CRETACEOUS/TERTIARY BOUNDARY EVENTS

Symposium

I. THE MAASTRICHTIAN AND DANIAN OF DENMARK

Edited by

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INTRODUCTION

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What we needed was a book stating the 'status quo' in Denmark regarding the stratigraphic knowledge of the boundary. This would hopefully act as a basis of facts at the symposium itself to keep the model-makers earthbound as they constructed variously ambitious hypotheses to explain the terminal Cretaceous events. When we issued invitations to 'the locals' for short papers summarizing their results concerning the boundary, we comforted ourselves that we might receive a grudging, 50% response from a lot of 'very busy people'. Instead, we received great enthusiasm for the project and a total response from all concerned. Furthermore, the manuscripts, far from repeating 'the old stuff' already published, were full of new material, showing that the old boundary still acts as an arena of seething research activity.

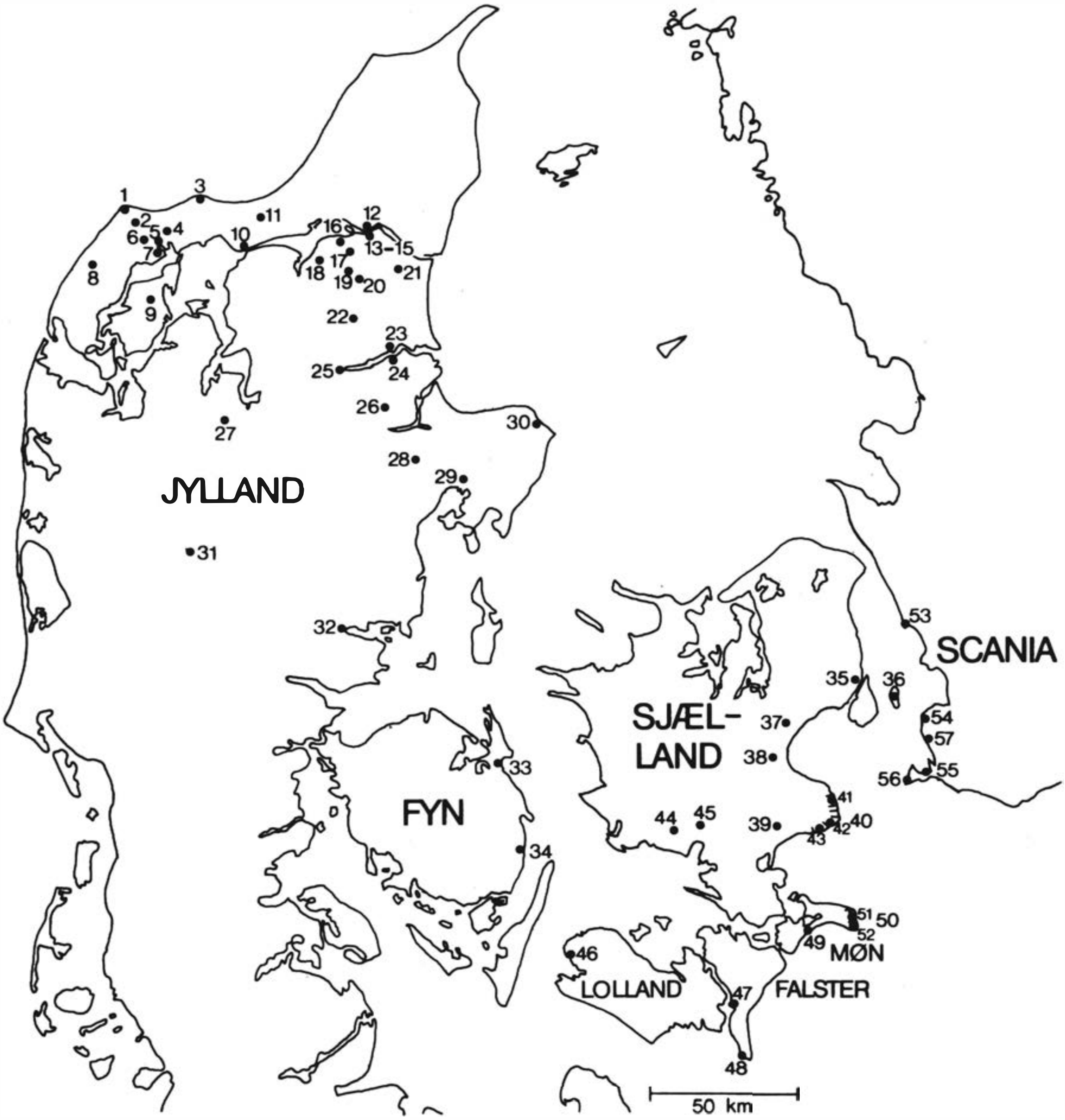
Each paper has been reviewed internally by at least two other authors. However, no attempt has been made to produce uniformity of scope, treatment or approach. Studies of very diverse assemblages, for instance, cover only the boundary layers, whereas other cases of a broader nature cover larger parts of the Maastrichtian and Danian.

Some papers, also, have their own locality maps, while others do not. We have retained the individual maps for easy reference, but have also collected all localities together onto a single map (Fig. 1), which will serve to cover the whole book.

If we were to pick out a few highlights from the following work, these would include cases where our conventional ideas are being shown to be wrong. Facies maps for the Danian, for example, indicate a gradual transgression over the Danish Basin followed by a short regression, in contrast to the usually assumed general regression. The attempt to compare all boundary sections in Denmark has clearly shown that the hiatus is smallest in northern Jylland, where both the Maastrichtian top and Danian base are most complete; this emerges nicely from foraminiferal, dinoflagellate and coccolith stratigraphy. Even the abrupt biological break is failing to stand up to close scrutiny within some animal groups. Corals and bivalves, for example, have 'Tertiary' genera in the topmost Maastrichtian. Indeed, in the bivalves it can now be shown that old taxa disappear while new ones survive, just as in normal evolutionary turnover.

We have not attempted to draw conclusions from the papers presented here; that is the business of the symposium itself. One large question is left entirely open: the positions of the boundaries of the Danian subdivisions. Each author has his lower, middle and upper Danian or lower and upper Danian, and not general acceptance has been reached over the actual placing of the boundaries. We hope that the publication of this book will play a role in stimulating discussion of this problem.

Fig. 1. Locality map. Aalborg 13; Aggersborggaard 10; Bjerre 2; Boesdal 43; Bulbjerg 3; Copenhagen (TUBA 13) 35; 'Dania' 24; 'Danmark 15; Daubjerg 27; Eerslev 9; Ellidshøj 20; Falsterbo 56; Fakse 39; Fjerritslev 11; Flødal 19, Frejlev 17; Gedser 48; Gudumholm 21; Hanstholm 1; Hasselø 47; Herlufsholm 45; Hillerslev 6; Hobro 25; Højerup 42; Höllviken 55; Horsens No. 1 32; Hov 7; Hvalløse 28; Hvide Klint 49; Hvidskud 52; Karlby Klint 30; Karlstrup 37; Kerteminde 33; Kjølby Gaard 4; Klagshamn 57; Klintholm 34; Kulsti Rende 41; Landskrona 53; Legind 8; Lellinge 38; Limhamn 54; Møns Klint 50; Nørholm 16; Nørre Uttrup 12; Nøvling No. 1 31; Nye Kløv 5; Rold 22; Rønde No. 1 29; Rørdal 14; Saltholm 13 36; Spentrup 26; Spjellerup 44; Stevns Klint 40; St. Stejlebjerg 51; Taars 46; Vive 23; Vokslev 18.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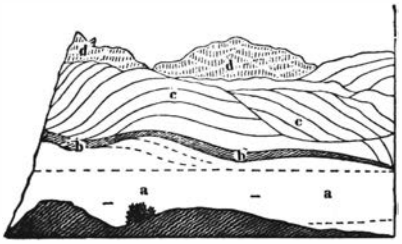

A DANISH HISTORICAL VIEW OF THE BOUNDARY

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The classical question in drawing the boundary between the Mesozoic and the Cenozoic is whether it should be drawn at the base of the Danian stage or at the top. This question, and matters connected with it, have been under debate for more than 150 years, if we admit Forchhammer's paper from 1825 to be the starting point of the discussion. A thorough historical survey of this largely biological problem is given by Berggren (1964) in English; readers of Danish will find supplementary information in Ravn (1903), Milthers (1908), Ødum (1926), Hintze (1937), and Garboe (1959, 1961).

Among the earliest writers describing localities with Maastrichtian and/or Danian strata one might mention Dyssel (1757), Abildgaard (1759, 1781), Pontoppidan (1763, 1767), Steffens (1810), Bedemar (1820), and Bredsdorff (1824a,b).

The first thorough descriptions of Stevns Klint and Møns Klint are found in Abildgaard's works from 1759 and 1781, respectively (see cover of the book).

In Forchhammer's paper (1825) "Om de geognostiske Forhold i en Deel af Sjælland og Naboeõerne", the strata in Stevns Klint were given their first clear description, as follows (from top to bottom):

Forchhammer 1825	Present interpretation
Kalksteen-Conglomerat	Quaternary breccia of lower Danian bryozoan limestone
Corallit-Kalksteen	Bryozoan limestone (lower Danian)

(cont.)

Forchhammer 1825	Present interpretation
Leer og Ceritkalksteen	Cerithium limestone (lower Danian) Fish clay (basal bed of the Danian) Indurated white chalk (Upper Maastrichtian)
Kridt med Flint	Upper Maastrichtian white chalk

From his "Ceritkalksteen" Forchhammer cited the following fossils: "En Trochus. Trochus niloticæformis Slotheim, To Cerithier, En Ampullaria(?), En Cypræa, En Buccinum (?), En Patella, En Arca, En Mytilus, En Pecten, En Turbinolia, En Dentalium, En Echinit". On the basis of these fossils and the fact that his "Ceritkalksteen" bed rests on white chalk, Forchhammer considered the "Ceritkalksteen" as an equivalent of the (Tertiary) "calcaire grossier" in France. The clay bed he saw as an analogy to the (also Tertiary) "Argile plastique" and London Clay in France and England. From the fossil fauna known to Forchhammer from the (middle Danian) limestone in Fakse ("Faxöe"), he concluded that there is such similarity between that and the fauna of his "Ceritkalksteen" in Stevns Klint that these limestones must be considered identical. This correlation was accepted for many years afterwards and consequently the "Ceritkalksteen" came to be known by the name of "Faxe-laget" (i.e. "the Fakse bed").

In the same paper Forchhammer (1825) concluded that the white chalk of Møns Klint (Maastrichtian), owing to its being sandwiched with Quaternary clays, belongs to the great pebble formation ("den store Rullesteens Samdanning" or Geschiebe), and was therefore, likewise, of Tertiary age. He supported this with fossil evidence, noting "*Ananchytes ovata*, *Ostrea vesicularis*, en *Gryphæa*, *Belemnites muscronatus*, to *Flustra* Arter" in common with the bryozoan limestone of Stevns Klint. His views were soon after repeated in English (1828) and in German (1829).

Among the geologists who read Forchhammer's papers with scepticism was Charles Lyell, who came to Scandinavia in 1834 and used the occasion to travel together with Forchhammer to Stevns Klint, Fakse and Møn. When seeing the cliffs of Møn, Lyell had to accept the fact that the white chalk lies intermingled with and in many places also lies on top of sands and boulder clay, but he was of the opinion that this mixing of deposits had taken place after the deposition of the chalk in an era of "comparatively modern date" (1837). There was thus no proof of all the beds having been formed at the same time, and Forchhammer's arguments for a Tertiary age of the Møn chalk were to be discarded. Lyell's views were published in a number of papers (e.g. 1837). His views on Stevns Klint and Fakse largely corresponded with Forchhammer's as far as the series of strata is concerned, and he accepted Forchhammer's theory of the identity between the "Ceritkalksteen" and the limestone in Fakse Quarry. For the whole series of limestones in Stevns Klint, however, he assumed a Cretaceous age.

His arguments for a Cretaceous age of the "Ceritkalksteen" (which he called "Faxoe bed") include the occurrence of "*Baculites faujasi*", "*Belemnites mucronatus*", and an "Ammonite". These fossils clearly derived from those parts of the basal Danian hardground that involve Maastrichtian host sediment, so Lyell's belief that the whole of this complex bed was Cretaceous is easily understandable.

It is less easy to give a plausible explanation of Lyell's statement that "*Belemnites mucronatus*" also occurs in the "Faxoe bed". Belemnites (*Belemnitella junior* and *Belemnella casimirovensis*) do occur in the Upper Maastrichtian white chalk of Stevns Klint, but they are very rare. There is little chance that Lyell himself actually found a belemnite *in situ* in the "Faxoe bed". It has been suggested that Lyell may have purchased a belemnite from workmen at Fakse quarry, where belemnites occur not uncommonly in the Quaternary deposits overlying the Danian limestone (Johnstrup, 1876).

In "Danmarks geognostiske Forhold ..." (1835) Forchhammer admitted his rashness in comparing his clay bed in Stevns Klint with the Argile plastique and his "Ceritkalksteen" with the Calcaire grossier. He now also referred the "Ceritkalksteen" (or "Faxöe-Kalk") to the Cretaceous, and there can be little doubt that this change of opinion was induced by Lyell's views. The logotype to this article reproduces Forchhammer's (1835) view of the Stevns Klint succession.

In the same book Forchhammer outlined the "Kridtformation" (Cretaceous formation) in Denmark and Scania as follows (from top to bottom):

4. Faxøekalk, Blegekridt (more or less indurated, white Danian limestone) and Limsteen (Danian bryozoan limestone)

3. Skrivekridt (white chalk)

2. Saltholms-Kalk (fine-grained, hardened limestone of Danian age)

1. Grønsand (greensand) and Gråkridt (grey chalk) in Bornholm and Scania

Although Forchhammer thus listed the Saltholm limestone as being older than the (Maastrichtian) white chalk, on another page he mentioned the possibility of its being younger (1835, p. 84). The proper age of the Saltholmskalk was only correctly established about a decade later.

In 1846 Desor coined the term "terrain danien" for the sequence of limestones resting upon the white chalk in Denmark and at the same time also indicated that some limestones in the Paris basin were to be seen as parallels of the "terrain danien" in Denmark. In Desor's opinion, this new stage evidently belonged to the Cretaceous as its fauna comprised fossils like "les Ananchytes (i.e. *Echinocorys*), les Holaster et les Micraster". For the "terrain danien" Forchhammer (at a meeting in 1847) proposed the Danish name "Det nyere Kridt" (i.e. "Newer Chalk").

In his paper from 1849 Forchhammer mentioned the fact that borings near Copenhagen had shown the "Saltholms-Kalk" to lie on top of the white chalk, thus showing the younger age of the former.

A major step forward was taken with Johnstrup's paper "Om Grønsandet i Sjælland" (1876) in which he published the results of 6 borings in the Lellinge area. In 1842 a greensand formation had been found in the area that was originally believed to correspond in age to the Upper Cretaceous greensand in the island of Bornholm (i.e. the Cenomanian Arnager Greensand and the Santonian Bavnodde Greensand). Johnstrup's borings at Lellinge showed the following sequence (from top to bottom):

4. Quaternary
3. Greensand
2. Saltholmskalk
1. Limsten (bryozoan limestone of the Danian).

Consequently the greensand at Lellinge was clearly younger than the Saltholmskalk, and Johnstrup referred the greensand to the "Nyere Kridt" as its youngest member. From the adjoined fauna lists by Mørch (also 1876) from the Arnager Limestone and greensands in Bornholm and from the Lellinge Greensand, respectively, Johnstrup concluded that the differences in fauna were so great that these greensands could not possibly be contemporaneous. Furthermore, Johnstrup stressed that whereas ammonites and belemnites occur in the white chalk, they are not found in the Fakse limestone at Fakse, nor are they found in the Limsten, Saltholmskalk, Blegekridt or (Lellinge) greensand. The fact that ammonites and belemnites are found in the "Faxelaget" ("Faxe bed") in Stevns Klint should not, according to Johnstrup, lead to the erroneous assumption that they are found in "Det nyere Kridt" proper. (His explanation of Lyell's belemnite from the "Faxoe limestone" has been commented upon already).

Johnstrup summed up the Upper Cretaceous and Danian deposits in Denmark as follows:

"Nyere Kridt" (=Danian) without *Belemn.mucronata*	Greensand Saltholmskalk Limsten	Lellinge
	Faxekalk and limsten Faxelaget Fiskeler	Stevns and Fakse
Younger Senonian Formation with *Belemn.mucronata*	Skrivekridt (=white chalk)	
Older Senonian Formation with *Belemn.westfalicus*	Arnagerkalk Grønsandsten	Bornholm

Von Koenen's work "Ūber eine Paleocāne Fauna von Kopenhagen" (1885) was a major palaeontological contribution through which the Selandian (Paleocene) fauna of Eastern Denmark was first really thoroughly described. Whereas Johnstrup had placed the Lellinge Greensand within the Danian, von Koenen the year after (1886) clearly stated that on palaeontological grounds the Lellinge Greensand ("Glaukonitsand-Formation") belonged to the Paleocene and not to the Cretaceous.

At the Naturalists' Meeting in Stockholm in 1898 K.A. Grõnwall (see Grõnwall, 1899), introduced the Zone of *Crania tuberculata*. This characteristic brachiopod is frequent in certain facies of the upper Danian and is also very abundant as a redeposited fossil in the basal conglomerate of the Selandian. In his Zone of *Crania tuberculata* Grõnwall included not only the upper Danian, but also the basal conglomerate of the Selandian, maintaining that one should place the Cretaceous/Tertiary boundary on top of the latter, i.e. between his "Crania limestone" and the Lellinge Greensand.

In his paper on the "Yngra Krita" (=Danian) of Scandinavia, Hennig (1899) concluded on the basis of the fauna as a whole that the Danian fauna is transitional between the Cretaceous fauna of the white chalk and the "Eocene" fauna of the "tuffeau de Ciply", but still retaining a distinctly Cretaceous character (p. 156).

Ussing (1899) stated, in his description of the Danian in "Danmarks Geologi ...", that the "Ceritkalk" in Stevns Klint (=the Cerithium limestone) is not an equivalent to the limestone in Fakse.

In Ravn's (1902-1903) classical works on the Mollusca of the Danish "Cretaceous" (i.e. Cretaceous and Danian) the Danian and "Younger Senonian" are outlined in like way:

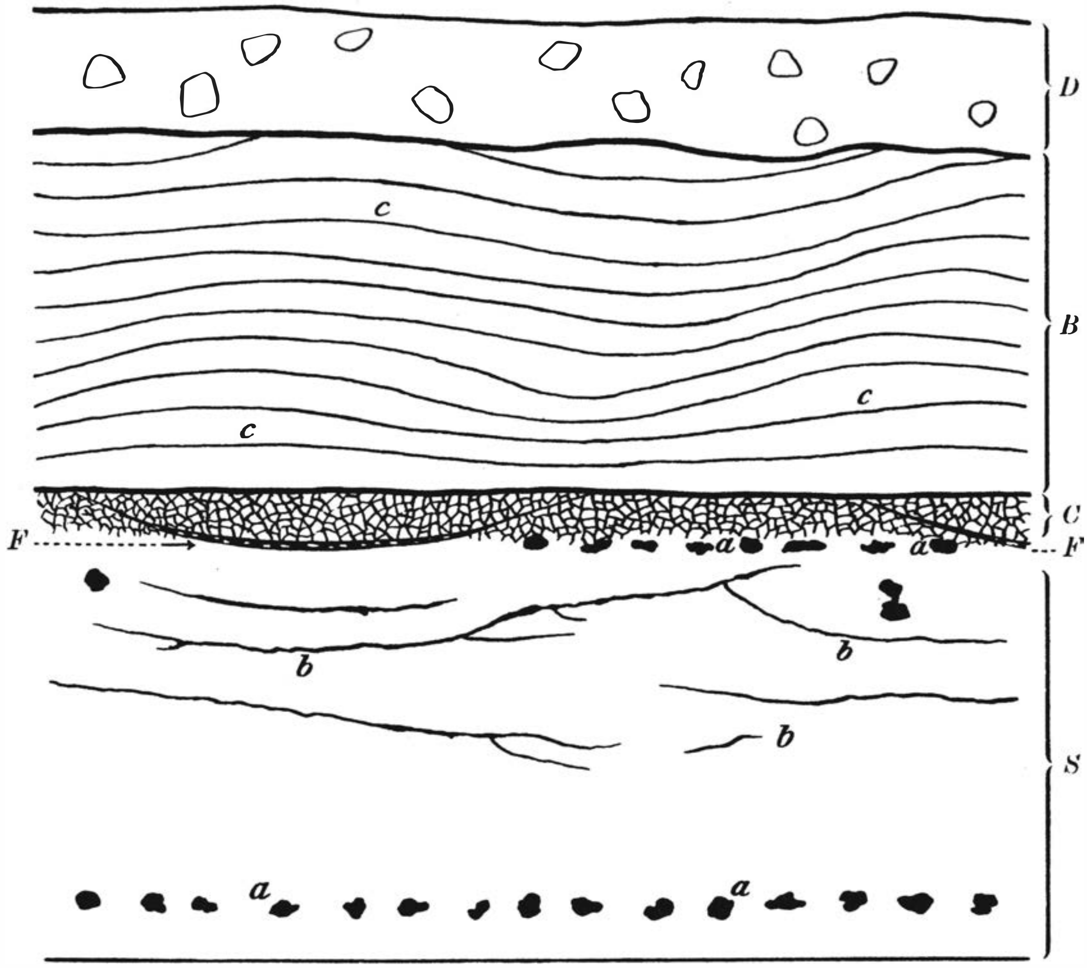
Danien.	**Craniakalk.**	*Crania tuberculata* Nilss.
	Saltholmskalk, Blegekridt, Bryozokalk, Koralkalk.	*Ananchytes sulcata* Goldf. *Dromiopsis rugosa* v. Schloth. sp.
	Lakune.	
Yngre Senon.	**Cerithiumkalk.**	*Ananchytes ovata* Leske. *Scaphites constrictus* Sow. sp. *Belemnitella mucronata* v. Schloth. sp.
	Fiskeler.	
	Skrivekridt.	

Thus, Ravn placed the boundary between the Maastrichtian (=Younger Senonian") and Danian above the Cerithium limestone, not below the Fish clay and Cerithium limestone as Forchhammer and other geologists had done. Ravn's view of the boundary is further elucidated by his drawing of the strata in Stevns Klint (Fig. 1) from which it is completely clear that by his "Cerithiumkalk" he not only means the (Danian) Cerithium limestone proper (*sensu* Rosenkrantz, see below) above the Fish clay, but also the lithologically very similar part of indurated white chalk of Maastrichtian age. The fauna lists compiled by Ravn thus come to be composed of a mixture of Maastrichtian and Danian species. From his fauna lists Ravn concluded that the fauna was clearly a "Senonian" one, and therefore he interpreted the "Cerithiumkalk" horizon (and the Fish clay within it) as the top of the "Upper Senonian" in Denmark.

Fauna lists published by Brünnich Nielsen (1917a) from the "Cerithiumkalk" horizon seemed to vindicate Ravn's view of this horizon as containing a clearly Senonian fauna.

In his paper from 1919 Brünnich Nielsen presented a long discussion of the Cretaceous or Tertiary affinities of the Danian. On faunistic grounds he found the Tertiary character of the Danian fauna quite evident.

Further evidence in support of a Tertiary age of the Danian was presented by Rosenkrantz in his important paper on the "Craniakalk" from 1920. Rosenkrantz showed that there is a number of Paleocene species common to both the "Lower Craniakalk" (=upper Danian) and the "Upper Craniakalk" (=the basal conglomerate of the Selandian) such as *Pecten sericeus*, *Lima testis*, *Argiope scabricula*, *Trochocyathus? calcitrapa*, *Nucula densistria*, and *Leda ovoides*, species which also occur in the Lellinge Greensand itself.



Skematisk Profil af Stevns Klint. — S. Skrivekridt; a, Lag af Flintknolde; b, Flint udskilt i Sprækker. F. Fiskeler. — C. Cerithiumkalk. — B. Bryozokalk; c, Flint i sammenhængende Lag. — D. Diluvium.

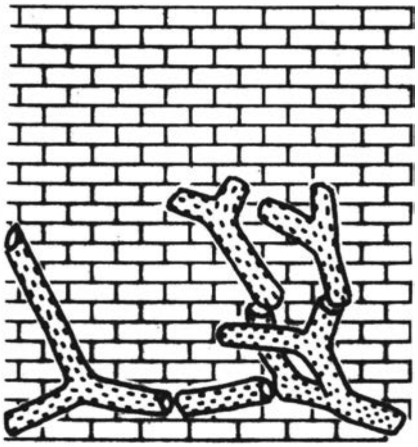
Fig. 1. Diagrammatic section of Stevns Klint from Ravn (1903 p. 388). S: White chalk; a, horizon of flint nodules; b, flint in crevices. F: Fish clay. C: Cerithiumkalk. B: Bryozoan limestone; c, coherent horizons of flint. D: Quaternary.

In his two papers from 1924 and 1940 Rosenkrantz was able to show that what had hitherto been called "Cerithiumkalk" was really a mixture of two things: 1) hardened Upper Maastrichtian white chalk ("hærdnet Skrivekridt") below the Fish clay and 2) Brissopneusteslaget" ("the Brissopneustes bed") *sensu* Rosenkrantz, 1924 = Cerithium limestone s.str. (*sensu* Rosenkrantz, 1940) above the Fish clay. The two limestones were shown to contain widely different faunas, the fauna in the Cerithium limestone s.str. showing a strong affinity to the Danian whereas the fauna of the hardened white chalk was found to be a typical Cretaceous fauna with ammonites, Cretaceous bivalves etc.

The importance of these two papers by Rosenkrantz can hardly be overrated, because herein the complex nature of the Maastrichtian/Danian boundary in Stevns Klint is for the first time described in the way that geologists today agree to interpret it.

The controversy among early Danish geologists on the Cretaceous/Tertiary boundary was first and foremost concerned with the problem of where to place the boundary in the sequence, a discussion in which Mesozoic and Cenozoic faunal affinities were the main tool.

This discussion has now ebbed away. Left for the present generation is a thorough analysis of the changes in macro- and micro-fauna and in micro-flora around the generally accepted boundary between Maastrichtian and Danian, supplied with sedimentological and geochemical investigations. Continued studies will throw light on the size of the Maastrichtian/Danian hiatus in different parts of the country and may also provide background information of importance for the evaluation of hypotheses trying to describe the reasons for the changes in biota at the Cretaceous/Tertiary boundary.



CHALK AND BRYOZOAN LIMESTONE: FACIES, SEDIMENTS AND DEPOSITIONAL ENVIRONMENTS

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The Maastrichtian/Danian boundary in Denmark is invariably marked by an omission surface. The beds above and below this junction are exclusively carbonate rocks, with the exception of a thin clay layer, the Fish clay. More detailed descriptions of the lithofacies of these rocks are given elsewhere in this book (Håkansson & Hansen; Håkansson & Thomsen; Floris; Surlyk) and it remains here to give a general introduction to the major facies types, their constituents, depositional environments and some diagenetic features.

LITHOFACIES TYPES

Apart from the Fish clay mentioned above, the rocks on either side of the boundary in Denmark comprise a closely related suite of facies. They have in common a very low terrigenous content and a matrix of coccolith-rich mud, containing a variable and diverse fraction of other skeletal material. The nature and abundance of the skeletals give rise to a wide range of contrasting and distinctive lithofacies. The central facies, being the common matrix of most of the other facies, is chalk.

Chalk

The word has ancient origins and has carried with it into geological usage a simple definition: "an opaque white earthy limestone" (Oxford English Dictionary); "a calcareous earthy substance, of an opaque white color, soft, and easily pulverized" (Webster's New Twentieth Century Dictionary). Thus, similar white, soft materials have been described as chalky, e.g. 'chalky aragonite' for a stage in calcitization of corals (Pingitore, 1976) and 'chalky deposits' for the rapidly laid down, soft shell layers in oysters (Yonge, 1960).

In the past decade there has been an explosive acceleration in chalk research, and our increasing knowledge of the facies is bringing about a concomitant refinement of the definition. Individual investigators nowadays define chalk in terms that accord with the approach and techniques they use. Thus, for example Scholle (1977a, p. 2), familiar with the downward increase in lithification of the chalk of the North Sea Basin, and with the appearance of the rock with SEM, defined chalk as "fine-grained carbonate sediments composed primarily of calcareous nannofossils (especially coccoliths) and calcareous microfossils (such as foraminifera and calcipheres). No limitation is placed on the degree of induration of a chalk".

This biological definition is of limited use for the field geologist, concerned with lithostratigraphy. He cannot determine the nature of the fine grains, whereas he can detect and use minute differences in hardness. In our facies descriptions here, therefore, we retain the old usage, calling the soft, white, fine-grained facies 'chalk', and reserving the more general term 'limestone' for the other facies. Thus our definition of chalk for our present needs is: poorly or unlithified, white or nearly white, pure calcilutite.

The proportion of sand-sized skeletals in the Danish chalk varies considerably (Håkansson *et al.*, 1974). In cases where skeletons of a particular group dominate the fabric this may be reflected in the subfacies name. Thus the uppermost Maastrichtian at Stevns Klint is represented by bryozoan chalk.

Bryozoan limestone

The lower Danian rocks of much of the area contain a higher proportion of bryozoan skeletons than the bryozoan chalk (Fig. 1; Cheetham, 1971, Fig. 13). Nevertheless, the fabric remains in large part mud-supported, and the rock is generally rather feebly lithified. Bedding is distinct, and in many places reveals large-scale mound structures. These rocks are grouped together as the bryozoan limestone facies, but details of composition, fabric and diagenetic alteration are very varied and produce a wide range of subfacies.

Moltkia limestone

In the middle Danian the distinctive coral limestone facies occurs at many localities, dominated by branched ahermatypic scleractinian corals in a mud matrix (see Floris, this volume). However, this facies is not known to occur close above the base of the Danian and so does not concern us here.

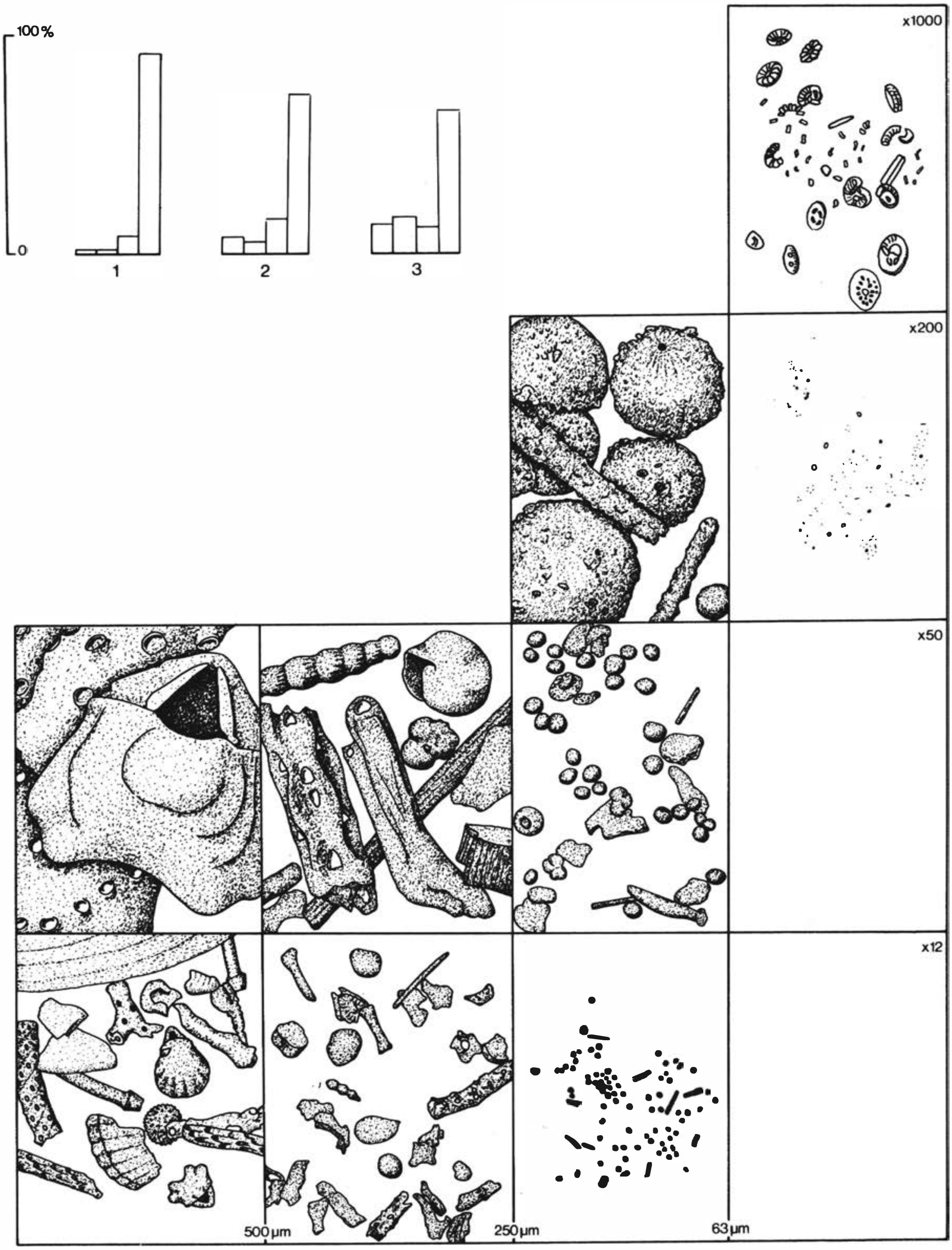
Fig. 1. Graphic representation of the grain-size and constitution of the sediments. Vertical columns represent four size fractions (screen sizes indicated at bottom). The fractions are shown at four magnifications (camera lucida X12 and 50, and sketches of SEM pictures). Note the extreme range of grain-size; at X50, where the >500 µm fraction is almost too large to depict, grains of the <63 µm fraction are not even visible. It should be remembered that the >500 µm fraction ranges up to whole skeletons several centimetres in size.

The histograms show the proportions of the same four fractions in different rocks (dry weight percent); 1: white chalk from 'Dania', 2 m below the boundary; 2: bryozoan chalk from Højerup, Stevns Klint, 2 m below the boundary (both from Håkansson *et al.*, 1974, Fig. 4); 3: bryozoan limestone from Limhamn, upper 1 m of lower Danian (after Cheetham, 1971, Fig. 13B)

Grain-size of the coursest fractions is gradational, the screens representing artificial boundaries. It is clear from the figure (X12), however, that there is a large size difference between these and the finest fraction, i.e. the 63 µm screen falls within a wide, natural hiatus. Thus, if intermediate fractions were considered, the histograms would be strongly bimodal.

Much of the 250-63 µm fraction consists of dismembered chambers of planktic foraminifera which, as whole skeletons, would rightly belong in the 500-250 µm fraction. If breakage occurred on the sea floor, the relative proportions of the two fractions represent the natural sediment. It is possible, however, that some breakage occurred during the maceration of the rock samples (by freeze-thaw with glauber salt) prior to seiving.

Finally, it should be pointed out that each grain of the larger fractions is coated with (Fig. 3) and filled with (Fig. 4) sediment of the finer fractions. A significant amount of the finest fraction is thereby locked up in the coarser fractions. The histograms thus under-represent the extreme dominance of the micrite fraction. Unmacerated lumps of micrite also occur in the coarser fractions, further distorting the results in the same direction.


100%
0
1
2
3
x1000
x200
x50
x12
500 µm
250 µm
63 µm

A boring in Fakse Bakke, however, revealed over 13 m of a special facies, which Rosenkrantz (1938) called Moltkia limestone, immediately overlying the basal Danian Cerithium limestone. Over 50% of the rock consisted of broken fragments of the octocoral *Moltkia* sp. Octocorals are locally a significant constituent in the bryozoan limestone (see Floris, this volume); they are abundant, for example, in core and transitional facies of middle Danian bryozoan limestone mounds at Limhamn (Cheetham, 1971, p. 30).

Marl and clay seams

Thin beds of marl, a few centimetres thick, occur within the chalk and bryozoan limestone facies. The sediment differs from the surrounding rock chiefly in having a higher non-carbonate content.

A particularly thick marl seam, about 35 cm thick, occurs in Jylland several metres below the top of the Maastrichtian chalk. This was designated as the Kjølby Gaard Marl Member by Troelsen (1955), who noted several distinctive features of the foraminiferal fauna of this bed in contrast to that of the surrounding chalk.

The Maastrichtian chalk in Jylland, e.g. at 'Dania', contains a number of argillaceous horizons some tens of centimetres thick where the colour of the chalk is tinted faintly brownish or greyish (see Jørgensen, 1975, Figs 2-3). The preservation of microfossils, nannofossils and small skeletal grains tends to be better in these horizons, and the diversity and abundance of coccoliths and foraminifera higher than in normal chalk (Jørgensen, 1975, p. 305; Stenestad, this volume).

The base of the Danian at Stevns Klint is marked by a clay bed unusual in both spatial extent and composition. It consists of a dark brown, calcareous clay and lies directly on the upper surface of the Maastrichtian bryozoan chalk in the troughs between the bioherms (Surlyk, this volume). At the centres of these troughs it is thickest, reaching over 15 cm, and is strongly laminated. Christensen *et al.* (1973) examined the clay minerals of the Fish clay and divided it into several sub-beds. A similar, but laterally more continuous, brown clay seam occurs at the base of the Danian at many localities, both in Sjælland and in Jylland (Hansen, 1977; Håkansson & Hansen, this volume).

Constituents

On both sides of the Maastrichtian/Danian boundary, the constituent particles of the rocks have similar origins; it is the great variation in proportion of these constituents that creates the variety of facies and subfacies. Indeed, equivalent seived and washed fractions of

Maastrichtian chalk and Danian limestone are almost indistinguishable under the microscope, until taxonomy of the skeletons is taken into consideration. (However, the Maastrichtian bryozoan colonies are larger and stouter, producing a large size-fraction that is hardly represented in the Danian). The constituents are almost exclusively of biogenic origin: skeletons of organisms that have been fragmented to different degrees, or preserved more or less whole. Not surprisingly, the different size fractions of grains have contrasting compositions (Fig. 1) owing to both the original size of the skeletons and to inherent differences of breakdown.

Some of the more important skeletons and their breakdown products are represented in Fig. 2. Clearly, the breakdown of skeletons introduces different degrees of difficulty of fragment recognition in different organism groups. Species distinctions are generally lost at an early stage of fragmentation. Echinoderms, however, yield numerous grains of highly diagnostic shape, yet of small size, such as minute spines, pedicellaria jaws, etc., that often can be recognized in finer sediment fractions (e.g. Nielsen, 1925). As usual in carbonate sediments, however, echinoderm fragments are particularly prone to precocious overgrowth by syntaxial cement, which obliterates details of morphology. Bryozoans are thus probably determinable in even smaller fragments than echinoderms.

At the other end of the scale, bioerosion processes give rise to a host of recognizable flakes and chips of hard substrates as a result, e.g. of gnawing by regular echinoids or scraping by crabs. The original scratches are clearly recognizable on preserved substrates (Bromley, 1970 , 1975a), showing that the process has, in fact, operated, but the resultant debris is unrecognizable. On the other hand the methodical production of silt-grade chips of substrates by boring sponges results in readily recognizable grains having arcuate surfaces (Fütterer, 1974). Sponge borings are abundant in the bryozoan limestone, though in the chalk they are rather sparse, owing to rarity of suitable substrates. Sponge chips have been included, therefore, in Fig. 2, although their presence has not yet been recognized in the rocks under consideration.

Finally, a problem that should be mentioned in grain identification is illustrated in Figs 3 and 4, namely that each grain is coated by a 'single layer' of the finest fraction of the sediment. Finer details of morphology and ultrastructure are thereby masked. Grains from argillaceous chalk are cleaner than those from normal chalk, indicating that the coating represents an early stage of intergranular cement, corresponding to the familiar, minute syntaxial overgrowth seen in coccoliths (Figs 5 and 6; Jørgensen, 1975; Perch-Nielsen, this volume).

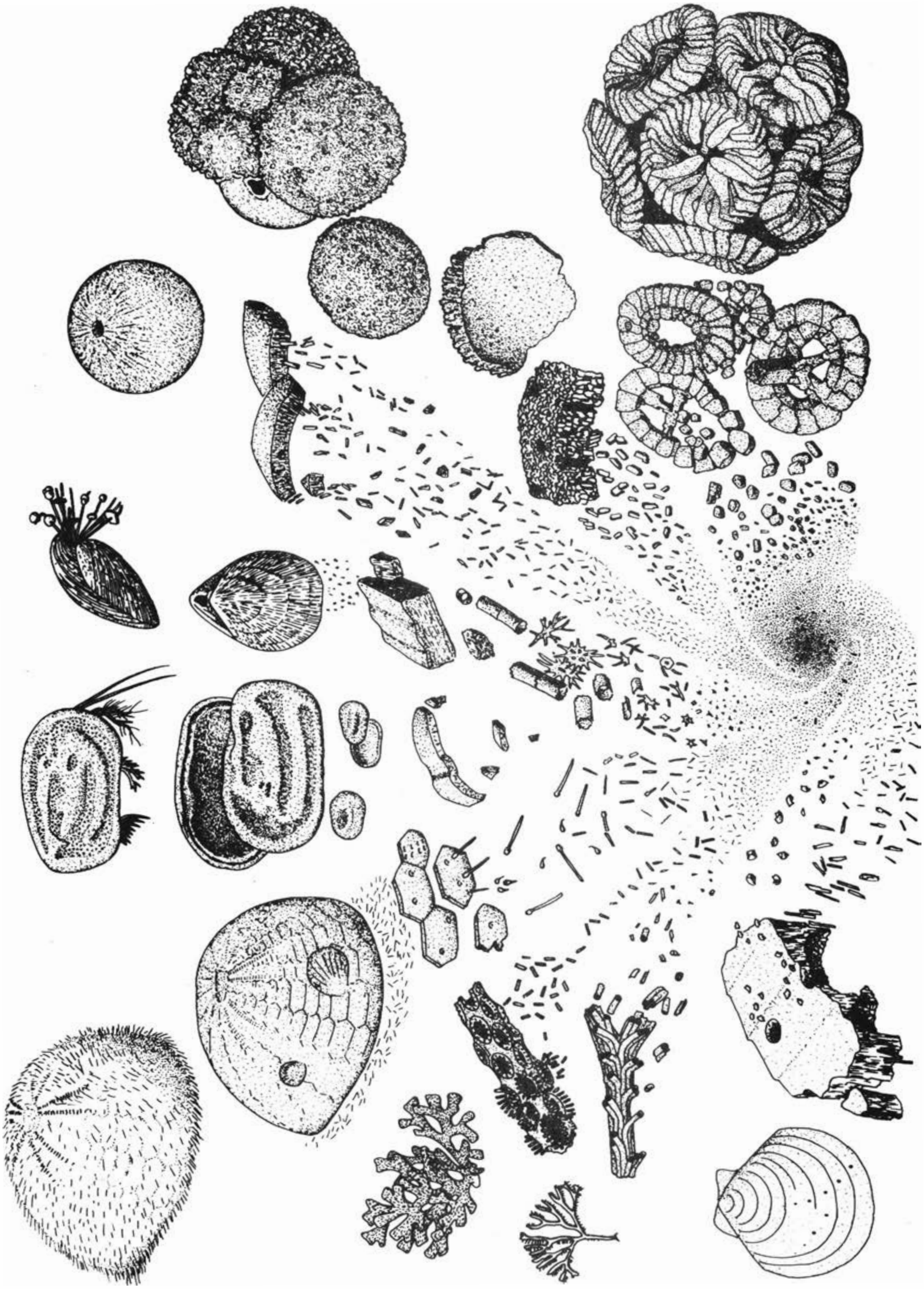


Fig. 2. Graphic representation of the constituents of chalk and bryozoan limestone. All stages of breakdown of skeletons occur in the final rock, but proportions of various breakdown stages and proportions of various organism groups vary considerably from facies to facies and from bed to bed. No indication of proportions is given here. Represented are (clockwise from lower left): bivalves and sponge borings; cyclostome and cheilostome bryozoans; echinoids, represented by a holasteroid irregular; crustaceans, represented by an ostracode (juvenile instars); brachiopod (valves and mesodermal spicules); calcispheres; planktic foraminifera and coccolithophores. Among the locally rock-forming groups omitted, for lack of space, are coelenterates (especially octocorals), serpulid worms, asteroids and the organisms having siliceous, purely aragonite or organic skeletons, which are represented in significant quantities in certain beds. Scale is variable, increasing and then decreasing again centripetally. Sources of information are numerous and divers, but much personal advice from colleagues is acknowledged. Original inspiration was Multer, Frost & Gerhard (1977, Fig. 8).

DEPOSITION

Chalk facies

The major fraction of the chalk is of pelagic origin and was produced in the water column above the sea floor. This material consisted largely of coccoliths (Figs 5 and 6), together with smaller amounts of planktic foraminifera, dinoflagellate cysts and radiolarians (though the latter were dissolved during early diagenesis). To this were added subordinate quantities of skeletal material produced by the benthos (Fig. 2).

According to Black (1965) the chief level of coccolith production in tropical seas today is about 50 m from the surface, and rather shallower in temperate seas. It is most probable that the majority of the coccolithophore algae, alive and dead, together with their shed coccoliths, were consumed by planktic predators and scavengers, and their skeletons bound together as faecal material. These excreta may have been consumed in turn by further scavengers and the cycle repeated several times before the coccolithic material arrived at the sea floor. The coccoliths may have accumulated as silt-sized bodies in this way, rather than settling individually as mud fraction.

Firm evidence for this is lacking in the sediments under consideration, any primary pellets having been obliterated by later biogenic reworking. In the less pure carbonate rocks of the Cretaceous of Kansas and

Saskatchewan, however, Hattin (1975) has demonstrated faecal pellets composed largely of coccoliths set in a matrix that is largely coccolith-free. Hattin argued that the pellets represented excreta of planktic coccolithophore predators, such as copepods.

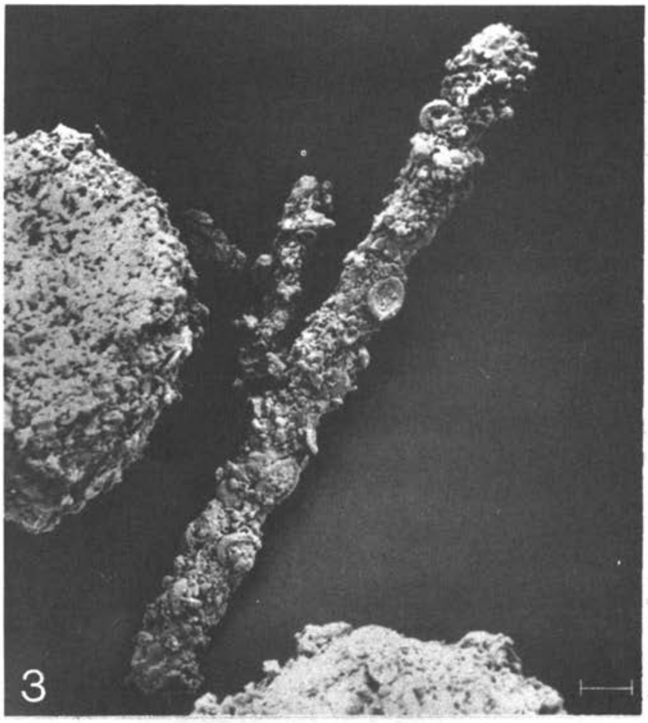
On the European chalk sea floor the detritus was rapidly recycled by deposit-feeding benthos. Evidence for this is provided by the preserved skeletons of superficial deposit-feeders such as echinoids, asteroids and ostracods. The sediment continued to be injested after burial to up to at least 1 m by the burrowing infauna of deposit-feeders, as demonstrated by the presence of the trace fossils *Thalassinoides*, *Chondrites* and *Zoophycos*.

The result of this activity must have been the production of an at least partially pelleted sediment at the sea floor. Individual pellets, however, have been preserved only rarely at a few horizons in abnormal microenvironments (Kennedy, 1970) associated with hardgrounds, phosphatic chalks and within macrofossils; the rocks do not exhibit a general pelletal texture.

Bryozoan chalk facies

In this facies, for example the grey chalk of Stevns Klint, the marked increase in contribution of benthic skeletons altered the depositional pattern of the sediment. Bedding changed from more or less horizontal to biohermal, with the production of low mounds (see Rosenkrantz & Rasmussen, 1960; Surlyk, this volume). These mounds have been considered by some to be comparable to megaripples, having a physical, grain-transport origin (e.g. Rasmussen, 1971). However, it is clear

Figs 3 - 6. SEM pictures of chalk. 3: Unidentifiable rods from 250-63 μm fraction, Maastrichtian, 'Danmark' chalk pit. Note coating of grains of next size fraction, obscuring all details. Scale bar 10 μm. 4: Spherical grain from same sample. It is filled with sediment of the next size fraction. The skeleton appears to have suffered some aggrading neomorphism, and a little overgrowth of epitaxial cement, rendering identification of the original ultrastructure and taxonomic position of the grain uncertain. Scale bar 10 μm. 5: Fracture surface of middle Danian chalk from Hanstholm Havn showing unusually low degree of fragmentation of coccoliths. Note overgrowths on individual crystals of the coccoliths. Scale bar 2 μm. 6: Fracture surface of Upper Maastrichtian chalk from Bjerre showing high degree of disintegration of coccoliths. Most of the small, rounded grains are probably dismembered coccoliths. Scale bar 2 μm. Figs 5 and 6, courtesy of N. O. Jørgensen.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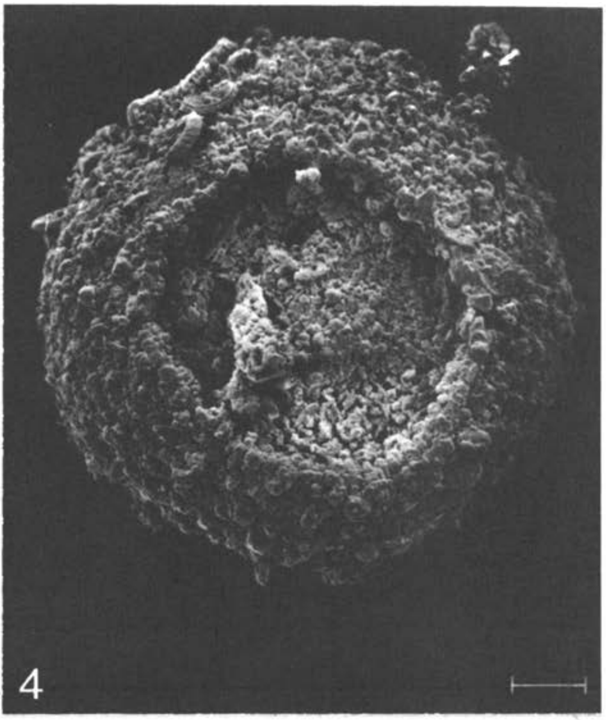
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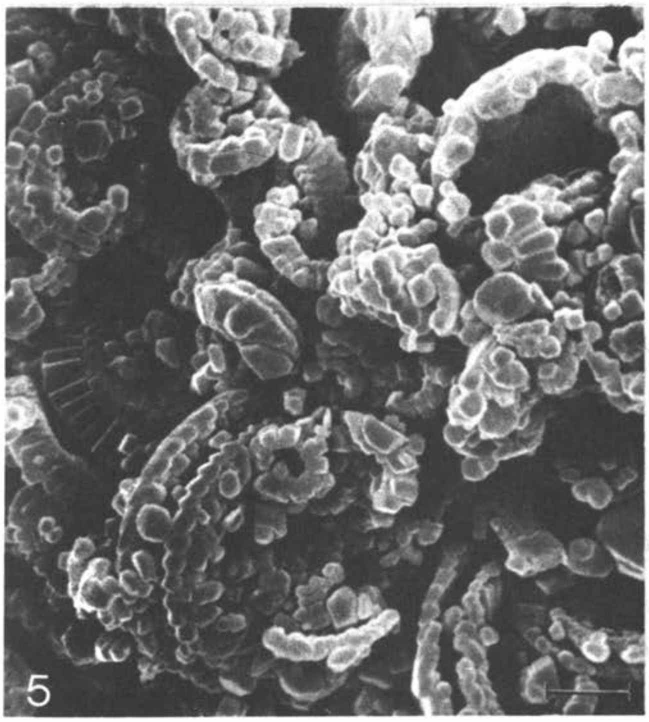
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from the form of the mounds and the distribution and nature of the grains that these are more or less autochthonous (Håkansson, 1971; Surlyk, 1972, p. 12).

Bryzoan limestone facies

A further increase in benthic skeletal production relative to pelagic input resulted in a facial change to bryozoan limestone. Bedding of this facies is locally biohermal, the scale of the structures being rather larger than that of the bryozoan chalk. Lower Danian mounds at Karlby Klint, Jylland, have been studied in detail by Thomsen (1976) who considered that his findings more or less were applicable to the facies in general.

None of the branched bryozoans have retained their erect life position or have remained unbroken. However, the distribution of encrusting bryozoans on the broken branched forms, together with the close proximity of fragments of the same colony, led Thomsen (1976, p.501-503; 1977a, Fig. 4) to consider the colonies to be virtually autochthonous and fragmentation to have occurred *in situ*.

On the basis of the assumption that erect colonies are thickened in response to increased current exposure, the relative distribution of colonies of different thicknesses indicated a clear current orientation of the Karlby Klint mounds (Thomsen, 1976, p. 503; 1977b, p. 363-364). The flanks containing the thicker colonies, interpreted therefore as having faced up-current, are steeper than the lee sides. Bed thickness is also greater on the steeper flanks than on the less steep, showing that the crest of the asymmetrical bank migrated gradually up-current.

Finally, it was also found that the fabric of the two flanks was different. The up-current fabric was mud-supported, the branched skeletons lying largely at random within the matrix, whereas the lee-side fabric was grain-supported, the bryozoans largely lying parallel to bedding. This was interpreted as due to a baffle effect, the stouter, more rapidly growing colonies on the up-current flank acting as a more efficient trap and producing a more open fabric than the leeside bryozoans (Thomsen, 1976, p. 503).

It remains to be seen to what extent this detailed interpretation can be applied to bryozoan limestone elsewhere. It should be pointed out that Cheetham (1971) looked very differently at the middle Danian bryozoan mounds of Limhamn. He saw lithic buildups grading through three different facies: core, transitional and flank, each having a distinctive biological constitution. Cheetham's core facies does not occur in the lower Danian mounds studied by Thomsen at Karlby Klint, or in those at Stevns Klint. It would seem likely, then, that study of bryozoan limestone in other areas will bring further differences to light.

Bioturbation levels of bryozoan limestone are normally low, bedding planes and, locally, fine lamination remaining distinct and largely undisturbed. Trace fossils are not easily detected in sediments of this type, dominated by coarse sand fraction. However, flint layers at many levels clearly demonstrate the existence of horizontal networks of *Thalassinoides*.

Depositional environments

The high mud content, parallel bedding and lack of signs of transport of grains indicate that the chalk was deposited in relatively still water. The asymmetrical mounds of the bryozoan chalk and, to a greater degree, the bryozoan limestone suggest deposition under the influence of a dominantly unidirectional water flow. All the sediments, therefore, appear to have accumulated below normal wave base.

Taking into account the palaeogeographical setting, the history of transgression and regression, and biological evidence, the depth of deposition of the sediments can be estimated.

Hancock (1975, p. 519) recently concluded from a variety of evidence that the white chalk of NW Europe was deposited under 100-600 m of water. 600 m is abnormally deep for a shelf sea, and a figure nearer Hancock's minimum would probably better fit the geological setting of the Maastrichtian chalk of Denmark.

Håkansson *et al.* (1974) discussed this problem and arrived at the conclusion that deposition occurred in a rather shallow epicontinental sea on the broad northwest European Maastrichtian shelf, but within the euphotic zone at only a few levels in restricted areas corresponding to the bryozoan chalk subfacies. Recent investigations based on lithology and microfauna led Ernst (1978) to suggest similar sea depths for the deposition of older chalk at Lägerdorf, north Germany.

The close of the Maastrichtian was marked by a considerable regression. Increase in benthic skeleton production may be correlated with shallowing, reaching a climax in the bryozoan chalk at the top of the Maastrichtian at Stevns Klint. Håkansson *et al.* (1974) considered this bryozoan chalk to have been deposited around the lower limit of light penetration, in about 150 m.

The characteristics that distinguish bryozoan chalk from white chalk are even more pronounced in bryozoan limestone, and we may therefore estimate that the bryozoan limestone accumulated in still shallower water. Calcareous red algal grains are entirely absent in the bryozoan limestone, however (E. B. Nielsen, pers. comm. 1979), and deposition appears to have occurred below wave base. Moreover, most of the exposed occurrences of bryozoan limestone in Denmark and Scania lie rather marginally around the Danish Basin (Håkansson & Thomsen, this volume), for which setting the depth range of 80-150 m suggested by Thomsen (1976, p. 486) does not seem unreasonable, though perhaps verging on the deep side.

Rates of deposition

Even in the more or less stable environment of the chalk, the rate of deposition must have varied considerably from place to place and from bed to bed. An average rate for a whole series of strata, arrived at by dividing thickness by duration, will therefore be of limited value for palaeobiological or sedimentological assessment of individual beds within that series. This is partly because the average figure includes hidden hiati (bedding planes, omission surfaces) of unknown duration - periods of time unrepresented by sediments - and the figure will therefore be lower than the true rate of deposition of individual beds. Furthermore, the post-depositional processes of compaction and stylolitization cause shortening of the rock column which influences the figure in the same way, causing underestimates of depositional rate.

Yet another potential source of error lies in the interpretation of marl seams. If these represent sudden influx of fine terrigenous material into the basin (e.g. Troelsen, 1955; Jefferies, 1963, p. 27), then marl seams may be considered to represent more rapid accumulation than normal. In contrast, however, marl seams may represent a failure of carbonate sedimentation owing to dissolution of calcite on the sea floor (Worsley, 1971; Hansen, 1977; Ernst, 1978). In this case, the seams will represent a drastic reduction of depositional rate, and an average figure for a chalk sequence containing several marl seams, such as the Maastrichtian chalk, will not be an accurate representation of the situation for either marl-depositing or chalk-depositing conditions.

Hancock (1975, p. 522) divided 700 m Maastrichtian chalk in the central part of the Danish Basin by 6 million years, and arrived at 117 m/m.y. or 11.7 cm/1000 years. This is the raw figure for rate of rock production.

Håkansson *et al.* (1974, p. 215), working with a duration of 6 m.y., took account of an assumed compaction of 10% and arrived at a figure of 15 cm/1000 years. If corrected to 6 m.y. this becomes 13 cm/1000 years. However, no account has been taken here of hiati or pressure solution effects, for both of which there is abundant evidence in the Maastrichtian chalk. Stylolites are particularly well developed in the more deeply buried chalk. The amount of column shortening for which this pressure solution has been responsible would be difficult to estimate, but at least it may be considered significant in the present context.

We may safely assume, therefore, that the figure 13 cm/1000 years is a considerable underestimate of the actual rate of accumulation of sediment in the white chalk during periods of deposition. Furthermore, the bryozoan chalk facies, included within this estimate, probably had a somewhat higher rate of accumulation, considering the increase in benthic skeletal input that characterizes it. A figure around 20-25 cm/1000 Years would probably be nearer the truth.

We may approach the bryozoan limestone with the same degree of caution. Although compaction and pressure solution have played minor roles in this facies there is evidence of numerous, long-lasting hiati within the sequence. Thomsen (1976, p. 506) reckoned with 50 cm of lower Danian bryozoan limestone covering a span of about 1 m.y. and so arrived at an average rate of 5 cm/1000 years. He suggested, on this basis, that accumulation on summits of bioherms proceeded at about 5 cm/1000 years, on the up-current flanks at 10 cm and on the lee surfaces at 3 cm.

These figures assume continuous deposition throughout the 1 m.y. period, and take no account of compaction. The figure 5 cm/1000 years is, in fact, no more than a rock production rate.

It is probable, in fact, that long periods of time elapsed while 'dead' bioherms were gradually buried by the accretion of neighbouring mounds; the surfaces of the 'dead' bioherms have locally been lithified as hardgrounds during that period of exposure. Bedding planes within the mounds also may indicate interruptions in accretion. In short, we can probably safely double the average figures in order to arrive at an approximate rate of accumulation of individual beds of bryozoan limestone: i.e. 10-20 cm /1000 years.

Early diagenesis

Post-burial diagenesis is beyond the scope of this paper, these processes having had little to do with Maastrichtian/Danish boundary events. Chalk diagenesis has been discussed by many authors (e.g. Neugebauer, 1973, 1975; Håkansson *et al.*,1974; Bromley *et al.*, 1975; Jørgensen, 1975; Scholle, 1977a & b), whereas this aspect of the bryozoan limestone has been relatively neglected (but see Jørgensen, 1975).

One aspect of sea floor diagenesis that should be mentioned here, however, is hardground development, as this is of widespread occurrence and great significance for the sedimentology and palaeontology of the boundary sequence.

The term hardground is applied to omission surfaces that have been synsedimentarily lithified to produce hard sea floors (Voigt, 1959a; Bromley, 1978). Two aspects of hardgrounds deserve special emphasis in the present context: stratigraphic condensation, and preservation of aragonitic faunas.

The presence of a hardground indicates a break in the depositional record with the omission of a certain amount of sediment. This omission may be primary, owing to non-deposition, or it may be secondary, in which case sediment that was once deposited was removed again by scour. It is not always easy to distinguish which of these two processes has been most significant at any given hardground. It is usually obvious, however, when secondary omission has occurred subsequent to lithification of the sea floor, by processes of erosion.

For several reasons, hardgrounds tend to be conspicuous in the field in pure and weakly lithified limestone sequences such as those with which we are dealing with here. The hardgrounds are highly lithified and jointed or shattered, and thus weather differently from the surrounding rock; they are topped by a distinct, sharp omission surface, which may be tinted with glauconite or ferruginous oxides; and a burrow system of *Thalassinoides* is normally well preserved in the hard rock, containing uncompacted, loose sediment from above the hardground.

It should be emphasized, however, that the conspicuous nature of hardgrounds does not necessarily mean that they represent correspondingly significant breaks in the succession. Omission surfaces today can be cemented rapidly, at least in shallow water, in a matter of decades (Shinn, 1969). Reasons for omission surfaces in some settings becoming cemented while others do not, involve such factors as the movement of major water masses, sea floor supersaturation with $CaCO_3$, etc., and not the period of exposure alone. An unhardened and inconspicuous omission surface may easily represent a longer depositional hiatus than a massive, jointed hardground nearby in the sequence.

Again, the degree of mineralization, e.g. glauconitization, of the surface may depend more upon the rate of the glauconitization process than on the length of exposure of the hardground. Some hardgrounds have been extensively bioeroded by boring organisms (e.g. that locally terminating the middle Danian at Limhamn) whereas others, equally well developed in other respects, contain few or no borings (e.g. the Cerithium limestone of Stevns Klint). Perhaps this is an indicator of the duration of the hiatus. By reference to Recent environments, however, we may equally well explain bioerosional differences by the degree of intermittant coverage of the surface by wandering waves of sediment, periodically burying and then uncovering the hardground and preventing the establishment of an endolithic community, or by the growth of an impenetrable layer of unpreserved organisms (sponges, algae) that prevented access of boring organisms.

In conclusion, then, it may be said that a hardground represents a distinct break in sedimentation, but the lithology of the hardground gives little evidence of the duration of the hiatus.

The other significant feature of hardgrounds is that, by rapid lithification of the sediment, the aragonitic element of the fauna may be preserved, in contrast to the normal situation in calcitic oozes, where it is lost. Preservation occurs as empty moulds owing to cementation of the surrounding sediment before dissolution of the aragonite skeleton. Likewise, siliceous sponges, normally poorly preserved in chalk, retain their shape uncompacted and display faithful moulds of the spicular skeleton in hardground preservation.

Moulds after aragonite do not occur in all hardgrounds, many of which are completely devoid of them (e.g. those on the flanks of the lower Danian bioherms at Stevns Klint). And in the best of cases, what may approach a representative of the entire aragonitic fauna is only preserved patchily and locally (e.g. patchily within the lower Danian Cerithium limestone of Stevns Klint). Again, the degree of aragonite mould preservation has no connection with the degree of lithification of the hardground beyond the fact that some initial lithification is necessary.

Aragonitic species are represented in the thin hardgrounds in the Lower Maastrichtian of Møns Klint, but are absent in the exceptionally well developed hardground that terminates the middle Danian at Limhamn.

At Stevns Klint the details of the era boundary are highly complicated (Bromley, 1975b, fig. 10; Surlyk, this volume). The conspicuousness of the major hardground long obscured the real nature of the boundary at this locality (Gravesen, this volume). However, now that the boundary has been revealed as the undulating crest of the biohermal bryozoan chalk, overlain by Fish clay in the intermound troughs, a potentially ideal situation presents itself for the study of the faunal turnover at the boundary. For the lithification at the cross-cutting hardground has alternately subjected topmost Maastrichtian chalk and basal Danian chalk to virtually identical diagenetic treatment. Both host sediments contain outstandingly well preserved, abundant moulds after aragonite and silica in addition to the calcitic element. Detailed studies of the faunas of the two rocks, Mesozoic and Tertiary, incorporated in the hardground, are yielding much information on the faunal change at the boundary. Two papers in this volume deal with molluscs from the Maastrichtian half of the double hardground (Heinberg; Birkelund), but there are several well represented groups (e.g. gastropods and sponges) about which we still know relatively little.

MG AND SR DISTRIBUTION IN CARBONATE ROCKS IN THE BOUNDARY SEQUENCE IN THE DANISH BASIN AND THE NORTH SEA CENTRAL GRABEN

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The usefulness of minor elements, i.e. Mg and Sr, as tools in facies analyses in sedimentary carbonate rocks has been intensively discussed by several authors (see Bathurst, 1976, for references). Consideration of possible regional and facies changes in Mg and Sr distribution are closely related to carbonate chemistry, mineralogy of skeletal carbonates and the effects of diagenetic processes. So many different factors have been taken into account as possible controls of these elements that interpretations are difficult and generalizations impossible.

Nevertheless, a characteristic negative correlation between the concentrations of Mg and Sr in the topmost Maastrichtian chalk has previously been recorded at two localities in the Danish Basin (Honjo & Tabuchi, 1970; Jørgensen, 1975). This observation has led the present author to initiate a comprehensive study of the Mg and Sr distribution in the Maastrichtian/Danian boundary sequence in the Danish Basin and the North Sea Central Graben.

The boundary sequence is characterized by a more variable lithology than generally observed in the Maastrichtian strata in the Danish Basin (see Rosenkrantz, 1966; Håkansson *et al.*, 1974; Jørgensen, 1975; Childs & Reed, 1975; Nielsen, 1976; Stenestad, 1976). However, in the present study only two major sediment types are considered: (1) Maastrichtian and Danian chalk, including subordinate marl layers and hardgrounds and (2) Danian bryozoan limestone.

Mg AND Sr DISTRIBUTION

The material studied includes a large number of samples from 13 outcrops or boreholes encompassing the Maastrichtian/Danian boundary

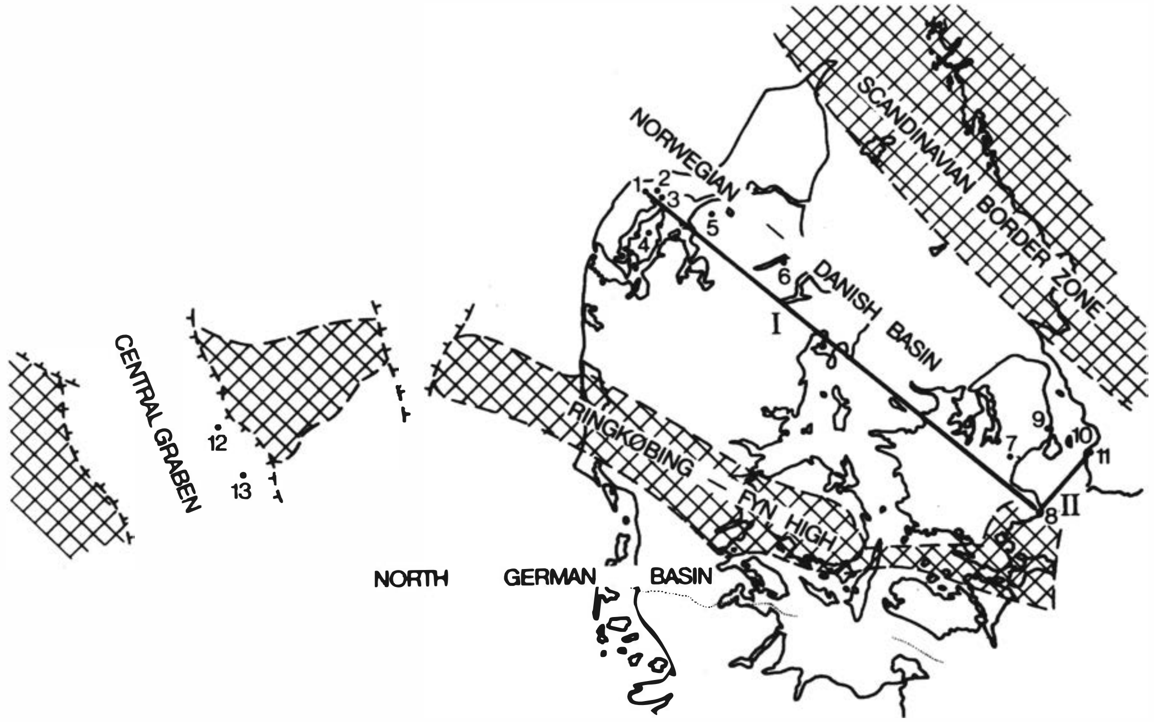


Fig. 1. Map of Denmark and the North Sea showing the 3 geographical areas and the localities studied in the present paper. (1) The North Sea Central Graben: 12: E-1, 13: M-1x. (2) The axial part of the Danish Basin (Section I): 1: Bjerre, 2: Kjølby Gaard, 3: Nye Kløv, 4: Eerslev, 5: Vokslev, 6: Dania, 7: Karlstrup, 8: Stevns. (3) The transitional marginal zone (Section II): 9: Copenhagen TUBA 13, 10: Saltholm, 11: Limhamn.

in the Danish Basin and the North Sea Central Graben (Fig. 1). The localities are divided into three groups on the basis of geographical location, lithology and elemental distribution. These are (1) the North Sea Central Graben, (2) the axial part of the Danish Basin (section I) and (3) a transitional marginal zone in the Danish Basin (section II) approaching the Fennoscandian Border Zone.

The Mg and Sr concentrations were determined by atomic absorption photospectrometry. The results are treated from two points of view: (1) stratigraphic distribution within the individual localities and (2) geographical pattern.

Stratigraphic distribution

The general distribution of the elements within the individual sequences is rather similar for all localities studied. The most conspicuous feature is the negative correlation between the two elements in the uppermost Maastrichtian chalk, i.e. increasing Mg and decreasing Sr concentrations towards the Maastrichtian/Danian boundary (Figs 2-4).

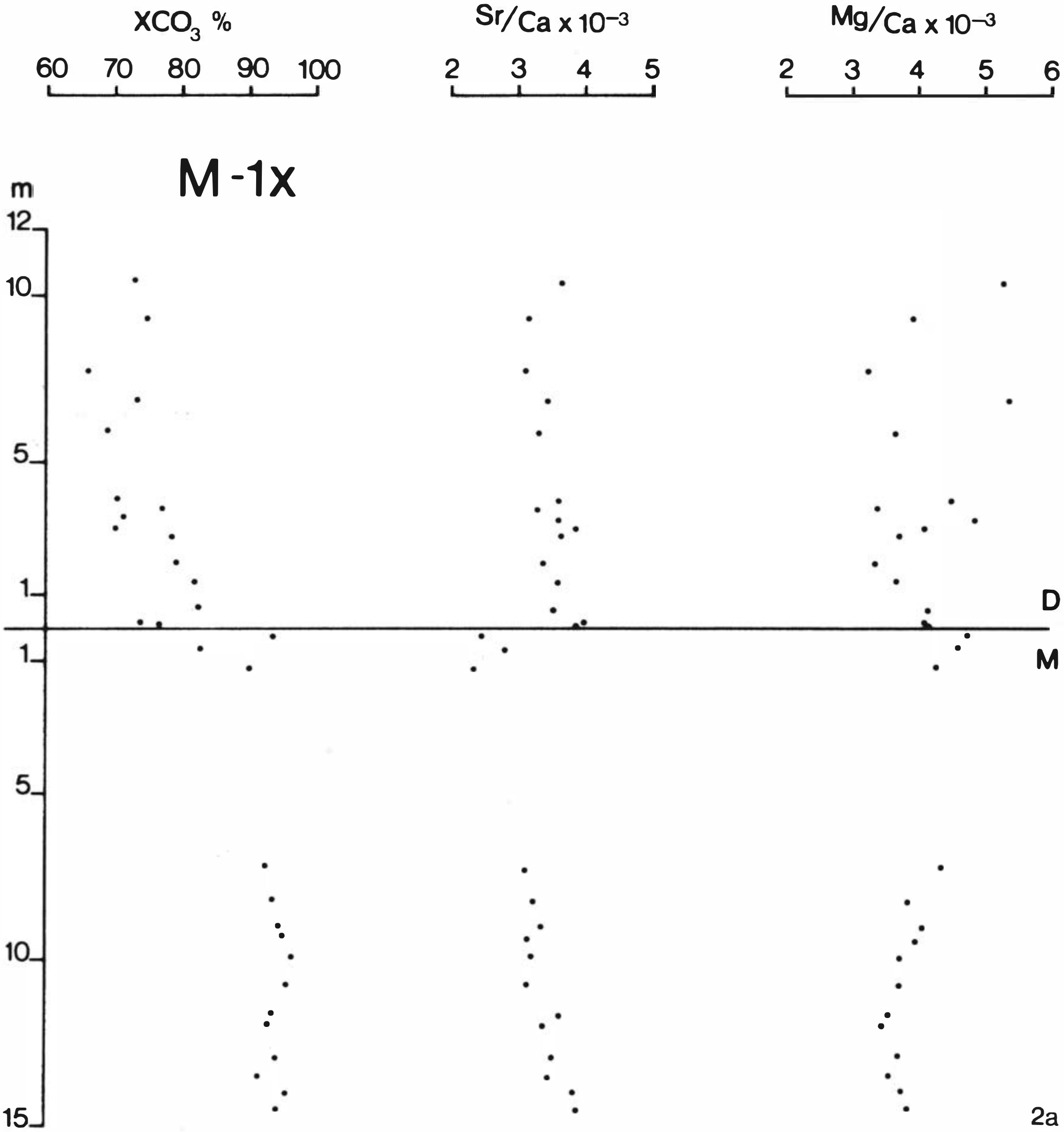
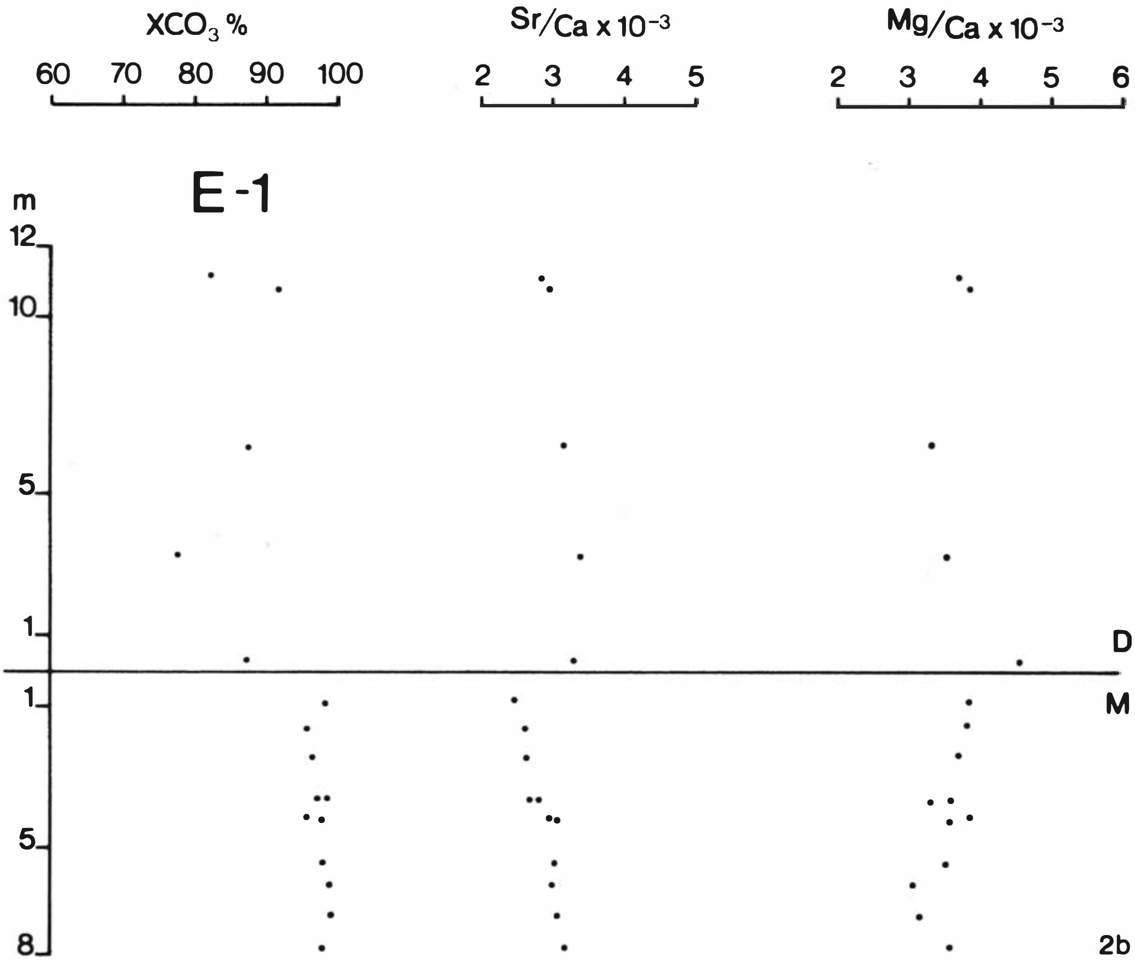


Fig. 2a-b. Mg and Sr distribution and carbonate concentration in the two North Sea boreholes studied. M/D: The Maastrichtian/Danian boundary.



The trend of the decreasing in Sr concentration is very constant, varying from 0.1 Sr/Ca × 10^{-3} per metre sediment in the North Sea Central Graben to 0.2 Sr/Ca × 10^{-3} per metre sediment in the Danish Basin. The only significant variability in Sr concentration in the Danish Basin is found in section II (Fig. 4). Variations in Mg concentration are much more pronounced. However, on the basis of the present data the trend of the increase in Mg concentration is estimated to be approximately 0.1 Mg/Ca × 10^{-3} per metre sediment.

The variable lithology of the Danish sequence to some degree blurrs the general pattern of the elemental distribution, but the negative elemental correlation obtained in the Maastrichtian strata is replaced here by a relatively constant proportion between the Mg and Sr correlations. Furthermore, there are significantly higher concentrations of Mg in the bryozoan limestone in comparison to the value found in the chalk.

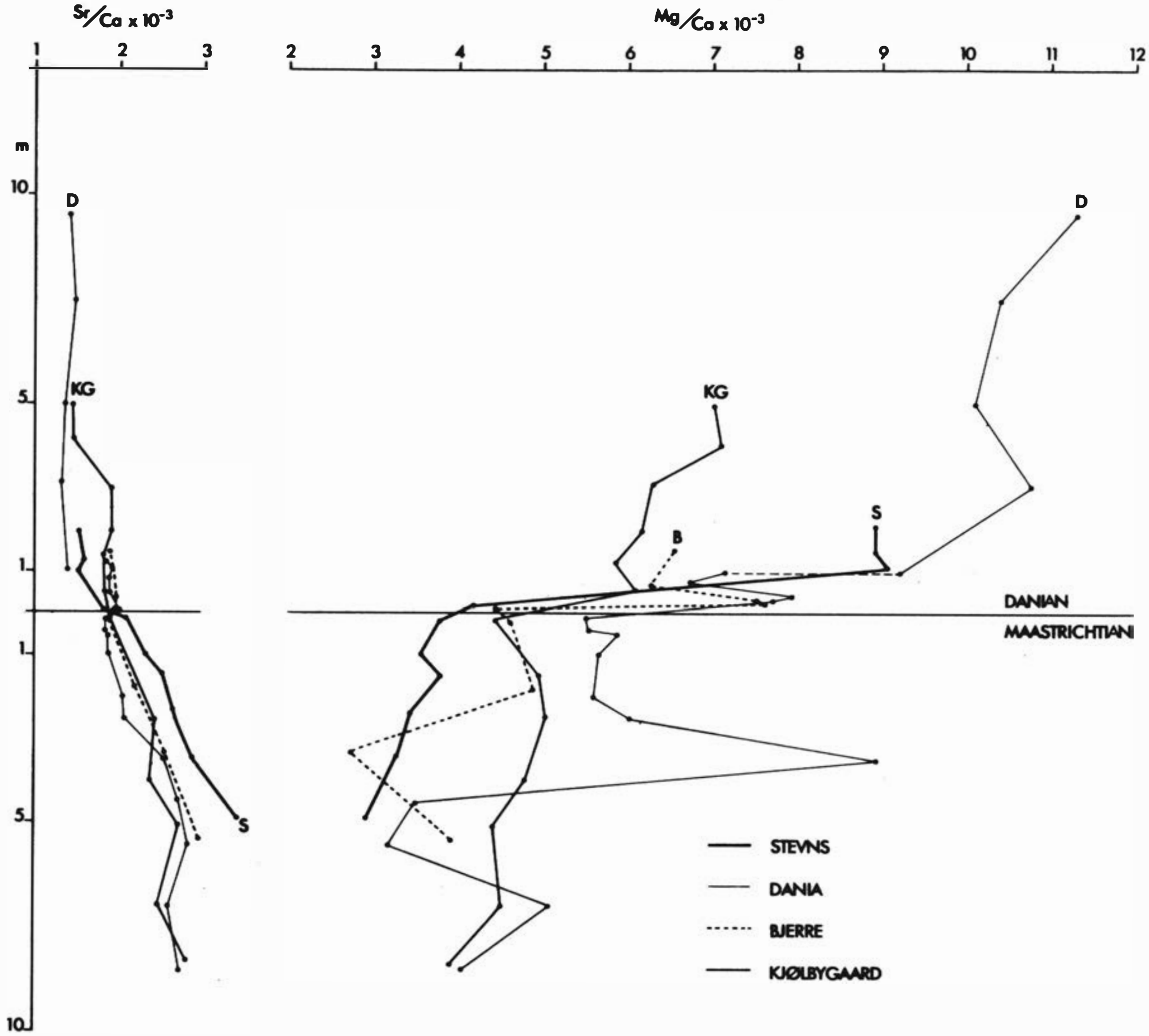


Fig. 3. Mg and Sr distribution at selected localities from the axial part of the Danish Basin (Section I).

Geographical distribution

The geographical distribution reveals a clear variation between the three areas studied. The differences are accompanied by textural modifications, particularly with respect to the carbonate mud. The term carbonate mud is here used for particles < 63 µm. These are of indeterminate origin and constitute the overwhelming majority of particles in both chalk and bryozoan limestone (Jørgensen, 1975; Nielsen, 1976; Bromley, this volume).

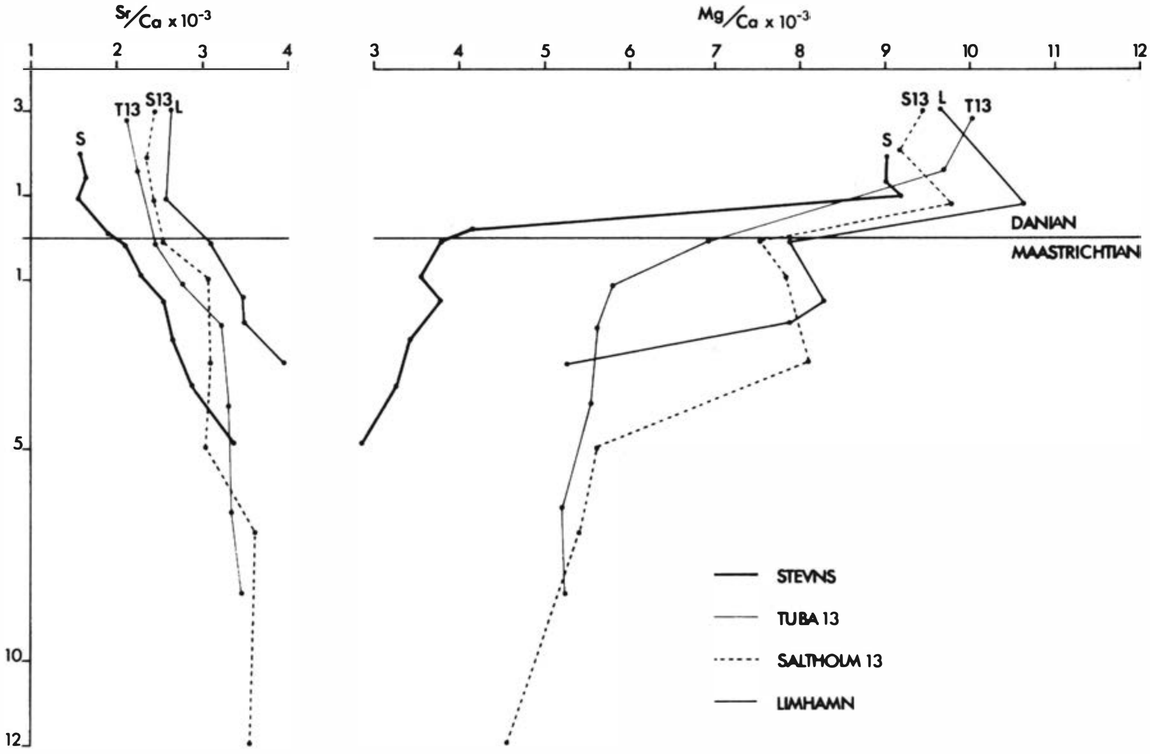
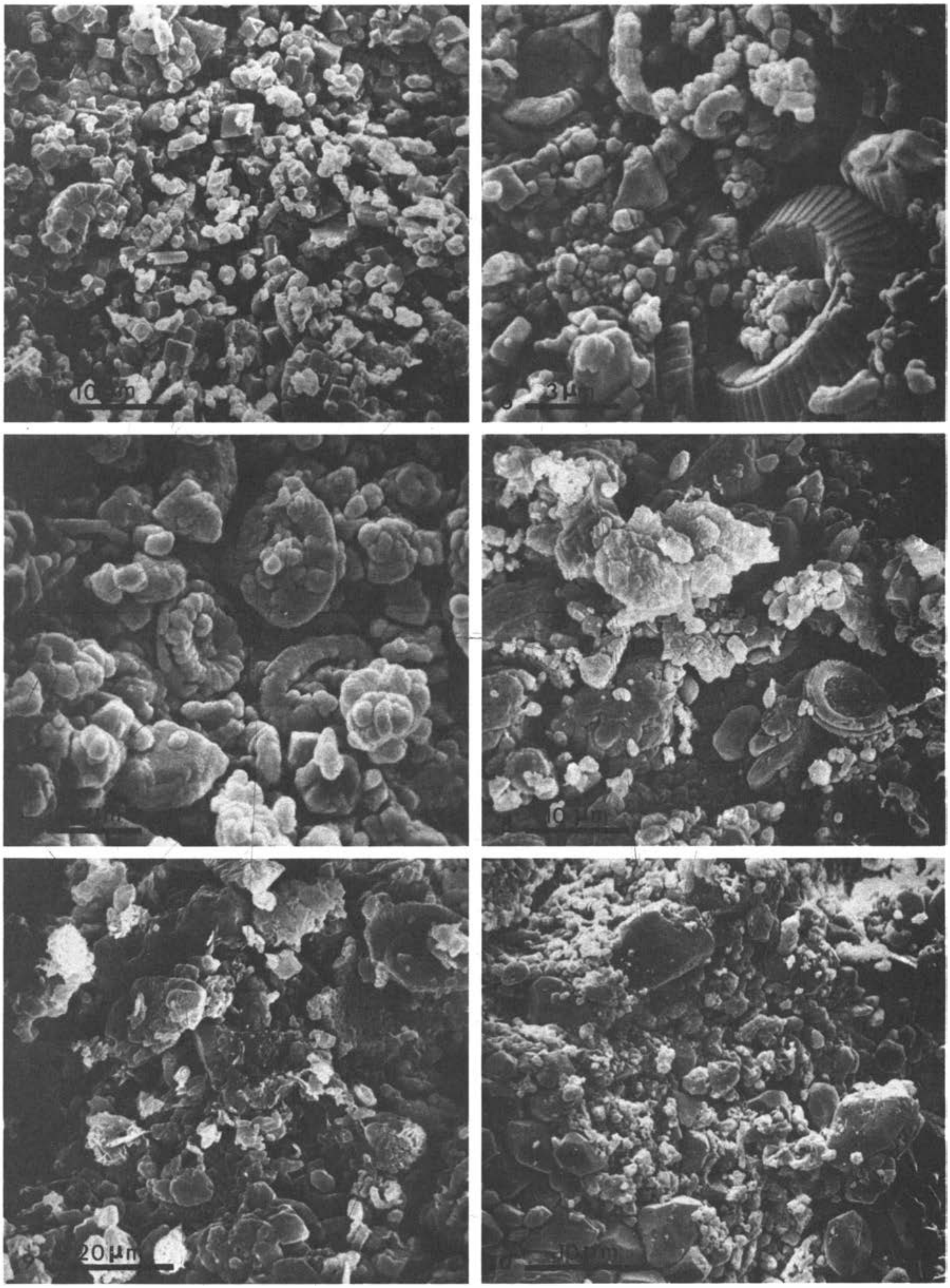


Fig. 4. Mg and Sr distribution at localities from the transitional marginal zone (Section II).

The carbonate mud of the North Sea chalk has a remarkably uniform textural appearance, i.e. regular grain shape and almost entirely micritic in size (Figs 5,6). Skeletons generally observed originate from pelagic micro- and nannofossils, whereas larger skeletal fragments are virtually absent. The elemental distribution is practically identical in the two boreholes studied.

The texture of the chalk in the axial part of the Danish Basin is quite similar to that of the North Sea chalk (Fig. 7), but the number of

Figs 5-10. SEM pictures of fracture surfaces. Fig. 5: Maastrichtian chalk from M-1x, the North Sea Central Graben. Fig. 6: Danian chalk from M-1x, the North Sea Central Graben. Fig. 7: Maastrichtian chalk from Vokslev, the axial part of the Danish Basin. Fig. 8: Danian bryozoan limestone from Stevns. Fig. 9: Maastrichtian chalk from Limhamn, the transitional marginal zone. Fig. 10: Cemented Maastrichtian chalk from Saltholm 13, the transitional marginal zone.


10 µm
b
3 µm
10 µm
20 µm
10 µm

larger skeletal fragments and the amount of insoluble residue are significantly greater and much more variable (Jørgensen, 1975). The elemental distribution recorded is almost identical to that found in the North Sea chalk, but is characterized by more variable concentrations.

The elemental distribution in the transitional marginal zone shows a clear trend of increasing Mg and Sr concentrations in a north-eastern direction. The texture of the carbonate mud is characterized by irregular and angular grain shape and a considerable number of the particles is within medium silt size fraction (Figs 8,9). A partial cementation of the rocks of the studied area may have an early date (Fig. 10).

CONCLUSION

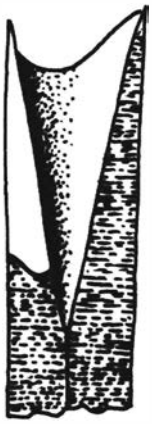
The negative correlation between the elements is restricted to a particular part of the stratigraphic sequence studied. The data derives from three different geographical areas with slightly different lithology and diagenetic impact. The elemental distribution is revealed not only by examination of bulk samples, but recent investigations of individual skeletons of different taxa have demonstrated a similar pattern (Jørgensen, 1975). The remarkably regular and organized stratigraphic and geographical distribution of Mg and Sr cannot be due to incidental diagenetic effects alone, but suggest a significant dependence on the original formation of the sediments. The almost totally biogenic origin of the carbonate constituents indicates that the phenomenon most likely is caused by the biochemical uptake of these elements. It is therefore believed that the elemental distribution to a certain degree reflects physicochemical alterations in the late Maastrichtian sea, e.g. temperature and salinity. Consequently, the general variations in the elemental distributions may be time correlative and thereby significant for stratigraphic and environmental interpretations.

The geographical distribution of the elements reveals the existence of two biogeochemical facies within the area studied: (1) an axial basinal facies including the North Sea Central Graben and the axial part of the Danish Basin and (2) a transitional marginal facies.

The basinal facies is characterized by a comparatively stable elemental composition, probably caused by the dominance of pelagic organisms among the identifiable skeletons and most likely also among the constituents of the carbonate mud.

The transitional marginal facies reveals metastable geochemical conditions as reflected by increasing Mg and Sr concentrations and the impact of diagenesis. The feature applies to both chalk and bryozoan limestone. The texture of the carbonate mud clearly indicates a different origin from the basinal carbonate mud. The geographical distribution of the elements suggests a northeastward increase in amount of metastable carbonate matter i.e. towards the margin of the Maastrichtian sea. Although there is no obvious authigenic source of metastable carbonate matter in the studied sequences, the existence of such a source cannot be excluded. However, a supply of metastable carbonate mud transported from near-shore environments to the transitional marginal zone should also be considered. The Maastrichtian littoral communities could certainly have supplied a considerable amount of magnesian calcite and aragonite in the form of metastable carbonate detritus.

The metastable carbonate mud in turn would have been influenced by the physicochemical changes in the late Maastrichtian sea. Thus the irregular distribution of the elements in the transitional marginal zone most likely is governed by two independent factors: (1) a dominant factor consisting of the physicochemical properties of the sea water and (2) the supply of metastable carbonate detritus.



MAASTRICHTIAN BELEMNITES FROM DENMARK

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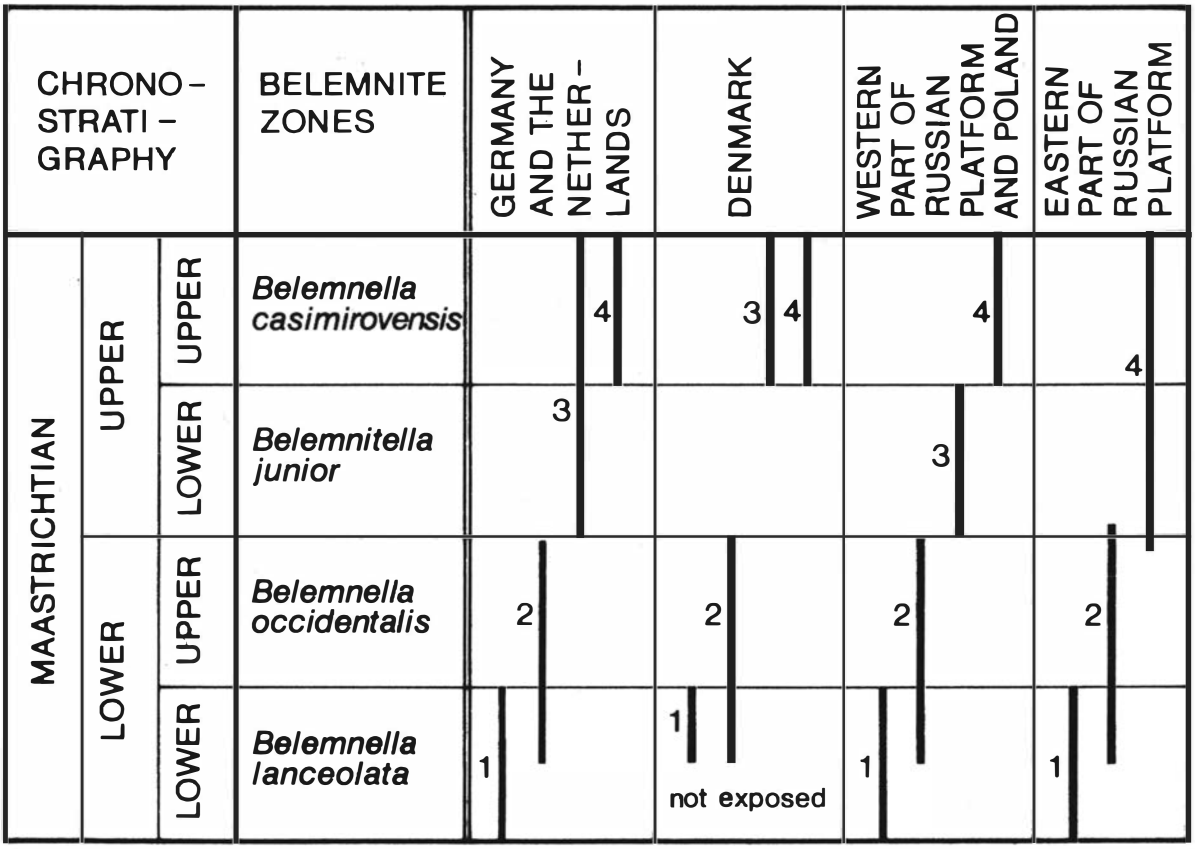
The Maastrichtian is defined as the chronozone of the ammonite *Scaphites (Hoploscaphites) constrictus* (Sowerby). In practise, however, the base of the Maastrichtian is defined by the first occurrence of the belemnite *Belemnella lanceolata* (Schlotheim), because *S. constrictus* is very rare or virtually absent in the lower part of the Maastrichtian. At one time several workers considered *S. constrictus* to have evolved from *S. tenuistriatus* Kner, which appears in the Upper Lower Maastrichtian. However, Schulz (1978) has shown that *S. constrictus* does indeed occur in the basal Maastrichtian in Kronsmoor Quarry (see Birkelund, this volume).

The Maastrichtian is dubdivided into four zones on the basis of belemnites (Jeletzky, 1951; Birkelund, 1957; Schmid, 1967); the zones are (Fig. 1, bottom to top): *Belemnella lanceolata* and *Belemnella occidentalis* Zones in the Lower Maastrichtian, and *Belemnitella junior* and *Belemnella casimirovensis* Zones in the Upper Maastrichtian. It should be mentioned that Schulz (in press), on the basis of a detailed biometric study of the morphological variation of the genus *Belemnella* in the Lower Maastrichtian, has subdivided the *B. lanceolata* Zone into three zones, viz. (bottom to top): *Belemnella lanceolata*, *Belemnella pseudobtusa*, and *Belemnella obtusa* Zones. He also refers to the *B. occidentalis* Zone as the *B. sumensis* Zone.

The best studied section in northern Europe exposing the Campanian/ Maastrichtian boundary is that of Kronsmoor, NW Germany (Schulz, 1978). There is here a gap of 5 m between the latest Campanian belemnite and the first occurrence of *Belemnella*.

The most detailed studied section in northern Europe exposing the Lower/Upper Maastrichtian boundary is that of Hemmoor, NW Germany (Schmid, 1975). In that chalk pit the boundary between the Lower and Upper Maastrichtian is placed conventionally at the "Tuffit-Schicht" -



1: *B. lanceolata*; 2: *B. occidentalis*; 3: *B. junior*; 4: *B. casimirovensis*

Fig. 1. Stratigraphic range of Maastrichtian zonal belemnites in various areas in northern Europe, based on Birkelund (1957), Christensen (1975, 1976), Jeletzky (1951, 1958), Naidin (1973, 1975), and Schmid (1967, 1975).

a marl layer interpreted by Valeton (1959) as a bentonite. The highest *Belemnella occidentalis cimbrica* Birkelund is found c. 1.5 m below that marl seam, while the lowest *Belemnitella junior* (Nowak) is found c. 5 m above it.

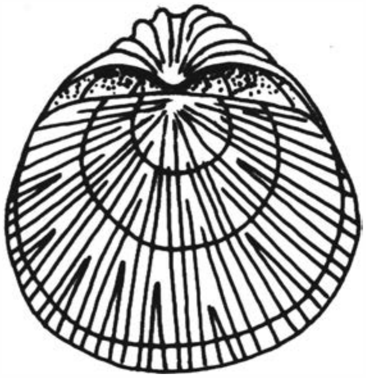
The Danish Maastrichtian belemnites have been studied, notably by Jeletzky (1951) and Birkelund (1957). According to Birkelund (1957) the genus *Belemnitella* is represented by *B. junior junior* and *B. junior nowaki* Jeletzky, and the genus *Belemnella* is represented by the following taxa:*B. lanceolata lanceolata*, *B.* aff. *lanceolata*, *B. occidentalis occidentalis* Birkelund, *B. occidentalis cimbrica* Birkelund, *B.* aff. *occidentalis*, *B. casimirovensis casimirovensis* (Skolozdrowna), *B. casimirovensis archangelskyi* Jeletzky, and *B. casimirovensis* n. subsp.

According to Birkelund (1957) *B. lanceolata* and *B. occidentalis* occur together below a thin hardground in the sequence exposed at Møns Klint. The basal Maastrichtian (the zone containing only *B. lanceolata*) does not outcrop in Denmark. The chalk above the hardground at Møns Klint is referable to the zone of *B. occidentalis* (Upper Lower Maastrichtian) (Birkelund, 1957).

Belemnitella junior and *Belemnella casimirovensis* occur together in the uppermost 25-30 m of the white chalk, and this part of the section is referred to the *B. casimirovensis* Zone (Surlyk, 1970b). The chalk in Denmark that is correlatable with the German *Belemnitella junior* Zone has not yielded any specimens of the index fossil (Surlyk, 1970b). This might be because *B. junior* is very rare in Denmark (Birkelund, 1957).

Belemnites occur rarely in the *B. casimirovensis* Zone in Denmark. The stratigraphically highest specimen was collected at Stevns Klint 30 cm below the Maastrichtian/Danian boundary (Birkelund, 1957). No belemnites have been recorded from the overlying Danian deposits.

The stratigraphic range of the Maastrichtian zonal belemnites in various areas in northern Europe is shown in Fig. 1. *Belemnitella junior* has not been recorded east of the Ukrainian syneclise, and in the eastern part of the Russian Platform transitional forms between *B. occidentalis* and *B. casimirovensis* span the Lower/Upper Maastrichtian boundary and *B. casimirovensis* range throughout the Upper Maastrichtian (Naidin, 1973, 1975).



MAASTRICHTIAN BRACHIOPODS FROM DENMARK

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The brachiopods of the Maastrichtian white chalk of Denmark have been studied in detail from taxonomic, stratigraphic and palaeoecologic points of view (Surlyk, 1969, 1970a, b, 1972, 1973, 1974).

The material numbers about 100.000 specimens obtained mainly from bulk samples (5 or 10 kg). The total fauna numbers about 45 species, 8 of which are inarticulate (Fig. 1). The majority of the species - and by far the most abundantly occurring - are minute articulate forms which rarely exceed an adult length of 2 - 4 mm. Those species may occur in hundreds or even thousands in each sample (Fig. 2). The larger articulate species are generally rare and were either loose lying on the sea floor or attached with a pedicle to large suitable substrates such as echinoid tests. The inarticulate species mainly belong to the Craniacea which had a cementing or eventually freely recumbent mode of life (Surlyk, 1973). The species *Lingula cretacea* is notable in that it represents a mainly infaunal, burrowing group of brachiopods which is normally claimed to live in very shallow marine waters. Here it occurs in a pelagic chalk deposited well below the photic zone in the deeper part of the shelf. *Lingula cretacea* belonged to the normal benthic fauna and quantitative data from the chalk of Rügen, East Germany (Steinich, 1972) shows that it varies in abundance in the same way as the main part of the other benthic species. An epiplanktic mode of life can thus be excluded.

The more precise substrate preference of some of the pedunculate minute brachiopod species (Fig. 1) can be ascertained by rare finds of specimens preserved *in situ*, still adjacent to the substrate to which they were attached (Surlyk, 1974) and by the discovery of minute borings of different types produced by the strands of brachiopod pedicles (Fig. 3) (Bromley & Surlyk, 1973).

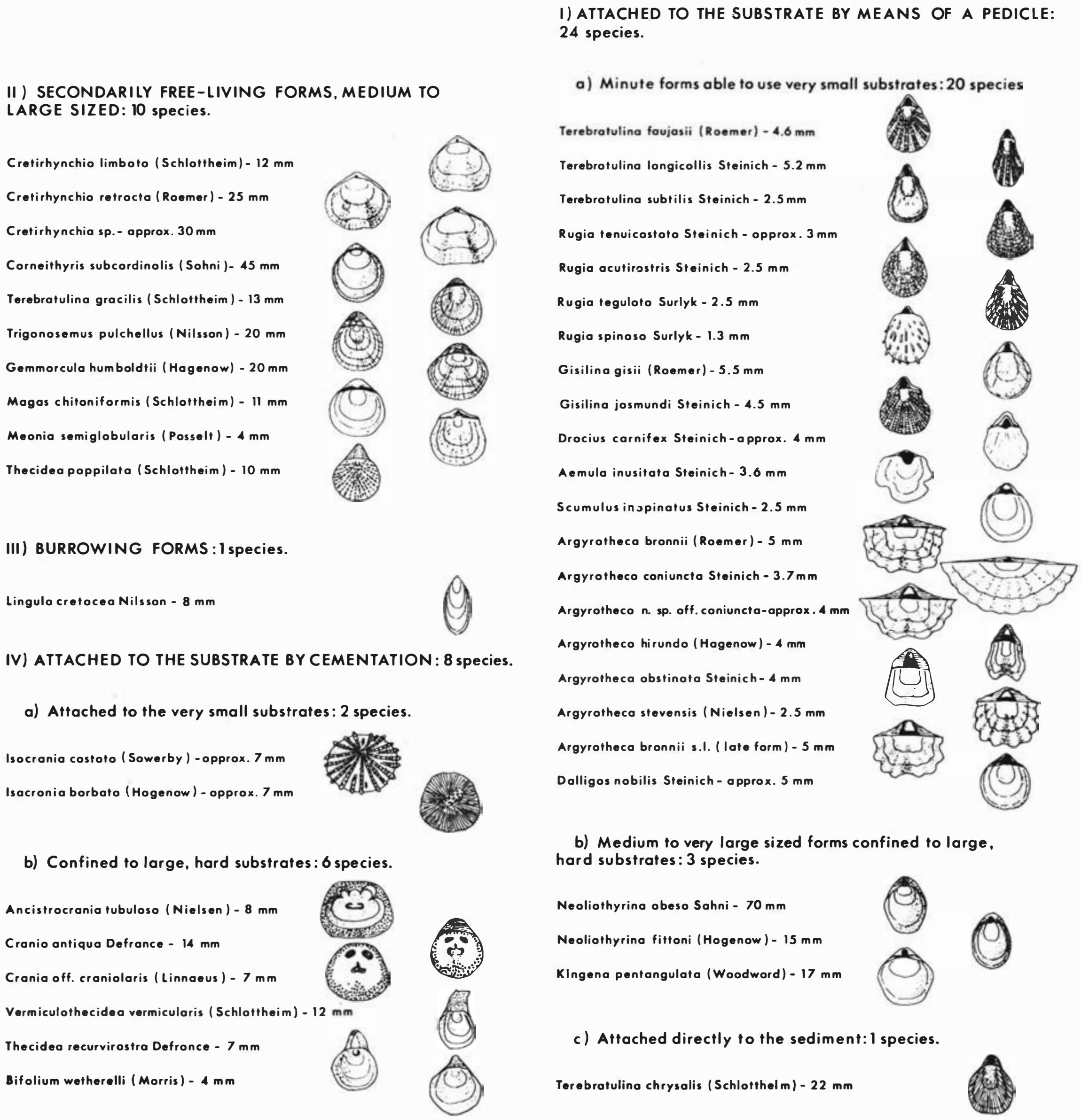


Fig. 1. The brachiopod species found in the Maastrichtian chalk of Denmark distributed on ecological groups (from Surlyk, 1972). A few additional rare species have been found later.

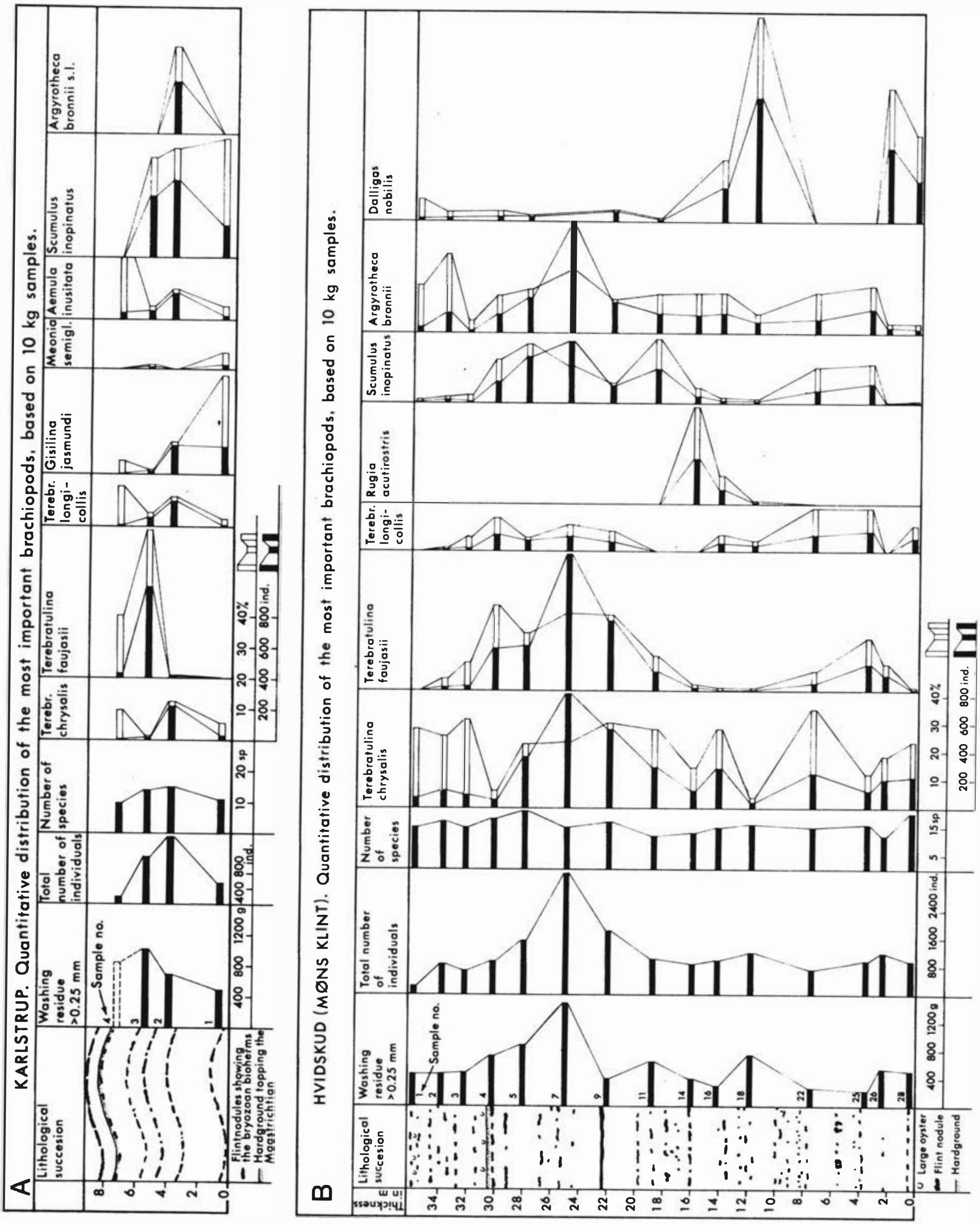


Fig. 2. A: The quantitative distribution of the most important brachiopod species in the Maastrichtian/Danian boundary section at Karlstrup, Sjælland, Denmark. B: The quantitative distribution of the most important brachiopod species in the Lower Maastrichtian section at Hvidskud, Møns Klint, Denmark (from Surlyk, 1972).

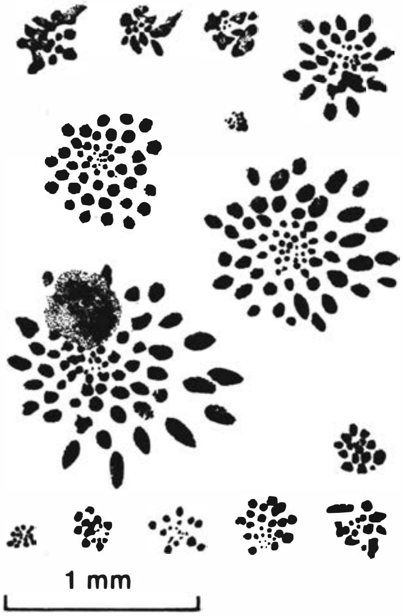


Fig. 3. Examples of borings (*Podichnus*) produced by brachiopod pedicles in a single Lower Campanian belemnite from Eastern England (from Bromley & Surlyk, 1973).

The brachiopods have proved to be of great biostratigraphical value in the chalk of NW Europe because many of the species have a limited vertical distribution, occur in great numbers, and are easy to determine (Steinich, 1965; Surlyk, 1970b; Surlyk & Birkelund, 1977). The Lower-Upper Maastrichtian boundary strata of Rügen were divided into five zones by Steinich (1965). Three of these zones could be recognized also in Denmark, and the whole of the Danish Maastrichtian was divided into 10 zones (Surlyk, 1970b). The boundaries of all the zones are defined by the first or last occurrence of a species whilst the zone itself is characterized by the presence of one or more species. Later, partly unpublished work has shown that the main zonation is also valid for the Maastrichtian of NW Germany (Surlyk, 1975), Eastern England and SW Sweden. A slightly modified version of this zonation is shown on Fig. 4. Apart from the zonation itself several important results emerged from the work on the stratigraphy of the brachiopod fauna. Firstly, a great number of localities were precisely dated for the first time (Surlyk, 1969) and, secondly, a thick chalk sequence above the last occurrence of *Belemnella occidentalis* and the first occurrence of *Belemnitella junior* and *Belemnella casimirovensis* (see Christensen, this volume) which earlier has been placed in the Lower Maastrichtian, was removed to the Upper Maastrichtian (Fig. 4) (Surlyk, 1970b). The key species in the zonation are the minute forms *Rugia spinosa*, *R.*

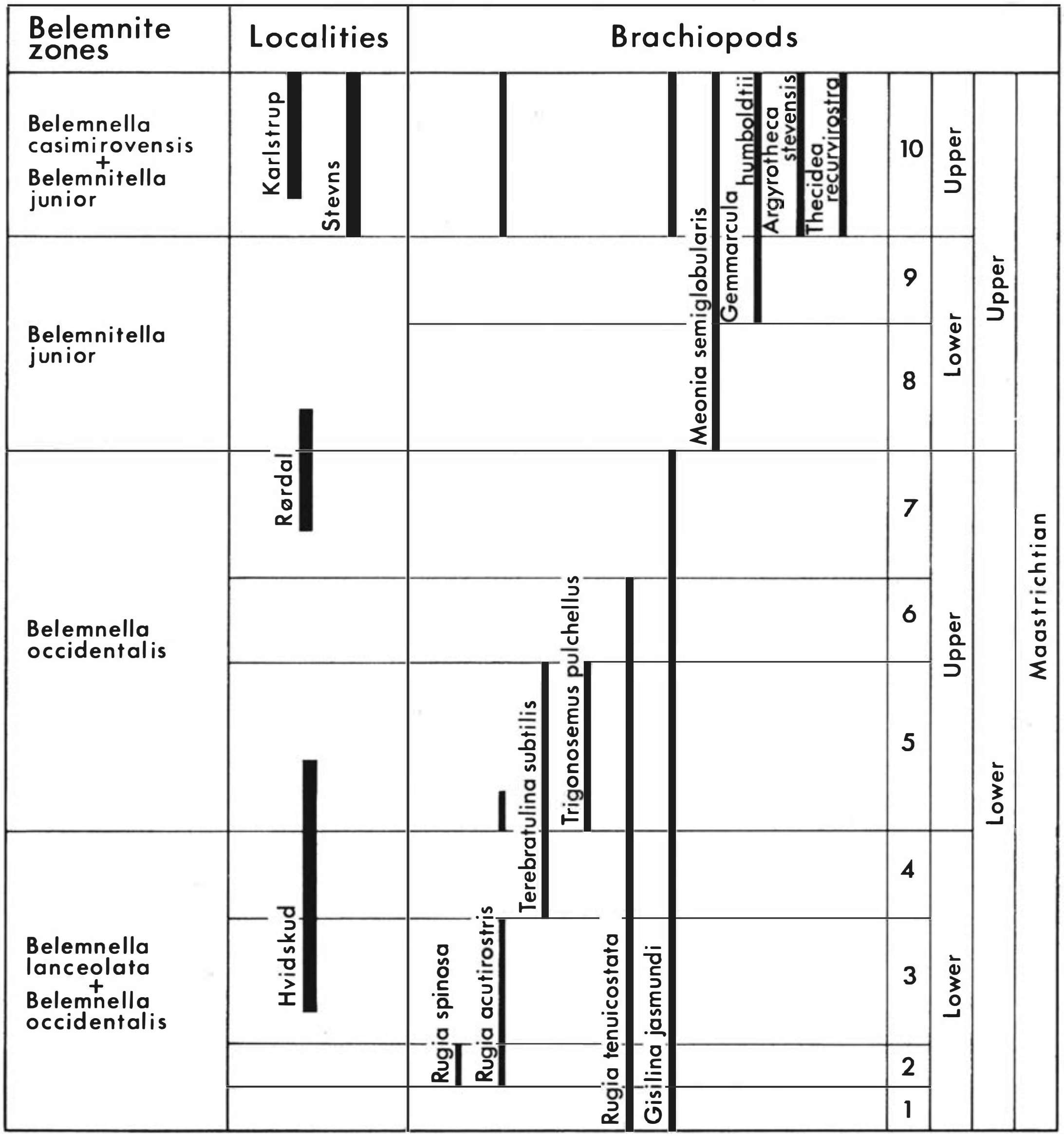
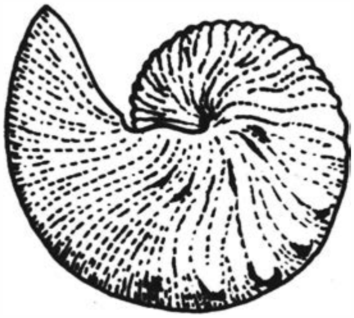


Fig. 4. The brachiopod zonation of the Maastrichtian of Denmark correlated with an earlier zonation based on belemnites (Birkelund, 1957) (from Surlyk, 1972).

acutirostris, *R. tenuicostata*, *R. tegulata*, *Gisilina gisii*, *G. jasmundi*, *Meonia semiglobularis*, *Argytotheca stevensis* and the larger forms *Trigonosemus pulchellus*, *Gemmarcula humboldtii* and *Thecidea recurvirostra* (Fig. 1).

The highest Maastrichtian chalk at all localities is characterized by the fauna of zone 10, which continues to the basal Danian bed. This fauna often shows extremely high densities and relatively high diversity.

The taxonomy and stratigraphy of the brachiopods of the Danian of Denmark are only known in broad outline, whereas the palaeoecology of the brachiopods from Fakse, type locality of the Danian, has been treated by Asgaard (1968). Consequently nothing detailed is known about extinctions and faunal turnover across the Maastrichtian/Danian boundary. The Maastrichtian and Danian stages have practically no brachiopod species in common. Preliminary data seem to suggest, however, that several of the latest Maastrichtian species pass into the lowest few metres of the Danian. Morphologically and palaeoecologically the Danian brachiopod fauna as a whole shows great resemblances with the Maastrichtian fauna. This is to be expected because the main facies of the two stages are quite similar.



THE LAST MAASTRICHTIAN AMMONITES

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The continuous decline in number of Cretaceous ammonites from Early Cretaceous time to their final extinction at the Maastrichtian/Danian boundary is well documented by e.g. Wiedmann (1969). This reduction in number of genera can also be demonstrated within the Maastrichtian, about 34 genera being known from Lower Maastrichtian, but only about half that number from the Upper Maastrichtian.

New collecting in Maastrichtian chalk of Denmark has extended our knowledge of the stratigraphic distribution of the last ammonites of the Boreal province. Representatives of seven ammonite genera have been found in the topmost layer of the Upper Maastrichtian, confirming the sudden disappearance of the very last ammonites. The occurrence of large numbers of juvenile ammonites at the top (not to be confused with dwarfs) is ascribed to changing ecological conditions caused by the regression of the sea.

NOTES ON THE AMMONITE SPECIES AND THEIR STRATIGRAPHIC OCCURRENCE (Fig. 1).

The new material supplements Ravn's (1902) description of Upper Cretaceous ammonites from Denmark. Stratigraphically the material has the draw-back that most of the specimens have not been collected directly in connection with bulk sampling because of their sparse occurrence. Generally, therefore, they have only been referred to the one or two brachiopod zones represented at the locality in question. Some of the stratigraphic data are supplemented with data on ammonites from Germany, especially Hemmoor. Zone numbers used below refer to brachiopod zones as defined by Surlyk (1972).

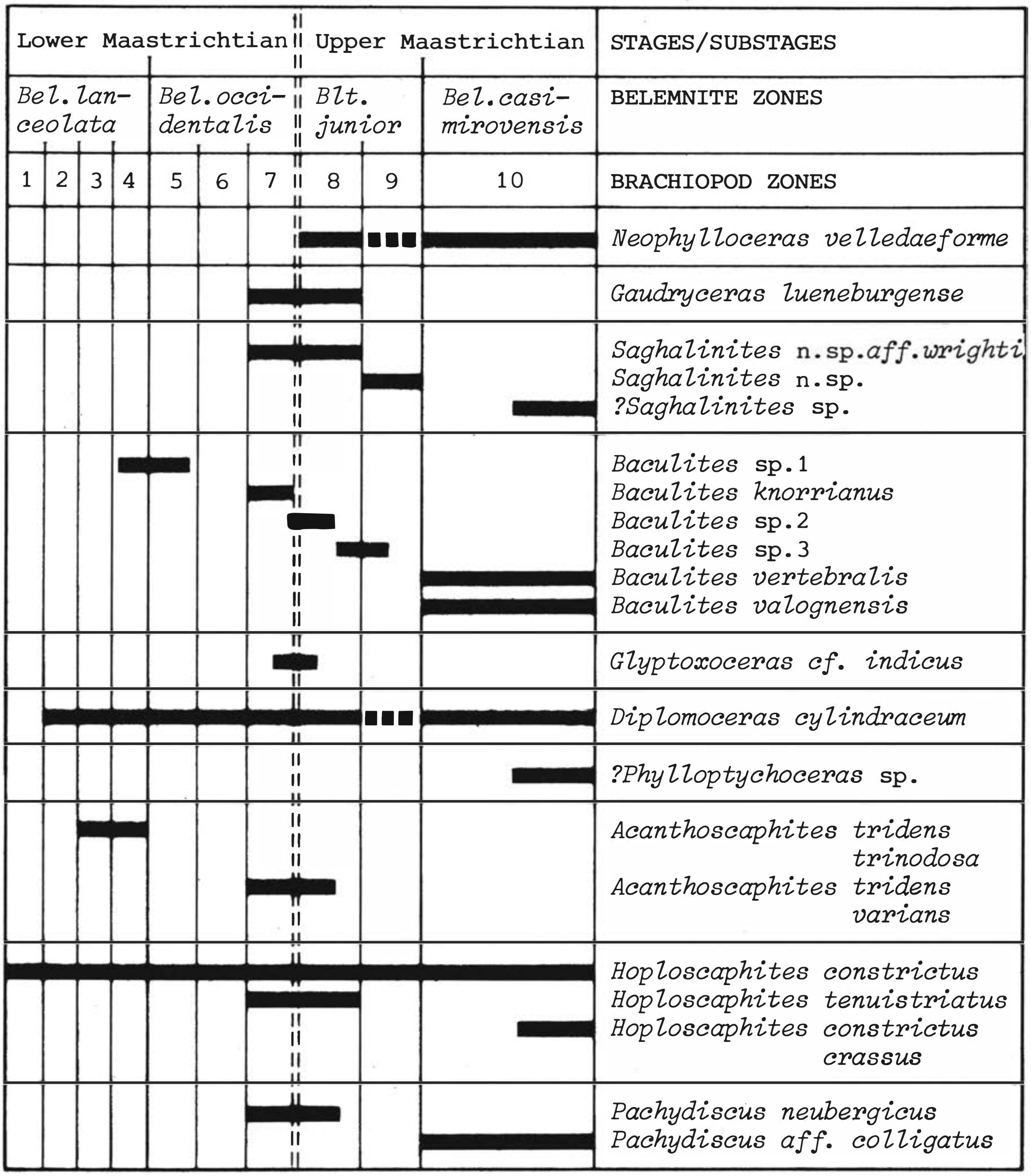


Fig. 1. Stratigraphic distribution of ammonites in the Maastrichtian white chalk of Denmark

Neophylloceras velledaeforme (Schlüter, 1876)

Very rare. One specimen from Fjerritslev described by Ravn (1902, p. 248, pl. 3, fig. 12). Now also known from Aalborg (zone 7-8), Dania (zone 10) and the topmost chalk at Stevns Klint in hardground facies.

Gaudryceras lueneburgense (Schlüter, 1872)

Very rare. Two specimens from Frejlev and Nørholm, respectively, mentioned by Ravn (1902, p. 252). Now also known from Hillerslev (zone 8) and Rørdal (zone 7-8). In Hemmoor it occurs in zone 8.

Saghalinites n.sp. aff. *wrighti* Birkelund, 1965

Specimens from Frejlev and Nørre Uttrup described by Schlüter (1876, p. 161, pl. 42, Figs 6-7) and Ravn (1902, p. 257, Pl. 3, Fig. 11) as *Ammonites* n.sp.? are closely related to *Saghalinites wrighti* Birkelund, 1965, from West Greenland. New material has been collected at Hillerslev, Rørdal and 'Danmark'. Zone 7-8. Also found at Hemmoor.

Saghalinites n.sp.

Rare. Occurs at Flødal (*Ammonites* n.sp.? in Ravn, 1902, p. 257), Hov and Bjerre. A specimen from Kunrade referred to *Gaudryceras* cf. *kayei* Forbes by Grossouvre (1908, p. 34, pl. 10, Fig. 5) may belong to this species. It differs from *Saghalinites* n.sp. aff. *wrighti* in having well developed constrictions and a wider umbilicus. Zones 9-10.

Baculites

The baculites are poorly preserved. The material is difficult to compare to other European *Baculites* because type material is poor and stratigraphic levels uncertain. Nevertheless, the collecting in the chalk shows that the ranges of the species are short, like those of the Western Interior of North America as described by Cobban (e.g. in Obradovich & Cobban, 1975). Thus *Baculites knorrianus* Desmarest, 1817, is restricted to zone 7-?8 (Rørdal) and *Baculites vertebralis* Lamarck, 1801, and *B. valognensis* Boehm, 1891, are only found in zone 10 (Dania, Stevns Klint). These species are often cited from other levels, but this is probably due to misidentification. A number of other *Baculites* species occur at other levels in the Danish chalk, but preservation is generally too poor for satisfactory description.

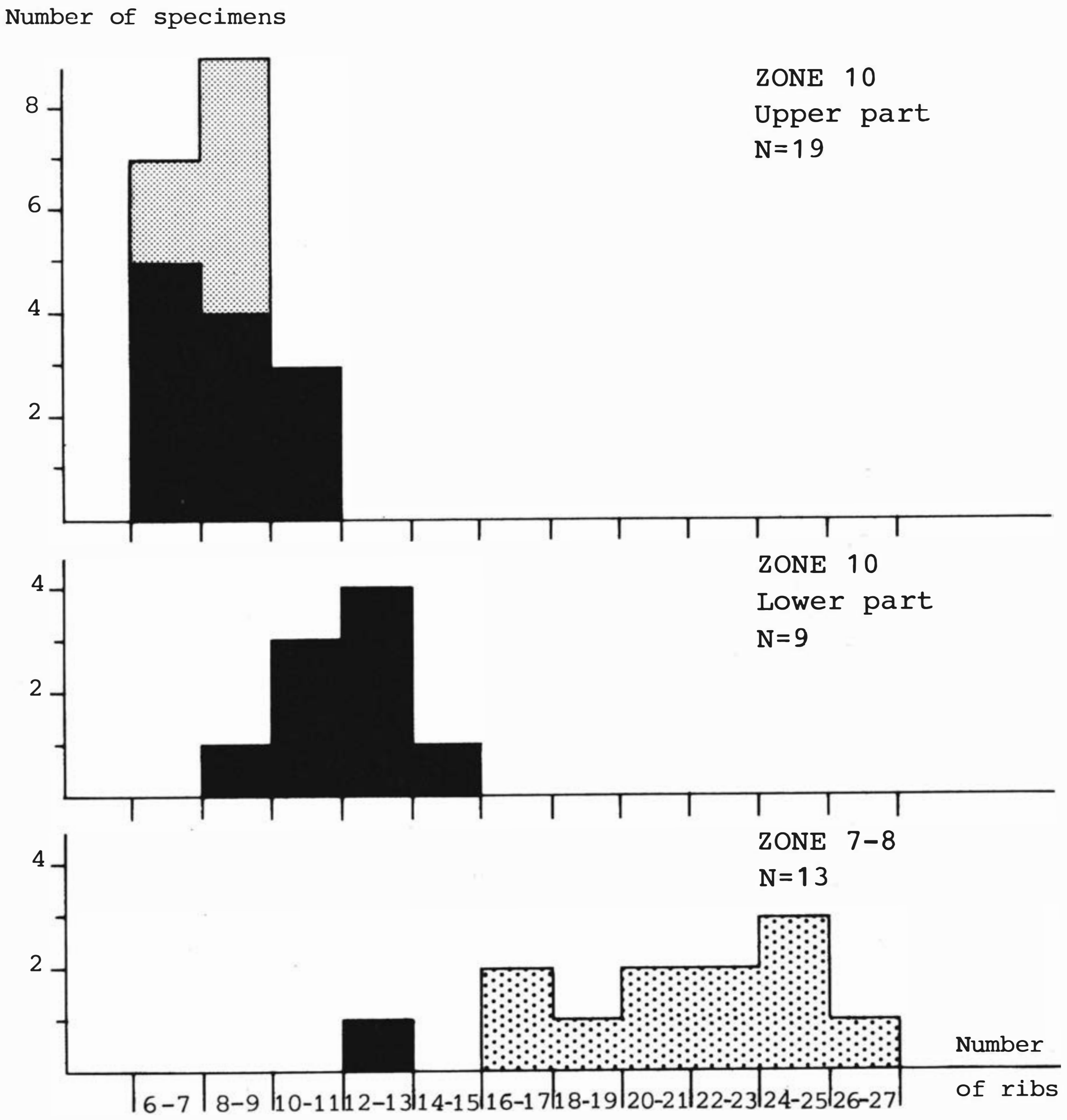


Fig. 2. Variation in number of ribs on the body chamber of mature macroconchs of *Hoploscaphites constrictus* ■, *H. constrictus crassus* ▒ and *H. tenuistriatus* ⁙. Number of ribs on 1 cm of the youngest part of the venter indicated.

Glyptoxoceras cf. *indicus* (Forbes, 1846)

One specimen has been found at Hillerslev (zone 7-8).

Diplomoceras cylindraceum (Defrance, 1816)

Fairly common. Described by Ravn (1902, p. 249). Has been found throughout most of the Maastrichtian and seems to occur to the top (Zones 2-8, 10).

Acanthoscaphites

Two subspecies have been found, both of limited stratigraphic extent: *Acanthoscaphites tridens trinodosa* (Kner, 1848) occurs in zones 3-4 of Møns Klint. The species is rare. *Acanthoscaphites tridens varians* (Lopuski, 1911) is rather common in Rørdal and Hillerslev in zones 7-8. It is also known from the same level in Hemmoor (e.g. Schmid, 1965).

The genus *Acanthoscaphites* is strictly European, most occurrences having been recorded from Poland and USSR.

Hoploscaphites

Hoploscaphites constrictus (Sowerby, 1817) is the classical guide fossil for the Maastrichtian and is distributed throughout the stage, but is rare in the lower part (see Schulz, 1978).

Although several hundred specimens have been collected, only a few characters can be systematically measured because of poor preservation.

Characters showing a definite stratigraphic variation are ribbing and distribution of nodes on the body chamber and youngest part of the phragmocone. Thus, the number of ribs on the youngest part of body chamber of macroconchs seems to decrease towards the top of Upper Maastrichtian (Fig. 2). A subspecies, *Hoploscaphites constrictus crassus* (Łopuski, 1911) may be separated on the basis of a more inflated shape and the development of strong nodes all the way from the phragmocone to the aperture. It occurs only at the top of zone 10.

Hoploscaphites tenuistriatus (Kner, 1848) occurs in zone 7-8 and has been found at the same level in Hemmoor. It differs from *H. constrictus* by finer ribbing on the body chamber and by having the nodes weakly developed or entirely lacking.

Pachydiscus

Two species have been found. *Pachydiscus neubergicus* (v. Hauer, 1858) is rare and occurs in zones 7-8. This species has been used in standard schemes as index for the Lower Maastrichtian; its occurrence just around the Lower/Upper Maastrichtian boundary renders this use problematical. *Pachydiscus* aff. *colligatus* (v. Binkhorst, 1861) is common in Zone 10 (especially in Dania), but has also been found in the top hardground of Stevns Klint. The species is well known from the Kunrade limestone of the Maastricht area, and has also been found in the Maastricht Tufkrijt, although generally replaced by *Sphenodiscus* spp. in this facies.

AMMONITES IN THE TOPMOST CHALK (HARDGROUND FACIES) OF THE MAASTRICHTIAN OF STEVNS KLINT

The topmost Maastrichtian chalk of Stevns Klint, where locally lithified by a hardground, contains many mature *Hoploscaphites* and *Baculites* of normal size and rare mature specimens of other genera. Together with these there are abundant juvenile specimens of scaphites and baculites, and juvenile *Saghalinites* sp., *?Phylloptychoceras* sp. and *Pachydiscus* sp. have also been collected. The following species are now known from this hardground:

Neophylloceras velledaeforme
Saghalinites sp.
Hoploscaphites constrictus constrictus
Hoploscaphites constrictus crassus
Baculites valognensis
Baculites vertebralis
Diplomoceras sp.
?Phylloptychoceras sp.
Pachydiscus aff. *colligatus*

Some juvenile ammonites from the hardground are shown in Fig. 3. Ammonitellas (i.e. the protoconch and first whorl terminating at the nepionic constriction) occur in profusion. Most of these ammonitellas are believed to belong to *Hoploscaphites* and *Baculites* because determinable later juvenile stages of these two genera are fairly common (Fig. 3A-C). The profuse occurrence of ammonitellas and absence of even younger stages seems to support the interpretation of the ammonitellas as embryos (Drushits & Khiami, 1970; Birkelund & Hansen, 1974). The change in growth at this constriction in *Baculites* from coiled to straight (Fig. 3G-H, also shown by Smith, 1901) adds further support.

The common occurrence of juveniles in this hardground is remarkable, as juveniles seem to be absent in other parts of the white chalk. In

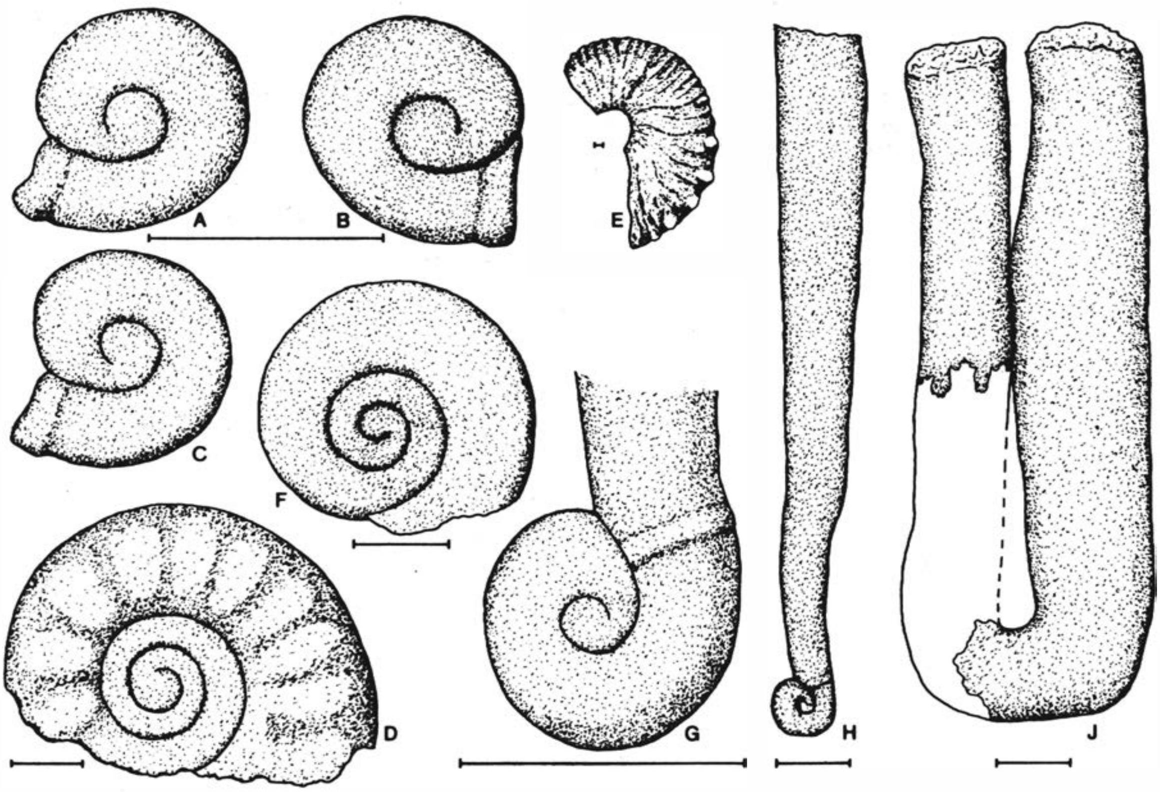
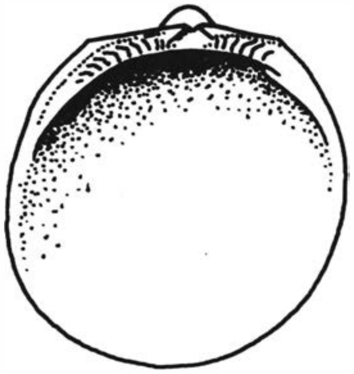


Fig. 3. Juvenile ammonites from the topmost chalk (hardground facies) of the Maastrichtian of Stevns Klint. Scales indicate 1 mm.
A-C: ammonitellas of *Baculites* or *Hoploscaphites* spp.;
D-E: juvenile stages of *Hoploscaphites constrictus;*
F: *?Saghalinites* sp.; G-H: *Baculites* sp.; J: *?Phylloptychoceras* sp.

clastic facies in North America and West Greenland juvenile scaphites become common in the Maastrichtian concurrently with the regression in these areas (Fox Hills, Waage, 1968; West Greenland, Birkelund, 1965), and it is tempting to consider a similar connection with the regression towards the top of the Maastrichtian at Stevns Klint.

In conclusion it is important to stress that there is no evidence to suggest that the ammonites were affected by poor living conditions to cause dwarfing or stunting (as supposed by Wiedmann, 1969, for a late Maastrichtian fauna of Zumaya, Spain); on the contrary, they seem to have lived perfectly well to the end.

In the Cerithium limestone above the Fish clay one or two fragments of baculites have been found. These specimens are considered to be reworked from the Maastrichtian as are some of the micro- and nannofossils.



BIVALVES FROM THE LATEST MAASTRICHTIAN OF STEVNS KLINT AND THEIR STRATIGRAPHIC AFFINITIES

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The topmost Upper Maastrichtian bryozoan chalk of Stevns Klint, Sjælland, is among the youngest Mesozoic strata yielding abundant macrofossils. Locally, this chalk has been cemented by early Danian hardground processes (Heinberg, 1976, Bromley, this volume; Surlyk, this volume).

In addition to calcitic skeletons, which are normally preserved in the chalk, the hardground limestone contains void moulds after originally aragonitic skeletons (Bromley, this volume) that are normally not preserved in the chalk. The presence of this aragonitic faunal element imparts a considerable importance to this bed for comparison of Cretaceous and Tertiary faunas (discussion by Russel, 1976). This importance has been accentuated by recent studies, which have revealed 14 aragonitic bivalve genera hitherto only known from the Cenozoic (Heinberg, 1976, 1979 and in prep.).

The stratigraphic range of genera present in the hardground is shown diagrammatically in Fig. 1. Three major types of time-range can be distinguished: (1) genera ranging from Upper Cretaceous (some appearing as late as the Upper Maastrichtian) to Recent, (2) genera ranging from Mesozoic (or earlier) to Cenozoic, (3) genera exclusively known from pre-Cenozoic deposits.

Genera originating in the Upper Cretaceous and continuing into the Cenozoic (group 1) are of special interest. The majority of these genera originated at the very top of the Maastrichtian (in the sediment beneath the hardground) within a community of extreme diversity and habitat diversification. It is noteworthy that it is among these highly specialized animals that we find the bulk of bivalve genera crossing the boundary.

Long-ranging Mesozoic-Cenozoic genera (group 2) are of limited stratigraphic interest, but important in the discussion of extinctions simply because they did survive the Cretaceous/Tertiary boundary.

Group 3, consisting of genera that became extinct at the Cretaceous/ Tertiary boundary, gives little information about the nature of the boundary events. They simply died out. The new genera occurring together with them and finally replacing them may very well tell more about the nature of these events.

In order to shed light on the reasons for the changes at the boundary, different aspects of the three groups will be compared.

When discussing faunal extinctions on a larger scale, so-called mass extinctions, at least three aspects must be taken into consideration with regard to biological properties:

1) Community structures and ecology of the faunas on both sides of the boundary.

2) The age of taxa that becomes extinct compared to those that survive.

3) The taxonomic change across the boundary with special reference to the new taxa following the event.

COMMUNITY STRUCTURE AND ECOLOGY

The community structure of the present Upper Maastrichtian bivalve fauna has been dealt with elsewhere (Heinberg, in press). The bivalves comprise a high number of species, many of which belong to the same genera, and which were members of an extremely diversified ecosystem. Low internal stability is characteristic of such a system (May, 1973), necessitating high environmental stability.

The ecology of the present genera is listed in Fig. 2, where the individual time-range classes are subdivided into four ecological groups. The bivalves are assigned to these groups on the basis of taxonomic and shell morphological criteria. The ecological groups are:

1) Endofaunal, deposit feeding prosobranchs.

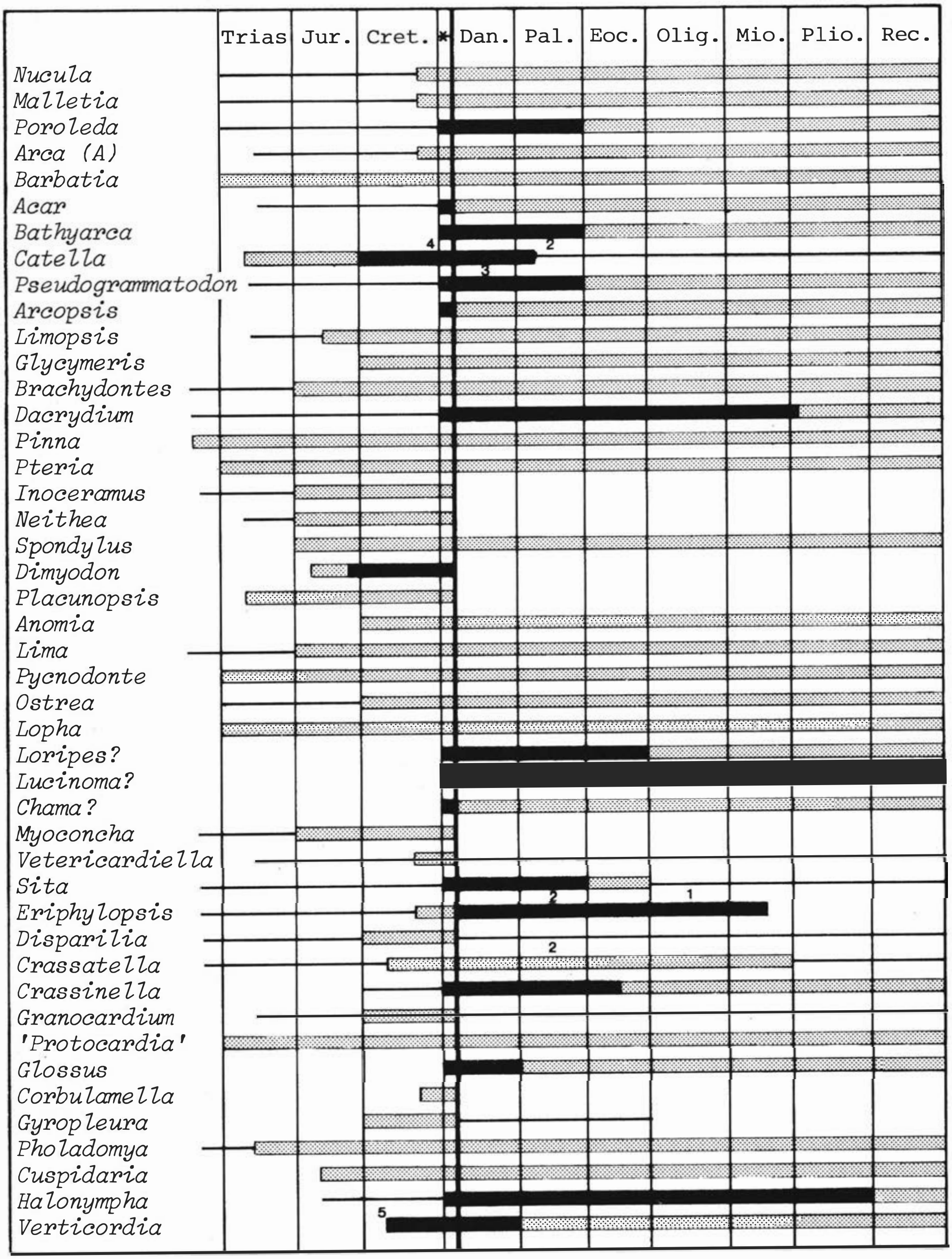
2) Low level suspension feeders (Turpaeva's group 'filter A' 1957) comprising freely burrowing forms (e.g. *Protocardium*), endobyssate species (e.g. *Limopsis*) and byssate semi-infaunal species (*Pinna*, *Inoceramus*).

Fig. 1. Range of genera occurring in the Upper Maastrichtian hardground at Stevns Klint. The hardground is marked by an asterisk. White bars show the range according to Moore (1969), while black bars represent extensions based on the fauna in the hardground, plus data from a few other sources: von Koenen, 1893(1); Ravn, 1933, 1939(2,3); Speden, 1970(4) and Kauffman, 1976(5). Thin lines indicate family range.

Ten genera are entirely Mesozoic: *Inoceramus*, *Neithea*, *Dimyodon*, *Placonopsis*, *Myoconcha*, *Vetericardiella*, *Disparilia*, *Granocardium*, *Corbulamella and Gyropleura*. Five of these are also restricted to the Mesozoic at family level.

The Mesozoic genera may be weighted differently as to their stratigraphic significance. *Corbulamella* is extremely restricted in its range, being hitherto known only from the Maastrichtian of North America (Speden, 1970). The recorded stratigraphic ranges of *Eriphylopsis* and *Disparilia* (Moore, 1969) are obviously too limited, owing to inadequate taxonomic knowledge, especially for Tertiary material. *Eriphylopsis*, e.g.,is probably represented by *Astarte trigonula* from the Paleocene of Copenhagen (Ravn, 1939). There remain as significant Mesozoic elements: *Inoceramus*, *Myoconcha*, *Neithea*, *Granocardium* and *Placunopsis*, all being Mesozoic also at family level.

New records for the Mesozoic are: *Poroleda*, *Acar*, *Bathyarca*, *Pseudogrammatodon*, *Arcopsis*, *Dacrydium*, *Sita*, *Crassinella*, *Glossus*, *Halenympha* and *Verticordia*; except for *Crassinella*, all are well defined genera. Especially important are the occurrence of *Acar* and *Arcopsis*, two genera widely distributed and relatively abundant in Cenozoic deposits. It is worth mentioning that *Acar* already appears in a Lower Maastrichtian hardground in Møns Klint. Two lucinids are tentatively referred to *Loripes* and *Lucinoma*, genera ranging from Oligocene to recent time. The species referred to *'Protocardia'* is an intermediate between the Mesozoic genus *Protocardia* and the Cenozoic genus *Nemocardium*, thus illustrating the danger of circular argument by referring a species to a certain genus not only because of morphology, but also under the impact of the stratigraphic distribution of the species.


Trias
Jur.
Cret.
*
Dan.
Pal.
Eoc.
Olig.
Mio.
Plio.
Rec.
Nucula
Malletia
Poroleda
Arca (A)
Barbatia
Acar
Bathyarca
Catella
Pseudogrammatodon
Arcopsis
Limopsis
Glycymeris
Brachydontes
Dacrydium
Pinna
Pteria
Inoceramus
Neithea
Spondylus
Dimyodon
Placunopsis
Anomia
Lima
Pycnodonte
Ostrea
Lopha
Loripes?
Lucinoma?
Chama?
Myoconcha
Vetericardiella
Sita
Eriphylopsis
Disparilia
Crassatella
Crassinella
Granocardium
'Protocardia'
Glossus
Corbulamella
Gyropleura
Pholadomya
Cuspidaria
Halonympha
Verticordia
4
2
3
2
1
2
5

3) High level suspension feeders (Turpaeva's group 'filter B' either byssate (e.g. *Limopsis*) or cemented (e.g. *Dimyodon*) epifauna.

4) Carnivores, exclusively septibranchs.

The individual behaviour of these ecological groups is of great significance to the elucidation of the extinction process. Disappearance of whole groups will indicate the operation of an extrabiological process, whereas extinction of only restricted numbers of several groups would indicate that the reason lies in community evolution, involving successional (evolutionary) shifts, where new species replace old. It is clear from Fig. 2 that the boundary was crossed by representatives of the whole ecological spectrum. The fact that all the genera that became extinct were filter feeders cannot lead to the conclusion that filter feeders were affected more severely than other ecological groups, since the majority of genera that crossed the boundary were filter feeders themselves.

The deposit feeding genera are the modern representatives of a very old mode of life among bivalves. In contrast, the carnivores represent a pioneering stage in bivalve history, dating back to the Jurassic, but with their major radiation in the Cenozoic.

In general, the Maastrichtian material contains representatives of all the important niches occupied by bivalves through the Cenozoic. It is noteworthy that within an advanced group like the carnivores a profound radiation took place prior to the Cretaceous/Tertiary event as exemplified by the presence of 7 coexisting species belonging to the genus *Cuspidaria*.

AGE OF THE GENERA

Not surprisingly it is seen that the genera that die out are relatively older than many of the genera that cross the boundary. Among the 34 genera that cross the boundary, 17 are new and 17 old. Of the 17 new, 5 originated in the Upper Cretaceous and 12 even within the Upper Maastrichtian. 8 old genera as opposed to 2 new die out at the boundary. It can thus be concluded that new genera present in the Upper Maastrichtian have a longer future than older ones. This conclusion supports the normal course of evolution, in constrast to the 'catastrophic' theories that underlie many interpretations of the events of the boundary.

Fig. 2. Distribution of genera according to ecological groups and time-range classes. A: aragonitic forms, X: genera restricted to the hardground in the Mesozoic part of their range.

	DEPOSIT FEEDERS	FILTER A	FILTER B	CARNIVORES
U.Cret.(U.Maastr.=X) to Recent New genera passing the boundary	*Nucula* A *Malletia* A *Poroleda* XA	*Bathyarca* XA *Dacrydium* XA *Sita* XA *Eriphylopsis* A *Crassatella* A *Crassinella* XA *Glossus* XA *Loripes?* A *Lucinoma?* A	*Arca* A *Acar* XA *Pseudogrammatodon* XA *Arcopsis* XA (*Chama?* X)	*Halonympha* XA *Verticordia* XA
Mesozoic (Palaeozoic) to Recent Old genera passing the boundary		*Glycymeris* A *Limopsis* A *Brachydontes* *Pinna* *Spondylus* *Anomia* '*Protocardia*' A *Pholadomya* *Pycnodonte* *Ostrea*	*Barbatia* A *Limopsis* A *Pteria* *Lima* *Lopha*	*Cuspidaria* A
Mesozoic (Palaeozoic) Old genera becoming extinct		*Inoceramus* *Neithea* *Granocardium* A *Disparilia* A	*Myoconcha* A *Dimyodon* *Placunopsis* *Gyropleura*	
U. Maastrichtian New genera becoming extinct		*Corbulamella* A *Vetericardiella* A		

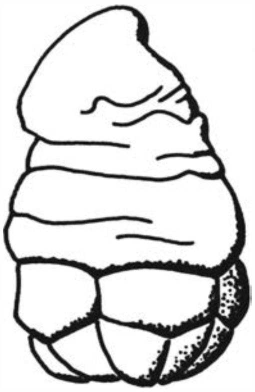
MINERALOGY

All 17 of the new genera that cross the boundary are aragonitic (Fig. 2). Among the 17 old genera that cross, only 7 are aragonitic, and among 8 genera that become extinct at the boundary only 3 are aragonitic (the range of one is doubtful). The apparently drastic faunal change in bivalves at the boundary (e.g. Rosenkrantz, 1966) may be explained, therefore, largely by this mineralogical distribution and the different preservation potential of the minerals.

Within the North European region aragonitic fossils are far better preserved in Tertiary rocks than in Cretaceous. This is mainly due to the lithology and diagenesis of the rocks. The Maastrichtian is dominated by chalk from which aragonite was lost soon after burial (Håkansson *et al.*, 1974; Bromley, this volume).

Evidence taken exclusively from the chalk facies has led to the 'catastrophic' view of the faunal change, the old fauna disappearing before the appearance of the new. Thanks to the early diagenetic hardening of the last 20 cm of the Mesozoic chalk this picture is now totally changed, showing a rich 'Tertiary' fauna living together with the last representatives of ammonites, inoceramids, myoconchids and mosasaurs.

In evolutionary perspective it is important to note that all the new taxa were already present as important members of a complex fauna before the faunal break at the Cretaceous/Tertiary boundary, occurring together with the taxa that were to die out at the boundary. In the case of the bivalves, therefore, there is no need to incorporate drastic external selective mechanisms in order to explain the extinctions. Adjustments within the ecosystem, caused by the development and introduction of novelties, were sufficient for the elimination of a few older and apparently adaptively inflexible taxa.



CRINOIDS, ASTEROIDS AND OPHIUROIDS IN RELATION TO THE BOUNDARY

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Fossil echinoderms were given considerable importance by Desor (1847) among his arguments for establishing the Danian as the uppermost stage of the Cretaceous System. They have continued to be emphasized during later discussions on the Cretaceous/Tertiary boundary and the affinities of the Danian. According to Nielsen (1919), the crinoid *Cyathidium holopus*, together with the Stylasterida, formed a modern element not belonging to a Mesozoic fauna. On the other hand, Ravn (1925) considered the Danian echinoderms to form a distinctly Cretaceous element of the fauna.

Today such argument will hardly be considered relevant, and there is no accepted codex on the fixation or change of a stratigraphic boundary. But we may still ask: How is the Cretaceous/Tertiary boundary reflected in the evolution and distribution of echinoderms? This question may be illustrated by Table 1-3, showing the fossil record of all genera of crinoids, asteroids and ophiuroids found in the Maastrichtian, Danian and Paleogene as well as genera presumed to have been there since they are recorded on both sides of this interval.

When the genera of crinoids and asteroids are considered (Table 1-2), it is quite obvious that the Maastrichtian/Danian boundary is of minor influence to this echinoderm fauna. The echinoderms form a very common faunal element on both sides of this boundary, and virtually all genera found in the Maastrichtian are represented by closely allied species in the Danian. On the other hand the Danian/Selandian boundary is distinctly reflected in the evolution and distribution of these echinoderms. The rich fauna of echinoderms is abruptly terminated at the Danian/Selandian boundary, not only in northern Europe, but universally. There are a few, uncertain survivors in the Selandian of Denmark, but they may well be redeposited Danian specimens. A unique locality where several Danian survivors, including some echinoderms, are found is the Vincentown formation in New Jersey, which has been

Table 1

Crinoid genera

xx = present
pp = presumed
vv = only Vincentown

	Pre-Maastr.	Maastrichtian	Danian	Paleogene	Neogene	Recent
Austinocrinus	xx	xx				
Jaekelometra	xx	xx	xx			
Amphorometra	xx	xx	xx			
Placometra	xx	xx	xx			
Nielsenicrinus	xx	xx	xx	pp		
Semiometra	xx	xx	pp	xx		
Bourgueticrinus	xx	xx	xx	vv		
Cyathidium	xx	xx	xx	pp	xx	xx
Chladocrinus	xx	pp	pp	xx	pp	xx
Isocrinus	xx					xx
Monachocrinus	pp	xx	xx	pp	pp	xx
Dunnicrinus		xx				
Doreckicrinus		xx	xx			
Isselicrinus		xx	xx	xx	xx	
Hertha		xx	xx	pp	xx	
Democrinus		xx	xx	xx	pp	xx
Metacrinus		pp	pp	xx	pp	xx
Bruennichometra			xx			
Bathycrinus			xx	pp	pp	xx
Cainocrinus				xx		
Vicetiametra				xx		
Microcrinus				xx		
Conocrinus				xx	xx	
Discometra				xx	xx	
Conometra				xx	xx	
Palaeantodon				xx	xx	
Himerometra				xx	pp	xx
Nemaster				xx	pp	xx

Table 2

Asteroid genera

xx = present
pp = presumed
vv = only Vincentown

	Pre-Maastr.	Maastrichtian	Danian	Paleogene	Neogene	Recent
Arthraster	xx	xx				
Metopaster	xx	xx	xx			
Aspidaster	xx	xx	xx			
Chomataster	xx	xx	xx			
Valettaster	xx	xx	xx			
Stauranderaster	xx	xx	xx	xx		
Coulonia	xx	pp	pp	xx		
Lophidiaster	xx	xx	xx	xx	xx	
Pycinaster	xx	xx	xx	xx	xx	
Ophryaster	xx	xx	pp	pp	xx	
Teichaster	xx	xx	xx	xx	xx	
Astropecten	xx	xx	xx	xx	xx	xx
Calliderma	xx	pp	pp	xx	pp	xx
Hippasteria	xx	pp	pp	xx	pp	xx
Paragonaster	xx	pp	pp	pp	xx	xx
Henricia	xx	pp	pp	pp	pp	xx
Sphaerodiscus	xx	pp	pp	pp	pp	xx
Linckia	xx	pp	pp	pp	pp	xx
Solaster	xx	pp	pp	pp	pp	xx
Odontaster	xx	pp	pp	pp	pp	xx
Asterias	xx	pp	pp	pp	pp	xx
Benthopecten	pp	pp	pp	pp	pp	xx
Recurvaster		xx	xx	vv		
Ceramaster		xx	xx	xx	pp	xx
Pseudarchaster				xx	xx	xx
Echinaster				xx	pp	xx

Table 3

Ophiuroid genera

xx = present
pp = presumed
vv = only Vincentown

	Pre-Maastr.	Maastrichtian	Danian	Paleogene	Neogene	Recent
Ophiura	xx	xx	xx	xx	xx	xx
Amphiura	xx	xx	xx	xx	xx	xx
Ophiomusium	xx	xx	xx	xx	pp	xx
Ophiacantha	xx	xx	xx	pp	pp	xx
Ophiocten	xx	pp	pp	pp	xx	xx
Ophiolepis	xx	pp	pp	pp	xx	xx
Ophiotrix	xx	pp	pp	pp	xx	xx
Ophiocoma	xx	pp	pp	xx	xx	xx
Ophiopeza	xx	pp	pp	pp	pp	xx
Nullamphiura	xx	pp	pp	pp	pp	xx
Hemieuryale	xx	pp	pp	pp	pp	xx
Asteronyx		xx	xx	pp	pp	xx
Amphiophiura				xx	xx	xx
Stegophiura				xx	pp	xx

recorded as Upper Paleocene or Landenian (Loeblich & Tappan 1957). Several new genera, mainly Comatulida, are found as uncommon Tertiary fossils scattered in southern parts of Europe and in a few North American localities, but they never again became a common element in the fossil fauna. It is very natural, therefore, that in 1846 Desor, the prominent echinoderm specialist, classified the new stage, the Danian, as the uppermost Cretaceous. The post-Danian boundary is reflected in the echinoderm fauna in a similar way as the post-Maastrichtian boundary is reflected in the cephalopod fauna.

It is also seen (Table 3) that all the ophiuroids are recorded under the name of recent genera, and that no evolution of ophiuroids is reflected. This does not prove a very close relationship to modern ophiuroids, but is simply due to the fact that a reliable determination of genus is seldom possible on the basis of the few Cretaceous and Tertiary fragments of ophiuroids preserved. The empty spaces in this table are due to the very few records, some of them based on a single fossil fragment. The false or failing conclusions from this table may be a reminder for those geologists who consider a correct determination of fossil genera to be of no importance in stratigraphy.

Table 4

Crinoid species in Denmark

xx = present in Denmark
?? = uncertain or redeposited
oo = not in Denmark

	Pre-Maastr.	Lower Maastr.	Upper Maastr.	Lower Danian	Middle Danian	Upper Danian	Post-Danian
Austinocrinus bicoronatus	x	x					
Bourgueticrinus brydonei	oo		xx				
Democrinus dubius	xx		xx				
Placometra laticirra	oo	oo		xx		xx	
Nielsenicrinus agassizii		xx					
Bourgueticrinus tenuis		xx					
Hertha pygmaea		xx					
Isselicrinus buchii		xx	xx				
Isselicrinus stelliferus		xx	xx				
Isocrinus lanceolatus		xx	xx				
Bourgueticrinus constrictus		xx	xx				
Bourgueticrinus hagenowi		xx	xx				
Amphorometra conoidea		xx	xx				
Hertha plana		xx	xx	xx	xx	xx	
Hertha mystica		xx		xx	xx	xx	
Democrinus gisleni		xx	xx			xx	
Bourgueticrinus bruennichinielseni		xx	xx	xx		xx	oo
Nielsenicrinus rosenkrantzi			xx				
Monachocrinus regnelli			xx	xx	xx	xx	
Cyathidium holopus			oo		xx		oo
Dorockicrinus miliaris				xx			
Bruennichometra parvicava				xx			
Doreckicrinus convexus				xx	xx	xx	
Nielsenicrinus fionicus				xx	xx	xx	
Isocrinus divergens				xx	xx	xx	
Isocrinus echinatus				xx	xx	xx	
Amphorometra semiglobularis				xx	xx	xx	
Isocrinus campanularis				xx		xx	
Bathycrinus windi				xx		xx	
Isselicrinus paucicirrhus				xx	xx	xx	??
Bourgueticrinus danicus				xx	xx	xx	??
Democrinus maximus				xx	xx	xx	??
Jaekelometra faxensis					xx		
Bruennichometra danica					xx		
Amphorometra bruennichi					xx	xx	
Bruennichometra granulata					xx	xx	
Isocrinus longus						xx	
Nielsenicrinus obsoletus						xx	??

Table 5

Asteroid species in Denmark

xx = present in Denmark
?? = uncertain or redeposited
oo = not in Denmark

	Pre-Maastr.	Lower Maastr.	Upper Maastr.	Lower Danian	Middle Danian	Upper Danian	Post-Danian
Metopaster tumidus		xx					
Chomataster spenceri		xx					
Ophryaster magnus		xx					
Pycinaster rasmusseni		xx					
Metopaster undulatus		xx	xx				
Recurvaster radiatus		xx	xx				
Teichaster favosus		xx	xx				
Chomataster wrighti		xx	xx				
Stauranderaster mixtus		xx	xx				
Lophidiaster pygmaeus		xx	xx				
Chomataster acules		xx	xx	xx	xx	xx	
Valettaster ocellatus		xx	xx	xx	xx	xx	
Metopaster poulseni			xx				
Metopaster laevis			xx				
Pycinaster crassus			xx				
Metopaster kagstrupensis				xx			
Metopaster spenceri				xx			
Teichaster anchylus				xx			
Stauranderaster pyramidalis				xx	xx		
Metopaster planus				xx	xx	xx	
Stauranderaster miliaris				xx	xx	xx	
Stauranderaster speculum				xx	xx	xx	
Lophidiaster punctatus				xx	xx	xx	
Valettaster granulatus				xx	xx	xx	
Recurvaster mammilatus				xx	xx	xx	oo
Metopaster elevatus					xx		
Metopaster maculatus					xx		
Ceramaster granulatus					xx		
Teichaster retiformis					xx	xx	
Pycinaster danicus					xx	xx	
Pycinaster cornutus						xx	
Metopaster carinatus						xx	
Ceramaster dividuus						xx	
Pycinaster rosenkrantzi						xx	
Astropecten postornatus						xx	

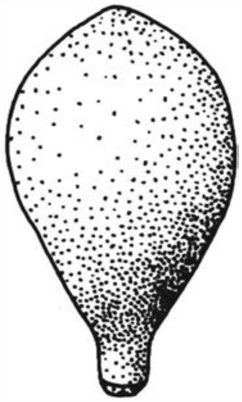
Table 6

Ophiuroid species in Denmark

xx = present in Denmark
?? = uncertain or redeposited
oo = not in Denmark

	Pre-Maastr.	Lower Maastr.	Upper Maastr.	Lower Danian	Middle Danian	Upper Danian	Post-Danian
Ophiura substriata		xx					
Ophiomusium subcylindricum		xx	xx				
Asteronyx ornatus		xx	xx				
Ophiura hagenowi		xx	xx	xx			
Ophiura serrata		xx	xx	xx	xx	xx	
Ophiacantha danica		xx		xx	xx	xx	
Amphiura senonensis		xx	xx	xx		xx	oo
Ophiomusium danicum						xx	oo

Echinoderms have been used as index fossils in the biostratigraphic subdivision of the Danian, and to some degree in the Maastrichtian. (Nielsen, 1937; Rosenkrantz, 1937; Rasmussen, 1950, 1961, 1965). They are common fossils in almost all facies and localities of the Maastrichtian and Danian in Denmark and this, combined with their restricted stratigraphic distribution and easy distinction, makes them useful in a subdivision of the Maastrichtian in two biozones and the Danian in three or four biozones. Table 4-6 show the fossil record of all species of crinoids, asteroids and ophiuroids found in the Maastrichtian and Danian of Denmark, arranged according to their first appearance.



REMARKS ON THE REGULAR ECHINOIDS IN THE UPPER MAASTRICHTIAN AND LOWER DANIAN OF DENMARK

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Our knowledge of the regular echinoids in the Maastrichtian and Danian deposits of Denmark is much in need of revision. The last comprehensive monograph is now 51 years old (Ravn, 1928). Since then, work on the regular echinoids of the Maastrichtian and Danian of Denmark (and Sweden) has mainly been concentrated on the species of *Tylocidaris* in the Danian. Among these studies should be mentioned Brotzen (1959) on the evolution of *Tylocidaris* species in the Danian of Limhamn (Southern Sweden) and the works by Nielsen (1938) and Wind (1953, 1954). A preliminary, annotated list by S. Bo Andersen (1973, unpublished) of the regular echinoids of the Danish Maastrichtian represents the latest survey of this animal group in the Danish white chalk.

According to our present knowledge the following regular echinoids seem to be frequent in the Danish Upper Maastrichtian:

Species of *Stereocidaris* belonging to the group of *S. pistillum* and
S. hagenowi (including *S. bolli*)
Typocidaris subvesiculosa (= *Stereocidaris subvesiculosa)*
Tylocidaris baltica
Phymosoma spp.
Gauthieria pseudoradiata

To these can be added the rare (or very rare):

Stereocidaris faujasi
Temnocidaris sp. (referred to *T. danica* by S. Bo Andersen, 1973)
Araeosoma mortenseni
Asthenosoma (?) striatissimum
Salenia pygmaea and *S. scutigera*
Salenidia anthophora

To the fauna of the Danish Maastrichtian (and Danian) can further be added the genus *Palaeodiadema* which is being studied at present (S. Bo Andersen, pers.comm.).

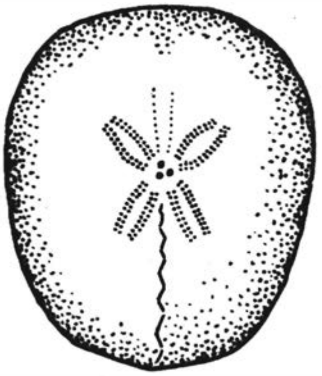
Contrasting the regular echinoid fauna of the Upper Maastrichtian with that of the lower Danian, only conditions in Eastern Denmark (Sjælland) are so far reasonably well known. Ødum (1926) presented information on many lower Danian localities in Western Denmark (Jylland), but before our picture of the regular echinoids in the lower Danian of Jylland is complete, we need two things: 1) a taxonomical revision of the Jylland material and 2) a detailed analysis of faunal composition versus facies.

Looking at conditions on Sjælland, the Fish clay in Stevns Klint contains locally many remains of regular echinoids, no doubt all of them redeposited from the upper Maastrichtian. The same is found in the Fish clay at Karlstrup (Kagstrup), also in Eastern Sjælland. In the Cerithium limestone in Stevns Klint regular echinoids are rare or absent. In contrast, the lower Danian bryozoan limestone on top of the Cerithium limestone is rich in regular echinoids, the most frequent of these being:

species of *Tylocidaris* (mainly the two zonal fossils *T. oedumi* and *T. abildgaardi*
Typocidaris rosenkrantzi
Typocidaris danica
Temnocidaris danica
Phymosoma sp. (or spp.)

Less frequently found is a species of *Salenia/Salenidia*. This faunal assemblage is found in Stevns Klint and Karlstrup.

Judging the change in the fauna of regular echinoids at the Maastrichtian/Danian boundary in Denmark it would seem from the information so far available that this is mainly a change at the species level, whereas the genera seem to cross the boundary rather unaffected. It remains for future work to assess the validity of this picture.



THE IRREGULAR ECHINOIDS AND THE BOUNDARY IN DENMARK

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No serious attempt has been made since Ravn (1927) to redescribe the echinoid fauna around the Maastrichtian/Danian boundary of Denmark. Possible exceptions are Wind (1953, 1954, 1959), who threw some light on stratigraphic distribution on the basis of localities in Jylland, and Kongiel (1949), who discussed the Danian species of *Echinocorys* of Denmark and Sweden.

The genus and species names are in need of revision and where the author is in doubt the names are placed in quotation marks. The holectypoids from the Maastrichtian were identified by S. Bo Andersen (unpubl. report and pers. comm.).

The zonation of the Danian used in the figures is according to Hansen (1977) who demonstrated that the dinoflagellates provide a more accurate zonation of the Danian than the traditionally used *Tylocidaris* species, which are more dependant on facies.

The distribution of the irregular echinoid taxa around the Maastrichtian/Danian boundary reflects (1) change in facies and (2) the introduction of 'modern' deep burrowing echinoids.

It should be noted that the northwestern outcrops in Jylland have been no less well investigated for echinoids than the rest of Denmark. However, the general impression is that echinoids in that region are very scarce in the chalk boundary layers (Rosenkrantz, 1924; Ødum, 1926).

Epibenthic holectypoids (*Galerites* and *Conulus* spp.) flourished in the top metres of chalk at Stevns Klint and Karlstrup, whereas they are not known from the localities in northern Jylland. They disappear at the boundary and first reappear in the middle Danian with patchy distributions of *Globator* spp. in the marginal part of the basin.

Cassiduloids are not found in the Maastrichtian and first turn up in the marginal facies of the middle and upper Danian.

Clypeasteroids are entirely lacking, although the coarser sediments of the marginal areas of the upper Danian would appear to represent favourable environments for this group. However, this was a very new group in the Paleocene, where it still had a highly restricted distribution (Tethys).

Among the ploughing to shallow-burrowing holasteroids, the ubiquitous shallow-ploughing *Echinocorys* spp. seemed unaffected by changes in facies, whereas the burrowing *Cardiaster*, *Cardiotaxis* and *Tholaster* spp. disappeared at the Maastrichtian/Danian boundary. *Hagenowia elongata* died out earlier in the Upper Maastrichtian.

No spatangoids so far have been described from the Maastrichtian of Denmark. This is surprising, since the chalk facies would appear to be suitable for *Micraster* spp. and this genus occurs in Poland in the Maastrichtian and Danian according to Kongiel (1935, 1950) and Kongiel & Matwiejewówna (1937). In the chalk of the lower Danian, however, brissids appear suddenly, represented first by *Cyclaster bruennichi*, then by *C. danicus*. These are the first forms to possess a peripetalous fasciole, better equipping them for a totally burrowing mode of life in a fine grained sediment (Asgaard, 1976). Deeply borrowing schizasterids make their first appearance in the upper Danian calcarenites.

Fig. 1. Distribution of irregular echinoids in the uppermost Maastrichtian and the Danian of Denmark. NW part of the Danish Basin. c: chalk, ca: calcarenites and calcirudites, b: bryozoan limestone, locally with coral limestone, m: marl. The thin horizontal lines are dinoflagellate zones (modified after Hansen, 1977).

Fig. 2. Distribution of irregular echinoids in the uppermost Maastrichtian and the Danian of Denmark. SE (marginal) part of the Danish Basin. c: chalk, ca: calcarenites and calcirudites, b: bryozoan limestone, locally with coral limestone, m: marl. The thin horizontal lines are dinoflagellate zones (modified after Hansen, 1977).

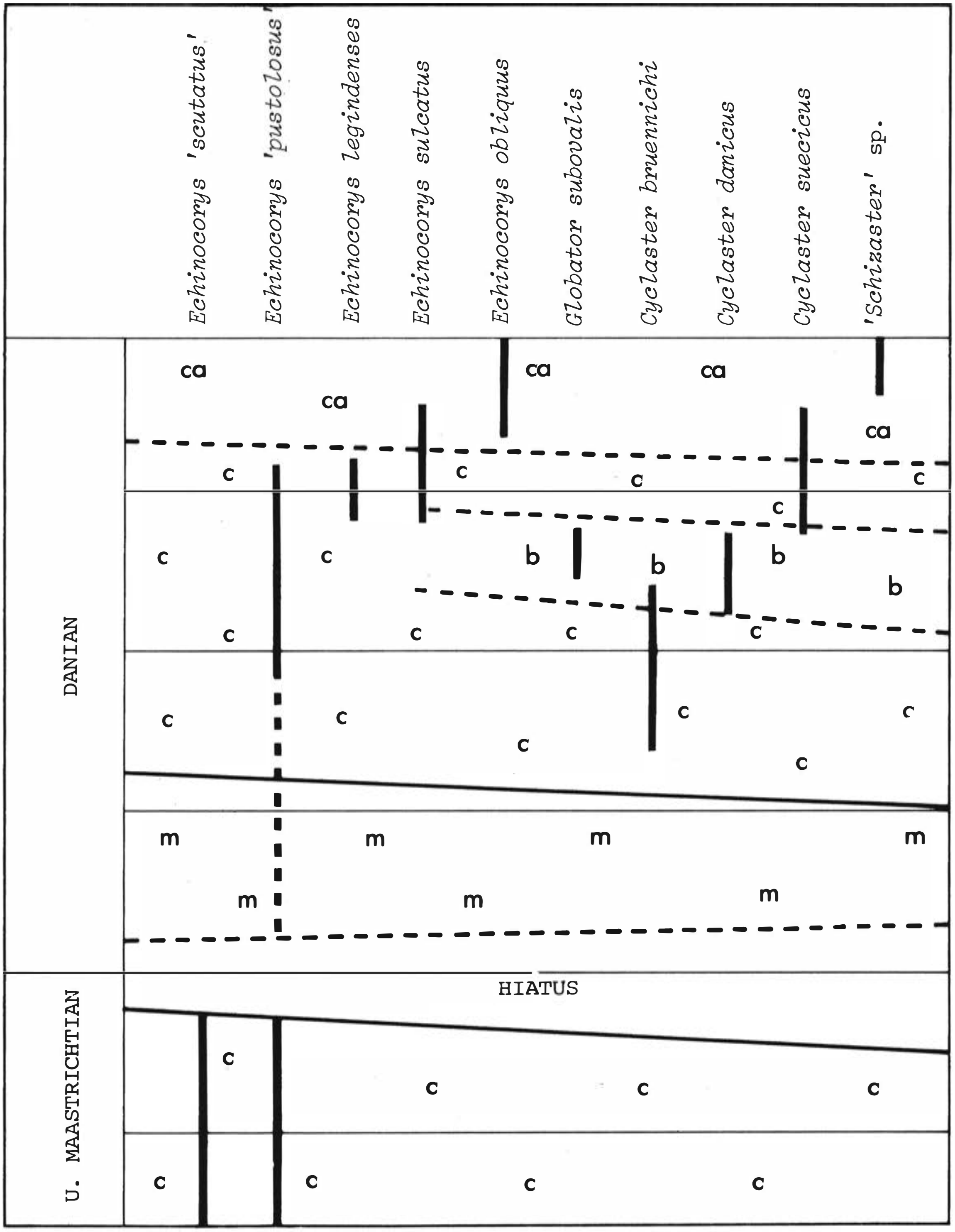
Echinocorys 'scutatus'
Echinocorys 'pustolosus'
Echinocorys legindenses
Echinocorys sulcatus
Echinocorys obliquus
Globator subovalis
Cyclaster bruennichi
Cyclaster danicus
Cyclaster suecicus
'Schizaster' sp.
DANIAN
U. MAASTRICHTIAN
HIATUS
ca
c
b
m

Fig. 1.

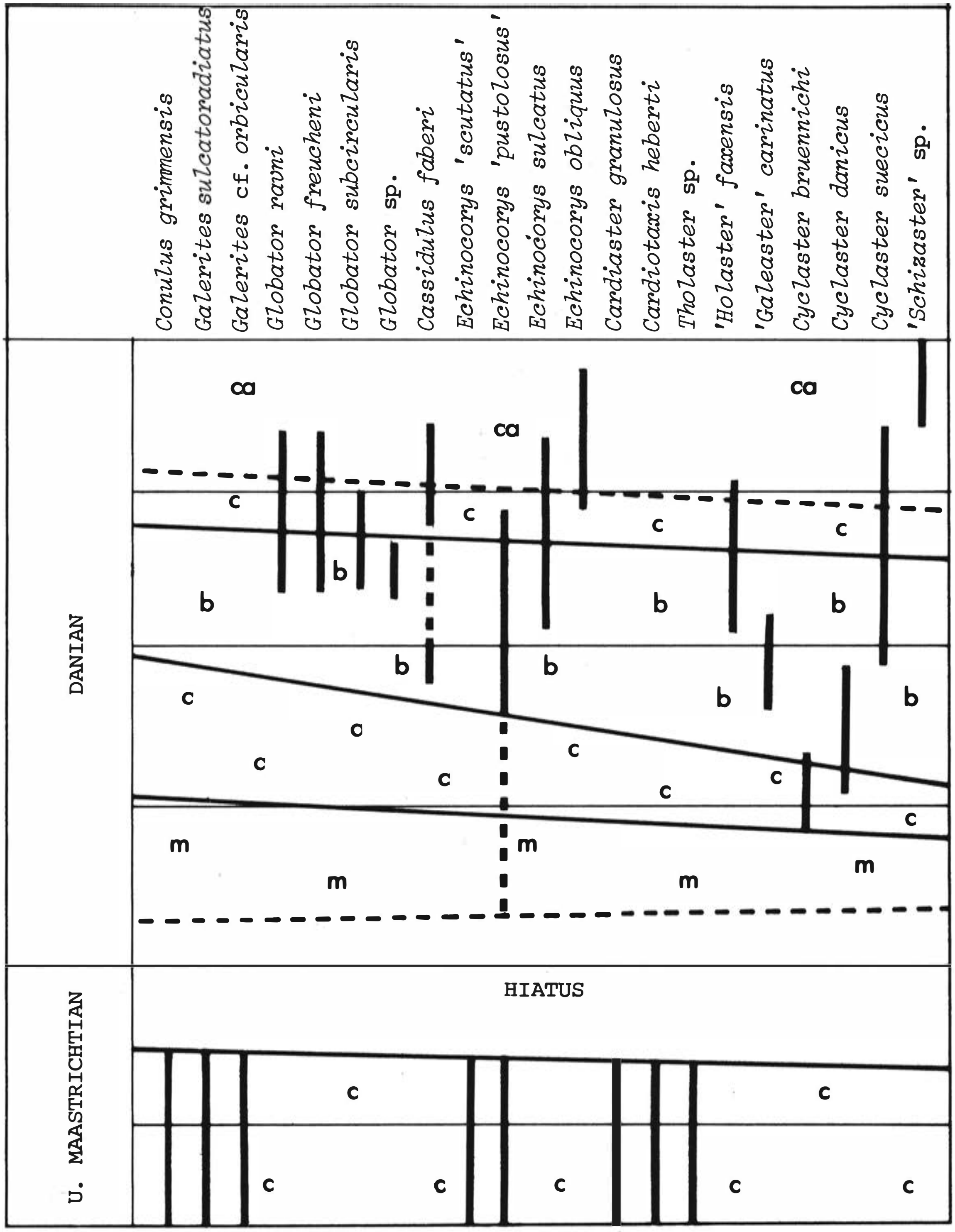
Conulus grimmensis
Galerites sulcatoradiatus
Galerites cf. orbicularis
Globator ravni
Globator freucheni
Globator subcircularis
Globator sp.
Cassidulus faberi
Echinocorys 'scutatus'
Echinocorys 'pustolosus'
Echinocorys sulcatus
Echinocorys obliquus
Cardiaster granulosus
Cardiotaxis heberti
Tholaster sp.
'Holaster' faxensis
'Galeaster' carinatus
Cyclaster bruennichi
Cyclaster danicus
Cyclaster suecicus
'Schizaster' sp.
DANIAN
U. MAASTRICHTIAN
HIATUS
ca
c
b
m

Fig. 2.

DISTRIBUTION AND TYPES OF BRYOZOAN COMMUNITIES AT THE BOUNDARY IN DENMARK

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In most Maastrichtian and Danian sediments in the North Sea region, bryozoans constitute the dominant macrofossil group both in terms of density and diversity (Berthelsen, 1962; Cheetham, 1971; Håkansson *et al.*, 1974) totalling well over 500 species in Denmark. The region was part of the western European sea which undoubtedly constituted the most significant centre of bryozoan evolution during late Cretaceous and Danian times. The development of the bryozoan fauna in the region during the Cretaceous/Tertiary boundary event may therefore be attributed global significance, particularly in view of the very short hiatus recorded at the boundary in most of the Danish Basin (Hansen, 1977, 1979; Håkansson & Hansen, this volume).

The immense bryozoan fauna of the Maastrichtian and Danian of this region has attracted the attention of several authors through the last 140 years, resulting in a number of impressive monographs (e.g. Pergens & Meunier, 1886; Marsson, 1887; Levinsen, 1925; Voigt, 1930; Berthelsen, 1962; Brood, 1973). Nevertheless, in spite of these efforts, a noticeable proportion of the fauna remains undescribed and, particularly important in the present context, only a few papers have been devoted to the development across the boundary (Voigt, 1959b, 1960, 1967, 1972). and then only in fairly broad terms. It is evident, however, that the turn-over in the bryozoan fauna at the Maastrichtian/Danian boundary is in no way comparable to the dramatic changes noted in other groups, although it may appear somewhat more noticeable than at the preceeding Upper Cretaceous stage boundaries (Voigt, 1967).

Comparing the Maastrichtian Stage in its entirety with the Danian it becomes evident that virtually no change is recorded at family (or higher) level (Larwood *et al.*, 1967); all developments are confined to low taxonomic levels. Also it appears that the cheilostomes uniformly constitute the more diverse group whereas in the Danian the cyclostomes

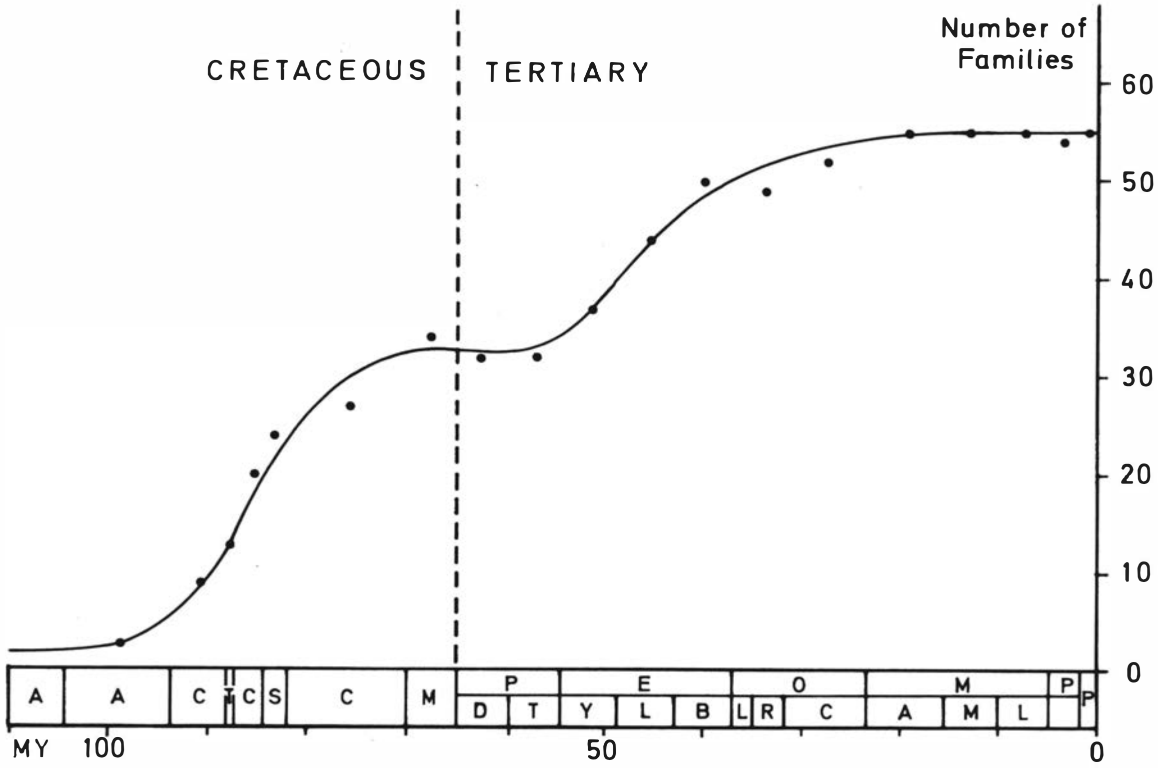


Fig. 1. Rate of evolution in cheilostome bryozoans expressed in number of families per stage. Two major episodes are discernible, and it appears that the Cretaceous/Tertiary boundary event falls within the interjacent plateau. (Modified from Cheetham (1971, fig. 1 with the timescale adjusted according to Obradowich & Cobban (1975) and Berggren (1972)).

commonly show the highest density. However, more detailed considerations are necessary in order to distinguish differences in development patterns in the Cyclostomata and the Cheilostomata (classified in separate bryozoan classes).

Cyclostome bryozoans have an extended geological record reaching back to the Ordovician and in general may be characterized as conservative, having a slow evolutionary rate and a correspondingly low diversity. In accordance with this, the diversity of the cyclostome fauna during the Danian is of the same order as the Maastrichtian diversity, and approximately 75% of the species occur in both faunas (in part based on data from Brood, 1973).

In contrast to this, the cheilostome bryozoans develop from a slow start late in the Jurassic, through their first, rapid radiation in the

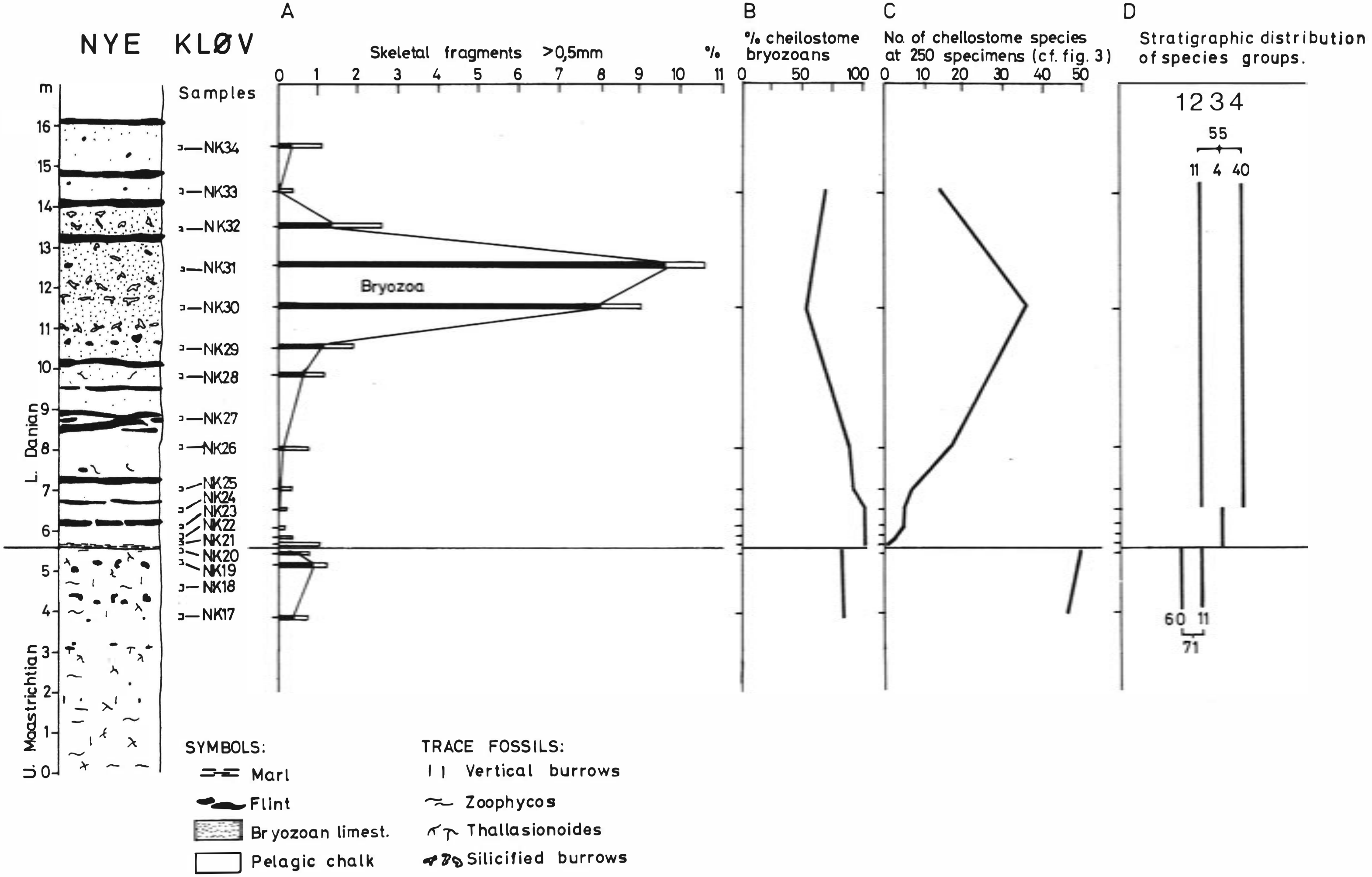
Upper Cretaceous to reach an evolutionary plateau by the end of the Cretaceous (Fig. 1). The Maastrichtian/Danian boundary event is - perhaps merely accidentally - concordant with this evolutionary standstill (Cheetham, 1971), and is totally overshadowed by the spectacular effects of the second major episode in cheilostome evolution (mainly during the Eocene). Boundary-related changes at the specific and generic level are, nevertheless, much more widespread than in the cyclostome fauna. Most readily, this is observed in the significant decrease in the total diversity as well as in community diversities; and, in strong contrast to the cyclostomes, less than 20% of the Maastrichtian cheilostome species survive into the Danian (in part based on data from Voigt (1930) and Berthelsen (1962)).

In spite of their abundance, bryozoans apparently have never been particularly attractive to biostratigraphers working in the Cretaceous and Paleogene, and the few studies that have been made have been on a broad scale (Berthelsen, 1962; Voigt, 1967; Brood, 1973). The obvious potential value, especially of the rapidly evolving cheilostome bryozoans in detailed stratigraphic investigations of the Maastrichtian and Danian, has so far remained largely unexplored. However, comparisons of the stratigraphic occurrence of the free-living cheilostome species in Denmark and northwest Germany indicate this potential to be very promising (Håkansson, 1978), approaching the level of the local brachiopod zonation (Surlyk, 1970).

Though overall comparisons of the Maastrichtian and Danian faunas as those presented above have a general significance, the faunal development through the Cretaceous/Tertiary boundary event in actual sequences is, of course, also of the utmost importance. Investigations of this kind based on bryozoans have not previously been published and we now present the preliminary results of a first attempt. The very detailed picture arising from investigations of actual boundary sequences is evidently influenced significantly by the local environment and, accordingly, is expected to be highly variable. Therefore, in order to maximize the general applicability of such results, understanding of the ecological tolerance of individual species plays a paramount role and, ideally, sequences having a uniform lithology and no depositional breaks should be preferred.

As one of the best approximations to this ideal we have chosen the sequence at the small abandoned chalk pit Nye Kløv as an example.

Fig. 2. Bryozoan faunal properties across the Maastrichtian/Danian boundary at Nye Kløv, based on samples of 1-1.2 kg. (Lithology after Håkansson & Hansen, this volume).


NYE KLØV
A
B
C
D
Skeletal fragments >0,5mm
%
0 1 2 3 4 5 6 7 8 9 10 11
% cheilostome bryozoans
0 50 100
No. of chellostome species at 250 specimens (cf. fig. 3)
0 10 20 30 40 50
Stratigraphic distribution of species groups.
1 2 3 4
55
11 4 40
60 11
71
m
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
L. Danian
U. Maastrichtian
Samples
NK34
NK33
NK32
NK31
NK30
NK29
NK28
NK27
NK26
NK25
NK24
NK23
NK22
NK21
NK20
NK19
NK18
NK17
Bryozoa
SYMBOLS:
Marl
Flint
Bryozoan limest.
Pelagic chalk
TRACE FOSSILS:
Vertical burrows
Zoophycos
Thallasionoides
Silicified burrows

FAUNAL DEVELOPMENT AT NYE KLØV

The lithology at Nye Kløv may be briefly characterized as follows (*cf.* Håkansson & Hansen, this volume): A Maastrichtian white chalk comparatively poor in macrofossils is overlain by a thin Danian marl rapidly changing upwards into a slightly granular chalk which in turn develops gradually into a bryozoan limestone (Fig. 2).

The Maastrichtian part of the section contains about 1% skeletal material > 0.5 mm (Fig. 2A). The material is dominated by bryozoans making up between 50% and 80% of the preserved fauna. Apart from the lowermost sample (NK 21) the Danian pelagic chalk is less fossiliferous than the Maastrichtian, particularly in regard to the amount of bryozoans. Within the first 2 m of the Danian, bryozoans are virtually absent and the fauna here is totally dominated by crinoids belonging to the genus *Bourgueticrinus*. Reworked fossils - distinguishable through a somewhat whitish appearance - are quite common in these levels, but have been excluded from faunal considerations. From approximately 2 m above the boundary the bryozoan content gradually increases, and in the higher parts of the section skeletal fragments constitute up to 10% of the sediment, with bryozoans making up almost 90% of the fauna. Towards the top of the sequence the amount of bryozoans drops again.

Cheilostome bryozoans dominate over cyclostomes throughout the sequence af Nye Kløv (Fig. 2B). This deviation from the general pattern, where cyclostomes typically dominate the Danian fauna, is noteworthy, especially since no cyclostomes at all were found in the four lowermost Danian samples. However, in the bryozoan rich level higher in the sequence, the picture approaches the normal situation with almost 50% cyclostomes.

The Cretaceous/Tertiary boundary is clearly reflected in the diversity index of the cheilostome bryozoans (Figs 2C, 3). The Maastrichtian populations are highly diverse, having a total of some 70 species. In strong contrast to this, the first Danian samples contain an extremely poor fauna comprising only four species; indeed, of these only a single species appears in the lowermost sample (NK 21). Following this extreme reduction, the diversity gradually rises to a maximum of more than 40 species in the bryozoan limestone (NK 30). The populations in the uppermost more pelagic sediments again show lower diversities. Thus, within the Danian part of the sequence, low diversity and low density are correlated as are high diversity and high density. In the Maastrichtian populations, on the other hand, high diversity associated with low density is characteristic. Moreover, in terms of species composition, the two faunas are quite different.

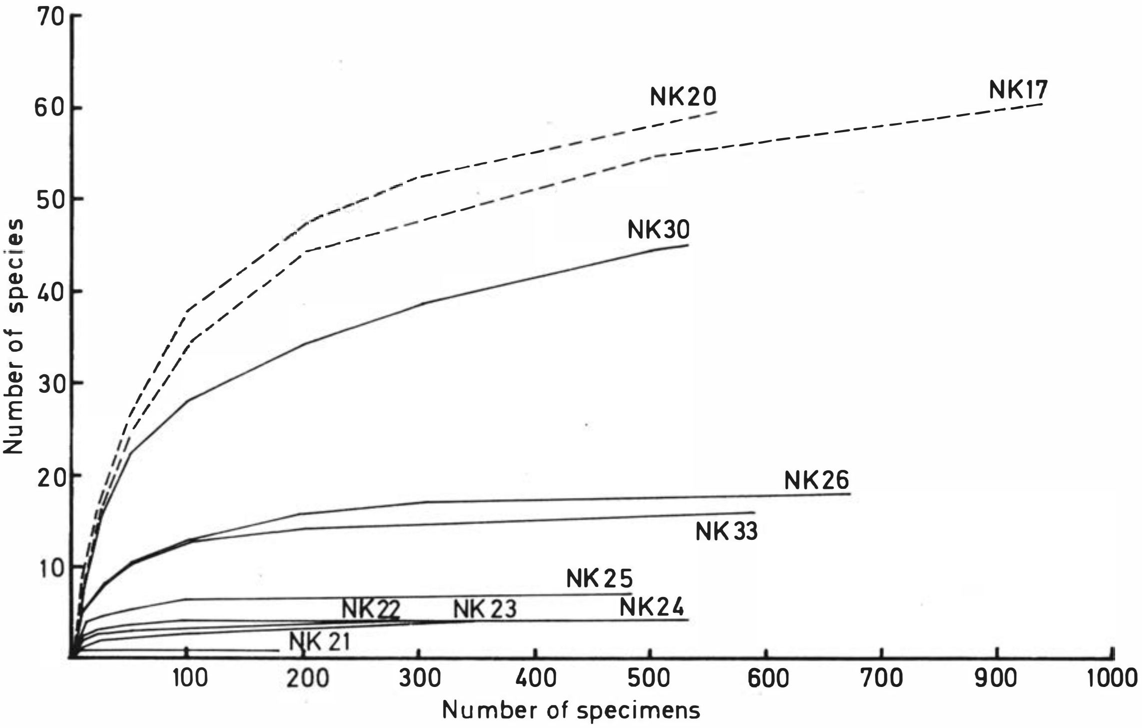


Fig. 3. Species rarefaction curves calculated for populations of cheilostome bryozoans across the Maastrichtian/Danian boundary at Nye Kløv (sample numbers refer to Fig. 2). Dashed lines: Maastrichtian populations; solid lines: Danian populations.

A total of 115 cheilostome species were recognized during the investigation of Nye Kløv. According to their stratigraphic distribution they may be classified into four distinct groups (Fig. 2D): (1) 60 species were recorded only from the Maastrichtian part of the sequence; (2) 11 species were found in both the Maastrichtian and the Danian part of the sequence; (3) 4 species have their main distribution in the lowermost part of the Danian, but also occur sporadically in other parts of the sequence; (4) 40 species were found only in the higher part of the Danian (a few of these occur in the Maastrichtian elsewhere in the basin).

Species showing a group 3 distribution constitute a very characteristic, low diversity bryozoan community which has been recognized immediately on top of the basal Danian marl layer at a number of localities in Jylland. This community appears to be dominated everywhere by free-living and radicelled ('rooted') species, with one free-living species (*Pavolunulites* n.sp.) constituting between 50% and 100% of the bryozoan fauna. It should be stressed that none of the species found in both the Maastrichtian and the Danian part of the sequence at Nye Kløv do in fact occur in this group 3 community; gradually they reappear in the higher, more bryozoan rich parts.

BRYOZOAN COMMUNITIES AND DEPOSITIONAL ENVIRONMENT

The Maastrichtian and Danian rocks of the entire region are uniformly developed in carbonate facies, typically having a significant carbonate mud component (see Bromley, this volume). Near-shore deposits are rare and associated with substantial sedimentary breaks, and are hence of little relevance in context with the detailed development in the boundary event. Basinal conditions, on the other hand, are more likely to preserve a sedimentary record containing negligible hiati in association with this event (Håkansson & Hansen, this volume).

Broadly speaking, bryozoans are, of course, as dependant on the sedimentary environment in which they live as are other benthic invertebrates. However, in the case of the Maastrichtian and Danian sediments in the Danish region the bryozoans themselves have a noticeable impact on this environment as is conspicuously expressed in the widespread bryozoan mounds.

The total range of carbonate environments in the Danish area during Maastrichtian and Danian time is most conveniently classified into two main types, i.e. pelagic chalk and bryozoan limestone, each supporting a number of bryozoan communities. Nevertheless it must be stressed that the two sediment types are merely portions of a continuum ranging from pure pelagic muds containing virtually no benthic skeletal material to limestones containing more than 50% of bryozoans by weight.

Pelagic chalk communities

These are particularly widespread in the Maastrichtian, but occur commonly in the Danian as well. They are associated with mud-supported chalks, dominated by coccoliths and planktic foraminifera and with varying, subordinate amounts of benthic forms (Håkansson *et al.*, 1974; Bromley, this volume). Most often the benthic fauna of pelagic chalk is dominated by bryozoans, but local concentrations of other phyla occur. Great variation is recorded in the composition of the bryozoan communities, with the water/sediment interface consistency and substrate availability as the main determining factors.

A considerable faunal element of the pelagic chalk communities is confined as encrusters to the rare, larger secondary hardbottoms (such as echinoid tests), and is accordingly not necessarily restricted to the chalk environment. Apart from the encrusting forms the chalk communities contain three main growth forms in varying proportions. Rigidly erect, more or less bushy colonies attached by a solid encrusting base constitute the most diverse and commonly the dominant group. On the other hand, flexible erect colonies with chitinous joints and, in particular, free-living colonies may occasionally dominate the fauna - probably as pioneer communities capable of direct colonisation of soft mud (Håkansson, 1974, 1976).

The chalk environment apparently was strongly influenced by changes in connection with the Cretaceous/Tertiary boundary event. While Maastrichtian chalks usually contain highly diverse, albeit thin, bryozoan communities (sample diversity commonly exceeding 100 species), the Danian chalks virtually lack bryozoans and exhibit very low diversities (sample diversity below 10 species).

Bryozoan limestone and bryozoan chalk communities

These communities occur commonly in both the Maastrichtian and the Danian. As noted above, the limit between pelagic chalk and bryozoan limestone is arbitrary in terms of depositional environment, and we do not feel it justified to suggest a definite limit expressed by, for example, bryozoan content. As, moreover, most coarse grains in these rock types are branching bryozoans, it is commonly impossible to establish whether a bryozoan limestone was originally grain-supported or not (*cf.* also Nielsen, 1976). Nevertheless, within the range of facies accepted as bryozoan limestones, both mud-supported and grain-supported types occur, and typically they are composed of coccoliths and planktic foraminifera in addition to substantial amounts of benthic remains (Håkansson *et al.*, 1974; Thomsen, 1976; Bromley, this volume). The benthic faunas in bryozoan limestones contain very little but bryozoans. Rigidly erect, branching colonies attached by a solid base dominate (by weight) in all bryozoan limestone communities, and commonly a certain amount of flexible, erect forms are present as well. A high proportion of the branching colonies support a highly diverse encrusting fauna (Thomsen, 1977b), which may have some resemblance to the encrusting communities of the secondary hardbottoms in pelagic chalk. Free-living bryozoans, on the other hand, play a very limited role in bryozoan limestone communities.

With regard to diversity, the bryozoan limestone communities of the Maastrichtian and Danian are very similar (diversity typically well over 75 species). However, the cyclostomes generally dominate by weight in the Danian communites, whereas they play a more subordinate role in the Maastrichtian communities.

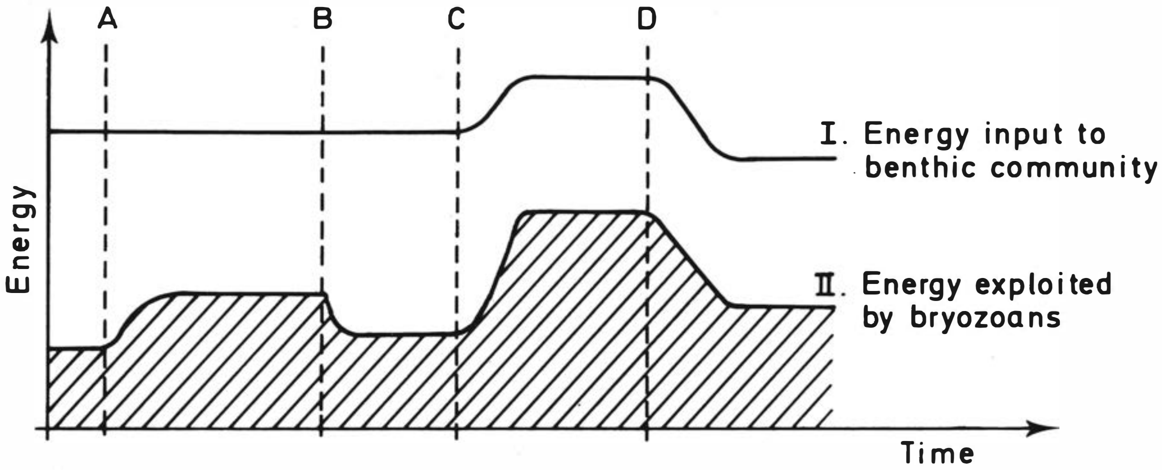


Fig. 4. Bryozoan community fluctuation patterns in a highly accommodated, stable community framework as in the Maastrichtian/Danian period in the Danish region. Upper curve indicates the level of the total energy (food) input to the benthic community, and the lower curve indicates the amount of this energy exploited by bryozoans. To each horizontal portion of the lower curve corresponds a unique bryozoan community, whereas oblique portions of this curve indicate transitional periods with mixed communities or - more precisely - rapid changes through a number of communities. Event A signifies a change in the total environment favouring bryozoan competition (as one likely example a diminishing accumulation of carbonate mud may be mentioned). Event B, on the other hand, signifies a similar change with the adverse effect (as for instance increase in the accumulation of carbonate mud). Events C and D illustrate changes in the amount of food available and possible effects on bryozoan compatibility (see the text for further discussion).

Bryozoan community adjustments

The sediments in the Maastrichtian and Danian of Denmark represent a broad, yet continuous range of environments, and it may be predicted that the gradational series of communities preserved in these sediments will closely follow changes in the environment (Nestler, 1967). As bryozoans are very important constituents of most communities, changes recorded in this part of the fauna, i.e. in the bryozoan communities as outlined above, in many instances may qualify as a sufficient approximation to the total community. Thus, changes recorded in the bryozoan communities may serve as a major tool in unravelling most of the significant changes in the overall environment, in particular as detailed bryozoan biofacies are more easily defined than ordinary sedimentary facies (Håkansson, 1974).

Fundamentally, these benthic communities were in perfect balance with the environment in which they lived and to which they were adapted. Environmental changes thus immediately led to adjustments in the community structure as expressed in both the relative importance of individual species and the species composition. Innumerable factors may be envisaged to have influenced the communities under study. However, in the environment of the Maastrichtian and Danian bottom dwelling communities, gradational changes in the amount of food (energy) and substrate quality or availability may be regarded as basic.

Speculating now that the food supply (energy input) was in general fairly stable through substantial lengths of time in the very stable depositional environment, competition among groups would lead to a very fine balance, i.e. mature, stable communities. Even minor changes in the substrate situation, as in any other basic factor, necessarily will alter the compatibility of the individual groups of organisms in this type of community and, thus, produce changes in their relative importance. This is expressed graphically in Fig. 4, where events A and B signify changes in some basic parameter in a constant food supply situation. In one case (A), bryozoan compatability on the whole is improved, with the result that a larger proportion of the available energy is exploited by bryozoans. Event B, on the other hand, reduces bryozoan compatibility once more and leads to a balance with a somewhat lower bryozoan component.

In bryozoan communities in a depositional regime dominated by pelagic mud, events A and B may illustrate changes in substrate availability, either numerically or perhaps qualitatively. In this depositional regime an important means for increasing the amount of substrate is a decrease in accumulation of pelagic mud. This decrease may result from a reduction in the actual supply owing either to reduced productivity in the pelagic community or to minor increase in calcite dissolution in the water column or on the sea floor.

An important aspect of this process is that even a small increase in the amount of substrate may trigger a self-increasing process based on the fact that most bryozoans utilize other bryozoans as substrate (*cf.* Surlyk & Birkelund, 1977).

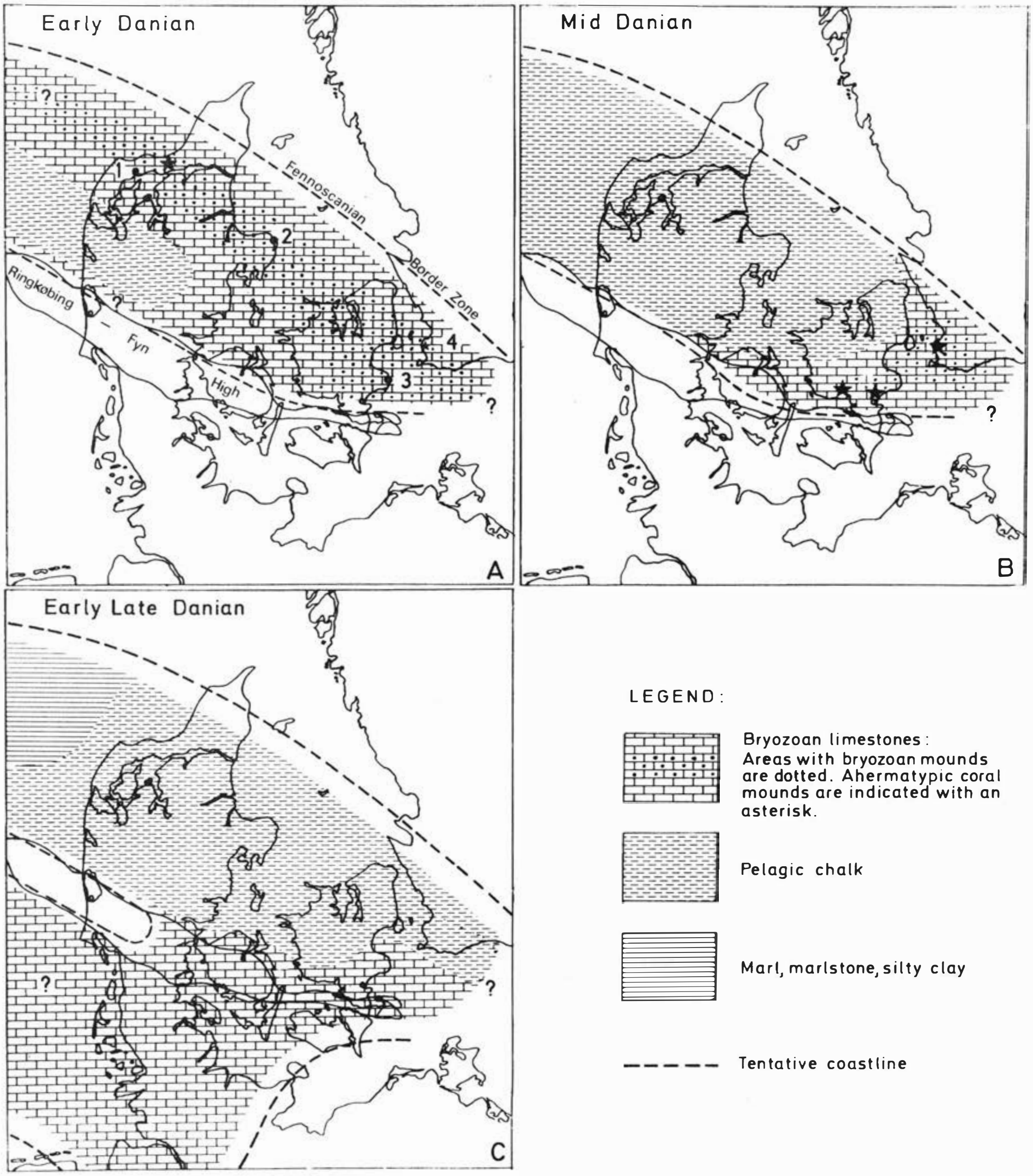
Moving water is another plausible means of reducing mud deposition. More important still, this is likely to increase the amount of food available to the benthic community simply by giving access to larger water masses. If, therefore, event C (Fig. 4) signifies the onset of moving water conditions, it combines the effect of more food (energy) to the community and increased substrate availability, with the probable result that bryozoan growth will be strongly promoted. This chain of events may lead to the overwhelming dominance of bryozoans recorded in some flat-bedded limestones where bryozoans constitute more than 50% (by weight) of the sediment.

Unidirectional water movement in particular is likely to have significantly changed the general environment of the benthic realm. Thus Thomsen (1976) concluded that fairly uniform northwesterly directed currents were the main controlling factor in the development of the lower Danian mounds in Karleby Klint. The proposed model accounts for the strong faunal differences on the upstream and downstream sides of the elongate mounds and suggests that baffling processes in the dense bryozoan cover on the upstream side caused the asymmetrical mound accretion (Thomsen, 1977a).

BRYOZOAN BIOFACIES DISTRIBUTION

The results of Håkansson *et al.* (1974) and Hansen (1977) reveal that changes in the sedimentary environment comparable to those detected through actual sequences occur also along time planes traceable through major parts of the basin. By inference, this is valid also for the range of bryozoan communities associated with these variations, i.e. the bryozoan biofacies distribution. Moreover, it is likely that the entire range of bryozoan communities was present at any one time in the Maastrichtian and Danian within the Danish area - with the possible exception of the period of time represented by the hiatus and the marl layer at the Maastrichtian/Danian boundary. Within a given area, provided that the distribution of community types and the time frame are reasonably well documented, the biofacies distribution may be mapped in some detail.

Fig. 5. Generalized Danian facies distribution. In the late Danian transgression (map C) the bryozoan limestone south of the Ringkøbing-Fyn High is somewhat marly towards the south, and it is not known whether the Danian was originally deposited also on top of the numerous north German salt structures (not shown here). Localities mentioned in the text are marked with numbers (in map A): 1) Nye Kløv, 2) Karleby Klint, 3) Stevns Klint, 4) Limhamn. In addition to extensive field observations data from the following sources have been included: Ødum (1926, 1928), Brotzen (1959), Berthelsen (1962), Sorgenfrei & Buch (1964), Larsen (1965), Rasmussen *et al.* (1971, 1973), Rasmussen (1974, 1978), Thomsen (1974), Dunn (1975), Stenestad (1976), Hansen (1977), and Baldschuhn (in press).


Early Danian
?
1
2
3
4
?
?
Fennoscanian
Border Zone
Ringkobing
Fyn
High
A
Mid Danian
?
B
Early Late Danian
?
?
C
LEGEND:
Bryozoan limestones: Areas with bryozoan mounds are dotted. Ahermatypic coral mounds are indicated with an asterisk.
Pelagic chalk
Marl, marlstone, silty clay
Tentative coastline

Very few levels within the Maastrichtian are represented at more than a few localities, so it is rather unrewarding at present to attempt detailed Maastrichtian facies maps for this region. It is noteworthy, however, that the ultimate Maastrichtian zones have hitherto been found only in the central part of the Danish Basin, i.e. in northern Jylland (*cf.* Håkansson & Hansen, this volume).

From the Danian, the areal coverage is significantly better and fairly reliable facies charts may be constructed (Fig. 5). This sequence of maps shows that early in the Danian, extended areas became covered with dense bryozoan growth (Fig. 5A), perhaps facilitated by extensive hardground development during lowermost Danian time in many areas. The apparent coast-parallel distribution of the mounds suggests that much of the facies distribution was related to depth and, thus, that the northwesterly directed current assumed to be responsible for the mound formation was restricted to a fairly narrow interval of depth. In close agreement with this notion, it is found that halokinetically induced local highs in areas otherwise characterized by pelagic mud deposition commonly are capped by bryozoan limestones (N. Svendsen, pers. comm. 1979).

Deposition of pelagic mud gradually increased in area up through the Danian, and by mid-Danian time bryozoans continued to flourish only along the south eastern margins of the Danish Basin (Fig. 5B). Early in the late Danian, parts of the Ringkøbing-Fyn High as well as large areas to its south were transgressed, probably for the first time since the Cretaceous/Tertiary boundary event (Fig. 5C). Here, bryozoan limestones were deposited, apparently without mound development, and in the Danish Basin pelagic mud totally dominated. Later in the Danian the preparation of subsequent facies maps is prevented by inadequacy of the stratigraphic and distributional data.

The facies distribution through the Danian traditionally has been interpreted to be the result of a general, slow regression lasting throughout the Danian (Ødum, 1926; Rosenkrantz, 1937; Hansen, 1977). However, in view of the probable depth relation of the main facies in the early Danian example (Fig. 5A) and the great extension of the late Danian sea (Fig. 5C) it may be suggested, on the contrary, that a prolonged transgressional phase was only replaced by a regression shortly before the close of the Danian.

In relation to the Danian facies pattern just described, a few notes on the Maastrichtian may be attempted as well. It is conceivable that Maastrichtian bryozoan chalk likewise developed mainly in areas where there were comparatively strong currents within a definite depth interval as, for instance, on the Ringkøbing-Fyn High (Thomsen, 1974) or in the moderately near-shore area around Stevns Klint in eastern

Sjælland. In the latter area, the Maastrichtian bryozoan chalk forms low bryozoan mounds very similar to the Danian mounds (Håkansson, 1971; Surlyk, this volume), and it is interesting to note that this region comprising eastern Sjælland and southwestern Scania is apparantly the location for the most prolonged mound formation (*cf.* Holland & Gabrielson, this volume, and Floris, this volume).

MAASTRICHTIAN AND DANIAN CORALS FROM DENMARK

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Corals are locally rock-building in the Danian deposits (e.g. Fakse Quarry), but they also occur fairly commonly elsewhere in the Danian. In the Maastrichtian white chalk, scleractinian corals are most common in the topmost part, where they profited from the relatively rich benthos, particularly bryozoans, which provided suitable substrates. It can be shown that the scleractinians of this uppermost Maastrichtian fauna are closely related to the Danian scleractinians.

'Hydrocorals'

A rich fauna of 'hydrocorals' (stylasterines and milleporines) occurs in the Danian coral limestone of Fakse (Nielsen, 1919). The occurrence here of the light-dependent *Millepora* has been used as a depth-indicator (Rasmussen, 1973). Rare finds of stylasterines have now also been made in the Maastrichtian.

Octocorals

Octocorals are normally rare in the soft white chalk of the Maastrichtian. Three to four species belonging to the genera *Epiphaxum*, *Isis* and *Moltkia* have been described (Nielsen, 1925a; Ødum 1926; Voigt, 1958). In addition, at least six, partly undescribed species of *Isis*, *Moltkia*, *Gorgonella* and *Graphularia* have now been found.

One of the richest and best known fossil octocoral faunas occurs in the Danian (Steenstrup, 1847; Hennig, 1899; Nielsen, 1913, 1917b, 1925, 1938; Rosenkrantz, 1920; Voigt, 1958). This fauna consists of 12-15 species belonging to the genera *Epiphaxum*, *Gorgonella*, *Graphularia*, *Heliopora*, *Isis*, *Moltkia* and *Primnoa*. (A further species, possibly representing a new genus, is being studied).

The octocorals are most common in bryozoan limestone facies. Locally (mainly in borings in southern Sjælland) the amount of skeleton fragments even indicates the development of thickets or similar structures, in some cases dominated by *Moltkia*. The light-dependent *Heliopora* occurs only in scleractinian coral limestone and has been considered in connection with depth estimates (Floris, 1962, 1971). *Graphularia* is restricted to soft bottoms.

Scleractinian corals

Scleractinians are well known both from the Maastrichtian and the Danian. They have mainly been studied by Beck *in* Lyell (1837), Hennig (1899), Nielsen (1922), Ødum (1926), Rosenkrantz (1939), Rasmussen (1966, 1977) and Floris (1967, 1968, 1972). Studies of the palaeoecology of the scleractinians have mainly concerned the middle Danian corals at Fakse (Floris, 1962, 1967, 1971, 1972, 1975).

In the following list of genera new records are indicated by an asterisk, and records redetermined here are cited in brackets. Only ahermatypic scleractinians have been found.

Genera in the Maastrichtian (representing about 16 species):

Oculina ('Amphihelia')
Caryophyllia *
Coelosmilia
*Dendrophyllia**
Parasmilia
Trochocyathus?

Genera in the Danian (representing about 35 species):

Brachycyathus?
Caryphyllia (incl. *'Ceratotrochus'* and possibly *'Rhizotrochus')*
Cyathoceras
Coelosmilia?
Dendrophyllia
Discotrochus
Faksephyllia
Flabellum
Oculina
Parasmilia (incl. *'Ceratotrochus, 'Epitrochus'* and *'Sphenotrochus')*
*Stenocyathus**
Trochocyathus?

Some of the Maastrichtian scleractinians belong to the wide-spread soft bottom fauna well known from Campanian/Maastrichtian chalk of NW Europe and USSR. The topmost Maastrichtian chalk in Denmark is relatively rich in benthic skeletons (bryozoan chalk facies) and in SE Denmark shows a concomittent increase in numbers of scleractinians. Among these, a species of *Oculina* may even have formed thickets. Remarkable in the Maastrichtian fauna is a very early *Dendrophyllia* sp.

The scleractinians of the Danish Danian show very close relationships to the Danian faunas of Sweden and West Greenland. The fauna was sparse in most localities and almost exclusively represented by solitary forms. Bryozoan limestone facies dominates at these localities. In a few places scleractinians proliferated and formed coral limestone (Aggersborggaard in northern Jylland; Fakse Quarry and borings at Spjelderup and Herlufsholm in southern Sjælland). The frame-building corals seem always to be one or more of the three dendroid species *Dendrophyllia candelabrum* (Hennig, 1899), *Faksephyllia faxoensis* (Beck *in* Lyell, 1837) and *Oculina becki* (Nielsen, 1922).

At present this coral limestone is only exposed in Fakse Quarry, where coral banks lie between bryozoan banks. At this locality only one scleractinian is common to bryozoan and coral limestone, and about 16 are restricted to the coral limestone. In the coral banks all three dendroid species mentioned above were frame-building. Associated corals mainly belong to the genera *Caryophyllia* and *Cyathoceras*.

It is believed that the coral banks of Fakse were formed in a subtropical sea, at a depth averaging about 50 m and with a temperature at the sea floor of probably about 18°. The absence of hermatypic scleractinians may be explained by low water temperature.

The question of modern parallels to the Fakse coral banks has been discussed for a long time. Among contributors are Darwin (*in* Lyell, 1837 - reef), Teichert (1958 - Norwegian banks) and Asgaard (1968 - banks off SW Europe). In a comparison with the Recent banks, Floris (1972) concluded that parallels preferably should be found in the shallowest *Dendrophyllia* banks off Morocco (Gruvel, 1923; 80 m, 15°-16° C) and also in Holocene *Dendrophyllia-Madracis* thickets in the Gulf of Guinea (Allen & Wells, 1962; 40 m, probably 15° - 20° C).

Remarkable in the Danian fauna is the occurrence of a very early *Cyathoceras*, and the *Dendrophyllia* and *Flabellum* are also among the earliest known.

MAASTRICHTIAN OSTRACODS FROM DENMARK

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The ostracod fauna from the Maastrichtian white chalk in Denmark forms an integrated part of the ostracod faunas described from the Upper Cretaceous of north-western European basins, which have been intensively studied within the last decades. Several large monographs have been published, among others by Veen (1932, 1934 - 1936, 1938), Bonnema (1940, 1941), Szczechura (1964, 1965), Deroo (1966) and Herrig (1966).

A thesis on the ostracods from the Maastrichtian white chalk of Denmark was written by the present author (Jørgensen, 1970) and as one of the results of this study two new species were described and a biostratigraphic zonation on basis of ostracods was established (Jørgensen, 1974, 1976, 1978). The ostracods from the Maastrichtian of Denmark show close affinity to the fauna from the Lower Maastrichtian chalk of Rügen, East Germany, described by Herrig (1966). The reader is referred to that paper for detailed taxonomy and synonyms.

FAUNA COMPOSITION AND ECOLOGY

The material studied originates from 20 outcrops or boreholes, 19 Danish and 1 Swedish, which fairly well represent the Maastrichtian sequence of white chalk in the Danish Basin (Fig. 1).

The ostracod fauna includes 95 species representing 34 different genera (Jørgensen, 1978). The fauna is characterized by a remarkably uniform composition throughout the strata studied. The genera *Bairdia*, *Cytherella*, *Cytherelloidea* and *Argilloecia* are present in all samples examined and are represented by several species and a large number of individuals. These genera dominate the fauna quantitatively.

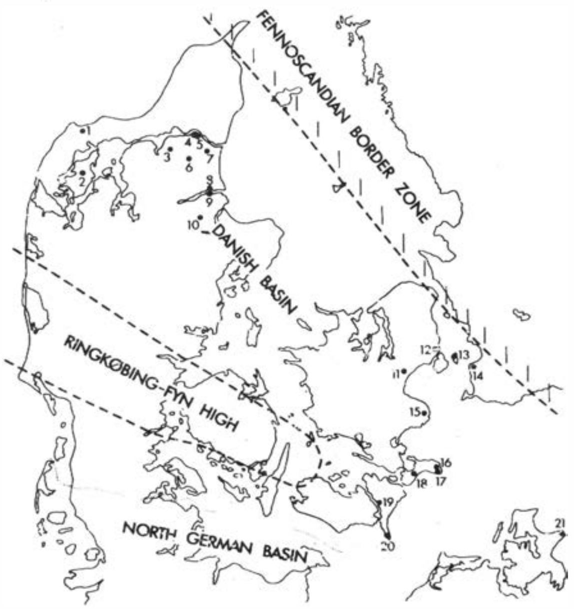


Fig. 1. Map of Denmark showing the localities studied in the present paper. 1. Bjerre, 2. Eerslev, 3.Vokslev, 4. Rørdal, 5. Danmark, 6. Ellidshøj, 7. Gudumholm, 8. Vive, 9. Dania, 10. Spentrup, 11. Karlstrup, 12. Copenhagen TUBA 13, 13. Saltholm 13, 14. Limhamn, 15. Stevns, 16. St. Stejlebjerg, 17. Hvidskud, 18. Hvide Klint, 19. Hasselø, 20. Gedser.

Accessory species belong to the genera *Krithe*, *Phacorhabdotus*, *Neocythere*, *Xestoleberis* and *Bythoceratina*. Representatives of these genera may be rare or even absent in some samples, but occur in large number in a few samples where they constitute more than 15% of the entire number of specimens.

The genus *Bythoceratina* is a particularly important element in the fauna. It contains 19 different species, i.e. approximately 20% of the total number of species recorded, and is morphologically the most variable genus in the material studied. The genus is represented in most samples, but by varying number of species and individuals.

All other genera have a rather scattered and patchy distribution. The majority of these genera are represented by few species only, and the number of individuals never exceeds 15% of the total number of specimens in a sample. Several are present only in very few samples. Though the rare species comprise only a minority of the total number of individuals, they make up more than 70% of the species recorded.

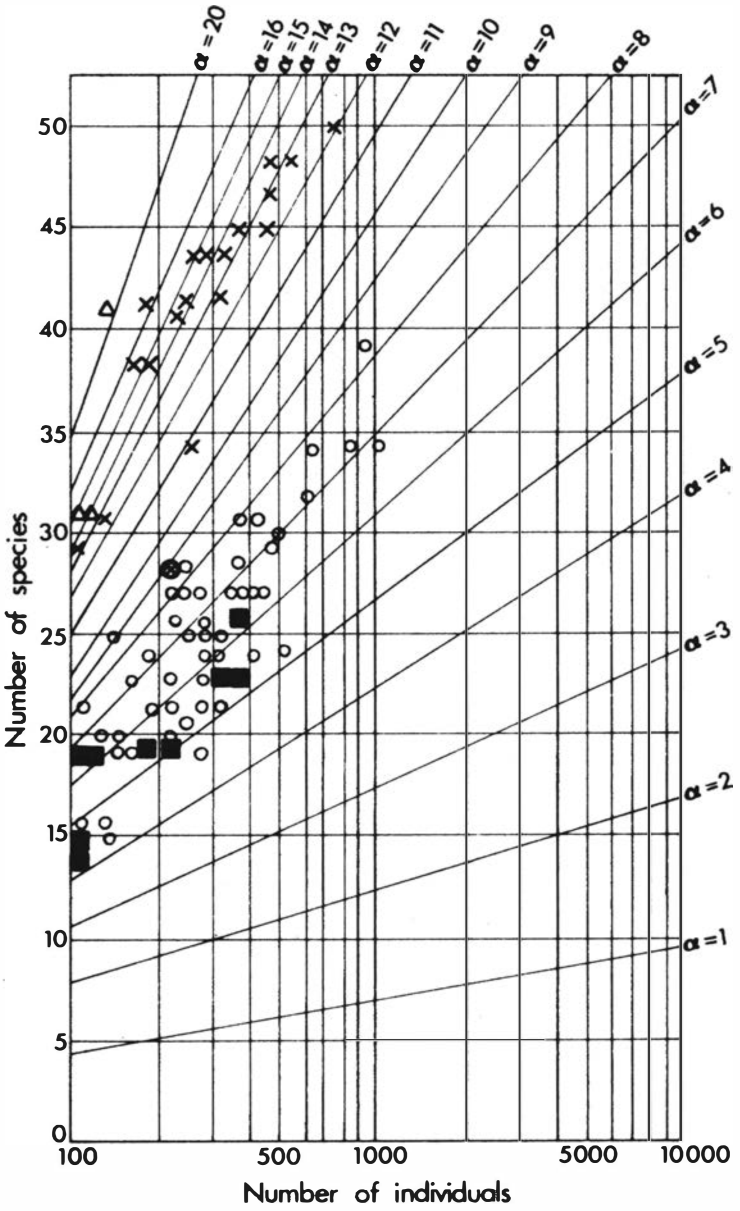


Fig. 2. Graph of Fischer-α diversity indices for the ostracod fauna from the Maastrichtian white chalk, Denmark. All values obtained are based on 100 g samples, which simultaneously gives the fauna density. Explanations: x: samples from Møn and Falster, i.e. loc. 16-18,20. o: samples from loc. 1-11,15. ■: Samples from loc. 12-14. Δ: Samples from the Maastrichtian chalk of Rügen, DDR.

The main characteristic of the fauna is the rather uniform composition. However, the density varies considerably, both vertically and horizontally in the sections studied (Fig. 2). A comparison between ostracod density and the size of the entire benthic invertebrate fauna reflected by the relative size of the wash residue of samples does not reveal any correlation between these two parameters (Jørgensen, 1978).

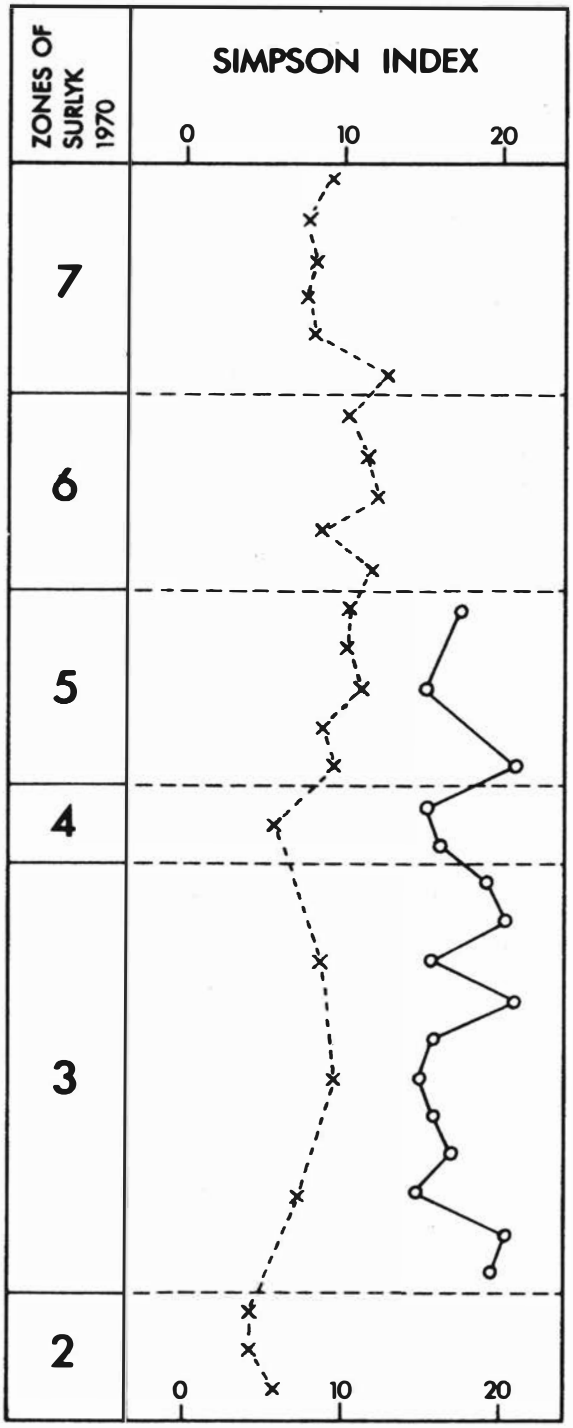
According to known bathymetric distributions of the respective genera, the chalk ostracod fauna indicates epicontinental sublittoral environments. The lack of typical plant dwellers indicates that the fauna studied characterizes environments below limits of algal growth. Furthermore, there are no indications that sedimentation in the studied sections took place within the euphotic zone (Håkansson *et al.*, 1974).

The diversity of the fauna is comparatively high, but there exists a significant geographical variation within the area studied (Fig. 2). A relatively highly diverse ostracod assemblage is found on the islands of Møn and Falster, located at the south-eastern extension of the Ringkøbing-Fyn High at the border of the North German Basin. A significantly lower diversity is generally recorded from the axial part of the Danish Basin. Furthermore, a continued trend of decreasing diversity is seen as the Fennoscandian Border Zone is approached. The geographical variations are significant at all stratigraphic levels studied (Fig. 3). It is believed that the diversity variations are governed by the environments, primarily the bathymetric conditions in the Maastrichtian sea.

STRATIGRAPHY

On the basis of ostracods a biostratigraphic subdivision of the Danish Maastrichtian chalk can be established by two species only, *Bythoceratina dania* Jørgensen, 1976 and *Bythoceratina umbonatoides* (Kaye, 1964). The distribution of the two species in comparison with the known stratigraphy of the Danish Maastrichtian is shown in Fig. 4.

B. umbonatoides is recorded from every locality that includes the brachiopod zones 1-8 and is one of the most frequent *Bythoceratina* species in this part of the sequence. *B. dania* characterizes the uppermost Maastrichtian, being found in brachiopod zones 9-10 only (Jørgensen, 1976). The species is quantitatively most frequent from localities in Jylland.



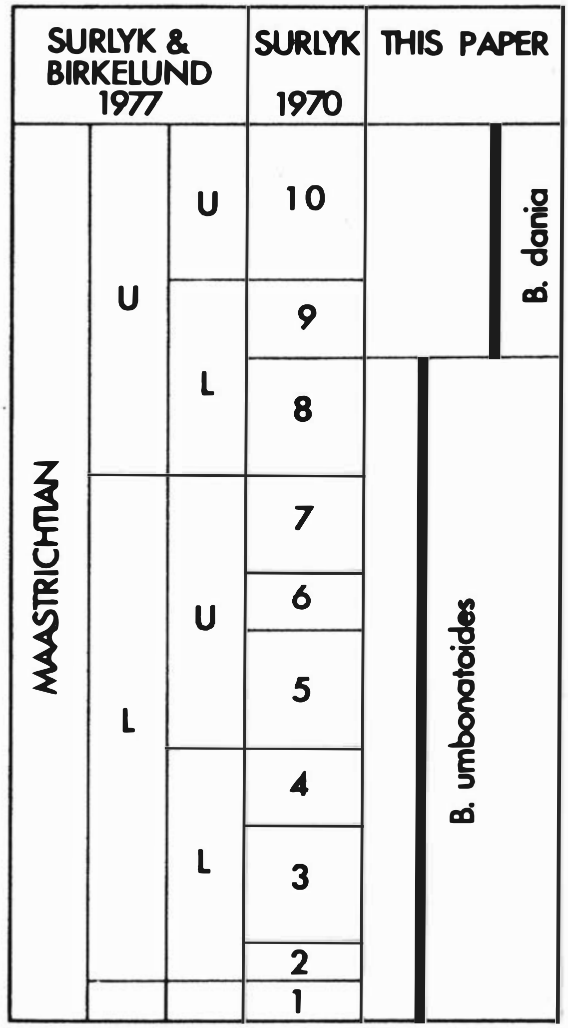


Fig. 3. Graph of Simpson diversity indices for the Maastrichtian ostracod fauna from two sections in the Danish Basin. x: Rørdal Quarry and borehole. o: Hvidskud, Møn.

Fig. 4. The biostratigraphic zonation of the Danish white chalk.

CONCLUSION

The homogenous composition, the large number of species and the relatively high diversity of the ostracod fauna indicate a mature and well-balanced community in middle and outer shelf environments. This is most likely related to the basinal chalk facies that dominates the Danish Maastrichtian. The relatively stable environments have involved slight changes only in the faunal composition for a comparatively long span of time, and consequently the stratigraphic significance of the ostracods is rather diminutive. However, the diversity variations recorded indicate some environmental dissimilarities with the Danish Basin, probably due to the bathymetric conditions in the Maastrichtian sea.

UPPER MAASTRICHTIAN FORAMINIFERA FROM THE DANISH BASIN

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The Maastrichtian white chalk of Denmark was subdivided by Troelsen in 1937 on the basis of foraminifera. Since then, extensive studies of material from deep drillings of the sequence up to 700 m thick, have considerably widened our knowledge of the foraminifera assemblages (Stenestad, 1971, 1973). In Fig. 1, Troelsen's and the author's zonations are correlated with belemnite and brachiopod zonations.

FORAMINIFERAL ZONES OF THE UPPER MAASTRICHTIAN

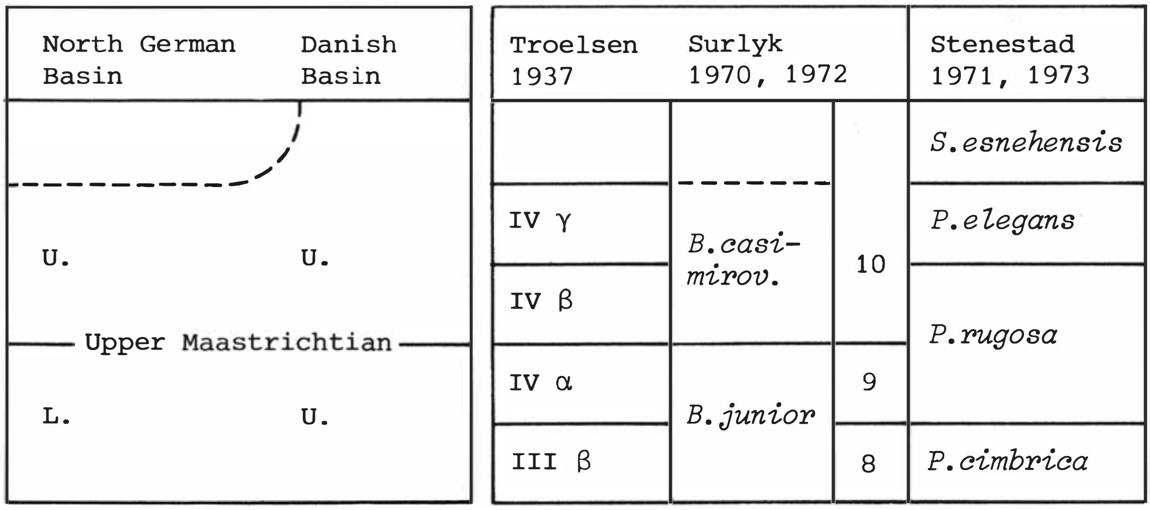
The lowermost foraminiferal zone of the Maastrichtian, which is characterized by *Bolivinoides draco miliaris* and other well-known early Maastrichtian species, is followed by a very long ranging zone, the *Bolivinoides decoratus laevigatus* Zone (256 m in the Rønde no. 1 well, Stenestad, 1971), and a small zone, the *Heterohelix dentata* Zone, together representing the rest of the Lower Maastrichtian.

The Upper Maastrichtian sequence can be referred to four zones, the *Pseudouvigerina cimbrica* Zone, the *Pseudouvigerina rugosa* Zone, the *Pseudotextularia elegans* Zone and the *Stensioeina esnehensis* Zone. The thicknesses of the zones vary within the basin. In the deep boreholes Rønde no. 1 and Nøvling no. 1 (Stenestad, 1971, 1973), situated in a central and a more marginal part of the basin respectively, the thicknesses are:

S. esnehensis Zone: 19/? m
P. rugosa Zone: 189/39 m
P. elegans Zone: 18/10 m
P. cimbrica Zone: 119/73 m

In Fig. 2 the ranges of some pertinent species are given.

Fig. 1.



North German Basin	Danish Basin	Troelsen 1937	Surlyk 1970, 1972		Stenestad 1971, 1973
				10	*S.esnehensis*
U.	U.	IV γ	*B.casimirov.*		*P.elegans*
		IV β			*P.rugosa*
L.	U.	IV α	*B.junior*	9	
		III β		8	*P.cimbrica*

UPPER MAASTRICHTIAN FORAMINIFERAL ASSEMBLAGES

The list of taxa (Fig. 3) gives some idea of the assemblages in the Upper Maastrichtian. It has not been attempted to revise the taxonomy, since most of the names are in common use and well-known from the literature.

The assemblages are believed to reflect changing conditions within the basin, e.g. in sea-level and current pattern, as well as changes with time during the general Late Maastrichtian regression.

In the deep borehole, Hobro no. 1 (and elsewhere in north Jylland), the *P. cimbrica* Zone contains abundant bryozoan remains. The density of foraminifera is low and agglutinating species are dominant. In the following zones the density of foraminifera increases. In the upper part of the sequence, referred to the *P. elegans* Zone, agglutinating species are not abundant. In this section it is suggested that shallow-water conditions were interrupted by the Tethyan "*P. elegans* transgression".

The upper part of the *P. elegans* Zone at Kjølby Gaard, however, demonstrates a marked increase in the amount of bryozoan remains towards the Danian boundary. Here, the general regression may have changed the environmental conditions a little earlier in the *P. elegans* Zone than at Hobro.

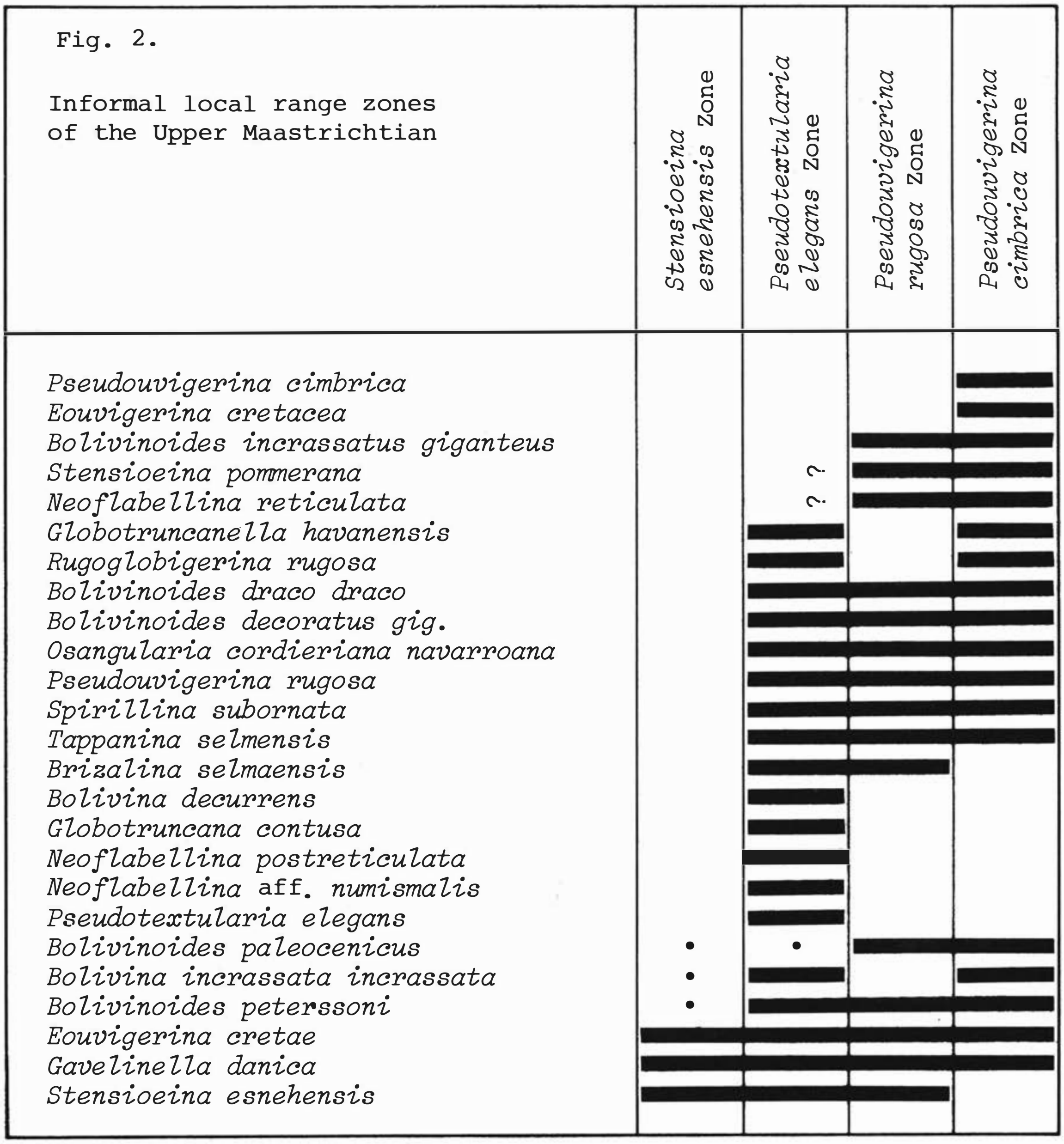


Fig. 2.

Informal local range zones of the Upper Maastrichtian

In the Kjølby Gaard section (Troelsen, 1955), the Dania section (Troelsen, 1937), the Rørdal (Aalborg) section and elsewhere in north Jylland, argillaceous horizons are present in the white chalk of the Upper Maastrichtian. The foraminiferal assemblages from the non-argillaceous white chalk and from the argillaceous horizons at Dania have been compared and found to be slightly different. In the argillaceous chalk the diversity of agglutinating taxa may be relatively high and benthic taxa seem in general to be more abundant.

Fig. 3.	*Stensioeina esnehensis* Zone	*Pseudotextularia elegans* Zone	*Pseudouvigerina rugosa* Zone	*Pseudouvigerina cimbrica* Zone
Abathomphalus mayaroensis				x
Alabamina dorsoplana		x		
Allomorphina halli		x		
Ammodiscus sp.		x		
Angulogavelinella bettenstaedti	x			
Anomalina polyraphes				x
Arenobulimina sp.sp.		x		x
Ataxophragmium sp.sp.		x		x
Biglobigerinella aspera		x		x
Bolivina decurrens		x		
Bolivina incrassata gigantea			x	x
Bolivina incrassata incrassata	(x)	x		x
Bolivinoides australis		x		x
Bolivinoides decoratus giganteus		x	x	x
Bolivinoides draco draco		x	x	x
Bolivinoides paleocenicus	(x)		x	x
Bolivinoides peterssoni	(x)	x	x	x
Brizalina selmaensis		x	x	
Bulimina stokesi		x		
Cibicides beaumontianus				x
Cibicides bembix		x	x	x
Cibicides complanata		x	x	x
Cibicides constricta		x		x
Cibicides involutiformis		x		
Cibicides cf. *plana*				x
Cibicides voltziana		x		
Coryphostoma cf. *plaita*		x		
Dentalina sp.				x
Dorothia oxycona		x		x
Dorothia sp.		x		
Eouvigerina cretacea				x
Eouvigerina cretae	x	x	x	x
Eponides frankei		x		
Eponides lunata		x		x

Fig. 3.

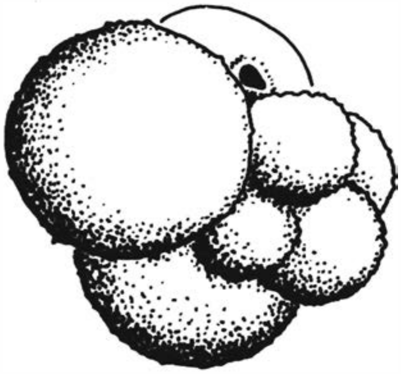
	Stensioeina esnehensis Zone	*Pseudotextularia elegans* Zone	*Pseudouvigerina rugosa* Zone	*Pseudouvigerina cimbrica* Zone
Frondicularia sp.		x		
Gaudryina rugosa				x
Gaudryina sp.		x		
Gavelinella costata	x		x	
Gavelinella danica	x	x	x	x
Gavelinella lorneiana		x		
Gavelinella pertusa	x	x	x	x
Gavelinella vombensis	x			
Globotruncana arca		x		
Globotruncana contusa		x		
Globotruncana cf. *contusa*		x		
Globotruncanella havanensis		x		x
Globotruncanella petaloidea		x		x
Globulina cf. *lacrima*				x
Glomospira sp.				x
Guttulina trigonula		x		x
Guttulina sp.				x
Gyroidinoides octocamerata		x		x
Hedbergella cf. *monmouthensis*		x		
Hedbergella sp.				x
Heterohelix dentata		x	x	x
Heterohelix striata		x	x	x
Heterostomella cf. *gracilis*		x		x
Lagena emaciata				x
Lagena isabella				x
Lagenidae indet.		x		
Lenticulina sp.				x
Lituolacea indet.		x		
Marginulina sp.				x
Marssonella oxycona		x		
Melonis nobilis		x		x
Neoflabellina aff. *numismalis*		x		
Neoflabellina postreticulata		x		
Neoflabellina reticulata		?	x	x

Fig. 3.	*Stensioeina esnehensis* Zone	*Pseudotextularia elegans* Zone	*Pseudouvigerina rugosa* Zone	*Pseudouvigerina cimbrica* Zone
Nodosaria sp.				x
Nonionella cf. *troostae*		x		
				x
Osangularia cordieriana navarroana		x	x	
Polymorphinidae indet.		x		x
Praebulimina aspera				x
Praebulimina carseyae				x
Praebulimina laevis	x	x	x	
Praebulimina parvula				x
Pseudotextularia elegans		x		x
Pseudouvigerina cimbrica				x
Pseudouvegerina cristata		x	x	
Pullenia sphaeroides		x		
Pyramidina minuta				
				x
Racemiquembelina fructicosa		x		x
Reussella cf. *paleocenica*		x		x
Reussella cf. *prolixa*				x
Rugoglobigerina cf. *pennyi*				
Rugoglobigerina rugosa		x		x
Spirillina cf. *minima*				x
Spirillina subornata		x	x	x
Spiroplectammina cf. *suturalis*		x		
Spiroplectinata cf. *dentata*		x		
Stensioeina esnehensis	x	x	x	x
Stensioeina pommerana		?	x	
Tappanina selmensis		x	x	x
Valvulineria sp.		x		

It is suggested that the distribution of species may be somewhat affected by the fact that the state of preservation of the fossils in general seems to be better in the argillaceous chalk.

The uppermost zone of the Maastrichtian, the *S. esnehensis* Zone, seems to represent the time from the end of the Tethyan transgression to the final Mesozoic regression in the Danish Basin. Planktic species are few and the assemblages may be described as a strongly reduced benthic component of the *P. elegans* assemblage.

Thus, the foraminiferal faunas demonstrate the withdrawal of the sea through rapidly changing assemblages, decreasing diversity and diminishing planktic-benthic index. When the Danian sea transgressed the area, very few of the Maastrichtian foraminiferal taxa had survived. Even though the environment was much the same as in the Maastrichtian, the fauna was, in contrast, a completely new one.



FORAMINIFERA IN THE LOWERMOST DANIAN OF DENMARK

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The faunal change in foraminifera at the Cretaceous/Danian boundary is well known. Among the benthic foraminifera, the disappearance of the genus *Stensioeina* and *Bolivinoides decorata* and *B. draco* groups is conspicuous.

The following list of species occurring in the Maastrichtian white chalk of Denmark and continuing into the Danian was given by Hofker (1966a):

Stilostomella spinosa Hofker
Neoflabellina numismalis (Wedekind)
Marssonella oxycona (Reuss)
Verneuilina limbata Cushman
Reusella cimbrica (Troelsen)
Bolivina (Tappanina) selmensis Cushman
Coleites reticulosus (Plummer)
Osangularia lens Brotzen
Gavelinonion nobilis (Brotzen)
Gavelinopsis involuta (Reuss)
Gavelinopsis bembix (Marsson)
Gaudryina supracretacea Hofker
Textularia agglutissima Hofker
Eponides frankei Brotzen
Bolivinoides paleocenica (Brotzen)
Cibicides beaumontianus (d'Orbigny)

To this may be added *Bolivinia* sp. and *Bolivinoides delicatula*, which continue to the middle Danian in certain facies.

Bolivinia basbeckensis gigantea Hofker, 1960, the very common *"Discorbis"* sp. 101 (Plate 1) and *Seabrookia* sp. can be regarded as guide fossils for the lowermost Danian.

The Danian limestones contain planktic foraminifera commonly in great quantities. They have been described from Stevns Klint by e.g. Hofker (1960, 1962b), Berggren (1962a) and Bang (1971). In the last mentioned paper, characteristic early forms of *Eoglobigerina* from Stevns Klint were described (e.g. *E. danica* (Bang) n. subsp. 1), which are now shown to be stratigraphically significant for the earliest Danian deposits of the whole region.

On the basis of a large number of sections in quarries and boreholes a lower Danian zone below the *Globoconusa daubjergensis* Zone can be established. This zone, the *Eoglobigerina danica* Zone, contains the very characteristic *E. danica* subspecies mentioned above as the only rotaliform globigerinacean. The upper boundary of the zone is defined by the first occurrence of *Globoconusa daubjergensis*.

In addition to the genus *Eoglobigerina*, the *E. danica* Zone is characterized by *Chiloguembelina* spp., *Woodringia* sp. and *Guembelitria* spp. Species of *Chiloguembelina* can be found at intervals throughout the Danian, but two species, at least, are restricted to the lower Danian. The genus *Guembelitria* is represented both in the Maastrichtian and in the Danian. Thus the very high-spired species *G. cretacea* Cushman seems to occur only in the Maastrichtian. Another very small *Guembelitria* sp. occurs also in the Maastrichtian. In the LM it resembles *Globoconusa daubjergensis*, but in SEM it can be distinguished on the basis of its bigger aperture, which always has a distinct lip. It may have given rise to Brotzen's comment (1959, p. 17) that *G. daubjergensis* appears in the uppermost part of the Maastrichtian of Sweden.

Besides the common occurrences around the Maastrichtian/Danian boundary, *Guembelitria* spp. tend to appear again in a special facies in the uppermost Danian. In this context it is interesting that Lutze & Pflauman (unpubl., paper read at the Plankt. Conf. Kiel 1974), in a faunal analysis of the Persian Gulf showed a *Guembelitria* to be the dominant gulf species, especially in shallow water. These workers compared the distribution with the results of Sliter (1972), who found Californian Cretaceous heterohelicids specially adapted to shelf sea conditions.

The environment of sedimentation is of special importance to foraminifera distribution as seen in the light of the theories advanced by Tappan (1968) and Worsley (1971) on the rise of the CCD at the end of the Cretaceous and it would be desirable to demonstrate the quantity of the planktic foraminifera in an attempt to elucidate the environment. The planktic foraminifera are very small, many below 50 µm, and only a few *Eoglobigerina* and a single species of *Chiloguembelina* reach 100 µm. This raises a practical obstacle for a planktic/benthic index. Instead, a scheme is given of the occurrence in some sections from northern Jylland (see Håkansson & Hansen, this volume).

NOTES ON DANIAN SECTIONS

Stevns Klint (see also Surlyk, this volume)

The Cerithium limestone at Højerup contains planktic foraminifera in most samples, but mostly diagenetically altered and in a very poor state of preservation. Owing to bioturbation it may be difficult to find an unmixed *E. danica* assemblage.

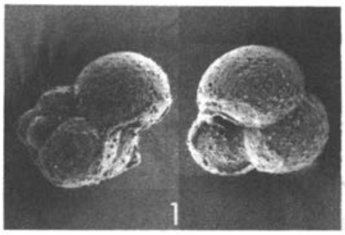
At the quarry of Boesdal (3 km SW of Højerup) a very rich planktic assemblage can be found in the lower Danian bryozoan limestone. The common Danian foraminifera *Globoconusa daubjergensis* (Bronniman), *Subbotina pseudobulloides* (Plummer), *S. trilobulinoides* (Plummer), *Eoglobigerina danica* (Bang) and *Planorotalia compressa* (Plummer) are accompanied by a number of other forms. Some of these have been described by Morozova from the Crimea as the *Eoglobigerina taurica* assemblage, comprising the following morphospecies: *Eoglobigerina eobulloides* Morozova, *E. tetragona* Morozova, *E. pentagona* Morozova, *E. hemisphaerica* Morozova, and *E. taurica* Morozova. She considered this assemblage to be older than the type Danian (*G. taurica* Zone, Morozova 1959, 1961).

A number of *Chiloguembelina* spp., *Woodringia* sp. and *Guembelitria* sp. from the lowermost zone still occur. **This assemblage is here referred** to the *E. eobulloides* Subzone of the earliest part of the *G. daubjergensis* Zone.

A well preserved fauna is also found within burrows at Højerup, dominated by *E. danica* subspp. and to a varying degree, elements of the *E. eobulloides* assemblage.

Pl. 1. *Eoglobigerina danica* Zone (lowermost Danian) x 300.

Fig. 1: *Guembelitria* sp. Figs 2, 3, 7, 8, 15: *Chiloguembelina* spp. Fig. 9: Juvenile *Woodringia* or *Chiloguembelitria* sp. Figs 4, 5, 10, 11, 13, 16: *Eoglobigerina danica* subsp. 1. Figs 6, 14: *'Discorbis'* sp. 101. Fig. 12: *Seabrookia* sp.
Figs 5 and 6 with micro-borings.
Figs 9, 10, 12, 15 from Kjølby Gaard sample KG 21. Fig. 14: Nye Kløv sample 4/8. Figs 1-6: Hanstholm well No. 10, lab.no. 293. Figs 8, 11, 13, 16: Hanstholm well No. 10, lab.no. 294. Fig. 7: Hanstholm well No. 3.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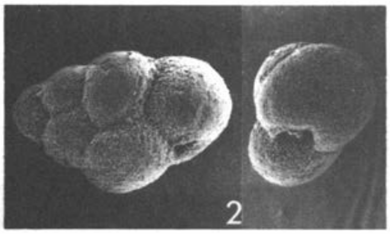
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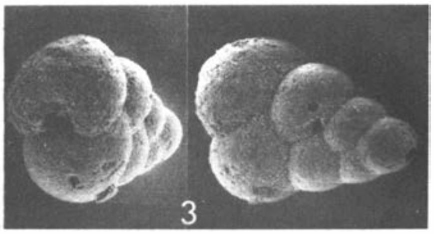
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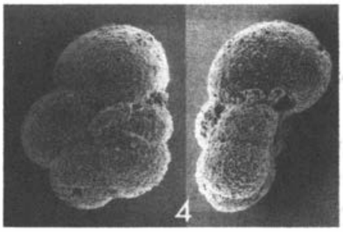
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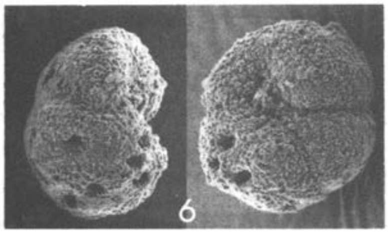
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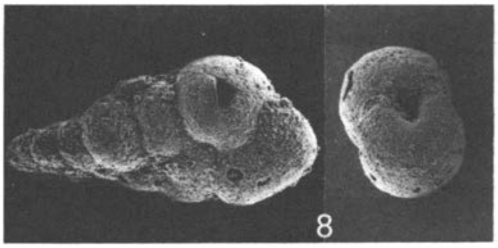
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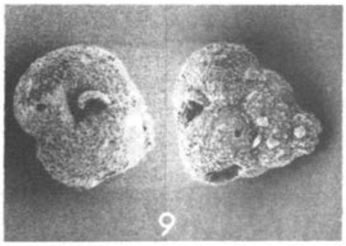
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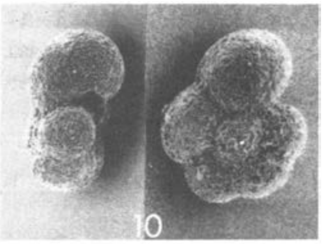
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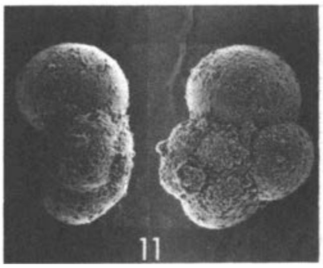
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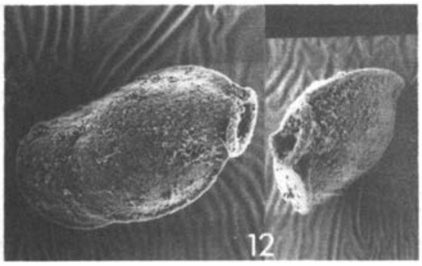
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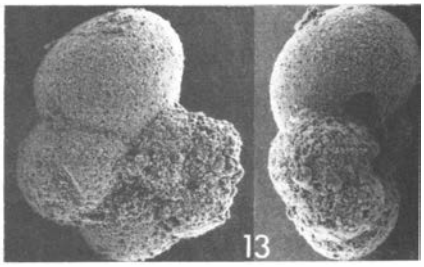
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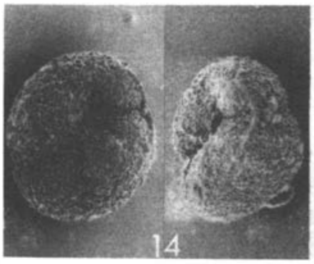
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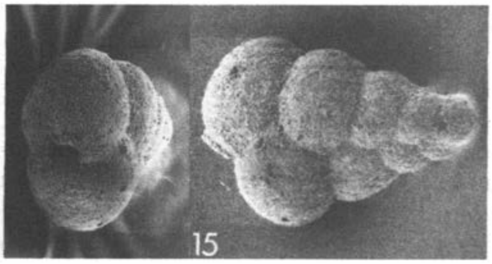
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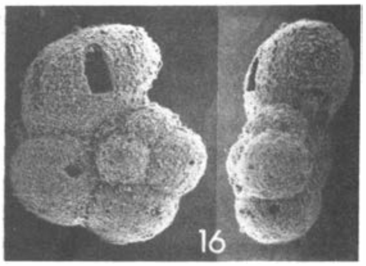
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Dania

Local structures (see Baartman Fig. 1 *in* Rasmussen, 1978) influence the section. In samples from the lowermost part of the Danian (see section in Håkansson & Hansen, this volume) large quantities of reworked Maastrichtian foraminifera occur together with very few foraminifera belonging to the *G. daubjergensis* Zone. Burrow fills within the hardground have shown a very well preserved fauna, dominated by large *Globoconusa daubjergensis*.

West of Dania, the lowermost Danian (*E. danica* Zone) has been found in the wells DGU file No. 33.406 and 39.393.

Eerslev and Legind

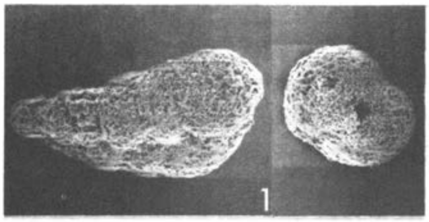
These quarries are influenced by their location on salt diapirs. In Legind the marl at the Maastrichtian/Danian boundary and the limestone above contain a mixture of Maastrichtian and Danian foraminifera (*E. danica* Zone and *G. daubjergensis* Zone).

Kjølby Gaard and Nye Kløv

The lowermost Danian is well developed in these sections. Data given in Håkansson & Hansen (this volume) show that the earliest samples from the Danian only contain reworked Maastrichtian planktic foraminifera (mostly *Heterohelix*) and above this the *E. danica* and *G. daubjergensis* Zones can be identified.

Pl. 2. *Eoglobigerina eobulloides* assemblage, Boesdal. (L. Danian).
x 250, apart from Fig. 16: x 200, detail x 1000

Figs 1, 2, 3: *Chiloguembelina* spp. Fig. 4: *Woodringia* sp. Fig. 5: *Guembelitria* sp. Figs 6, 8: *Globoconusa daubjergensis*. Fig. 9: *Planorotalia* cf. *compressa*. Fig. 13: *Planorotalia compressa*. Fig. 11: *Eoglobigerina eobulloides*. Figs 7, 12: *Eoglobigerina danica* s.l. Figs 10, 16: *Subbotina triloculinoides*. Fig. 16 with detail of surface of last chamber. Fig. 14: *Subbotina pseudobulloides*. Fig. 15: *Eoglobigerina hemisphaerica*.
Figs 1, 4, 7, 8, 9, 13, 14, 15: sample Boesdal 77/8. Figs 2, 3, 5, 6, 10, 11, 12: sample Boesdal 77/4. Fig. 16: sample Boesdal 176.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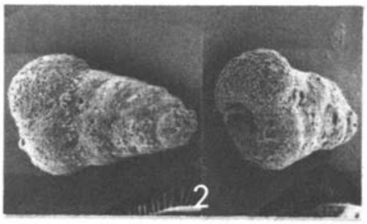
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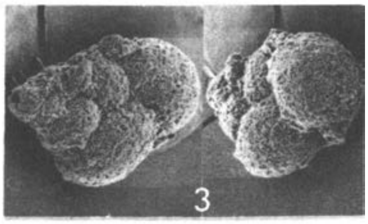
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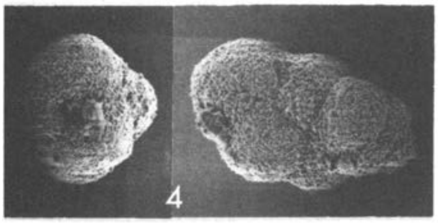
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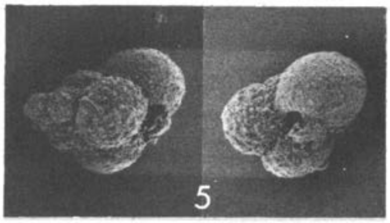
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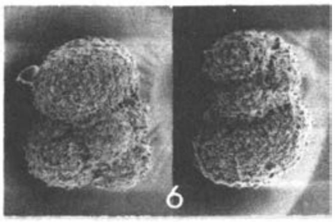
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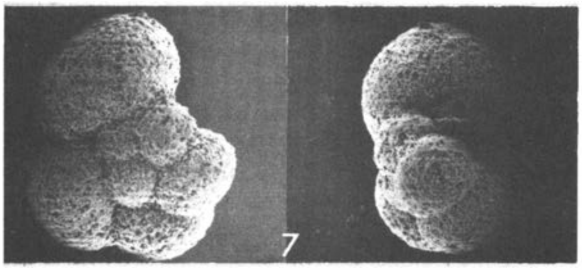
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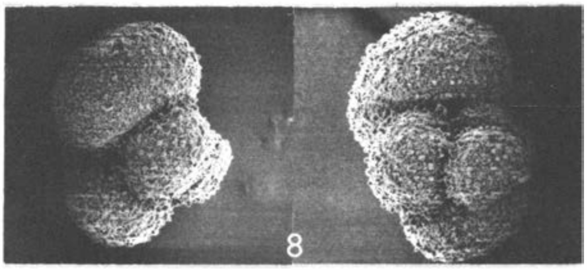
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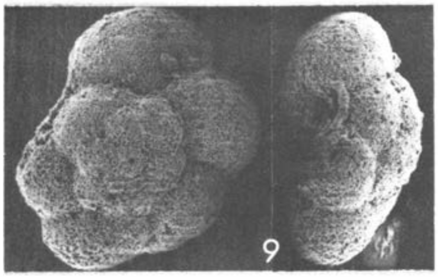
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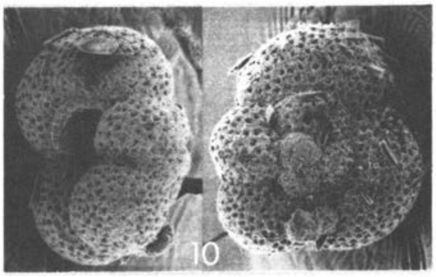
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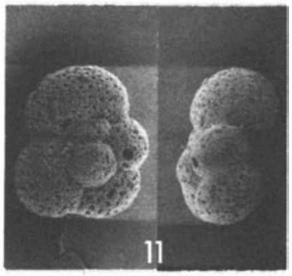
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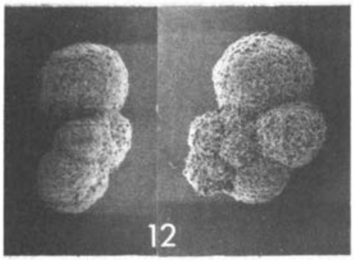
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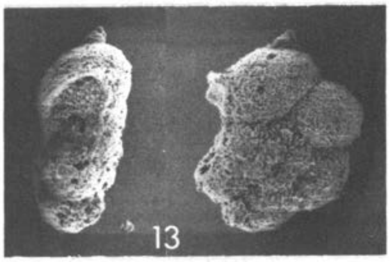
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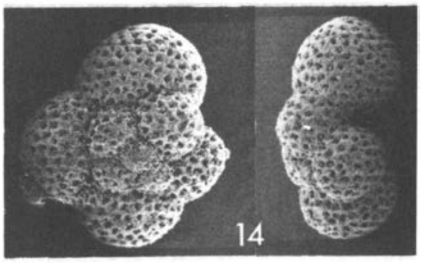
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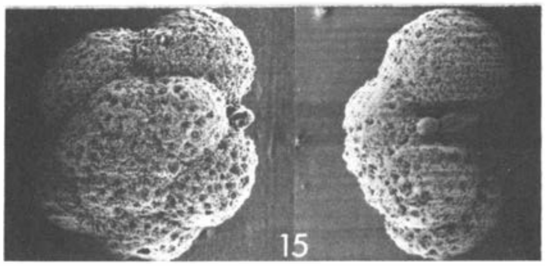
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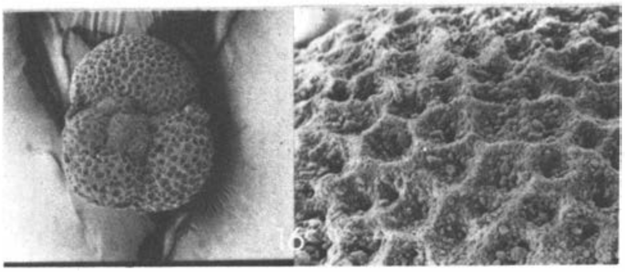
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North Sea

In the Danish part of the North Sea, the Danian and Upper Cretaceous have been examined in series of exploration drillings (Rasmussen, 1974, 1978). In all drillings the boundary has been determined by petrophysical logs, in this case Borehole Compensated Sonic Logs, at the log marking indicating base of "Tight Zone" (Lieberkind, 1977). So far the lowermost Danian has been found in Danish North Sea T-1x, while parts of the Danian sequence are missing in Danish North Sea E-2, M-1, and N-1.

CALCAREOUS NANNOFOSSIL ZONATION AT THE CRETACEOUS/TERTIARY BOUNDARY IN DENMARK

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Many small and larger outcrops of Maastrichtian and Danian sediments as well as borings are available for the investigation of calcareous nannofossils in Denmark. Those mentioned in the text or from which coccoliths are illustrated are shown in Fig. 1. The localities in Jylland and Fyn are described in Ødum (1926), those on Sjælland in Floris *et al.* (1971). At several localities, the Cretaceous/Tertiary boundary, taken here to be the Maastrichtian/Danian boundary, is visible and can be studied in detail. Remarks about some of these localities (Stevns Klint, Dania, Kjølby Gaard, Nye Kløv and Eerslev in Denmark and Limhamn in Southern Sweden) are to be found in the Excursion Guides; more complete information can be found in the Symposium Volume II as presentation of Cretaceous/Tertiary boundary sections (Perch-Nielsen, 1979a).

The sequence of calcareous nannofossil events taking place in the Maastrichtian and in the Danian of Denmark (Tab. 1) has been established over the past 10 years from the investigation of numerous sections and some borings through the Danian. It has been tested and found to be useful, also in the North Sea area, but cannot be used generally outside this region. Illustrations of Danish Maastrichtian coccoliths can be found in Perch-Nielsen (1968, 1973, in print). Danish Danian coccoliths are shown in Plates 1-4 and can also be found in Perch-Nielsen (1969b, 1971a).

MAASTRICHTIAN

In the Lower Maastrichtian of e.g. Møns Klint, *Arkhangelskiella cymbiformis* occurs together with *Reinhardtites anthophorus* and *R. levis*. At the same locality we can also observe the last occurrence of *R. anthophorus* and subsequently *R. levis*, a sequence of events described by Sissingh (1977). The first occurrence of *Lithraphidites quadratus*,

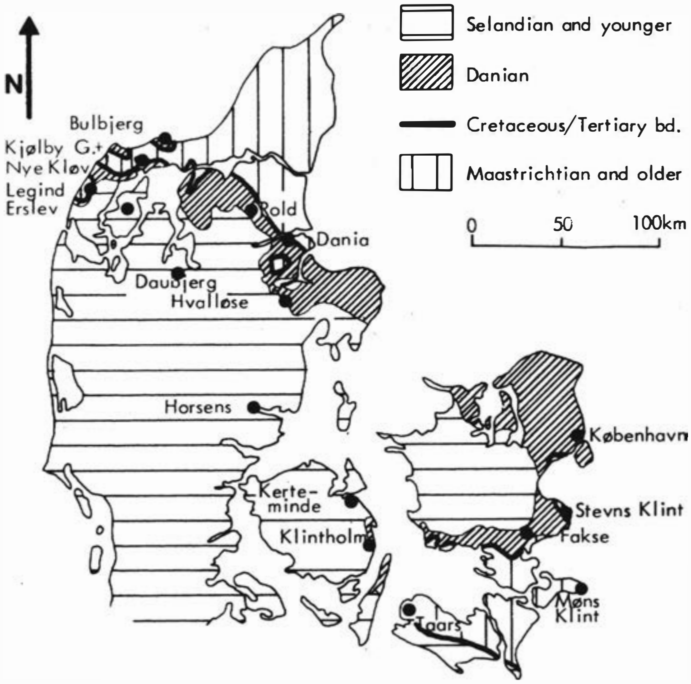


Fig. 1. Map of Denmark showing the localities studied in the present paper.

a useful event in many areas to further subdivide the Maastrichtian, seems very unreliable here due to the high latitude or the often poor preservation of the assemblages. The next event, the first occurrence of *Nephrolithus frequens* could not be observed in any sequence, since this form is present in all Upper Maastrichtian outcrops, where *Cribrosphaerella? daniae* usually also is found. *Micula murus* s.str. was found at several localities, while the younger *Micula prinsii* (see Perch-Nielsen, in print) was only found at 'Dania'. It is thus in Jylland that we find the youngest Cretaceous in the North Sea area.

DANIAN

The zonation of the Danian can be refined considerably from that suggested as Standard Zonation by Martini (1971), or by Bukry (1973). While the type Danian can be subdivided into 3 zones according to Martini (1971), the whole Danian would fall within the basal Tertiary zone of Bukry (1973). The detailed investigation of many sections in the type area has led to a very fine subdivision which, however, cannot be found outside the type area. This may suggest that, especially in the Danian, the accumulation rate was higher in many parts of Denmark than in most other areas so far investigated, where the Danian often is missing or very thin. In most Cretaceous/Tertiary boundary sections the lowermost 2 zones of Martini, NP 1 and NP 2, are absent or extremely thin. In many such sections, even the basal 3 or 4 Standard Zones are missing and the Tertiary assemblage starts with the sudden appearance of more than 20 newly evolved species. In Denmark, however, we can observe the gradual increase of newly evolved species through the Danian (see Fig. 2) and use it for a fine subdivision of the sequence (Table 1). As has been observed again and again, most Maastrichtian cocoliths disappear at the Cretaceous/Tertiary boundary and their occasional occurrence in Danian sediments is attributed to reworking. This reworking is also found in the Danian of Denmark and decreases rapidly from the basal Fish clay, where Maastrichtian coccoliths constitute 99% of the assemblage, to a few specimens in the Bryozoan limestone above. Ideas concerning the surviving Maastrichtian forms, the evolution of new Danian forms and a discussion of the suggestion of a "brackisk Arctic Ocean origin" of the Danian coccolith assemblage (Gartner & Keany, 1978) can be found in Symposium Volume II (Perch-Nielsen, 1979b).

In the following, the subdivision of the Danian (D1 to D10, see Table 1) is commented in some detail.

NP 1, *Markalius inversus* Zone, D1 and D2

In the field, the base of the Tertiary or the Danian is placed at the base of the Fish clay, where the latter is present. Where the Fish clay is missing, a hardground usually takes its place (but see Håkansson & Hansen, this volume). In terms of coccoliths, the change observable can be very small between the Maastrichtian chalk and the assemblage present in the Fish clay. While *Thoracosphaera* is found in the Maastrichtian in other areas, it is restricted (with extremely rare exceptions) to the Danian and younger sediments in Denmark and the North Sea area. It is thus present in the Fish clay together with *Biantholithus sparsus*, another form not found in the underlying Maastrichtian. Already in the Fish clay we can observe an increase of *Biscutum*, *Crepidolithus* and *Cyclagelosphaera* relative to other forms which occur also in the Maastrichtian. This cannot be attributed to dissolution of other Maastrichtian forms since, in even very poorly preserved Maastrichtian assemblages these forms are no more abundant than in well preserved Maastrichtian assemblages. It is assumed, therefore, that these genera survived the Cretaceous/Tertiary boundary event together with some others, not all represented in the Danish

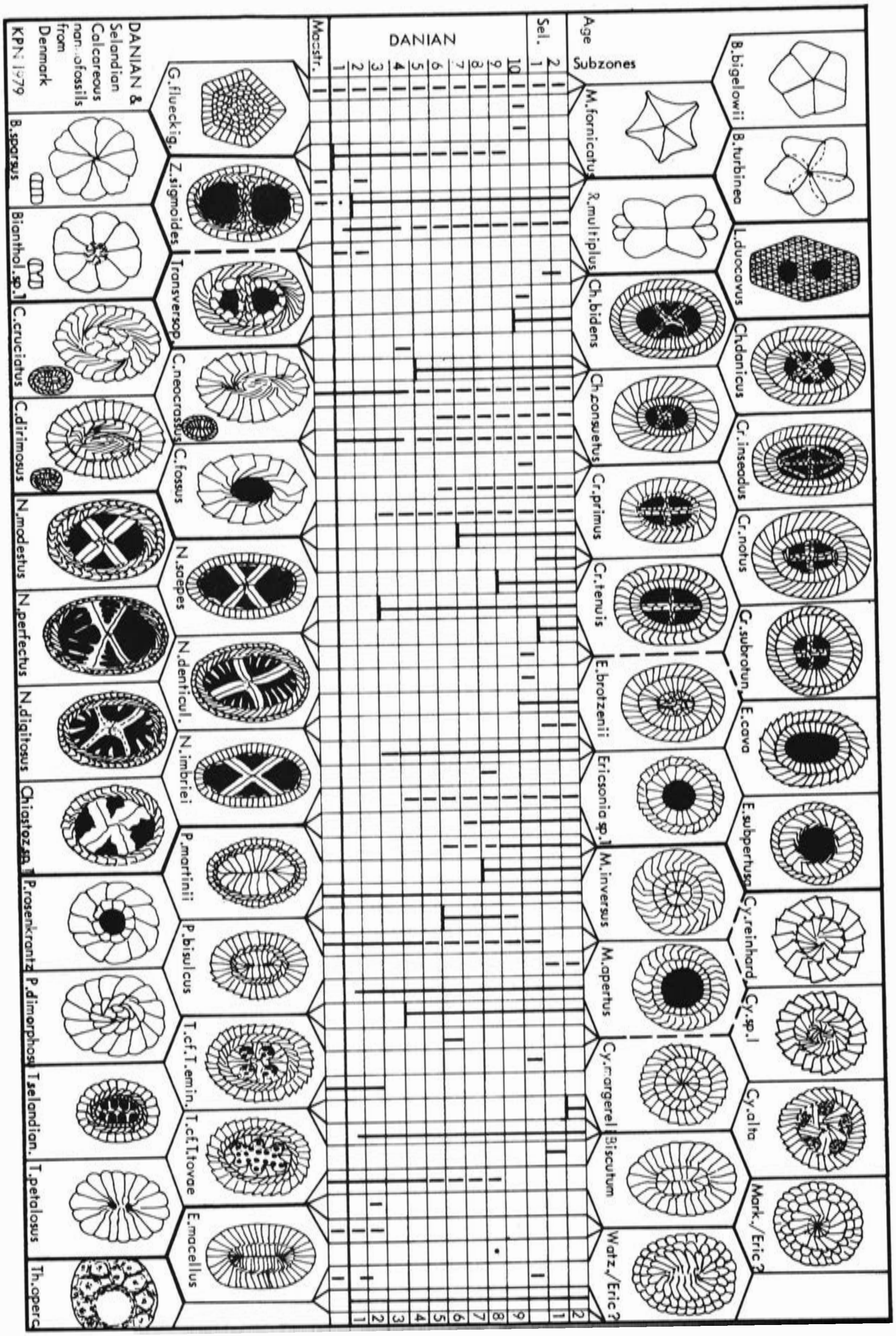

DANIAN & Selandian Calcareous nannofossils from Denmark KPN 1979
Age
Maastr.
DANIAN
Sel.
Subzones
1
2
3
4
5
6
7
8
9
10
1
2
B.sparsus
Bianthol.sp.1
C.cruciatus
C.dirimosus
N.modestus
N.perfectus
N.digitosus
Chiastoz.sp.1
P.rosenkrantzi
P.dimorphos.
T.selandian.
T.petalosus
Th.operc.
G.flueckig.
Z.sigmoides
Transversop.
C.neocrassus
C.fossus
N.saepes
N.denticul.
N.imbriei
P.martinii
P.bisulcus
T.cf.T.emin.
T.cf.T.tovae
E.macellus
M.fornicatus
R.multiplus
Ch.bidens
Ch.consuetus
Cr.primus
Cr.tenuis
E.brotzenii
Ericsonia sp.1
M.inversus
M.apertus
Cy.margerel
Biscutum
Watz./Eric.?
B.bigelowii
B.turbinea
L.duocavus
Ch.danicus
Cr.inseadus
Cr.notus
Cr.subrotun.
E.cava
E.subpertusa
Cy.reinhardt.
Cy.sp.1
Cy.alta
Mark./Eric.?

Fig. 2.

Danian, while the bulk of the other forms are reworked from the Maastrichtian (Perch-Nielsen, 1969b).

Zygodiscus sigmoides is absent or occurs extremely rarely in D1, the lower subzone of NP 1; it is possibly reworked from the Maastrichtian. The re-occurrence, often in large numbers, of *Z. sigmoides* marks the base of D2. *Z. sigmoides* is also known from the Maastrichtian, but seems to be absent just above the Cretaceous/Tertiary boundary. It soon dominates the assemblage of the upper part of NP 1, where reworked Maastrichtian coccoliths thin out and the assemblage otherwise consists of *Biscutum*, *Crepidolithus*, *Cyclagelosphaera* (mainly *C. reinhardtii*) and, in some sections, *Russellia multiplus*. In some sections NP 1 is over 7 m thick, in others only a few dm or it can be absent.

NP 2, *Cruciplacolithus tenuis* Zone, D3 and D4

The first occurrence of *C. tenuis* marks the base of NP 2 and D3. *Ericsonia cava* or forms very similar to it, also occur at about the same level, as does *C. primus*. No interval with only *C. primus*, an early form of *Cruciplacolithus* occurring before the typical *C. tenuis* at DSDP Site 356 in the South Atlantic (Perch-Nielsen, 1977), has been found in the North Sea area. In the upper part of NP 2, the first representative of the Prinsiaceae, *Prinsius dimorphosus*, appears in low numbers and marks the base of D4. Usually, *Markalius inversus* and *M. apertus* become more common in NP 2 than they were in NP 1, and in D4 round forms of *Ericsonia* occur (*Ericsonia* sp.1, Pl. 1, Fig. 11), but not yet *E. subpertusa*. Quite often, the assemblage is dominated by *Z. sigmoides*. Also NP 2 is rarely over 7 m thick, its usual thickness being closer to 1 or 2 m. It can be locally absent.

NP 3, *Chiasmolithus danicus* Zone

The rest of the type Danian can be assigned NP 3, if the original diagnosis of this zone is followed. There, the base of the next zone, NP 4, is defined by the first occurrence of *Ellipsolithus macellus* and *Heliorthus concinnus* is reported to occur in the upper part of NP 4 (Martini, 1971, p. 752). At that time Martini probably used *H. concinnus* for any small, Paleocene form having a zeugoid rim and a central X. Such forms occur in Danmark in the upper part of what here appears to be NP 3, since *E. macellus* is absent. So far only 2 specimens of *E. macellus* have been found in Upper Danian samples from Denmark, both at Daubjerg, where *Neochiastozygus modestus* and *Prinsius martinii* are also present (D8). It is thus likely that parts of the type Danian should be correlated to NP 4 rather than NP 3. *E. macellus* is a very fragile form and its absence can easily be explained by dissolution, or else the high latitude of the North Sea area was not suitable for its primary occurrence in reasonable numbers. For practical reasons, the Danian will probably remain correlated to NP 3 or a combined NP 3/4, at best.

A subdivision of the NP 3/4 interval is possible, however, in the type area of the Danian with the help of the Prinsiaceae, *Chiasmolithus* and *Neochiastozygus*.

The first occurrence of *Chiasmolithus danicus* defines the base of NP 3 and D5. It can be difficult to distinguish in the LM between *C. tenuis* and *C. danicus*, when the central X of the latter is oriented between its normal position and that of the central + of *C. tenuis*. In the lowermost part of NP 3, *P. dimorphosus* is the only representative of the Prinsiaceae. The base of D6 is marked by the appearance of *Prinsius rosenkrantzii*, which commonly dominates the assemblage. Both *P. dimorphosus* and *P. rosenkrantzii* are very small coccoliths, usually only 2-4 µm, and may be difficult to distinguish in the LM. *P. dimorphosus* is elliptic and its central area is bright between crossed nicols, while *P. rosenkrantzii* is round or subcircular and shows a dark, empty central field between crossed nicols. D5 was found in several localities. D6 is best represented by the "Næsekalk" at Fakse Quarry.

The first occurrence of *Neochiastozygus modestus* marks the base of D7, where *Chiastozygus* sp. 1 seems also to have its first appearance. The next new *Prinsius*, *P. martinii*, appears at the base of D8, before the first occurrence of the next *Neochiastozygus*, *N. saepes* (large variation, 5-7 µm) which marks the base of D9. The sequence of these two events needs some further investigation, since small *N. saepes* (4-5.5 µm) were found in one sample well below the first occurrence of *P. martinii* or the large variety of *N. saepes* in the Hvalløse boring. While the Prinsiaceae are very resistant forms and often dominate the Danian assemblages, *Neochiastozygus* are usually rare and often missing in samples where they would be expected, probably owing to dissolution. In the upper Danian the first *Chiasmolithus bidens* also are found. Their appearance marks the base of D10, a subzone well represented at Hvalløse.

SELANDIAN

Overlying the light, calcareous sediments of the type Danian are the dark, detritic sediments of the Selandian. Their coccolith content varies greatly and a large amount of reworked Maastrichtian coccoliths are commonly present. The continuing appearance of new species can, however, also be observed in the Selandian. Since some reworking

Table 1.

Age	Zone/Subzones		Marker species
Sel.	NP 5?	S 2	Toweius selandianus *
		S 1	Neochiastozygus perfectus *
Danian	NP 4?	D 10	Chiasmolithus bidens *
		D 9	Neochiastozygus saepes *
	NP 3	D 8	Prinsius martinii *
		D 7	Neochiastozygus modestus *
		D 6	Prinsius rosenkrantzii *
		D 5	Chiasmolithus danicus *
	NP 2	D 4	Prinsius dimorphosus *
		D 3	Cruciplacolithus tenuis *
	NP 1	D 2	Zygodiscus sigmoides *Acme
		D 1	Biantholithus sparsus *
Maastrichtian	M.prinsii		Micula prinsii *
	N.frequens		Nephrolithus frequens *
	L.quadratus		Lithraphidites quadratus *
	A.cymbiformis		Reinhardtites levis +
	R.levis		Reinhardtites anthophorus +
	R.anthophorus		

probably also took place from the Danian into the Selandian and some Selandian is found in cracks and burrows in the uppermost Danian, it is not absolutely certain whether the first occurrence of *Neochiastozygus perfectus*, e.g. at Hvalløse, falls within the Danian or marks the base of the Selandian. *N. perfectus* continues up through the coccolith-bearing part of the Selandian and is accompanied there by the first *Toweius* with large holes, *T. selandianus*, the first occurrence of which marks the base of S 2. The correlation of S 1 and S 2 to the Standard Zonation of Martini (1971) again poses problems. Martini defines the base of NP 5 by the first occurrence of *Fasciculithus tympaniformis*.

This species was not found in the Tertiary of Denmark. On the other hand, he also mentions the presence of *C. bidens*, which is found in the Selandian and uppermost Danian. Forms similar to *N. perfectus* also are found in other areas in the *F. tympaniformis* Zone, so the correlation of S 1 and S 2 to NP 5 would seem to be good guess.

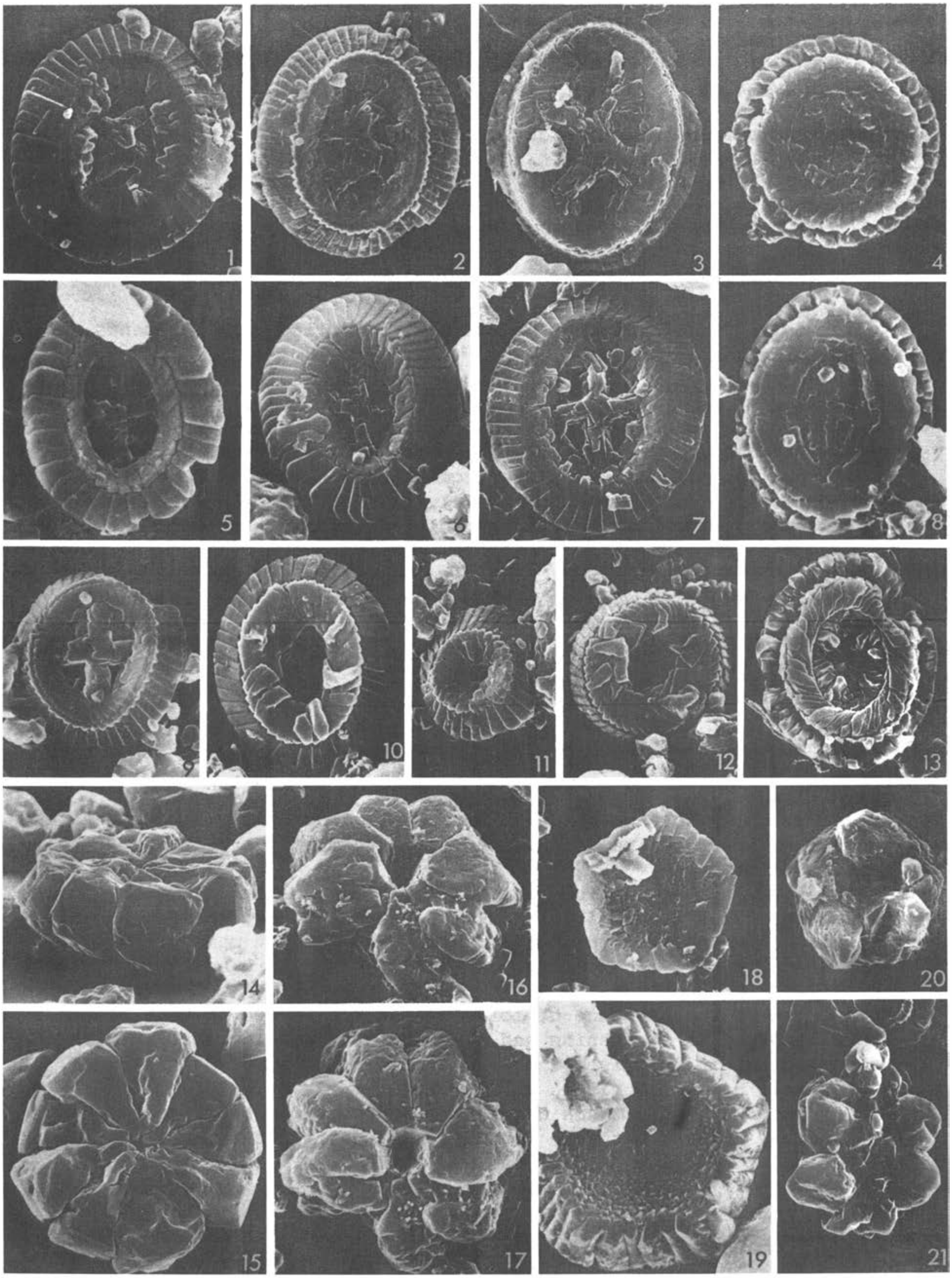
SYSTEMATIC REMARKS

Plates 1-4 show most calcareous nannofossils so far observed in the type Danian. Illustrations of the Maastrichtian forms from Denmark are to be found in Perch-Nielsen (1968, 1973, in print). Systematic remarks about most of these forms are available from the above mentioned publications and from Perch-Nielsen (1969a, 1969b, 1971a). In the following some new species are described and remarks are made about some rare forms not yet described and/or understood. The genera are treated in alphabethical order.

Biantholithus sp. 1. Pl. 1, Figs 16,17

Biantholithus sp. 1 is higher than what is usually called *B. sparsus* and shows a well defined central depression, a feature that has so far not been observed in typical *B. sparsus*. *Biantholithus* sp. 1 has been found in the lower Danian at Bulbjerg only.

Plate 1. 1: *Chiasmolithus consuetus*, 6500x, distal view, 170/5. 2: *Chiasmolithus danicus*, 3750x, distal view, 399. 3: *Chiasmolithus bidens*, 3750x, distal view, 170/7. 4: *Cruciplacolithus subrotundus*, 8000x, distal view, 170/1. 5: *Cruciplacolithus primus*, 10.000x, distal view, 170/5. 6:*Cruciplacolithus tenuis*, 5000x, distal view, 85G. 7: *Cruciplacolithus notus*, 4500x, distal view, 170/2. 8: *Cruciplacolithus inseadus*, 8000x, proximal view, 170/1. 9: *Cruciplacolithus?* sp.1, 5000x, distal view; note double central cycle, 352/78. 10: *Ericsonia cava*, 5000x, distal view, 170/7. 11: *Ericsonia?* sp.1, 5000x, distal view (early form of *C. formosus*), 364/1. 12: *Ericsonia subpertusa*, 5000x, distal view; note overlapping central elements, 173. 13: *Ericsonia brotzenii*, 3750x, proximal view, 170/6. 14,15: *Biantholithus sparsus*, 4000x, turned specimen, 81/5. 16,17: *Biantholithus* sp.1, 4500x, turned specimen; note central depression, 66. 18,19: *Goniolithus flueckigeri*, 5000x & 7500x, distal and proximal view, 170/1. 20: *Braarudosphaera turbinea*, 5000x; not very typical specimen, 170/1. 21: *Russellia multiplus*, 5000x; overgrown, as most specimens in the Danian, 173. Location of samples listed p.135.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Chiastozygus sp. 1. Pl. 2, Fig. 8

See *Neochiastozygus* and *Chiastozygus* sp. 1.

Crepidolithus cruciatus n.sp. Pl. 2, Figs 11-13,25,26

Holotype: Pl. 2, Fig. 12.
Type level: Danian
Type locality: Legind, Jylland, Denmark
Diagnosis: A form of *Crepidolithus* with inclined wall elements and a proximal cross.
Description: The wall consists of about 40 inclined elements and the construction of the distal central part is not known. On the proximal side an outer cycle of elements surrounds a cross-like arrangement of elements filling the rest of the central proximal plate.
Remarks: *C. cruciatus* differs from other species of *Crepidolithus* by the cross-like arrangement of the elements of the proximal centre. Most other species have only one cycle of radially arranged elements. *C. cohenii* has concentric cycles of elements and *C. fossus* has an open centre.
Occurrence: *C. cruciatus* has only been found in the Danian of Legind, Denmark.

Crepidolithus dirimosus n.sp. Pl. 2, Figs 16-18,23,24

Holotype: Pl. 2, Fig. 16.
Type level: Danian
Type locality: Stevns Klint, Denmark.
Diagnosis: A form of *Crepidolithus* having inclined wall elements and a wall with two cycles, the second cycle forming the filling of the distal centre.
Description: The wall consists of about 40 inclined elements. The elements of the inner distal wall cycle are inclined in the opposite direction to those of the outer cycle. They almost completely fill the distal centre of the form. Radial elements form a relatively small proximal plate.
Remarks: The occurrence of forms having two cycles of wall elements is widespread in the Danian and the rest of the Paleocene: this feature also evolves in *Zygodiscus* and *Neochiastozygus*. *C. neocrassus* and *C. cohenii* have only single wall cycles (Pl. 2, Fig. 19).
Occurrence: *C. dirimosus* occurs from the lowermost Danian through Selandian, but has not been found in the Maastrichtian.

Crepidolithus sp. 1. Pl. 2, Figs 27-30

In some Danian samples, large forms of *Crepidolithus* sp. 1 have been found. They have about 20 wall elements arranged more or less vertically. Their size is about twice that of most other *Crepidolithus*. It seems not impossible that these forms are merely heavily overgrown forms of other *Crepidolithus* species, where the radial proximal elements grew relative to the wall elements.

Cruciplacolithus? sp. 1. Pl. 1, Fig. 9

The specimen figured in Pl. 1, Fig. 9 looks superficially like a *C. tenuis*. It differs from this species, however, in an extra cycle of elements between the distal shield and the radial elements surrounding the open central area. Such double central covers are typical of the Prinsiaceae *Prinsius* and *Toweius*, but have only been found in a few Danian specimens of *Cruciplacolithus*? and *Ericsonia*?. Were such forms unsuccessful competitors for the Tertiary seas? The figured specimen was found in the lowermost part of the *C. danicus* Zone (D5), other specimens in the upper part of the *C. tenuis* Zone (D4).

Cyclagelosphaera alta n.sp. Pl. 3, Figs 2,3,4,7

Holotype: Pl. 3, Fig. 7.
Type level: Danian
Type locality: Dania, Jylland, Denmark
Diagnosis: *Cyclagelosphaera* having a distal superstructure with 4 to 6 depressions around the elevated central part.
Description: The distal shield is larger than the proximal shield. It consists of a cycle of inclined elements forming an obtuse cone. Another obtuse cone, built of inversely oriented elements, forms the distal centre. It has 4-6 depressions of about equal size. The proximal shield consists of radially oriented elements.
Remarks: *C. alta* differs from all other species of *Cyclagelosphaera* by the depressions in the central obtuse cone. *C. alta* shows some common features with the Eocene *Rhabdolithus vitreus* in Perch-Nielsen (1971b) and might be an ancestor of some rhabdoliths.
Occurrence: *C. alta* was found in the Danian and Selandian of Denmark from the upper part of the basal Danian D1 zone.

Cyclagelosphaera sp. 1. Pl. 3, Fig. 8

Cyclagelosphaera sp. 1 has a distal cone constructed of two cycles of elements, while *C. reinhardtii* has only one cycle. In both forms, the proximal shield is smaller than the distal shield, while it is of about the same size in *C. margerelii* (Pl. 3, Fig. 5).

Plate 2. 1: *Neochiastozygus saepes*, 9000x, distal side, early form, 347/43. 2: *Neochiastozygus saepes*, 7000x, proximal side, typical form, 170/1. 3: *Neochiastozygus imbriei*, 7500x, distal side of broken specimen, 347/15. 4: *Neochiastozygus denticulatus*, 10 000x, distal side, 170/1. 5: *Neochiastozygus digitosus*, 10 000x, distal side, 39. 6: *Neochiastozygus modestus*, 9000x, distal view of typical, late form, 170/5. 7: *Neochiastozygus modestus*, 10 000x, distal view of early form, 347/55. 8: *Chiastozygus* sp.1, 10 000x , distal view; note simple wall, 170/5. 9: *Neochiastozygus perfectus*, 5000x, distal view of late form, 170/8. 10: *Neochiastozygus perfectus*, 5000x, distal view of early form with plate elements, 170/2. 11: *Crepidolithus cruciatus* n.sp., 7500x, distal view, 364/1. 12: *Crepidolithus cruciatus* n.sp., 8000x, proximal view of holotype, 364/1. 13: *Crepidolithus cruciatus* n.sp., 7500x, proximal view, 364/1. 14: *Crepidolithus fossus*, 9000x, proximal view, 170/7. 15: *Crepidolithus fossus*, 9000x, distal view, 170/7. 16: *Crepidolithus dirimosus* n.sp., 7500x, distal view of holotype, 85G. 17: *Crepidolithus dirimosus* n.sp., 7500x, proximal view, 85G. 18: *Crepidolithus dirimosus* n.sp., 7500x, distal side view, 85G. 19: *Crepidolithus neocrassus*, 10 000x, distal view, 85C. 20: *Prinsius rosenkrantzii* n.sp., LM 3200x, crossed nicols, 399. 21,22: *Crepidolithus neocrassus*, LM 3200x, parallel & crossed nicols, 85G. 23,24: *Crepidolithus dirimosus* n.sp., LM 3200x parallel & crossed nicols, 85G. 25,26: *Crepidolithus cruciatus* n.sp., LM 3200x, parallel & crossed nicols, 364/1. 27,28: *Crepidolithus* sp.1, LM 2000x, parallel & crossed nicols, 352/80A. 29,30: *Crepidolithus* sp.1, 3750x & 5000x, proximal and side view of turned specimen; note larger size than other *Crepidolithus* and the near vertical rim elements. Overgrown 'normal', small *Crepidolithus?*, 352/80A. Location of samples listed p.135.


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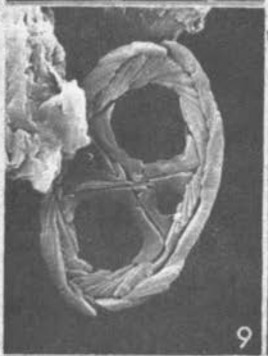
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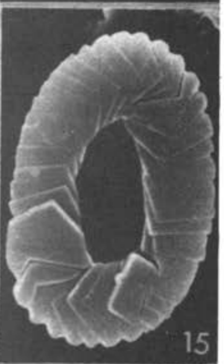
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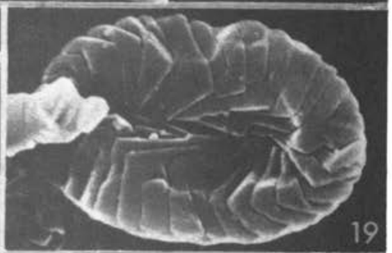
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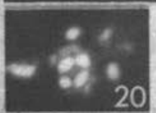
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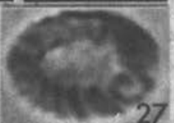
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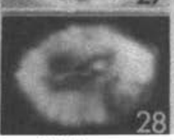
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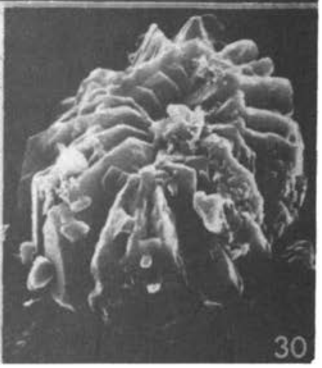
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Ericsonia? sp. 1. Pl. 1, Fig. 11

The oldest round form of *Ericsonia* is usually considered to be *E. subpertusa*, (Pl. 1, Fig. 12), which occurs from about D6. Round forms already occur, however, in D4. These forms, here assigned to *Ericsonia?* sp. 1, are somewhat smaller than typical *E. subpertusa* and differ from the latter by the radial elements that form the central cover around the central opening. The size of this opening varies, as it varies in *E. subpertusa*, where the elements are arranged tangentially and overlap each other considerably. The distal shield of *E. subpertusa* is very narrow, while it is wide in *Ericsonia* sp. 1.

Markalius apertus n.sp. Pl. 3, Figs 11-13,16

Holotype: Pl. 3, Fig. 16.
Type level: Danian
Type locality: Stevns Klint, Denmark
Diagnosis: *Markalius* with an open centre.
Description: The distal shield is larger than the proximal shield and they consist of an equal number of elements. The large or small central opening is surrounded by a cycle of elements visible from both sides.
Remarks: *M. apertus* differs from *M. inversus* in the absence of radial elements covering the centre. Structurally, the radial elements covering the centre in *M. inversus* correspond with the circle of elements surrounding the centre in *M. apertus*. This is also easily visible in the LM, where they appear bright between crossed nicols (Pl. 3, Figs 10,12).
Occurrence: *M. apertus* was found in the Danian and Selandian of Denmark from the upper part of the basal Danian D 1 zone.

Markalius/Ericsonia? sp. 1. Pl. 3, Fig. 18

Pl. 3, Fig. 18 shows the proximal side of a *Markalius*-like form, where the proximal shield has two cycles. The inner cycle consists of radial extensions of the cycle of elements covering the centre. Such 'double' proximal shields are the rule in Tertiary Coccolithaceae as *Ericsonia*, *Chiasmolithus* and *Cruciplacolithus* where, as in *Markalius*, the distal shield shows no birefringence between crossed nicols, while the proximal shield is bright. Several such forms as shown in Pl. 3, Fig. 18 have been found in the lowermost Danian (D1 and D2) and in the uppermost Maastrichtian (*M. prinsii* Zone at Dania). So far no forms suggesting an evolution from such forms to *Cruciplacolithus*, *Chiasmolithus* or typical *Ericsonia* have been observed, but it would seem to be worthwhile to search for them!

Neochiastozygus and *Chiastozygus* sp. 1. Pl. 2, Figs 1-7,9,10

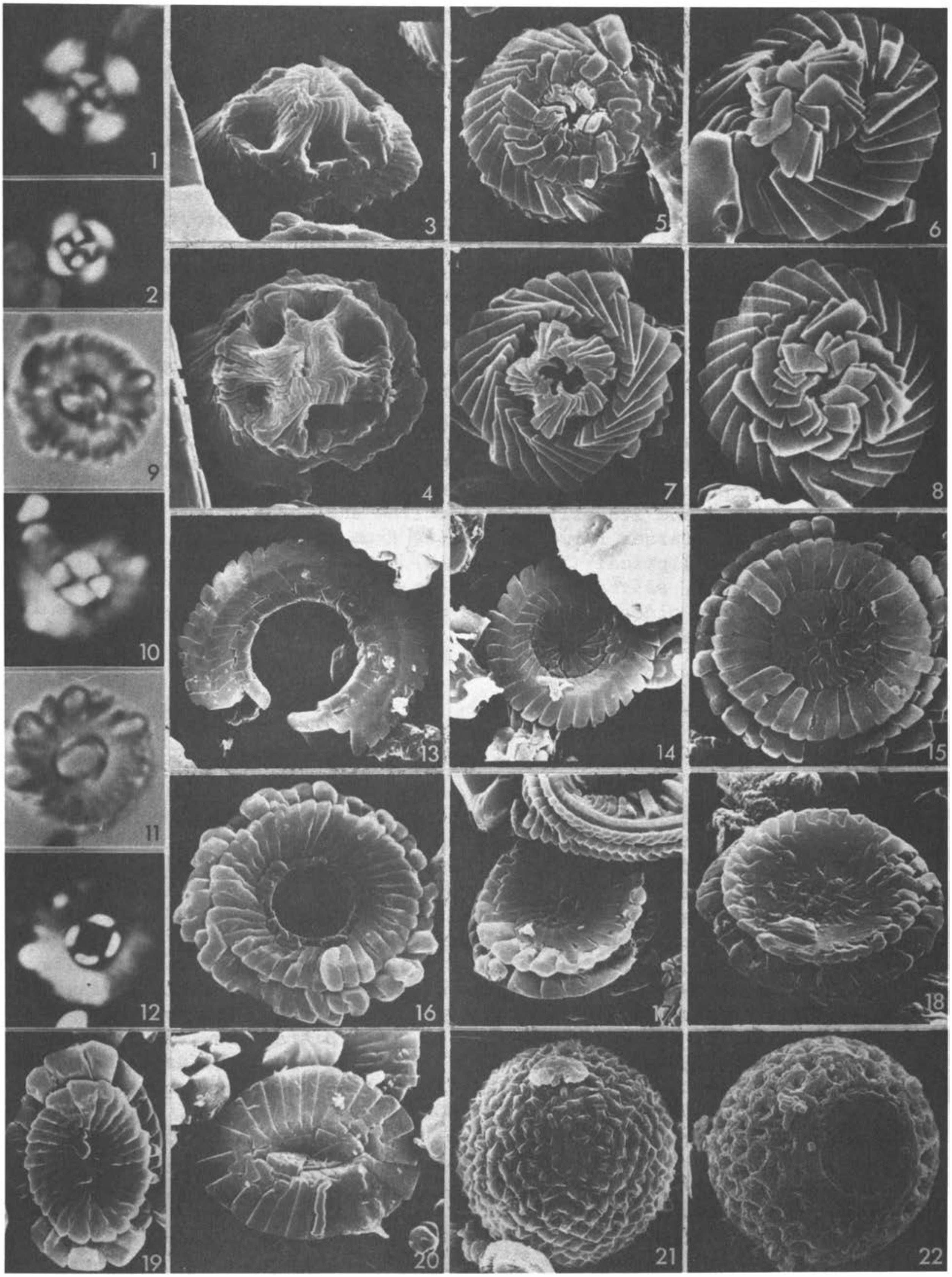
Members of *Neochiastozygus* are important for the biostratigraphy of the Danian and Selandian of Denmark and the North Sea area. Distinction can usually be made by light microscope (see Perch-Nielsen, 1971b, where light micrographs of all species are given), but is easier with the SEM. *N. modestus* is a relatively small (4-5 µm) form and looks clumsier than the larger and later occurring *N. perfectus* (6-8 µm). The wall is usually thinner in the latter and the central cross appears more elegant. In both forms the wall consists of two cycles of inclined elements. In *N. modestus* both cycles are of about equal height, in *N. perfectus* the inner cycle is reduced in height. *N. saepes* has a wall consisting of vertically oriented elements. This can be observed in the LM, where, between crossed nicols, the extinction figure of the wall is a straight line. It is a curved line in all other species of the genus. The outline of *N. saepes* is usually a somewhat elongated ellipse tending to pointed ends. Early forms are smaller than later forms (4-5.5 µm to 5-7 µm). In *N. denticulatus* the central cross consists of unequal arms, the longer one being oriented with a low angle to the major axes of the ellipse. Plate elements extend from the wall towards the centre and fill up most of the open space between the central cross arms. *N. denticulatus* can be confused with early forms of *N. modestus*, where the central cross also seems to be more asymmetrical than in the later forms. *N. digitosus* is a small, slender form with the central structure formed like an H rather than X. Delicate plate elements extend from the thin wall towards the centre. *N. digitosus* occurs together with *N. perfectus*, from which it is easily distinguished by its smaller size (3-5 µm) and the different shape of the central structure. *N. imbriei* is very rare in Denmark and shows a wall consisting of vertical elements and a central cross with unequal bars. *Chiastozygus* sp. 1 has a central cross with more or less equal bars, but only a simple wall consisting of one cycle. Such 'simple' walls are more common in the Cretaceous than in the Tertiary and can be considered 'relicts' from the Cretaceous coccolith assemblage. In Denmark, however, such forms have only been found from D7 and upwards, thus co-occurring with *N. modestus*, the first representative of *Neochiastozygus* in this area.

Prinsius rosenkrantzii n.sp. Pl. 2, Fig. 20; Pl. 4, Figs 1-5

Holotype: Pl. 4, Fig. 4.
Type level: Danian
Type locality: Fakse, Denmark
Diagnosis: A round or nearly round form of *Prinsius* with a central opening, a double proximal shield and more or less radial distal central elements.
Description: The distal shield consists of usually 10-15 adjacent or

slightly overlapping elements and is larger than the proximal shield. The latter consists of two cycles of radially oriented elements. The inner cycle varies in radius and surrounds the central opening on the proximal side. Distally, the central opening is surrounded by a cycle of more or less radially oriented, blocky elements.
Remarks: The new species is comparable in size with *P. dimorphosus*, which is elliptical and already occurs earlier. The centre is usually closed in *P. dimorphosus* and surrounded by one or two cycles of tangentially oriented, overlapping elements on the distal side.
P. martinii also is elliptical and larger.
Occurrence: *P. rosenkrantzii* (name after the late Prof. A. Rosenkrantz, Copenhagen) was found in the upper Danian of Denmark, where it often occurs as a dominant form of the assemblage.

Plate 3. 1: *Cyclagelosphaera reinhardtii*, LM 3200x, crossed nicols; large form, 81/5. 2: *Cyclagelosphaera alta* n.sp., LM 3200x, crossed nicols, 81/5. 3,4: *Cyclagelosphaera alta* n.sp., 7500x, distal and side view of late specimen, 170/2. 5: *Cyclagelosphaera margerelii*, 5000x, distal view, 85E. 6: *Cyclagelosphaera reinhardtii*, 7500x, distal view; note single distal central cycle, 142/7. 7: *Cyclagelosphaera alta* n.sp., 7500x, distal view of holotype, an early form, 81/5. 8: *Cyclagelosphaera* sp.1, 10 000x, distal view; note two distal central cycles, 142/7. 9,10: *Markalius inversus*, LM 3200x, parallel & crossed nicols, 85F. 11,12: *Markalius apertus* n.sp., LM 3200x, parallel & crossed nicols, 85F. 13: *Markalius apertus* n.sp., 4500x, distal view of broken specimen, late form, 170/2. 14: *Markalius inversus*, 5000x, distal view of eroded specimen, 170/7. 15: *Markalius inversus*, 4000x, proximal view of large specimen, 142/7. 16: *Markalius apertus* n.sp., 5000x, proximal view of holotype, an early form, 85F. 17: *Watznaueria/Ericsonia??* sp.1, 5000x, proximal view; note double proximal shield, 81/10. 18: *Markalius/ Ericsonia??* sp.1, 5000x, proximal view; note double proximal shield, 66. 19: *Biscutum* sp., 5000x, proximal view; note single proximal shield, 85F. 20: *Biscutum* sp., 5000x, distal view, 81/6. 21: *Thoracosphaera?* sp.1, 2500x, 170/1. 21: *Thoracosphaera operculata*, 2500x, sphere with open operculum, 399.Location of samples listed p.135.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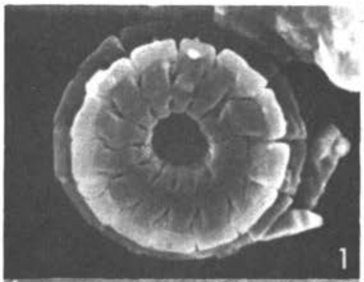
Toweius selandianus n.sp. Pl. 4, Figs 17-20

Holotype: Pl. 4, Fig. 20.
Type level: Selandian
Type locality: Copenhagen
Diagnosis: Small form (2-4 µm) of *Toweius* with large central holes.
Description: The distal shield is larger than the proximal shield. Distally, the central area is surrounded by two cycles of elements, a feature typical for *Toweius* species. Distally, the central area is well defined, proximally, the elements of the proximal shield extend into the central area and there form the central net which, in not overgrown specimens, has large holes.
Remarks: Hay & Mohler (1967), who described the genus *Toweius* and its generotype *T. craticulus*, defined the genus for round to subcircular placoliths. *T. selandianus* is elliptical and even elongate, but otherwise fits the description of *Toweius* well. The main difference of the new species from *T. craticulus*, which was described from the Upper Paleocene *D. multiradiatus* Zone, is the smaller size of *T. selandianus* and its elliptical outline and large holes in the central area. Larger forms of *Toweius* from the Selandian (Pl. 4, Fig. 16) are also elliptical (*Toweius* sp.2).
Occurrence: *T. selandianus* occurs in the Selandian of Denmark. It seems to be the oldest form of the genus to have well defined holes in the central area.

Plate 4. 1-5: *Prinsius rosenkrantzii* n.sp., 10 000x and 8000x (Fig. 4, holotype); proximal views, 399; (1,3; note double proximal shield) and distal views, 142/10, 364/1. 6: *Toweius petalosus* (?), 10 000x, proximal view, 66. 7-9: *Prinsius dimorphosus*, 10 000x and 7500x (Fig. 9), distal views (7,9) and proximal view, 364/5, 142/1, 342/11. 10: *Toweius cf. T. eminens*, 10 000x, distal view, 170/1. 11: *Toweius cf. T. tovae*, 7500x, distal view, 170/2. 12: *Prinsius martinii*, 10 000x, distal view, 347/11. 13: *Prinsius bisulcus*, 10 000x, distal view, 170/5. 14: *Lanternithus duocavus*, 10 000x; note holococcolithic structure, 39. 15: *Toweius?* sp.1, 10 000x, distal view, 170/1. 16: *Toweius* sp.2, 7500x, proximal view, 170/2. 17-20: *Toweius selandianus* n.sp., 10 000x, proximal views (17,18) and distal views; holotype Fig. 20, 50. 21-23: *Toweius?* sp.3, 10 000x & 9000x (Fig. 22), distal views, 352/80A. 24: *Transversopontis?* sp.1, c. 6000x, distal view, 170/1. 25: *Zygodiscus sigmoides*, 5000x, distal view of late form, 170/7. Location of samples listed p.135.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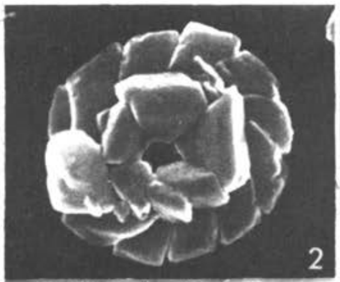
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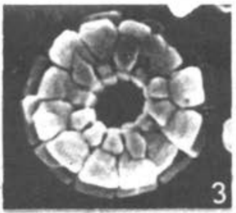
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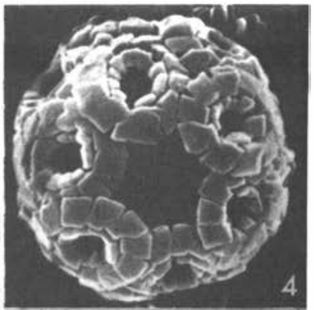
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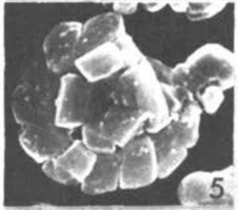
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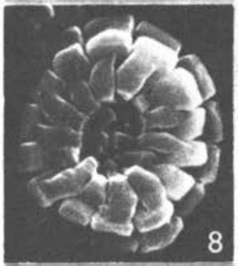
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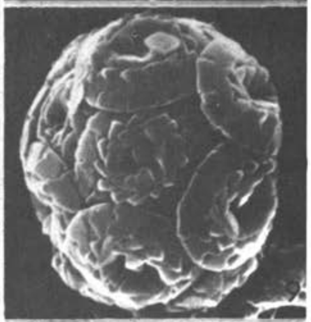
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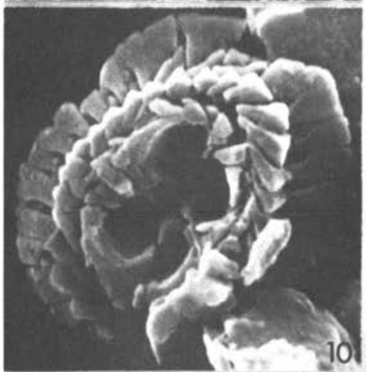
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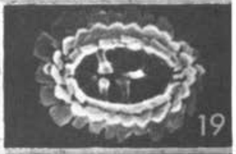
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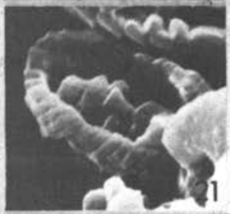
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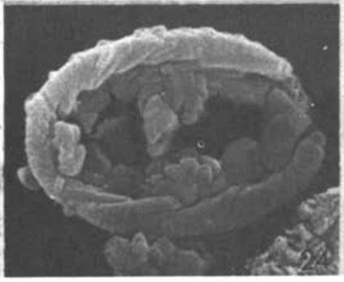
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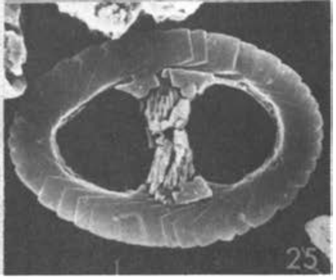
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Toweius? sp. 1. Pl. 4, Fig. 15

A small, elliptical coccolith (less than 2 µm) was found in the uppermost Danian sample from Hvalløse. It has two shields of about equal size and the well defined central area is covered by blocky elements. Its assignment to *Toweius* is due to the lack of any more likely genus to which it could be assigned.

Toweius sp. 2. Pl. 4, Fig. 16

In the Selandian of Denmark, large, elliptical forms of *Toweius* occur together with the smaller *T. selandianus*. They have several cycles of holes in the central net and the distal shield is considerably larger than the proximal one. They differ from *T. craticulus* through their elliptical outline, *T. craticulus* being round to subcircular.

Toweius? sp. 3. Pl. 4, Figs 21-23

Two specimens of small (3-4 µm), elliptical forms having a relatively low distal shield and a large central area were found in the Danian of Rold. The central area is occupied by more or less radially oriented elements (overgrown in the specimens illustrated). No proximal sides were found. The assignment to *Toweius* is mainly due to the lack of any more likely genus to which this form could be assigned.

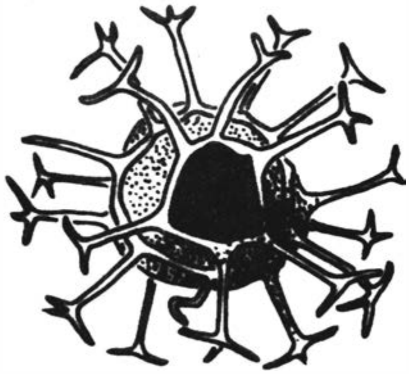
Transversopontis? sp.1. Pl. 4, Fig. 24

The distal view of a single specimen of an early form of *Transversopontis* was found in the uppermost Danian sample at Hvalløse. This form still shows a single cycle wall and a central bridge spanning the open central area. The two resulting holes are each surrounded by a cycle of blocky elements. Such elements are lacking in *Zygodiscus sigmoides* (Pl. 4, Fig. 25), with which *Transversopontis?* sp.1 has many features in common. Later, typical forms of *Transversopontis* show a double cycle wall.

Watznaueria/Ericsonia? sp.1. Pl. 3, Fig. 17

Pl. 3, Fig. 17 shows the proximal side of a *Watznaueria*-like form, where the proximal shield has two cycles. The inner cycle consists of more or less radially oriented extensions of the elements covering the central area. Such 'double' proximal shields are typical of the Tertiary Coccolithaceae *Ericsonia*, *Chiasmolithus* and *Cruciplacolithus*, which do not occur at the base of the Danian. The specimen shown here was found in the uppermost Maastrichtian (*Micula prinsii* Zone) at Dania, but similar forms were also found in the basal Danian at Stevns. As with the circular forms assigned to *Markalius/Ericsonia?* sp. 1, no forms suggesting an evolution from such forms to typical *Ericsonia* or to *Cruciplacolithus* have so far been found.

Sample number	locality - collector - stage
39	Vestre Gasværk, Copenhagen A. Rosenkrantz 1930, Selandian
50	Sundkrogen, Copenhagen harbour A. Rosenkrantz 1920, Selandian
66	Bulbjerg, Jylland (zone B of Ødum) K. Perch-Nielsen 1967, Danian
81/5	Dania, Jylland (Bryozoan limestone) K. Perch-Nielsen 1967, Danian
81/6	Dania, Jylland (Cerithium limestone) K. Perch-Nielsen 1967, Danian
81/10	Dania, Jylland (marl) K. Perch-Nielsen 1967, Maastrichtian
85 E,F,G,	Stevns Klint, Højerup (Bryozoan limestone) K. Perch-Nielsen 1967, Danian
85 C	Stevns Klint, Højerup (Fish clay) K. Perch-Nielsen 1967, Danian
117	Kerteminde (Fyn) W. Wetzel/G. Deflandre, Selandian
142/1,5,7,10	Boring Taars (see Perch-Nielsen 1972) I. Bang, Geological Survey of Denmark, Danian
170/1	Hvalløse (Jylland) H. J. Hansen 1967, Danian
170/2,5,6,7,8	Hvalløse (Jylland) H. J. Hansen 1967, Selandian
173	Klintholm Sydbrud (Fyn) H. J. Hansen, Danian
342/11	Horsens I (boring Jylland) P. McDaniel, Geological Survey of Denmark, Danian
347/11,15,43,55	Hvalløse (boring Jylland) P. McDaniel 1971, Danian
352/78,80A	Trælborg ved Rold (boring Jylland) P. McDaniel 1971, Danian
364/1,5	Legind (Jylland) P. McDaniel 1971, Danian
399	Fakse 'Næsekalk' A. Rosenkrantz 1933, Danian



DINOFLAGELLATE ZONATION AROUND THE BOUNDARY

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A new dinoflagellate stratigraphy for the Upper Maastrichtian and Danian of Denmark was proposed by the author in 1977. This zonation included three Upper Maastrichtian and four Danian biostratigraphic units (Hansen, 1977). One further Maastrichtian zone (*Chiropteridium inornatum - Palynodinium grallator* Zone) can now be separated (Hansen, 1979b). This zone is restricted to the uppermost c. 0.5 m of the Maastrichtian chalk in northern Denmark, where the most complete sequence is represented. The refined dinoflagellate zonation allows the Maastrichtian/Danian hiatus to be analysed in greater detail than has hitherto been possible.

GENERAL CHARACTERISTICS OF THE CRETACEOUS/TERTIARY BOUNDARY

The stratigraphy of the Campanian-Maastrichtian and Paleocene (Danian-Selandian) dinoflagellates from Denmark has been studied by e.g. Wilson (1974), Morgenroth (1968) and Hansen (1977, 1979a, 1979b). This work has given general insight into the behaviour of dinoflagellates at the Cretaceous/Tertiary boundary.

A characteristic feature seems to be the gradual increase in number of Tertiary species and genera occurring already in the Lower Maastrichtian (*Deflandrea diebeli*), the Upper Maastrichtian (e.g. *Deflandrea galeata*, *Thalassiphora pelagica*, *Spiniferites cornutus*, *Hafniasphaera fluens*, *Chiropteridium inornatum*), and lower Danian (e.g. *Danea mutabilis*, *Carpatella cornuta*, *Membranilarnacia tenella*, *Hafniasphaera* spp. *Xenicodium* spp., *Achomosphaera alcicornu*). However, much more striking is the profound change of the dinoflagellate flora that takes place in the upper Danian and Selandian, where the genera *Areoligera* and *Cyclonephelium* completely dominate the assemblages. In contrast to this, the Maastrichtian and lower Danian assemblages are dominated by

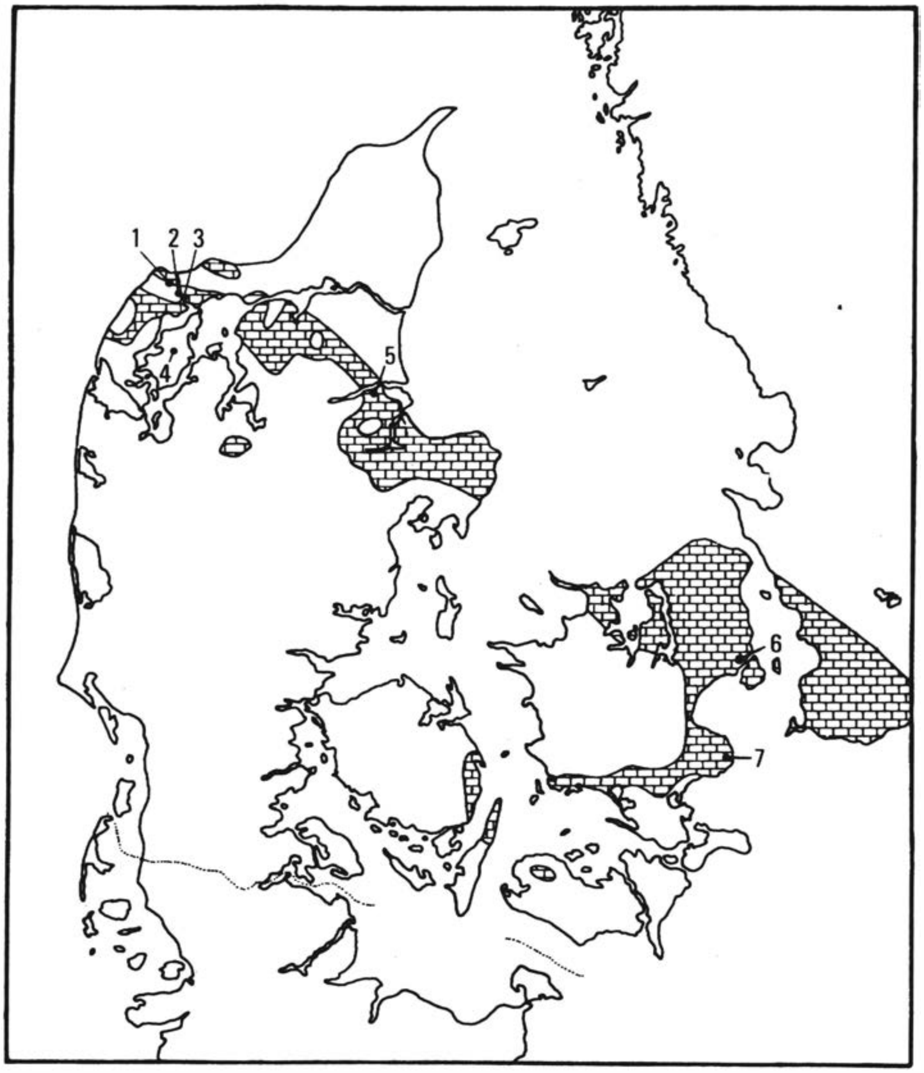

Fig. 1. Geological map of the Danian showing position of localities. 1: Bjerre. 2: Kjølby Gaard. 3: Nye Kløv. 4: Eerslev. 5: Dania 6: Copenhagen TUBA 13. 7: Stevns Klint.

Spiniferites. Neither *Areoligera*, *Cyclonephelium* nor *Spiniferites* contain many stratigraphically diagnostic species. This turn-over should rather be interpreted as a result of global palaeoenvironmental (e.g. climatic) changes, since this change is obviously recorded from most places in the world.

In the upper Danian the number of species with a restricted Tertiary occurrence is further increased, especially with species of *Deflandrea*

	KJØLBY GÅRD	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	EERSLEV	DANIA	BJERRE	KJØLBY GÅRD	NYE KLØV	DANIA	STEVNS KLINT	TUBA 13	BJERRE	KJØLBY GÅRD	NYE KLØV	DANIA	STEVNS KLINT	TUBA 13
S RAM. CAVISPINOSUS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		(●)		(●)	(●)							
P. GRALLATOR			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		(●)	(●)	(●)	(●)			(●)				
T. PELAGICA										●	●	●	●	●	●	●	●	●		●	●	●		●	●		●	●		●			●
C. INORNATUM																	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
D. MUTABILIS																						●	●	●	●	●	●	●	●	●	●	●	●
H. HYALOSPINOSA																										●	●					●	●
M. TENELLA																						●	●	●	●	●	●	●	●	●			●
C. CORNUTA																						●	●	●	●	●	●	●	●	●			●
H. SEPTATA																													●	●		●	●
X. RETICULATUM																													●			●	●
X. RUGULATUM																												●	●	●	●	●	●
	V a (WILSON 1974)		TANYOSPHAERIDIUM MAGDALIUM SUBZONE							THALASSIPHORA PELAGICA SUBZONE							CHIROPTERIDIUM INORNATUM - PALYNODINIUM C.R. ZONE NOV.					CARPATELLA CORNUTA ZONULE						XENICODINIUM RUGULATUM ZONULE					
																						CHIROPTERIDIUM INORNATIUM SUBZONE											
			PALYNODINIUM GRALLATOR ZONE																			DANEA MUTABILIS ZONE											

Fig. 2. Scheme showing the occurrences of some stratigraphically significant species at different localities and at different stratigraphic levels.

and related groups (e.g. *Deflandrea striata*, *Palaeocystodinium* sp.). This process is continued during the Selandian with the first occurrence of e.g. *Deflandrea speciosa*, *D. phosphoritica*, *Spinidinium densispinatum*, *Albertia dilwynensis* and in particular in the Upper Selandian with the first occurrence of the *Wetzeliella* group.

BIOSTRATIGRAPHICALLY DIAGNOSTIC DINOFLAGELLATES

Close sampling of the Maastrichtian/Danian boundary sections at Nye Kløv, Kjølby Gaard, Bjerre, Eerslev and Dania in northern Jylland (Figs 1-2) has been carried out and compared to samples from Stevns Klint and Copenhagen (core Copenhagen Tuba 13) (Figs 1,3).

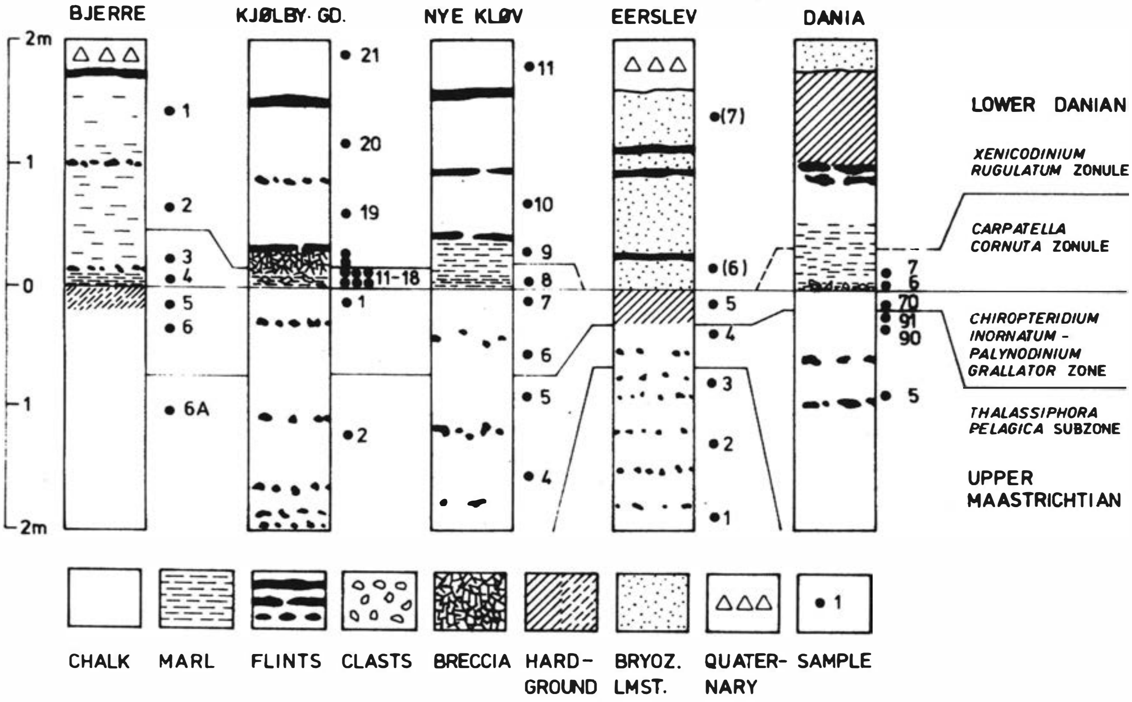

Fig. 3. Lithological sections of the upper 2 m of the Maastrichtian and the lower 2 m of the Danian in northwestern Denmark. Dinoflagellate zonation and position of samples indicated. The uppermost Maastrichtian chalk at Bjerre is only weakly hardened.

Chiropteridium inornatum Drugg, 1970 has been found to occur below the Maastrichtian/Danian boundary in all the sections in northern Jylland shown in Fig. 2, whereas at other localities investigated (Stevns Klint, core Copenhagen Tuba 13) *C. inornatum* occurs only above the Maastrichtian/Danian boundary together with characteristic Danian dinoflagellate species such as *Danea mutabilis* Morgenroth, 1968, *Carpatella cornuta* Grigorovitsch, 1969, *Membranilarnacia tenella* Morgenroth, 1968, and *Hafniasphaera hyalospinosa* Hansen, 1977. This biostratigraphic differential development of the Maastrichtian/Danian boundary in Denmark is believed to reflect a more complete sequence across the boundary in northern Denmark than in the type area of the Danian in eastern Denmark.

This interpretation is supported by lithological evidence. The important event in dinoflagellate stratigraphy at the base of the *Danea mutabilis* Zone (base Danian) (Fig. 3) at most localities takes place at the base of a marl layer containing clasts of Upper

Maastrichtian age indicating that a part of the section is missing (Fig. 2). However, in the marl at Stevns Klint (the Fish clay) the clasts are rounded, giving the marl layer a conglomeratic appearance, whereas in Kjølby Gaard and Dania the clasts are angular, giving the marl layer as well as the overlying sediment in Kjølby Gaard a bracciated appearance. Furthermore, the clasts in Kjølby Gaard are derived from Maastrichtian as well as Danian sediments (Håkansson & Hansen, this volume). The sections at Eerslev (where the marl layer is missing) and Kjølby Gaard are situated above halokinetically induced structures elevating Mesozoic and Tertiary strata (*cf.* Rasmussen, 1978). This deformation of the strata combined with the different competence of the flint-poor Maastrichtian chalk and the flint-rich Danian chalk and bryozoan limestones might explain the brecciation of the Maastrichtian/Danian boundary strata at Kjølby Gaard, whereas at Stevns Klint the clasts are more likely to have formed during the slow accumulation of the marl layer (see Hansen, 1977 for discussion). Therefore it would seem that the sedimentological development of the boundary strata indicates a hiatus at Stevns Klint and Eerslev, whereas incomplete preservation of the boundary strata at other localities may be partly explained by post-sedimentary deformation and solution (Håkansson & Hansen, this volume). This point of view is supported by the fact that hardgrounds in contact with the Maastrichtian/Danian boundary are only clearly developed at Stevns Klint and Eerslev.

It should be stressed that cases of paleoenvironmentally controlled differences do occur in the Danish Basin, as reflected first and foremost in the relative abundance of certain species. Thus, *Hafniasphaera hyalospinosa* has not been found at all in northwestern Denmark, whereas it is abundant in eastern Denmark. A similar pattern is observed with respect to the species *Carpatella cornuta* and *Membranilarnacia tenella*, which are most frequent in northwestern Denmark.

Several diagnostic dinoflagellates from the boundary layers, including *Carpatella cornuta*, *Danea mutabilis* and *Chiropteridium inornatum* have also been reported from North America (Drugg, 1967 and 1970, Evitt, 1973) and Europe (Grigorovitsch, 1969, Jan du Chêne, 1977). Consequently the stratigraphic scheme presented here may prove to be an effective tool in the palaeontological dissection of the Cretaceous/Tertiary boundary.

Some taxonomic problems concerning some of the species here discussed are treated in Hansen (1979b).

DINOFLAGELLATE LIST

The 40 most abundant dinoflagellates from the Maastrichtian/Danian boundary sections at Bjerre, Kjølby Gaard, Nye Kløv and Eerslev are listed below. The letters 'M' and 'D' indicate that the species has been found in Maastrichtian and Danian sediments respectively.

Achomosphaera ramulifera, M + D
Achomosphaera sagena, M
Amphidiadema rectangularis, M
Cannosphaeropsis utinensis, D
Carpatella cornuta, D
Areoligera spp., M + D
Catillopsis sp., D
Cordosphaeridium inodes, M + D
Chiropteridium inornatum, M + D
Cyclonephelium spp., M + D
Danea mutabilis, D
Deflandrea diebeli, M
Deflandrea galeata, M
Eisenackia circumtabulata, D
Fibradinium annetorpense, D
Gonyaulacysta wetzeli, M + D
Hafniasphaera septata, D
Hafniasphaera sp., M
Hexagonifera chlamydata, D
Hystrichokolpoma bulbosa, M + D
?Hystrichokolpoma fimbriata, D
Hystrichosphaeridium recurvatum, M + D
Hystrichosphaeridium tubiferum, M + D
Lanternosphaeridium axiale, M + D
Lanternosphaeridium ovale, M + D
Membranilarnacia tenella, D
Palaeocystodinium sp., M
Palaeoperidinium pyrophorum, M + D
Palynodinium grallator, M
Pyxidiella sp., D
Rhenidinium membraniferum, D
Spiniferites ramosus cavispinosus, M
Spiniferites ramosus granosus, M + D
Spiniferites ramosus ramosus, M + D
Spiniferites cf. cornutus, M + D
Spongodinium delitiense, D
Tanyosphaeridium magdalium, M + D
Thalassiphora pelagica, M + D
Trithyrodinium sp., M
Xenicodinium rugulatum, D

GUIDE TO LIMHAMN QUARRY

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The quarry at Limhamn, south Sweden (located immediately south of Malmö) is today the principle exposure of the Danian Stage in Scandinavia. (Figs 1-2). More than 60 m of uppermost Maastrichtian chalk and Danian limestones are exposed in the quarry. Prior to 1965 nearly 20 m of uppermost Maastrichtian chalk were exposed in the deepest part of the quarry. Today, however, that section is under water and only 3 m of chalk at the Maastrichtian/Danian boundary are accessible (although with great difficulty). A detailed profile of the section comprising the Maastrichtian/Danian boundary at Limhamn is presented in Fig. 4, while a more generalized profile of the Danian exposed in the quarry is shown in Fig. 3.

These sediments are only exposed together at this outcrop. However, Maastrichtian and Danian limestones otherwise occur throughout the southwesternmost part of southern Sweden, and, except for extremely restricted and small occurrences of Middle Paleocene sediments (Brotzen, 1948; Gustafsson & Norling, 1973), are the youngest pre-Quaternary rocks in Sweden. The depositional basin that these and underlying Mesozoic sediments were deposited in is considered part of the Danish Basin. In Sweden this basin is bordered along the northeast by the Fennoscandian Border Zone of the Baltic Shield, the border being distinctly recognized as the Tornquist Line (see discussion in Bergström *et al.*, 1973; Baartman & Christensen, 1975).

Whereas the Maastrichtian chalk appears to have a fairly uniform distribution throughout the basin, the facies and thickness of the Danian is not uniform over the entire area. During Danian times sediment deposition appears to have been affected by the existence of basement controlled swells and depressions running approximately parallel to the Fennoscandian Border Zone and reflecting the prevalent tectonic pattern of the Danish Basin adjacent to the zone.

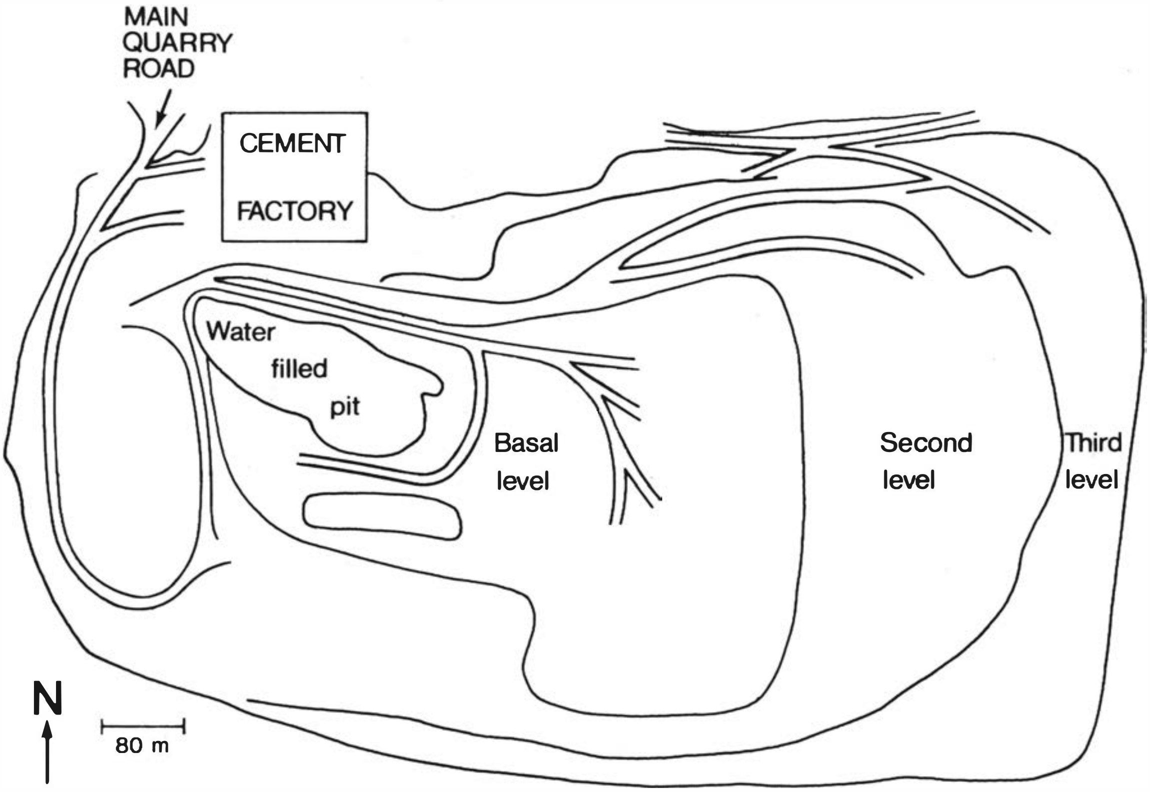


Fig. 1. Map of Limhamn Quarry, south Sweden. The various levels of the quarry mentioned in the text are indicated.

The Alnarp Graben, adjacent to the Tornquist Line, possesses thick Danian sequences, the Danian bryozoan limestones at Landskrona reaching 180 m in thickness. Two distinct areas occurring away from the border zone which may represent swell-like structures have thinner Danian sequences, one of which shows evidence of condensation. They extend from the Limhamn area across the Öresund towards the Copenhagen region and along the south coast of Sweden from the Falsterbo peninsula eastwards to the border zone. At Limhamn the Danian, approximately 60 m thick, is represented by a nearly complete sequence of the stage, although several horizons in the quarry show evidence of condensation. On the Falsterbo peninsula 48 m and 46 m of Danian limestones were penetrated in two drillings (Brotzen, 1944). Comparable thicknesses, approximately 40 m, of Danian limestones are met with along the south coast to Ystad. At Ystad the Danian carbonates are replaced by a more

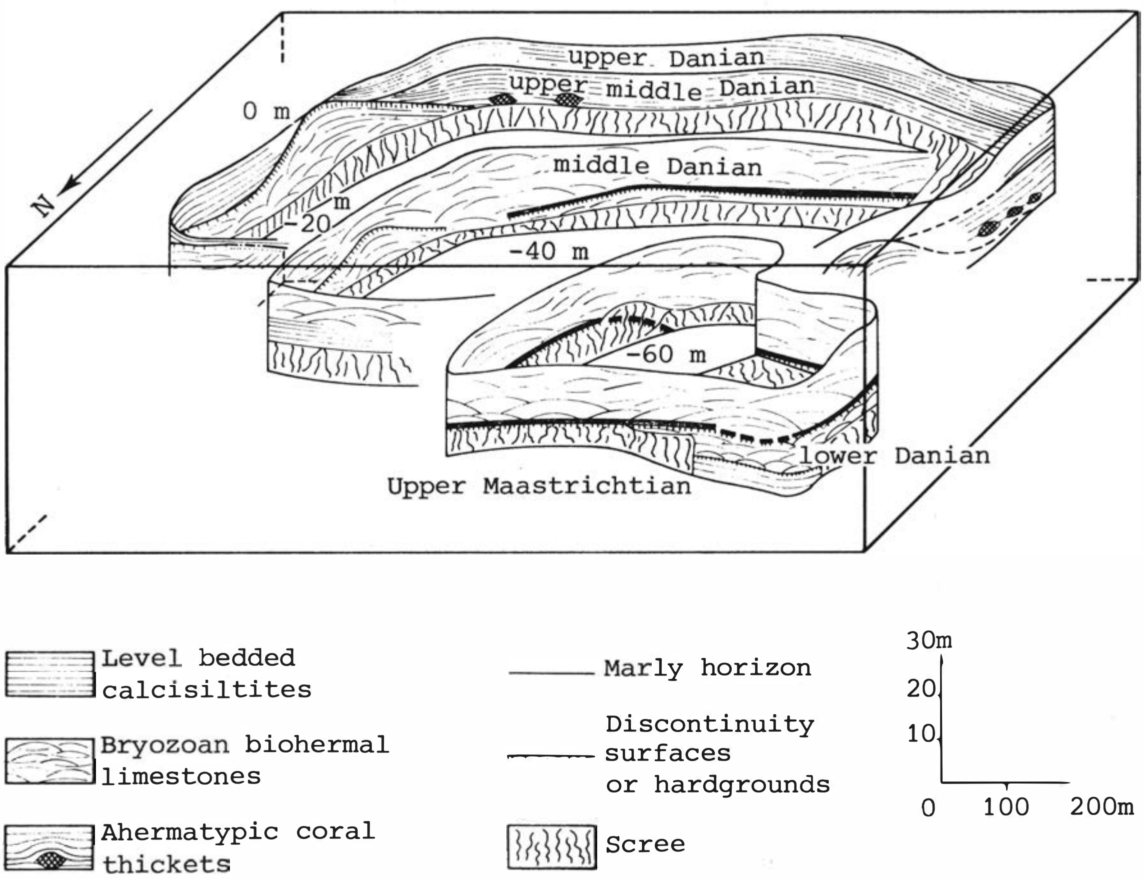


Fig. 2. Schematic view of Limhamn Quarry. After unpubl. drawing by Finn Jacobsen.

arenaceous facies (Brotzen, 1948). These two areas of thinner Danian sequences are separated by a shallow trough with somewhat thicker Danian deposits. The total thickness of the Danian in this trough is not known exactly, but at Klagshamn, 5 km south of Limhamn, more than 60 m of limestones were penetrated in a drilling without reaching the base of the Danian (Brotzen, 1940).

The occurrence and stratigraphy of the Maastrichtian and Danian in Sweden are chiefly known through the publications by Brotzen (1940, 1944, 1948, 1959). Other studies on the Danian at Limhamn include those by Hennig (1899) and Hadding (1933, 1941) (see also the exhaustive bibliography in Brotzen, 1959).

The systematics and stratigraphic distribution of planktic foraminifera from the Maastrichtian and Danian strata of southern Sweden have been studied by Troelsen (1957), Berggren (1960, 1962a, b,) and Malmgren (1974, 1976). Berggren erected a 3-fold zonation of the Danian: the Danian Stage is equated with the *Globoconusa daubjergensis* zone P1, while the three subzones are, from the base of the Danian, *Subbotina pseudobulloides* Subzone P1a, *S. triloculinoides* P1b, and *Planorotalites compressa* P1c.

Malmgren (1974, p. 78) found it possible to recognize a further subdivision of the P1c Subzone, applicable to the Danian of southern Scandinavia. This zonule, the *S. pseudobulloides* Right Coiling Zonule, is characterized by (1) the presence of *P. compressa* and (2) statistically significant right coiling of *S. pseudobulloides*. Berggren's and Malmgren's zonations are summarized and correlated with the Limhamn section in Fig. 3.

Ødum (1971) summarized the data collected from a number of boreholes penetrating Danian and Maastrichtian strata on the Falsterbo peninsula, 20 km south of Limhamn. Kjellström (1973) described Maastrichtian dinoflagellates from the Höllviken 1 borehole located here. Cheetham (1971) examined the distribution and palaeoecology of cheilostome bryozoans in the Danian bryozoan mounds exposed in the Limhamn Quarry, while Brood (1973) treated the cyclostome bryozoan fauna from the Maastrichtian and Danian at Limhamn.

THE LIMHAMN QUARRY

Brotzen (1959) described in detail the section at Limhamn and recognized the Maastrichtian/Danian boundary. The Danian sequence was divided by him into four zones based on the spines of the regular echinoid *Tylocidaris*. A *Tylocidaris* zonation had earlier been applied at Danian localities in Denmark, including the type localities Stevns Klint and Fakse (Ødum, 1926; Wind, 1954; see Asgaard, this volume). Brotzen correlated the Limhamn section with the type Danian sections and the Limhamn area was considered by him as part of a type region of the Danian.

Recent work by Hansen (1977) on the dinoflagellate distribution in the Danian of Denmark has demonstrated that the *Tylocidaris* zonation is diachronous relative to the dinoflagellate zonation. The various *Tylocidaris* species are apparently each restricted to particular facies. Thus, the *Tylocidaris* zones of the Danian at Limhamn, each well defined lithologically, should be perhaps regarded as informally denoting lithostratigraphic units. It is in this form that they are retained in this guide.

The uppermost Maastrichtian

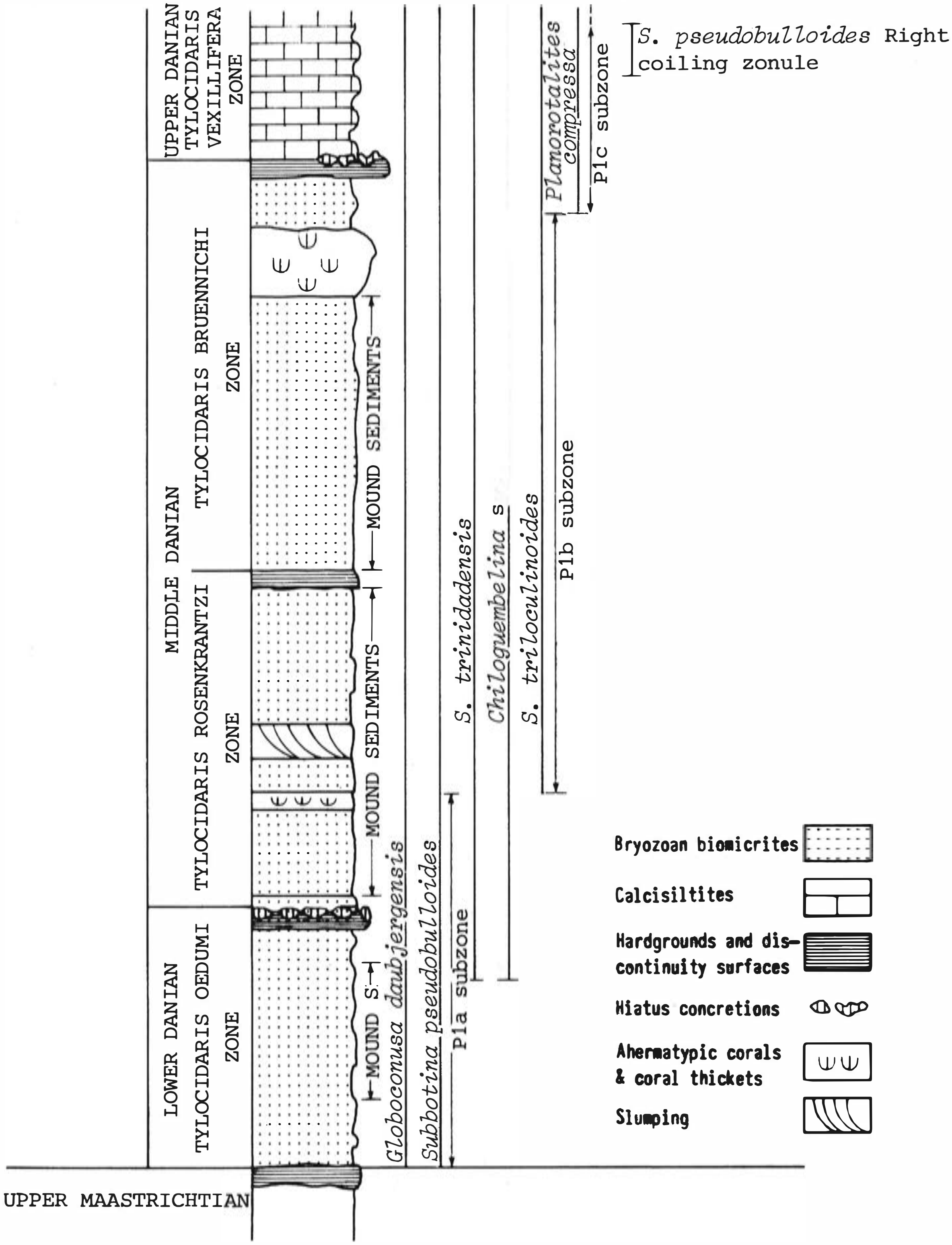
Approximately 3 m of uppermost Maastrichtian chalk are exposed in a very small section at the base of the quarry along the west wall just above the water filled pit. The lithology and the planktic foraminiferal fauna of five samples taken from the chalk are schematically shown in Fig. 4. The planktic foraminiferal fauna includes the following species: *Pseudotextularia elegans*, *Heterohelix striata*, *Planoglobulina brazoensis*, *Guembelitria cretacea*, *Globigerinelloides multispina*, and *Hedbergella monmouthensis*.

The Maastrichtian exposed here is composed of rather hard white chalk intercalated with two marly layers and five beds with flint-filled burrows (*Thalassinoides*). The Maastrichtian sequence is topped by a hardground. Although no encrusting or boring organisms are present on the hardground surface, the presence of angular fragments of the hardground together with hiatus sediments in burrows in the hardground indicate that this bed underwent synsedimentary lithification prior to the deposition of the overlying sediments of Danian age. The planar upper surface of the hardground and the occurrence of different sediments in the burrows show that there has been a period of alternating sedimentation and erosion and scour before uninterrupted sedimentation resumed. Thus, a hiatus of unknown duration marks the boundary between the Maastrichtian and the Danian here. The section at Limhamn differs considerably from the boundary section at Stevns Klint (*cf.* Rosenkrantz & Rasmussen, 1960; Håkansson, 1971; Surlyk, this volume). No Fish clay or bed comparable to the Cerithium limestone as found above the Maastrichtian at Stevns Klint is present above the hardground at Limhamn.

The lower Danian

The lower Danian, the *Tylocidaris oedumi* Zone, is exposed around the entire basal level (- 60 m BSL) of the quarry. Above the Maastrichtian hardground the first 3 m of the Danian are developed as alternating hard and soft, level-bedded bryozoan biomicrites (bryozoan limestone facies). Beds with black flint occur at various intervals, these appear mainly as replacements of burrow fills (*Thalassinoides*) and occur throughout the whole Danian sequence here. The succeeding 8 m of the

Fig. 3. Schematic and composite section of the Maastrichtian and Danian sequence at Limhamn. The *Tylocidaris* zones, the standard planktic foraminiferal zones (P1a-c) and the occurrence and range of the planktic foraminifera of the Danian sequence are shown.


UPPER DANIAN
TYLOCIDARIS VEXILLIFERA ZONE
MIDDLE DANIAN
TYLOCIDARIS BRUENNICHI ZONE
TYLOCIDARIS ROSENKRANTZI ZONE
LOWER DANIAN
TYLOCIDARIS OEDUMI ZONE
UPPER MAASTRICHTIAN
MOUND SEDIMENTS
MOUND SEDIMENTS
MOUND S.
Globoconusa daubjergensis
Subbotina pseudobulloides
P1a subzone
S. trinidadensis
Chiloguembelina s
S. triloculinoides
P1b subzone
Planorotalites compressa
P1c subzone
S. pseudobulloides Right coiling zonule
Bryozoan biomicrites
Calcisiltites
Hardgrounds and discontinuity surfaces
Hiatus concretions
Ahermatypic corals & coral thickets
Slumping

lower Danian are developed as bryozoan biomicrite mounds. The mounds that occur throughout the lower and middle Danian at Limhamn are in lateral contact with one another for the most part and appear to have grown upwards overlapping older mounds. Thus, an intermound facies is difficult to distinguish. The uppermost 4 m of the lower Danian shows a return to essentially level-bedded biomicrites. This zone is topped by a massive limestone bed approximately 1 m thick which can be followed around the entire basal floor of the quarry. The upper surface of this bed is paved with hiatus concretions. These synsedimentarily lithified concretions indicate a pause in deposition and some degree of submarine erosion. No indication of subaerial exposure of this bed has been observed. The hiatus concretions are slightly phosphatized and have been colonized chiefly by boring sponges.

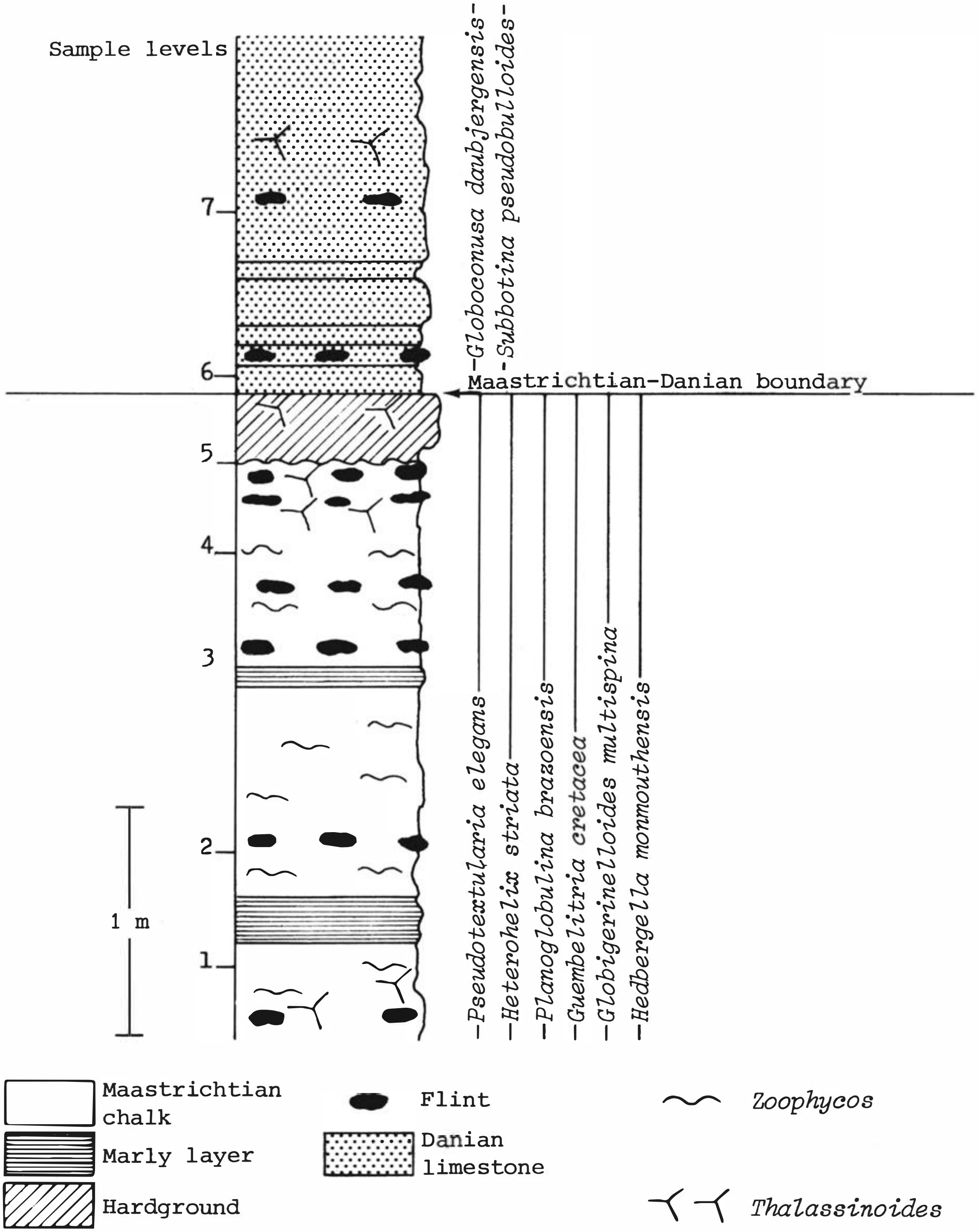
Already in the lowermost bed of this zone *Globoconusa daubjergensis* and *Subbotina pseudobulloides* occur. *S. trinidadensis* and *Chiloguembelina* spp. appear approximately 4 m below the uppermost bed of this zone.

The middle Danian

The middle Danian is comprised of a lower and upper bryozoan biomicrite mound complex. These are referred to the *Tylocidaris rosenkrantzi* Zone and the *T. bruennichi* Zone respectively. The middle Danian sequence begins with 0.5 - 1 m alternating hard and soft biomicrite beds. These beds are replaced upwards by the lower bryozoan mound complex. This complex is approximately 12 m thick. 6 - 7 m above the base of the middle Danian thin lenses (50 cm thick and 3 - 4 m long) of ahermatypic corals are intercalated with the bryozoan biomicrites. The upper parts of these mounds in this complex throughout the quarry frequently show evidence of slumping, with up to 6 - 10 m lateral and downward displacement of mound sediments. Both simple displacement and mushroom-like anticlinal folds, accentuated by late flint diagenesis within burrows, can be seen in the north wall of the basal level of the quarry.

A minor discontinuity surface has been observed approximately 20 m above the base of the middle Danian and can perhaps be regarded as marking the boundary between the two *Tylocidaris* zones of the middle Danian. It is, however, difficult to discern in the exposure. The next level of the quarry exhibits the upper middle Danian bryozoan bioherms or mounds.

Fig. 4. Detailed section of the Maastrichtian/Danian boundary at Limhamn, south Sweden, indicating the occurrence of planktic foraminifera.


Sample levels
7
6
5
4
3
2
1
1 m
Maastrichtian-Danian boundary
Globoconusa daubjergensis
Subbotina pseudobulloides
Pseudotextularia elegans
Heterohelix striata
Planoglobulina brazoensis
Guembelitria cretacea
Globigerinelloides multispina
Hedbergella monmouthensis
Maastrichtian chalk
Marly layer
Hardground
Flint
Danian limestone
Zoophycos
Thalassinoides

A major change in the depositional environment is indicated in the uppermost middle Danian, exposed in the third level of the quarry. Here, an extensive level of ahermatypic coral thickets is developed on the crests and flanks of the large middle Danian mounds. These lenticular shaped thickets range in size from 3 - 15 m long and 2 - 4 m high. These thickets are highly fossiliferous and suppert a diverse invertebrate fauna (Brotzen, 1959, p. 23; Hadding, 1933). The sporadic occurrence of the light dependant coral *Heliopora incrustans* indicates growth of these thickets at least within the lower limits of the photic zone. The bryozoan mounds are believed to have been deposited in perhaps somewhat deeper water, around 100 - 200 m (see discussion in Cheetham, 1971, with review of earlier literature). The ahermatypic coral thickets are covered by 1 - 4 m level bedded biomicrites. The uppermost bed of the middle Danian is a discontinuity surface which shows great lateral variation and development. Along the northern half of the quarry the discontinuity surface is represented by a complex well-developed hardground and hiatus concretions. Southwards in the quarry these synsedimentarily lithified sediments are replaced by an unlithified discontinuity surface.

Brotzen (1959) regarded the ahermatypic coral thickets and the overlying discontinuity surface as evidence of a period of shallowing and emergence. However, the thickets are essentially composed of a deeper water coral fauna (Floris, 1972) and the hardground and hiatus concretions show no evidence or indication of subaerial exposure.

Approximately 7 m above the base of the middle Danian *Subbotina triloculinoides* appears, while *Planorotalites compressa* makes its first appearance 3 m below the discontinuity surface marking the top of the middle Danian.

The upper Danian

The upper Danian, *Tylocidaris vexillifera* Zone, is best exposed along the south wall of the upper level of the quarry. Here 8 - 10 m of alternating hard and soft calcisiltites occur above the discontinuity surface that tops the middle Danian. Grey to black flint-filled *Thalassinoides* are prominent throughout the sequence. The uppermost beds of the Danian have been glacially eroded and the sequence is covered by Quaternary deposits.

While Brotzen (1940, 1959) suggests that the lower part of the upper Danian is represented at Limhamn and the uppermost beds of the Danian exposed at Klagshamn 5 km south, it should be borne in mind that the hardground-discontinuity surface at the base of the upper Danian at Limhamn represents a hiatus of unknown duration.

DISTRIBUTION OF CALCAREOUS NANNOFOSSILS, RESUMÉ SUPPLIED BY KATHARINA PERCH-NIELSEN

Samples from the quarry as well as from cores provided by Euroc Corp. have been studied. In the Maastrichtian, at the bottom of the quarry and in the cores, the *Nephrolithus frequens* Zone is represented with its usual assemblage. Above the Cretaceous-Tertiary boundary, assemblages of the lower and the upper part of NP1 were found. They include varying amounts of reworked Maastrichtian forms, but are dominated by the genera already known in the Maastrichtian and surviving into the Danian: *Biscutum*, *Crepidolithus* and *Cyclagelosphaera*, and in the upper part of the zone: *Zygodiscus* and *Markelius*. NP1 is about 7 m thick and the overlying NP2 seems to reach a similar thickness. As at Stevns Klint, the 2 subzones could be distinguished in NP 2, the upper one characterized by the presence of *Prinsius dimorphus*. The coccoliths of the overlying NP3 are usually poorly preserved and rare. *Neochiastozygus* was, however, found in a few samples in the cores. Thus it can be assumed that besides the basal part of NP3, the next subzone is also represented at Limhamn. No well developed, typical *Prinsius martinii* and no *Neochiastozygus saepes* were found in the quarry or in the cores, indicating that the uppermost Danian is probably missing here.

At Klagshamn quarry, 5 km south of Limhamn, the uppermost Danian preserved here also belongs to the *Neochiastozygus modestus* assemblage and no *N. saepes* was found. In the overlying Selandian (Middle Paleocene) the coccolith assemblage contains *Prinsius martinii* and *Neochiastozygus perfectus*, thus the uppermost Danian with *N. saepes* seems to be missing in this area.

GUIDE TO FAKSE LIMESTONE QUARRY

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Øster Voldgade 5-7, DK-1350 Copenhagen K

The quarry is situated immediately to the east of the small town of Fakse in southern Sjælland, about 20 km from Stevns Klint and about 65 km SSW of Copenhagen. Earlier spellings of Fakse vary considerably. Limestone from quarries at Fakse was used for building churches in Mediaeval times and later on in secular buildings and for agricultural and other purposes.

The earliest mention of fossils from the limestone are from the second half of the 18th century. The locality was effectively brought to the attention of geologists by the papers of Steffens and Bedemar (see Garboe, 1959) and especially by Forchhammer (1825).

There were originally a number of small quarries in the hill Fakse Bakke, almost all traces of which have now been obliterated by the present extensive workings. Before he established the Danian Stage in 1847, Desor visited one or more of these small quarries and also considered Stevns Klint; Grõnwall (1899) and Nielsen (1909) later placed the quarry within a subdivided Danian stratigraphy and Rosenkrantz (1938) described a borehole on Fakse Bakke that penetrated the underlying lower Danian and entered the Maastrichtian chalk. Rosenkrantz & Rasmussen (1960) gave a general account of the quarry and many of the lithofacies it exposes, and quarry sections have been published by Asgaard (1968) and Cheetham (1971). A description of the quarry was published in Danish by Floris (1971).

Today the large quarry covers 1 km^2 and is about 50 m deep. The present quarrying methods of blasting and harrowing are not favourable to the production of clean sections, and exposures *in situ* are limited. Large quantities of highly fossiliferous bryozoan limestone and coral limestone are available on the quarry floor, however, which yield extensive faunas. All the rocks exposed are of *Tylocidaris bruennichi* Zone, middle Danian (see Asgaard, this volume). All samples so far studied from the quarry and from a boring belong to nannoplankton zone NP 3 (Perch-Nielsen, this volume). The absence of typical *Prinsius martini* and *Neochiastozygus* also in a sample from the now totally worked out 'Næsekalk' chalk facies, which furnished the best preserved coccoliths at Fakse, indicates that only the lower part of NP 3 is represented at Fakse. *Chiasmolithus danicus* is well developed and the Prinsiaceae are dominated by *Prinsius rosenkrantzi.*

In earlier days it was seen that the bryozoan limestone largely occurred as a complex of mounds, intercalated by banks or lenses of coral limestone. This relationship can only locally be seen today (Fig. 2). In most places the material appears to be more or less autochthonous, but at some localities within the pit (Fig. 1, D,F), steep, intraformational submarine talus slopes of abraded intraclastic debris occur (Asgaard, 1968, Fig. 3).

The two major facies of limestone occur in a wide range of subfacies, owing in part to local depositional differences and in part to local variation in diagenesis.

Bryozoan limestone

This facies ranges from a mud-supported, chalk-like, uncemented rock containing sparse skeletal grains, through wackestones and packstones, variously cemented, and dominated by bryozoan skeletons, to grainstones with little or no micrite matrix. The latter commonly fills thalassinoid burrows in coral limestone, thereby presenting a spectacular and characteristic facies of Fakse bryozoan limestone (Fig.3).

Locally the bryozoan limestone contains greyish or brownish flint, developed as thin sheets or layers that follow and emphasize bedding. Ghosts of the replaced bryozoans remain visible within the silicified sediment to produce a very characteristic flint facies. In a few places dolomitization has produced well-developed cannon-ball concretions, commonly in association with flint layers.

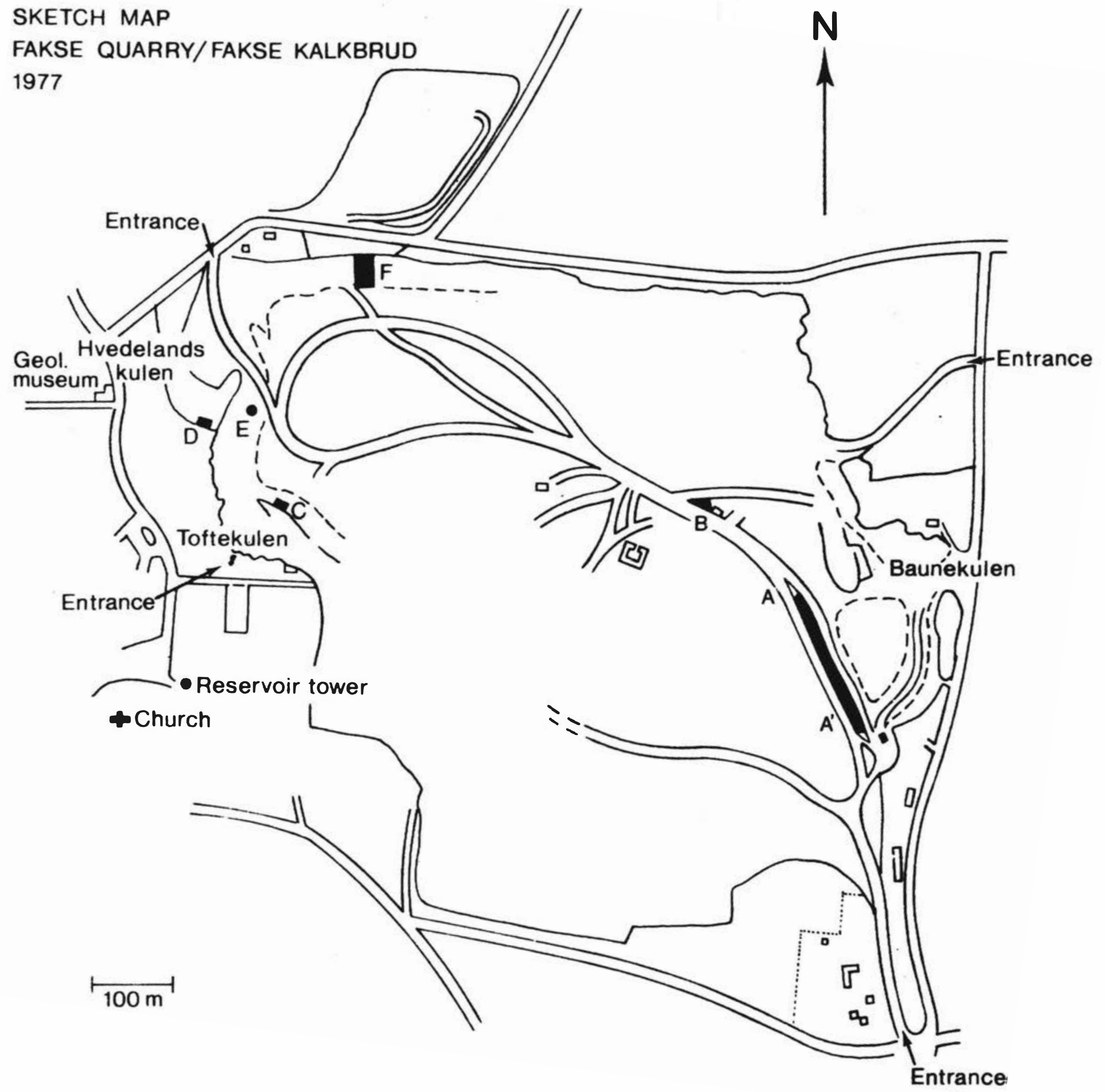
Coral limestone

The coral limestone facies is largely unbedded, flintless, and occurs as much larger banks or lenses than at Limhamn (Holland & Gabrielson, this volume). The rock has arisen through the extensive growth of coral, dominated by three slenderly branching scleratinian species, *Dendrophyllia candelabrum*, *Faksephyllia faxoensis* and *Oculina becki.* Micrite has filled the interstices within this coral frame to varying degrees, and sizeable regions to small patches have remained mud-free (Fig. 4). The corals are clearly autochthonous; however, they are never found actually in life position (Floris, 1967), but always show various degrees of tilting and fragmentation.

The main sub-lithofacies of coral limestone to be found at Fakse are: (1) uncemented chalk containing calcitized corals; (2) the same, but thoroughly cemented; (3) the same, thoroughly cemented micrite, but with the corals dissolved to leave a network of branching, empty voids ('piped limestone'); (4) corals standing free, without matrix except within the skeleton between the septa, the aragonite calcitized and normally overgrown by calcite cement crusts (Fig. 6). Among the more or less complete corals (Fig. 5), debris of corals is also common, probably largely the result of *in situ* fragmentation. In many cases the coral skeleton was riddled by boring sponges, which must have promoted such fragmentation.

Fig. 1. Sketch map of Fakse Quarry, 1977. Owing to the rate of exploitation, individual exposures are normally only temporary in nature. However, it is hope that the following localities within the quarry will be available. A-A'. Section described by P.C.Rasmussen, herein (Fig. 2). B. Bryozoan mound. Irregular flints indicate burrows in the biomicrite. C. Oyster-conglomerate with matrix of bryozoan fragments, coral fragments, and small amounts of micrite (as partial fillings of the oyster shells). Transport probably over a very limited distance. D. Conglomerate of pebbles of local coral limestone ('piped limestone') in a matrix of bryozoan fragments. At least some of the pebbles were rolled after dissolution of the coral skeletons. E. Dolomite concretions; bulbous masses of dolomite or of dolomite crystals in apparently concretionary calcite. Dolomite is rare in Fakse Quarry and has been found only in the bryozoan limestone. F. A coral bank core overlies bedded coral limestone and a large unit of bryozoan limestone. The boundary between the two latter is locally subvertical, sharp and uneven. The unit of bryozoan limestone contains large rounded boulders (20 - 30 cm in diameter) of 'piped limestone'. The bedded coral limestone probably represents the flank of a coral bank and consists of thin beds of 'piped limestone', of coral fragments, and of coarse bryozoan fragments. In places it is conglomeratic, with pebbles of 'piped limestone' in a matrix of bryozoan fragments (at least some of the pebbles were deposited, while the aragonitic skeletons were still present). Some blocks of bryozoan limestone have only been slightly displaced.

In the lower part of the bedded complex are 'dykes' of bryozoan limestone with sharply outlined lumps of bedded coral limestone and diffusely outlined lumps of 'piped limestone'. The 'dykes' may be interpreted as fillings of canals, which had been eroded in a bank slope.


SKETCH MAP
FAKSE QUARRY/FAKSE KALKBRUD
1977
N
Entrance
F
Entrance
Geol. museum
Hvedelands kulen
D
E
C
B
Toftekulen
Baunekulen
Entrance
A
A'
Reservoir tower
Church
100 m
Entrance

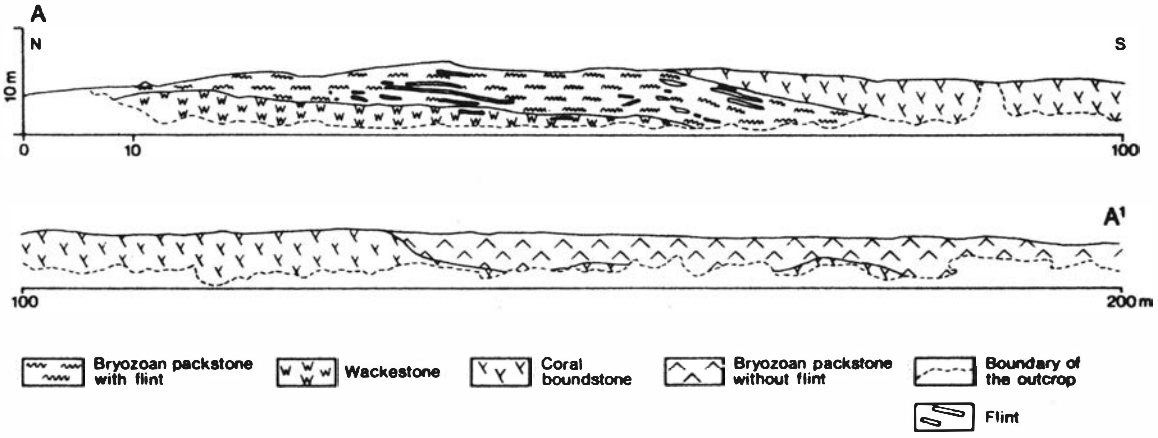


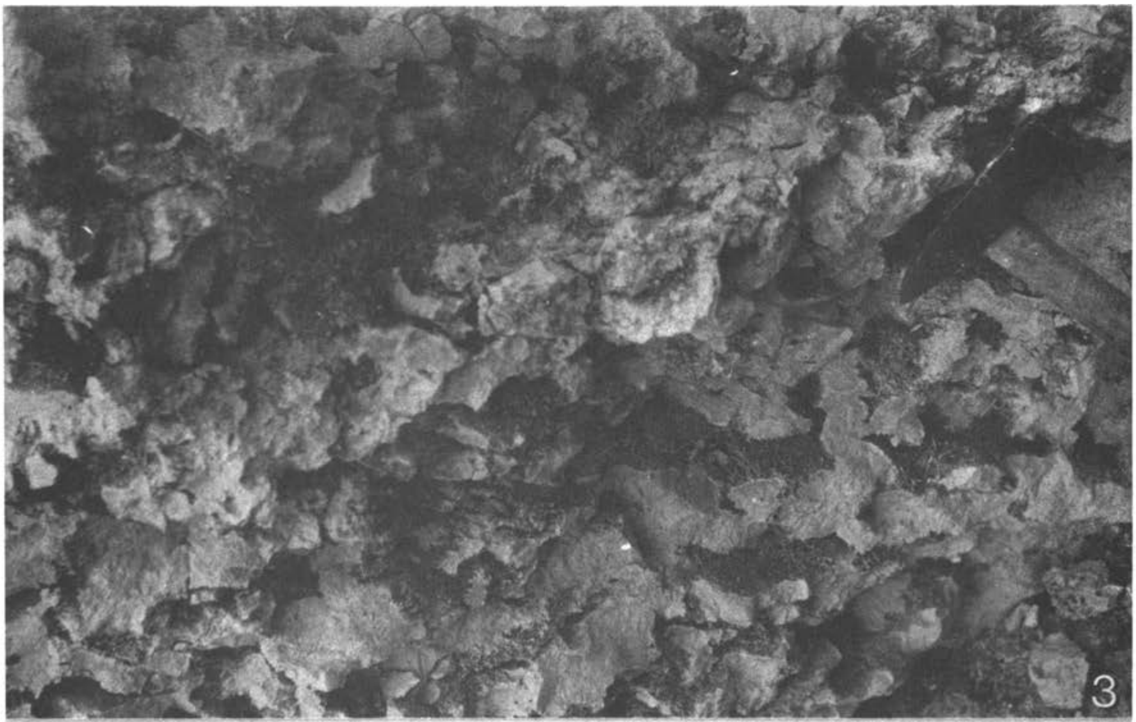
Fig. 2. Section A-A' (Fig. 1), described by P. C. Rasmussen in the text.

In contrast, skeleton debris has also been observed on 40°-50° slopes that had a topographic expression of over 20 m. These slopes carry material transported from the tops of densely populated coral banks. In contrast to the unbedded cores of the coral mounds, these talus slopes and mound flanks represent a bedded subfacies of coral limestone. In both bedded and unbedded varieties of coral limestone, the matrix fill between the skeletons can be either complete or incomplete, leading to the full range of rock facies described above, as seen at loc. F (Fig. 1).

Some of the cement of the coral limestone was very early, as is demonstrated by the presence of intraformational conglomerates of limestone blocks and fragments (locs D and F), in a bryozoan limestone matrix. Normally the coral skeletons are cut off flush with the matrix and are now empty voids, into which the bryozoan limestone sediment has not penetrated. Thus it is clear that aragonite dissolution post-dated lithification, break-up, transport and redeposition of the limestone fragments.

Fig. 3. Top of a coral limestone mound, penetrated by a network of voids, largely representing burrow systems, and filled with an open bryozoan grainstone.

Fig. 4. Core of coral limestone mound. Note the extensive areas and small patches within the coral frame that escaped mud filling.
R.G. Bromley, photos.



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Not unexpectedly, the faunas of the bryozoan limestone and coral limestone are widely different (e.g. Asgaard, 1968; Floris, this volume), owing to the extreme difference in substrate offered to the benthic community by the two sediments. The bryozoan limestone as a substrate is discussed by Håkansson & Thomsen, this volume, and Heinberg, this volume.

The coral limestone presented a very large area of hard substrate, well aerated and standing well proud of the depositional interface. Besides the remains of corals the sediment that accumulated on the coral banks was a mud. The fauna is thus a mixture of hard substrate epibenthos and mud-dwelling endobenthos, dominated by the former. Thus, a number of species of brachyuran crab and several cirripeds are common, several epibyssate bivalves and a large fauna of gastropods occur, together with diverse brachiopods adapted to several different niches among the branching corals (Asgaard, 1968), while boring sponges and microphytes (?) penetrated the skeletons.

The soft mud was burrowed by crustaceans, probably by nephropids, of which both skeletons and gastroliths have been recognized (Rasmussen, 1973). The mud was subsequently lithified, allowing an encrusting fauna to colonize the burrow walls and ceilings of larger cavities. This cryptic fauna included both the stalkless crinoid *Cyathidium holopus* and several sclerosponges (Rasmussen, 1973). Finally, the burrows were normally filled with bryozoan sand that filtered into the cavity system when the coral bank was buried by bryozoan limestone sediment (Fig. 3).

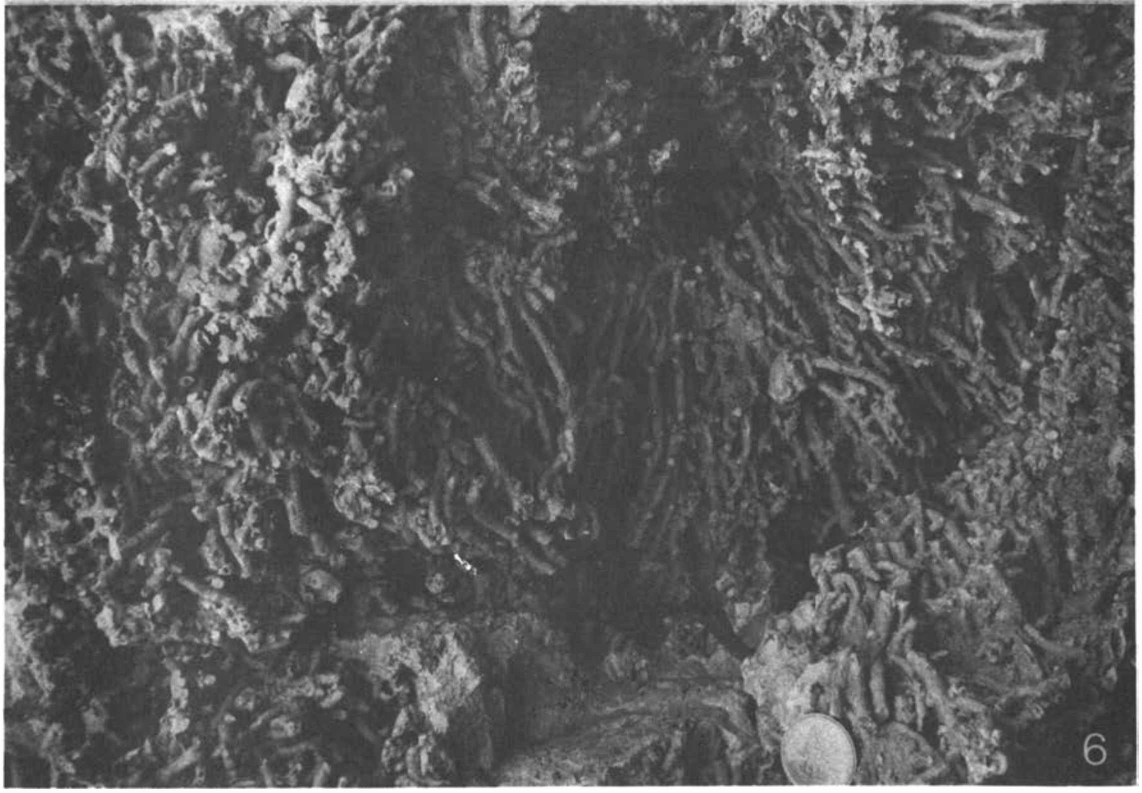
The coral limestone is particularly rich in well preserved fossils. Aragonitic forms are preserved as empty voids. Typical examples of the fauna are illustrated in Fig. 7.

The presence of light-dependant organisms (*Heliopora incrustans* and *Millepora parva*), together with the cryptic habit of light-shy forms (*Cyathidium holopus* and sclerosponges) demonstrates that the coral growth took place within the photic zone (Floris, 1962, 1971; Rasmussen, 1973). According to Floris (1975) the water depth probably averaged about 50 m.

Fig. 5. Core of a coral limestone mound, showing the unbroken nature of the corals.

Fig. 6. Close-up of part of Fig. 5, showing an area of coral thicket largely free of matrix. The corals are mainly calcitized and bear a thin epitaxial fringe of cement that partly obscures the encrusting fauna on the coral surfaces. Coin 2.5 cm. R. G. Bromley, photos.

5



6

A special feature of Fakse Quarry is the close proximity of a great variety of carbonate rocks. We append here, therefore, a description of a section (Fig. 2, A-A' in Fig. 1) by P. C. Rasmussen. Four main rock types are demonstrated in the section:

(1) Bryozoan packstone with flint (Fig. 8) forms a bryozoan biomicrite mound. It is a weakly lithified rock with sheets and nodules of flint, depicting the bedding planes of the mound. The rock has a weak lamination and is partly bioturbated; e.g. in the upper, lithified part of the mound some *Thalassinoides* occur.

(2) Coral boundstone (Fig. 9) is an early lithified rock consisting mostly of spar and micrite. The corals are preserved as cement filled voids. Most of the spar is a radiaxial cement, but other types of spar also occur. The matrix of the rock is bioturbated. *Thalassinoides* is seen near the boundary to the bryozoan packstone without flint. Silicified fossils and minute cavities filled with quartz are common.

(3) The less widespread wackestone (Fig. 10) is a white, weakly lithified rock, with a random orientation of the few fossils (mostly bryozoans, corals and planktic foraminifera). No sedimentary or biogenic structures are evident, but the rock is probably thoroughly bioturbated.

(4) Bryozoan packstone without flint (Fig. 11) is a biomicrite or, in places, a biosparite. In addition to bryozoans, the rock contains some corals and a few echinoid fragments. It has a weak lamination and is only weakly bioturbated; typically it contains open burrows after crustaceans.

All these rock types are autochthonous or only a little transported, but in other parts of the quarry signs of substantial transport have been recorded. General lithification is early and probably has taken place in immediate vicinity to the sea bottom; later most of the components have recrystallized, probably in a subaerial environment. However, typical subaerial or vadose diagenetic features, such as gravity- and meniscus cement, have not been seen.

Fig. 7. Examples of the Danian macro-fauna in Fakse Quarry. 1. *'Rhynchonella' flustracea*. 2. *'Terebratula' fallax*. 3. *C. incisa*. 4. *Argyrotheca faxensis*. 5. *Calantica dorsata*. 6. *Dromiopsis rugosa*. 7. *D. elegans*. 8. *Notidanus dentatus*. 9. *Lamna appendiculata*. 10. *Scaphanorhynchus tenuis*. 11. *Orthacodus lundgreni*. 12. *Thoracosaurus* sp. 13. *Emarginula coralliorum*. 14. *Palaeocypraea spirata*. 15. *Fusinus faxensis*. 16. *Charonia subglabrum*. 17. *Pleurotomaria niloticiformis*. 18. *Campanile pseudotelescopium*. 19. *Voluta faxensis*. 20. *Barbatia forchhammeri*. 21. *Cucullaea crenulata*. 22. *Isoarca obliquedentata*. 23. *Crassatella faxensis* 24. *Protocardia vogeli*. 25. *Meiocardia faxensis*, (after Rasmussen, 1966).

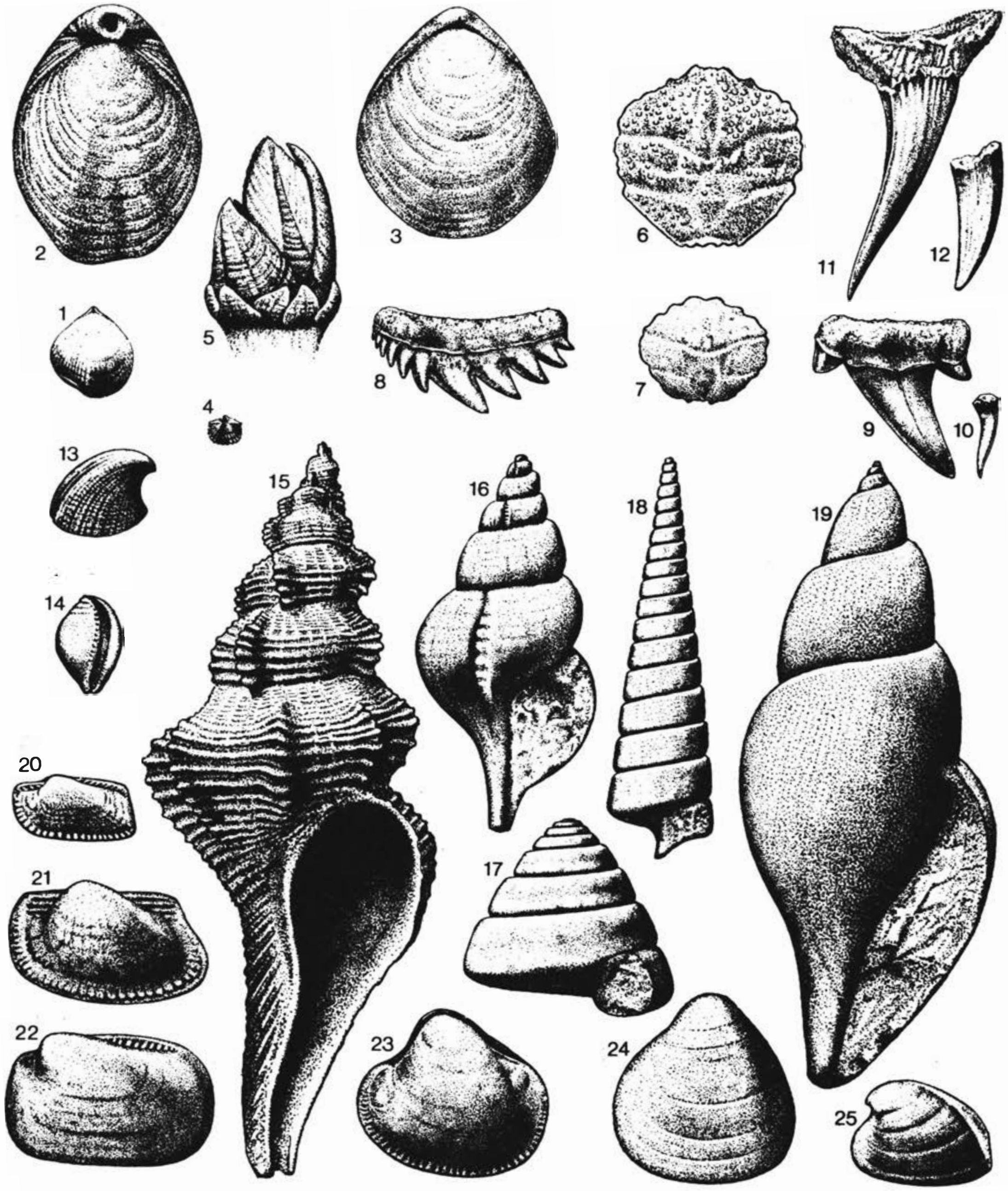

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Fig. 8. Bryozoan packstone with flint. Ramose specimens of cyclostome bryozoans in transverse and longitudinal sections. Most colonies are broken and fragmented after imbedment.

Fig. 9. Coral boundstone (coral biomicrite). Transverse section of a coral showing well-developed septa in clear sparry calcite. Matrix is a very fine mud.

Fig. 10. Wackestone. Ostracode shell with preserved radiating prismatic structure and smaller recrystallized skeletal fragments in a mud matrix.

Fig. 11. Bryozoan packstone without flint. Transverse sections of bryozoans in a spar and mud matrix. Note the geopetal structures.


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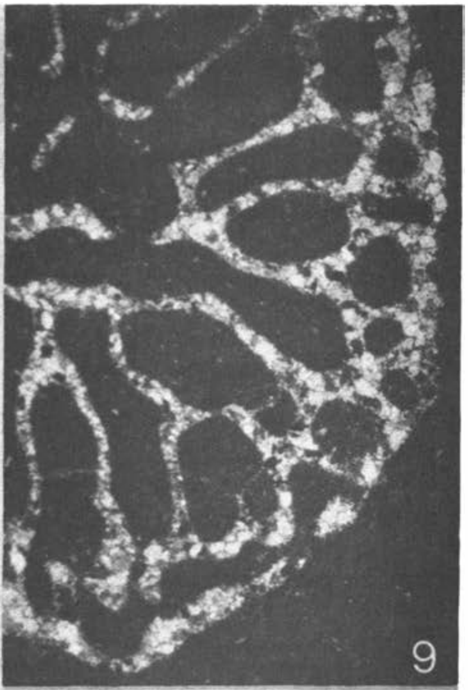
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GUIDE TO STEVNS KLINT

Finn Surlyk

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Øster Voldgade 5-7, DK-1350 Copenhagen K

Map sheets: 1512 I NØ & 1512 I SØ, 1:25.000.

Position: East coast of the Stevns peninsula 40 km due south of Copenhagen.

Type of exposure: 12 km long and 20-41 m high beautifully exposed cliff with easy access at many places. Several quarries along the cliff margin.

Stratigraphy: Uppermost Maastrichtian-middle Danian. The Maastrichtian-Danian boundary is extremely well exposed. Stevns Klint and Faxe Quarry constitute together the classical type area of the Danian Stage (Desor, 1847).

Earlier work: The section has been studied by many Danish geologists since the first description by Abildgaard (1759). A review is given by Milthers (1908) and the complicated stratigraphical nature of the Maastrichtian/Danian boundary was unravelled by Rosenkrantz (1924). The stratigraphic position of the Maastrichtian section was studied by Troelsen (1937), Birkelund (1957) and Surlyk (1970b), whilst Berggren (1962a, 1964) and Hofker (1962a) discussed both the Maastrichtian and Danian stages and the boundary between them. Aspects of the lithology have been described by Rosenkrantz & Rasmussen (1960), Surlyk (1969, 1972), Bromley (1967, 1968, 1975b), Håkansson (1971), Håkansson *et al.* (1974) and Svendsen (1975).

The basal Danian marl layer - the Fish clay has been described in detail by Christensen *et al.* (1973), whilst the impressive Danian bioherms have received little more than general study. Svendsen (1975) has, however, examined a section in some detail.

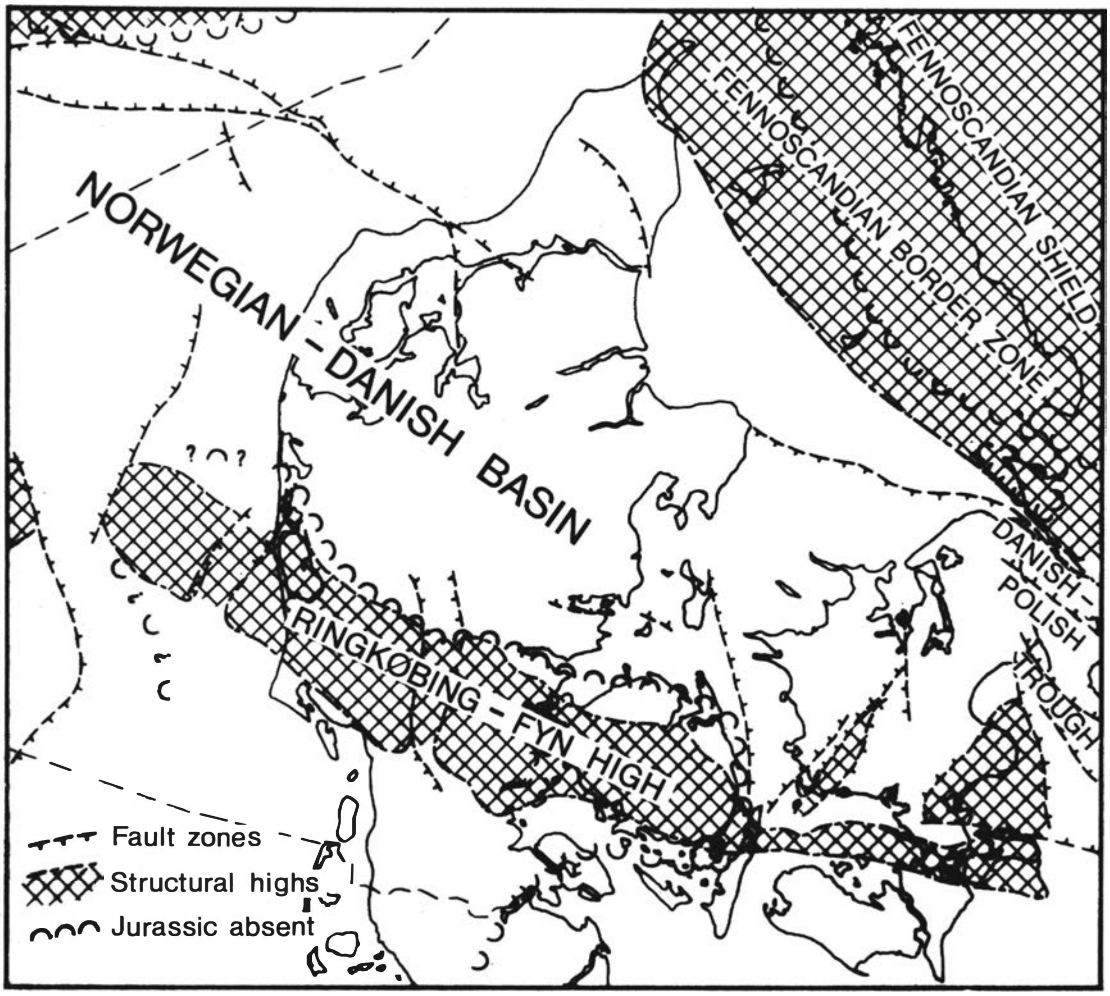

Fig. 1. Schematic structural map of Denmark (from Rasmussen, 1978).

GEOLOGIC SETTING

Stevns Klint is situated over a fault limited structural high between the eastern end of the Ringkøbing-Fyn High and the Fennoscandian Border Zone (Fig. 1). The Maastrichtian facies types are of more shallow water types than in the majority of exposures in Denmark.

THE MAASTRICHTIAN SEQUENCE

The Maastrichtian is represented by different subfacies of chalk and a total thickness of c. 35 m is exposed along the cliff (Fig. 2). The

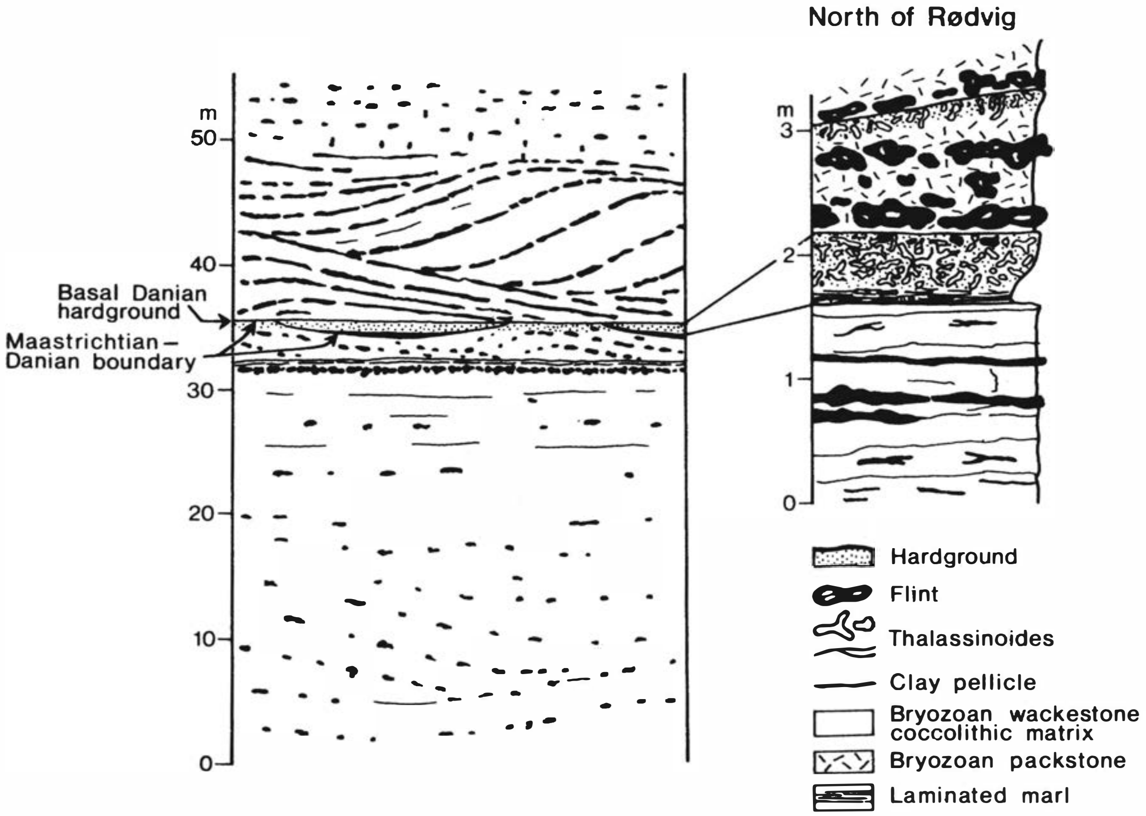

Fig. 2. Simplified composite section of the sequence exposed at Stevns Klint.

lowest 5-10 m of the exposed sequence comprise white chalk with a large content of bryozoans. The chalk was deposited as low mounds revealed most notably by the undulating course of the flint bands. Some of the mounds show a slight overlap. The level with mounds is followed upwards by about 20 m of horizontally bedded chalk with scattered flint nodules and a lower fossil content. This unit is characterized by a high density of *Zoophycos* burrows. A prominent nodular flint layer occurs about 3-4 m below the Maastrichtian-Danian boundary. This layer can be traced almost along the whole length of the cliff. Along the main part of the cliff the flint layer is followed by two omission surfaces topping weakly lithified chalk. These surfaces are outlined by a yellowish rusty colour and form the top of the normal soft white chalk. Both surfaces are extremely irregular, probably as a result of erosion after a stage of early nodular lithification. The highest of these incipient hardgrounds underwent small-scale overthrusting reminiscent of teepee structures.

The upper surface forms the base for a sequence of grey chalk 2.5 - 3.5 m thick showing a very high content (up to 20%) of small benthic fossils, notably bryozoans. The grey chalk was deposited as low asymmetric, biohermal ridges or mounds each of which overlap the next ridge to the south. The southern flank is steepest and shortest and strong flint bands are only found within the less steep northern flank. The bioherms are characterized by *Thalassinoides*, the fill of which is sometimes burrowed by *Chondrites*. The highest density of recognizable *Thalassinoides* occur in 50 cm thick bands which dip to the north parallel to the surface of the bioherms. Synsedimentary slumping and slurry flows were characteristic processes on the flanks. The flows were normally of a rather small size incorporating masses of chalk at maximum a few tens of centimetres thick and 1-2 metres long. The growth of the bioherms can probably be explained by the same model as proposed by Thomsen (1976, 1977b) for other Danian bryozoan bioherms. According to Thomsen the mounds grew under influence of unidirectional currents which promoted growth in an upcurrent direction. The Maastrichtian bioherms are altogether richer in matrix than their Danian analogues and the sediment can be classified as a bryozoan wackestone all through the mound structures (Svendsen, 1975). They can probably be considered a slightly deeper water, early stage of the more impressive and more benthos rich Danian mounds.

THE DANIAN SEQUENCE

Maastrichtian carbonates are abruptly overlain by a dark-grey marl band, the so-called Fish clay constituting the basal Danian bed. It occurs in the low basins between the summits of the Maastrichtian bryozoan bioherms and reaches a thickness of 20-35 cm in the deepest parts of the basins. It wedges out completely towards the margins of the basins. The Fish clay has been studied in some detail by Christensen *et al.* (1973) who distinguished 4 beds, beginning with 1) a grey laminated marl, followed by 2) black marl with pyrite concretions, which again is overlain by 3) black laminated marl. This gives way to 4) light-grey marl with flattened lenses of white chalk, which gradually passes into the indurated Cerithium limestone (Fig. 3). The fine, undisturbed lamination of especially bed 3) and the abundant occurrence of pyrite concretions suggest euxinic conditions during deposition of the lower part of the Fish clay. The provenance of the bed seems to be in part terrigenous (quartz and feldspar) in part authigene (mixed-layer clay minerals).

The Fish clay contains relatively few fossils such as fish scales and teeth, which have given name to the unit. Reworked late Maastrichtian fossils are quite abundant and the coccolith assemblage consists of reworked Upper Maastrichtian forms (99%) and only very few indigenous

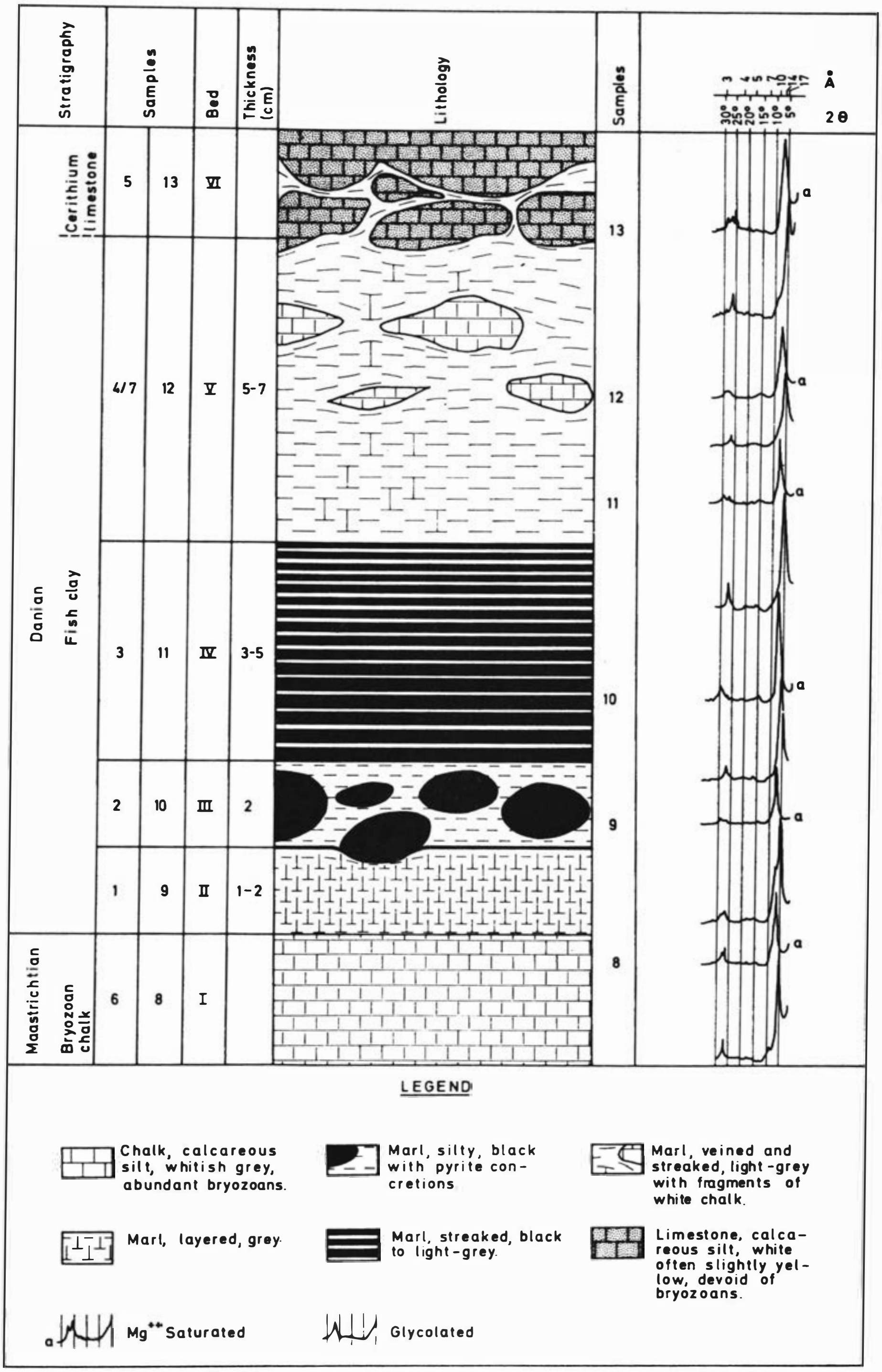

Fig. 3. Detailed section of the Maastrichtian/Danian boundary at Stevns Klint (from Christensen *et al.*, 1973).

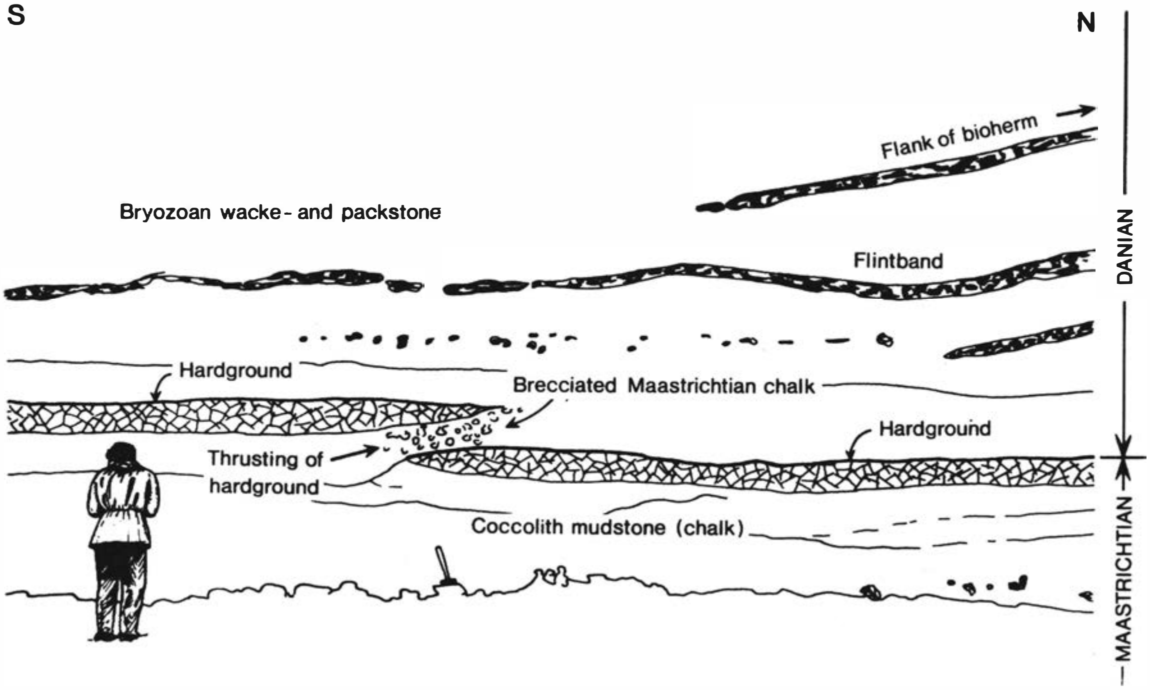

Fig. 4. Early diagenetic thrusting of basal Danian hardground. The thrusted sequence is underlain by undisturbed Maastrichtian coccolithic chalk and overlain by Danian bryozoan wacke- and packstones. Stevns Klint, north of Kulsti Rende (from Surlyk, 1969).

species characteristic for the lowest Tertiary nannoplankton zone (NP1) (K. Perch-Nielsen, pers. comm., 1979).

The Fish clay gives way with a gradual transition to the hard yellow Cerithium limestone. The latter is penetrated by innumerable *Thalassinoides* burrows and micro-faults with slickensides. The next stage was characterized by erosion of the top part of the Cerithium limestone and the intervening crests of the Maastrichtian bioherms. In this way a horizontal erosion surface was developed which cuts alternately through the highest Maastrichtian bryozoan chalk and the lower Danian Cerithium limestone. This process was probably submarine and was followed by early diagenetic submarine cementation down to a depth of about 30 cm. The *Thalassinoides* burrows comprise both pre-omission and omission suites. The latter are deformed by concurrent activity of the burrowing infauna and the lithification processes (Bromley, 1967, 1975b).

The planar erosion surface cuts through the remains of horizontal burrow networks destroying the upper half. Some of these burrows reach a diameter of 12 cm (Bromley, 1968). The fill of the burrows mainly comprises the delicate skeletons of Danian bryozoans and often shows some degree of silicification. To the south are seen all stages from grey, porous chalcedonic flint to solid, black flint. These variations can occur even within one burrow (Surlyk, 1969). The burrow wall is the preferential site of silicification and in more advanced stages the fill and the surrounding limestone is also silicified. At several localities along the cliff early diagenetic thrusting of the hardground has taken place (Fig. 4, Surlyk, 1969). This is interpreted as being due to a diagenetically caused volume increase and expansion analogous to the thrusts and folds described by Shinn (1969) from hardgrounds in the Persian Gulf.

The hardground itself contains a diverse fauna comprising among others originally aragonite shelled gastropods and bivalves. Tests of the lower Danian echinoid *Brissopneustes danicus* are commonly found in the burrow fill.

The erosion surface of the basal Danian hardground formed the foundation for the upbuilding of the very impressive lower Danian bryozoan bioherms (Fig. 2).

The Danian bioherms show the same type of asymmetry as those in the top Maastrichtian, but they are larger, contain more flint arranged in thick, often continuous, layers and have a much higher grain/matrix ratio. The dominant grains are stems of delicate bryozoans, but whole and fragmented echinoid skeletons are also conspicuous constituents. The biohermal sequence reaches thicknesses of about 20 m at the southern end of the cliff decreasing to 8-10 m to the north. This thickness trend together with the overlapping nature of the bioherms (the northern bioherms overgrow their southern neighbours) suggest a considerable northwards younging of the whole Danian sequence. The bioherms were probably formed by upcurrent growth of bryozoan mounds as described for contemporaneous mounds in eastern Jylland by Thomsen (1976).

Some southern flanks of bioherms are encased by thin hardgrounds which may reach from the summit of the bioherm and right down to the basin between two bioherms. In this way a flank hardground can come into direct contact with the ubiquitous basal Danian hardground which comprises both the Cerithium limestone and the top of the Maastrichtian bioherms. Care in collection of fossils and samples is essential in such cases to avoid mixed faunas (of three different ages).

Apart from hardgrounds the flanks are characterized by abundant evidence of mass-flows such as slurry and debris flows. Thin beds composed solely of skeletal debris without the usual coccolithic matrix may suggest periods of current winnowing.

GUIDE TO MAASTRICHTIAN AND DANIAN BOUNDARY STRATA IN JYLLAND

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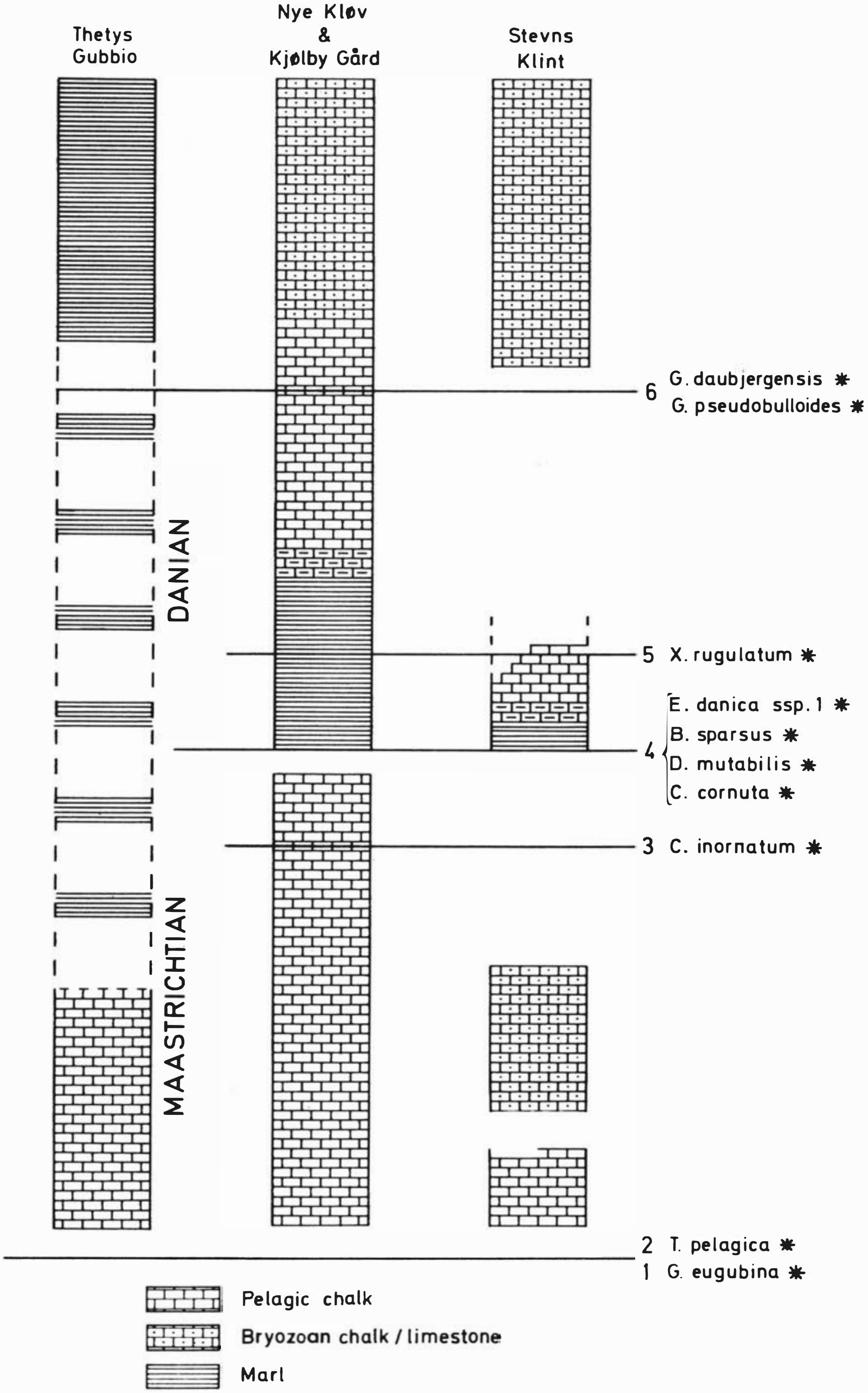
In northern Jylland a number of outcrops from the central part of the Danish Basin exhibits a remarkably complete sequence of strata across the Maastrichtian/Danian boundary. Within this basin, accumulation of pelagic chalk persisted above the boundary in the northwestern part, whereas the classic development seen at Stevns Klint (Surlyk, this volume) is approached towards the southeast. This trend of a gradually more complex development of the boundary strata towards Stevns Klint appears to be associated with an increase in the time represented by hiati and residual marl (Fig. 1). Apparently the time interval at the boundary also increases towards the off-shore North Sea area (Bang, this volume) where, however, the preferred drilling sites on structural units may conceal a generally more complete depositional record.

The boundary strata in Jylland were first described in detail by Jessen & Ødum (1923) and Ødum (1926) who included most known localities. The sediments are uniform, pure carbonates ranging from pelatic chalk with virtually no benthic constituents to bryozoan limestones (see Bromley, this volume, for lithological descriptions). The only important exception to this is the thin residual marl bed constituting the lowermost Danian bed in most localities (Hansen, 1977), which contains a significant amount of non-carbonate, has a distinct lower limit and, typically, grades upwards into pure carbonates.

STRATIGRAPHY

Being the type of the lower part of the Danian and - by implication - the termination of the Maastrichtian, the floral and faunal sequence at Stevns Klint should retain a central position in the development


Thetys Gubbio
Nye Kløv & Kjølby Gård
Stevns Klint
DANIAN
MAASTRICHTIAN
6 G. daubjergensis *
G. pseudobulloides *
5 X. rugulatum *
4 E. danica ssp. 1 *
B. sparsus *
D. mutabilis *
C. cornuta *
3 C. inornatum *
2 T. pelagica *
1 G. eugubina *
Pelagic chalk
Bryozoan chalk / limestone
Marl

of a coherent international biostratigraphic scheme to cover the Cretaceous/Tertiary boundary. Unfortunately the state of biostratigraphic resolution of the boundary strata in Denmark has been somewhat inadequate, but recent progress has been substantial, allowing a number of improvements in correlation. Thus, at Stevns Klint the Danian is initiated at the base of the thin marl layer (the Fish clay, see Surlyk, this volume) as is the case in most Danish boundary sequences (Hansen, 1979).

The development of the pelagic flora and fauna in particular has been investigated and, although correlation between the groups has not been fully tested, a provisional zonal scheme may be put forward to cover the Cretaceous/Tertiary boundary event in Denmark (Fig. 2). How much of this zonation has a more than basin-wide application remains to be tested, but a single, crucial question requires some comments.

In apparently continuous pelagic sequences in the Alpine region, Luterbacher & Premoli Silva (1964) and Premoli Silva (1977) defined the *'Globigerina' eugubina* Zone and claimed it to be the basal Danian zone. This dating of the *'G.' eugubina* Zone has been widely accepted, in particular in connection with the Deep Sea Drilling Project where, for instance, Premoli Silva & Bolli (1973), Boersma (1977) and Premoli Silva & Boersma (1977), and Thierstein & Berger (1978) use the first occurrence of *'G.' eugubina* as datum for the onset of the Danian.

In Denmark, Inger Bang (1979, Symposium Volume II, and personal communication) recently has found a planktic foraminiferal fauna (informally named the 'Lønnerup Assemblage') which she considers a lateral equivalent of the *'G.' eugubina* Zone. In Denmark, however, this 'Lønnerup Assemblage' has been identified also in the topmost, ammonite bearing Maastrichtian, below the marl at the boundary (*cf.* also Hofker, 1966b). Returning now to the Alpine sequences containing

Fig. 1. Bio- and lithostratigraphy in the type Danian at Stevns Klint and at Gubbio, Italy (*cf.* Arthur & Fischer, 1977) compared to the sequence in northwestern Jylland. The two Danish sequences are closely correlatable due to a high degree of biostratigraphic solution, whereas only two significant biostratigraphic events have so far been identified in the comparable part of the sequence at Gubbio. Datum levels: 1-2) First occurrence of *'Globigerina' eugubina* and *Thallasiphora pelagica*, 3) first occurrence of *Chiropteridium inornatum*, 4) first occurrence of *Carpatella cornuta*, *Biantolithus sparsus*, *Eoglobigerina danica* sp. 1, etc., 5) first occurrence of *Xenicodinium rugulatum*, 6) first occurrence of *Globoconusa daubjergensis* and *Globorotalia pseudobulloides*.

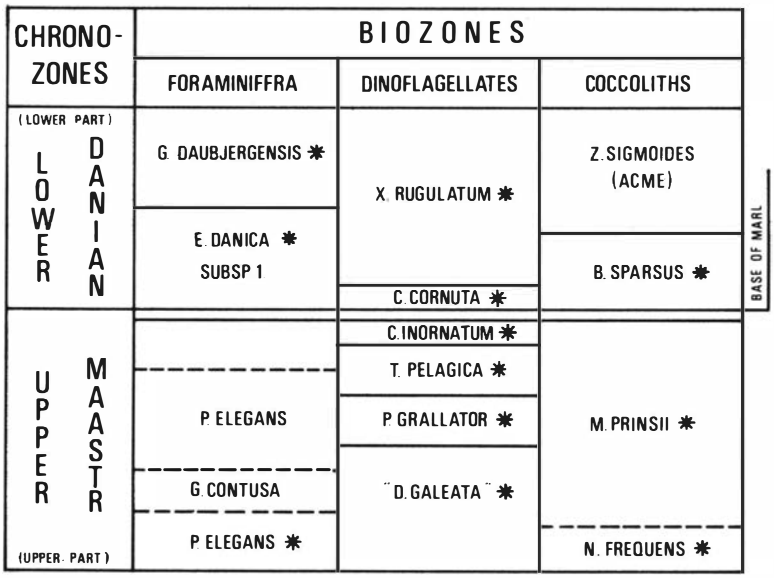


Fig. 2. Zonal scheme covering the Cretaceous/Tertiary boundary event in Denmark. The compilation is largely based on data from Troelsen (1955), Hansen (1977, 1979), Perch-Nielsen (this volume), and I. Bang (pers. comm. 1979).

the *'G.' eugubina* Zone it is striking to note that in both places the first occurrence of the fauna of the *'G.' eugubina* Zone is situated just below a marl (or shale) layer (Luterbacher & Premoli Silva, 1964, fig. 1; Arthur & Fisher, 1977, fig. 1) as is the case in Denmark. Comparable developments have apparently been recorded in at least the Atlantic Ocean where, for instance, a hiatus is present above the *'G.' eugubina* Zone at site 152 (Premoli Silva & Bolli, 1973), and a distinct marl is associated with this zone at site 356 (Perch-Nielsen, Supko *et al.*, 1977, p. 184).

Thus, based on the faunal development in the Danian type area, it seems fairly obvious to conclude that the *'G.' eugubina* fauna is at least partly of Maastrichtian age (*cf.* also Hofker, 1978). And as a direct result of this conclusion it becomes increasingly evident that the formation of a marl layer in the base of the type Danian is closely related to a single, world-wide event responsible also for the formation of the marl layers or hiati in the Alpine region and the deep oceans. This event then marks the Cretaceous/Tertiary boundary.

Tappan (1968) and Worsley (1971) proposed that fluctuations in the CCD were responsible for this world-wide interval of carbonate non-deposition and laying down of residual marls. Much as we are in favour of this hypothesis, we feel it necessary to point out that subsequent attempts at confirming this notion through biostratigraphic dating of the event (Worsley, 1974) was less successful, in particular as regards Danish localities. Nevertheless, in view of the improved zonal scheme now available (Fig. 2), a correlation between the zonation in the Danish Basin and more fully oceanic sequences (here exemplified by Gubbio, Italy) may be attempted (Fig. 1), reassessing the biostratigraphic frame for the Worsley/Tappan notion.

BOUNDARY TYPES IN JYLLAND

Within the Danish Basin there is a great deal of variation in the detailed lithology in relation to the Maastrichtian/Danian boundary. Most notable in this respect is a seemingly regional trend from highly complex lithological developments in the type Danian at Stevns Klint to the almost continuous pelagic development in northern Jylland. In Jylland the outcrops containing the boundary strata may be arranged in three somewhat artificial groups according to their boundary development.

A number of outcrops encircling the halokinetically controlled, low Hanstholm dome (Fig. 3) exhibits the most complete, undisturbed sequence known in the basin (Håkansson & Hansen, 1977). In these outcrops the boundary is marked as a thin marl in an otherwise monotonous sequence of pelagic chalk. Local variations in the development of the marl layer are largely attributed to postdepositional movements in the dome where the marl acted as an internal smear surface. As indicated from the sedimentational monotony the dome was probably not activated until after the Cretaceous/Tertiary boundary event; and during the Holocene the elevation has been in the order of 5-10 m. Two small abandoned chalk pits from this area will be visited during the excursion: Nye Kløv and Kjølby Gaard.

The outcrop at Eerslev owes its particular development to a location on another halokinetically controlled structure, but in this case the outcrop is situated directly on top of a transpiercing diapir. The top Maastrichtian is developed as a comparatively thick hardground and no marl is found at this locality. Since the sequence is condensed and the boundary hiatus may be slightly longer than in neighbouring outcrops (Hansen, 1979) the Eerslev diapir was probably active some time close to the Cretaceous/Tertiary boundary event. Similar transpiercing structures are quite common in large parts of the North Sea Basin but, most likely, they will exhibit local deviations in their boundary development corresponding to differences in the periods of activity.

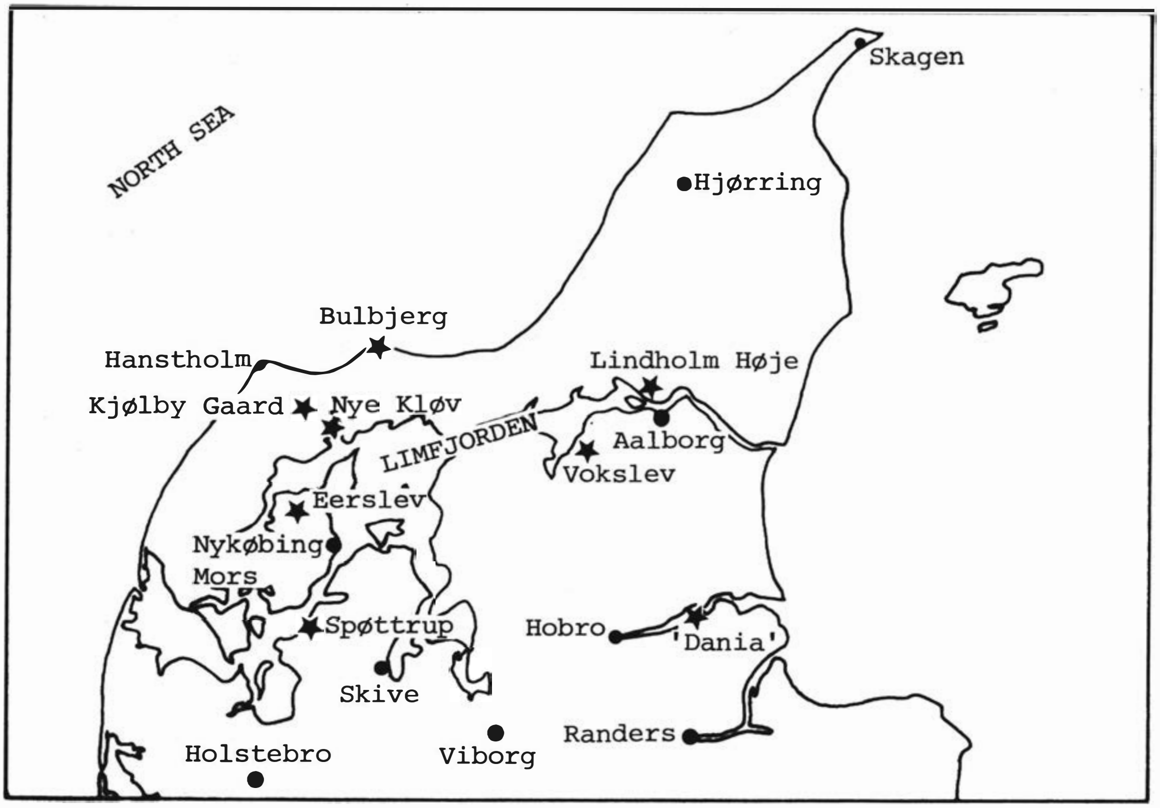


Fig. 3.

ROAD LOG - EXCURSION STOPS

1st day: Kjølby Gaard (M/D boundary)
Nye Kløv (M/D boundary)
Bulbjerg (Lower Danian bryozoan limestone with well developed bryozoan mounds)
Hanklit (Upper Paleocene-Lower Eocene diatomite with volcanic ash layers)
Eerslev (M/D boundary)

Night in Nykøbing Mors

2nd day: Spøttrup (Castle from the 14th century)
Vokslev (M/D boundary)
'Dania' (M/D boundary)
Lindholm Høje (Viking cemetery)

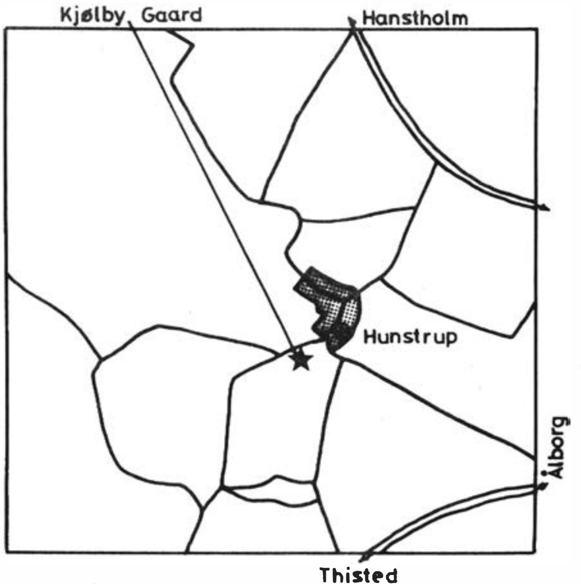


Fig. 4.

The last boundary type includes outcrops recording a depositional history intermediate between the outcrops in northwestern Jylland and the type Danian at Stevns Klint. In this type the boundary is associated with a thin marl interrupting a pelagic sequence, and the pelagic sediments are abruptly overlain by bryozoan limestone. Thus, at Vokslev the pelagic regime is terminated by a simple erosional phase in the early Danian, whereas at Dania the pelagic sedimentation was succeeded by the development of a complex hardground. Rather complicated structural patterns in the subsurface have recently been recorded in eastern Jylland, and perhaps the erosion and hardground formation affecting these areas in the early Danian may be associated with the development of highly localized inversion axes around active salt structures.

Kjølby Gaard

A small abandoned quarry in an old sea cliff c. 300 m west of the church in Hunstrup (Fig. 4).

The sequence at Kjølby Gaard is dominated by pelagic chalk with scattered flints and only at the extreme top does it approach a typical lower Danian bryozoan limestone (Fig. 5). Low in the section the Kjølby Gaard Marl (M 9; *cf.* Troelsen, 1955) exhibits a characteristic lithology with 'reverse' trace-fossils (i.e. white *Zoophycos* in the grey marl) which is found also in a number of marl layers in 'Dania'.

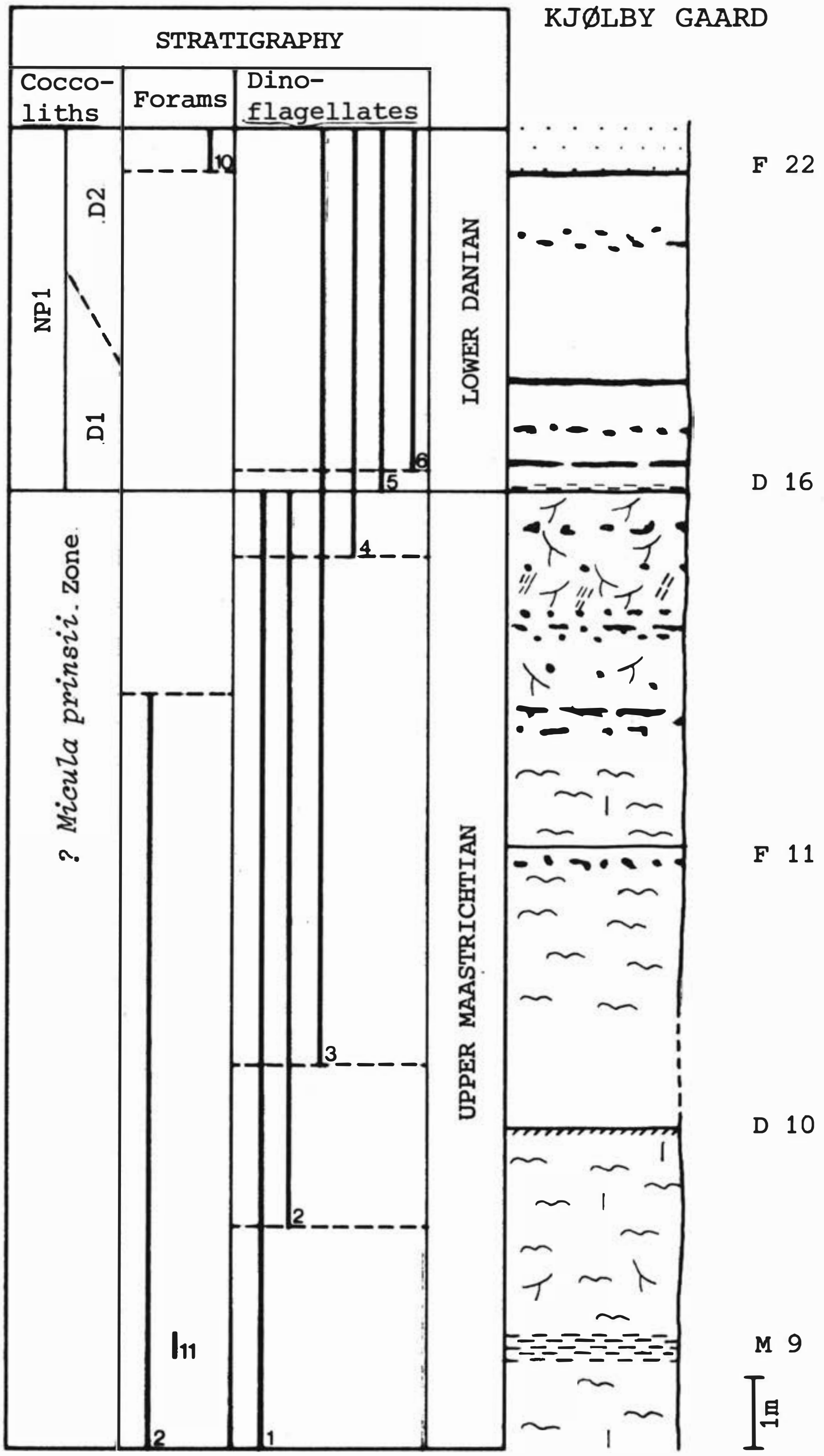
The basal Danian marl (M 17) has the appearence of a conglomerate with angular to rounded clasts of pelagic chalk. However, as the dinoflagellate flora of individual clasts prove a multiple origin from both below and above the marl itself, they have most likely been displaced at a later date as a result of halokinetic movements in the subsurface dome. In accordance with this the rocks between M 17 and F 18 appear distinctly brecciated.

Macrofossils are comparatively scarce throughout the sequence at Kjølby Gaard. In the Maastrichtian chalk ammonite moulds are fairly abundant, in particular in a level approximately 4 m below the boundary. Echinoids (including *Tylocidaris baltica*), bryozoans, and bivalves are also recorded from the Maastrichtian.

The stratigraphic columns compiled for this as well as the other localities include most of the available information about the planktic groups. The detailed coccolith zonation used here is discussed elsewhere (Perch-Nielsen, this volume). However, as in most localities, *Micula prinsii* itself has not been identified among the coccoliths from Kjølby Gaard. Through correlations it is believed, nevertheless, to have been originally a member of the pelagic flora in at least the higher parts of the Maastrichtian at Kjølby Gaard, in particular as preferential dissolution of certain species is known to be frequent in the top Maastrichtian chalk (Perch-Nielsen, 1973 and this volume). The foraminiferal zonation is still insufficiently developed and here is only indicated the distribution of a small number of species believed to be of stratigraphic significance. Noteworthy in particular in Kjølby Gaard is the occurrence of double keeled *Globotruncana* spp. (mostly *G. contusa*) in the Kjølby Gaard Marl (Troelsen, 1955). Finally the distribution of seven selected species of dinoflagellates defines the zonation developed by Hansen (1977, 1979).

Selected literature: Ødum (1926), Troelsen (1955), Perch-Nielsen (1969, 1973), Worsley (1974), Håkansson & Hansen (1977), Hansen (1977, 1979), Jørgensen (this volume).

Fig. 5. Kjølby Gaard. Lithological profile measured in 1975 by E. Håkansson and J.M. Hansen. Coccolith data provided by K. Perch-Nielsen (pers. comm. 1979); Foraminifera: 2) *Pseudotextularia elegans*, 11) *Globotruncana contusa*, 10) *Globoconusa daubjergensis* (data from Troelsen, 1955 and I. Bang, pers. comm. 1979); Dinoflagellates: 1) *Spiniferites ramosus cavispinosus*, 2) *Palynodinium grallator*, 3) *Thallasiphora pelagica*, 4) *Chiropteridium inornatum*, 5) *Danea mutabilis* and *Carpatella cornuta*, 6) *Xenicodinium rugulatum* (*cf.* Hansen 1977, 1979).


KJØLBY GAARD
STRATIGRAPHY
Cocco-liths
Forams
Dino-flagellates
NP1
D2
D1
? Micula prinsii. Zone
LOWER DANIAN
UPPER MAASTRICHTIAN
10
6
5
4
3
2
1
2
11
F 22
D 16
F 11
D 10
M 9
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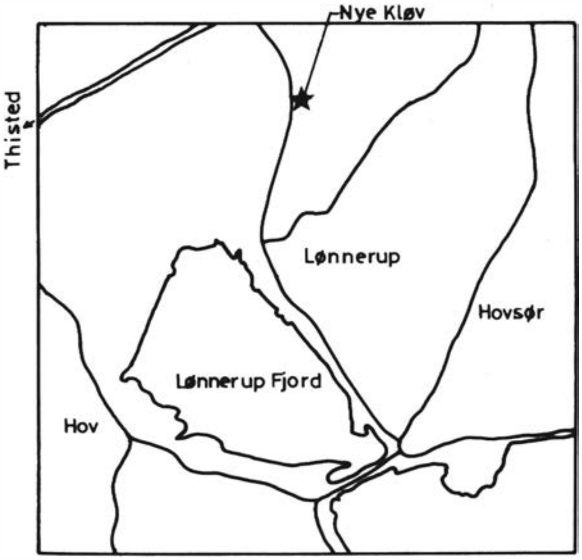


Fig. 6.

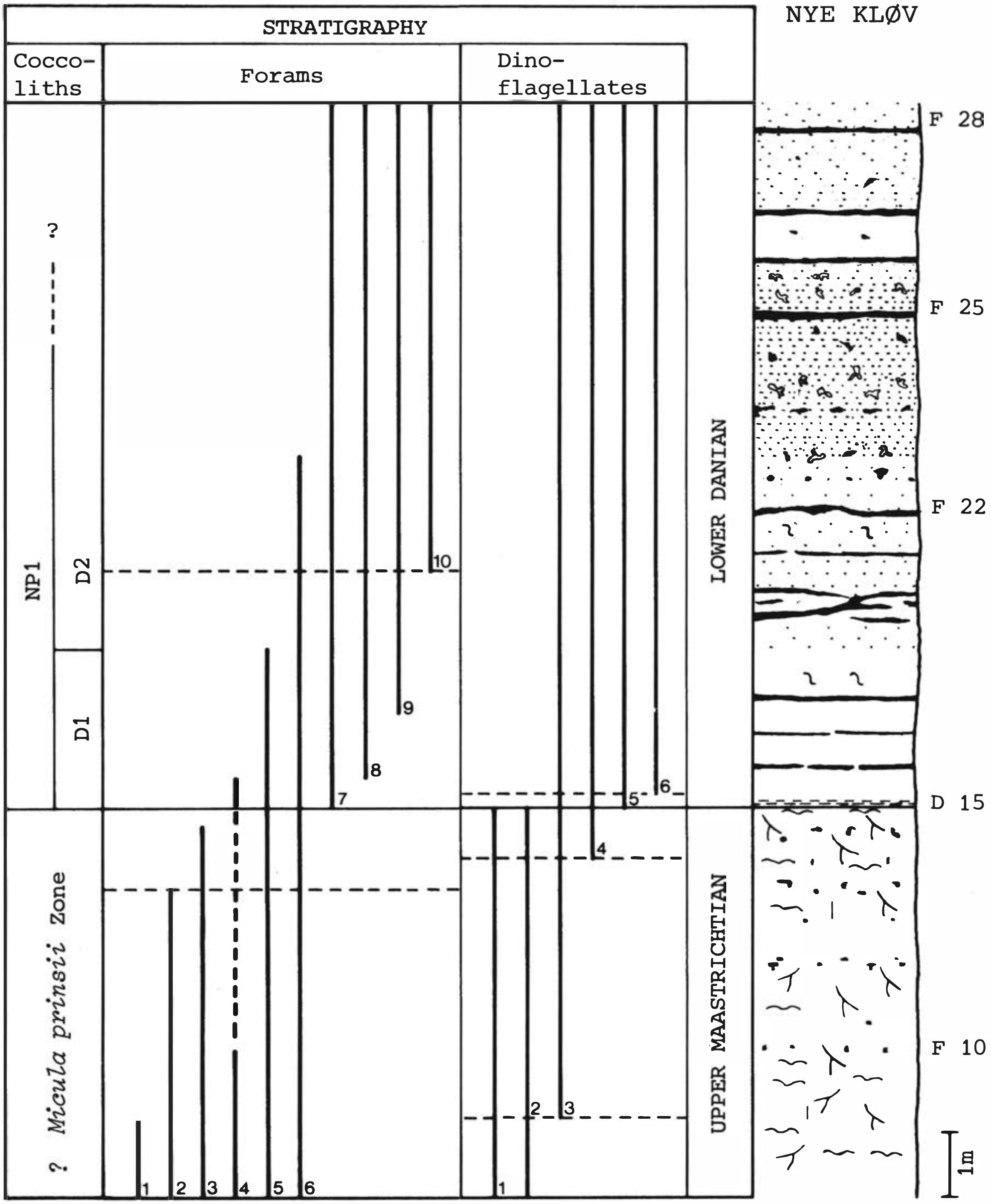
Nye Kløv

A small abandoned quarry in an old sea cliff facing the inner, drained parts of Lønnerup Fjord (Fig. 6).

The sequence at Nye Kløv compares closely with that of Kjølby Gaard, but, in addition, exhibits a more complete transition into bryozoan limestone in the lower Danian (Fig. 7). However, no bryozoan mounds are developed. In contrast to the sequence at Kjølby Gaard the basal Danian marl at Nye Kløv (M 16) appears largely undisturbed by later movements.

Apart from a significant bryozoan content in the higher parts of the Danian (*cf.* Håkansson & Thomsen, this volume) macrofossils are comparatively scarce in the rocks exposed at Nye Kløv. From the Maastrichtian chalk *Baculites* and *Inoceramus* may be emphasized, and in the Danian bryozoan limestone *Tylocidaris abildgaardi* occurs.

Fig. 7. Nye Kløv. Lithological profile measured in 1978 by E. Håkansson and J.M.Hansen. Coccolith data provided by K. Perch-Nielsen (pers. comm.) 1979); Foraminifera: 1) *Globotruncana arca*, 2) *Pseudotextularia elegans*, 3) *Globotruncanella petaloides*, 4) Elements of the 'Lønnerup Assemblage', 5) *Heterohelix* spp., *Hedbergella* spp., and *'Globigerinella' aspera*, 6) *Guembelitria* spp., 7) *Chiloguembelina* spp., 8) *Woodringina* sp., 9) *Eoglobigerina danica* s.l., 10) *Globoconusa daubjergensis* (data provided by I. Bang, pers. comm. 1979). Dinoflagellates: see Fig. 5.


STRATIGRAPHY
Cocco-liths
Forams
Dino-flagellates
NYE KLØV
?
NP1
D2
D1
? *Micula prinsii* Zone
1
2
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6
LOWER DANIAN
UPPER MAASTRICHTIAN
F 28
F 25
F 22
D 15
F 10
1m

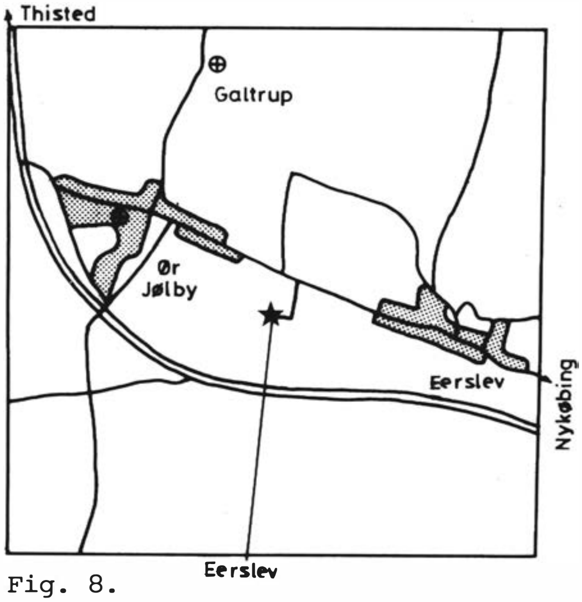

Fig. 8.

In addition to the general stratigraphic information the distribution of the planktic foraminifera in the sequence at Nye Kløv has been investigated more thoroughly than at other localities visited by the excursion. Note that a group of characteristic Maastrichtian forms (here united in column 5) have been extensively reworked into the basal Danian beds. This is true also for the coccoliths (Perch-Nielsen, this volume) and, typically, the lowermost meter or so of the Danian strata in northern Jylland is totally dominated by reworked Maastrichtian plankton. Interesting in this connection is the occurrence of species belonging to the 'Lønnerup Assemblage' (column 4) which show a similar distribution and, possibly, have also been reworked into the Danian (I. Bang, personal communication 1979).

Selected literature: Ødum (1926), Hansen (1979), Håkansson & Thomsen (this volume), Jørgensen (this volume).

Eerslev

In a group of abandoned chalk pits situated between the villages Øster Jølby and Eerslev (Fig. 8) a single section comprising the Maastrichtian/Danian boundary may still be visited. As a result of its position centrally on the Eerslev diapir this sequence deviates significantly from the remaining localities in Jylland, partly in the lack of a basal Danian marl and partly in the development of a hardground (Fig. 9). Additionally, the thin Danian sequence preserved below the Quaternary cover exhibits bryozoan limestone developed directly on top of this hardground.

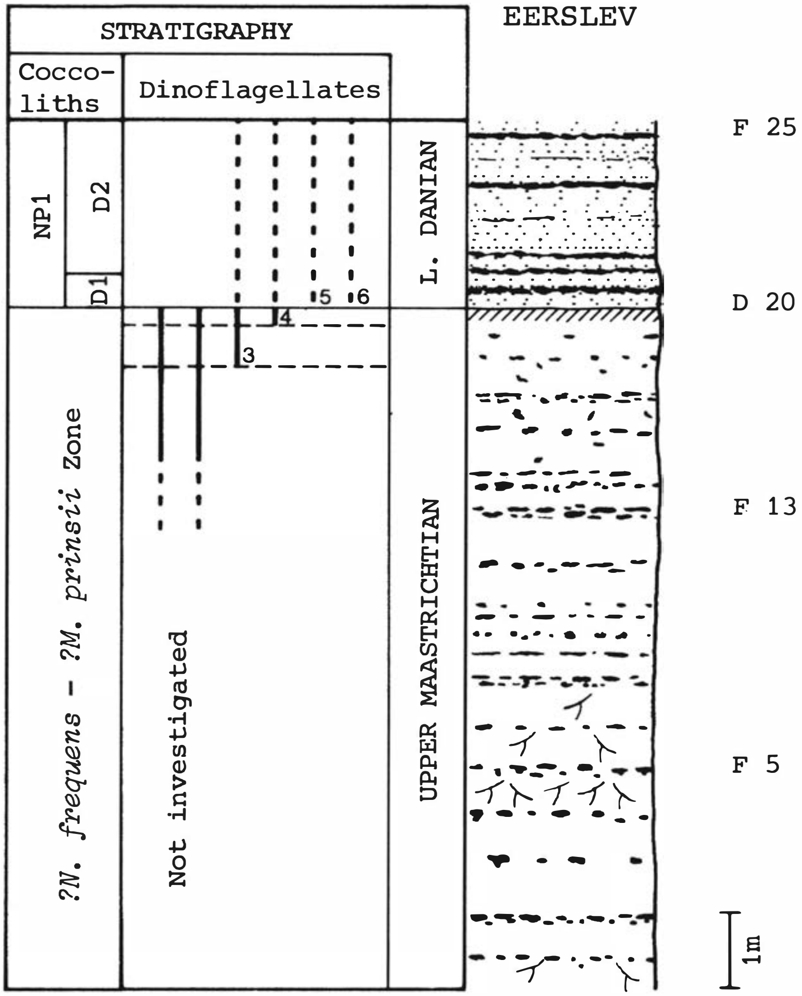

Fig. 9. Eerslev. Lithological profile measured in 1972 by F. Surlyk. Coccolith data provided by K. Perch-Nielsen (pers. comm. 1979). Dinoflagellates: see Fig. 5 (note that no dinoflagellates are preserved in the Danian part of the sequence).

The macrofauna from Eerslev is scarce, and from the Maastrichtian may be mentioned ammonites, echinoids (including *Tylocidaris baltica*) as well as bryozoans.

From the distributional data of the planktic biota it appears that the sequence at Eerslev, in spite of the lithological differences, is almost as complete as in other parts of northern Jylland. However,

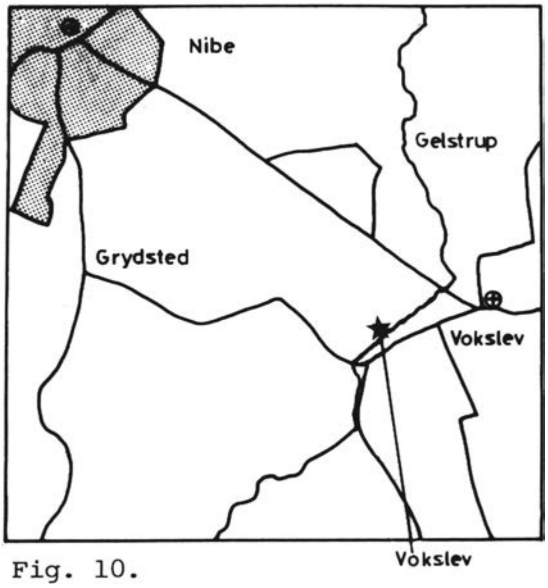

Fig. 10.

the sequence is obviously condensed, probably reflecting synsedimentary activity in the underlying Eerslev diapir.

Selected literature: Ødum (1926), Håkansson *et al.* (1974), Hansen (1977, 1979), JØrgensen (this volume).

Vokslev

The Cretaceous/Tertiary boundary at Vokslev was investigated early in the century (Jessen & Ødum, 1923) in an erosional slope made by a small stream just outside the village Vokslev (Fig. 10). Until very recently it has not been accessible.

By comparison with the boundary sequence in 'Dania' it appears reasonable to expect the sequence at Vokslev to contain an almost complete record across the boundary (Fig. 11). In contrast to 'Dania' no hardground formation seems to be associated with the termination of the pelagic chalk regime. An apparently abrupt change from pelagic chalk to bryozoan limestone is recorded across a massive flint (F 10) which possibly conceals a simple erosional surface.

The Maastrichtian macrofauna at Vokslev is somewhat richer than in northwestern Jylland, and *Baculites*, bryozoans and fairly abundant echinoids (including *Tylocidaris baltica*) may be mentioned. While the Danian pelagic chalk is poor in macrofossils the bryozoan limestone (mostly visible in a nearby quarry) contains the macrofauna typical of

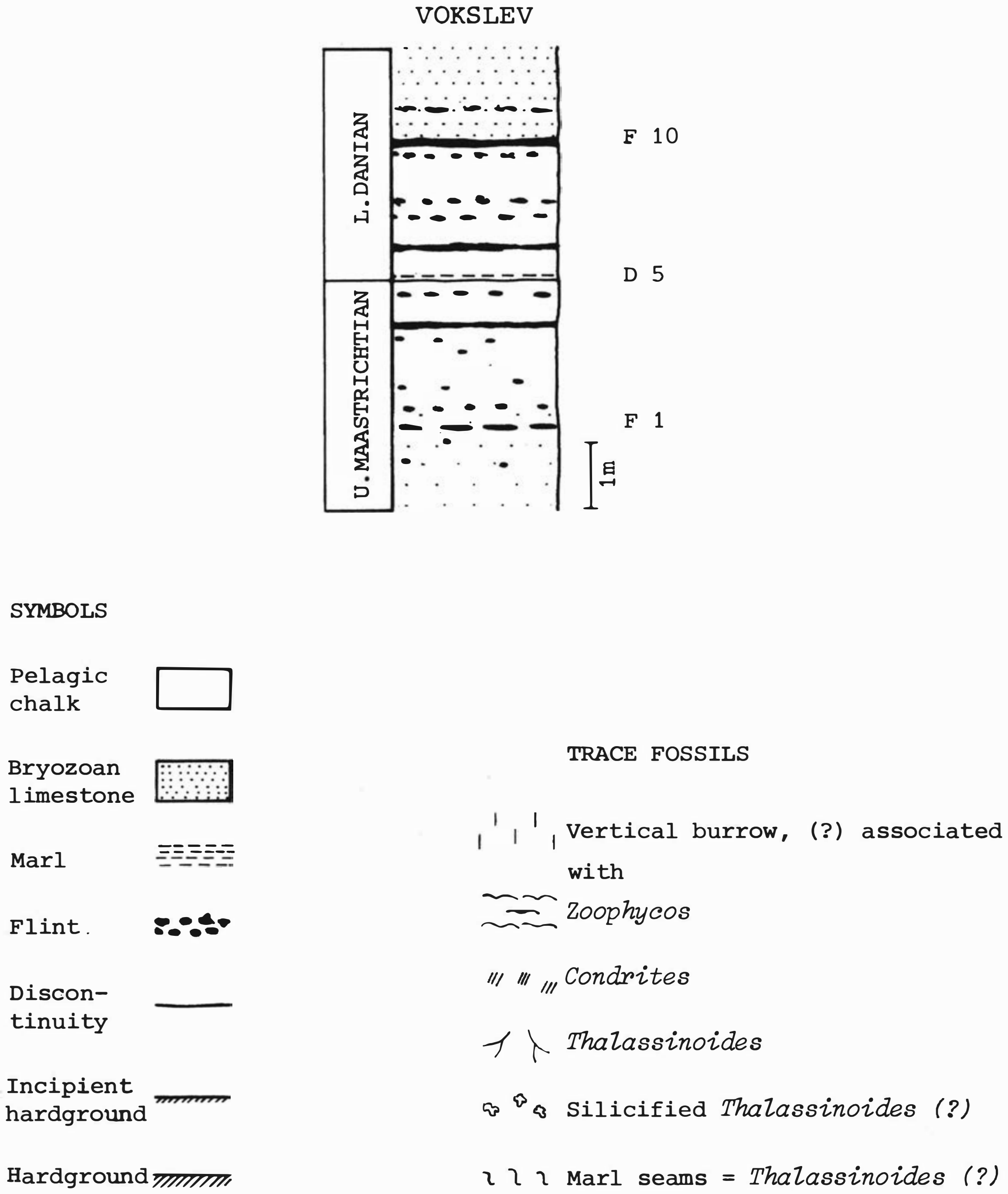

Fig. 11. Vokslev. Lithological profile measured in 1979 by E. Thomsen, C. Heinberg, and E. Håkansson.

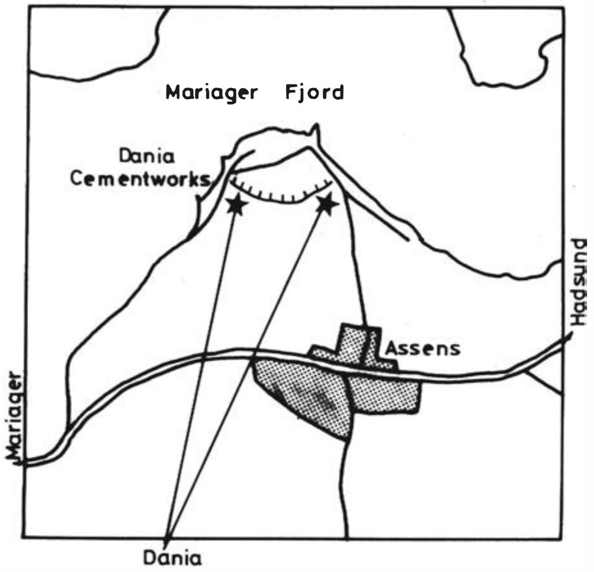

Fig. 12.

this sediment with echinoids, brachiopods and bivalves in addition to the dominating bryozoans.

Selected literature: Jessen & Ødum (1923), Ødum (1926).

'Dania'

In a very long, at present abandoned wall in the quarry of the 'Dania' cement work (Fig. 12) is exposed a series of more than 30 m of carbonate rocks spanning the Maastrichtian/Danian boundary (Fig. 13).

The Maastrichtian chalk at 'Dania' is exceptionally rich in marly horizons corresponding in lithology to the Kjølby Gaard Marl (*cf.* Troelsen, 1955). The basal Danian marl may be divided into a lower conglomeratic unit (M 29) and an upper more uniform unit gradually changing into a pure pelagic chalk. Upwards this pelagic sequence is developed into a thick hardground terminated by an erosional surface (D 31). In the hardground is found rounded, hard clasts of chalk and rolled glauconitised fossils testifying to a complex depositional history involving at least two episodes of cementation and erosion. The remaining Danian strata are developed as bryozoan limestones, but in spite of the sometimes very high bryozoan content no mounds have been developed.

Macrofossils are fairly abundant at most levels in 'Dania'. The Maastrichtian pelagic chalk in particular contains a highly diverse

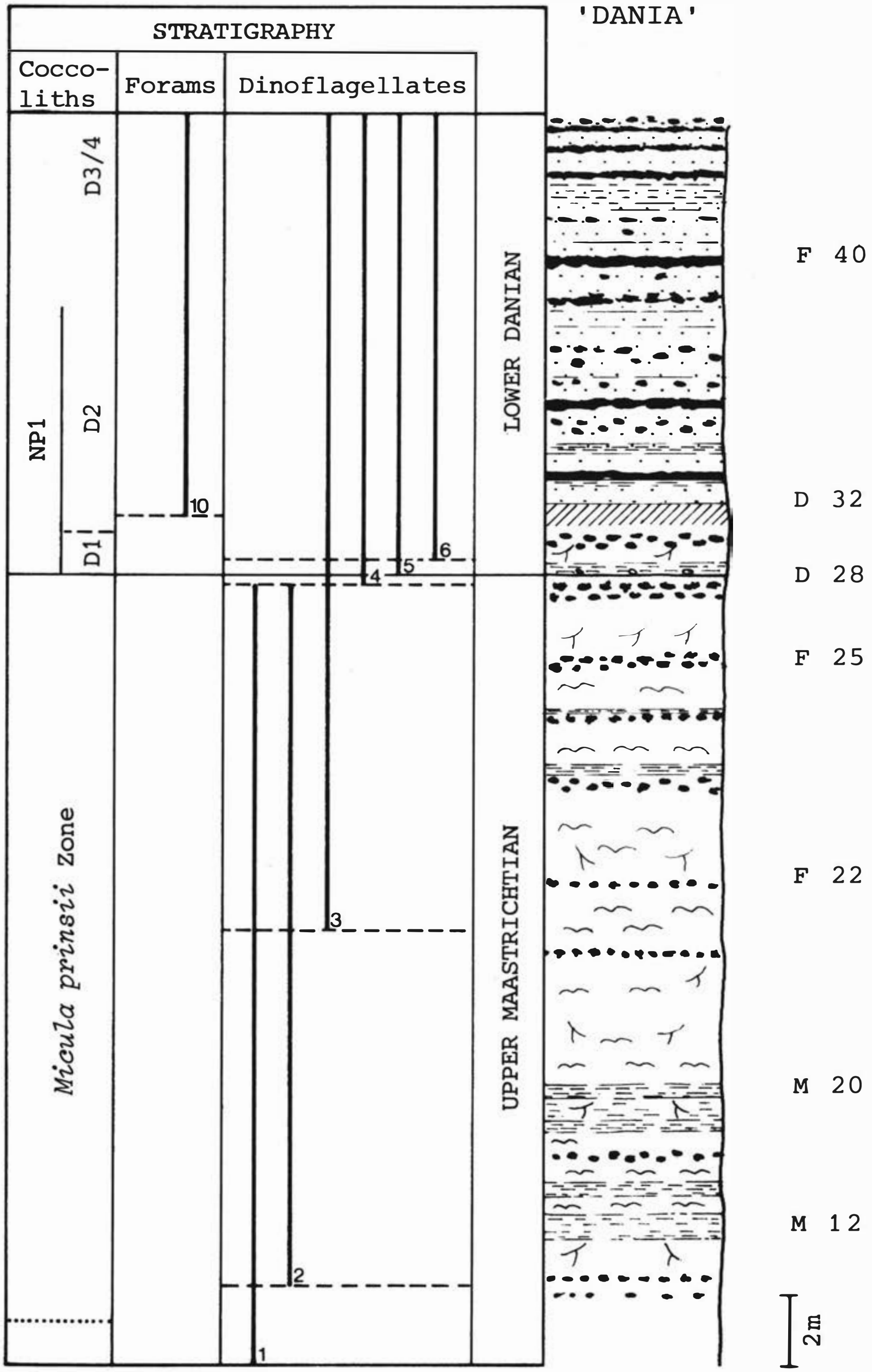

Fig. 13. 'Dania'. Lithological profile measured in 1972 by F. Surlyk and E. Håkansson. Coccolith data provided by K. Perch-Nielsen (pers. comm. 1979); Foraminifera: 10) *Globoconusa daubjergensis* (data provided by I. Bang, pers. comm. 1979); Dinoflagellates: see Fig. 5.

fauna including several ammonite species, belemnites, echinoids (including *Tylocidaris baltica*), bivalves, brachiopods, bryozoans, etc. In the Danian pelagic chalk a single echinoid species is the only abundant form, whereas in the bryozoan limestone the diversity rises again, and from here *T. abildgaardi* may be mentioned.

The sequence at 'Dania' is unique among Danish boundary sequences by containing the topmost Maastrichtian zonal species *Micula prinsii*. However, as it has only been recorded from one of the marl layers low in the sequence (Perch-Nielsen, pers. comm. 1979), *M. prinsii* has probably suffered almost as severe dissolution here as in other Danish top Maastrichtian sequences. The isolated occurrence in 'Dania' agrees well with the unusually high standard of preservation noted earlier for this locality (Perch-Nielsen, 1973).

The stratigraphic distribution of the dinoflagellates in 'Dania' suggests that accumulation of pelagic mud during the Maastrichtian has been almost twice as high here as compared to other localities. This is interpreted as a strictly local phenomenon, related to synsedimentary structural developments in the subsurface.

Selected literature: Troelsen (1955), Perch-Nielsen (1969, 1973), Håkansson *et al.* (1974), Worsley (1974) Jørgensen (1975), Hansen (1977, 1979), Jørgensen (this volume).

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