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*,

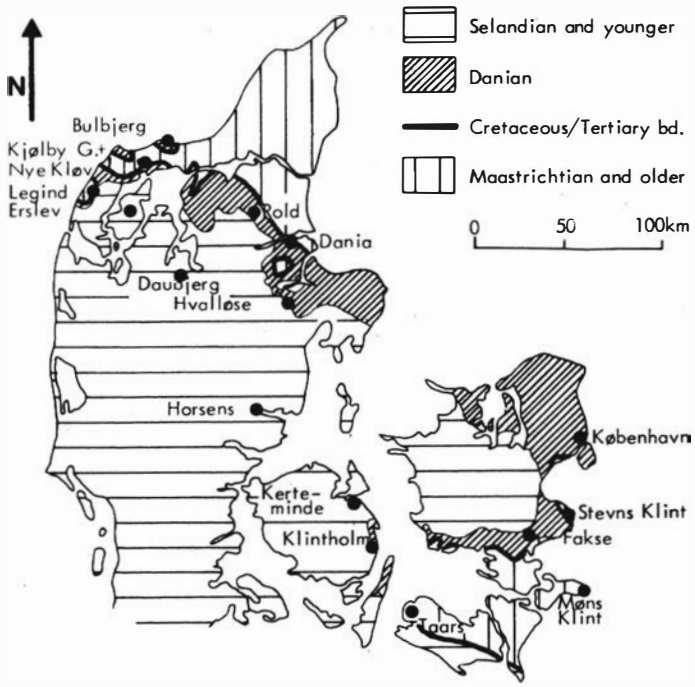


Fig. 1. Map of Denmark showing the localities studied in the present paper.

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

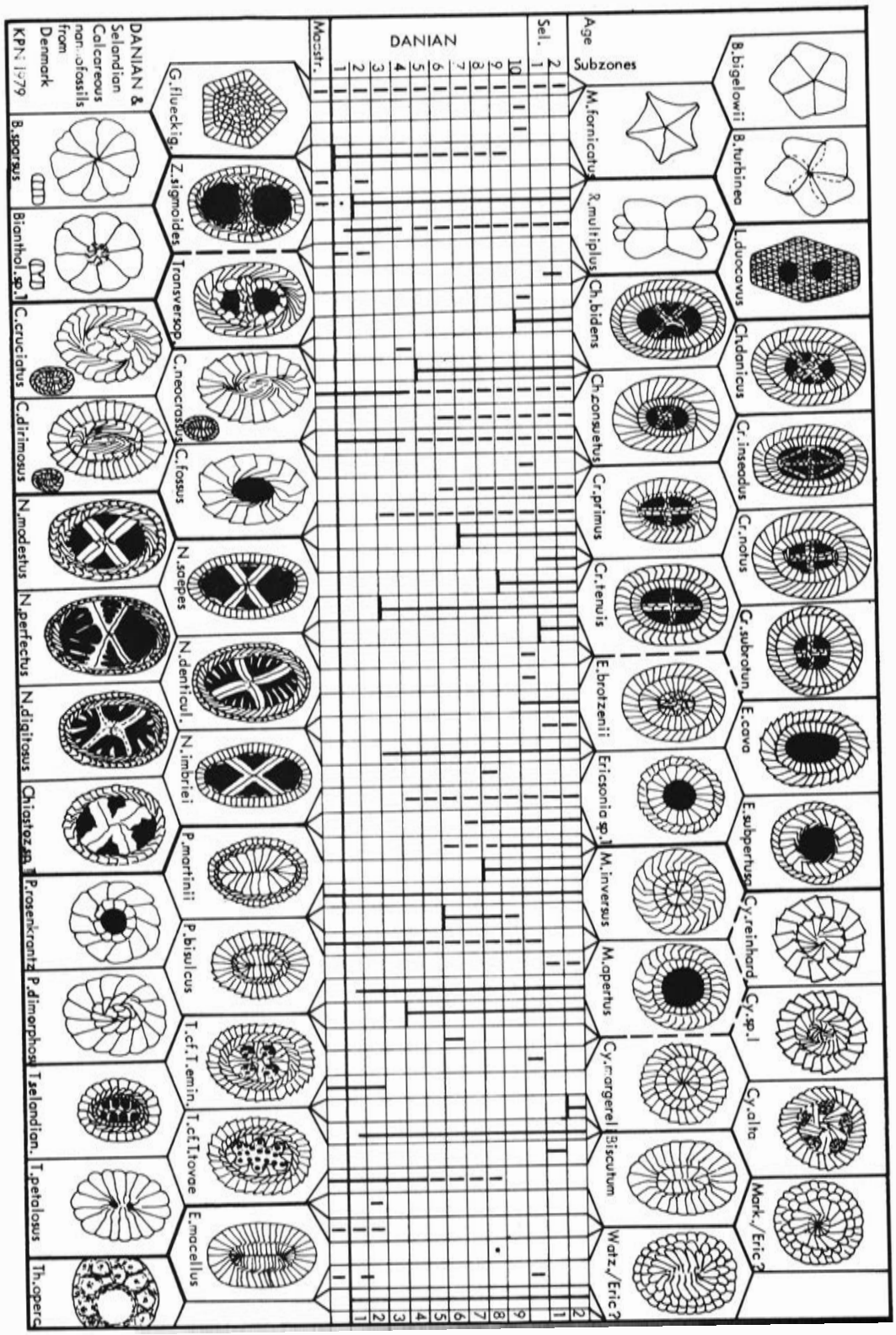

DANIAN & Selandian Calcareous nannofossils from Denmark
KPN 1979
Age
Subzones
Sel.
Maastr.
DANIAN
B.sparsus
Bianthol.sp.1
C.cruciatus
C.dirimosus
N.modestus
N.perfectus
N.digitosus
Chiastozsp.1
P.rosenkrantzi
P.dimorphosus
T.selandian.
T.petalosus
Th.operc
G.flueckig.
Z.sigmoides
Transversop.
C.neocrassus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

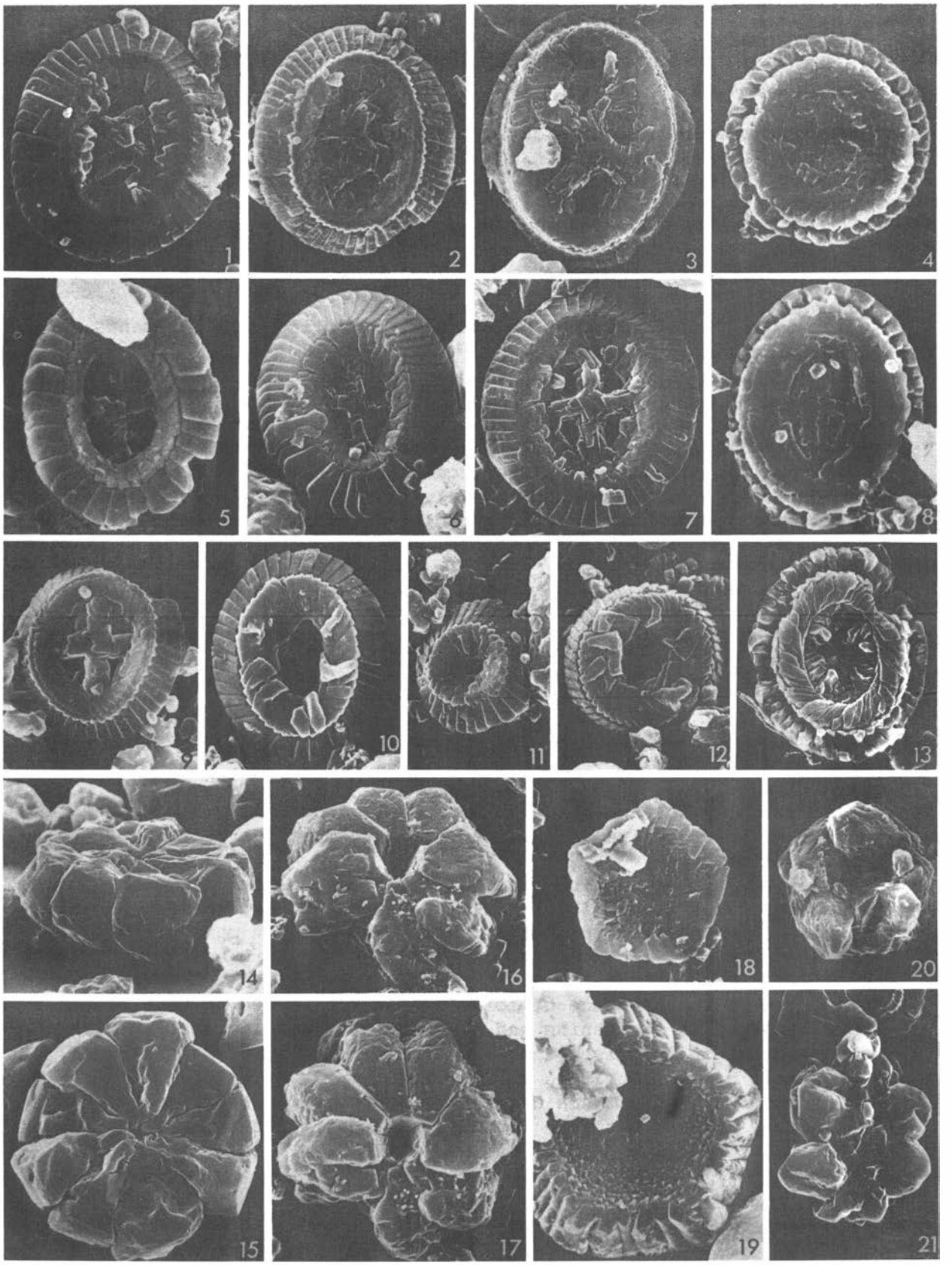
SYSTEMATIC REMARKS

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).

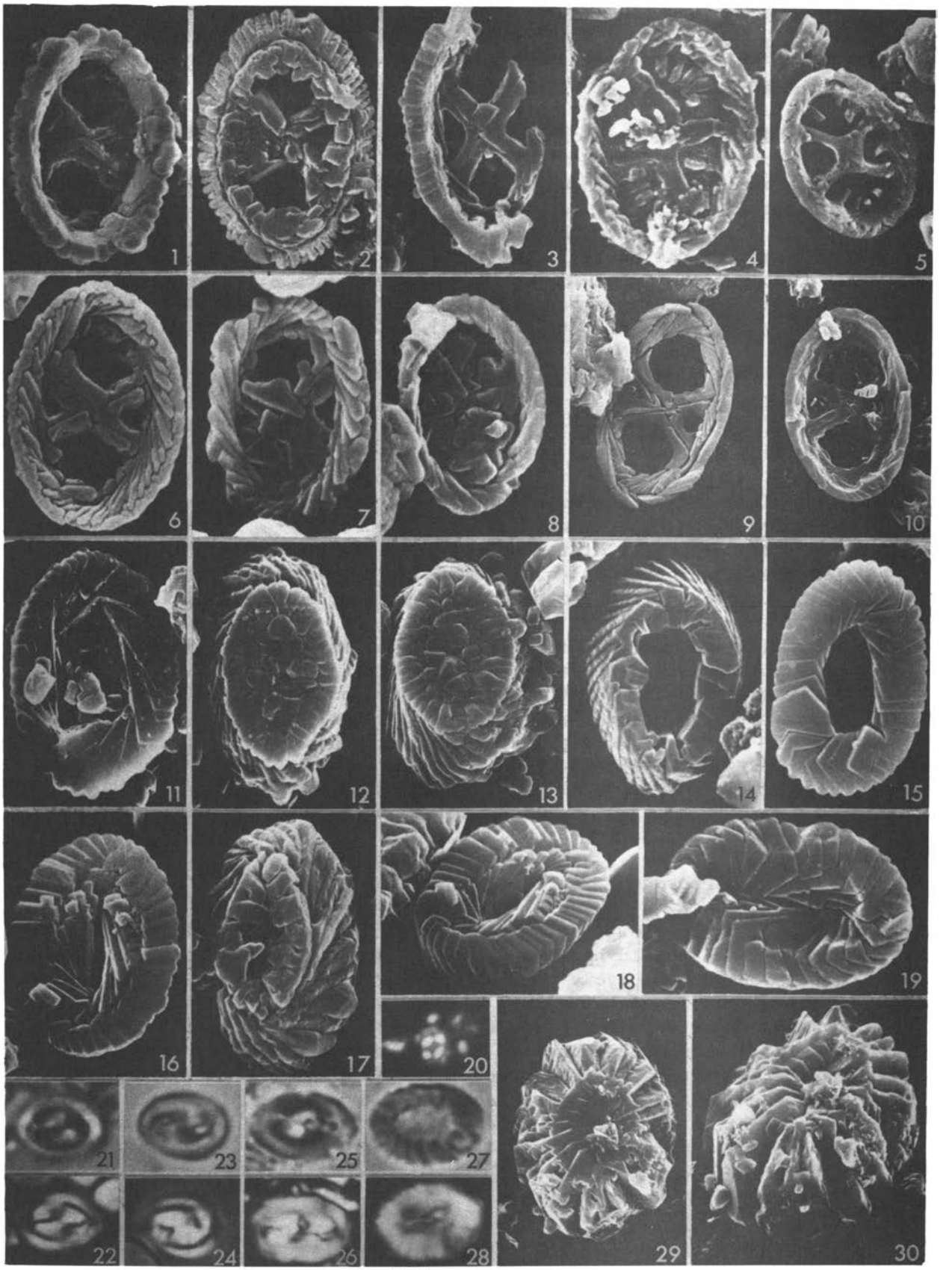
Cyclagelosphaera alta n.sp. Pl. 3, Figs 2,3,4,7

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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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

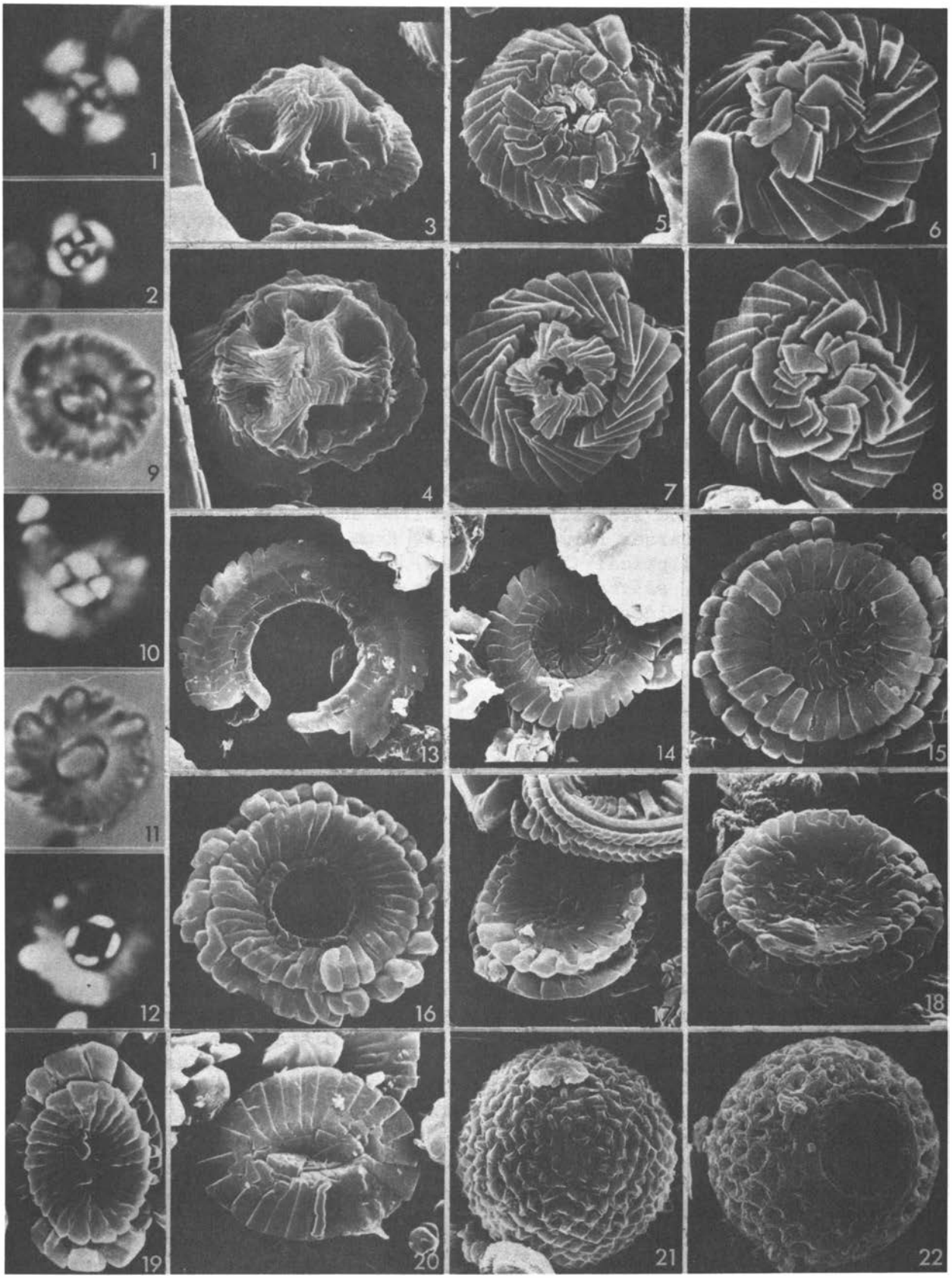
Members of *Neochiastozygus* are important for the biostratigraphy of the Danian and Selandian of Denmark and the North Sea area. Distinction can usually be made by light microscope (see Perch-Nielsen, 1971b, where light micrographs of all species are given), but is easier with the SEM. *N. modestus* 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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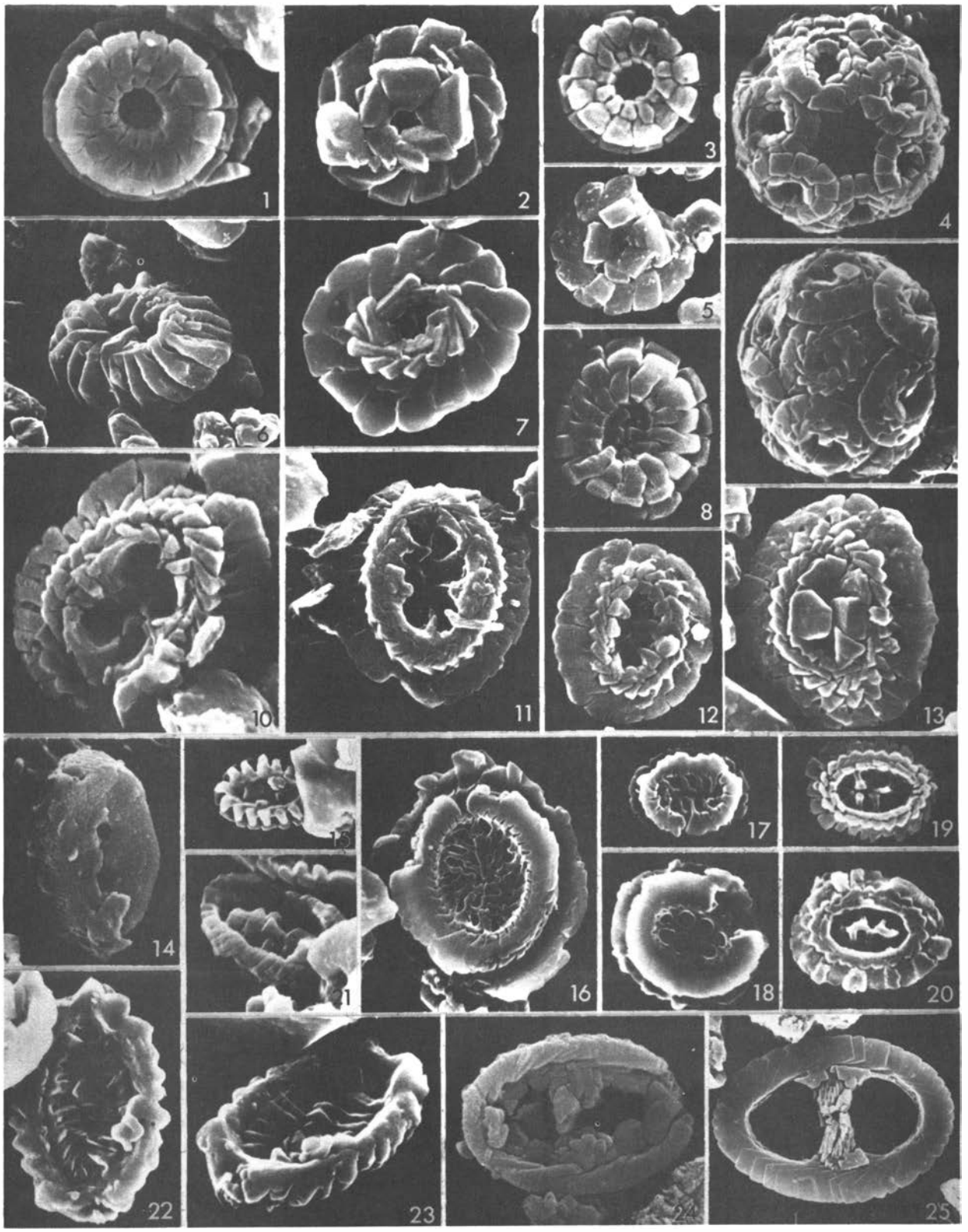
Toweius selandianus n.sp. Pl. 4, Figs 17-20

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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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