O. Andersson pers. comm. 1996).

Material and methods

The material used in this study was obtained from two bore holes along the City Tunnel Line in Malmö, one hammer drilled hole and one core drilled hole. Both bore holes were drilled during the summer of 1995; the hammer drilled hole by Malmbergs in Yngsjö AB and the core drilled hole by United Drilling Contractors. There are differences between the two drilling techniques. In a core drilled hole the sample materials are *in situ* while in a hammer drilled hole the individual sample material is mixed. The drilling technique for core holes is described by Finkel & Thoring (1989) and the drilling technique for hammer holes is described by Andersson (1981).

The hammer drilled hole has a total depth of 41 m and the core drilled hole has a total depth of 40.3 m including Quaternary strata. The samples were only collected from the Danian limestone. Samples from the hammer drilled hole were collected from about every five meters, each sample including a 20 to 25 cm interval (Figs. 3 and 4B). Samples from the drill core were collected from about the same levels as the hammer drilled hole, each sample including a 2 to 5 cm interval (Figs. 3 and 4A). The choice of samples from the bore holes was made according to special induration criteria. For the hammer drilled hole the following induration criteria were used: (1) can easily be formed with the fingers, (2) can be scratched with a nail, (3) can be scratched with brass, (4) can be scratched with a knife and (5) can not be scratched

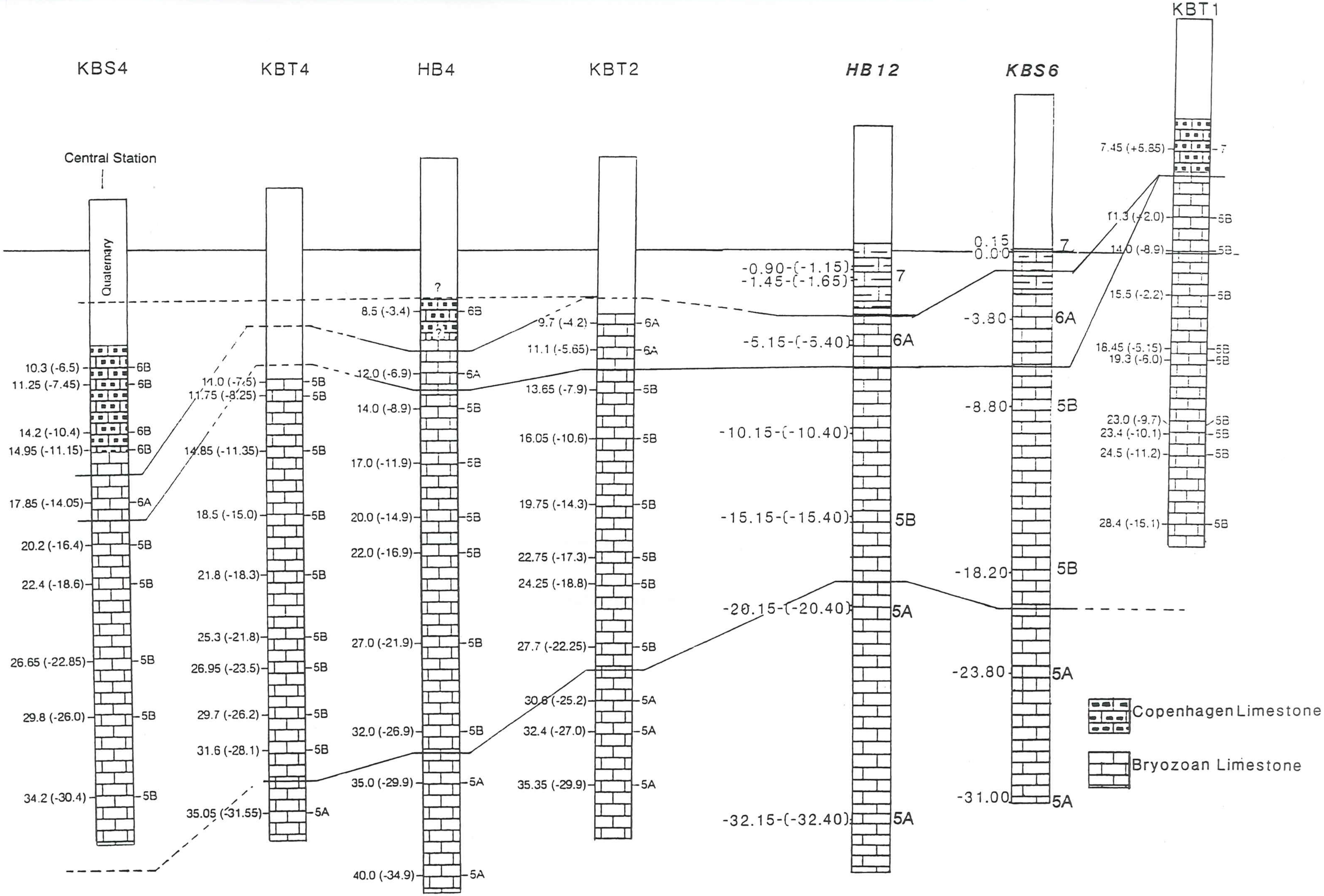


Fig 3 Biostratigraphic division of the Danian limestones in the boreholes discussed. KBS4, KBT4, HB4, KBT2 and KBT1 were investigated by Thomsen (1995*b*). HB12 and KBS6 are the bore holes investigated in this study. The sample levels are marked on the left side of the bore holes and the zones/subzones to the right.

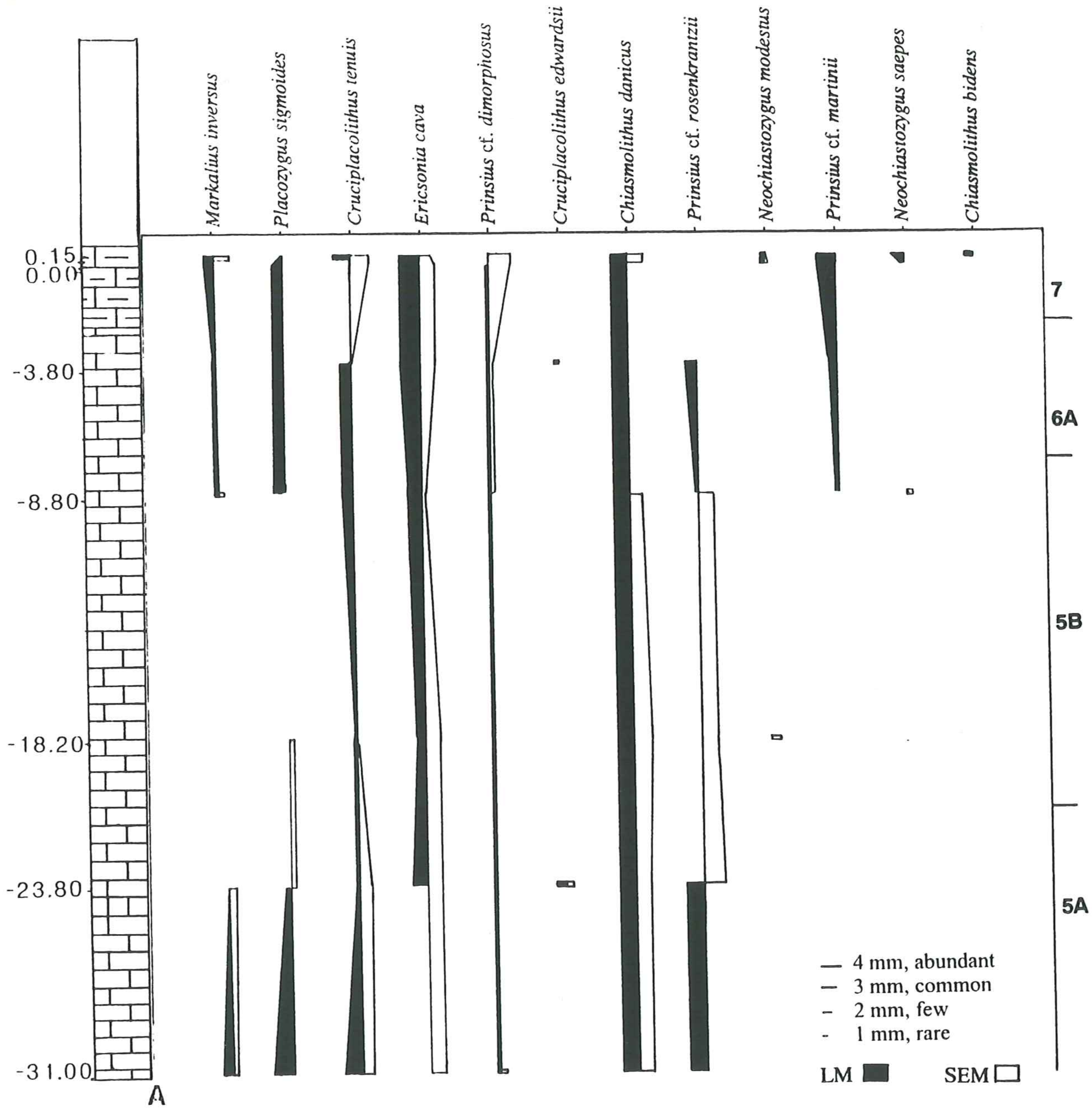


Fig. 4A. Distribution of the coccoliths in **KBS6** with zonation used in this study. The levels of the samples are marked on the left side.

with a knife. For the drill core the following induration scale was used: (1) can easily be formed with the fingers, (2) can easily be worked with a knife, (3) can be worked with a knife, (4) can be scratched with a knife and, (5) can not be scratched with a knife. Samples from 1 to 3 on both scales were chosen. The samples were collected from seven levels in each bore hole. From each of the seven levels two samples were taken, one for Light Microscopy (LM; slides) and one for Scanning Electron Microscopy (SEM; stubs). Thus, there was a total of 28 samples. Three to four slides and one to two stubs were prepared from each level. The two upper samples in both bore holes (KBS6 and HB12) belong to the Copenhagen Limestone and the lower samples to the Bryozoan Limestone (Figs. 3 and 4).

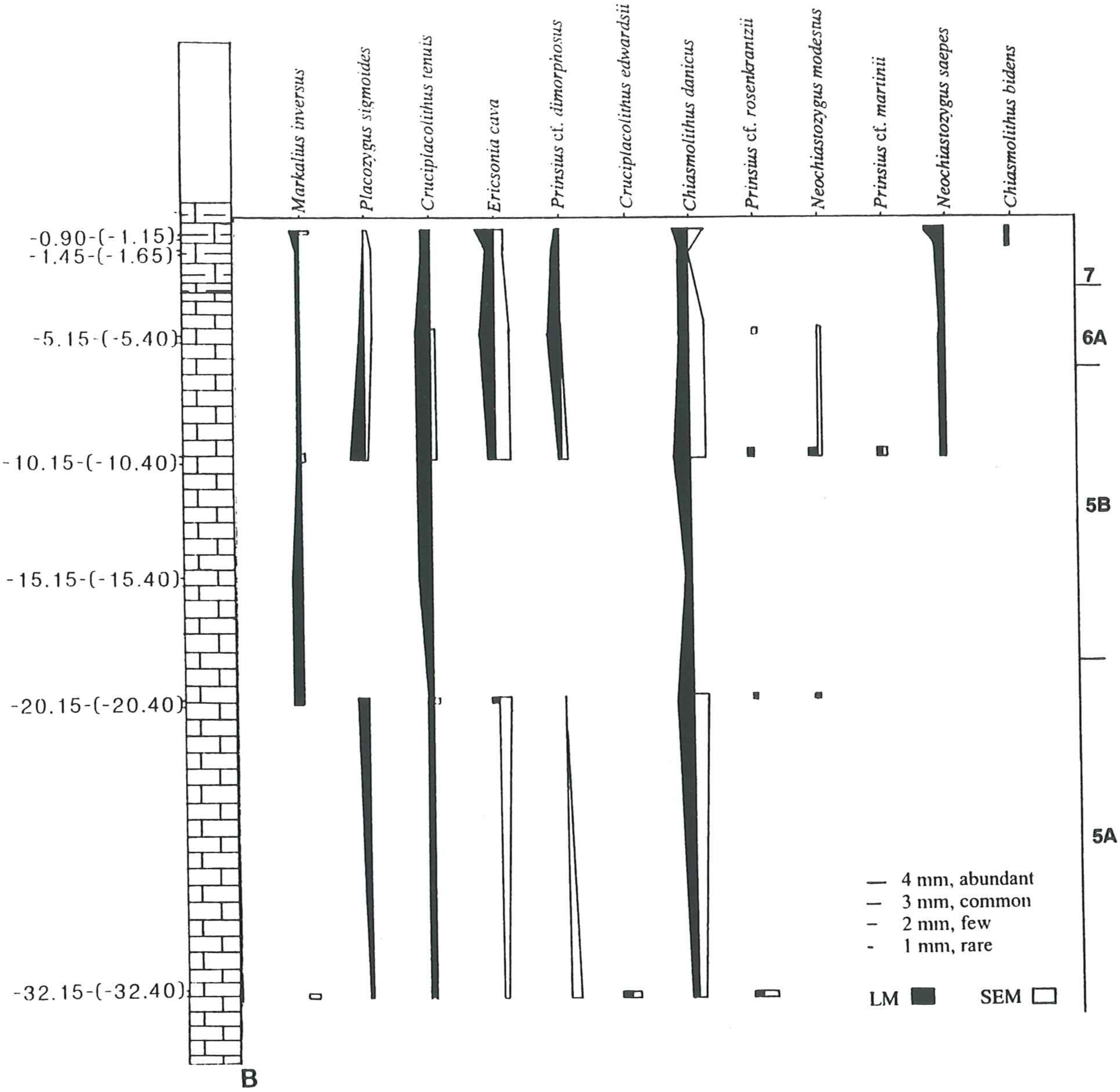


Fig. 4B. Distribution of the coccoliths in **HB12** with zonation used in this study. The levels of the samples are marked on the left side.

In a previous study by Thomsen (1995*b*) material from four drill cores and one hammer bore hole, in the same area, was examined with a total of 51 samples analysed. The bore holes are KBS4, KBT4, HB4 (hammer drilled hole), KBT2 and KBT1 (Fig. 3). All the bore holes are located along the City Tunnel Line as are my two borings (HB12 and KBS6). The boundary between the Copenhagen Limestone and the Bryozoan Limestone in Thomsen´s (1995*b*) study is based on lithological evidence. As datum level the top of the limestone was used, above which are Quaternary strata. A comparison and a biostratigraphical classification has previously been made for the five borings. A stratigraphical correlation was performed with the two borings investigated in more detail in this study (Figs. 3 and 4).

The preparations for the LM and SEM studies were made using standard methods briefly described here. Cuttings from the hammer drilled hole or a piece of core from the drill core were chosen from a clean area. By removing the outermost layer of a piece of rock an area is cleaned and by scratching off a small amount of material from there a sample is prepared. The small sample was then put into a test tube, distilled water was added and the samples were treated ultrasonically for ten seconds. To remove clay particles, the samples were then centrifuged (up to 2 000 r. p. m.). A drop of the suspension was put on either a stub (SEM) with a circular glass top or on a slide (LM). The samples were then dried in an oven (50° C). When the samples were dry the stub was sputter-coated with gold. For the LM preparation a drop of glycerine, silicon oil or Gurr (a non fluid mounting medium) was put on the slide and covered with a cover-glass. The crack between the slide and the cover-glass was then sealed with nail polish (if Gurr was used this part is excluded). Different preparation methods of coccoliths have been described by Forchheimer (1968) and Perch-Nielsen (1985). Different methods for viewing the same specimen first by LM and then by SEM were described by Perch-Nielsen (1967), Thierstein et al. (1971), Forchheimer (1974) and Smith (1981). These methods are more useful for taxonomic studies and have not been performed during this study.

The Light Microscope

The LM was equipped with an eye piece lens (x12,5) and two different ocular lenses, x40 and x100 (requires oil-immersion). The x40 ocular lens was used for searching over the slide and also in some instances to identify the coccoliths. The x100 ocular lens was used for identifying the coccoliths. Only normal light was used. Through focusing at different levels on the coccoliths it was possible to identify them and to study some of the details. For easy return to a specimen previously examined, an England finder was used. A Nikon HFX-DX, Optiphot-2 microscope was used and the photos were taken with a Nikon Fx-35 DX camera with a Kodak 100 pro T-max. 36 film.

It has long been known that when coccoliths are examined between crossed nicols in a petrological microscope, they exhibit interference effects which could only be produced by structures much more complicated than any that can be seen through an oil-immersion objective under the most favourable conditions (Black & Barnes 1959). This can be important for identification of coccoliths.

The Scanning Electron Microscope

The SEM is a topographic instrument giving topographical images. The SEM gives the image by bombarding the surface of a specimen held in a high vacuum with a stream of electrons (Goldstein et al. 1981). The resolving power for SEM is about 200 to 500 Å with a depth of focus 300 times greater than that of a LM. Magnifications used in SEM varied between 750 and 10000 times. The lower magnifications were used for searching over the stub while the higher magnifications were used for identifying the coccoliths and studying details. The SEM has the possibility of tilting and rotating the specimen which allows observation from different angles. A digital co-ordinate (LINK) system helped returning to the same specimen again. A Jeol JSM 6400 Scanning Microscope was used. The photos were taken with a Polaroid camera using a Polaroid 665 ISO 80/120 Film-Pack Instantané Positif/Négatif film.

Comparisons with species previously published and illustrated with LM and SEM could be made. In order to avoid mistakes it would, however, be necessary to study the holotype material.

Coccoliths and biostratigraphy

Coccolithophorids are among the most abundant organisms in the oceanic phytoplankton and together with diatoms they are the most important primary food resource for zooplankton in the sea (Tappan 1980 cited not seen). Coccolithophorids first occurred in the early Jurassic and since the Cretaceous they have been the most important carbonate building group (Thomsen 1995*a*). It is mainly the size of the coccoliths, their world-wide distribution and their great abundance that make them so useful in biostratigraphy.

The discovery of coccoliths

Coccoliths were first discovered by Ehrenberg (1836) who studied and illustrated specimens found in samples of chalk. He suggested that they were of inorganic origin and called them Cretaceous morpholiths. Huxley (1858) was doubtful about their inorganic origin. Due to the fact that they looked somewhat like cells of the alga *Protococcus* he called them coccoliths (Forchheimer 1970). The inorganic origin of coccoliths was, however, accepted until 1861, when Sorby (1861) and Wallich (1860 and 1861 as referred by Forchheimer 1972) found that the minute bodies are not separate individuals, but parts of cells with a diameter a few times greater than their own. Sorby (1861) found that they formed walls of small spheres, not flat discs as described by Ehrenberg (1836) and concave on one side and convex on the other side. The biostratigraphic value of coccoliths and discoasters was predicted by Bramlette & Riedel (1954). At about the middle of this century the investigation of coccoliths increased rapidly due to the introduction of the new microscopes Transmission Electron Microscope (TEM) and Scanning Electron Microscope (SEM).

Three different taxonomy catalogues have been published (Farinacci 1969-1970; Loeblich & Tappan 1966-1969 and Reinhardt 1970) dealing with taxonomy, morphology and stratigraphy of coccoliths (Forchheimer 1974). Farinacci´s (1969-1970) catalogue was used in this investigation.

Coccoliths and sedimentology

Coccolithophorids are exclusively planktic marine organisms and are distributed from open oceanic, pelagic environments to near shore littoral and inshore lagoonal environments. Postmortem disintegration of the coccosphere usually dislodges and scatters the shields (coccoliths) before they settle on the ocean bottom (Haq 1978). With increasing depth the coccoliths tend to dissolve or disaggregate into dispersed carbonate matter. Unfortunately, there is a tendency for calcite overgrowth or recrystallisation to occur in coccoliths, obscuring their morphology (Wise 1973). Another disadvantage to the stratigrapher is the ease with which coccoliths are reworked into younger sediments without showing outward signs of wear.

The history of coccolithophorids has bearing on the overall history of life (Loeblich & Tappan 1963), as they are both a primary source of food in the oceans and a significant producer of atmospheric oxygen. Their numbers and taxonomic diversity increased steadily until the late Cretaceous. Then there was a major marine transgression and a further, explosive radiation of many planktic groups. These conditions led to the deposition of chalk (mainly consisting of coccoliths) over vast areas of the continental platforms. It has been observed that most Maastrichtian coccoliths disappear at the Cretaceous-Tertiary boundary and their occasional occurrence in Danian sediments is attributed to reworking (Perch-Nielsen 1979*a*). The coccolith distribution in the Danian of Denmark has been investigated by Perch-Nielsen (1969*a*, 1969*b*, 1971*a*, 1979*a* and 1979*b*) and Romein (1979).

The abundance and preservation of the Danian coccoliths varies within the Danish-Polish Basin. Coccoliths are in general less common and more poorly preserved in the Fennoscandian Border Zone than in the western part of the basin (Thomsen 1995*b*).

Biostratigraphic zonation of the Danian

During the Danian there was a great and rapid development of new species. Perch-Nielsen (1979*a*) came to the conclusion that with help of coccoliths the Danian can be divided into 10 so called D-zones (Fig. 5). The subzonal boundaries are based on the first occurrence of species. Last occurrences are usually less reliable due to possible reworking. Several biostratigraphic zonation schemes based on coccoliths have been proposed (e. g. Heck & Prins 1987 as referred by Thomsen 1995*b*). The Danian limestone (Bryozoan- and Copenhagen Limestones) can be divided into 6 to 8 intervals characterised by different coccolith taxa (Thomsen 1995*b*). These intervals or zones can be used in the Danish-Norwegian basin and in the North Sea area. In this study the coccolith zonation schemes by Perch-Nielsen (1979*a*) and Thomsen (1995*b*) were used. Perch-Nielsen´s (1979*a*) zonations have been modified by Heck & Prins

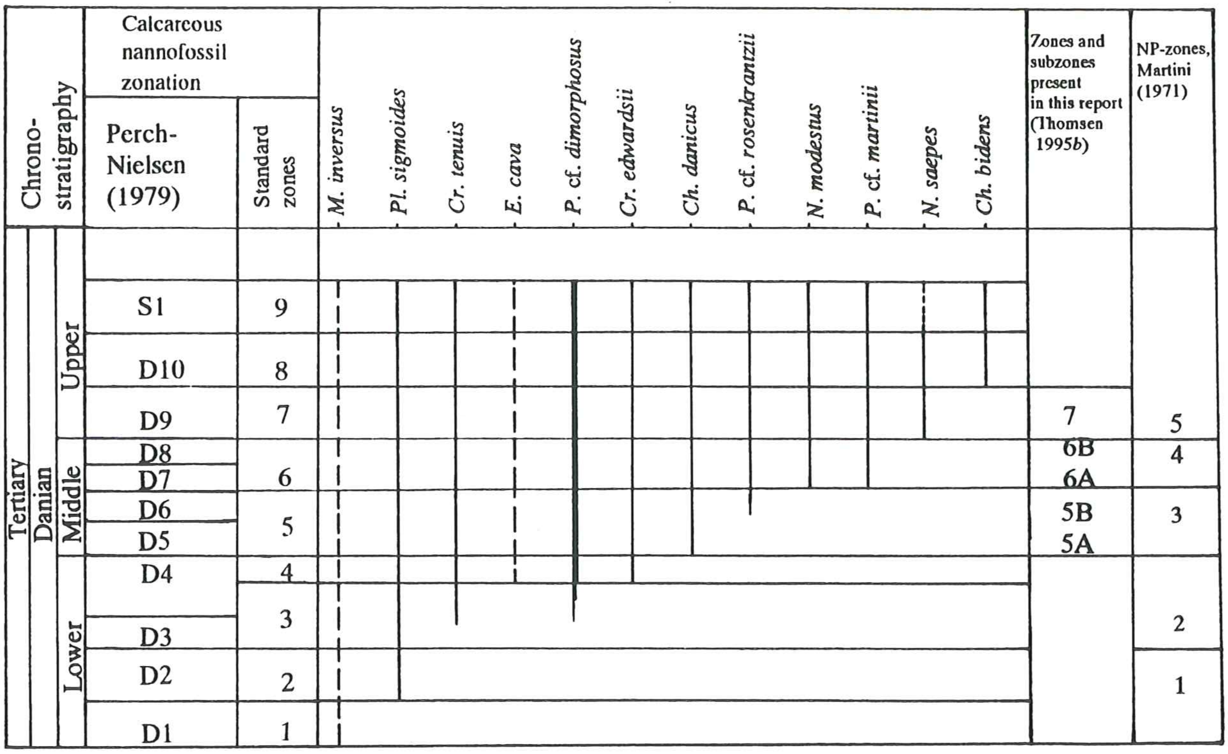


Fig. 5. Distribution of biostratigraphically important coccoliths in the Danian deposits of the North Sea Basin with the zonation scheme after Perch-Nielsen (1979*a*), the standard zonation scheme after Thomsen (1995*b*) and the stratigraphical zonation by Martini (1971). Zonal denominators are: S1 (S=Selandian) - *Neochiastozygus perfectus*, D10 (D=Danian) - *Chiasmolithus bidens*, D9 - *Neochiastozygus saepes*, D8, (6B) - *Prinsius martinii*, D7, (6A) - *Neochiastozygus modestus*, D6, (5B) - *Prinsius rosenkrantzii*, D5, (5A) - *Chiasmolithus danicus*, D4 - *Prinsius dimorphosus*, D3 - *Cruciplacolithus tenuis*, D2 - *Placozygus sigmoides* and D1 - *Biantholithus sparsus*. *Markalius inversus* and *Ericsonia cava* were added to the diagram in this study, so these range lines are dashed.

(1987 as referred by Thomsen 1995*b*) and Thomsen (1988 as referred by Thomsen 1995*b*; Fig. 5). **Zone 1**: Lower boundary, first occurrence of *Biantholithus sparsus*. In this zone *Markalius inversus* has its first appearance. Upper boundary, first occurrence of *Placozygus sigmoides*. **Zone 2:** Lower boundary, first occurrence of *Pl. sigmoides*. Upper boundary, first occurrence of *Cruciplacolithus tenuis*. **Zone 3:** Lower boundary, first occurrence of *Cr. tenuis*. Upper boundary, first occurrence of *Prinsius dimorphosus*. In this zone *Ericsonia cava* has its first appearance. **Zone 4:** Lower boundary, first occurrence of *P. dimorphosus*. Upper boundary, first occurrence of *Chiasmolithus danicus*. *Prinsius dimorphosus* is not very abundant in the lower part, but suddenly becomes very abundant in the higher parts. *Cruciplacolithus edwardsii* (Fig. 6F) has its first appearance in this zone. **Zone 5:** Lower boundary, first occurrence of *Ch. danicus*. Upper boundary, first occurrence of *Neochiastozygus modestus*. The upper boundary is difficult to define precisely. This zone can be divided into subzones A (D5) and B (D6; Thomsen 1995*b*). The evidence used for distinguishing between these subzones is the morphology of the central cross of *Ch. danicus*. The central cross becomes slightly more bent in subzone 5B (Fig. 8K1) than in 5A (Fig. 8K2; Heck & Prins 1987 as referred by Thomsen 1995*b* and E. Thomsen pers. comm. 1996). **Zone 6:** Lower boundary, first occurrence of *N. modestus*. Upper boundary, first occurrence of *Neochiastozygus saepes*. Zone 6 is divided into two subzones 6A and 6B. Subzone 6B (D8) is distinguished from subzone 6A (D7) in having larger (>2.5 µm) and more abundant specimens of *N. modestus* (Heck & Prins 1987 as referred by Thomsen 1995*b* and E. Thomsen pers. comm. 1996). **Zone 7** (D9): Lower boundary, first occurrence of *Neochiastozygus saepes*. Upper boundary, first occurrence of *Chiasmolithus bidens*. **Zone 8** (D10): Lower boundary, first occurrence *Ch.*

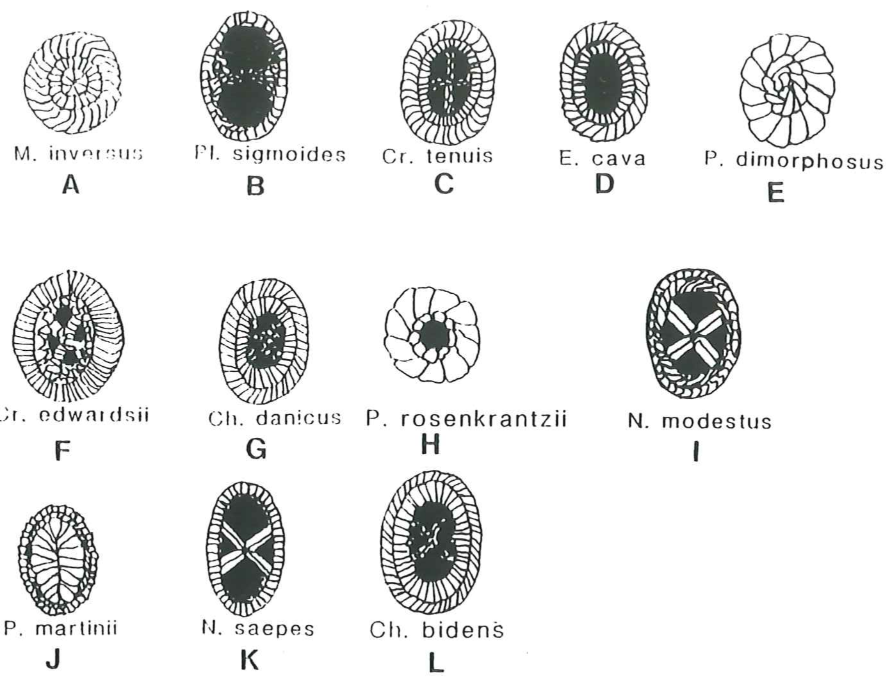


Fig. 6. Coccoliths used in the biostratigraphic subdivision. Drawings **A** to **B**, **D** to **E** and **G** to **L** are from Farinacci (1971), while **C** *Cruciplacolithus tenuis* is after Romein (1979) and **F** *Cr. edwardsii* by the author.

bidens. The upper boundary is drawn where *N. saepes* becomes considerably less abundant than previously.

Internationally the Danian is divided into five NP (nannoplankton) zones (Martini 1971 cited not seen). The NP zones are biostratigraphical, but have reached a status as chronostratigraphical units (Fig. 5).

Terminology and descriptions of coccoliths

The morphological characteristics of a coccolith are the shape, the structure of the central area (cross, bridge, opening and perforation) and the striae of the rim (Forchheimer 1972; Fig. 7). The size of a coccolith is 2 to 30 μm in diameter.

Chiasmolithus is used for forms with a central cross in X and H form. The central cross consists of two straight and two slightly bent arms which meet slightly offset. *Chiasmolithus bidens* (Bramlette & Sullivan 1961) Hay & Mohler (1967), first occurring in zones D10 and 8, has a small X-shaped structure. The distal shield is composed of 60-75 segments that are slightly imbricated dextrally and that have sutures showing slight clockwise inclination in distal view (Figs. 6L and 8R). *Chiasmolithus danicus* (Brotzen 1959), Hay & Mohler (1967), first occurring in zones D5, NP3, 5A and 5B, has a distal shield and is composed of 40 to 50 dextrally imbricate, wedge shaped segments. The X-shaped structure in the central area is robust and constructed of large fused calcite rhombs leaving only small openings (Figs. 6G, 8J, 8K and 8L).

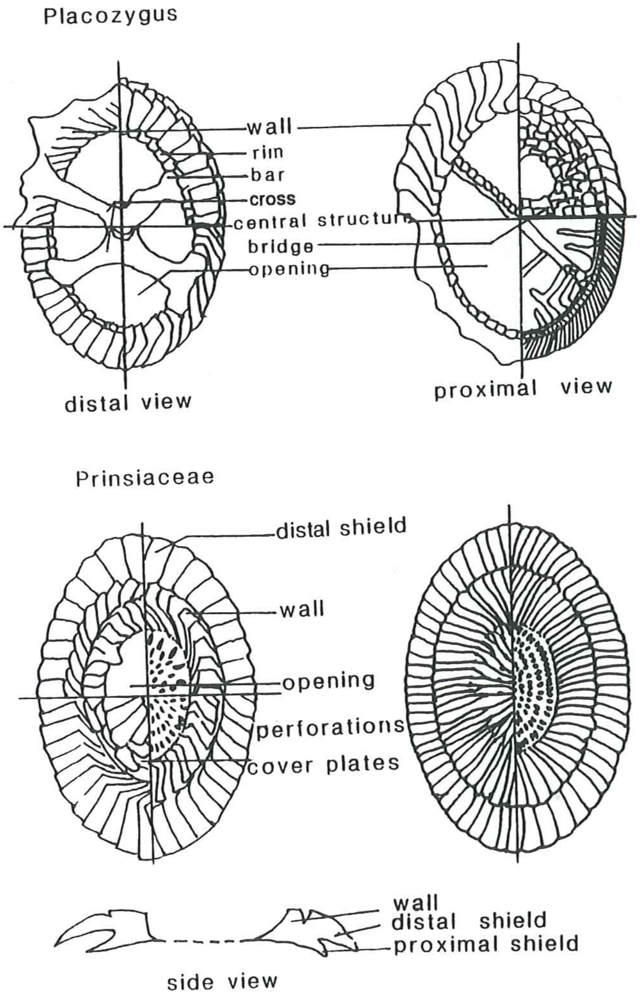


Fig. 7. Terminology for describing coccoliths. After Perch-Nielsen (1985).

Neochiastozygus, Perch-Nielsen (1971*b*), has an X-shaped central structure with a proximal garland. *Neochiastozygus saepes* Perch-Nielsen (1971*b*), first occurring in zones D9, NP5 and 7, has a subelliptical outline in plane view, the walls are high and narrow (Figs. 6K and 8P). *Neochiastozygus modestus* Perch-Nielsen (1971*b*), first occurring in zones D7, NP4 and 6A, is characterised by two equally well developed walls and a nearly symmetrical central X (Figs. 6I, 8O and 8Q). It is smaller compared to the later forms of the genus.

Prinsius dimorphosus (Perch-Nielsen 1969*a*) Perch-Nielsen (1977), first occurring in zones D4, NP2 and 3, has a central area which is covered by one or two cycles of elements. It is usually 2-3 µm in diameter and elliptical to broadly elliptical in outline (Figs. 6E and 8G). *Prinsius martinii* (Perch-Nielsen 1969*a*), Haq (1972), first occurring in zones D7, NP5 and 7, is elliptical to long-elliptical. It is about 3-5 µm; the central area is covered distally by a wall with more or less radially oriented cover plates (Fig. 6J). *Prinsius rosenkrantzii* (Perch-Nielsen 1979*a*) Perch-Nielsen (1984), first occurring in zones D6, NP3 and 5B, is a minute, nearly circular form of the genus *Prinsius*. It has a central opening and a double proximal shield with more or less radial central elements (Figs. 6H, 8M and 8N). In polarised light it would be easier to see the differences between the three *Prinsius* species.

Cruciplacolithus is used for forms with a central cross aligned with the axes; it has an elliptical to circular outline. In *Cr. edwardsii* Romein (1979), first occurring in zones D4, NP2 and 4, each cycle in the margin is composed of 50-60 elements. The bars of the central cross are wide and sturdy so that they almost close the central area (Fig. 6F). *Cruciplacolithus tenuis* (Stradner 1961 as referred by Perch-Nielsen 1985), Hay & Mohler *in* Hay et al. (1967 as referred by Perch-Nielsen 1985), has its first occurrence in zones D4, NP2 and 3. According to Romein (1979) and E. Thomsen (Århus, pers. comm. 1996) it has small "feet" at the end of the bars of the central cross (Figs. 6C, 8C and 8D).

Ericsonia cava (Hay & Mohler 1967) Perch-Nielsen (1969*a*), first occurring in zones D4, NP2 and 4, is an elliptical to subelliptical coccolith with a well defined central opening surrounded by three, apparently concentric, rings of granules which are differently oriented. It has 30-46 elements (Figs. 6D, 8E and 8F).

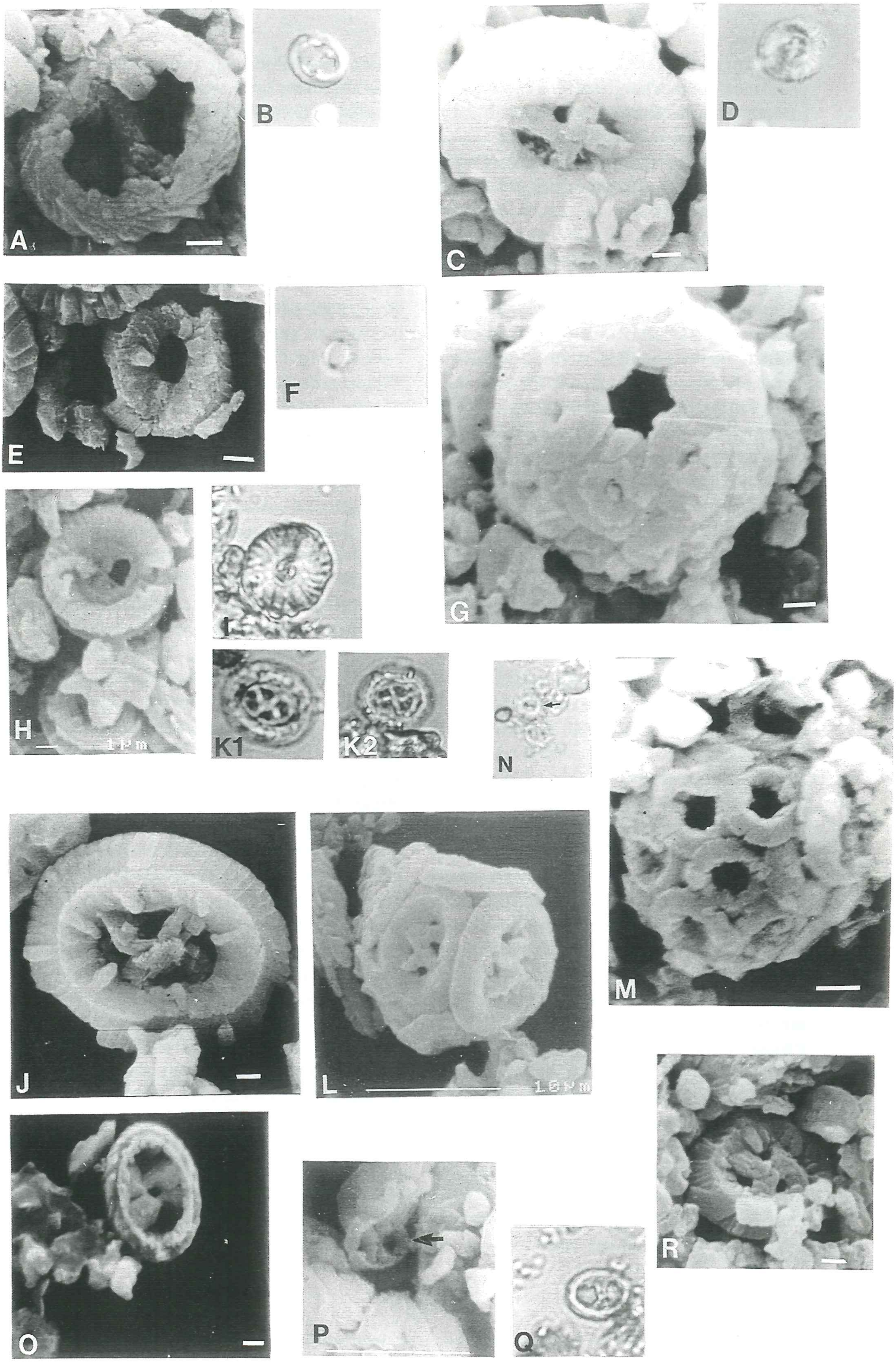
Placozygus sigmoides (Bramlette & Sullivan 1961) Romein (1979), first occurring in zones D2, NP1 and 2, has a margin composed of a low wall, surmounted by a high rim. The wall consists of plate-like imbricating elements. This species has an I-shaped bridge (Figs. 6B, 8A and 8B).

Markalius inversus (Deflandre & Fert 1954 as referred by Perch-Nielsen 1985) Bramlette & Martini (1964), first occurring in zones D1, NP1 and 1, has a central area covered by radial elements reaching the central area (Figs. 6A, 8H and 8I).

Results

The results in this study have been compared and correlated with the results from the five borings investigated by Thomsen (1995*b*). The comparison and the correlation corresponds

Fig. 8. Coccoliths recovered from the Danian, City Tunnel line. All coccoliths are illustrated in a proximal view. All the SEM illustrations have the same scale, 1µm, except **L** and **P** which has a 10 µm scale. **A**. *Placozygus sigmoides* x6.500, SEM, from KBS6 at -23.8 m. **B**. *Pl. sigmoides* x1.250, LM, from HB12 at -20.15 - (-20.40) m. **C**. *Cruciplacolithus tenuis* x5.000, SEM, from HB12 at -5.15 - (-5.40) m. **D**. *Cr. tenuis* x1.250, LM, from KBS6 at -23.80 m. **E**. *Ericsonia cava* x5.500, SEM, from HB12 at -5.15 - (-5.40) m. **F**. *E. cava* x1.250, LM, from HB12 at -0.90 - (-1.15) m. **G**. *Prinsius* cf. *dimorphosus* sphere x5.000, SEM, from KBS6 at -23.80 m. **H**. *Markalius inversus* x5.000, SEM, from KBS6 at 0.00 m. **I**. *M. inversus* x1.250, LM, from KBS6 at -31.00 m. **J**. *Chiasmolithus danicus* x5.000, SEM, from HB12 at -5.15 - (-5.40) m. **K1**. The young form of *Ch. danicus* x1.250, LM, from HB12 at -5.15 - (-5.40) m. **K2**. The old form of *Ch. danicus* x1.250, LM, from HB12 at -32.15 - (-32.40) m. **L**. *Ch. danicus* sphere x3.500, SEM, from KBS6 at 0.15 m. **M**. *Prinsius* cf. *rosenkrantzii* sphere x8.000, SEM, from KBS6 at -23.80 m. **N**. *P.* cf. *rosenkrantzii* x1.250, LM, from KBS6 at -18.20 m. **O**. *Neochiastozygus modestus* x5.000, SEM, from HB12 at -32.15 - (-32.40) m. **P**. *N. saepes* x3.700, SEM, from HB12 at -32.15 - (-32.40) m. **Q**. *N.* cf. *modestus* x1.250, LM, from KBS6 at 0.00 m. **R**. *Ch. bidens* x4.000, SEM, from KBS6 at 0.15 m.



A
B
C
D
E
F
G
H
1 µm
I
K1
K2
N
M
J
L
10 µm
O
P
Q
R

well (Fig. 3) and a biostratigraphical division could be made. The coccoliths investigated from the Danian of the two borings HB12 and KBS6 include genera and species previously known from the Danian. Thomsen (1995*b*) concluded that the abundance and preservation of Danian coccoliths are poor and few in the bore holes carried out in Malmö. This is in agreement with my investigations performed on bore holes KBS6 and HB12. Coccoliths are generally poorly preserved but always present, except in sample HB12 -15.15 - (-15.40) made for investigations in SEM. An estimated abundance of coccoliths was made for both bore holes, KBS6 (Fig. 4A) and HB12 (Fig. 4B) and classified as follows; abundant - more than 10 specimens per slide or stub, common - 3 to 10 specimens per slide or stub, few - 1 to 3 specimens per slide or stub and rare - 1 specimen per slide or stub.

The core drilled hole, KBS6

The distribution of the coccoliths can be seen in Fig. 4A. The samples collected from levels -31.00 m and -23.80 m belong to zone 5A. In these two samples coccoliths like *Markalius inversus, Placozygus sigmoides, Cruciplacolithus tenuis, Ericsonia cava, Prinsius* cf. *dimorphosus* (rare), *Cruciplacolithus edwardsii* and *Chiasmolithus danicus* (the old form) were found. Specimens of *Prinsius* cf. *rosenkrantzii* are rather common. This may be due to contamination, first occurrence (Fig. 5) or inaccuracy in classification. The next two samples at -18.20 m and -8.8 m are indicative of zone 5B. *Prinsius* cf. *rosenkrantzii* was found here in addition to all the coccoliths found in the samples mentioned above, except *Cr. edwardsii*. *Neochiastozygus saepes* was also found in one of the samples from -8.80 m, due to contamination. *Chiasmolithus danicus* has a slight morphological change in it its central cross and the arms are more bent than in the specimens from subzone 5A. This difference in morphology, as mentioned earlier, is the main criterion distinguishing subzones 5A and 5B. The sample at -3.8 m is indicative of zone 6A, although the characteristic *Neochiastozygus modestus* was not found. On the other hand *Prinsius* cf. *martinii*, first occurring in zone 6A, was found. This zone continues up to the Copenhagen Limestone. Zone 6B is lacking, since the larger forms of *N. modestus* characteristic of that interval were not found. *Prinsius* cf. *martinii, Neochiastozygus saepes* and *Chiasmolithus bidens*, found together, characterises zone 7. That zone includes the two top samples at 0.00 m and level 0.15 m. *Prinsius* cf. *dimorphosus* becomes slightly more common in the uppermost samples, in the SEM studies, as it should be (Figs. 4A and 5).

The hammer drilled hole, HB12

The distribution of the coccoliths can be seen in Fig. 4B. The two lowermost samples -32.15 - (-32.40) m and -20.15 - (-20.40) m belong to zone 5A. Coccoliths such as *M. inversus, Pl. sigmoides, Cr. tenuis, E. cava, P.* cf. *dimorphosus, Cr. edwardsii* and *Ch. danicus* (the old form) were found here. *Prinsius* cf. *rosenkrantzii* and *N. modestus* were also found here, but their presence is due to contamination. The older form of *Ch. danicus* indicates that this is zone 5A. The boundary to the next zone, 5B, lies between -20.15 - (-20.40) m and -15.15 - (-15.40) m. In zone 5B, -15.15 - (-15.40) to -10.15 - (-10.40), those coccoliths previously mentioned in zone 5A, except *Cr. edwardsii*, are present along with *P.* cf. *rosenkrantzii* which, together with *Ch. danicus* (with the morphological changes), are indicative of this zone. *Prinsius* cf. *martinii* and *N. saepes* are also present, due to contamination. Zone 5B continues almost up to sample -5.15 - (-5.40) m where zone 6A begins. The characteristic species in this zone is *N. modestus*. Zone 6B is lacking, as the larger form of *N. modestus* was not found. On top of zone 6A follows zone 7. It includes the uppermost samples at -1.45 - (-1.65) m and -0.90 - (-1.15) m, where *N. saepes* and *Ch. bidens* were found, among others.

Discussion

As shown in this and previous studies by various authors, both Light Microscopy and Scanning Electron Microscopy can be used in biostratigraphic investigations and correlations using coccoliths. In several ways SEM is better suited for these kinds of investigations, mainly because of the high resolution. It has the possibility of tilting and rotating the specimen which allows observation from different angles. The wide field of view and the improved depth of focus are the characteristics of the SEM, which allows better qualitative assessments of fossil nannofloras than can be achieved by standard optical techniques (Ramsay 1971). The size of an individual coccolith lies near the limit of optical resolution and it is only by the application of SEM techniques that sufficient morphological data have become available to interpret phylogenetic series within the coccolithophorid-bearing alga.

In the present investigation identification of species is somewhat uncertain because of difficulties in discerning details by means of the techniques used and because of inadequacies of most of the illustrations in the existing literature. Optical photomicrographs of coccoliths are considered to be inadequate because of the limited depth of field and marginal resolution. It is easier to identify a coccolith when actually studying it under one of the microscopes than from photos. In order to avoid mistakes it would be necessary to study holotype material, which has not been possible in this study.

A weakness in this study is that I was not able to use polarised light. This could have been used when classifying for example the genus *Prinsius* (referring to Black & Barnes 1959, and mentioned under materials and methods of the LM).

For examinations of details and for illustrations, the SEM is far superior to the optical methods. All investigations prior to 1965 were carried out by means of LM. Several problems have arisen when comparing forms described by LM and those identified by SEM or vice versa, but these are not insurmountable and can be resolved by the kind of method outlined by Perch-Nielsen (1967).

SEM is well suited for quantitative and qualitative analyses of coccoliths, which are used in stratigraphical interpretations, as it allows scanning of many thousands of specimens within the course of a few hours and since some index species are rare. There is one reason why LM sometimes is a better suited instrument, though, and that is the economy. LM studies can be made less expensively compared to SEM studies. Preparation methods are about the same and equally time consuming for both instruments. It is possible to use only one of the methods, but if using LM, it is recommended that more samples at different levels are taken in consideration and correlated with nearby located bore holes.

Problems with preparations of LM slides, when using the described method (under material and methods), is the nail polish which is needed as a barrier for the glycerine between the slide and the cover-glass. Sometimes the barrier will not stay in place and the slide is damaged. The fluid (glycerine or silicon oil) between the cover-glass and the slide sometimes flows which causes the coccoliths to move and it is not possible to find the same specimens again. Of course Canada balsam or similar non fluid materials as Gurr can be used, but there are other problems with them, such as refraction. Another problem with Canada balsam is that the coccoliths dissolve after some time (E. Thomsen pers. comm. 1996).

There are differences in the results when comparing the LM slides with the SEM stubs. One explanation is that a particular species in fact is present in both samples but is not found in one of them due to poor abundance. Differences in the two samples can also be due to inaccuracy in classification, specially when it comes to the genus *Prinsius*. Another factor that makes a difference is how much material there is on the slide or the stub; this can be due to the hardness of the sample. The harder the material is the more difficult it is to prepare the coccoliths. Of course small pieces of rock can be used for the stubs instead of the prepared solution used in this study. The problem with this is that if the sample is too soft it will not be possible to mount the piece on to the stub.

No coccoliths at all were found in sample -15.15 - (-15.40) HB12 studied in SEM. This is probably due to poor preservation, low abundance (some coccoliths were found in the LM studies of the same sample) and the hardness of the limestone at this level.

The two techniques will have to be used side by side until, as technology goes further, maybe one day it will be cheaper and easier to use SEM.

Sample quality and drilling technique

Hammer drilling can be used in coccolith biostratigraphy, but there are, however, several contamination problems with it. Problems arise during the drilling because of the transportation of the cuttings before sampling, which gives an inaccuracy in measurement of ±0.5 m. Another problem occurs when the material is transported upwards, through flushing. Material can get stuck in the passage between the hammer and the bore hole wall, which means that this material can loosen at any time and contaminate the sample (Andersson 1981). In the screen bucket, when collecting the cuttings, there is another risk for material to get stuck in the screen net and it can loosen at any time. Another contamination risk arises when actually picking the small sample for preparation. Stratigraphically younger layers can fall into underlying layers and contaminate them, and as different intervals can look the same, this can be a problem when choosing samples for preparation. All the contamination problems mentioned must be considered in the biostratigraphical analyses. Hammer drilling can be made to a much lower cost compared to core drilling. The core drilling method is in most ways better suited for studying stratigraphy, as less contamination occurs in drill cores. Whether the contamination of the drill core in this study was due to the drilling method, the secondary handling (e. g. storage and drying of the core) or the laboratory method is impossible to tell.

Conclusions

Coccoliths studied under a Light Microscope can be used for quantitative investigations and SEM for qualitative and quantitative investigations. If using the LM it is suggested that the results are compared and correlated with SEM studies. LM is a fairly cheap method when studying coccoliths, while SEM is rather expensive. This is one of the reasons why mixed investigations continue.

Coccolith analyses can be used in either hammer holes or in core holes, though hammer drilling has a higher contamination risk. For a more complete study additional samples should be investigated, about three samples per every five meters. A core drilled hole from nearby should be used as a reference when investigating hammer drilled holes for biostratigraphy. In this core drilled hole both SEM and LM investigations should be made.

A suggestion is that it should be investigated if there is a better method to prepare LM slides. When making preparations from hammer drilled holes for LM and SEM, it is recommended that the dominating material in the samples should be chosen, to avoid contamination from foreign material.

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