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A contribution to EFP-83 project: Jurassic-Lower Cretaceous stratigraphy and basin development of the Danish North Sea sector

Key words:
Calcareous nannofossils, Lower Cretaceous, Biostratigraphy, North Sea.

Vignette:
East-west section through the Tail End Graben

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Preface

The present paper is one of several reports issued as the result of a research project carried out by the Geological Survey of Denmark in cooperation with the Geological Institute at the University of Copenhagen. The project has been financed by special contributions from the Ministry of Energy for the period from August 1st 1983 to December 31st 1985.

The project was entitled "Jurassic – Lower Cretaceous stratigraphy and basin development of the Danish North Sea sector". It was decided to limit the study area to the Danish Central Trough, and effort has been concentrated on the Middle Jurassic, Upper Jurassic, and Lower Cretaceous.

The scope of the project was to coordinate analyses of the stratigraphy, facies development and burial history in order to create a basis for predicting possible occurrences of reservoir rocks. The following reports have been printed in 1986.

Frandsen, N.: Middle Jurassic deltaic and coastal deposits in the Lulu-1 well of the Danish Central Trough. Danm. geol. Unders., Ser. A, 9.

Hoelstad, T.: Palynology of the Middle Jurassic Lower Graben Sand Formation of the U-1 well, Danish Central Trough. Danm. geol. Unders., Ser. A, 14.

Hoelstad, T.: Palynology and palynofacies analyses of the Middle Jurassic to Lower Cretaceous in the Danish Central Trough. Danm. geol. Unders., Internal report.

Jensen, T.F., Holm, L., Frandsen, N. & Michelsen, O.: Jurassic - Lower Cretaceous lithostratigraphic nomenclature for the Danish Central Trough. Danm. geol. Unders., Ser. A, 12.

Møller, J.J.: Seismic structural mapping of the Middle and Upper Jurassic in the Danish Central Trough. Danm. geol. Unders., Ser. A, 13.

Vejbæk, O.V.: Seismic stratigraphy of the Lower Cretaceous in the Danish Central Trough. Danm. geol. Unders., Ser. A, 11.

The following reports (including the present one) will be issued in 1987:

Heilmann-Clausen, C.: Lower Cretaceous dinoflagellate biostratigraphy in the Danish Central Trough.

Michelsen, O., Frandsen, N., Holm, L., Jensen, T.F., Møller, J.J. & Vejbæk, O.V.: Jurassic - Lower Cretaceous of the Danish Central Trough; - depositional environments, tectonism, and reservoirs.

Poulsen, N.: Callovian (Jurassic) to Ryazanian (Cretaceous) dinoflagellate biostratigraphy of the Danish Central Trough.

Thomsen, E.: Lower Cretaceous calcareous nannofossil biostratigraphy in the Danish Central Trough.

DGU, 30th November 1986 Olaf Michelsen

Contents

Abstract

Calcareous nannofossils are described from Lower Cretaceous strata of four borings in the Central Trough of the Danish North Sea sector, and from three Aptian units on Helgoland and at Sarstedt, northern Germany. The assemblages range in age from Upper Hauterivian to Albian-?Cenomanian.

Abundances of calcareous nannofossils varied considerably throughout the investigated sequences. They were rock-forming in several Lower Barremian - Aptian sediments, but rare or lacking in many of the Hauterivian and Albian strata. The Middle Barremian - Lower Aptian assemblages were often dominated by nannoconids. Preservation was generally bad in chalk and good in marl deposits. Some finely laminated black sediments yielded extremely well-preserved assemblages.

One hundred and sixteen species were recognized. Eighteen species were selected as biostratigraphically particularly useful and their chronostratigraphic ranges are shown and discussed. The ages of the investigated sequences were determined on the basis of the selected nannofossil events. Some distinct sedimentary units in the North Sea could be correlated with time-equivalent formations in eastern England and northern Germany.

Introduction

During the Early Cretaceous up to 1.200 m of sediments were deposited in the Central Trough of the Danish North Sea. The Ryazanian to mid Hauterivian sequence consists mainly of homogeneous clay deposits. It attains a thickness of 800–900 m. Deposition was controlled by faults bordering small basins with local depocentres (Vejbæk 1986).

From mid Hauterivian time the pattern of small basins with differential subsidence gradually gave way to the regional subsidence characteristic of the Late Cretaceous. At the same time the rate of subsidence decreased. Compared to the homogeneous lowermost Cretaceous the deposits of mid Hauterivian to Albian age consist of relatively thin sedimentary units which exhibit pronounced vertical changes in facies. The units can usually be correlated regionally (Jensen *et al.* 1987).

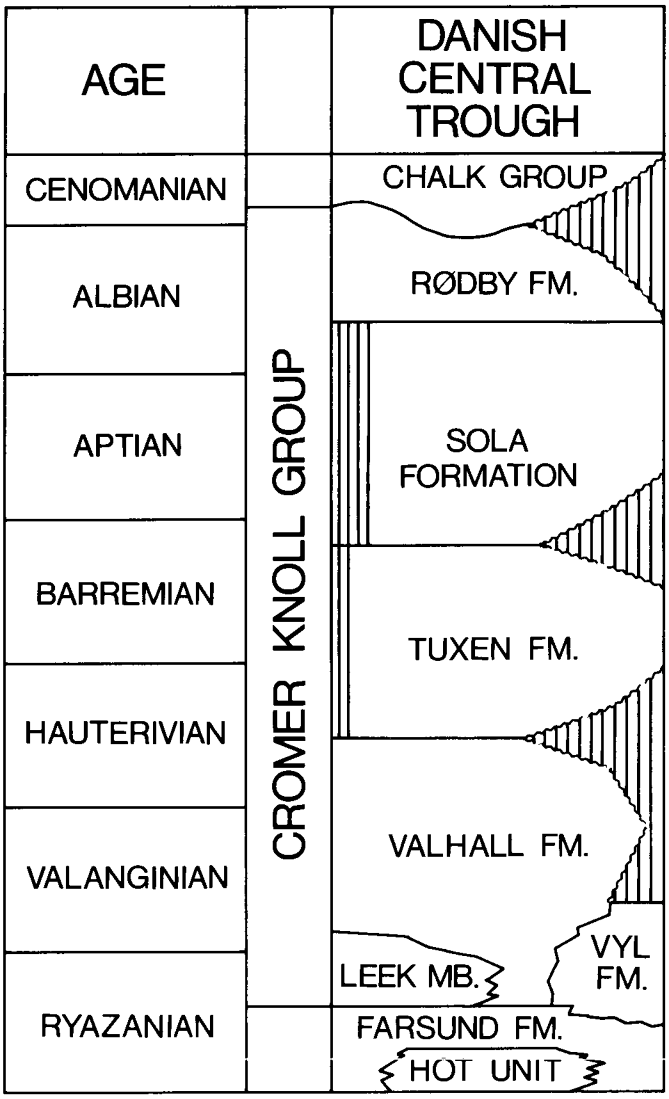


Fig. 1. Lithostratigraphical subdivision of the Lower Cretaceous deposits in the Danish Central Trough.

The oldest Lower Cretaceous sediments in the Danish Central Trough belong to the Farsund Formation (Fig. 1). The remaining units are included in the Cromer Knoll Group of Rhys (1974) and Deegan & Scull (1977). The subdivision of this group has been repeatedly refined as a result of our increasing knowledge of the Lower Cretaceous. Jensen *et al.* (1987) subdivided the Cromer Knoll Group into five formations (Fig. 1). Four of these – namely the Valhall, Tuxen, Sola, and Rødby Formations – are widespread and can be found in both the Danish, Norwegian, British, and German sectors.

The Valhall Formation is predominantly composed of calcareous claystones. The maximum thickness is 800–900 m. The Tuxen Formation is dominated by marlstone in the lower part and chalk in the upper. The thickness increases from 20–30 m in the southern part of the Danish sector to about 80 m near the boundary to the Norwegian sector (Michelsen *et al.* 1987).

A thin bed of black fine-laminated marlstone with a high content of organic carbon is often observed in the upper part of the Tuxen Formation in cored sequences. The bed was described as the Munk Marl Bed by Jensen *et al.* (1987). It produces a characteristic high gamma ray peak, which has been recognized in many wells in the central North Sea.

The lower part of the Sola Formation consists of a dark grey, finely laminated, organic rich calcareous shale, while the upper part is dominated by reddish and light grey claystones and marlstones. The Sola Formation varies in thickness from about 20 m to about 80 m. The Rødby Formation consists mainly of red-brown marlstone. Its thickness is between 15 m and 44 m.

The purpose of the present study was to date a number of boundaries and horizons in the Hauterivian to Albian sequence on the basis of calcareous nannofossils. Main emphasis was placed on determining the age of the lower and upper boundary of the Tuxen Formation and on the age of several distinct horizons within the Sola Formation.A few beds from the Rødby Formation were also examined.

This study is part of a broader project: "Jurassic – Lower Cretaceous stratigraphy and basin development of the Danish North Sea sector", carried out by the Geological Survey of Denmark. The general biostratigraphy of the Lower Cretaceous in the project was mainly based on dinoflagellates (Heilmann-Clausen, 1987). However, dinoflagellates were absent in some of the calcareous units in the upper part of the Lower Cretaceous, where calcareous nannofossils were common.

Material and methods

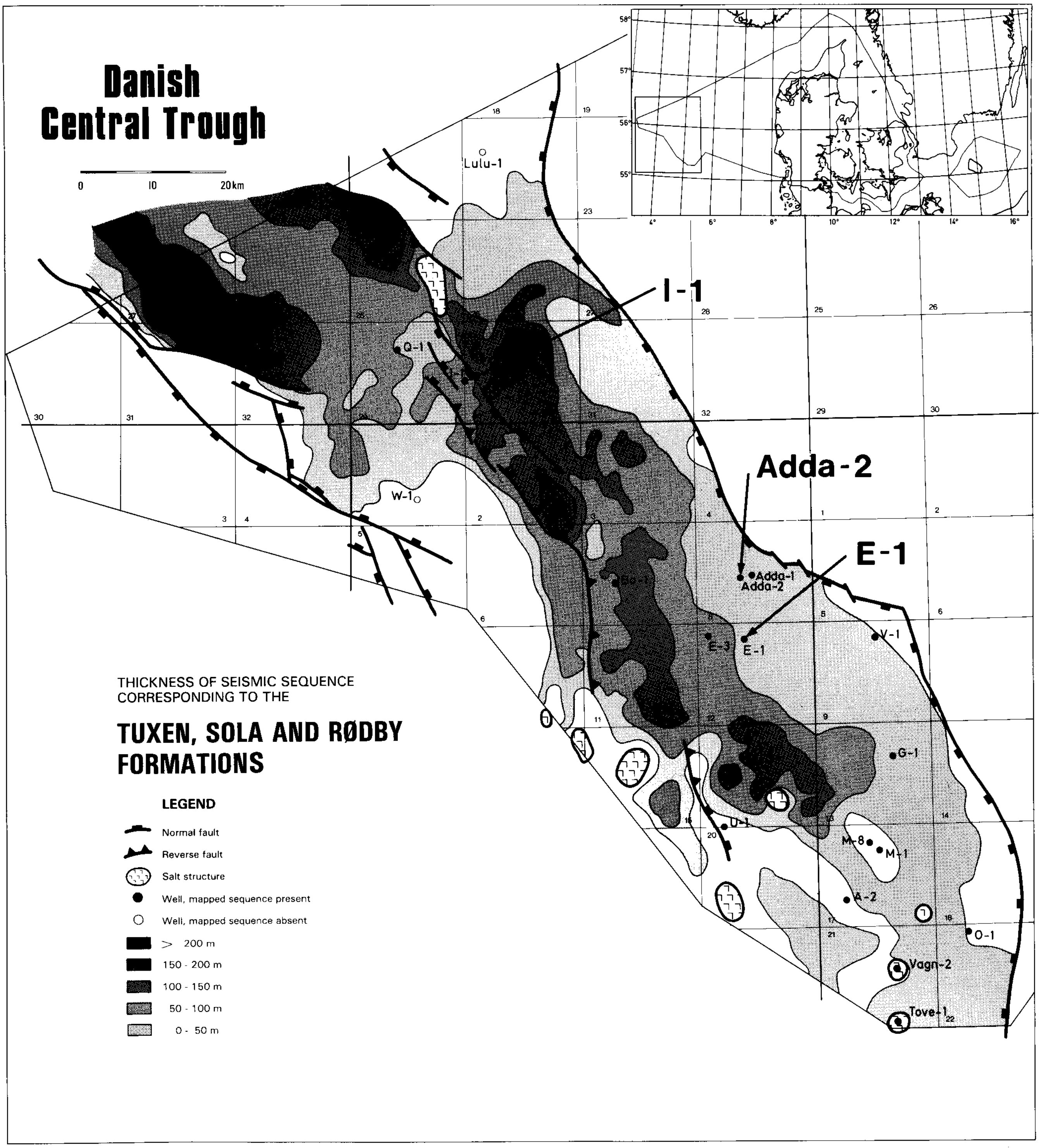


Fig. 2. Thickness and distribution of the Tuxen, Sola, and Rødby Formations (from Jensen et al. 1987) and position of studied wells.

Material

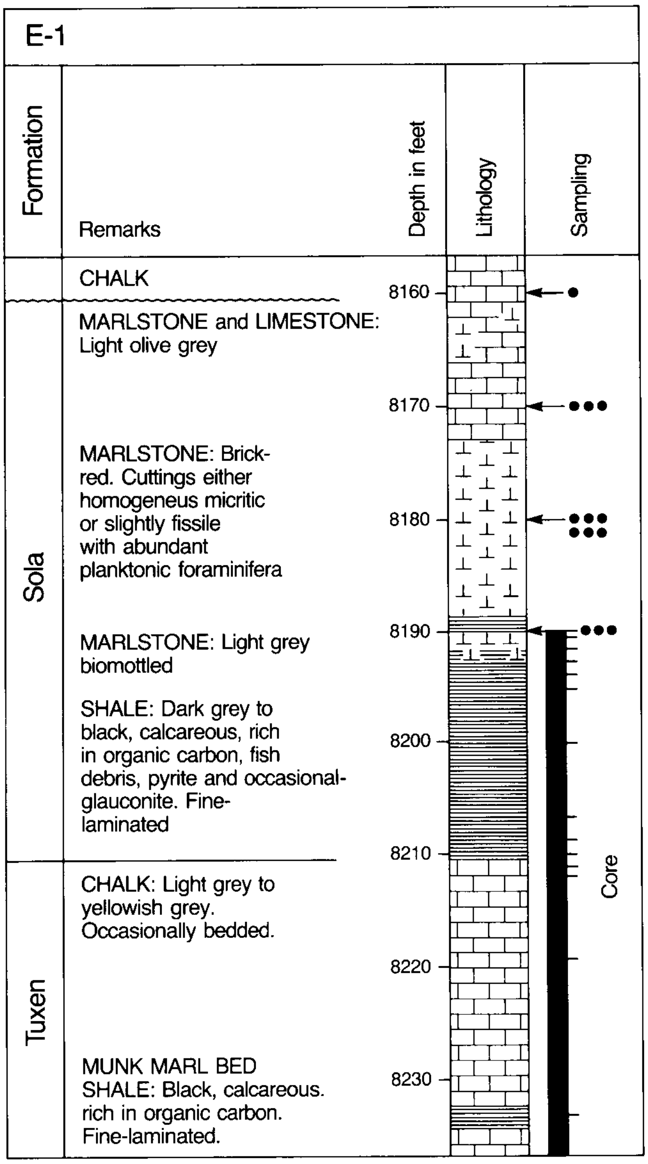
Samples from four wells, E-1, Adda-1, Adda-2 and I-1 were analysed (Fig. 2). A short description of the investigated sequences together with the position of the samples will be given below. A more complete description is given in Jensen *et al.* (1987) and Jensen & Buchardt (1987). In the descriptions of the formations Jensen et al. (1987) used wire-line log depths. In the present paper all references to depth refer to sample depth unless otherwise indicated.

E-1. The investigated sequence from 8160 to 8233 feet b. KB included the upper part of the Tuxen Formation and the Sola Formation (Fig. 3). The Tuxen Formation and the lower part of Sola Formation was cored. The boundary between the two formations was placed at 8211 feet in the core. Gamma and sonic logs, however, indicate that the depth is 8219 feet b. KB. The Munk Marl Bed occurred about 21 feet below the top of the Tuxen Formation.

The lithology of the core was described by Jensen & Buchardt (1987). The lithology of the upper part of the Sola Formation was interpreted from cutting samples taken at 10 feet intervals.

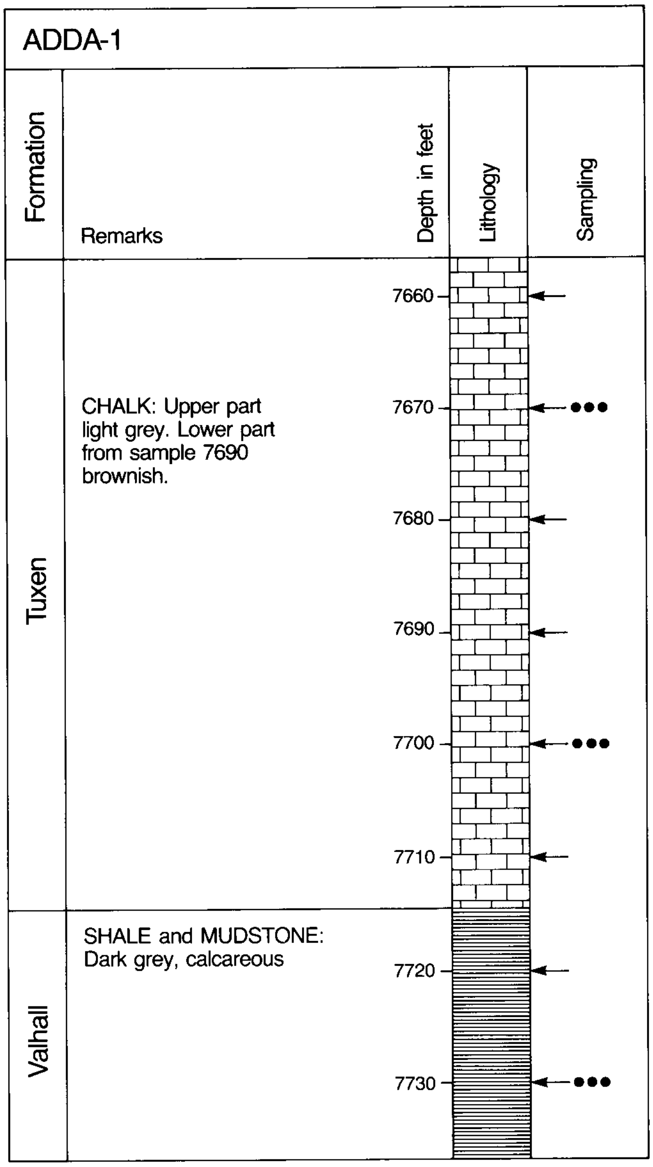
Adda-1. The investigated sequence from 7670 to 7730 feet b. KB included the upper part of the Valhall Formation and the lower part of the Tuxen Formation (Fig. 4). The boundary between the two formations was placed at approximately 7715 feet b. KB. based on the cutting samples. The log boundary was at 7700 feet b. KB.

Adda-2. The investigated sequence from 7750 to 7841 feet b. KB included most of the Tuxen Formation and the Sola Formation (Fig. 5). The whole sequence was cored. The depth of the boundary in the core (7777 feet b. KB) coincides with the log boundary. The Munk



● Preparations of cutting samples
— Core samples

Fig. 3. Lithostratigraphy and position of samples in the investigated sequence of the E-1 well.

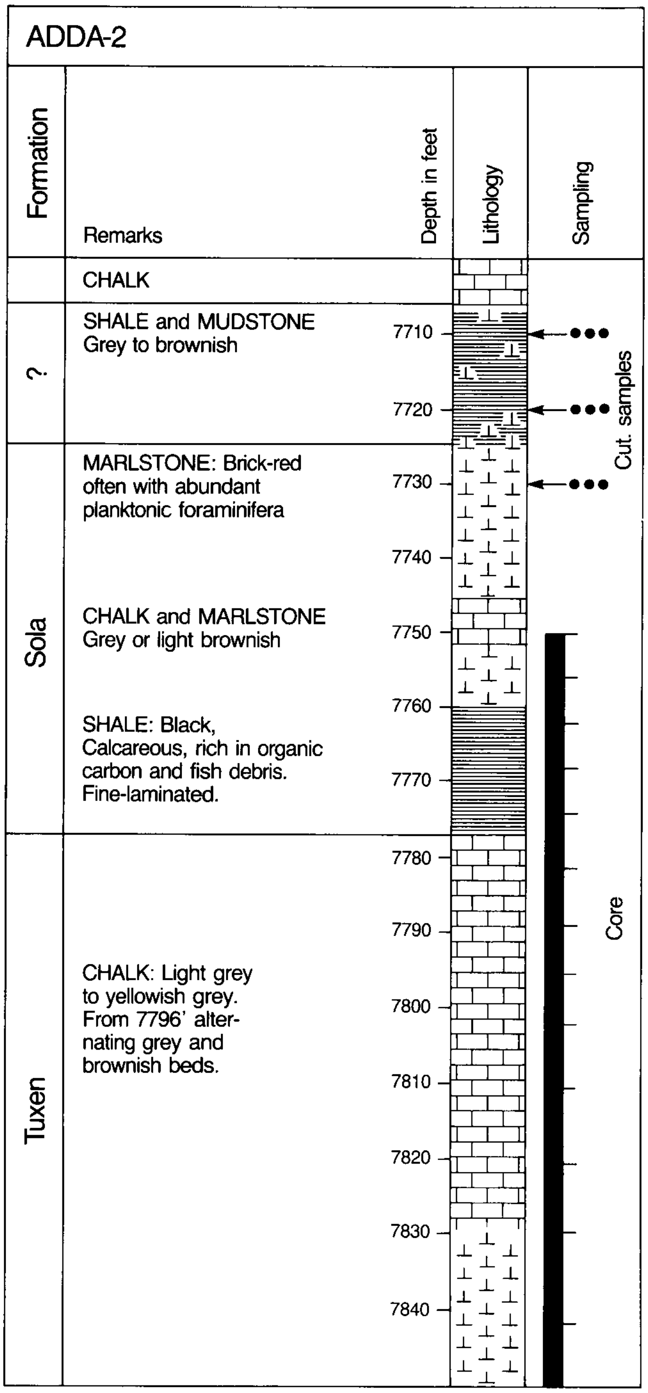


● Preparation of cutting samples

Fig. 4. Lithostratigraphy and position of samples in the investigated sequence of the Adda-1 well.

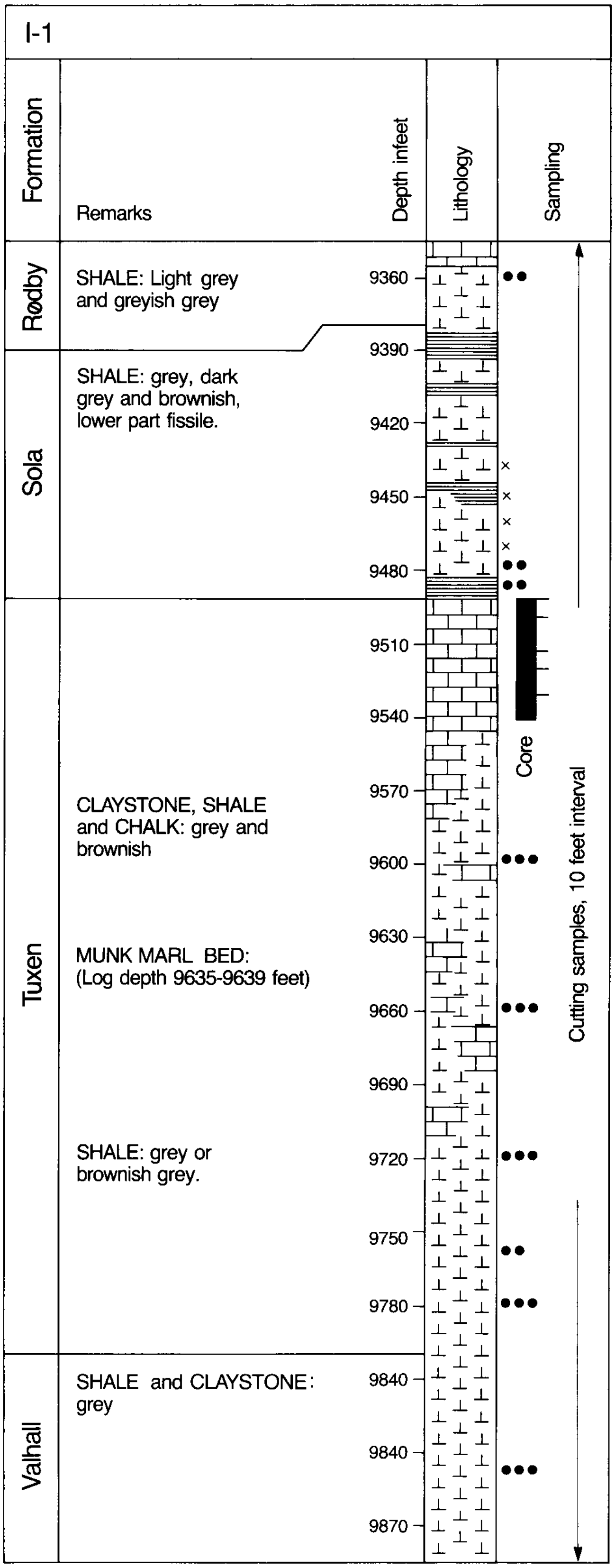
Marl Bed was absent, probably due to local submarine erosion (Jensen *et al.* 1987). The lithology of the core was described by Jensen & Buchardt (1987).

I-1. The investigated sequence from 9490 to 9850 feet b. KB included the upper part of the Valhall Formation, the Tuxen Formation, the lower part of the Sola Formation and the Rødby Formation (Fig. 6). The upper part of the Tuxen Formation was cored. Otherwise the sequence was represented only by cutting samples. Judging from the core and the cutting samples the boundary between the Sola and the Tuxen Formations is at 9394 feet b. KB. The logs indicate that the depth is about 13 feet deeper at 9507 feet b. KB. The boundary between the Valhall and Tuxen Formation is not visible lithologically based on cutting samples. On the logs it is



● Preparations of cutting samples
— core samples

Fig. 5. Lithostratigraphy and position of samples in the investigated sequence of the Adda-2 well.



● cutting samples
— Core samples
× Barren

Fig. 6. Lithostratigraphy and position of samples in the investigated sequence of the I-1 well.

defined to be at 9798 feet b. KB. The gamma log places the Munk Marl Bed between 9635 and 9639 feet.

In addition to the North Sea material four sedimentary units of Aptian age from Helgoland and Sarstedt, northern Germany were investigated. (see appendix).

Methods

In surface sections and cored boreholes stratigraphic zonations are generally based on first occurrences of species. Last occurrences are usually less reliable due to possible reworking. Using coccoliths this preference is accentuated as coccoliths are reworked more easily than any other fossil group used in stratigraphy.

When working with cutting samples from boreholes, however, the use of first occurrences can be problematic. Due to caving cutting samples of older sediments are often contaminated by younger fossils.

The material in the present study consisted of both core and cutting samples. I have, nevertheless, decided to base the zonation primarily on first occurences. The problem of contamination in the cutting samples was dealt with in the following way: Three preparations of single sediment grains were made from each cutting sample. The grains were washed and cleaned. In case the three preparations gave different results the oldest date was used. Grains that gave younger dates were considered to be caved from higher levels. Additional preparations were made if less than two of the preparations gave the same result. Discrepancy in age between preparations was rare when grains were selected in agreement with the general composition of the sample.

The light microscope (LM) and the scanning electron microscope (SEM) preparations were made using standard methods, such as those described by Perch-Nielsen (1985). All samples were treated ultrasonically for a few seconds. Clayey sediments were centrifuged to remove clay particles. Most of the study, including the estimates of the relative abundances and the state of preservation, was done on a SEM.

Stratigraphic distribution of calcareous nannofossils in the Lower Cretaceous

Chronostratigraphic subdivision of the Lower Cretaceous

One of the purposes of the present study was to fill in the stratigraphic gaps in a parallel dinoflagellate study. In order to facilitate comparision it was decided as far as possible to use the same chronostratigraphic scheme in both studies. The selected scheme was a slightly modified version of the zonation of Rawson *et al.* (1978). The stages and substages of this zonation are defined on the basis of the current ammonite zonation of the English Lower Cretaceous. The distribution of ammonites in the Lower Cretaceous in the Boreal regions of Europe is well known and ammonites appear to be the best tool for correlation.The ammonite zones used in England can be recognized over most of northwest Europe.

A slightly modified version of the zonation of Rawson *et al.* (1978) was used in this project. Only one change affected the Hauterivian – Albian part of the Lower Cretaceous. Following Kemper *et al.* (1981) the Hauterivian-Barremian boundary was placed below the *variabilis* ammonite Zone, while in the original scheme the boundary was placed above. In the present study of the calcareous nannofossils a further modification was made in the definition of the substages of the Aptian.

The distribution of calcareous nannofossils has been studied in detail in only a few ammonite-dated northwest European sections of Early Cretaceous age. Nannofossils from the lower part of the Aptian Stage are particularly poorly known. Correlation in the Aptian was, therefore, primarily made with sections in the Tethys region. The boundary between the Lower and Upper Aptian in the present study is equivalent to the boundary between the Bédoulien and the Gargasien stages as defined in southern France. It is not clear where this boundary should be placed in the ammonite zonation of northern Europe. Faunal provinciality and few ammonites in the stratotypes have, hitherto, prevented a reliable correlation. Casey (1961) and Rawson (1983) suggested that the Bédoulian – Gargasian boundary corresponds to the boundary between the *bowerbanki* and the overlying *martinoides* ammonite Zones in northwestern Europe. Kemper (1982) followed the traditional subdivision and placed the boundary below the *bowerbanki* Zone.

The latter placing seems to be in closest agreement with the distribution of the calcareous nannofossils (see appendix), and will, therefore, be used in the present paper (fig. 7).

Calcareous nannofossil studies of the Lower Cretaceous

The most detailed studies of the stratigrafic distribution of Lower Cretaceous calcareous nannofossils in surface sections in northwestern Europe are those of Black (1972, 1973, 1975), Taylor (1978, 1982) and Köthe (1981). Köthe (1981) analysed the Upper Hauterivian – Lower Barremian section in a clay pit at Moorberg/ Sarstedt, northwest Germany. Taylor (1978, 1982) described the fossils in the important Lower Cretaceous section at Speeton, eastern England. The Late Ryazanian – Middle Albian is represented in this section with only a few gaps. The higher parts representing the Aptian and the Albian stages are, however, poorly exposed. Samples from Speeton have also been investigated by Black (1971), Thierstein (1973), Sissingh (1977) Perch-Nielsen (1979), and Crux (1987).

In England Black (1971) and Taylor (1982) studied the Upper Aptian Sutterby Marl. Black (1972, 1973, 1975) and Thierstein (1971, 1973) have described the nannofossils of the Gault Clay in great detail. This formation is of Middle and Late Albian age and outcrops widely in southern England. Reports have also been published on the distribution of nannofossils in the Tealby Clay (Upper Hauterivian) at Nettleton, eastern England (Thierstein 1973, Burns 1976).

In northern Germany nannofossils have been described from several localities and borings by Reinhardt (1964, 1966), Stradner & Grün (1973), Čepek (in Kemper & Zimmerle 1978), Čepek & Kemper (1981), Čepek (1982), Crux (1987), and Mutterlose & Harding (1987). Nannofossils of Albian age from Holland have been studied by Stradner, Adamiker & Maresch (1968). Biostratigraphical use of Early Cretaceous calcareous nannofossils in the Tethys region is mainly based on the works of Thierstein (1971, 1973). His studies were primarily concentrated on the classic sections in southern France and Switzerland. Included in his investigations were several stratotypes and parastratotypes of Lower Cretaceous stages. The stratotypes of the Aptian substages were reinvestigated in greater detail by Barrier (1977a, b).

The sequence of events recognized in these and many other studies of surface sections have generally been found again in the numerous borings that have been studied. Several borings of the Deep Sea Drilling Project have reached Lower Cretaceous sediments and many detailed reports have been published, e.g. Worsley (1971), Roth & Thierstein (1972), Thierstein (1974), Wise & Wind (1977), Roth (1983), Wind & Čepek (1979), Watkins & Bowdler (1984), Wiegand (1984) and Covington & Wise (1987).

Material from borings on the shelf off northern Norway has also been investigated (Aarhus *et al.* 1986), and, recently Jakubowski (1987) proposed a Lower Cretaceous nannofossil zonation for the Moray Firth area of the North Sea.

Chronostratigraphic distribution of important species

Several stratigraphic subdivisions of the Lower Cretaceous have been proposed (Manivit 1971, Thierstein 1973 1976, Sissingh 1977, Roth 1978, Perch-Nielsen 1979 1985, Taylor 1982, and Jakubowsky 1987). Perch-Nielsen (1979 1985), Taylor (1982), and Jakubowski (1987) review and discussed some of the more widely used zonations.

No single zonal scheme was found satisfactory for the North Sea material in the present study. Most of the schemes are based upon material from the Tethyan Region and are difficult to use in the North Sea. Many warm water species are absent or rare in the Boreal Realm. Only the zonation of Taylor (1982) and Jakubowski (1987) are based upon examinations of boreal sections. Several of the marker species used in these two zonations are also used in the present paper, although the zonations as a whole could not be adopted. Some of the species that defines the zones of Taylor (1982) are rare or have clearly different ranges in my material, and the zonation of Jakubowski (1987) is based primarily upon extinctions. It is designed mainly for the oil industry.

Instead of creating a new scheme by combining parts of earlier zonations it seemed preferable to use all reliable first or last occurrences of species as datum levels. Age assignments of the selected events were based on the studies mentioned above with a few corrections based on my own studies of samples from the Aptian sequence of Helgoland (see appendix).

The ranges of the most important species in northwestern Europe appear to be close to the total known ranges of these species. This is clearly not the case for rare species and species that seem to have preferred warmer seas. The stratigraphic range of these species are inferred from correlation to the Tethyan region, where numerous sections have been studied in great detail and where more reliable ranges have been established.

About one hundred and sixteen species of calcareous nannofossils were identified in the four wells. Most of the species are known to occur throughout the Lower Cretaceous. About forty five species appear or disappear in the Hauterivian to Albian interval. However, many are rare and cannot always be considered to yield reliable datings. Only eighteen species were relatively common, with ranges in the North Sea that seemed to approximate the total range of the species.

The stratigraphic correlations in this paper are primarily based on these eighteen species. Their chronostratigraphic occurrences are shown in the distribution chart in Fig. 7. Details about the distribution of the individual species will be given below. Full citation of species names and authors can be found in the list of species. Species of secondary stratigraphic importance will be discussed later.

Tegulalithus septentrionalis

The first records of this species (Stradner 1963, Reinhardt 1966) were from Upper Hauterivian sediments of Austria and north Germany. Köthe (1981) found it to be common in the Upper Hauterivian *Staffi* (= *Speetonensis* Zone of Rawson *et al.* 1978) and *Gottschei* ammonite Zones at Mooberg/Sarstedt, northwest Germany. Thierstein (1973) and Burns (1976) observed the species in sediments of Upper Hauterivian age at Nettleton, eastern England. According to Taylor (1982), and Jakubowski (1987) the species is common in the Hauterivian of northwest Germany and rare at Speeton.

T. septentrionalis is easily recognized and resistant to solution. It is, therefore, an important marker for the Upper Hauterivian (Köthe 1981, Jakubowski 1987). However, according to Jakubowski (1987) the species also occurs rarely in the lowermost Barremian *variabilis* ammonite zone. Specimens from the middle Barremian illustrated by Mutterlose & Harding (1987) and assigned to *Eprolithus septentrionalis* (= *T. septentrionalis*) seem different from the species as accepted here.

In the material from the Danish North Sea the species was normally common when present.

Chiastozygus striatus

Black (1971) and Perch-Nielsen (1979) both recorded this species from the Hauterivian sequence in the section at Speeton, eastern England. Taylor (1978, 1982) studied the same profile and found it also in the Barremian, although it was much more common in the Hauterivian. According to Covington & Wise (1987) it occurs also in Aptian sediments in the western North American Basin. In the present study *C. striatus* has only been found together with *Tegulalithus septentrion-*

alis in samples of inferred Hauterivian age. *C. striatus* has possibly in some cases been confused with *Tegumentum stradneri*, and its upper range in the Barremian should, therefore, be reinvestigated.

Conusphaera rothii.

The extinction of this species in the Tethyan Region has been used as a datum level in the Aptian (Perch-Nielsen 1979, Roth 1983). However, its last occurrence in the boreal realm is earlier, and Jakubowski (1987) used its disappearence from the North Sea as an important marker in the Middle Barremian. The latest record of *C. rothii* in the northern Germany is approximately of the same age (above the Hauptblätterton in the *Paracrioceras elegans* ammonite zone) (Mutterlose & Harding 1987). The species was rare in my material, but it was so consistently present that its disappearance

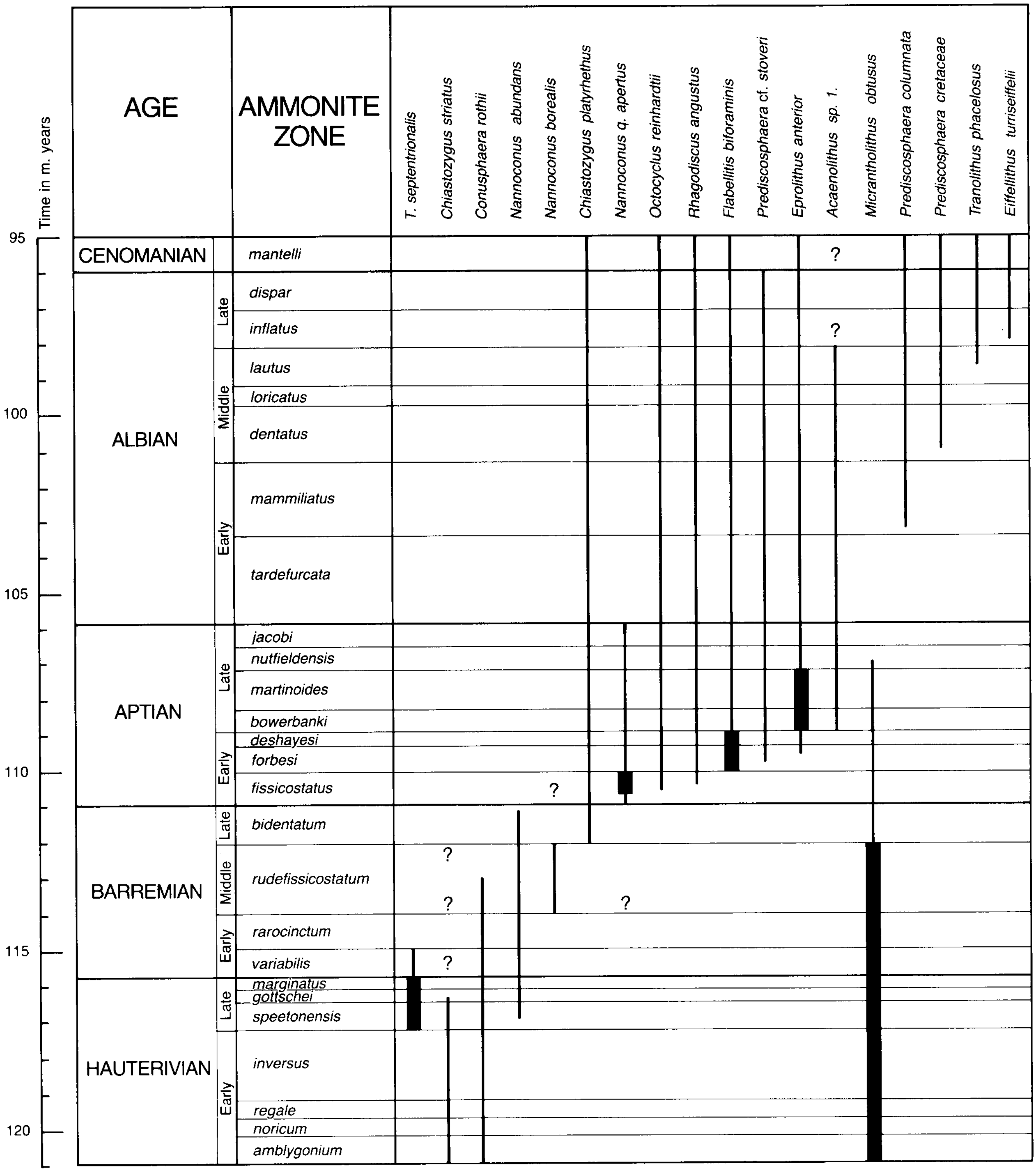


Fig. 7. Chronostratigraphical ranges of the stratigraphically most important species of calcareous nannofossils in the Lower Cretaceous of the Danish Central Trough. The ammonite zonation is modified from Rawson et al. (1978). The time-scale is from Haq et al. (1987).

could be used as a biostratigraphic marker. The last occurrence was in the Tuxen Formation shortly above the Munk Marl Bed. This bed is undoubtedly time-equivalent with the Hauptblätterton in northern German (Jensen & Buchardt 1987) and it is, therefore, of Middle Barremian age.

Nannoconus abundans

This species was first described from Lower Barremian deposits near Salzgitter, northern Germany (Stradner & Grün 1973). Cepek & Kemper (1981) illustrated it from Lower Barremian clays south of Braunschweig. In the section at Speeton Taylor (1978, 1982) found *N. abundans* in all ammonite zones of the Barremian (middle *variabilis* Zone to near the top of the *bidentatum* Zone). Perch-Nielsen (1979) also recorded the species in middle Barremian deposits at Speeton. According to Köthe (1981) *N. abundans* appears in the uppermost Hauterivian sediments at Mooberg/Sarstedt, northwestern Germany. Taylor (1982) and Jakubowski (1987) used *N. abundans* as a zonal marker in the Lower Cretaceous.

In the present study the disappearance of *N. abundans* in the lower part of the Sola Formation can probably be correlated with its last occurrence in the upper part of the *bidentatum* ammonite Zone at Speeton, eastern England.

It should, however, be noted that the use of *N. abundans* for correlation purposes can be problematic unless the nannoconid flora is well known over a considerable time span. *N. abundans* as defined by Taylor (1982) and used in the present paper is a very simple and unspecialized form. Several Lower Cretaceous species, eg. *N. quadriangulus* and *Nannoconus sp.* 1, have a similar general shape and construction. They differ in the presence of small but important special characters. Specimens which undoubtedly belong to one of these other species but on which these characters are only weakly developed can hardly be distinguished from *N. abundans* unless a large population is observed. Such specimens are quite common in many samples, due to the extremely large variability among the nannoconids.

Nannoconus borealis

This species was first described from the Middle Barremian Cement Beds at Speeton, eastern England (Perch-Nielsen, 1979). According to Deres & Achéritéguy (1980) it is possibly also present in the Lower Aptian of southern France. Jakubowsky (1987) used *N. borealis* as a marker species for the Middle Barremian. In my material it was only found in the upper part of the Tuxen Formation (M. Barremian).

Chiastozygus platyrhethus

The first occurrence of this species has been used as a marker for the base of the Lower Aptian (Thierstein 1973, 1976, Sissingh 1977, Roth 1978, Perch-Nielsen 1979). However, there is much confusion over the identification and stratigraphic range of *C. platyrhethus* (Perch-Nielsen 1985). Thierstein (1973) recorded it (as *C. litterarius*) in the uppermost Barremian at La Charce (Drôme), southern France. Perch-Nielsen (1979) observed it (as *Chiastozygus* spp.) in a sample from the Upper Barremian UB-beds at Speeton. It has also been noted from the Hauterivian at Speeton, but the specimen illustrated by Taylor (1982) is different from *C. platyrhethus* as used here. It should also be mentioned that *Chiastozygus tenuis* Black (1971) described from the Hauterivian of England differs only slightly from *C. platyrhethus,* and that Covington & Wise (1987) traced specimens virtually indistinguishable from *C. litterarius* (= *C. platyrhethus*) as far down as the Upper Hauterivian. It seems most likely that the first occurrence of *C. platyrhethus* took place before the beginning of the Aptian in northwestern Europe. Dinoflagellate datings of samples from the North Sea near to the first appearance of *C. platyrhethus* (sample E-1 8208 feet) gave an age close to the Middle to Late Barremian boundary (Heilmann-Clausen 1987).

The earliest specimens of *C. platyrhethus* from the Tuxen Formation and the lower part of the Sola Formation are clearly smaller and more delicately constructed than later specimens (Plate 2, Fig. 9) , and they compare more closely with *C. tenuis* (as illustrated by Taylor 1982). Possibly *C. platyrhethus* developed from *C. tenuis* sometime during the Barremian.

Octocyclus reinhardtii

Taylor (1982) used the first occurrence of this species as a secondary marker for the basal Aptian. It appears in the upper part of the *fissicostatus* ammonite Zone in the section at Speeton.

The species was relatively rare in the North Sea material and it cannot be used as a consistent marker here.

Nannoconus quadriangulus apertus

According to Deres & Acheriteguy (1980) this species is present only in the Upper Aptian. In the North Sea material, however, it occurred well before the the Lower Aptian markers *Rhagodiscus angustus* and *Eprolithus apterior*. Dinoflagellate datings (Heilmann-Clausen 1987) of samples with *N. q. apertus* suggest that its first appearance is close to the Barremian-Aptian boundary, perhaps in the latest Barremian.

Rhagodiscus angustus

R. angustus is in most stratigraphic schemes used as an indicator for the base of the Upper Aptian (Thierstein 1973 1976, Perch-Nielsen 1979, Taylor 1982, Jakubowski 1987).

However, the use of *R. angustus* was questioned by Sissingh (1977) and Perch-Nielsen (1979), and in the present study the species was found in sediments of early Aptian age from Helgoland.

Sissingh (1977) identified *R. angustus* in Barremian and Hauterivian strata at Speeton, eastern England, and Perch-Nielsen (1979) found small specimens very similar to *R. angustus* in the same beds. According to Perch-Nielsen (1979) these early forms lack granules in the basal floor and have slightly convex sides. They have later been described as *Zeugrhabdotus pseudoangustus* by Covington & Wise (1987).

The earliest specimens of *R. angustus* in the North Sea material were also very small with convex sides, but they had granules in the floor (Plate 16, Figs. 6–8). These forms appeared in the interval between the first occurrences of *C. platyrhethus* and *E. apterior*. Small, but typical specimens of *R. angustus* with parallel or slightly concave sides (Plate 16, Figs 9, 10)appeared later, but still before the first occurrence of *E. apterior*. The first appearance of large *R. angustus* (Plate 16, Fig. 11) higher in the sequence coinceded with an increase in the size and relative abundance of *E. apterior*.

Small typical specimens of *R. angustus* were common in the "Fischschiefer" of Helgoland. This formation has been dated to the lower part of the *Deshayesaites* Zone (= to the upper part of the *forbesi* Zone in the scheme of Rawson et al. 1978) using ammonites (Kemper *et al.* 1974). On the basis of the results from Helgoland it must be assumed that the first appearance of small *R. angustus* in the North Sea took place in the *fissicostatus* Zone. Future morphometric analyses of the early development of *R. angustus* would undoubtedly enhance its stratigraphic value.

Flabellites biforaminis

The oldest dated observations of this species are from the Lower Aptian "Fischschiefer" of Helgoland (see appendix). In the Tethyan region Barrier (1977a) recorded the species from the upper part of the Bédoulian stratotype at Cassis-La Bédoule. Thierstein (1973) found it in sediments ranging from the Upper Aptian to the Upper Cenomanian.

F. biforaminis is common in the North Sea, especially in the lower part of its range. The species is distinctive and resistent to solution. It is, therefore, regarded as an important marker in the Lower Aptian. Possibly, however, it can only be used locally in Europe. Roth (1983) in a LM study of the calcareous nannofossils from the Deep Sea Drilling Project Site 534 in the Blake-Bahama Basin, claimed, that *F. biforaminis* (as *W. oblonga*) occurs scattered at least from the Hauterivian.

Prediscosphaera cf. stoveri

P. cf. *stoveri* is the earliest species of the genus *Prediscosphaera*. The oldest dated occurrence is from the Lower Aptian "Fischschiefer" of Helgoland. Barrier (1977b) recorded it from the stratotype of the Gargasian in southern France. Its last occurrence is probably in the Cenomanian (Perch-Nielsen 1985).

Eprolithus apterior

This important species is used by most workers as a primary or secondary marker for the base of the Upper Aptian (Thierstein 1973 1976, Perch-Nielsen 1979 1985, Roth 1983, Wise 1983, Jakubowski 1987). However, Barrier (1977a) recorded *E. apterior* in two samples from the Lower Aptian stratotype at Cassis-La Bédoule in southern France, and in the present study the species was found in the "Fischschiefer" of Helgoland. This formation is referred to the upper part of the *forbesi* ammonite Zone. (Plate 22, Figs. 5–7 and 9, 10). *E. apterior* was rare, and small in the "Fischschiefer", but was larger and much more common in the overlying yellow "*ewaldi*-Kreide" (*bowerbanki* ammonite Zone).

Acaenolithus sp.1

Black (1973) described four species of this genus from the Skegness Clay (Upper Aptian) and the lower Gault Clay (Middle Albian) of eastern England. Differentiation between them is very difficult. On Helgoland the genus was present in the yellow and red "*ewaldi*-Kreide", but absent in the "Fischschiefer" (see appendix). The first appearance of *Acaenolithus* sp.1 seems, therefore, to be close to the boundary between the Lower and Upper Aptian. The North Sea specimens resemble forms described from the Aptian of southern Atlantic by Wise (1983).

Micrantholithus obtusus

M. obtusus is generally very common in the Hauterivian and Lower Barremian. The latest record of *M. obtusus* is from Speeton, eastern England, where it disappears in the lower part of the Aptian *nutfieldensis* ammonite Zone (Taylor 1982). The last occurrence of *M. obtusus* has been used as a marker in the Aptian in several zonations (Thierstein 1976, Perch-Nielsen 1979 1985, Jakubowski 1987).

In my material *M. obtusus* occurred in abundance in the Valhall Formation and the lower part of the Tuxen Formation (Upper Hauterivian – Lower Barremian). It was very common in the Munk Marl Bed and the upper part of the Tuxen Formation (Middle Barremian). It was consistently present in the laminated lower part of the Sola Formation (Upper Barremian and Lower Aptian) but rare in the Upper Aptian limestone and marlstone.

Prediscoscosphaera columnata

P. columnata is the earliest circular species of the genus *Prediscosphaera*. Its first appearance approximates the Lower – Middle Albian boundary (Perch-Nielsen 1979). Thierstein (1973) recorded the genus from the uppermost Lower Albian in southern France.

Prediscosphaera cretacea

In well preserved material several species of *Prediscosphaera* with a central cross can be recognized. (Perch-Nielsen 1979). Only two species were distinguished in the North Sea material in the present study. Small delicate specimens were referred to *P. columnata*, while larger and more robust forms were assigned to *P. cretacea*. According to the stratigraphic scheme of Perch-Nielsen (1979) *P. columnata* first appears close to the boundary between the Lower and Middle Albian. *P. cretacea* appears slightly later, probably in the *loricatus* ammonite Zone. In the section at Speeton the first specimens of *Prediscosphaera* occur close to the base of the Middle Albian in the lower part of the *dentatus* ammonite Zone (Taylor 1982).

Tranolithus phacelosus

The first occurrence of *Tranolithus phacelosus* in England is in the lower part of the *lautus* ammonite Zone (Taylor 1982, as *T. orionatus*). According to the distribution charts of Thierstein (1973) the species appears slightly earlier in the Tethyan region. The global first occurrence of *T. phacelosus* can, therefore, probably be dated to the *loricatus* ammonite Zone.

Eiffellithus turriseiffelii

The first occurrence of this important species is dated to the lower part of the *inflatum* ammonite Zone in both the North Sea area and the Tethyan region (Taylor 1982, Thierstein 1973). The first appearance of *E. turriseiffelii* can, therefore, be used as a marker for the Middle to Upper Albian boundary.

In addition to the taxa mentioned above the following five species contributed to the age determinations. They have all well-dated first or last occurrences in the Hauterivian to Albian, but they were relatively rare in the North Sea material. They cannot, therefore, be relied upon as consistent markers.

Braarudsphaera hockwoldensis

Known range: Upper Lower Aptian – Albian (Perch-Nielsen 1979).

Chiastozygus bifarius

Known range: Cenomanian – Turonian (Crux 1982).

Cretarhabdus loriei

Known range: Aptian – Cenomanian (Taylor 1982).

Cribricatillus robustus

Known range: Upper Albian (Black 1973).

Eprolithus varolii

Known range: Occurs in the Upper Aptian *nutfieldensis* ammonite zone at Sarstedt, northwest Germany. Its extinction is close to the Aptian – Albian boundary according to Jakubowski (1987). First cccurrence is probably in the Lower Aptian.

Rucinolithus irregularis

Known range: Lower Aptian (Upper Barremian) – Middle Albian. (Thierstein 1976, Wise 1983)

Seribiscutum primitivum

Known range: Lower Barremian – Santonian. Common only in the Albian (Jakubowski 1987).

Stoverius achylosus

Known range: Upper Aptian – Cenomanian. (Thierstein 1976).

Other species that have been used as zonal markers in the Lower Cretaceous by various authors were not used in this study, either because they were not recorded or because the observed ranges differed significantly from the ranges given in the litterature. *Calcicalathina oblongata* (Worsley, 1971) Thierstein (1971), for example, was not observed. This species is an important mid-Barremian marker in the Tethyan realm. *Diazomatolithus lehmannii*, which Jakubowski (1987) considered to be a reliable marker in the Lower Barremian of the North Sea, occurred in my material consistently in the Middle Barremian and rarely in the Upper Barremian and Lower Aptian. The absence of *Speetonia colligata* Black (1971) and *Cruciellepsis cuvillieri* (Mannivit, 1966) Thierstein (1971), on the other hand, may simply indicate that the investigated sequences are above the last appearance two species. They are both considered to disappear in the Upper Hauterivian (Perch-Nielsen 1985), although *S. colligata* recently has been observed also in the lowermost Barremian (Jakubowski 1987).

Biostratigraphy

The following section presents the age determinations of the investigated sequences and discusses the evidence on which the conclusions are drawn.

E – 1

The E – 1 well is situated centrally in the Lower Cretaceous basin of the Central Trough (Fig. 2). The boundary between the Upper and the Lower Cretaceous was penetrated at a depth of 8160 feet (Fig. 3). The investigated sequence comprised the uppermost 75 feet of the Lower Cretaceous. The upper part from 8160 – 8211 feet belongs to the Sola Formation, the lower part to the Tuxen Formation. Sample positions and a short description of the lithology are given in Fig. 3. The distribution of calcareous nannofossils is shown in Fig. 8.

8160 – 8190 feet. The cutting sample at 8160 feet was composed exclusively of chalk grains of typical Upper Cretaceous lithology. They were barren of calcareous nannofossils, but the dinoflagellates suggest a Late Cretaceous age (Heilmann-Clausen 1987). The first sample of Early Cretaceous age was at 8170 feet. The grains consisted of light grey to greenish-grey calcareous shale and marlstone. Nannofossils were abundant but poorly preserved. The presence of numerous *Eprolithus apterior* and the absence of *Prediscosphaera columnata* and *Micrantholithus obtusus* points to a latest Aptian to Early Albian age.

The samples taken at 8180 and 8190 feet were dominated by grains of brick-red marlstones and limestones, but a few grey and greenish-grey grains were also present. Most of the grey grains contained a nannofossil assemblage that was similar to the assemblage found in sample 8170 feet, but a few grains included *Micrantholithus obtusus*. This strongly indicates that the lower part of the grey marlstone belongs to the lower Upper Aptian.

Two slightly different types of brick-red marlstone could be distinguished. One type was characterized by numerous planktonic foraminifers imbedded in a rather coarse matrix that often was weakly laminated. The other type was more fine-grained with fewer foraminifers and with no sign of lamination. The boundary between the red marlstone and the overlying grey-greenish unit is probably close to 8175 feet.

Calcareous nannoplankton were common in the red marlstone, but their preservation was generally poor.The presence of *Micrantholithus obtusus* together with numerous specimens of *Eprolithus apterior* suggests that the marlstone can be assigned to the lower part of the Upper Aptian. Other important species were *Rhagodiscus angustus*, *Stoverius achylosus*, *Braarudosphaera hockwoldensis*, and *Acaenolithus* sp. 1.

The remaining part of the investigated sequence was cored (Fig. 3). The upper part of the core from 8190 to 8211 feet belongs to the Sola Formation like the strata above. The sediment, however, was quite different, as it mainly consisted of a dark, finely laminated, organic rich shale with numerous remains of fish debris and abundant pyrite. A bioturbated two feet thick marl unit interrupted the uniform shale sediments a few centimetres below the top of the core. The boundary between the dark shale and the overlying red marlstone should probably be placed a few feet above the top of the core (Jensen pers. com. 1986).

The calcareous nannofossils indicate that the shale unit belongs to the Upper Barremian and the lower most Aptian. This conclusion is based on the presence of *Chiastozygus platyrhethus*, *Nannoconus abundans*, and *Octocyclus reinhardtii* and on the absence of *Eprolithus anterior*, typical *Rhagodiscus angustus, and Flabellites biforaminis*.

The first occurrence of *C. platyrhethus* is in many Lower Cretaceous zonations used as a marker for the Lower Aptian, but the species has also been recorded from the Upper Barremian (Thierstein 1973, 1976, Perch-Nielsen 1979). A Late Barremian rather than an Early Aptian age is suggested for the lowermost part of the shale by the presence of *Nannoconus abundans*. According to Taylor (1982) the last occurrence of *N. abundans* at Speeton is in the Upper Barremian *bidentatum* ammonite Zone very close to the Aptian boundary.

The highest record of *N. abundans* was in sample E-1 8208.5 feet. The same sample showed the first appearance of *Nannoconus quadriangulus apertus*. This subspecies, which became increasingly abundant towards the top of the core, has previously only been reported from the Upper Aptian of the Tethys region. Its first occurrence is clearly older in the North Sea, and at present the species cannot be used as a chronostratigraphic marker. It seems, however, to be useful for local correlations.

The first dependable Lower Aptian marker was *Oc-*

tocyclus reinhardtii at 8190.6 feet. However, the species is rare and cannot be relied upon as an indicator for the exact position af the Barremian – Aptian boundary. It seems more probable that the boundary is closer to the last occurrence of *Nannoconus abundans* at 8207.6 feet.

The absence of *Eprolithus apterior*, typical *Rhagodiscus angustus*, and *Flabellites biforaminis* shows that the cored sequence cannot be younger than the early part of the *forbesi* ammonite Zone.

Four samples were investigated from the Tuxen Formation. The uppermost sample at 8211.2 feet contained both the Upper Barremian marker *C. platyrhethus* and the middle Barremian marker *N. borealis,* and the sample is, therefore, placed close to the boundary between the two substages. *C. platyrhethus* was not found in the subsequent samples at 8211.4, 8219, and 8232.8 feet. The uppermost two of these samples are referred to the upper part of the Middle Barremian because of the absence of *Conusphaera rothii*. The sample at 8232.8 feet from the Munk Marl Bed is assigned to the lowermost Middle Barremian or the Lower Barremian due to the presence of *C. rothii* and the absence of *Tegulalithus septentrionalis*.

Adda-1

The Adda-1 well is situated marginally in the Lower Cretaceous basin of the Central Trough close to the Ringkøbing – Fyn High (Fig. 2). The investigated sequence included the boundary between the Tuxen and the Valhall Formations. Sample positions and a short description of the lithology are given in Fig. 4. The distribution of calcareous nannofossils is shown in Fig. 8.

The lowermost two samples from the Tuxen Formation (7700 and 7710 feet) and the sample from the Valhall Formation (7730 feet) are assigned to the Upper Hauterivian because they contained *Tegulalithus septentrionalis*. This species was not recorded in the sample from 7670 feet which, therefore, must be of Barremian age. An Early to lower Middle Barremian age is indicated by the presence of *Conusphaera rothii* and the absence of *Chiastozygus platyrhethus*.

Adda-2

The well is situated marginally in the Lower Cretaceous basin near the Ringkøbing – Fyn High, a few kilometers west of Adda 1 (Fig. 2). The investigated sequence comprised an unidentified Upper Albian or Cenomanian formation, the Sola Formation, and most of the Tuxen Formation. Sample positions and a short description of the lithology are given Fig. 5. The distribution of calcareous nannofossils is shown in Fig. 9.

The cutting sample at 7700 feet was composed of Upper Cretaceous Chalk. The subsequent samples at 7710 feet and 7720 feet contained, in addition to caved Upper Cretaceous chalk, a variety of grains of light to dark coloured mudstone and marlstone. Most of the cuttings were barren, but a few grains of a light grey marlstone yielded a typical Upper Albian to Cenomanian assemblage. Important species were *Eiffellithus turriseiffelii*, *Prediscosphaera cretaceae*, and *Tranolithus phacelosus*. The presence of *Tetrapodorhabdus decorus* and common *Biscutum* in the sample at 7720 feet suggests a Late Albian age (Jakubowski 1987, Mortimer 1987). *T. decorus* was not observed in the more poorly preserved sample at 7710 feet, which thus may be slightly younger (late Late Albian or ?Cenomanian). It should be noted, however, that *Chiastozygus bifarius* which was found in sample 7720, has not been observed in sediments below the Cenomanian to-date (Crux 1982).The exact origin of the light grey marlstone grains is not known. They may have been caved from basal marly beds of the white Chalk or from the Rødby Formation.

The sample from 7730 feet contained cuttings of a brick-red marlstone. The nannofossil flora included, in addition to numerous specimens of *Eprolithus apterior* and *Eprolithis varolii*, a few specimens of typical *Rhagodiscus angustus* and *Micrantholithus obtusus*. The sample was assigned to the lower part of the Upper Aptian (*bowerbanki* to *martinoides* ammonite Zones). The uppermost Aptian – Middle Albian is apparently missing in the Adda-2 boring.

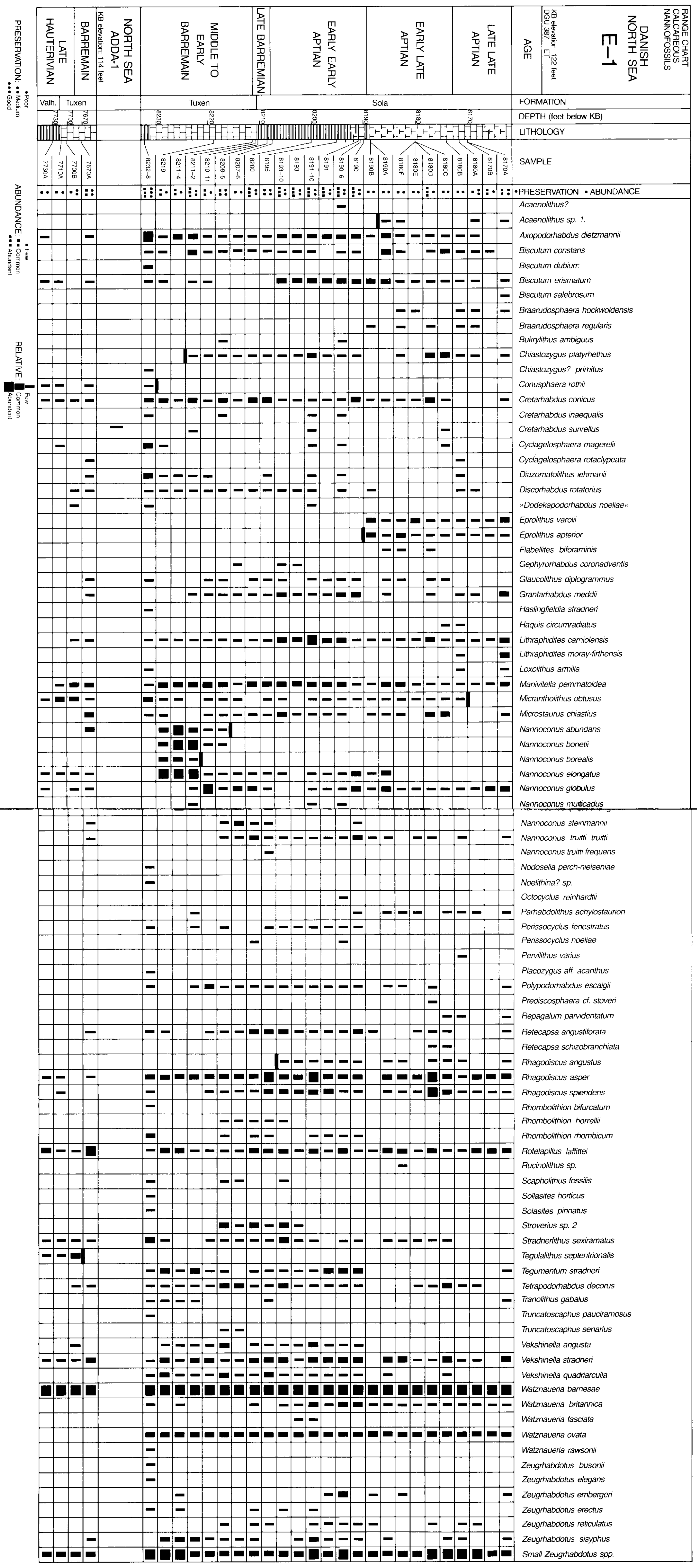
The remaining part of the investigated sequence from 7750 to 7841 feet was cored. The uppermost ten feet from 7750 to 7760 feet consisted of greyish and brownish marlstones and chalks, and was dated to the early Late Aptian on the basis of the same species as in the sample at 7730 feet.

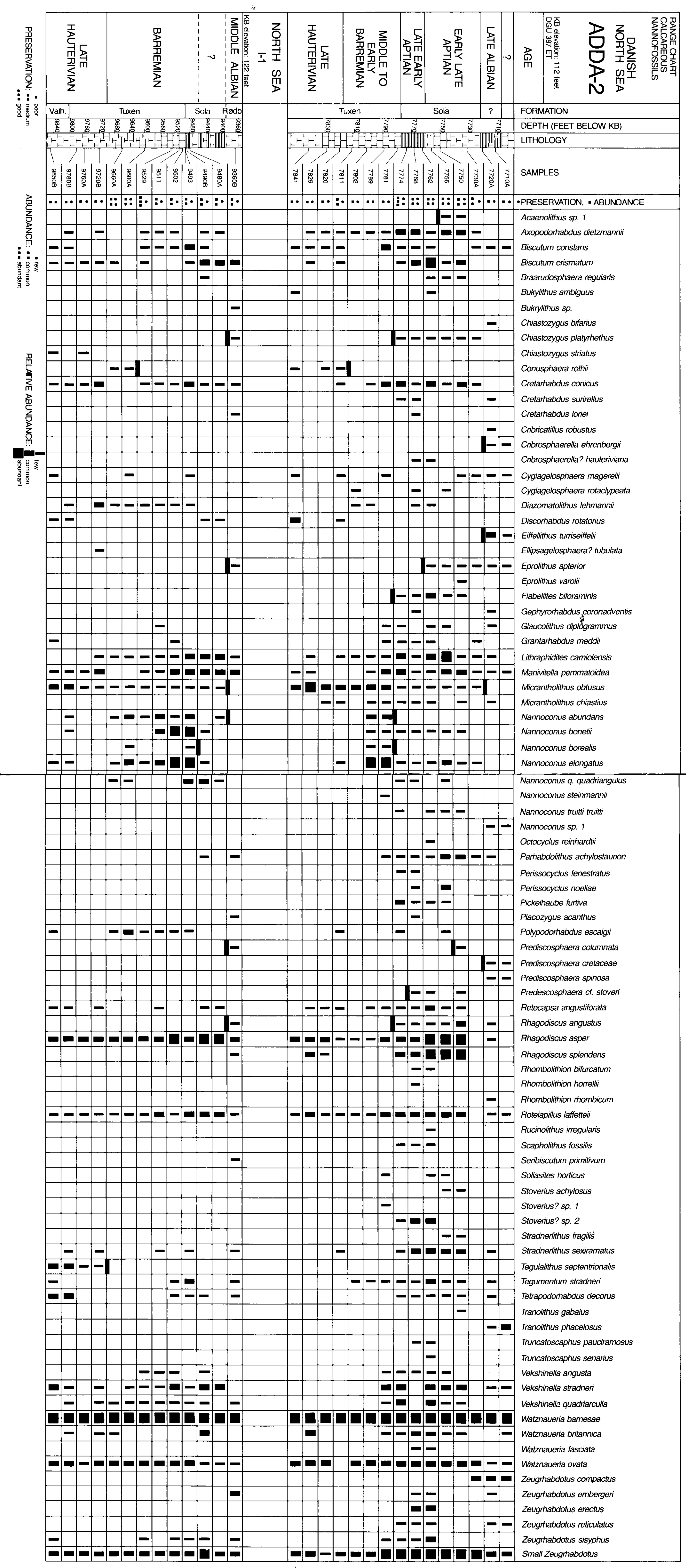
An approximately 17 feet thick unit of finely laminated bituminous shale occurred under the marlstone. The sample at 7762 feet contained a diverse assemblage with rare specimens of *Eprolithus apterior* and typical *Rhagodiscus angustus* besides *Flabellites biforaminis* and *Chiastozygus platyrhethus*. A very similar assemblage has been recovered from the "Fischschiefer" of Helgoland (see appendix) and the two deposits are undoubtedly of nearly the same age. The "Fischschiefer" has been dated to the upper part of the *forbesi* and possibly the lower part of the *deshayesi* ammonite Zones (Lower Aptian) on the basis of ammonites (see appendix).

The subsequent samples at 7768 feet and 7774 feet were also of Early Aptian age, but a more precise dating is difficult. The presence of *Flabellites biforami-*

▸

Fig. 8. Distribution chart of calcareous nannofossils in the E-1 and the Adda-1 wells.


RANGE CHART
CALCAREOUS
NANNOFOSSILS
DANISH
NORTH SEA
E–1
KB elevation: 122 feet
DGU 387 ET
NORTH SEA
ADDA-1
KB elevation: 114 feet
AGE
LATE HAUTERIVIAN
BARREMAIN
MIDDLE TO EARLY BARREMAIN
LATE BARREMIAN
EARLY EARLY APTIAN
EARLY LATE APTIAN
LATE LATE APTIAN
FORMATION
Valh.
Tuxen
Sola
DEPTH (feet below KB)
7730
7700
7670
8230
8220
8210
8200
8190
8180
8170
LITHOLOGY
SAMPLE
7730A
7710A
7700B
7670A
8232–8
8219
8211–4
8211–2
8210–11
8208–5
8207–6
8200
8195
8193–10
8193
8191–10
8191
8190–6
8190
8190B
8190A
8180F
8180E
8180D
8180C
8180B
8180A
8170B
8170A
•PRESERVATION ▪ABUNDANCE
Acaenolithus?
Acaenolithus sp. 1.
Axopodorhabdus dietzmannii
Biscutum constans
Biscutum dubium
Biscutum erismatum
Biscutum salebrosum
Braarudosphaera hockwoldensis
Braarudosphaera regularis
Bukrylithus ambiguus
Chiastozygus platyrhethus
Chiastozygus? primitus
Conusphaera rothii
Cretarhabdus conicus
Cretarhabdus inaequalis
Cretarhabdus surirellus
Cyclagelosphaera margerelii
Cyclagelosphaera rotaclypeata
Diazomatolithus lehmanii
Discorhabdus rotatorius
»Dodekapodorhabdus noeliae«
Eprolithus varolii
Eprolithus apterior
Flabellites biforaminis
Gephyrorhabdus coronadventis
Glaucolithus diplogrammus
Grantarhabdus meddii
Haslingfieldia stradneri
Haquis circumradiatus
Lithraphidites carniolensis
Lithraphidites moray-firthensis
Loxolithus armilla
Manivitella pemmatoidea
Micrantholithus obtusus
Microstaurus chiastius
Nannoconus abundans
Nannoconus bonetii
Nannoconus borealis
Nannoconus elongatus
Nannoconus globulus
Nannoconus multicadus
Nannoconus steinmannii
Nannoconus truitti truitti
Nannoconus truitti frequens
Nodosella perch-nielseniae
Noelithina? sp.
Octocyclus reinhardtii
Parhabdolithus achylostaurion
Perissocyclus fenestratus
Perissocyclus noeliae
Pervilithus varius
Placozygus aff. acanthus
Polypodorhabdus escaigii
Prediscosphaera cf. stoveri
Repagalum parvidentatum
Retecapsa angustiforata
Retecapsa schizobranchiata
Rhagodiscus angustus
Rhagodiscus asper
Rhagodiscus splendens
Rhombolithion bifurcatum
Rhombolithion horrellii
Rhombolithion rhombicum
Rotelapillus laffittei
Rucinolithus sp.
Scapholithus fossilis
Sollasites horticus
Solasites pinnatus
Stroverius sp. 2
Stradnerlithus sexiramatus
Tegulalithus septentrionalis
Tegumentum stradneri
Tetrapodorhabdus decorus
Tranolithus gabalus
Truncatoscaphus pauciramosus
Truncatoscaphus senarius
Vekshinella angusta
Vekshinella stradneri
Vekshinella quadriarculla
Watznaueria barnesae
Watznaueria britannica
Watznaueria fasciata
Watznaueria ovata
Watznaueria rawsonii
Zeugrhabdotus busonii
Zeugrhabdotus elegans
Zeugrhabdotus embergeri
Zeugrhabdotus erectus
Zeugrhabdotus reticulatus
Zeugrhabdotus sisyphus
Small Zeugrhabdotus spp.
PRESERVATION: • Poor •• Medium ••• Good
ABUNDANCE: ▪ Few ▪▪ Common ▪▪▪ Abundant
RELATIVE: Few Common Abundent


RANGE CHART CALCAREOUS NANNOFOSSILS
DANISH NORTH SEA
ADDA-2
KB elevation: 112 feet
DGU 387 ET
AGE
?
LATE ALBIAN
EARLY LATE APTIAN
LATE EARLY APTIAN
MIDDLE TO EARLY BARREMIAN
LATE HAUTERIVIAN
NORTH SEA I-1
KB elevation: 122 feet
MIDDLE ALBIAN
?
BARREMIAN
LATE HAUTERIVIAN
FORMATION
Valh.
Tuxen
Sola
Rødb
Tuxen
Sola
?
DEPTH (FEET BELOW KB)
9840
9800
9760
9720
9680
9640
9600
9560
9520
9480
9440
9400
9360
7830
7810
7790
7770
7750
7730
7710
LITHOLOGY
SAMPLES
9850B
9780B
9760A
9720B
9660A
9600A
9529
9511
9502
9493
9490B
9480A
9360B
7841
7829
7820
7811
7802
7789
7781
7774
7768
7762
7756
7750
7730A
7720A
7710A
•PRESERVATION, ▪ ABUNDANCE
Acaenolithus sp. 1
Axopodorhabdus dietzmannii
Biscutum constans
Biscutum erismatum
Braarudosphaera regularis
Bukylithus ambiguus
Bukrylithus sp.
Chiastozygus bifarius
Chiastozygus platyrhethus
Chiastozygus striatus
Conusphaera rothii
Cretarhabdus conicus
Cretarhabdus surirellus
Cretarhabdus loriei
Cribricatillus robustus
Cribrosphaerella ehrenbergii
Cribrosphaerella? hauteriviana
Cyglagelosphaera magerelii
Cyglagelosphaera rotaclypeata
Diazomatolithus lehmannii
Discorhabdus rotatorius
Eiffellithus turriseiffelii
Ellipsagelosphaera? tubulata
Eprolithus apterior
Eprolithus varolii
Flabellites biforaminis
Gephyrorhabdus coronadventis
Glaucolithus diplogrammus
Grantarhabdus meddii
Lithraphidites carniolensis
Manivitella pemmatoidea
Micrantholithus obtusus
Micrantholithus chiastius
Nannoconus abundans
Nannoconus bonetii
Nannoconus borealis
Nannoconus elongatus
Nannoconus q. quadriangulus
Nannoconus steinmannii
Nannoconus truitti truitti
Nannoconus sp. 1
Octocyclus reinhardtii
Parhabdolithus achylostaurion
Perissocyclus fenestratus
Perissocyclus noeliae
Pickelhaube furtiva
Placozygus acanthus
Polypodorhabdus escaigii
Prediscosphaera columnata
Prediscosphaera cretaceae
Prediscosphaera spinosa
Predescosphaera cf. stoveri
Retecapsa angustiforata
Rhagodiscus angustus
Rhagodiscus asper
Rhagodiscus splendens
Rhombolithion bifurcatum
Rhombolithion horrellii
Rhombolithion rhombicum
Rotelapillus laffetteii
Rucinolithus irregularis
Scapholithus fossilis
Seribiscutum primitivum
Sollasites horticus
Stoverius achylosus
Stoverius? sp. 1
Stoverius? sp. 2
Stradnerlithus fragilis
Stradnerlithus sexiramatus
Tegulalithus septentrionalis
Tegumentum stradneri
Tetrapodorhabdus decorus
Tranolithus gabalus
Tranolithus phacelosus
Truncatoscaphus pauciramosus
Truncatoscaphus senarius
Vekshinella angusta
Vekshinella stradneri
Vekshinella quadriarculla
Watznaueria barnesae
Watznaueria britannica
Watznaueria fasciata
Watznaueria ovata
Zeugrhabdotus compactus
Zeugrhabdotus embergeri
Zeugrhabdotus erectus
Zeugrhabdotus reticulatus
Zeugrhabdotus sisyphus
Small Zeugrhabdotus
PRESERVATION: • poor •• medium ••• good
ABUNDANCE: ▪ few ▪▪ common ▪▪▪ abundant
RELATIVE ABUNDANCE: few common abundant

nis suggests that the samples did not belong to the oldest parts of the Aptian. The absence of *Eprolithus anterior* and typical specimens of *Rhagodiscus angustus,* on the other hand, indicated an age not younger than the early part of the *forbesi* ammonite Zone.

The samples from the upper part of the Tuxen Formation (7781, 7789, and 7802 feet) were assigned to the uppermost Middle Barremian because of the absence of both *Chiastyzygus platyrhethus* and *Conusphaera rothii.* The latter species appeared at 7811 feet. This sample was consequently referred to the lower part of the Barremian. The absence of the Munk Marl Bed suggests a hiatus in the Middle Barremian.

The deeper part of the Tuxen Formation was referred to the Upper Hauterivian on the basis of the appearance of *Tegulalithus septentrionalis* at 7820 feet. This conclusion is strongly supported by the recovery of a specimen of the index fossil of the *gottschei* ammonite Zone at 7833 feet (Birkelund in Heilmann-Clausen 1987).

I-1

This well is situated in the Arne-Elin graben in the northern part of the Danish sector (Fig. 2). The investigated sequence comprised The Rødby Formation, the lower part of the Sola Formation, the Tuxen Formation and the upper part of the Valhall formation. Sample positions and a short description of the lithology are given in Fig. 6. The distribution of calcareous nannoplankton is shown in Fig. 9.

The sample from the Rødby Formation at 9360 feet was referred to the Middle Albian because of the presence of *Prediscosphaere columnata* and the absence of *Tranolithus phacelosus* and *Eiffellithus turriseiffelii.*

The samples from 9350 to 9470 feet were barren. The subsequent samples at 9480 feet 9490 feet and 9493 feet from the lower part of the Sola Formation contained an assemblage which occurred first in the uppermost part of the Tuxen Formation in the other wells. Characteristic species were *Nannoconus quadriangulus quadriangulus* and *Nannoconus abundans.* The important Barremian markers *Chiastozygus platyrhethus* and *Conusphaera rothii* were absent and the samples were, therefore, referred to the uppermost Middle Barremian. *Conusphaera rothii* appeared in the sample at 9600 feet.

The last significant nannofossil event in the investigated sequence was the appearance of *Tegulalithus septentrionalis* at 9720 feet. This Upper Hauterivian marker was present in the lowermost three samples from the Tuxen Formation and the sample from the Valhall Formation.

◄
Fig. 9. Distribution chart of calcareous nannofossils in the Adda-2 and the I-1 wells.

Correlation of the lithological units and boundaries

This chapter presents a biostratigraphical correlation of some of the most distinctive units in the studied area. The purpose of the correlation was to evaluate if the units and their boundaries were isochronous, and to analyse the distribution of hiati. The boundaries under consideration were the upper and lower boundary of the Tuxen Formation. The lithological units were a number of well-defined within the Sola Formation.

The boundary between the Valhall and the Tuxen Formation

The sequence containing this boundary was investigated in the I – 1 and the Adda – 1 wells. The boundary falls in both cases within the interval with common *Tegulalithus septentrionalis*. This species occurs in abundance in the Upper Hauterivian (Köthe 1981, Jakubowski 1987), but it has also been reported from the lowermost Barremian *variabilis* ammonite Zone (Jakubowski 1987). However, the consistent occurrence of *T. septentrionalis* in the lower part of the Tuxen Formation strongly suggests that the boundary falls within the Upper Hauterivian.

The actual boundary was not available for investigation in the Adda-2 well, but samples from 13, 25, and 34 feet above the boundary all included *T. septentrionalis*. Therefore, the boundary is also most likely to be of Late Hauterivian age here.

The Valhall/Tuxen boundary is tied to an important seismic reflector (base LCF seismic unit) in the North Sea (Vejbæk 1986). The calcareuos nannofossil evidence suggests that the boundary is isochronous within the investigated area, and give no indication of a hiatus.

The Tuxen Formation and the Sola Formation

This boundary was studied in the I-1, Adda-2, and E-1 wells (Fig. 10). The Tuxen Formation, consisted of a chalk or a chalky marlstone dominated by calcareous nannofossils. Nevertheless, despite of the abundance of nannofossils biostratigraphical correlation within the Tuxen Formation was difficult, as the preservation of the nannofossils was bad and biostratigraphically reliable markers were hard to recognize.

The most obvious change in the upper part of the Tuxen Formation was a considerable increase in the relative abundance of nannoconids. The most common species were *N. elongatus, N. bonetii, N. abundans,* and *N. q. quadriangulus* in all three wells. This strikingly similar change in the composition of the nannofossil assemblages towards the top of the formation suggests that the age of the upper boundary in the three borings is roughly the same. The presence of *N. abundans* indicates a Barremian age.

More detailed age-assignments of the Tuxen Formation are very tentative. The presence of *Chiastozygus platyrhethus* in sample E-1 8211.2 feet suggests that the top of the formation in the E-1 well may be of Late Barremian age, while it is probably of late Middle Barremien age in the Adda-2 and the I-1 wells. However, early forms of *C. platyrhethus* are rather delicate, and their presence or absence in a sample may be attributed to differences in the state of preservation. The nannofossils of sample E-1 8211.2 feet were well preserved compared to the bad preservation in the Tuxen Formation in general.

The Sola Formation consisted in both the E-1 and the Adda-2 wells of an approximately 20 feet thick lower unit of organic rich, finely laminated calcareous shale and an upper unit, between 25 and 30 feet thick, of variously coloured limestones and marlstones. Only the lowermost 13 feet of the Sola Formation was investigated in the I-1 well. The sediment was a calcareous shale, but it contained less organic material and was more coarsely laminated than the sediment in the E-1 and the Adda-2 wells.

The base of the Sola Formation is clearly diachronous. The oldest sediments of the formation were recovered in the I-1 well. (Fig. 10). Grains from cutting samples 3 and 13 feet above the base of the formation contained an assemblage that was very similar to the assemblage from the upper part of the Tuxen Formation. *Chiastozygus platyrhethus*, which was consistently present at the base of the Sola Formation in the other borings, was lacking. It is probably of late Middle Barremian age, and there is no indication of a hiatus between the Tuxen and the Sola Formations.

In the E-1 well *Chiastozygus platyrhethus* occurred in nearly all samples from the Sola Formation. It was fairly common even in samples taken just a few inches above the lower boundary. The age of the basal beds is probably Late Barremian, as discussed in the previous chapter. Although the same age was estimated for the uppermost part of the Tuxen Formation a small hiatus is most likely present between the two formations. The top of the Tuxen Formation consisted of a *Nannoconus* chalk dominated by elongate forms with a narrow central tube such as *N. elongatus* and *N. bonetii*. Nannoconids were also abundant in the lower part of the Sola Formation, but the important species were of a very different architecture. They were shaped like a ball with a large central cavity. Taxonomically they were classified as *N. globulus*. The abrupt replacements in the dominating planktonic floras and the marked facies change between the Sola and Tuxen Formation most likely reflects a stratigraphic break.

A clear hiatus between the Tuxen and the Sola Formations could only be biostratigraphically demonstrated in the Adda-2 well. Several stratigraphically important and characteristic species, which in E-1 were completely lacking or first appeared several feet above the lower boundary of the Sola formation, were present

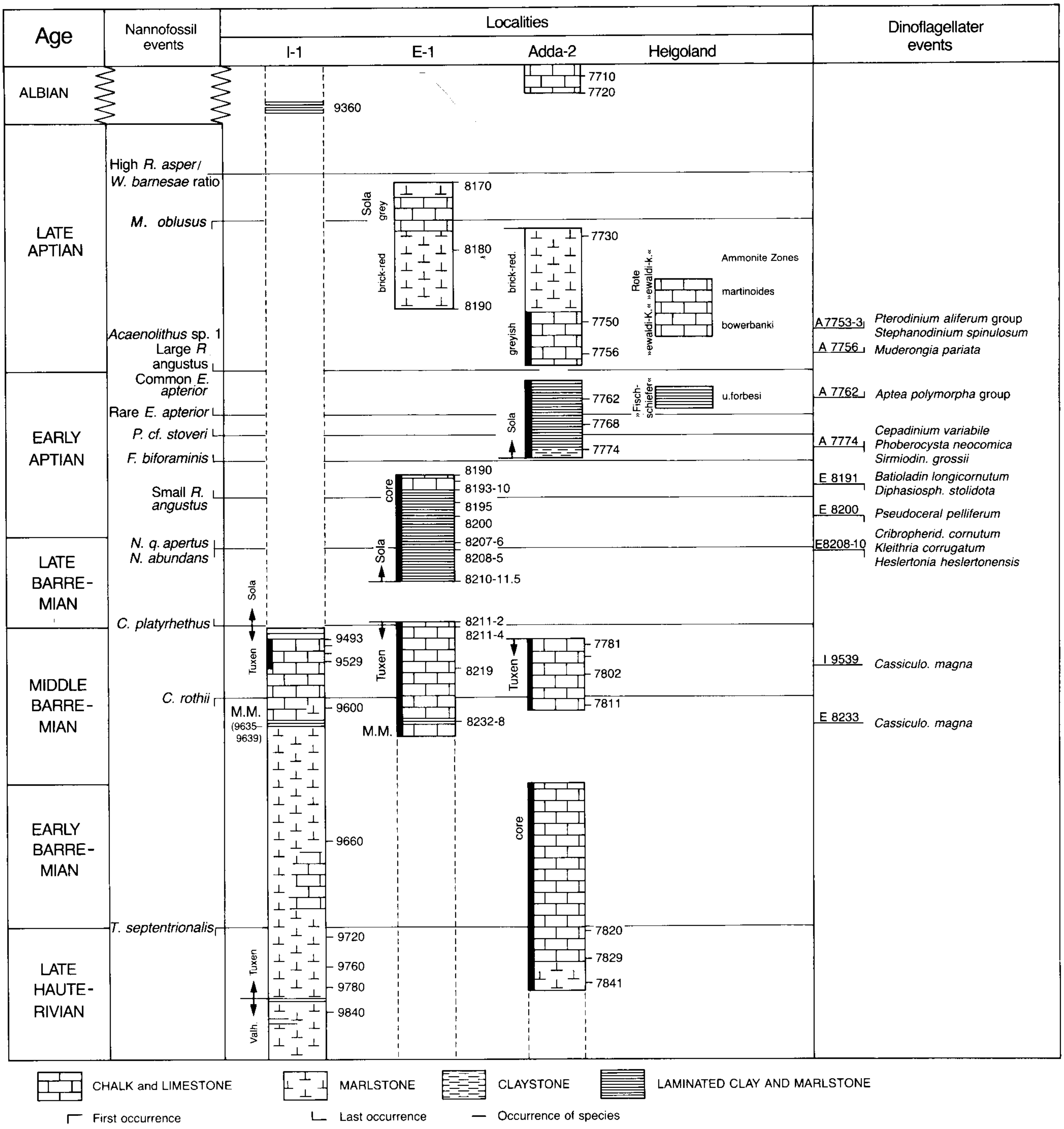


Fig. 10. Correlation of Barremian and Aptian beds using calcareous nannofossils from I-1, E-1, Adda-2 and Helgoland. Dinoflagellate events are from Heilmann-Clausen (1987). A-samples are from the Adda-2, E-samples from the E-1, and I-samples from the I-1 well. Heilmann-Clausens (1987) age determinations are in agreement with the nannofossil ages, except for sample E-1 8208-10, which he interprets as Middle Barremian.

in the basal beds of Adda-2. Examples are *Rhagodiscus angustus, Flabellites biforaminis,* and *Pickelhaube furtiva*.

Thus, it seems that despite considerable lithological similarity, there is little or no biostratigraphical overlap between the laminated sequences of the two borings. However, it should be noted that the lowermost 3 feet in the Adda-2 boring were barren of calcareous nannofossils. This deepest level is intensively burrowed (Jensen & Buchardt 1987), and is possibly time-equivalent to a similar burrowed sequence at the top of the E-1 well.

The assemblage in the upper part of the laminated sequence in Adda-2 (sample 7762) is very similar to assemblages recovered from "Fischschiefer" of Helgoland (see appendix). This formation has been correlated with the upper part of the *forbesi* ammonite Zone on the basis of ammonites.

The laminated unit in Adda-2 was superposed by an approximately 25 feet thich sequence of non or weakly laminated marl- and limestone (Fig. 11). The lower part was grey to light brownish, the upper part brick-red. In E-1 the laminated unit was overlain by a deposit very similar to the brick-red section in Adda-2, followed by a sequence of light grey marlstone and limestone. Deposits equivalent to the lower grey to brownish beds in Adda-2 were lacking in E-1.

The uppermost light grey sequence in E-1 is of latest Aptian – Early Albian age. The remaining part of the marl and limestone deposits in both the Adda-2 and the E-1 wells contained a nannofossil flora that is typical for the lower part of the Upper Aptian. A comparable assemblage has been recovered from the lithologically very similar "*ewaldi*-Kreide" on Helgoland in the Northwest German Basin in the southeastern part of the North Sea (Fig. 11) (see appendix).

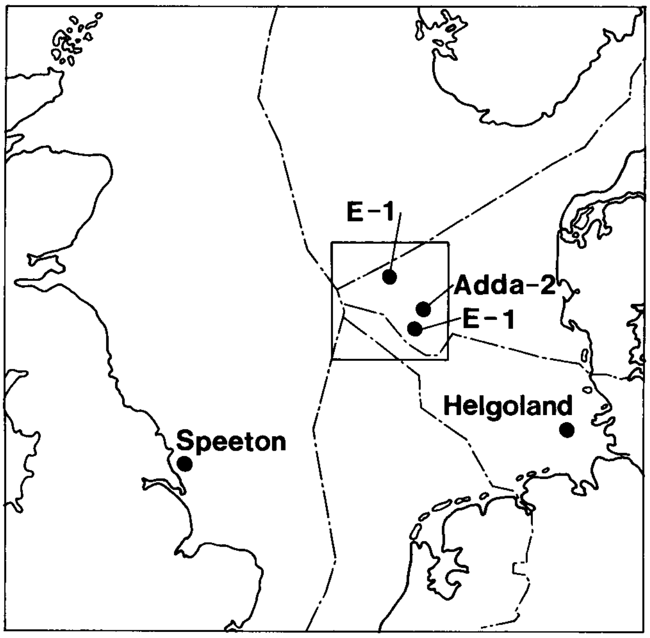


Fig. 11. Map of the North Sea area showing the positions of the investigated wells and the Lower Cretaceous sections on Helgoland and at Speeton.

Hence, it appears that the characteristic Aptian sequence described from northern Germany as a finely laminated shale unit deposited under anoxic conditions and overlain by a unit of variagated marlstone and limestone, can be traced over large areas of the central North Sea Basin.

Palaeecological interpretation of the Upper Hauterivian – Aptian sequences

The Barremian and Upper Hauterivian sequences in the North Sea area are characterized by considerable lateral facies changes. In the Central Trough of the Danish North Sea Sector this interval is dominated by chalk and marl deposits (Fig. 11 and 12). On Helgoland and in northern Germany the equivalent sediments are composed mainly of clays with a rather low carbonate content (Kemper *et al.* 1974, Mutterlose 1984, Mutterlose & Harding 1987).

The only Upper Hauterivian to Barremian lithological unit that can be recognized in both areas is a relative thin laminated, black marly shale with a high content of organic material. This unit is known as the Hauptblätterton in northern Germany, where it has been dated to the early Middle Barremian (in the zonation of Rawson *et al.* 1978) on the basis of belemnites (Mutterlose & Harding (1987).

The Munk Marl Bed in the central North Sea is undoubtedly equivalent to the Hauptblätterton. It is lithologically very similar (Jensen & Buchardt 1987) and in the same stratigraphic position as far as can be established on the basis of fossils. However, whereas

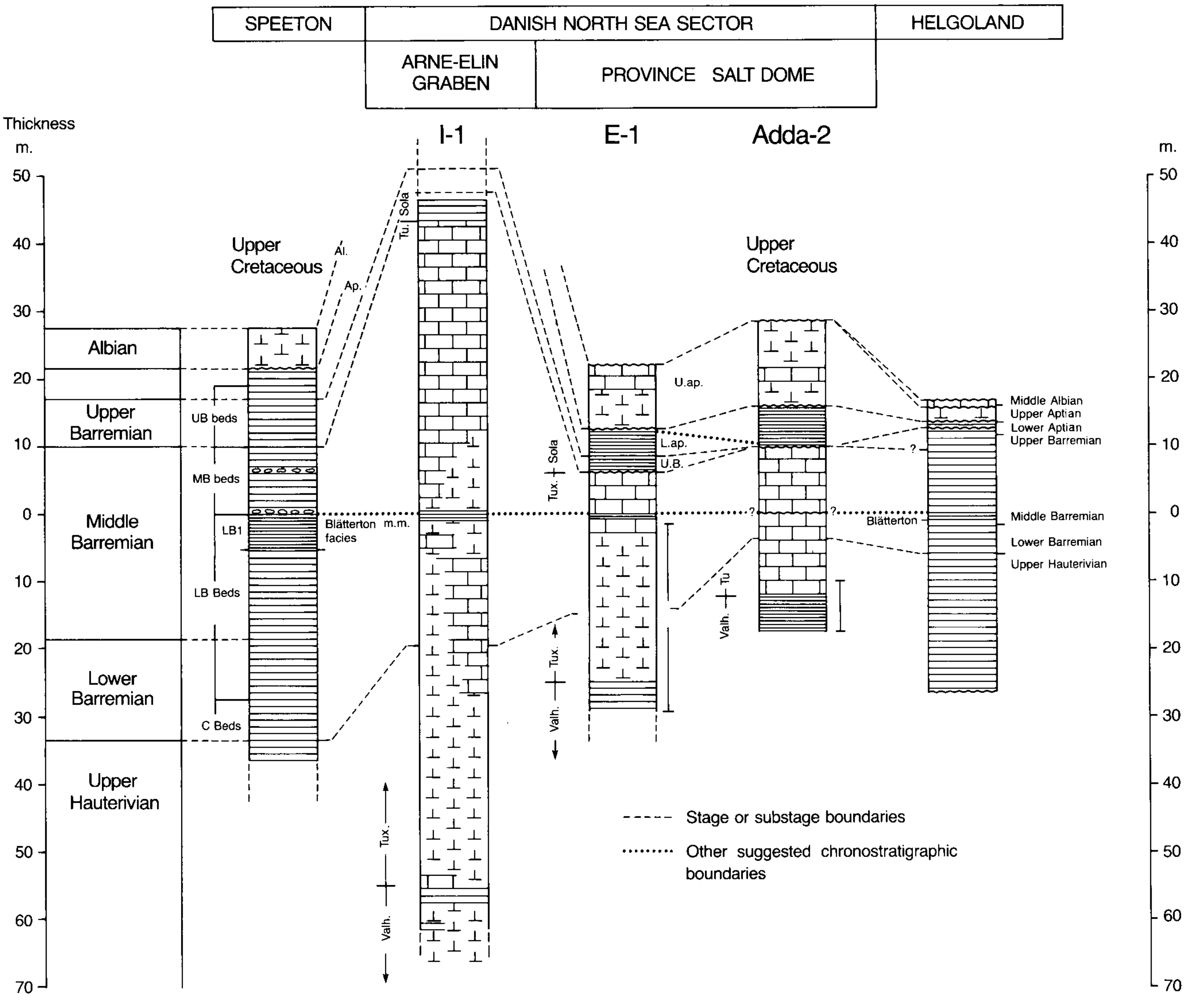


Fig. 12. Correlation of Upper Hauterivian, Barremian and Aptian beds from the Danish Central Trough, Helgoland and Speeton. The lithology and stratigraphy og the section on Helgoland is interpreted from Bartenstein & Kaever (1973) and Kemper et al. (1974). The lithology and stratigraphy of the section at Speeton is after Rawson et al. (1978) and Rawson & Mutterlose (1984).

the carbonate content of the Hauptblätterton is higher than in the surrounding sediments it is lower in the Munk Marl Bed. The Munk Marl Bed occur within a nearly pure chalk sequence.

A mid-Barremian laminated sequence has also been observed at Speeton, eastern England (Fig. 11 and 12). Although not yet described in detail the beds LB1A – LB1F of the Lower B Beds appear comparable to the Hauptblätterton (Rawson & Mutterlose 1983). At Speeton, as in northern Germany, the laminated beds occur in a sequence of clay sediments.

Palaeoecological interpretation of the facies differences in the Upper Hauterivian – Middle Barremian sequences seems relatively simple. Helgoland and Speeton represent nearshore areas characterized by a large supply of terrigenous material. Sedimentation in the central North Sea, on the other hand, was dominated by pelagic calcareous nannofossils. Material derived from land makes up only a small fraction of the deposits. Deposition in the central North Sea took place at a considerable distance from larger land areas.

If this interpretaton is correct it seems reasonable to assume that the change in the latest Hauterivian from a mainly siliciclastic to a mainly pelagic chalk sedimentation in the Central Trough was the result of a sea level rise. Furthermore, the decreasing content of clayey material upwards in the chalk indicates that the transgression continued into the Lower and Middle Barremian. It should be noticed, however, that the increasing deposition of chalk from the latest Hauterivian probably cannot be understood in terms of sea level fluctuations only. Evolutionary changes in the nannoplankton should also be considered. During the Early Cretaceous calcareous nannoplankton experienced an enormous expansion in both diversity and productivity, and the Tuxen Formation is the oldest major deposit of an open marine pelagic chalk in northwest Europe.

Seismic evidence indicates that the lower boundary of the chalk is an unconformity (Vejbæk 1986). It is, therefore, likely that the transgression in the latest Hauterivian was preceded – by a period of regression during which the top of the argillaceous Valhall Formation was eroded. This event cannot be demonstrated biostratigraphically, and it must have been of short duration.

The deposition of the Tuxen Formation took place in an open marine environment with well oxygenated bottom waters, except for short stagnant periods during which the Munk Marl Bed and other subordinate laminated units were deposited.

The sedimentation pattern changed from pelagic chalk deposition in the Middle Barremian to the deposition of organic rich laminated marls in the latest Barremian and earliest Aptian. Widespread unconformities in the Upper Barremian and Lower Aptian sequences indicate a return to more shallow water conditions. The uppermost few metres of the chalk and the lower part of the laminated unit are characterized by a considerable increase in the amount of nannoconids over coccoliths. This may also indicate a slight shallowing. According to Roth & Krumbach (1986) nannoconids are indicative of a shallow neritic environment. However, ecological information on nannoconids is scarce and uncertain, and the increase may instead be the result of a temperature rise (sensu Mutterlose & Harding 1987).

The laminated sequence, which is referred to the Sola Formation, was deposited in a stagnant basin interrupted by short periods with well oxygenated bottom conditions (Jensen *et al.* 1987). The upper part of the sequence is richer in calcareous nannofossils and early on the in the Late Aptian (*bowerbanki* ammonite Zone) pelagic chalk sedimentation and well oxygenated conditions returned to the central North Sea. The limestone is a biomicrite composed mainly of calcareous nannofossils and planktonic and benthonic foraminifera. The nannofossils are dominated by coccoliths while nannoconids are rare. Disregarding the numerous foraminifera this gives the limestone a certain resemblance with the Lower Barremian part of the Tuxen Formation. The Aptian limestones were probably deposited in deeper water than the underlying laminated sequence, but in shallower water than the Tuxen Formation. However, sediments from the latest Aptian are often missing and it seems, therefore, that regression recommenced before the end of the Aptian.

The regressive/transgressive events reconstructed above agree well with the Lower Cretaceous eustatic sea level curves of Haq *et al.* (1987). They also agree on many points with the interpretations of Michael (1974), Kemper & Zimmerle (1978), Rawson & Riley (1982), Mutterlose & Harding (1987), and Tyson & Funnell (1987). When disagreement exists this seems mostly to be due to differences in the local conditions or to differences in the biostratigraphical controls on the lithological and biological evidence.

List of species

The one hundred and sixteen species of calcareous nannofossils found in the present study are listed alphabetically according to the genus epithet. The species are illustrated on Plates 1–22. Remarks on the taxonomic consepts of the species are added to some of the species.

Acaenolithus sp. 1.
Plate 22, Figs. 12,13. Pl. 1, Fig. 1.
Remarks. A few specimens from the Upper Aptian of the North Sea and from the "*ewaldi* Kreide" of Helgoland are assigned to the genus *Acaenolithus* Black (1973). Black included four Albian to Cenomanian species in this genus. Distinction between them is very difficult. The specimens from the North Sea seem most closely to resemble *A. galoisii* Black (1973), but specimens from the southern Atlantic illustrated by Wise (1983) as *Acaenolithus* sp. are also very similar. A specimen from sample E-1 8190'6" (Pl. 1, Fig. 1) is clearly smaller and can only with uncertainty be assigned to the genus.

Axopodorhabdus dietzmannii (Reinhardt, 1965) Wind & Wise (1983).
Plate 12, Fig. 1.

Biscutum constans (Gorka, 1957) Black *in* Black & Barnes (1959).
Plate 1, Figs. 15,16.

Biscutum dubium (Noël, 1965) Grün, Prins & Zweili (1974).
Plate 1, Fig. 17.

Biscutum erismatum (Wind & Wise *in* Wise & Wind, 1977) Grün & Zweili (1980).
Plate 1, Figs. 18–20.

Biscutum salebrosum (Black, 1971) Perch-Nielsen (1984).
Plate 1, Figs. 21–23.

Braarudosphaera hockwoldensis Black (1973).
Plate 2, Fig. 2.

Braarudosphaera regularis Black (1973).
Plate 2, Fig. 3.

Bukrylithus ambiguus Black (1971).
Plate 1, Figs. 12,13.
Remarks. The areas between the broad fibrous cross and the wall are covered by a floor. The large hollow distal spine and the fibrous cross give the species a resemblance to *Vekshinella quadriarculla.* It differs in its larger size and in the presence of a floor.

Bukrylithus? sp.
Plate 1, Fig. 14.
Remarks. The systematic position of this Albian species is uncertain because of poor preservation. It has many characteristics in common with *B. ambiguus*, but differs in the size of the coccolith and in the large irregular elements which partly close the central area and hide the fibrous arms of the cross. This gives the species a resemblance to the genus *Eiffellithus.*

Chiastozygus bifarius Bukry (1969).
Plate 20, Fig. 3.

Chiastozygus platyrhethus Hill (1976).
Plate 2 Figs. 9–14; Plate 22, Figs. 8,11.
Remarks. The specimens of *Chiastozygus* found in the present material can undoubtedly be referred to the same species as the *Chiastozygus* forms that have been used as markers of the latest Barremian or the earliest Aptian by many workers. The taxonomic identification of this species is uncertain. It has been attributed to the poorly known upper Cretaceous species *C. litterarius* (Gorka, 1957) Manivit (1971), to the mid Cretaceous species *C. platyrhethus* Hill (1976), and to *C. tenuis* Black (1971) from the late Hauterivian. I have followed Perch-Nielsen (1985) and refer the species to *C. platyrhethus.* If the species is present in the late Hauterivian as suggested by Taylor (1982) and Covington & Wise (1987) its value as a marker for the Barremian-Aptian boundary is doubtful (Perch-Nielsen 1985). In the present study a trend towards greater size can be observed. Early forms from the top of the Tuxen Formation are clearly smaller and more delicately constructed than later forms from the Sola Formation.

Chiastozygus? primitus Prins (1969) ex Rood *et al.* (1973).
Plate 17, Figs. 17,18.

Chiastozygus striatus (Black, 1971).
Plate 3, Figs. 1,2.

Conusphaera rothii (Thierstein, 1971).
Plate 3, Figs. 15,16.

Cretarhabdus conicus Bramlette & Martini (1964).
Plate 12, Figs. 11–12.

Cretarhabdus inaequalis Crux (1987).
Plate 14, Figs. 1–5.

Cretarhabdus surirellus (Deflandre, 1954) Reinhardt (1971).
Plate 14, Fig. 8.

Cretarhabdus loriei Gartner (1968).
Plate 14, Fig. 10.

Cribricatillus robustus Black (1973).
Plate 20, Figs. 1,2.
Remarks. The central area possesses a broad cross alligned with the axes of the coccolith on one specimen. On other specimens the area is covered by many small elements.

Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre *in* Piveteau (1952).
Plate 20, Fig. 6.

Cribrosphaerella hauteriviana (Black, 1971) Perch-Nielsen (1984).
Plate 5, Figs. 3,4.

Cyglagelophaera magerelii Noël (1965).
Plate 3, Figs. 19,20,21.

Cyglagelosphaera rotaclypeata Bykry (1969).
Plate 3, Figs. 17,18.

Diazomatolithus lehmannii Noël (1965).
Plate 3, Figs. 12,13,14.

Discorhabdus rotatorius (Bukry, 1969) Thierstein (1973).
Plate 2, Fig. 1.

"Dodekapodorhabdus noeliae"
Plate 12, Fig. 7.
Remarks. D. noeliae Perch-Nielsen (1968) was discribed from the Campanian and Maastrichtian. It has twelve openings surrounding a hollow stem which is usually broken off. The present species has only eleven openings and is much smaller than *D. noeliae sensu strictu*. However, the structure of both the rim and the central area are very similar. *Perissocyclus noeliae* Black (1971) and *Perissocyclus fenestratus* Black (1971) have a variable number of openings, but the construction of the coccoliths are very different.

Eiffellithus turriseiffelii (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1965).
Plate 20, Figs. 4,5.

Ellipsagelosphaera? tubulata Grün & Zweili (1980).
Plate 4, Fig. 13.

Eprolithus varolii Jakubowski (1986).
Plate 15, Figs. 1–5. Pl. 21, Fig. 13.
Remarks. Specimens of *Eprolithus* with ten or more (normally 16–20) elements are assigned to *E. varolii*. Specimens with nine elements are assigned to *E. apterior*. However, it should be noted that many specimens of *E. varolii* has fewer elements in the wall than in the floor due to fusion of wall elements (Plate 15, Fig. 1). This makes seperation of the two species difficult in poorly preserved material.
E. varolii has only been found in the Upper Aptian, where it occurs together with *Eprolithus apterior. E. varolii* is often more common than *E. apterior*, especially in the lower part.

Eprolithus apterior Black (1973)
Plate 15, Figs. 6–9. Pl. 20, Fig. 7. Pl. 22, Figs. 5–7,9,10.
Remarks. Specimens from the Lower Aptian are smaller and more irregular than later forms (Pl. 15, Figs. 5–7). Specimens occur with nine floor elements and more than nine wall elements and vise versa.

Flabellites biforaminis Thierstein (1973).
Plate 4, Figs. 15,16.

Gephyrorhabdus coronadventis (Reinhardt, 1966) Hill (1976).
Plate 14, Figs. 14,15.

Glaukolithus diplogrammus (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1974).
Plate 17, Figs. 27–29.
Remarks. The suture which separates the central bridge into two elements is often closed by overgrowth on the distal side.

Grantarhabdus meddii Black (1971).
Plate 14, Figs. 16,17.

Haqius circumradius (Stover, 1966) Roth (1978).
Plate 4, Fig. 14.

Haslingfieldia stradneri Bukry (1969).
Plate 1, Fig. 2.

Lithraphidites carniolensis Deflandre (1963).
Plate 5, Fig. 7.

Lithraphidites moray-firthensis Jakubowski (1986).
Plate 5, Figs. 5,6.

Loxolithus armilla (Black, 1959) Noël (1965).
Plate 19, Fig. 3.

Manivitella pemmatoidea (Deflandre *in* Manivit, 1965) Thierstein (1971).
Plate 5, Figs. 1,2.

Micrantholithus obtusus Stradner (1963).
Plate 2, Figs. 4–6.
Remarks. M. obtusus and *M. hoschulzii* (Reinhardt, 1966) Thierstein (1971) are not separated in the present study.

Microstaurus chiastius (Worsley, 1971) Grün *in* Grün & Allemann (1975).
Plate 14, Figs. 6,7.

Nananoconus Kamptner (1931).
Remarks. Nannoconus forms are common in most of the investigated material. They are rock forming in the limestone of the Tuxen Formation and abundant in the lower part of the Sola Formation. Nannoconids have been used in biostratigraphy in the Lower Cretaceous, expecially in the Tethys area. They are commoner at low latitudes. More than fifty species have been described (Deres & Achériteguy 1980).

Nannoconus species are mainly distinguished on the basis of the size and changes in the nannolith and in the shape of the central cavity or canal. The original descriptions and most of the work on nannoconids are, therefore, based on light microscope examinations. In the present study the nannoconids were registered in SEM together with the coccoliths. A number of samples were also examine with the LM in order to see if a given species could be identified in both LM and SEM. Well preserved samples with only one or few dominating species of nannoconids were selected and in a number of cases safe identifications could be made using both media.

In spite of the large number of specimens in the Lower Cretaceous it can generally be stated that even in well preserved floras only a small fraction of the specimens can be taxonomically identified. The majority are intermediate or incomplete. The present study, furthermore, showed that the external appearance of the tests changed according to the lithology of the deposits in which the specimens were found. The wedge-shaped elements that form the walls of the nannoliths are much thicker in limestone than in marl or clay deposits. Compare Plate 7, Fig. 3 (clay) with Plate 7, Fig. 9 (limestone); Plate 9, Fig. 3 (clay) with Plate 9, Fig. 2 (limestone); and Plate 10, Fig. 1 (clay) with Plate 10, Fig. 2 (limestone). This difference was probably due to variations in the amount of secondary overgrowth and/or solution. Overgrowth was clearly more pronounced in limestone deposits.

Nannoconus abundans Stradner & Grün (1973) sensu Taylor (1978).
Plate 6, Figs. 10-13; Plate 10, Fig. 13.
Remarks. In some North Sea samples *N. abundans* closely resembled the specimens from Speeton, described by Taylor (1978). They lacked the pronounced distal flange described by Stradner & Grün (1973) in the original material. In other samples, however, a flange was observed. *Nannoconus borealis* Perch-Nielsen (1979) has also a flange and small or incomplete specimens of this species can be difficult to distinguish from *N. abundans* (see Plate 8, Fig. 5). *N. abundans* may also be difficult to separate from *Nannoconus quadriangulus* and *Nannoconus* sp. 1.

Nannoconus bonetii Trejo (1959).
Plate 8, Figs. 9–11, Plate 9, Figs. 1–3; Plate 11, Figs. 4–11.
Remarks. Typical specimens are dumb-bell- or elongate pear-shaped. The walls are relative thin and the central cavity preserves the shape of the exterior.

Nannoconus borealis Perch-Nielsen (1979).
Plate 8, Figs. 1–6, Plate 11, Figs. 1–3.
Remarks. The enlarged basal part makes this form very distinctive, and even incomplete specimens can normally be identified.

Nannoconus elongatus Brönnimann (1955).
Plate 8, Figs. 7,8; Plate 11, Figs. 11–17.
Remarks. This form is characterized by an elongate cylindrical exterior and a straight canal. The canal was narrower in limestone, where overgrowth both externally and internally was more pronounced. Intermediate forms between *N. elongatus* and *N. bonetii* are common. Specimens which are transitional to *N. borealis* have also been observed (Plate 11, Figs. 16,17).

Nannoconus globulus Brönnimann (1955).
Plate 7 Figs. 1–18. Plate 10 Figs. 20–29.
Remarks. N. globulus sensu stricto has a subspherical shape, relatively thin walls, and a large central cavity (Plate 10, Figs. 1–6,9; Plate 10, Figs. 19–21). In the present study specimens of the same general architecture show great variation in shape. Spherical, oval, rectangular, and more or less irregular forms have been observed. They are all assigned to *N. globulus*.

Nannoconus multicadus Deflandre & Deflandre-Rigaud (1960).
Plate 9, Figs. 6,7; Plate 11, Figs. 21,21.

Nannoconus quadriangulus Deflandre & Deflandre-Rigaud (1962).

Plate 5, Figs. 7–13; Plate 6, Figs. 1–9; Plate 10, Figs. 9–12.
Remarks. N. quadriangulus is shaped like a cup with a small hole at the bottom. Although very variable the species is distinctive. Variation is seen in the height of the cup, in wall-thickness and the external shape of the nannolith. The diameter may increase or decrease upwards, but mostly it is unchanged. Due to external ridges a few specimens are star-shaped in transverse sections. Deflandre & Deflandre-Rigaud (1962) distinguished between two subspecies of *N. quadriangulus*. *N. q.* subsp. *quadriangulus* (Plate 6, Figs. 6–9) is smaller with thicker walls and a thinner central canal. *N. q.* subsp. *apertus* (Plate 5, Figs. 7–13, Plate 6, Figs. 1–5, Plate 10, Figs. 9–12) is much more open with a wide central canal. Both forms were present in the North Sea material. Differentiation between them was attempted, but intermediate forms occurred. Some specimens of both subspecies can be difficult to distinguish from *Nannoconus abundans*.

Nannoconus sp. 1.
Plate 20, Figs. 12,13; Plate 21, Fig. 15.
Remarks. The test is shaped like a short spiral in typical specimens. The spiral runs in the same direction as the spiral arrangement of the individual elements. The tests are oval in transverse section. There is a gradual transition to circular specimens on which the spiral is only weakly developed or completely missing. These latter specimens show great resemblance to *Nannoconus abundans*.

Nannoconus spp.
Plate 10, Figs. 1–8; Plate 11, Figs. 18–20, 23–25.
Remarks. Many specimens could not be assigned with certainty to a given species. Examples are shown on Plate 10 and 11. The specimen shown on Plate 10, Fig. 1 shows affinity to *N. grandis* Deres & Acheriteguy (1980), The specimens on Figs. 7 and 8 to *N. donna – tensis* Deres & Acheriteguy (1980). The architecture of the specimens on Plate 10, Figs. 3–6 and Plate 10, Figs. 24,25 resembles the structure of *N. borealis* Perch-Nielsen (1979).

Nannoconus steinmannii Kamptner (1931).
Plate 9, Figs. 4,5.

Nannoconus truitti truitti Brönnimann (1955).
Plate 6, Figs. 14-18; Plate 10, Figs. 14–17.

Nannoconus truitti Brönnimann (1955) subsp. *frequens* Deres & Achéritéguy (1980).
Plate 6, Figs. 19–21; Plate 10, Figs. 18,19.
Remarks. This form differs from *N. truitti truitti* in its larger size and in a slightly more rectangular shape. *N. t.* subsp. *frequens* has been found only in sample E-1 8195'.

Nodosella perch-nielseniae (Filewicz *et al. in* Wise & Wind, 1977) Perch-Nielsen (1984).
Plate 17, Fig. 14.

Noelithina? sp.
Plate 19, Figs. 22,23.
Remarks. The genus *Noelithina* Grün & Zweili (1974) contains only two species. Both have been found in the Lias. The present species differs from these two in possessing transverse elements between the bars that connect the central cross with the wall.

Octocyclus reinhardtii (Bukry, 1969) Wind & Wise (1977).
Plate 12, Fig. 8.
Remarks. Octocyclus magnus Black (1972) from the Albian is considered to be synonymous with the Aptian *O. reinhardtii*, although the Albian forms are larger than the Aptian forms. *Octopodorhabdus decussatus* (Manivit, 1961) Rood, Hay & Bernhard (1971), a small species from the Upper Jurassic, which some authors (e.g. Grün & Zweili 1980) also consider synonymous with *O. reinhardtii*, is here regarded as a different species.

Parhabdolithus achylostaurion Hill (1976) emend. Crux (1982).
Plate 17, Figs. 1,2.
Remarks. The specimens from the North Sea resemble specimens from SE England illustrated (SEM) by Crux (1981) and Taylor (1982). Taylor (1982) gave a range of U. Aptian-Turonian for the species. In the present study it was also recorded from the Barremian. The central cone is less distinct in the Barremian than in later forms.

Perissocyclus fenestratus Black (Stover, 1966) Black (1971).
Plate 12, Figs. 9,10.

Perissocyclus noeliae Black (1971) (emend. Wind & Čepek (1979).
Plate 12, Figs. 5,6.

Pervilithus varius Crux (1982).
Plate 16, Fig. 3.

Pickelhaube furtiva (Roth, 1983) Applegate, Covington & Wise (1987) *in* Covington & Wise (1987), emend. n. comb.
Plate 13, Figs 1–7; Plate 11, Figs. 26,27. Plate 22, Fig. 1.

Placozygus acanthus Reinhardt (1965).
Plate 19, Fig. 14.

Placozygus aff. *acanthus* Reinhardt (1965).
Plate 19, Figs. 15,16.

Remarks. The specific assignment of this specimen is uncertain. It is clearly smaller than *P. acanthus*.

Polypodorhabdus escaigii Noël (1965).
Plate 14, Figs. 12,13.

Prediscosphaera columnata (Stover, 1966); Perch-Nielsen (1984).
Plate 16, Fig. 5.

Prediscosphaera cretacea (Arkhangelsky 1912) Gartner (1968).
Plate 20, Figs. 8,9.

Prediscosphaera spinosa (Bramlette & Martini, 1964) Gartner (1968).
Plate 20, Figs. 10,11.

Prediscosphaera cf. *stoveri* (Perch-Nielsen, 1968) Shafik & Stradner (1971)
Plate 16, Fig. 4; Plate 22 Figs. 2,3.
Remarks. Some specimens from the North Sea and from the Lower Aptian of Helgoland resemble *P. stoveri. Prediscosphaera* has usually 16 elements in each shield. The present material possesses about 20 elements. Specimens with 18–19 elements have been described from the Upper Aptian of southern France (Barrier, 1977b). The specimens from Helgoland are the earliest representatives of the genus.

Repagulum parvidentatum (Deflandre & Fert, 1954) Forcheimer (1972).
Plate 19, Figs. 20,21.

Retecapsa angustiforata (Black, 1971).
Plate 14, Fig. 9.

Retecapsa schizobranchiata (Gartner, 1968) Grün *in* Grün & Allemann (1975).
Plate 14, Fig. 11.

Rhagodiscus angustus (Stradner, 1963) Reinhardt (1971).
Plate 16, Figs. 6–11; Plate 22, Figs. 4,14.
R. angustus is used together with *Eprolithus apterior* Black (1973) as zonal markers in the Aptian. Perch-Nielsen (1979), however, found small forms hardly distinguishable from *R. angustus* as far down as the Upper Hauterivian at Speeton. Similar specimens from the same stratigraphic level were observed by Sissingh (1977) and Crux (1987). They have recently been described by Bralower, Applegate, Covington & Wise *in* Covington & Wise (1987) as *Zeugrhabdotus? pseudoangustus.* In the present study *R. angustus* was found at deeper levels than *E. apterior,* but still in the the Aptian. The deepest specimens of *R. angustus* were very small (max length around 4 μm) and had slightly convex sides. Granules, however, were clearly visible (Plate 16, Fig. 6). Upwards in the borings the largest specimens gradually increased in size while at the same time the sides became more parallel. (Plate 16, Figs. 7–11).

Rhagodiscus asper. (Stradner, 1963) Reinhardt (1967).
Plate 16, Figs. 12,13.
Remarks. Specimens herein referred to *P. asper* have a broad oval shape. The rim is relatively wide and surrounds a central area with 8–20 large depressions which are often arranged in irregular cycles. The hollows can be partly concealed by calcite growing from the rim elements (Plate 16, Fig. 12). In proximal view the central opening is small or may be missing.

Rhagodiscus splendens (Deflandre, 1953) Verbeek (1977).
Plate 16, Figs. 14–18.
Remarks. Specimens referred to *P. splendens* have a relatively narrow rim elevated above a smooth central floor formed by a mosaic af granular crystals. Radial ridges are developed along the inner margin of the rim on a few poorly preserved Albian specimens.

The shape varies from nearly circular to elongate specimens with nearly parallel sides. The latter may resemble specimens of *Parabdolithus angustus* but the narrow ridges between the central process and the sides present in *P. angustus* are always missing.

The poorly preserved Albian specimens (Plate 16, Fig.17) resemble specimens illustrated and referred to *P splendens* by Forchheiner (1972), Roth & Thierstein (1972) Verbeek (1977), Wise & Wind (1977), Barrier (1977a), and Wise (1983). On most specimens in the present study radial ridges are poorly developed or completely missing (Plate 16, Figs. 14,15,16). Similar specimens have been referred to *P. splendens* by Stradner, Adamiker & Maresch (1968). Other authors however, assign such specimens to *P. asper.* Roth & Thierstein (1972), Perch-Nielsen (1985), and Roth & Thierstein (1972) illustrate possible intermediates between them and *P. asper.* Intermediate specimens have not been observed in the present study. Hill (1976) emphasizes that the correct identification of *P. asper* and *P. splendens* is problematic. The holotypes of both species are poorly illustrated.

Rhombolithion bifurcatum (Noël, 1973) Grün & Zweili (1980).
Plate 17, Fig. 13.

Rhombolithion horrellii (Rood & Bernhard, 1972) Perch-Nielsen (1984).
Plate 17, Figs. 15–16.
Remarks. Several very small rhombic coccoliths have been discribed from the Jurassic (see Perch-Nielsen 1985). The present U. Barremian – L. Aptian form is

characterized by a great variability in the construction of the filling of the central area. Some specimens have ten bars in the central area arranged as in *R. horrelii* from the Upper Jurassic (Pl. 17, Fig. 15). On other specimens, however, the number and arrangement of the bars are much more irregular (PL. 17, Fig. 16). Sometimes individual bars cannot be distinguished. They seem to fuse and form a continuous floor.

Rhombolithion rhombicum (Stradner & Adamiker, 1966) Black (1973).
Plate 17, Fig. 9.

Rotelapillus laffittei (Noël, 1957) Noël (1973).
Plate 17, Figs. 21,22.

Rucinolithus irregularis Thierstein *in* Roth & Thierstein (1972).
Plate. 16, Fig 2.

Rucinolithus terebrodentarius Applegate Bralower Covington & Wise *in* Covington & Wise (1987).
Fig. 13.
Remarks. The occurrence of this blocky form is not shown in the distribution charts because it was considered to be of non-biologic origin. However, it has since been described as a calcareous nannofossil. In my material from the North Sea it was present in most samples from the Upper Hauterivian to the Aptian. It was especially common in clayey sediments. It occurred in abundance in some samples from the "Fischschiefer" of Helgoland (Lower Aptian). The rather similar *Assipetra infracretacea* (Thierstein, 1973) Roth (1973) also occurred in many samples.

Rucinolithus sp.
Plate 16, Fig. 1.
Remarks. Rucinolithus Stover (1966) is characterized by five or more inclined elements forming a rosette. A single specimen of *Rucinolithus* from the North Sea had seven elements. The same number can be found in *R. irregularis* and *R? magnus* Bukry (1975), but they are otherwise very different from the North Sea specimens.

Scapolithus fossilis Deflandre in Deflandre & Fert (1954).
Plate 2, Figs. 7,8.

Seribiscutum primitivum (Thierstein, 1974) Filewicz *et al. in* Wise & Wind (1977)
Plate 1, Figs. 24,25.

Sollasites horticus (Stradner *et al. in* Stradner & Adamiker, 1966) Čepek & Hay (1969).
Plate 17, Fig. 5.

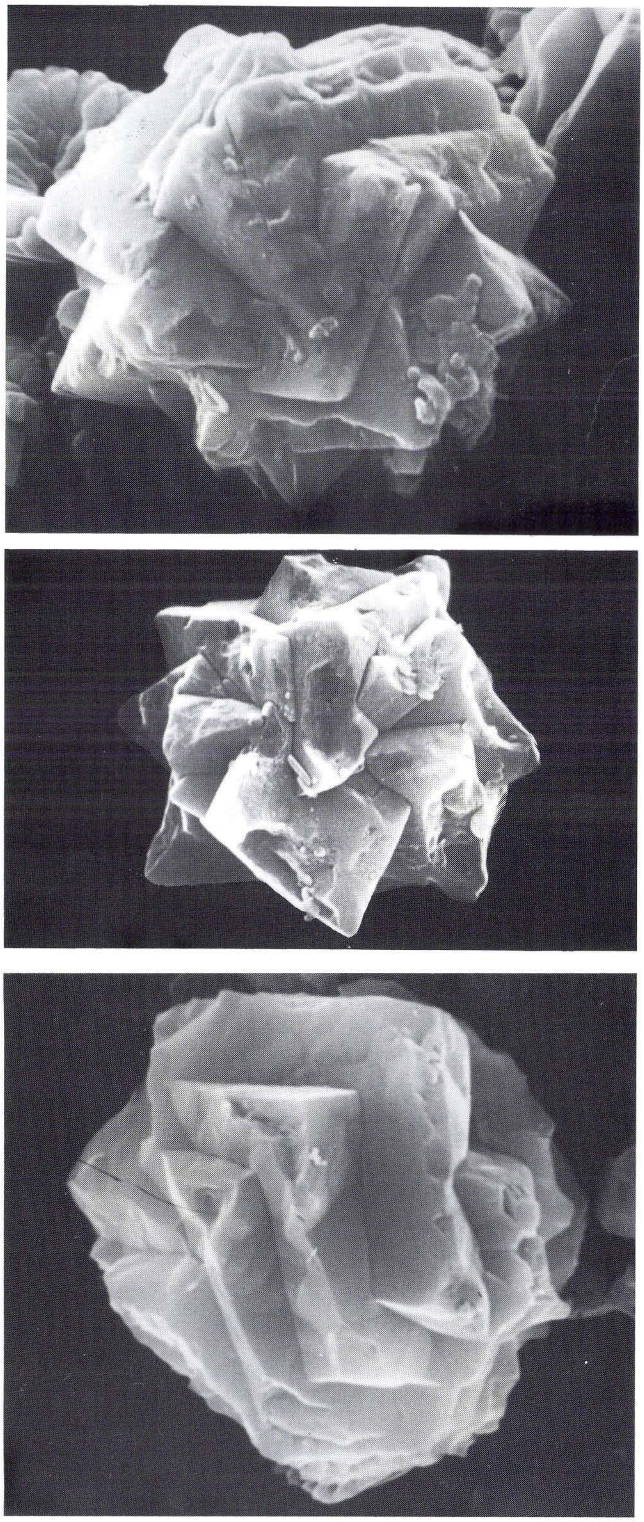


Fig. 13. Rucinulithus terebrodentarius Applegate, Bralower, Covington & Wise (1987). Sample Adda-1 7700'A. Magnifications × 7000.

Sollasites lowei (Bukry, 1969) Roth (1970).
Plate 21, Fig. 14.

Sollasites pinnatus (Black, 1971) Perch-Nielsen (1984).
Plate 17, Figs. 3,4.

Stoverius achylosus (Stover, 1966) Perch-Nielsen (1984).
Plate 17, Fig. 20.

Stoverius? sp. 1.
Plate 17, Fig. 19.
Remarks. A few small specimens with a central cross have a rim of two cycles of which the outer one is composed of nearly vertical elements They can probably be assigned to the genus *Stoverius* Perch-Nielsen (1984). A specific assigment was not possible because of the sparse material.

Stoverius? sp. 2.
Plate 17, Figs. 24–26.
Remarks. Unattached solid rods with parallel sides are common in many samples of the present material. In well preserved samples it was revealed that most of these rods apparently are central processes of small coccoliths. The coccoliths shown in Pl. 17, Figs. 24–26 are oval with a rim of two cycles. The central cross is alligned with the axis of the ellipse. The species is tentavely assigned to the genus *Stoverius*.

Stradnerlithus fragilis (Rood & Bernard 1972) Perch-Nielsen (1984).
Plate 17, Fig. 10.
Remarks. The specimens from the North Sea are similar to specimens from the Aptian of the South Atlantic assigned by Wise (1983) to *Corollithion fragilis* (Rood & Bernhard, 1972) Wind & Wise (1977).

Stradnerlithus sexiramatus (Pienaar, 1969) Perch-Nielsen (1984).
Plate 17, Figs. 6–8.

Tegulalithus septentrionalis (Stradner, 1963) Crux (1986).
Plate 15, Figs. 10–16.
Remarks. Kötke (1981) pointed out that specimens assigned to *Tegulalithus septentrionalis* (as *Lithastrinus septentrionalis*) by Thierstein (1973) clearly do not belong to this species. *T. septentrionalis* is thus confined to the Upper Hauterivian and the lowermost Barremian (Köthe 1981, Jakubowski 1987). It is common and, therefore, of great biostratigraphical value (Köthe 1981). A few specimens (Plate 15, Fig. 15) show some similarity to *Eprolithus varolii* and it is possible that the two species are closely related.

Tegumentum stradneri Thierstein *in* Roth & Thierstein (1972).
Plate 3, Figs. 3–11.

Tetrapodohabdus decorus (Deflandre *in* Deflandre & Fert, 1954) Wind & Wise *in* Wise & Wind (1977).
Plate 12, Figs. 2–4.
Remarks. Forms with an x-shaped crossbar (*T. decorus*, Fig. 4) were not distinguished from forms with a simple bridge *(Hemiporhabdus gorkae* (Reinhardt, 1979) Grün (1975), Fig. 3). Grün & Allemann (1975) demonstrated a continuous transition between the two forms. The incomplete form shown in Fig. 2 was common in many samples.

Tranolithus gabalus Stover (1966).
Plate 19, Fig. 19.

Tranolithus phacelosus Stover (1966).
Plate 20, Figs. 15–18.

Truncatoscaphus pauciramosus (Black, 1973) Perch-Nielsen (1984).
Plate 17, Figs. 11,12.

Truncatoscaphus senarius (Wind & Wise *in* Wise & Wind, 1977) Perch-Nielsen (1984).
Plate 17, Fig. 23.
Remarks. T. senarius was described from the Upper Jurassic. The present observation is the first from the Lower Cretaceous.

Vagalapilla matalosa (Stover, 1966) Thierstein (1973).
Plate 21, Fig. 12.

Vekshinella angusta (Stover, 1966) Verbeek (1977).
Plate 1, Figs. 6–8.
Remarks. Specimens of the genus *Vekshinella* with the arms of the central cross alligned parallel to the principal axes of the elliptical coccolith were assigned to *V. stradneri*. Specimens with the arms clearly rotated were assigned to *V. angusta.* Transitional forms have not been observed in the present material.

Vekshinella stradneri Rood, Hay & Bernhard (1971).
Plate 1, Figs. 3–5.

Vekshinella quadriarculla (Noël, 1965) Rood, Hay & Bernhard (1971).
Plate 1, Figs. 9–11.

Watznaueria barnesae (Black *in* Black & Barnes, 1959) Perch-Nielsen (1968).
Plate 4, Figs. 1–5.
Remarks. The definition of *W. barnesae* varies greatly between authors. Some define the species narrowly to include only forms in which the central opening is not formed like a tube. The opening may be completely closed by blocky elements. Many authors adopt a wider definition and incorporate various other forms. In the present paper the forms shown in Plate 4, Figs. 1–5 are all referred to *W. barnesae*.

Only forms with a narrow central opening were referred to *W. barnesae*. Specimens with a large opening were referred to *W. ovata* Transitional specimens occurred and it is possible that *W. barnesae* and *W. ovata* should not be regarded as separate species. Also included in *W. barnesae* are *Calolithus martelae* Noël (1965) and forms similar to *Coptolithus virgatus* Black (1973). These forms could be incompletely developed coccoliths or the result of dissolution (Grün *in* Grün & Allemann, 1975 Perch-Nielsen 1985).

The specimen shown in Plate 4, Fig. 5 is similar to specimens illustrated by Barrier (1977a). The specimen shown in Plate 4, Fig. 13 and attributed to *E? tubulata* of Grün & Zweili (1980) could also possibly be an aberrant form of *W. barnesae*. Forms of *W. Barnesae* with a narrow central tube were the most common coccoliths in all samples. The other forms, including *W. barnesae sensu strictu*, were relatively rare.

Watznaueria britannica (Stradner, 1963) Reinhardt (1964).
Plate 4, Figs. 10,11.

Watznaueria fasciata Wind & Cepek (1970).
Plate 4, Fig. 12.

Watznaueria ovata Bukry (1969).
Plate 4, Figs. 8,9.

Watznaueria rawsonii Crux (1987).
Plate 4, Figs. 6,7.

Zeugrhabdotus compactus Bukry (1969).
Plate 21, Figs. 1–6.
Remarks. According to Bukry (1969) *Z. compactus* lacks a spine. Burns (1976), however, in a study from the Cenomanian of eastern England observed spines on all specimens. In the North Sea material both specimens with and without a spine have been found. The original spine is small and formed like a rosette, but very often it is overgrown with large blocky elements to form a cube.

Zeugrhabdotus bussonii
Plate 19, Figs. 17,18.

Zeugrhabdotus elegans (Gartner, 1968).
Plate 18, Figs. 7,8.

Zeugrhabdotus embergeri Noël (1959) Perch-Nielsen (1984).
Plate 18, Figs. 4–6.

Zeugrhabdotus erectus (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1965).
Plate 19, Fig. 13.

Zeugrhabdotus reticulatus (Black, 1971) Black (1973).
Plate 21, Figs. 7–11. Plate 18, Figs. 9–11. Plate 19, Figs. 1,2.
Remarks. The specimens shown from the distal side on Plate 19, Figs. 1,2 are only tentatively referred to *Z. reticulatus*.

Zeugrhabdotus sisyphus (Gartner, 1968).
Plate 18, Figs. 1–3.

Zeugrhabdotus ssp.
Plate 19, Figs. 4–12.
Remarks. Specimens of small *Zeugrhabdotus* (max. length between 2,5 and 4,5 um) were common in most samples. Specific identification has not been attempted, but apparently several species are represented.

Appendix

Aptian calcareous nannofossils from Helgoland and Sarstedt, Germany.

During the course of the present study it became evident that some of the sedimentary units in the North Sea were very similar to units of Aptian age described from Helgoland and northwestern Germany. For comparison purposes calcareous nannofossils have been investigated from three of these units, namely the "Fischschiefer" and the *"ewaldi* Kreide" from Helgoland and the *"inflexus"* marl from Sarstedt, southeast of Hannover.

Helgoland is situated in the southern part of the North Sea about 270 km southeast of the E-1 boring (Fig. 11). A condensed Cretaceous sequence is exposed in a submerged cliff northeast of the island. Loose blocks have been collected on the beach and on the sea floor by skin divers. Both the submerged section and the loose blocks have been intensively studied. The material is rich in fossils e.g. ammonites, belemnites, foraminifers, and ostracods, and the stratigraphy of the sequence is well established (Bartenstein & Kaever 1973, Kemper et al. 1974).

The Valanginian to Barremian sequence is composed mainly of dark calcareous clays. They will not be dealt with here. The Aptian to Albian sequence is very condensed. The lowermost unit consists of a 1 m thick finely-laminated bituminous shale with pyrite, a high content of organic material, and abundant fish remains. This "Fischschiefer" is widespread in northern Germany. It is lithologically very similar to the lower part of the Sola Formation in the North Sea (Jensen & Buchardt 1987). The "Fischschiefer" has on the basis of ammonites been dated to the lower part of the *Deshayesites* zone (Kemper *et al.* 1974). This zone corresponds to the *forbesi* and *deshayesi* Zones in the zonation of Rawson *et al.* (1978). The "Fischschiefer" can be assigned to the upper part of the *forbesi* Zone and possibly the lowermost part of the *deshayesi* Zone (The ammonite zonation is shown in Fig. 7).

The "Fischschiefer" is overlain by the *"ewaldi*-Kreide". This formation is 2 m thick and consists of a lower yellow ("gelbe *ewaldi*-Kreide") and an upper red unit ("rote *ewaldi*-Kreide") (Kemper *et al.* 1974). The yellow unit belongs to the *bowerbanki* Zone and possibly to the uppermost part of the *deshayesi* Zone. The red unit is assigned to the *martinoides* Zone (Kemper *et al.* 1974).

In addition to the material from Helgoland a single sample from Sarstedt of the so-called *"inflexus* Marl" was investigated. This sample belonged the upper part of the *nutfieldensis* Zone.

Calcareous nannofossils were examined in four samples from the "Fischschiefer", two samples from each of the two units of the *"ewaldi-Kreide"* and one sample from the *"inflexus* Marl".

The "Fischschiefer" contained numerous calcareous nannofossils. Preservation was fairly good, although signs of dissolution could be observed on many specimens. The fine-grained matrix of the *"ewaldi*-Kreide" was composed almost exclusively of calcareous nannofossils. Preservation was moderately good, being poorest in the lower yellow unit. Many specimens were slightly overgrown. The *"inflexus* Marl" contained fewer nannofossils. Preservation was moderate due to dissolution.

The distribution of calcareous nannofossils in the investigated formations is shown in Fig. 11. The exact position of the samples from the "Fischschiefer" and each of the two units of the *"ewaldi*-Kreide" was not known. The samples were very similar and they are, therefore not shown separately.

Eprolithus apterior and *Rhagodiscus angustus*

The distribution of *Eprolithus apterior* and *Rhagodiscus angustus* is especially noteworthy. *E. apterior* was found in three out of four samples in the "Fischschiefer", but it was always rare. It was moderately common in the lower yellow unit of the *"ewaldi*-Kreide" and very common in the upper, red unit. The specimens from the "Fischschiefer" were generally smaller than the specimens from the *"ewaldi*-Kreide".

R. angustus was moderately common in all samples from Helgoland. The specimens from the "Fischschiefer" were always much smaller than the specimens from the yellow and red units of the *"ewaldi*-Kreide".

E. apterior and *R. angustus* are in many zonations used as markers for the Upper Aptian (Thierstein 1973, 1976; Perch-Nielsen 1979, 1985) although their application have been questioned. Barrier (1977a) found *E. apterior* in the Lower Aptian stratotype at La Bédoule, southern France, and Sissingh (1977) and Perch-Nielsen (1979) noted *R. angustus* or very similar forms in sediments as old as the Hauterivian at Speeton.

The occurrence of both species in the Lower Aptian "Fischschiefer" confirms that they cannot be used strictly as markers for the Upper Aptian.

Comparison with the Aptian stratotypes in southern France.

Except for the absence of *Rhagodiscus angustus* the nannofossil assemblage of the "Fischschiefer" is very similar to the assemblage described from the Lower Aptian stratotype at La Bédoule, southern France (Barrier 1977a). The "Fischschiefer" is as noted above also of Early Aptian age.

The red "*ewaldi*-Kreide" is of Late Aptian age (*martinoides* ammonite Zone according to Kemper *et al.*, 1974). The calcareous nannofossil flora also suggests a Late Aptian age, as it shows greater affinity to the flora from the Gargasian stratotype (described by Barrier 1977b) than to the flore from the Bédoulian. This is especially reflected in the numerous specimens of *Eprolithus apterior* and in the large size of *R. angustus.*

The yellow unit of the "*ewaldi*-Kreide" is situated between the "Fischschiefer" and the red "*ewaldi*-Kreide". According to Kemper *et al.* (1974) it can be referred to the *bowerbanki* ammonite Zone. This zone has traditionally been referred to the Upper Aptian (see e.g. Kemper 1971, 1982), but in many newer zonations (e.g. Casey 1961, Rawson *et al.* 1978) it is regarded as the uppermost zone of the Lower Aptian.

The calcareous nannofossil floras of the yellow and red "*ewaldi*-Kreide" resemble each other closely. The only consistent difference seems to be a slightly lower proportion of *E. apterior* in the yellow unit. The "Fischschiefer", on the other hand, is clearly different. For example, *E. apterior* is very rare in the "Fischschiefer", while it is fairly common in both units of the "*ewaldi*-Kreide". *Rhagodiscus angustus* is represented by small specimens in the "Fischschiefer"and large in the "*ewaldi*-Kreide". It should also be mentioned that *Acaenolithus* sp.1, a species that hitherto has only been found in Late Aptian or younger sediments (Black 1973), is present in both units of the "*ewaldi*-Kreide", but absent in the "Fischschiefer".

The calcareous nannofossil flora of the yellow "*ewaldi*-Kreide" is, therefore, more similar to the Gargasian flora than to the Bédoulian. The boundary between the Lower and the Upper Aptian is, consequently in the present paper, placed below the *bowerbanki* Zone. It should be noted, however, that the correlation between the formations on Helgoland and the Bédoulian and Gargasian stratotypes is based on quantitative similarities only. Reliable Bédoulian or Gargasian markers have not been found on Helgoland.

The calcareous nannofossil flora in the sample from Sarstedt was characterized by numerous specimens of *Rhagodiscus asper. Watznaueria barnesae*, which normally predominates in the Lower Cretaceous, was rare. A similar unusual relationship between the two species was also noted by Čepek (1982) in samples of approximately the same age (upper *nutfieldensis* Zone) from Kanal Mehrum-Schwicheldt near Hannover, Germany.

▶

Fig. 14. Distribution of calcareous nannofossils in samples from the Aptian of Helgoland and Sarstedt.

Ammonite Zone	nutfieldensis	martinoides	bowerbanki	upper forbesi
Formation	"inflexus Marl"	"Rote ew.-Kreide"	"Gelbe ev.-Kreide"	"Fischschiefer"
Acaenolithus sp. 1		I	I	
Axopodorhabdus dietzmannii	▮	▮	I	
Biscutum dubium				▮
Biscutum erismatum	I	I		▮
Braarudosphaera hockwoldensis		I	I	I
Bukrylithus ambiguus	I			
Chiastozygus platyrhethus	I	▮	▮	I
Cretarhabdus conicus	I	I	I	▮
Cretarhabdus surirellus	I	I	I	I
Cyclagelosphaera magerelii				I
Discorhabdus rotatorius	I	I		
Eprolithus anterior	I	▮	▮	I
Eprolithus varolii	I	I	I	I
Flabellites biforaminis	I	I	I	▮
Gephyrorhabdus coronadventis	I			
Glaucolithus diplogrammus	I	I	I	I
Grantarhabdus meddii	I			
Lithraphidites carniolensis	I	▮	▮	I
Loxolithus armilla	I			
Manivitella pemmatoidea	I	I	▮	▮
Micrantholithus obtusus		I	I	I
Microstaurus chiastius		I	▮	▮
Nannoconus sp. 1	▮			
Nannoconus spp.	▮	I	I	I
Octocyclus reinhardtii	I			
Parhabdolithus achylostaurion		▮	▮	▮
Pickelhaube furtiva			I	I
Placozygus acanthus				I
Polypodorhabdus escaigii	I			I
Prediscosphaera spinosa	I			
Prediscosphaera cf. stoveri				I
Retecapsa angustiforata	I	I	I	I
Rhagodiscus angustus	I	I	I	I
Rhagodiscus asper	■	▮	▮	▮
Rhagodiscus splendens	▮		I	▮
Rotelapillus laffittei	▮	I	I	▮
Scapholithus fossilis				I
Seribiscutum primitivum	I			
Sollasites horticus	I			
Sollasistes lowei	I			
Stoverius sp. 1				I
Stradnerlithus fragilis			I	
Stradnerlithus sexiramatus		I	I	
Tegumentum stradneri	I	I		I
Tetrapodorhabdus decorus	I	I	I	I
Tranolithus gabalus		I	I	I
Valgalapilla matalosa	I			
Vekshinella angusta				
Vekshinella stradneri	I	I		▮
Vekshinella quadriarculla	I			I
Watznaueria barnesae	I	■	■	■
Watznaueria britannica				▮
Watznaueria ovata	I	I	I	▮
Zeugrhabdotus compactus	I			
Zeugrhabdotus erectus			I	
Zeugehabdotus reticulatus	I	▮	I	I
Zeugrhabdotus sisyphus	▮	I	I	I
Small Zeugrhabdotus spp.	I	▮	▮	▮

Acknowledgements

I wish to thank Claus Heilmann-Clausen and Thorkild Feldthusen Jensen for many valuable discussions of problems of Lower Cretaceous sedimentology and stratigraphy in the North Sea area. Katharina Perch-Nielsen carefully read the manuscript and suggested many improvements. David Penney is thanked for correcting the English manuscript. I am grateful to Edwin Kemper at Bundesanstalt für Geowissenschafte und Rohstoffe for providing samples from Helgoland and Sarstedt. Karen Birgit Pauli is thanked for prosessing the samples. Helle Zetterwall drew the figures.

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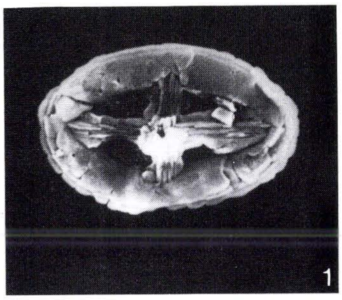
PLATES 1–22

PLATE 1

Fig. 1. *Acaenolithus?* sp. E-1 8190'6''.
Fig. 2. *Haslingfieldia stradneri* Bukry (1969). E-1 8232'8''.
Figs. 3–5. *Vekshinella stradneri* Rood, Hay & Bernhard (1971). Fig. 3, I-1 9511'. Fig. 4, E-1 8211'2''. Fig. 5, E-1 8191'.
Figs. 6–8. *Vekshinella angusta* (Stover, 1966) Verbeck (1977). Fig. 6.7, E-1, 8208'5''. Fig. 8, E-1 8207'6''.
Figs. 9–11. *Vekshinella quadriarculla* (Nöel 1965) Rood, Hay & Bernhard (1971). Figs. 9–11, E-1 8208'5''.
Figs. 12, 13. *Bukrylithus ambiguus* Black (1971). Fig. 12, E-1 8190'6''. Fig. 13, Adda-2 7762'.
Fig. 14. *Bukrylithus?* sp. Fig. 14, I-1 9360'A.
Figs. 15–16. *Biscutum constans* (Gorka, 1957) Black *in* Black & Barnes (1959). Fig. 15, I-1 9493'. Fig. 16, Adda-2 7781'.
Fig. 17. *Biscutum dubium* (Noël, 1965) Grün, Prins & Zweili (1974). E-1 8232'8''.
Figs. 18–20. *Biscutum erismatum* (Wind & Wise *in* Wise & Wind, 1977) Grün & Zweili (1980). Figs. 18–20, E-1 8193'10''.
Figs. 21–23. *Biscutum salebrosum* (Black, 1971) Perch-Nielsen (1984). Figs. 21–23, E-1 8170'A.
Figs. 24–25. *Seribiscutum primitivum* (Thierstein, 1974) Filewicz *et al.* *in* Wise & Wind (1977). Figs. 24–25, I-1 9360'A.

Magnifications: × 7000.

PLATE 1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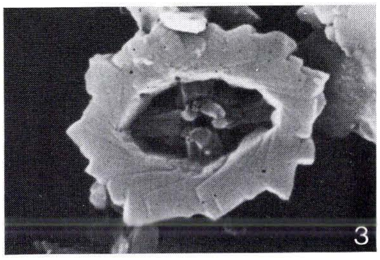
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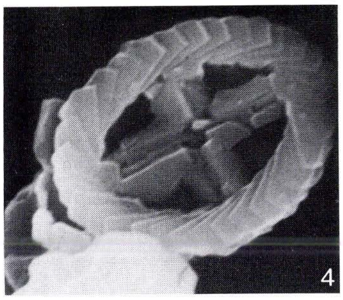
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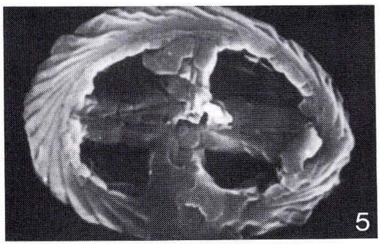
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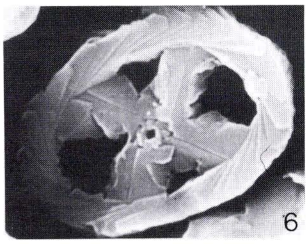
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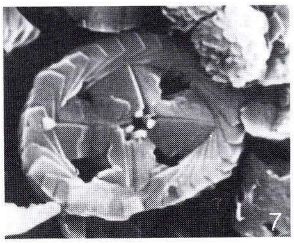
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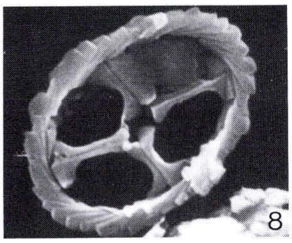
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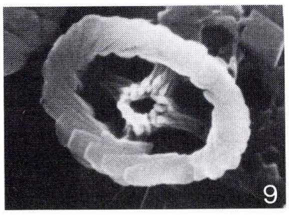
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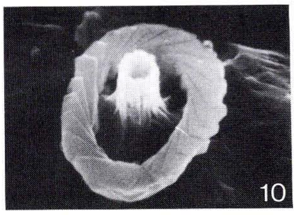
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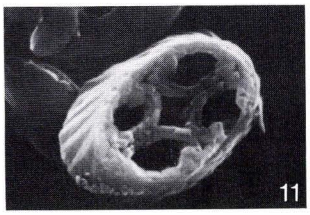
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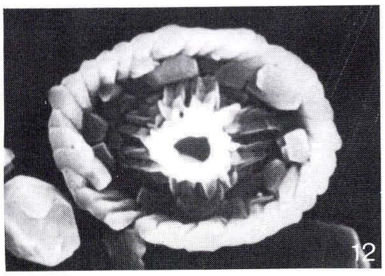
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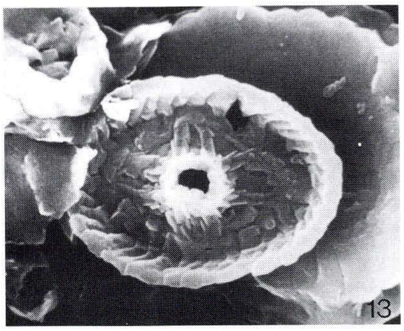
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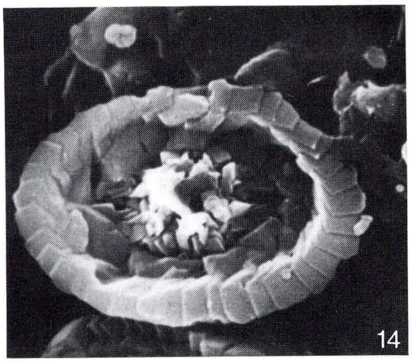
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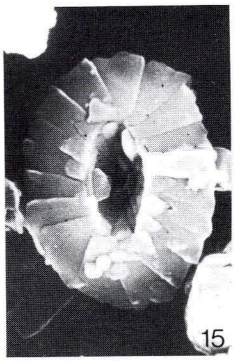
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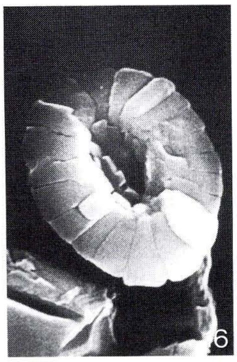
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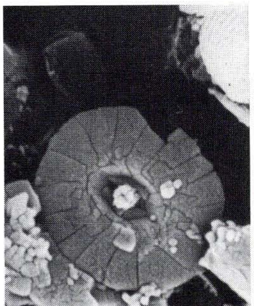
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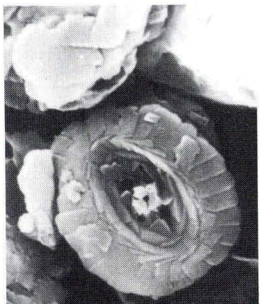
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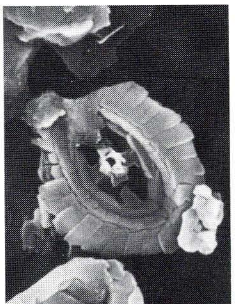
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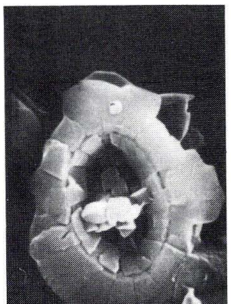
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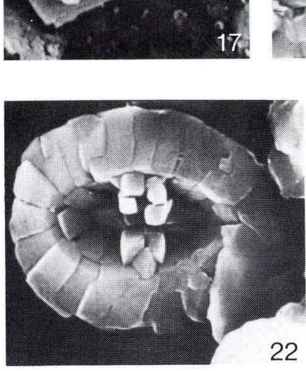
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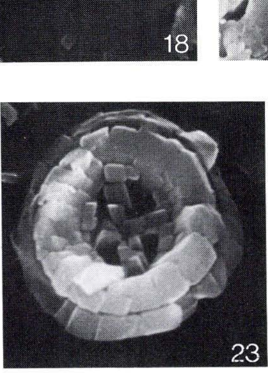
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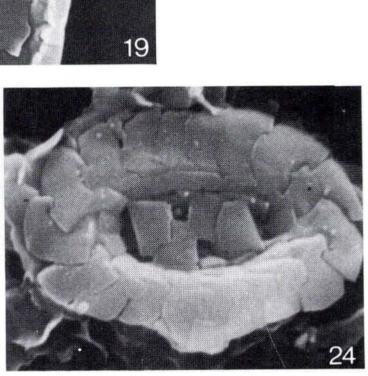
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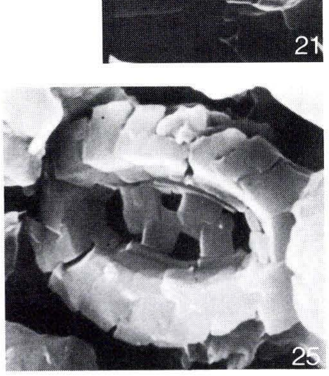
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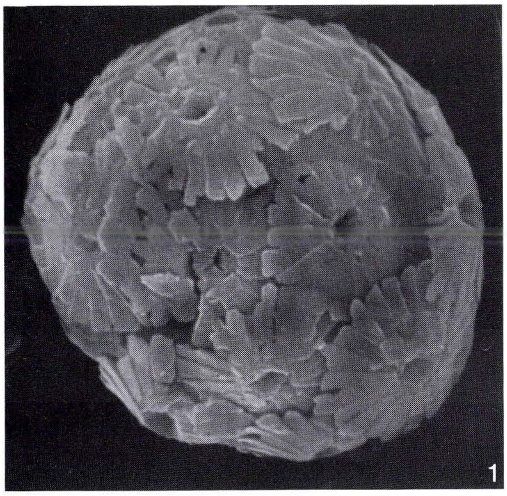
PLATE 2

Fig. 1. *Discorhabdus rotatorius* (Bukry, 1969) Thierstein (1973). E-1 8195'.
Fig. 2. *Braarudosphaera hockwoldensis* Black (1973). E-1 8180'A. Poor preservation.
Fig. 3. *Braarudosphaera regularis* Black (1973). E-1 8180'A.
Figs. 4–6. *Micrantholithus obtusus* Stradner (1963) Fig. 4, E-1 8195'. Fig. 5, E-1 8190'. Fig. 6, I-1 9850'B.
Figs. 7,8. *Scapholithus fossilis* Deflandre (1954). Adda-2 7762'.
Figs. 9–14. *Chiastozygus platyrhethus* Hill (1976). Fig. 9, E-1 8211'2''. Fig. 10, E-1 8208'5''. Figs. 11–13, E-1 8180'C. Fig. 14, E-1 8207'6''.

Magnifications: × 7000.

PLATE 2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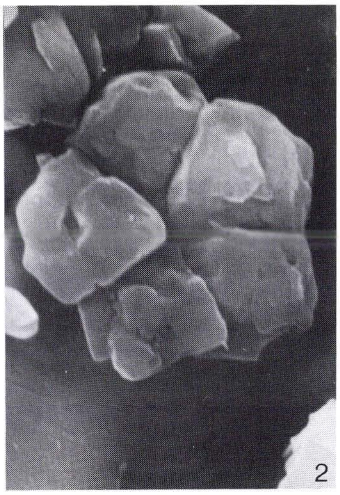
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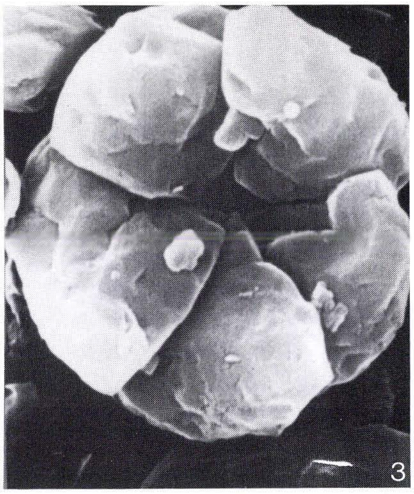
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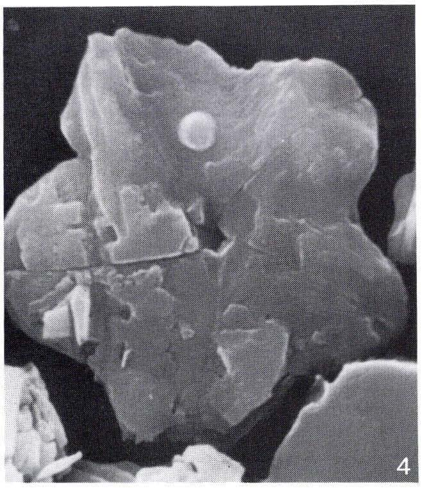
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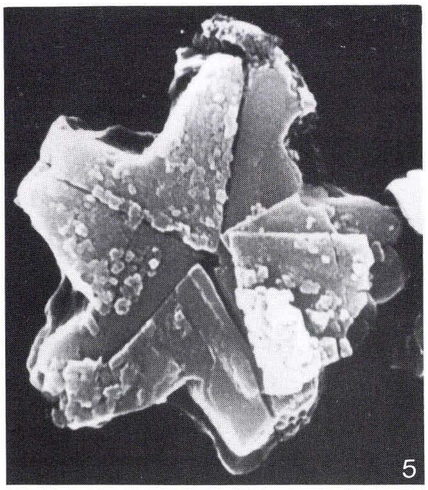
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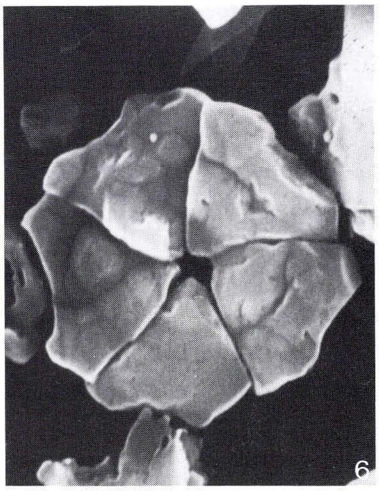
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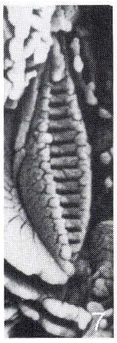
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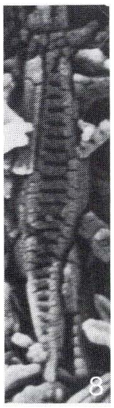
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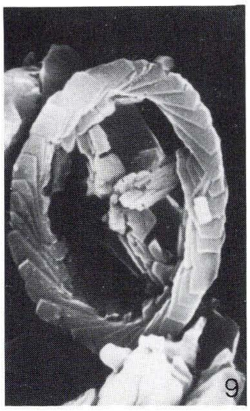
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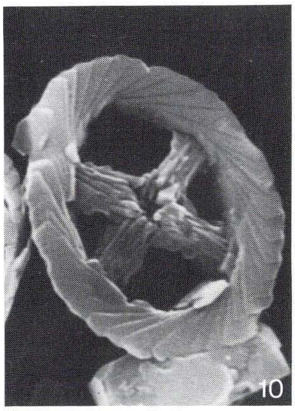
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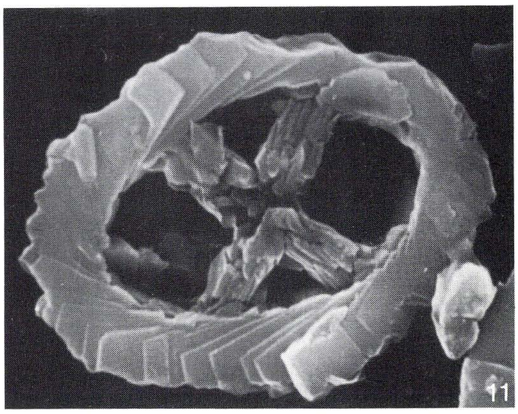
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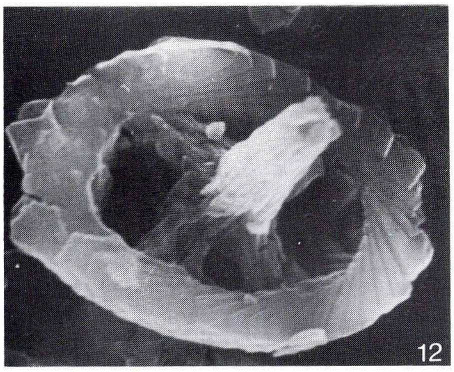
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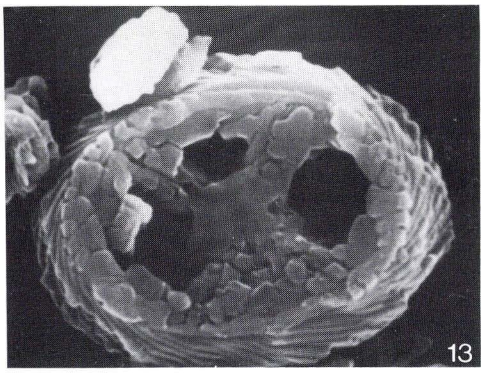
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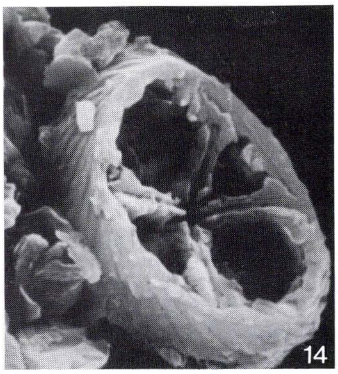
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PLATE 3

Figs. 1,2. *Chiastozygus striatus* Black (1971). Figs, 1,2, I-1 9850'B.
Figs. 3–11. *Tegumentum stradneri* Thierstein *in* Roth & Thierstein (1972). Fig. 3, E-1 8190'. Fig. 4, E-1 8191'10''. Fig. 5, Adda-2 7774'. Fig. 6, E-1 8193'10''. Fig. 7, E-1 8190'. Figs. 8, 9, E-1 8219'. Fig. 10, E-1 8190'6''. Fig. 11, E-1 8211'2''.
Figs. 12 13,14. *Diazomatolithus lehmannii* Noël (1965). Fig. 12, E-1 8232'8''. Fig. 13, Adda-2 7762'. Fig. 14, Adda-2 7781'.
Figs. 15,16. *Conusphaera rothii* (Thierstein, 1971). Figs. 15,16, I-1 9600'A.
Figs. 17,18. *Cyglagelosphaera rotaclypeata* Bukry (1969). Fig. 17, E-1 8180'A. Fig. 18, Adda-2 7756'.
Figs. 19,20,21. *Cyglagelosphaera margerelii* Noël (1965). Figs. 19,20, I-1 9600'A. Fig. 21, I-1 9493'.

Magnifications: × 7000.

PLATE 3


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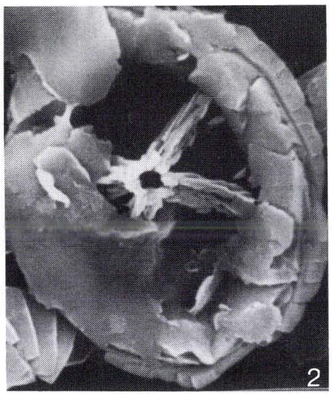
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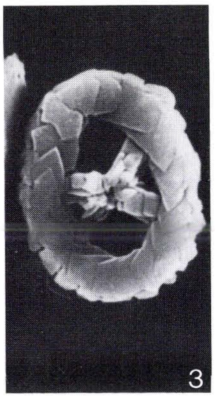
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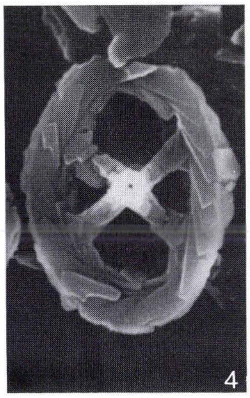
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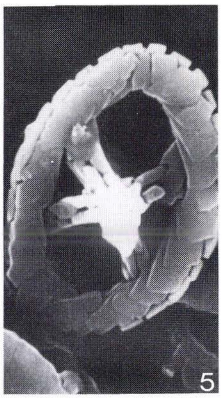
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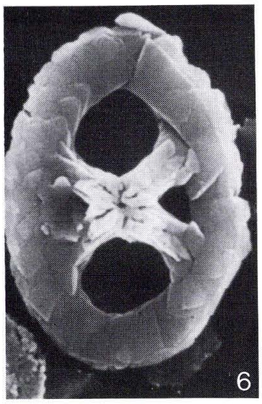
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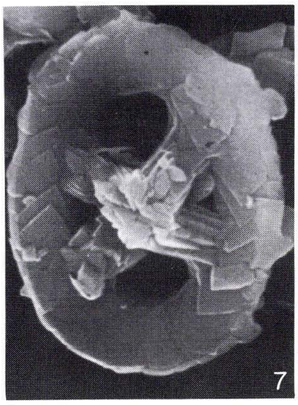
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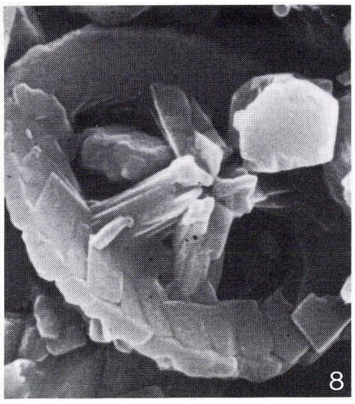
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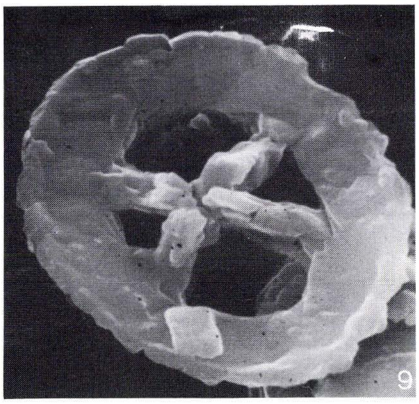
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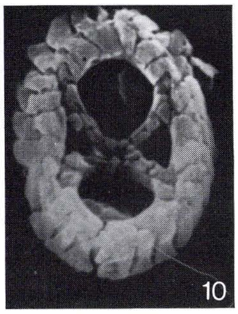
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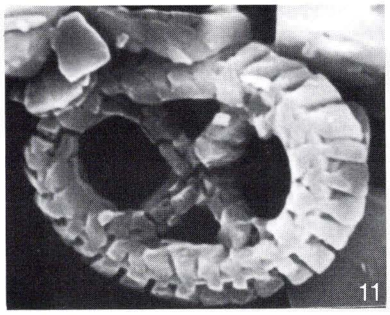
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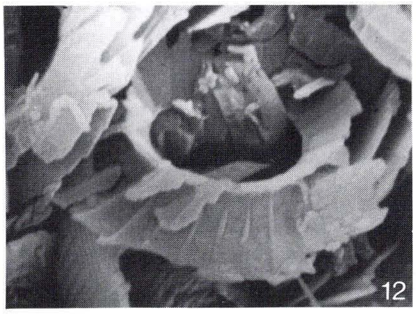
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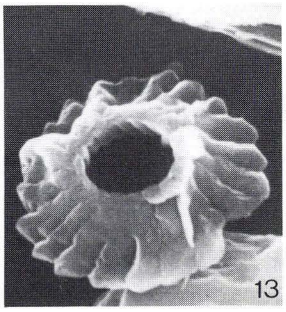
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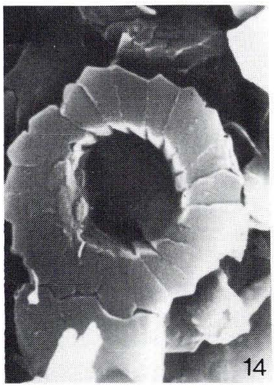
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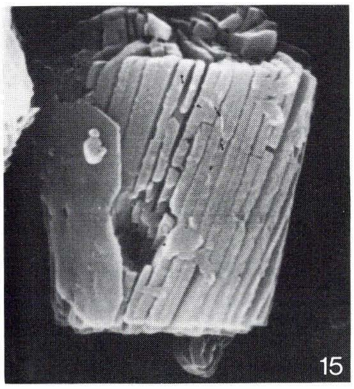
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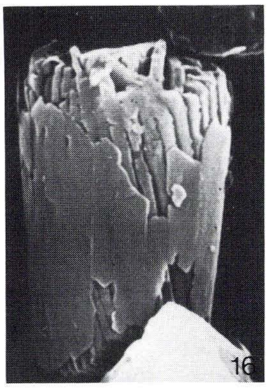
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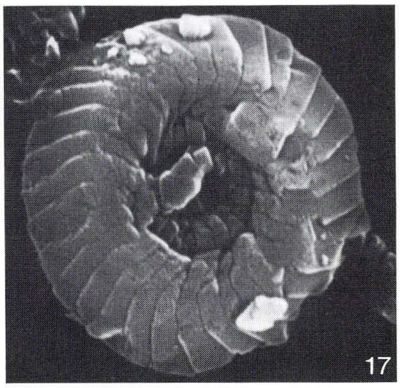
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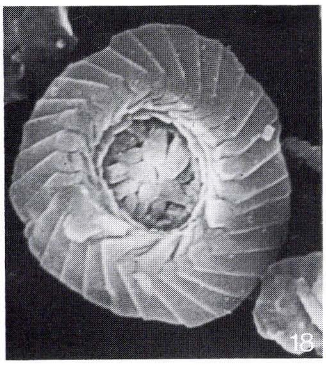
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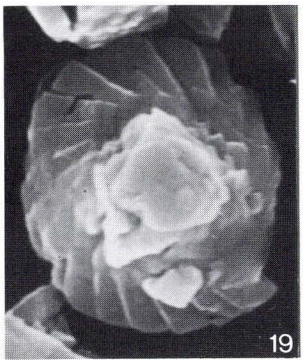
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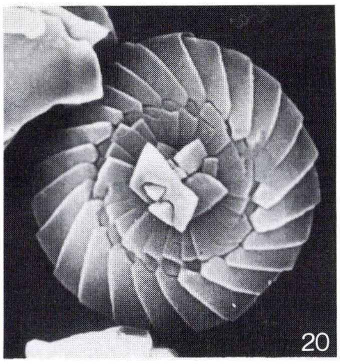
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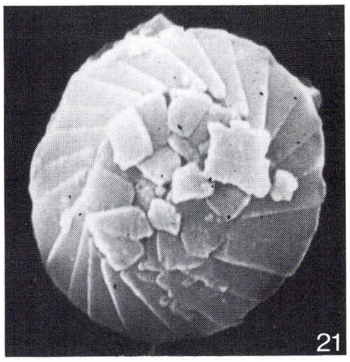
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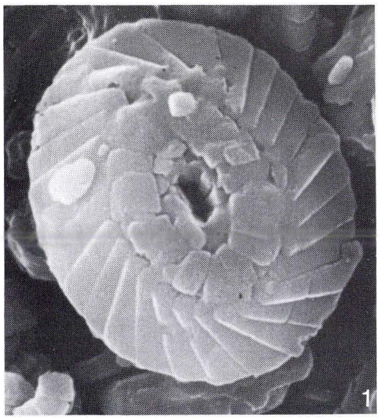
PLATE 4

Figs. 1–5. *Watznaueria barnesae* (Black & Barnes, 1959) Perch-Nielsen (1968). Fig. 1, Adda-2 7781'. Fig. 2, E-1 8208'5''. Fig. 3, Adda-2 7774'. Figs. 4,5, Adda-2 7774'.
Figs. 6,7. *Watznaueria rawsonii* Crux (1967). E-1 8232'8''.
Figs. 8,9. *Watznaueria ovata* Bukry (1969). Fig. 8, E-1 8190'A. Fig. 9, I–1 9511'.
Figs. 10,11. *Watznaueria britannica* (Stradner, 1963) Reinhardt (1964). Fig. 10, E-1 8190'6''. Fig. 11, Adda-2 7762'.
Fig. 12. *Watznaueria fasciata* Wind & Cepek (1970). E-1 8193'.
Fig. 13. *Ellipsagelosphaera? tubulata* Grün & Zweili (1980). I-1 9720'A.
Fig. 14. *Haqius circumradiatus* (Stover, 1966) Roth (1978). E-1 8180'C.
Figs. 15,16. *Flabellites biforaminis* Thierstein (1973). Fig. 15, Adda-2 7774'. Fig. 16, E-1 8180'A.

Magnifications: × 7000.

PLATE 4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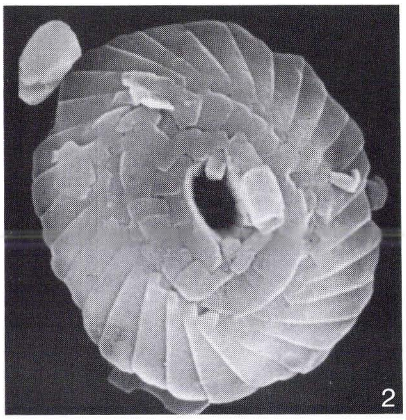
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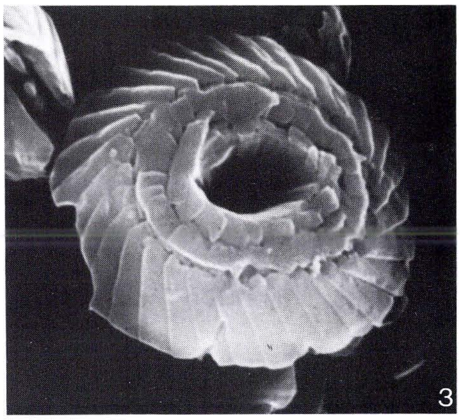
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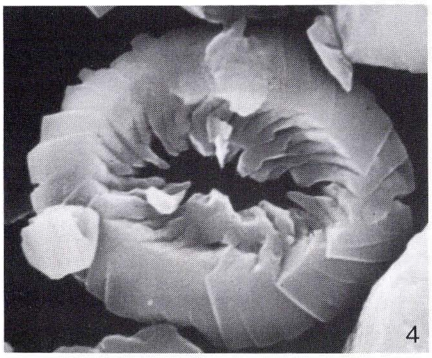
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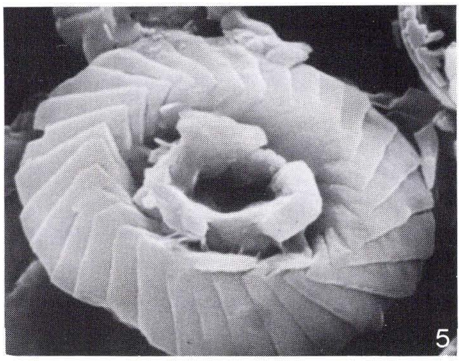
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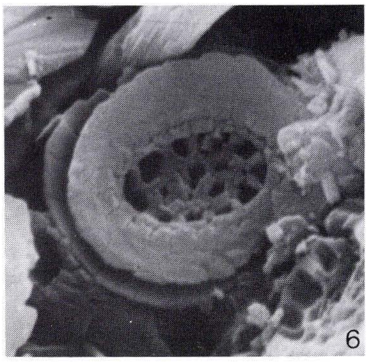
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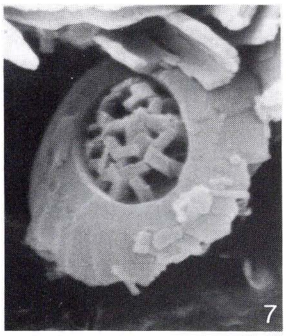
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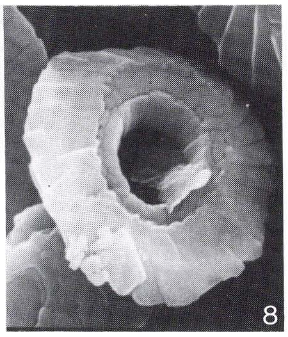
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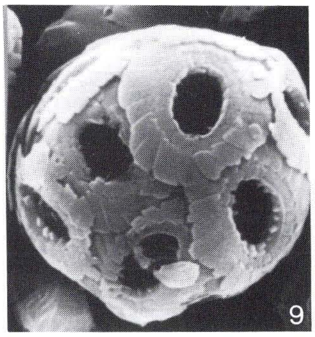
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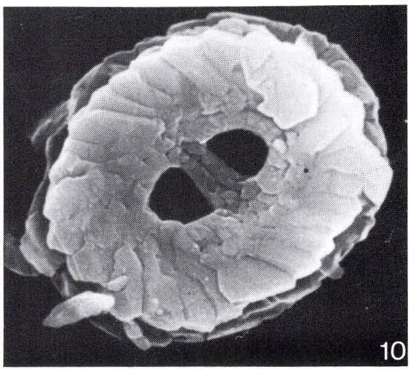
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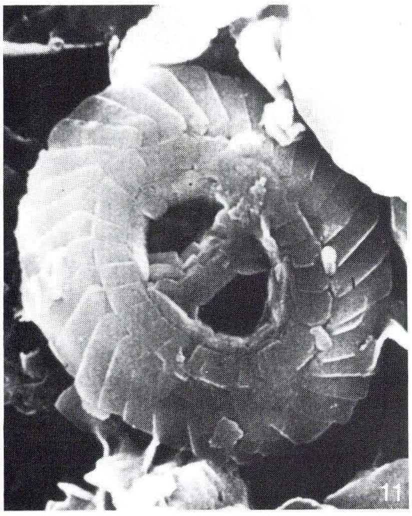
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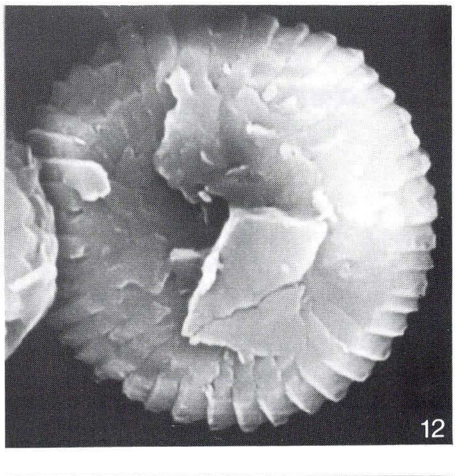
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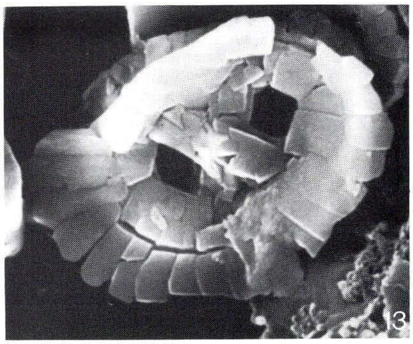
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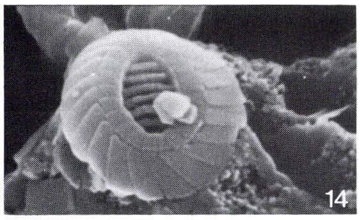
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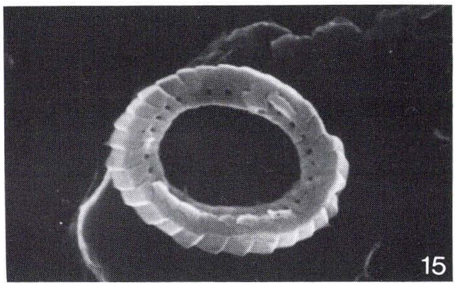
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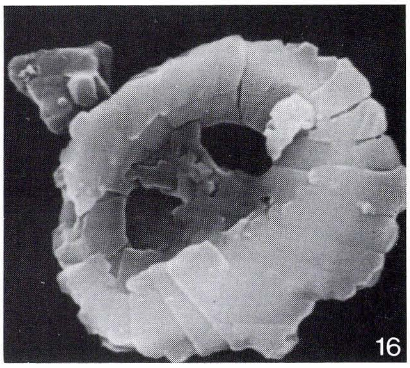
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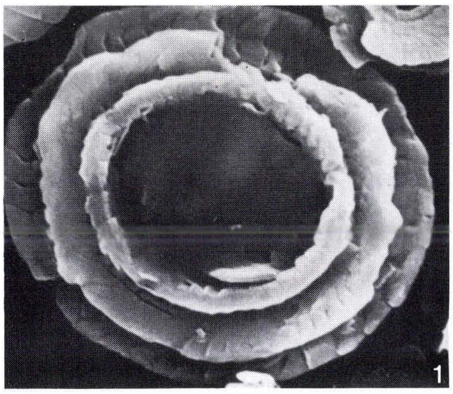
PLATE 5

Figs. 1,2. *Manivitella pemmatoidea* (Deflandre *in* Manivit, 1965) Thierstein (1971). Fig. 1, E-1 8191'10''. Fig. 2, I-1 9493'.
Figs. 3,4. *Cribrosphaerella? hauteriviana* (Black, 1971) Perch-Nielsen (1984). Fig. 3, Adda-2 7768'. Fig. 4, Adda-2 7762'.
Figs. 5,6. *Lithraphidites moray-firthensis* Jakubowski (1986). E-1 8170'A.
Fig. 7. *Lithraphidites carniolensis* Deflandre (1963). Adda-2 7774'.
Figs. 8–14. *Nannoconus quadriangulus* Deflandre & Deflandre (1967) subsp. *apertus*. Figs. 7,8,10,12,13 and 14, E-1 8191'10''. Fig. 9, E-1 8193'.

Magnifications: Figs. 1–7 × 7000. Figs. 8–14 × 3500.

PLATE 5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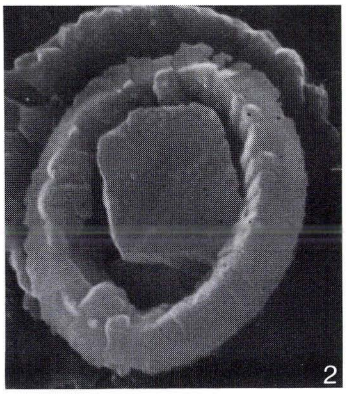
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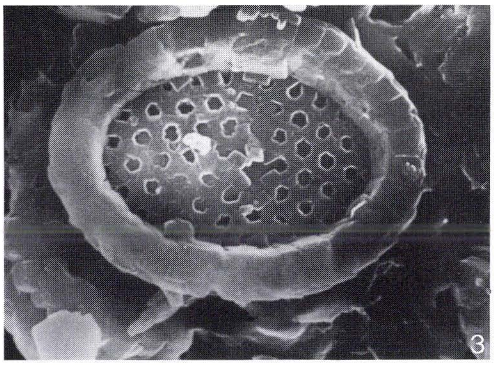
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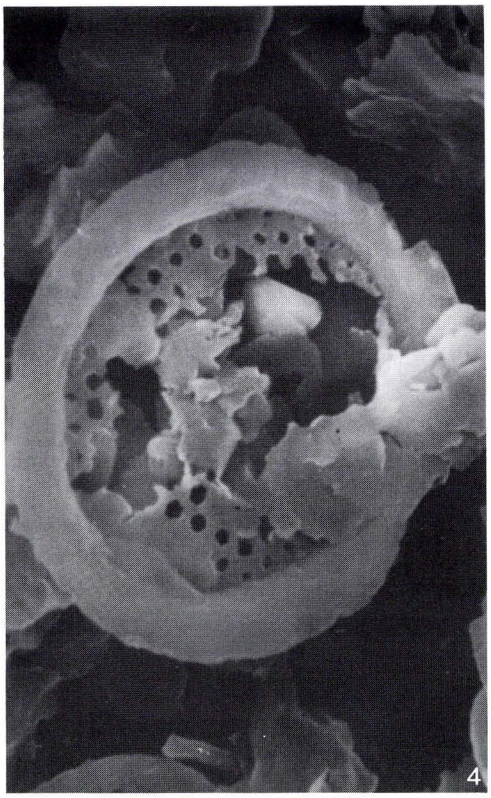
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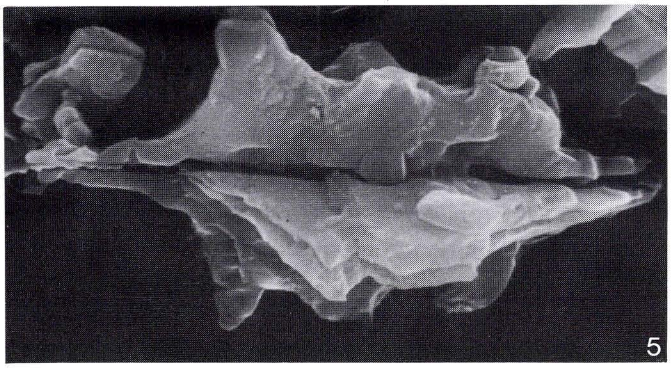
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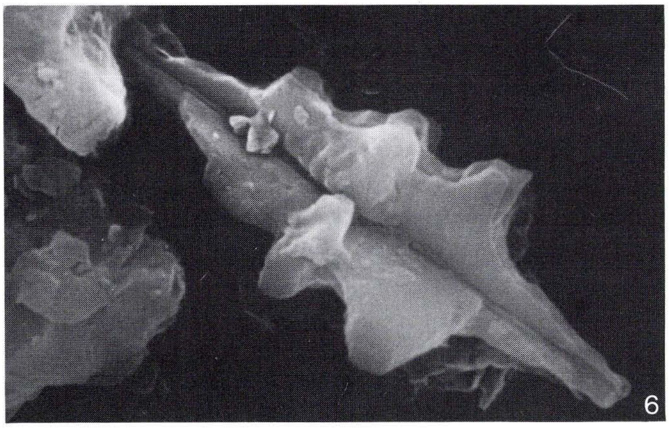
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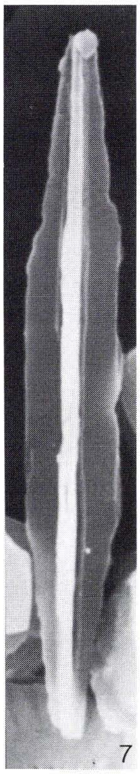
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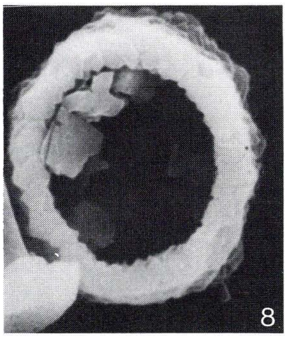
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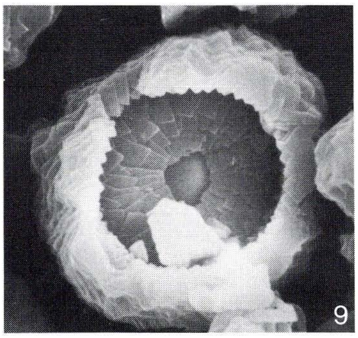
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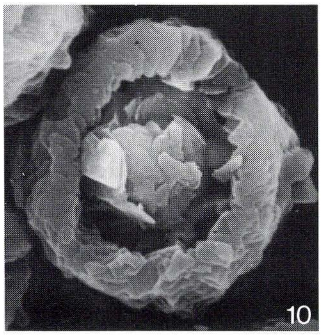
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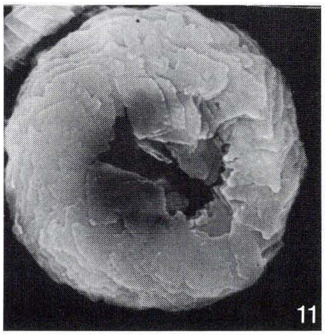
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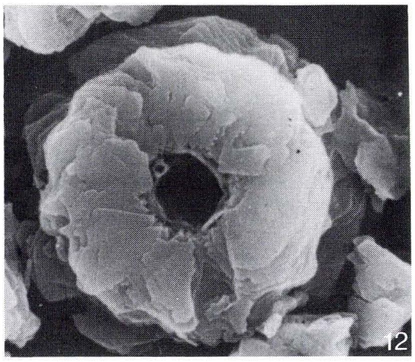
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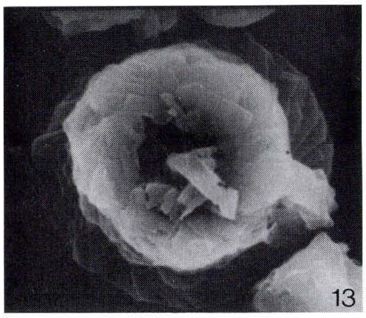
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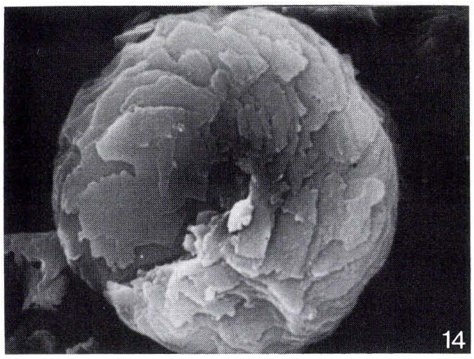
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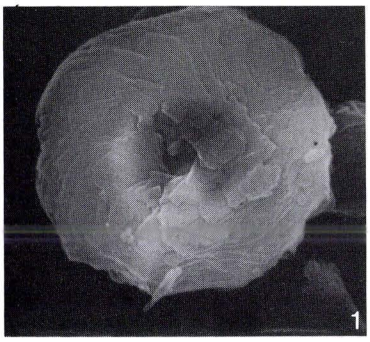
PLATE 6

Figs. 1–5. *Nannoconus quadriangulus* Deflandre & Deflandre-Rigaud (1967) subsp. *apertus*. Figs. 1–3, 5, E-1 8190'10''. Fig. 4, E-1 8200'.
Figs. 6–9. *Nannoconus quadriangulus* Deflandre & Deflandre-Rigaud (1967) subsp. *quadriangulus*. Fig.5, E-1 8190'10''.
Figs. 10–13. *Nannoconus abundans* Stradner & Grün (1973). Fig. 10, I-1 9493'. Figs. 11,12, I-1 9511'. Fig. 13, E-1 8208'5''.
Figs. 14–18. *Nannoconus truitti truitti* Brönnimann (1955). Figs. 14,17, E-1 8208'. Fig. 15, E-1 8190'. Fig. 16, E-1 8207'. Fig. 18, E-1 8195'.
Figs. 19–21. *Nannoconus truitti* Brönnimann (1955) subsp. *frequens* Deres & Achériteguy (1980). Figs. 19,20,21, E-1 8195'.

Magnifications: × 3500.

PLATE 6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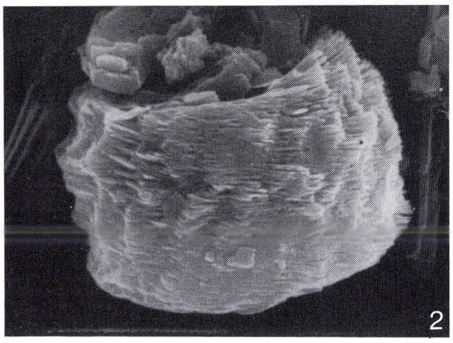
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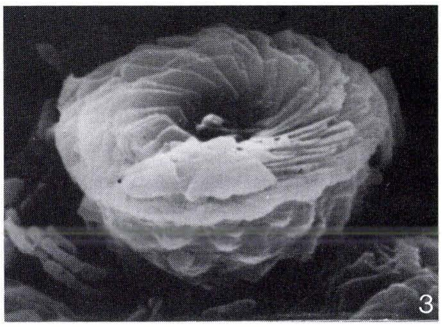
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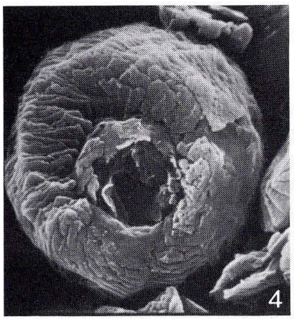
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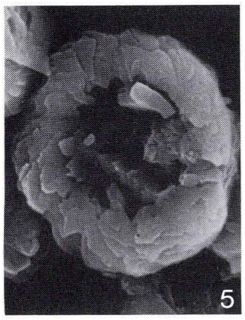
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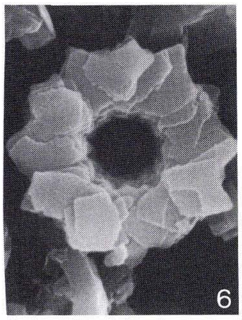
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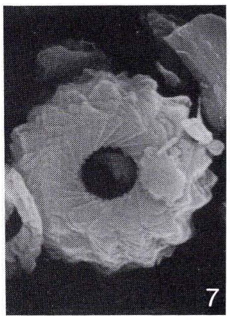
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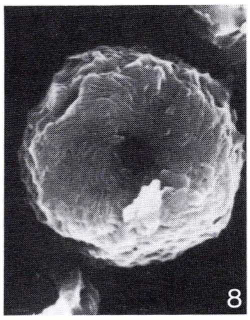
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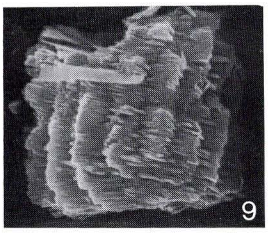
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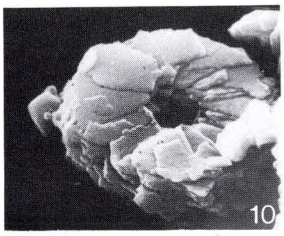
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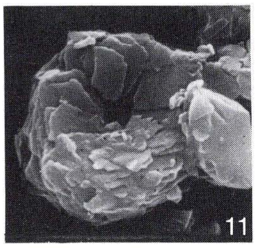
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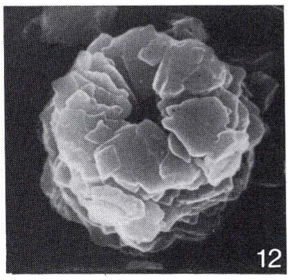
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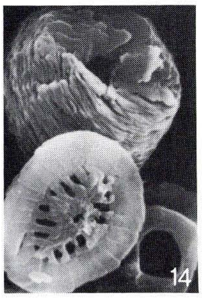
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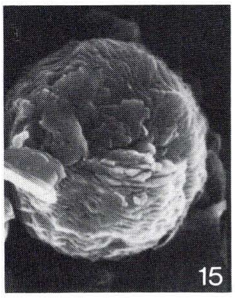
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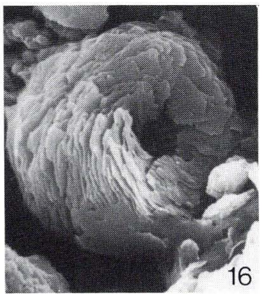
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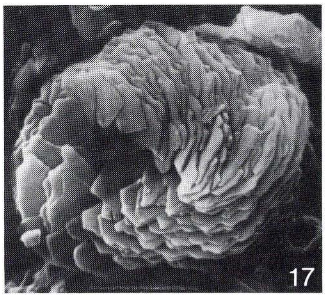
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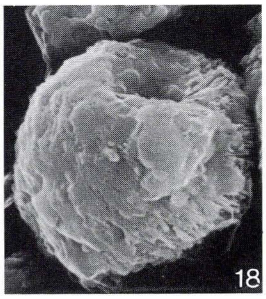
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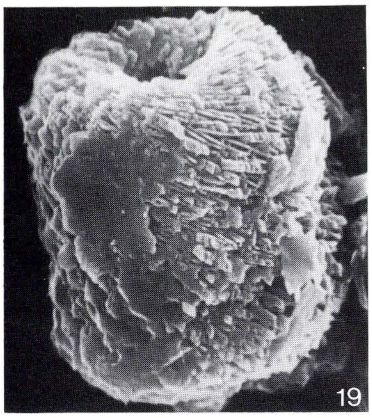
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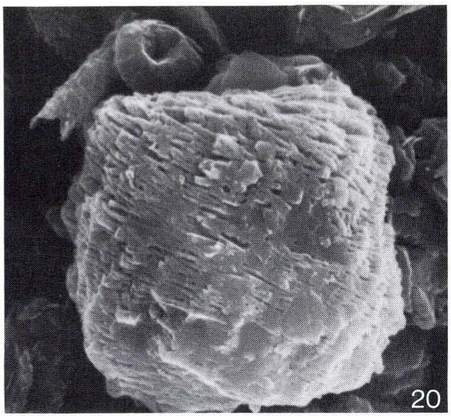
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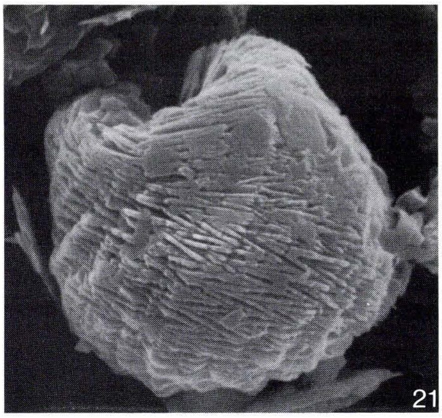
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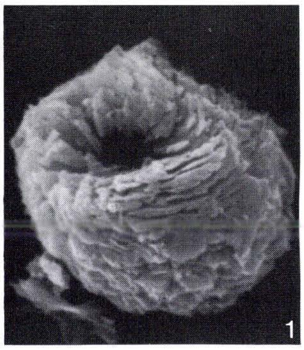
PLATE 7

Figs. 1–18. *Nannoconus globulus* Brönnimann (1955). Figs. 1–3, 5–8, 11,12, E-1 8207'6''. Figs. 4,10,16, E-1 8190'. Figs. 9,13,14, E-1 8211'2''. Figs. 15,17,18, I-1 9850'B.

Magnifications: × 3500.

PLATE 7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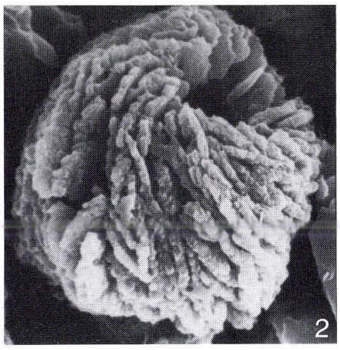
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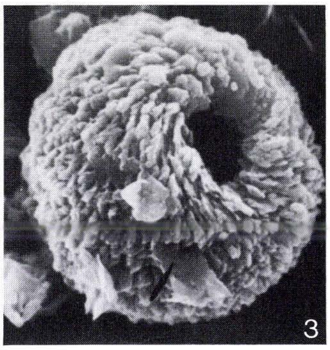
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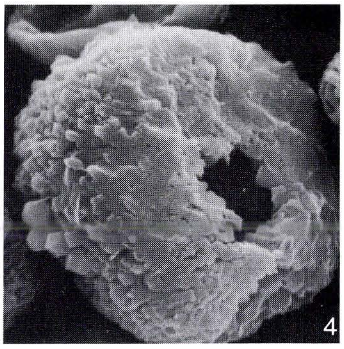
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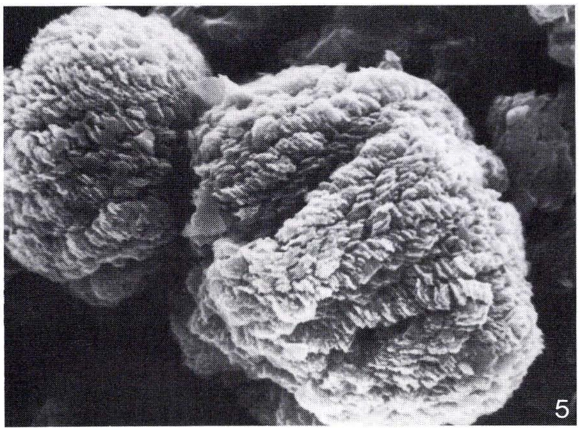
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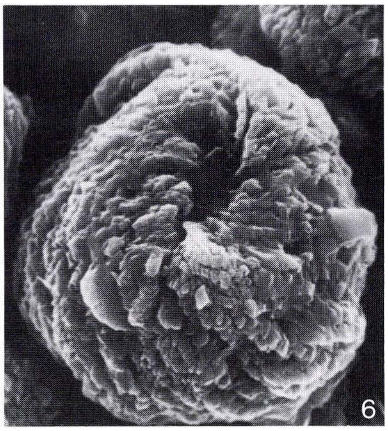
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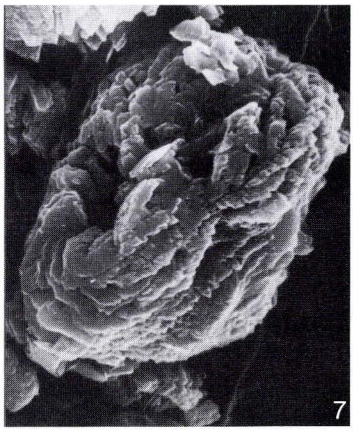
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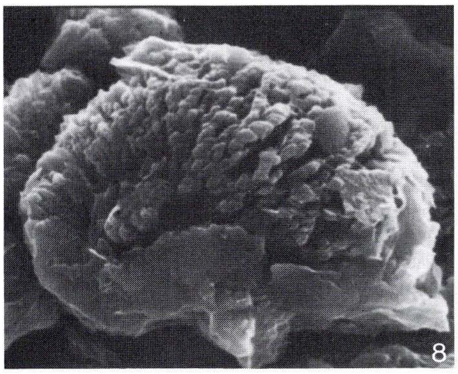
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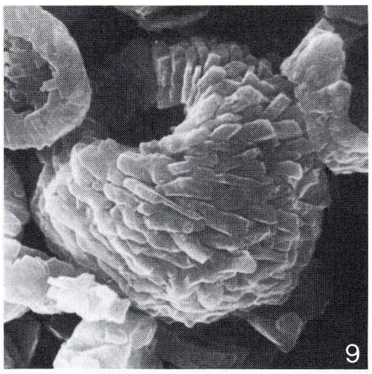
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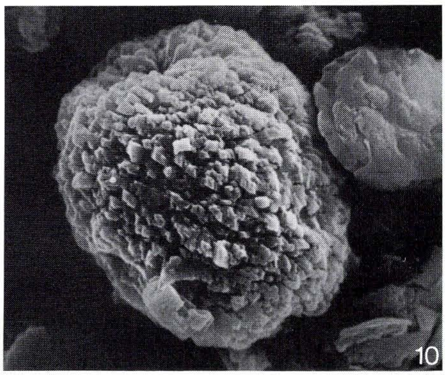
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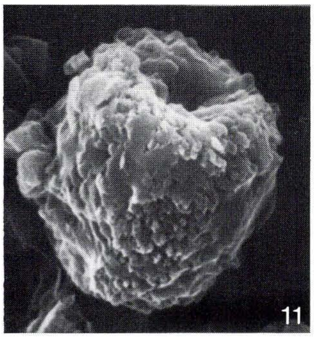
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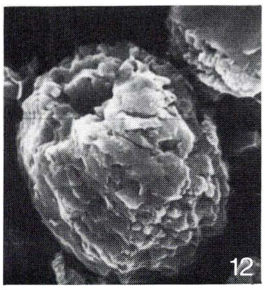
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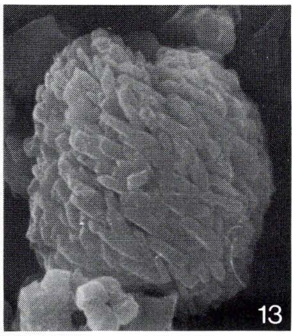
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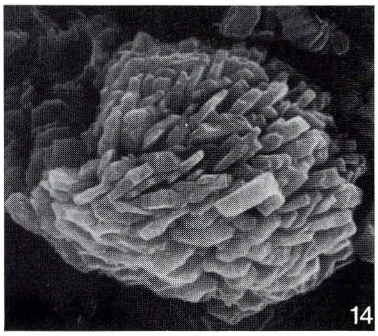
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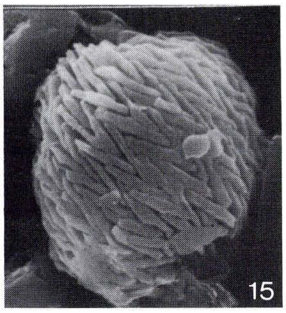
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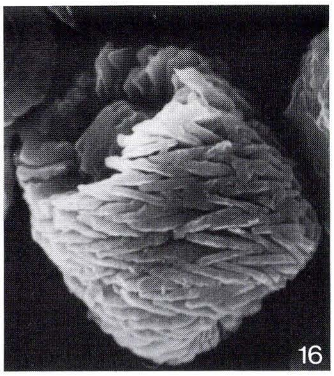
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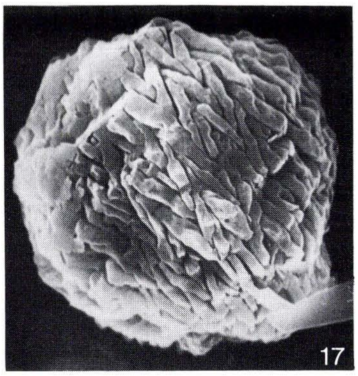
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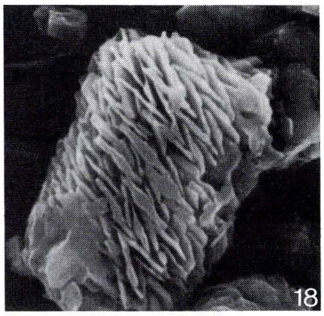
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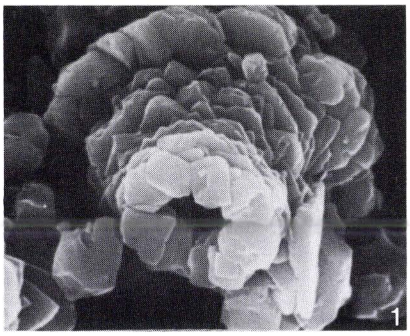
PLATE 8

Figs. 1–6 *Nannoconus borealis* Perch-Nielsen (1984). Fig. 1, E-1 8211'2''. Figs. 2–6, Adda-2 7781'. Fig. 5, top view. Fig. 6, bottom view.
Figs. 7,8. *Nannoconus elongatus* Brönnimann (1955). Fig. 7, E-1 8219'. Fig. 8, E-1 8211'2''.
Figs. 9–11. *Nannoconus bonetii* Trejo (1959). Figs. 9–11, E-1 8211'2''.

Magnifications: × 3500.

PLATE 8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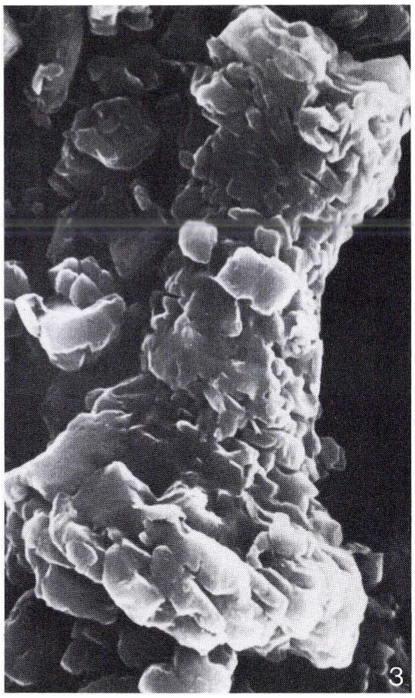
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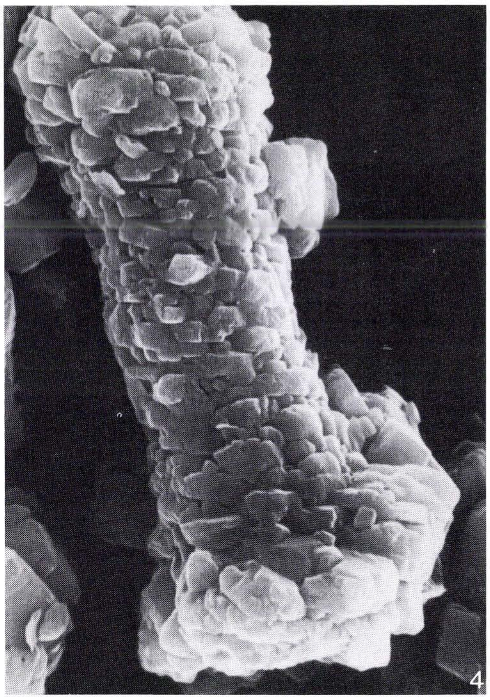
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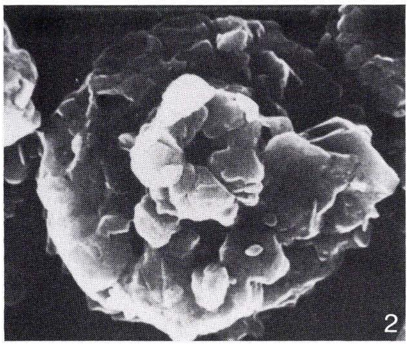
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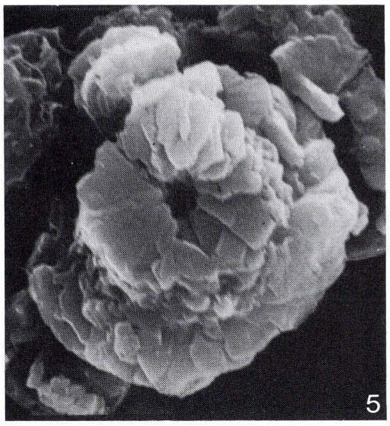
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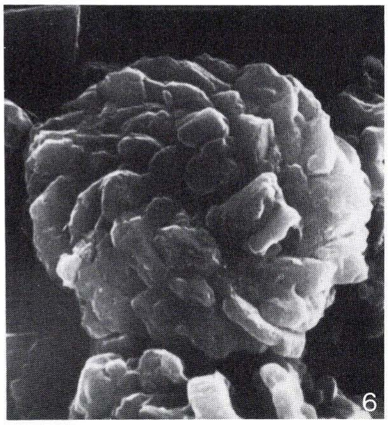
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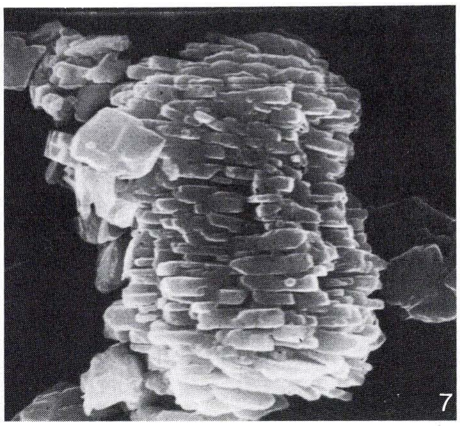
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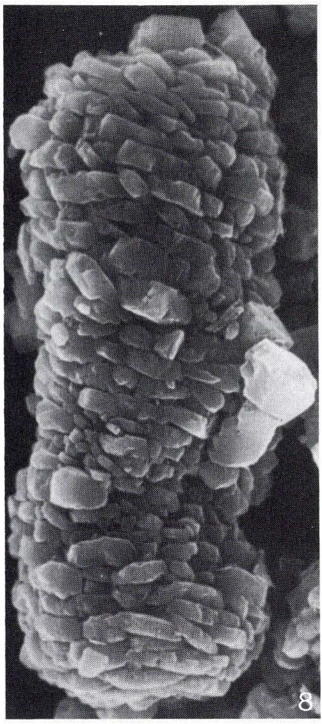
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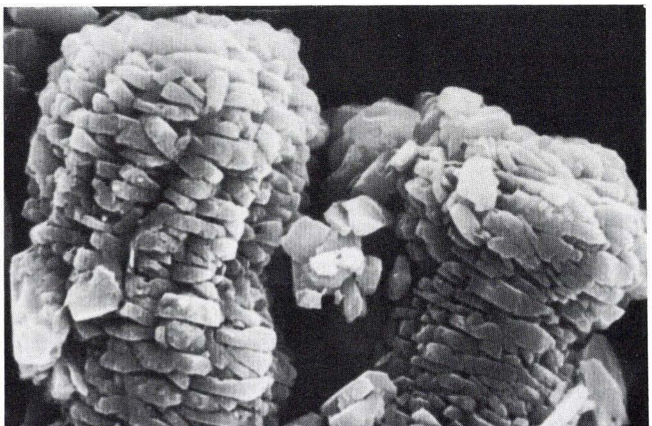
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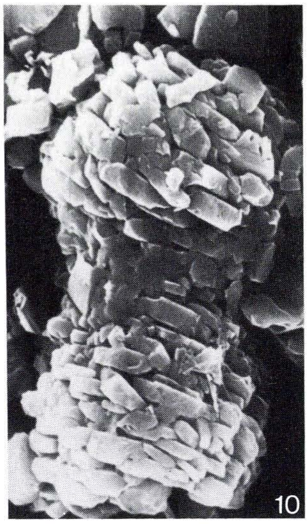
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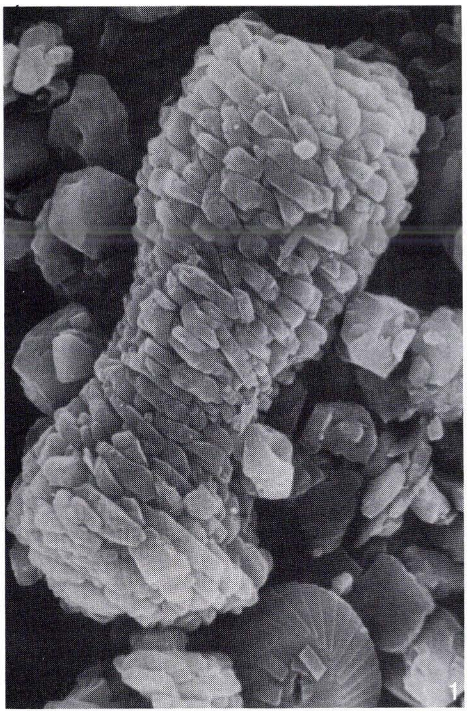
PLATE 9

Figs. 1–3. *Nannoconus bonetii* Trejo (1955). Figs. 1,2, E-1 8211'2''. Fig. 3, E-1 8190'.
Figs. 4,5. *Nannoconus steinmannii* Kamptner (1931). Fig. 4, E-1 8190'. Fig. 5, E-1 8211'2''.
Figs. 6,7. *Nannoconus multicadus* Deflandre & Deflandre-Rigaud (1960). Fig. 6,7. E-1 8190'.

Magnifications: × 3500.

PLATE 9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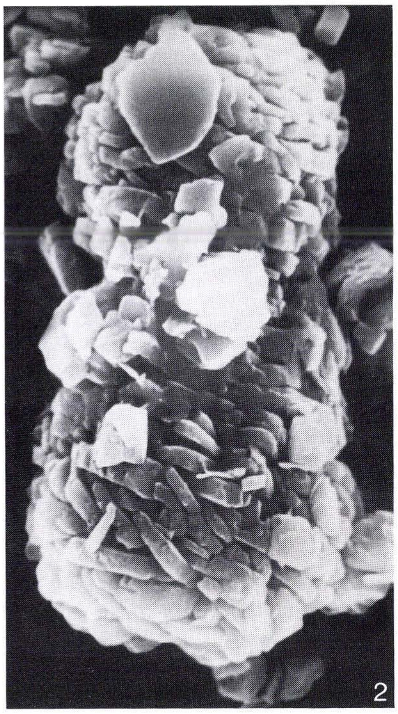
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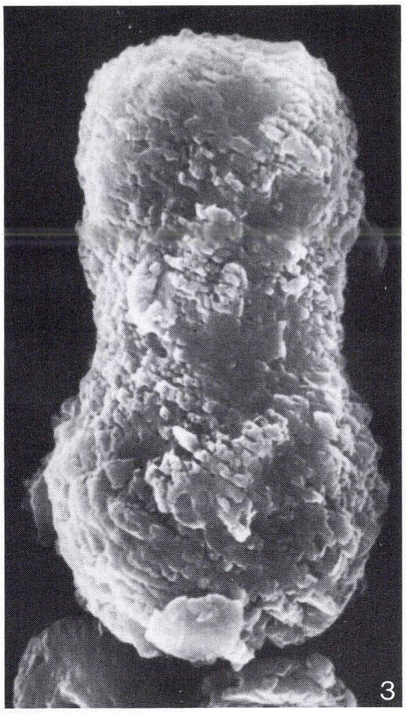
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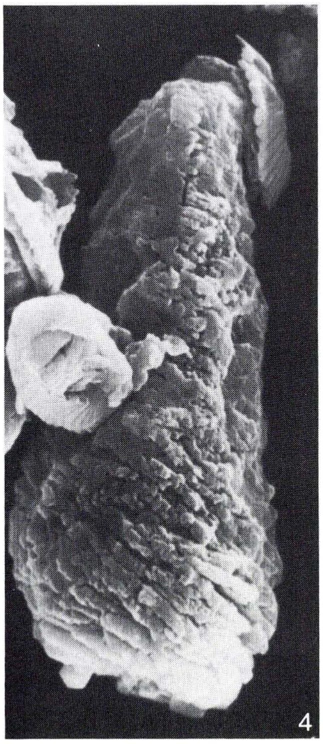
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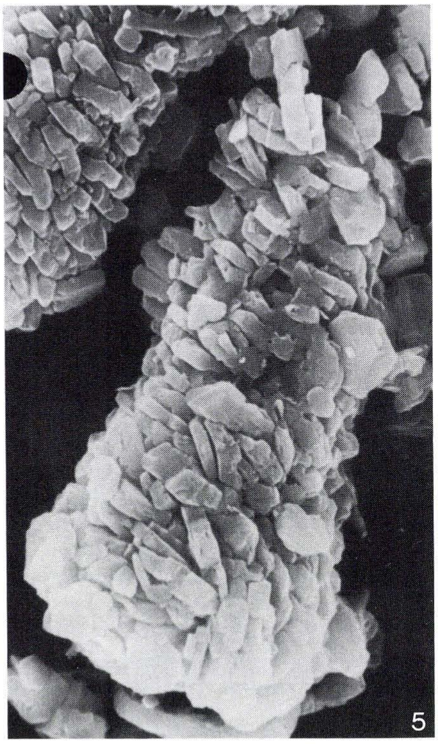
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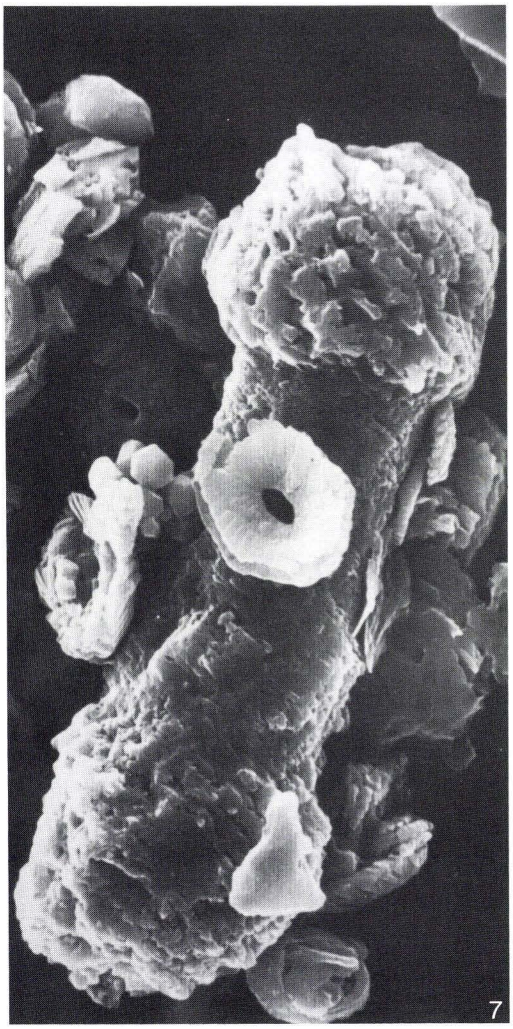
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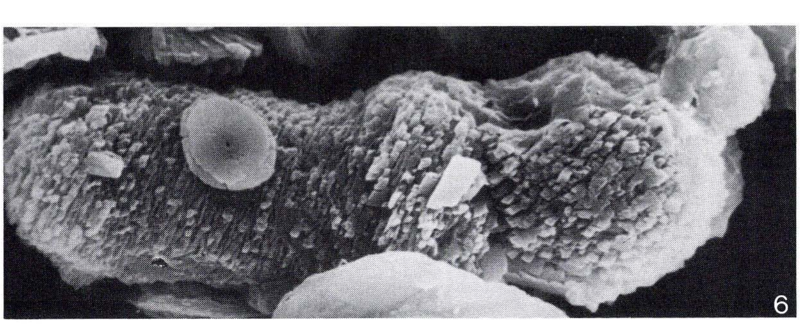
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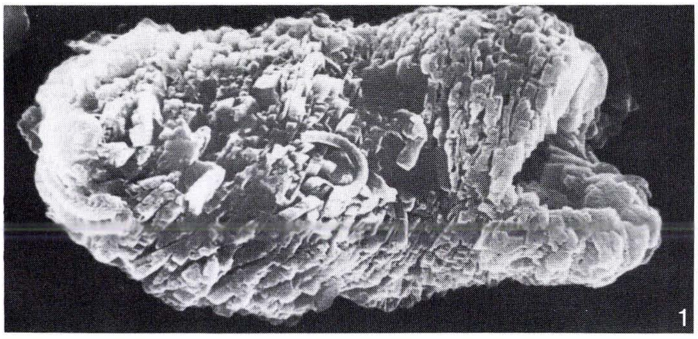
PLATE 10

Figs. 1–8. *Nannoconus* spp. Fig. 1–3, 5–7, E-1 8190'. Fig. 4, E-1 8191'. Fig. 8, E-1 8211'2''.
Figs. 9–12. *Nannoconus quadriangulus* Deflandre & Deflandre-Rigaud (19679. subsp. *apertus*. Figs. 9–12, E-1 8191'10''.
Fig. 13. *Nannoconus abundans sensu* Taylor (1978). E-1 8219'.
Figs. 14–17. *Nannoconus truitti truitti* Brönnimann (1955). Figs. 14–17, E-1 8200'.
Figs. 18,19. *Nannoconus truitti* Brönnimann subsp. *frequens* Deres & Achériteguy. Fig. 18, E-1 8195'. Fig. 19, E-1 8190'.
Figs. 20–29. *Nannoconus globulus* Brönnimann (1955). Fig. 20, Adda-2 7781'. Figs. 21–23, 26–28, E-1 8207'6''. Figs. 24,25,29, E-1 8210'11 1/2''.

Magnifications: Figs. 1–8 (SEM) × 3500. Figs. 9–29 (LM) × 1750.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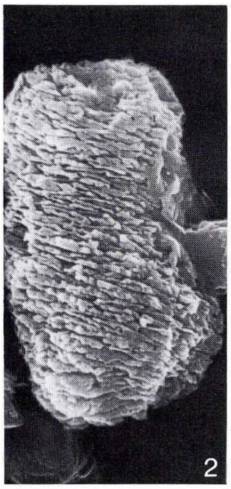
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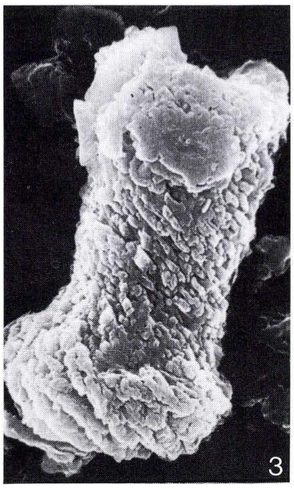
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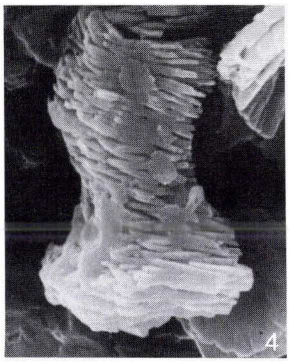
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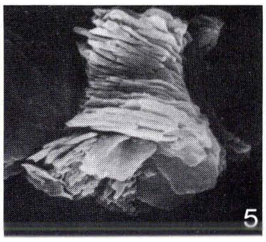
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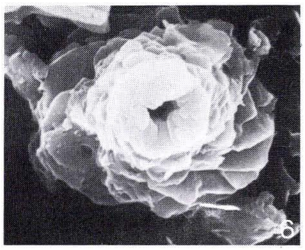
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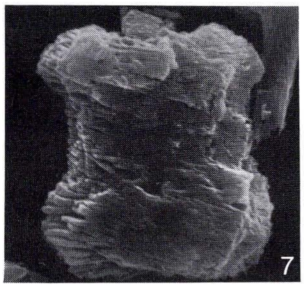
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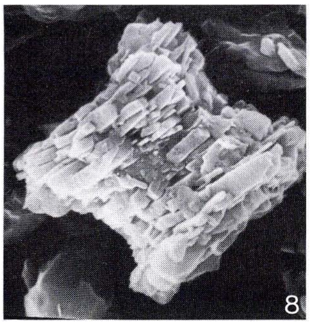
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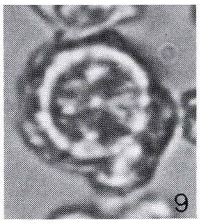
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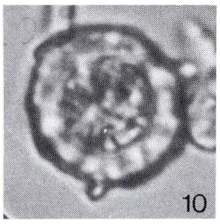
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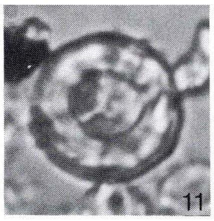
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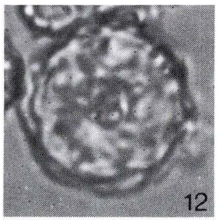
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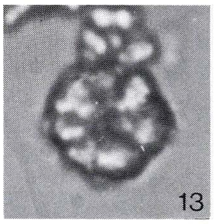
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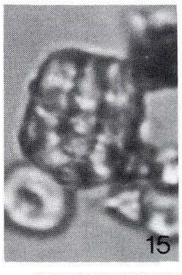
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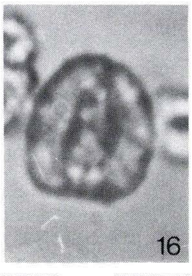
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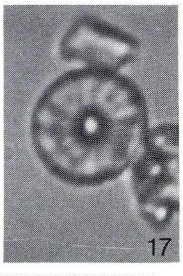
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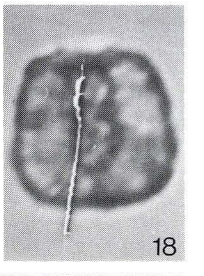
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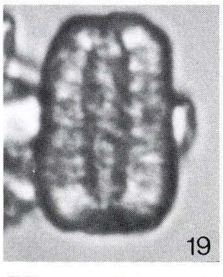
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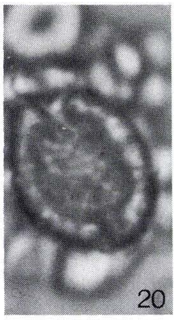
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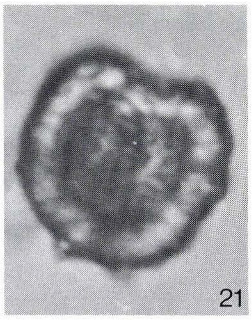
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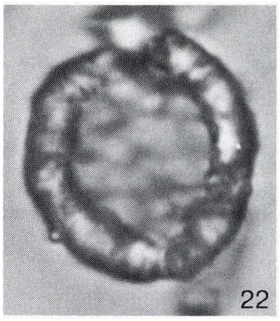
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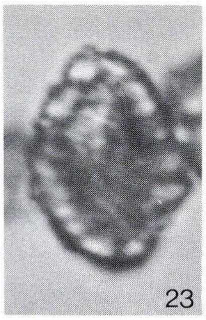
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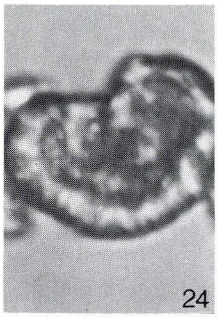
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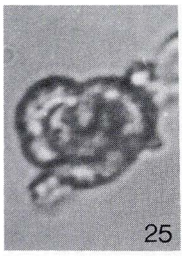
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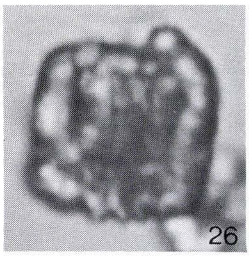
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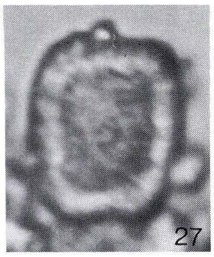
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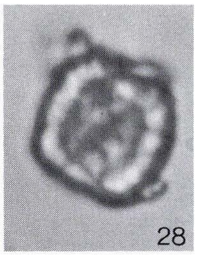
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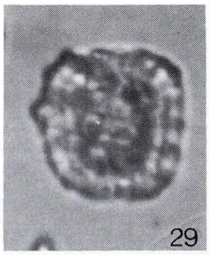
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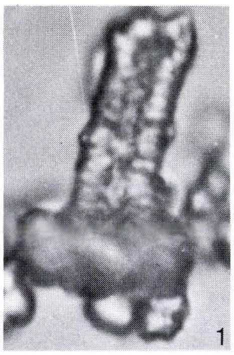
PLATE 11

Figs. 1–3. *Nannoconus borealis* Perch-Nielsen (1984). Figs. 1–3, Adda-2 7781'.
Figs. 4–10. *Nannoconus bonetii* Trejo (1959). Figs. 4,9,10, E-1 8190'. Figs. 5–7, E-1 8211'2''. Fig. 8, E-1 8207'6''.
Figs. 11–17. *Nannoconus elongatus* Brönnimann. Figs. 11,14, E-1 8211'2''. Figs. 12,13, E-1 8219'. Fig. 15, Adda-2 7781'. Figs. 16,17, E-1 8190'.
Figs. 18–20, 23–25. *Nannoconus* spp. Fig. 18, E-1 8211'2''. Fig. 19, E-1 8200'. Fig. 20, E-1 8190'. Figs. 24,25, E-1 8207'6''. Fig. 23, E-1 8210'11 1/2''.
Figs. 21,22. *Nannoconus multicadus* Deflandre & Deflandre-Rigaud (1960). E-1 8211'2''.
Figs. 26,27. *Pickelhaube furtiva* (Roth, 1983) Applegate, Covington & Wise (1987). Adda-2 7774'.

Magnifications: × 1750.

PLATE 11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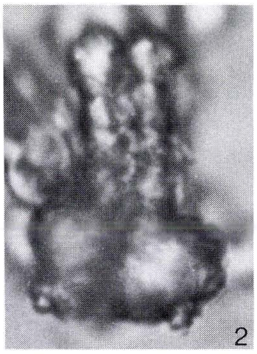
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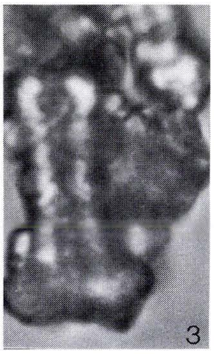
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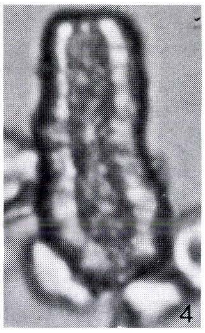
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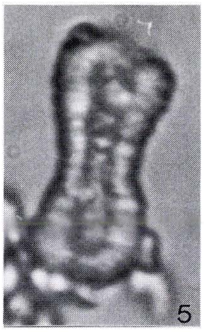
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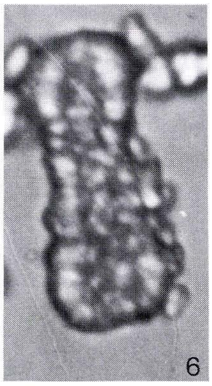
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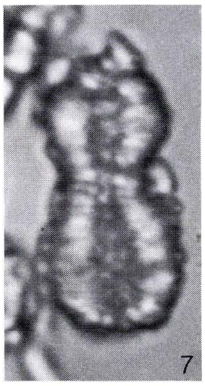
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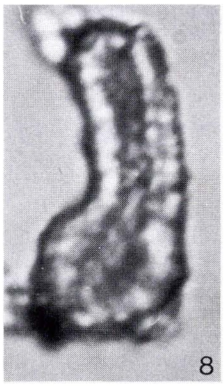
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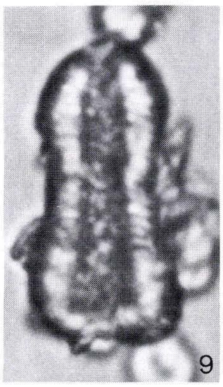
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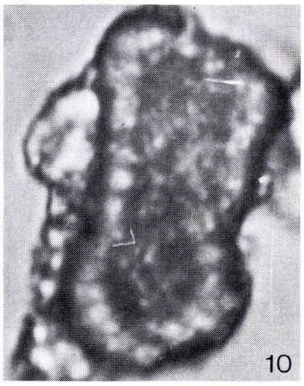
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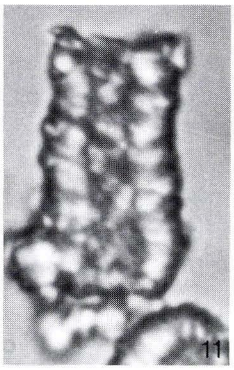
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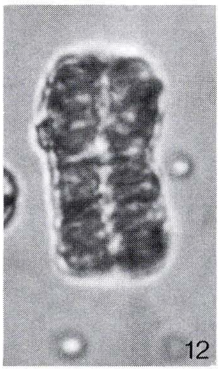
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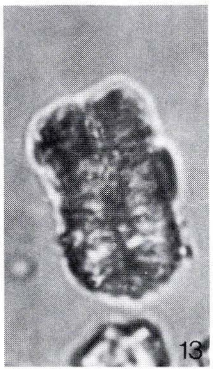
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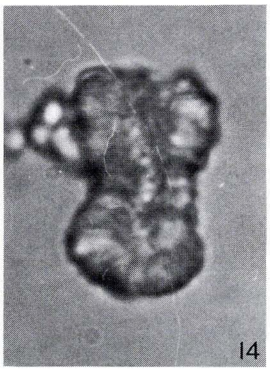
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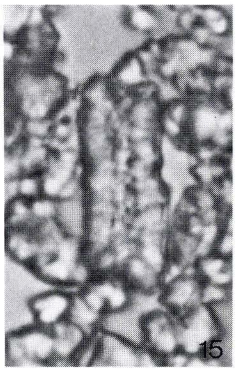
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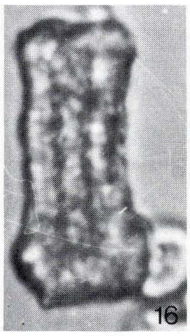
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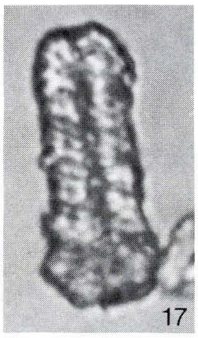
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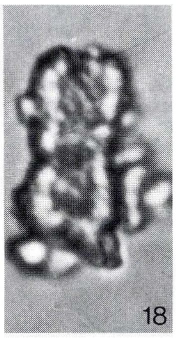
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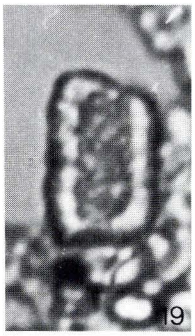
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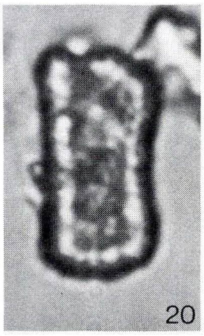
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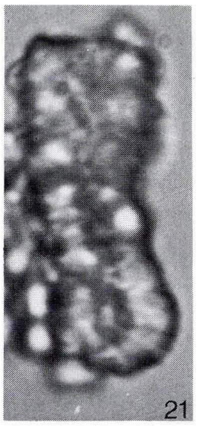
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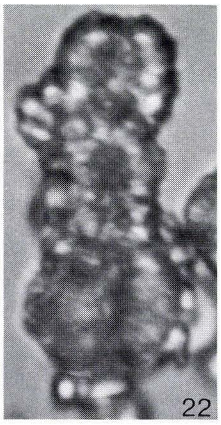
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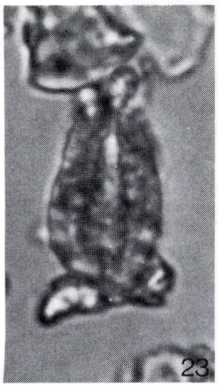
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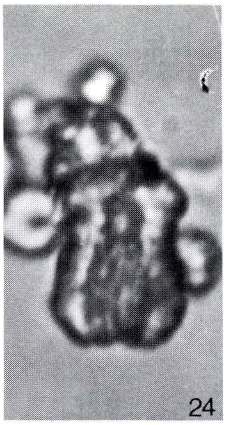
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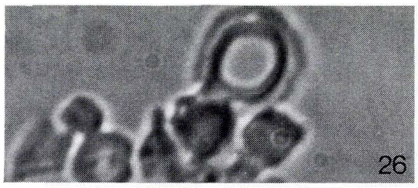
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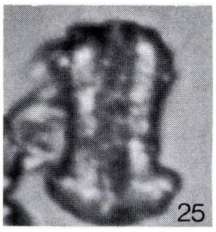
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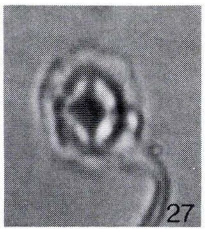
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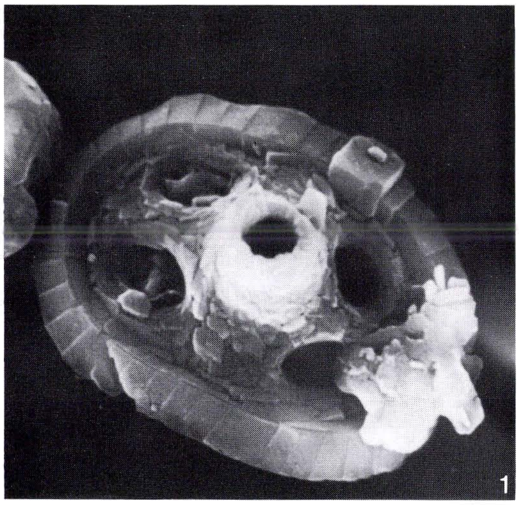
PLATE 12

Fig. 1. *Axopodorhabdus dietzmannii* (Reinhardt, 1965) Wind & Wise (1983). E-1 8190'.
Figs. 2–4. *Tetrapodorhabdus decorus* (Deflandre *in* Deflandre & Fert, 1954) Wind & Wise *in* Wise & Wind (1977). Fig. 2, E-1 8208'5''. Fig. 3, I-1 9780'B. Fig. 4, I-1 9780'A.
Figs. 5,6. *Perissocyclus noeliae* Black (1971) emend. Wind & Cepek (1979). Fig. 5, E-1 8232'8''. Fig. 6, Adda-2 7756'.
Fig. 7. *"Dodekapodorhabdus noeliae"* (1968). E-1 8190'6''.
Fig. 8. *Octocyclus reinhardtii* (Bukry, 1961) Wind & Wise (1977). Adda-2 7762'.
Figs. 9,10. *Perissocyclus fenestratus* (Stover, 1966) Black (1971). Fig. 9, E-1 8190'. Fig 10, E-1 8190'5''.
Figs. 11–12. *Cretarhabdus conicus* Bramlette & Martini (1964). Fig. 11, E-1 8208'5''. Fig. 12, Adda-2 7774'.

Magnifications: × 7000.

PLATE 12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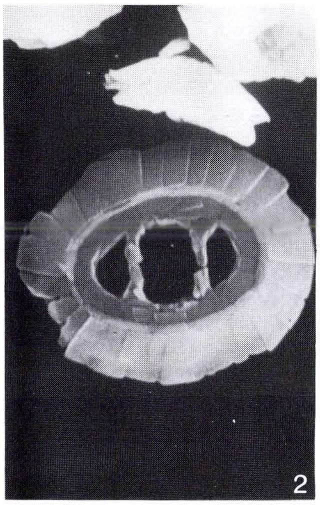
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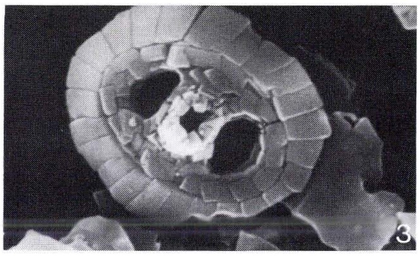
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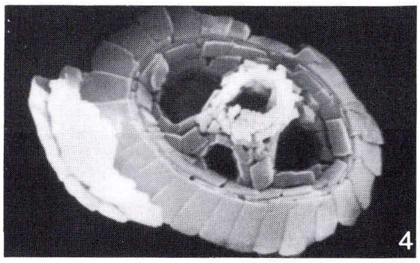
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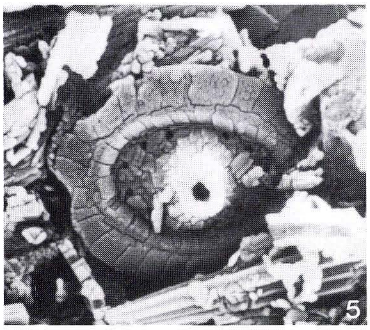
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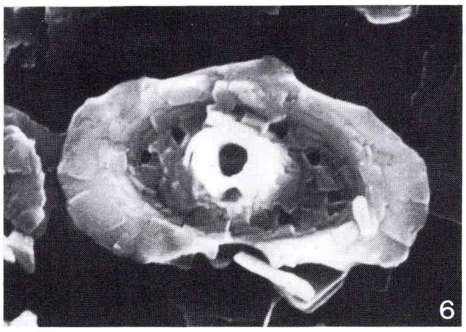
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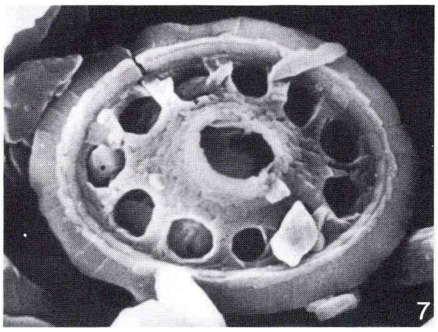
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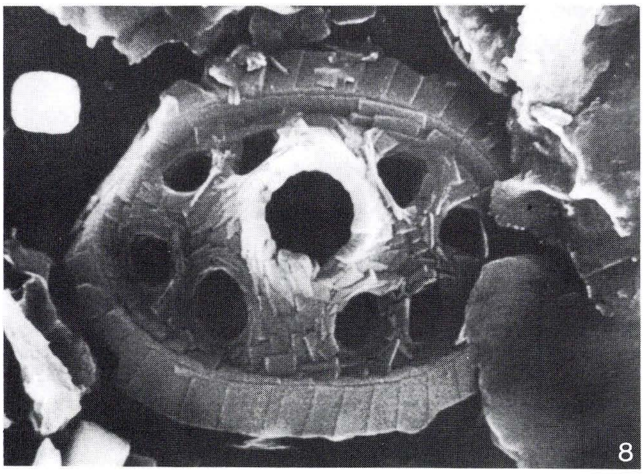
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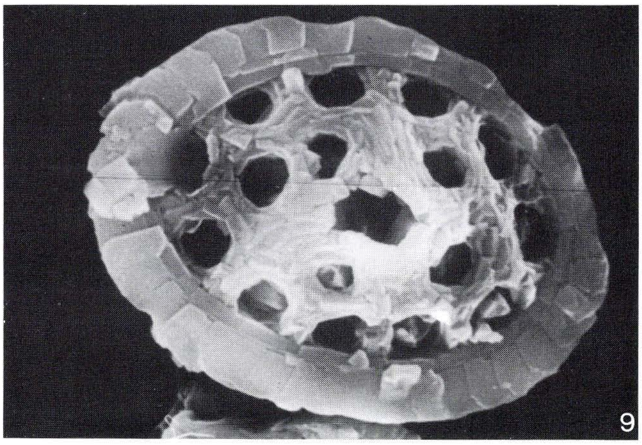
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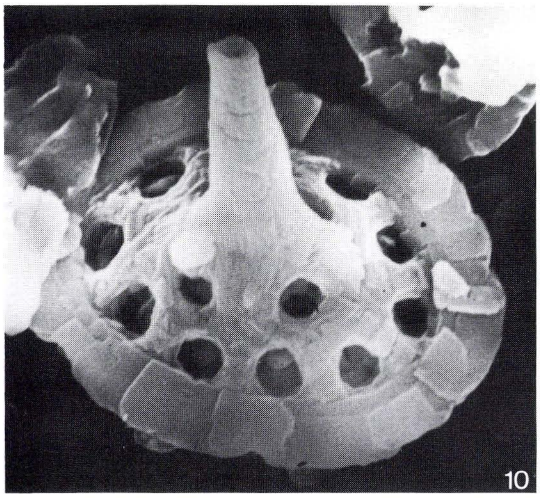
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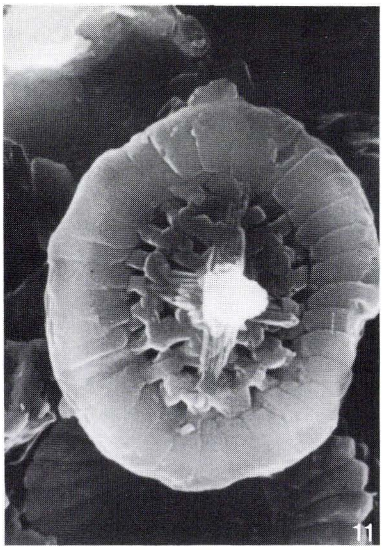
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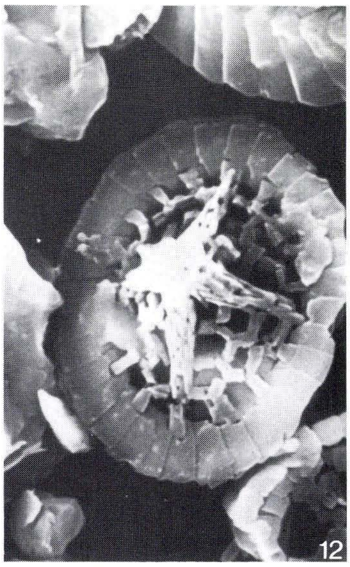
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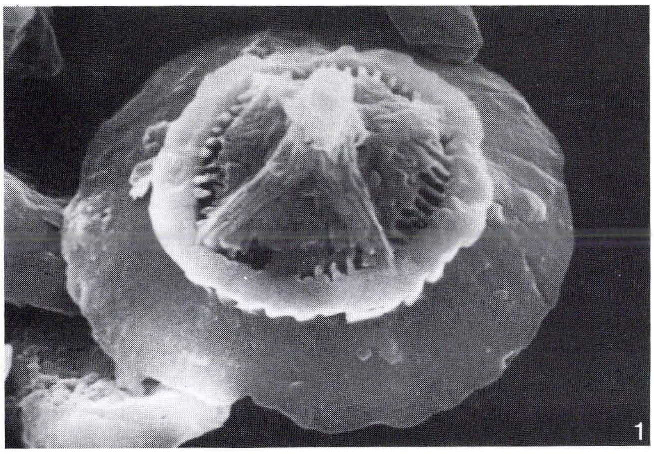
PLATE 13

Figs. 1–7 *Pickelhaube furtiva* (Roth, 1983) Applegate, Covington & Wise (1987), Adda-2 7774'.

Magnifications: × 7000.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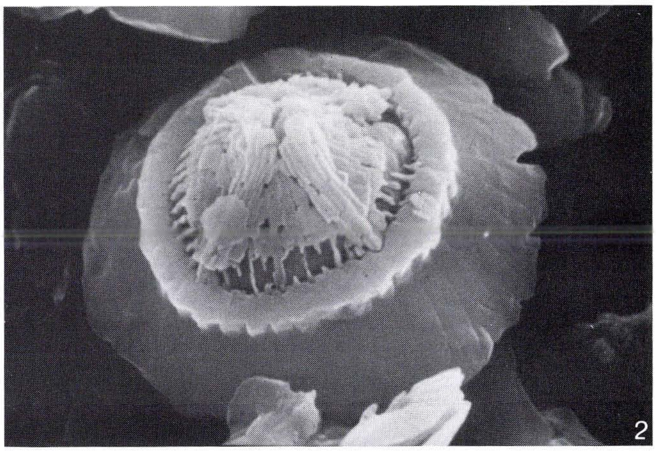
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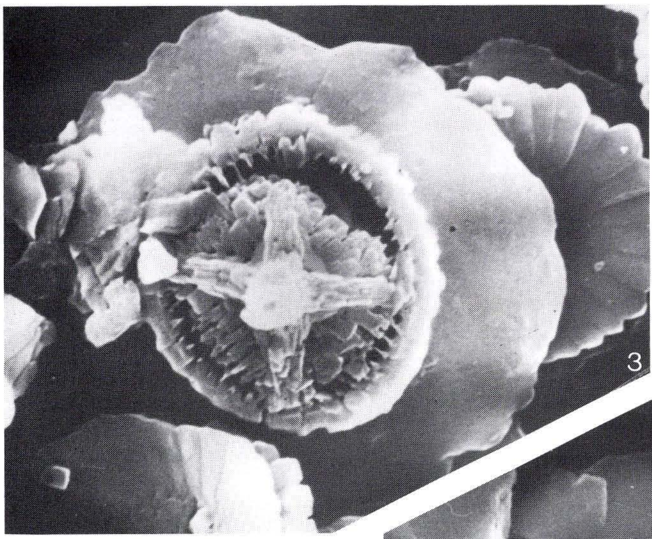
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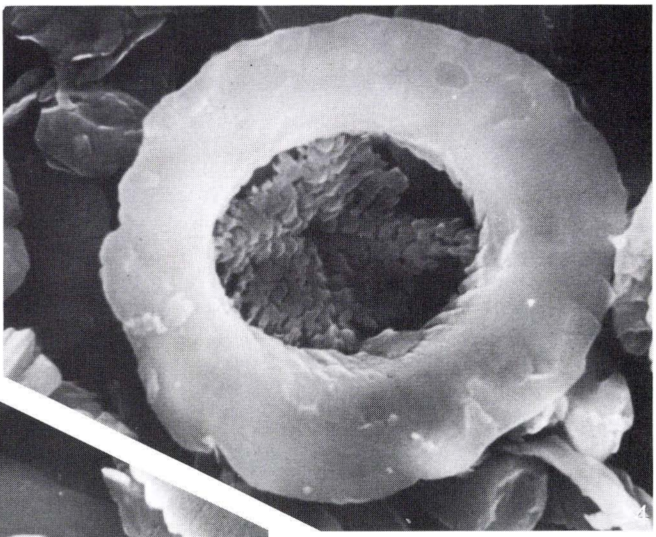
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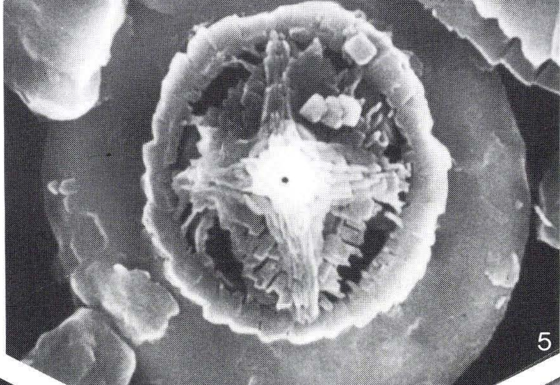
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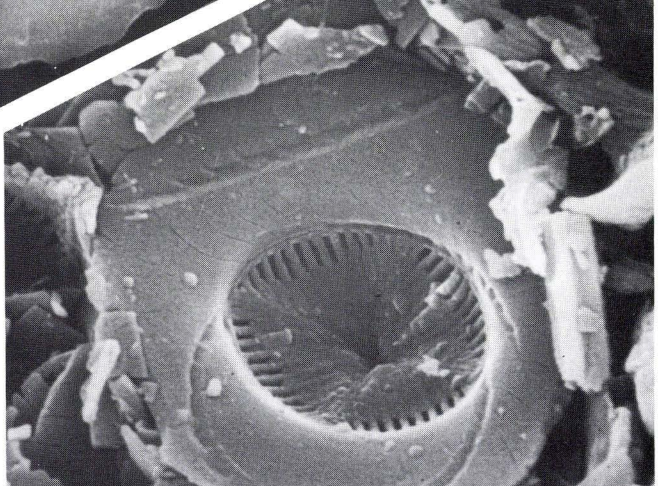
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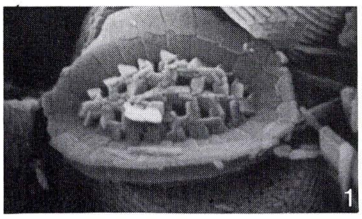
PLATE 14

Figs. 1–5. *Cretarhabdus inaequalia* Crux (1987). Figs. 1–3, E-1 8232'8''. Figs. 4,5, E-1 8190'6''.
Figs. 6,7. *Microstaurus chiastius* (Worsley, 1971) Grün *in* Grün & Allemann (1975). Fig. 6, Adda-2 7781'. Fig. 7, E-1 8180'C.
Fig. 8. *Cretarhabdus surirellus* (Deflandre, 1954) Reinhardt (1970) Adda-2 7768'.
Fig. 9. *Retacapsa angustiforata* Black (1971). E-1 8195'.
Fig. 10. *Cretarhabdus loriei* Gartner (1968). I-1 9360'.
Fig. 11. *Retecapsa schizobrachiata* (Gartner, 1968) Grün *in* Grün & Allemann (1975). E-1 8180'C.
Figs. 12,13. *Polypodorhabdus escaigii* Noël (1965). Fig. 12, E-1 8190'. Fig. 13, E-1 8108'5''.
Figs. 14,15. *Gephyrorhabdus coronadventis* (Reinhardt, 1966) Hill (1976). Adda-2 7768'.
Figs. 16,17. *Grantarhabdus meddii* Black (1971). Fig. 16, Adda-2 Fig. 17, E-1 8108'5''.

Magnifications: × 7000.

PLATE 14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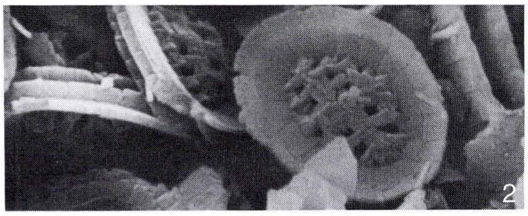
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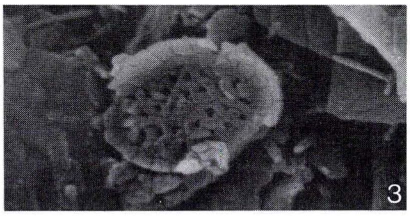
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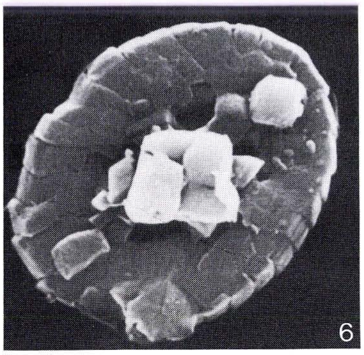
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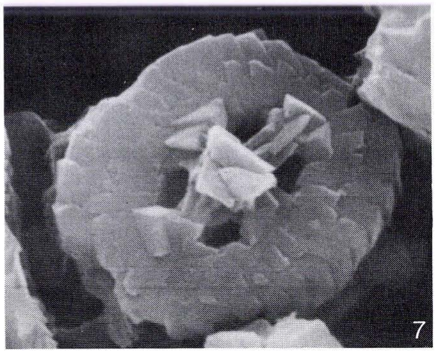
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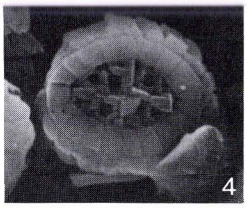
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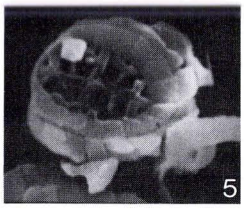
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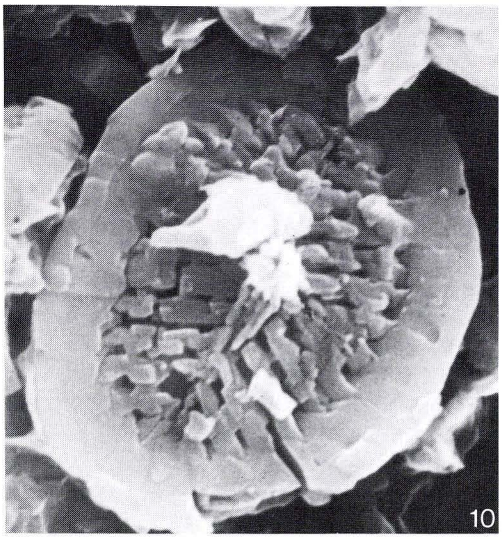
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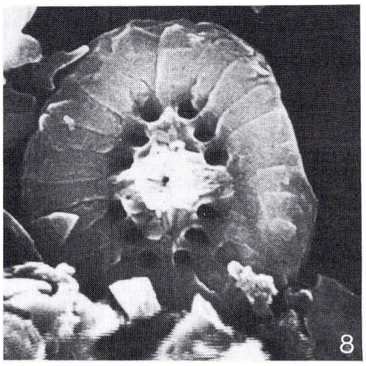
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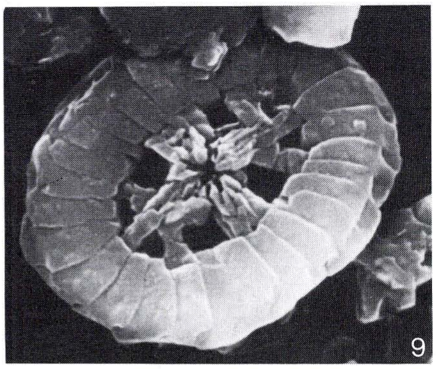
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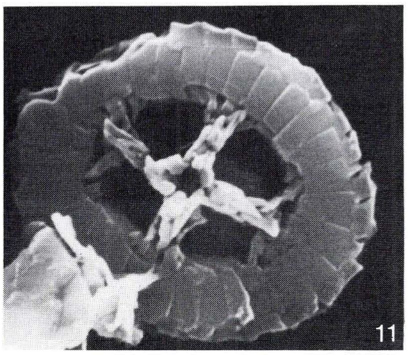
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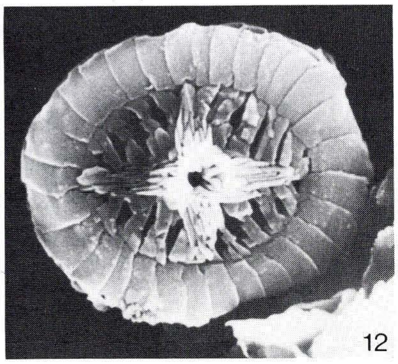
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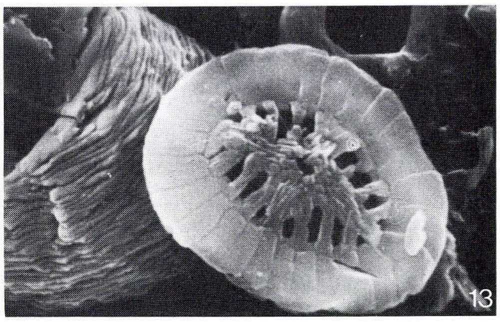
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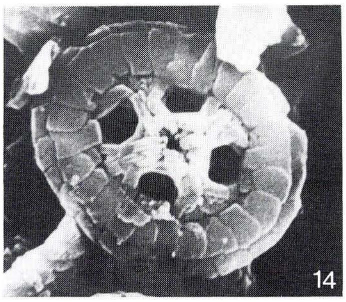
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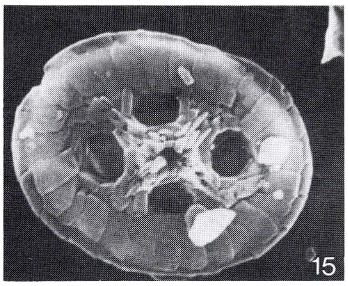
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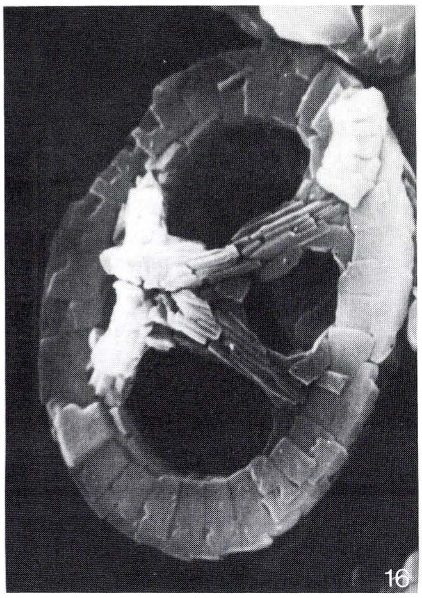
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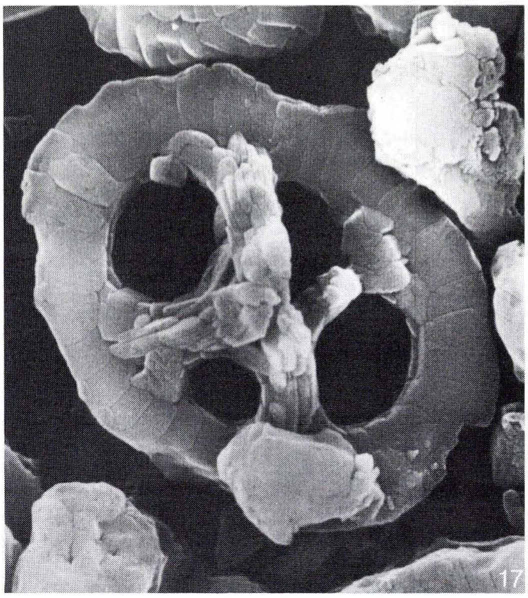
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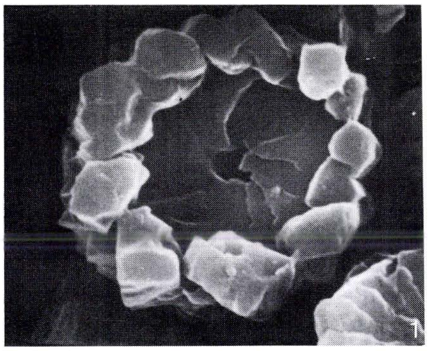
PLATE 15

Figs. 1–5. *Eprolithus varolii* Jakubowski (1986). Fig. 1,4, E-1 8180'B. Figs. 2,3,5, E-1 8180'A.
Figs. 6-9. *Eprolithus apterior* Black (1973). Fig. 6, Adda-2 7762'. Fig. 7, I-1 9360'A. Fig. 8, E-1 8180'A. Fig. 9, E-1 8180'C.
Figs. 10–16. *Tegulalithus septentrionalis* (Stradner, 1963) Crux (1986). Figs. 10,11,13,15 and 16, I-1 9780'B. Fig. 12, I-1 9850'B. Fig. 14, Adda-2 7820'.

Magnifications: × 7000.

PLATE 15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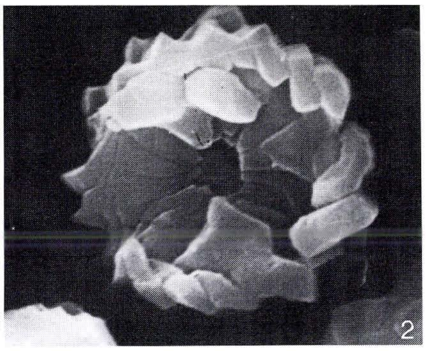
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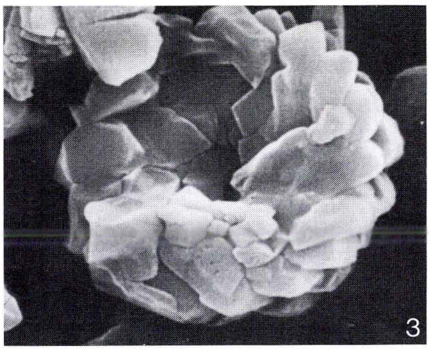
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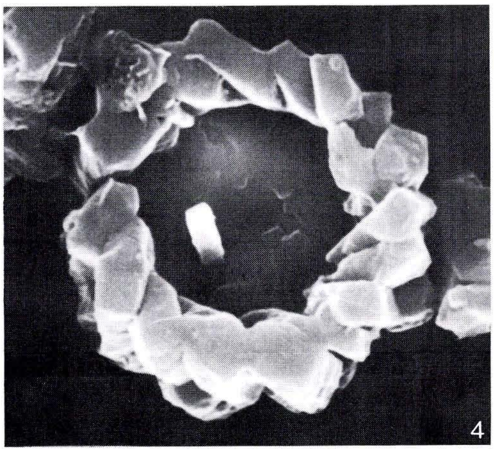
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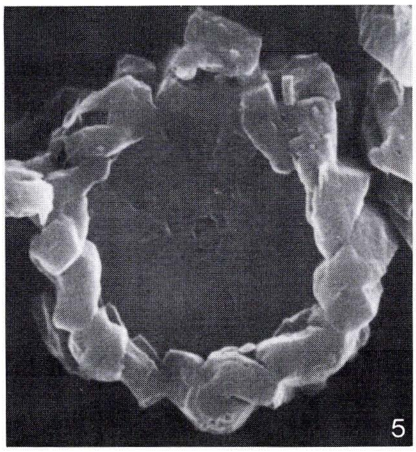
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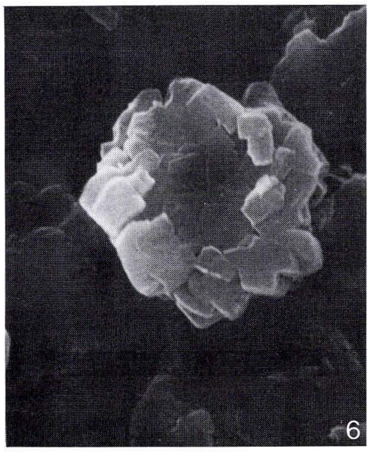
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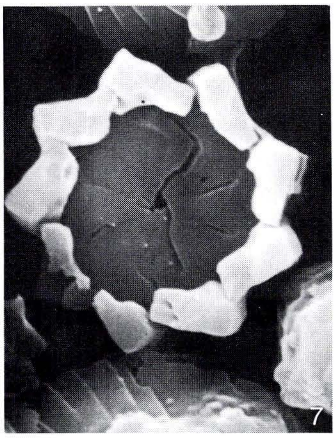
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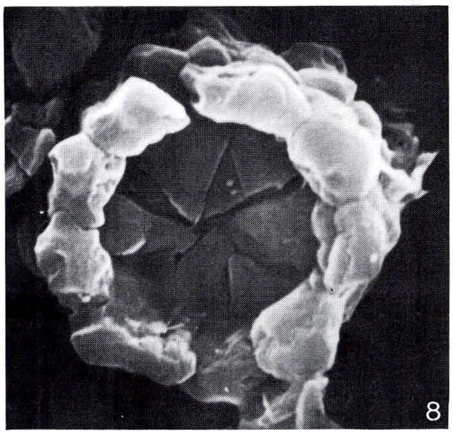
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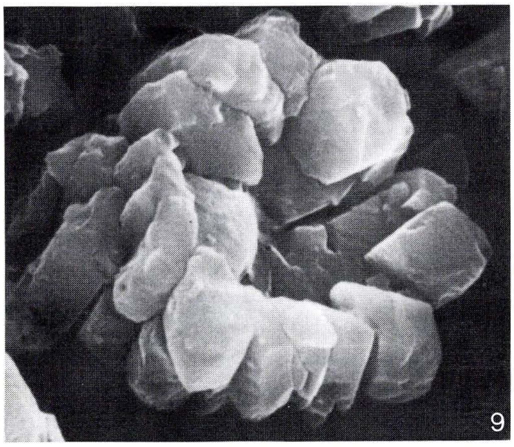
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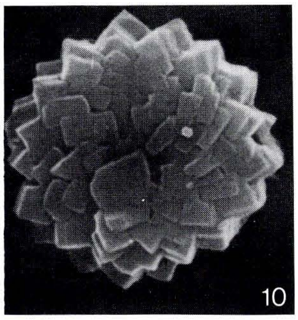
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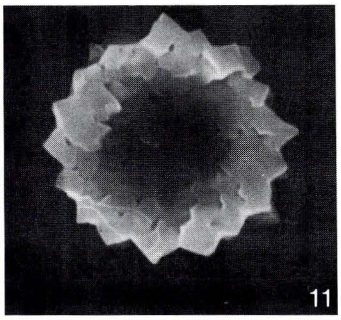
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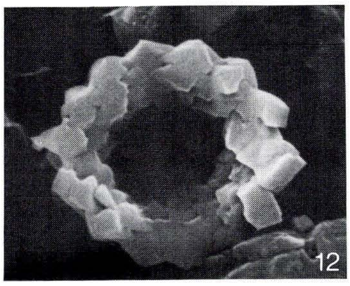
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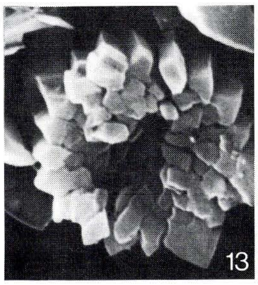
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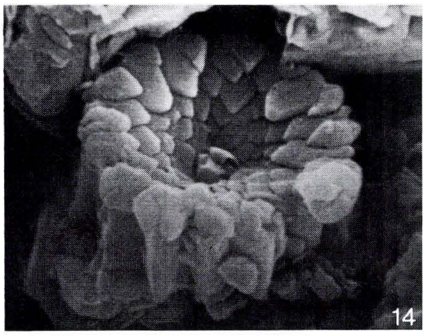
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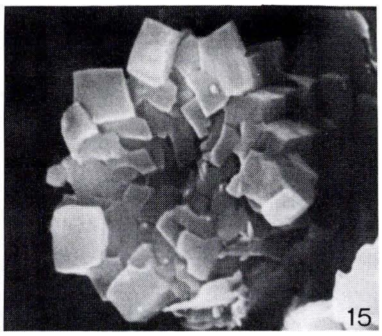
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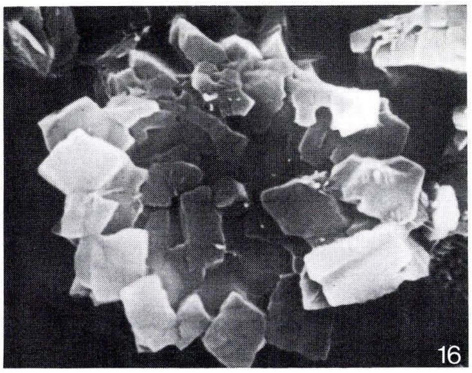
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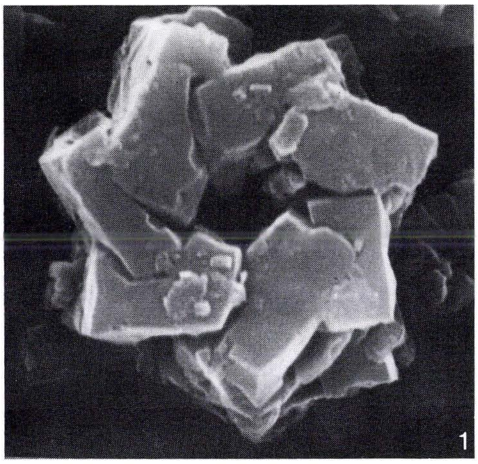
PLATE 16

Fig. 1. *Rucinolithus* sp. E-1 8180'F.
Fig. 2. *Rucinolithus irregularis* Thierstein *in* Roth & Thierstein (1972). Adda-2 7762'.
Fig. 3. *Pervilithus varius* Crux (1982). E-1 8180'A.
Fig. 4. *Prediscosphaera cf. stoveri* (Perch-Nielsen, 1968). Adda-2 7768'
Fig. 5. *Prediscosphaera columnata* (Reinhardt, 1965) Perch-Nielsen (1984). I-1 9360'A.
Figs. 6–11. *Rhagodiscus angustus* (Stradner, 1963) Reinhardt (1971). Fig. 6, E-1 8193'. Fig. 7, Adda-2 7774'. Fig. 8, E-1 8190'6''. Fig. 9, Adda-2 7768'. Fig. 10, Adda-2 7762'. Fig. 11, E-1 8180'C.
Figs. 12, 13. *Rhagodiscus asper* (Stradner, 1963) Reinhardt (1967). Figs. 12, I-1 9493'. Fig. 13, E-1 8208'5''.
Figs. 14–18. *Rhagodiscus splendens* (Deflandre, 1963) Verbeek (1977). Fig. 14, E-1 8190'. Fig. 15, E-1 8195'. Fig. 16, E-1 8191'10''. Fig. 17, I-1 9360'A. Fig. 18, E-1 8193'10''.

Magnifications: × 7000.

PLATE 16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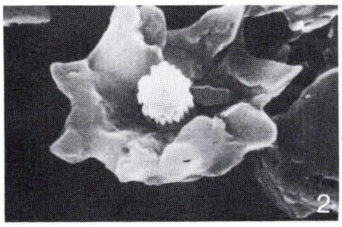
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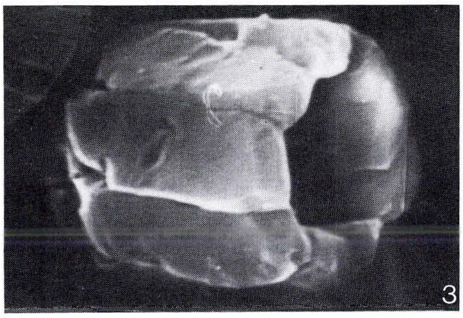
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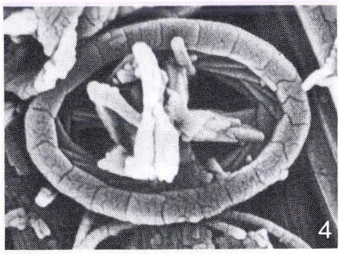
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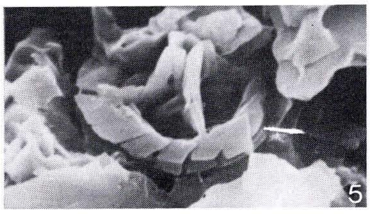
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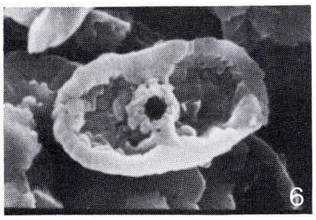
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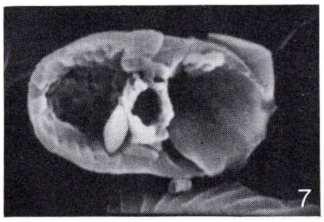
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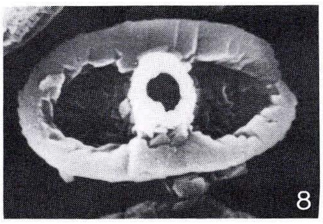
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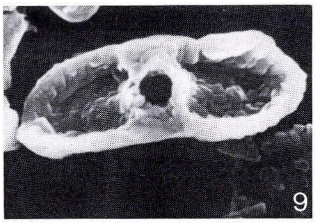
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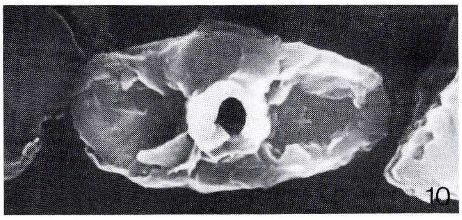
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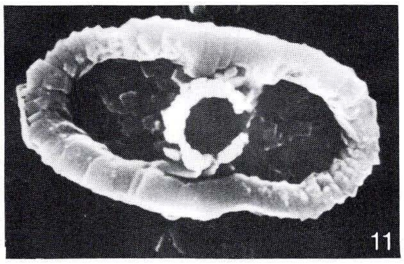
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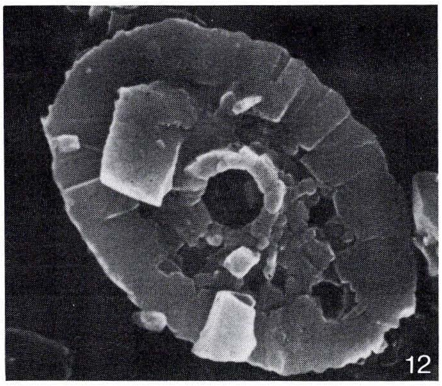
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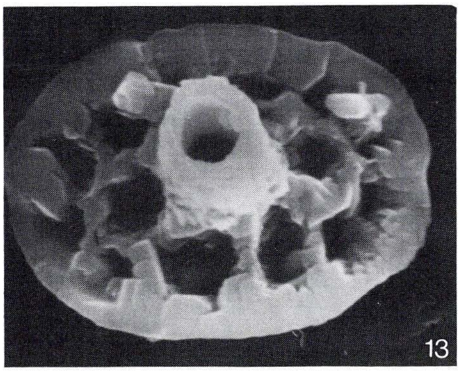
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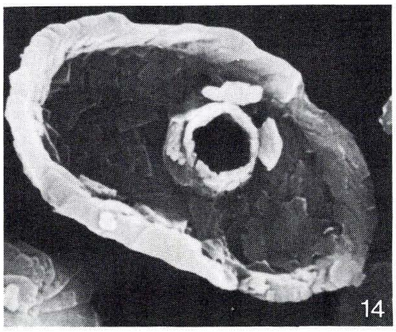
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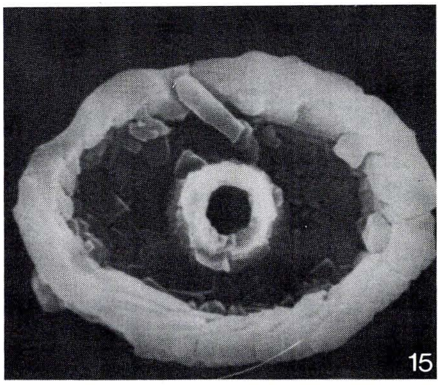
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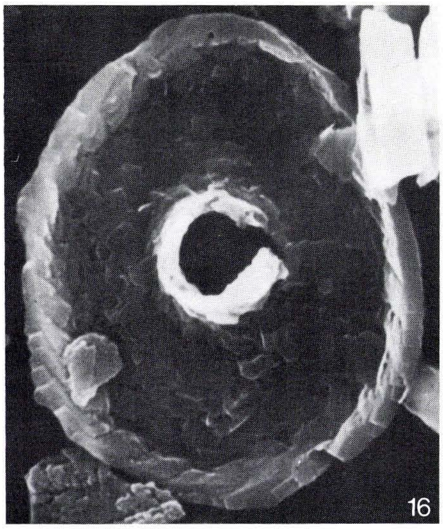
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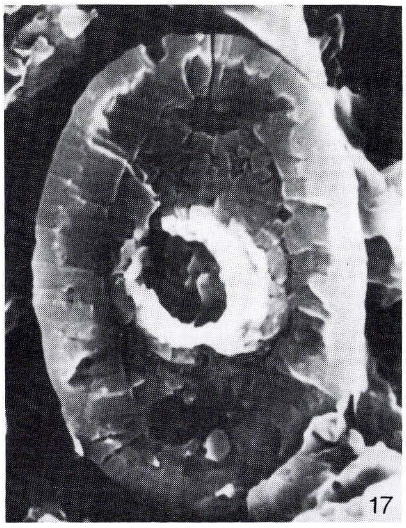
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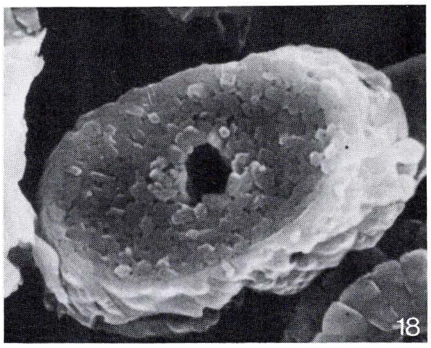
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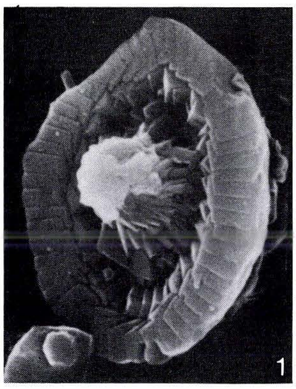
PLATE 17

Figs. 1,2. *Parhabdolithus achylostaurion* Hill (1976). Fig. 1, E-1 8190'A. Fig. 2, E-1 8190'.
Figs. 3,4. *Sollasites pinnatus* (Black, 1971) Perch-Nielsen (1984). E-1 8232'8''.
Fig. 5. *Sollasites horticus* (Stradner *et al.* *in* Stradner & Adamiker, 1966) Cepek & Hay (1969). E-1 8232'8''.
Fig. 6–8. *Stradnerlithus sexiramatus* (Pienaar, 1969) Perch-Nielsen (1984). Figs. 6,8, E-1 8232'8''. Fig. 7, E-1 8208'5''.
Fig. 9. *Rhombolithion rhombicum* (Stradner & Adamiker, 1966) Black (1973), E-1 8208'5''.
Fig. 10. *Stradnerlithus fragilis* (Rood & Bernhard, 1972) Perch-Nielsen (1984). Adda-2 7756'.
Figs. 11,12. *Truncatoscaphus pauciramosus* (Black, 1973) Perch-Nielsen (1984). E-1 8232'8''.
Fig. 13. *Rhombolithion bifurcatum* (Noël, 1973) Grün & Zweili (1980). E-1 8232'8''.
Fig. 14. *Nodosella perch-nielseniae* (Filewicz *et al.* *in* Wise & Wind, 1977) Perch-Nielsen (1984). E-1 8232'8''.
Figs. 15,16.*Rhombolithion horrellii* (Rood & Bernhard, 1972) Perch-Nielsen (1984). Adda-2 7762'.
Figs. 17,18. *Chiastozygus? primitus* Prins (1969). Fig. 17, Adda-2 7756'. Fig. 18, E-1 8232'8''.
Fig. 19. *Stoverius*? sp. 1. Adda-2 7781'.
Fig. 20. *Stoverius achylosus* (Stover, 1966) Perch-Nielsen (1984). Adda-2 7756'.
Figs. 21,22. *Rotalapillus laffittii* (Noël, 1957) Noël (1973). Fig. 21, E-1 8119'. Fig. 22, E-1 8190'6''.
Fig. 23. *Truncatoscaphus senarius* (Wind & Wise *in* Wise & Wind, 1977) Perch-Nielsen (1984). E-1 8208'5''.
Fig. 24–26. *Stoverius?* sp. 2. Adda-2 7762'.
Figs. 27–29. *Glaukolithus diplogrammus* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1964). Figs. 27,29, E-1 8190'. Fig. 28, E-1 8193'10''.

Magnifications: Figs. 1–14 and 17–29 × 7000. Figs. 15,16 × 14000.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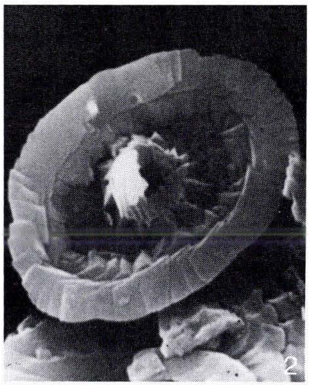
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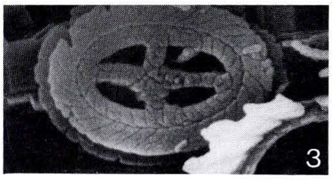
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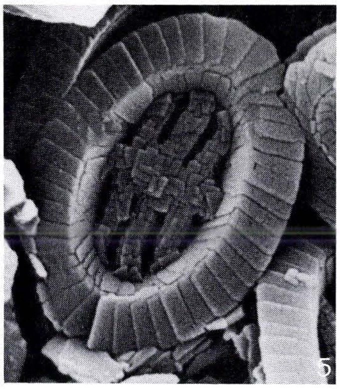
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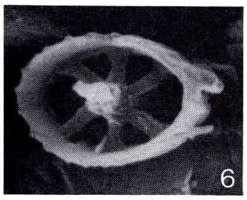
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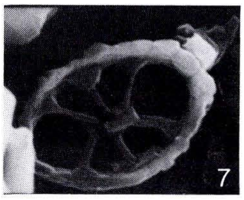
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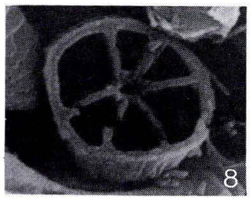
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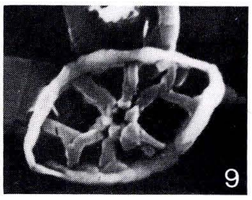
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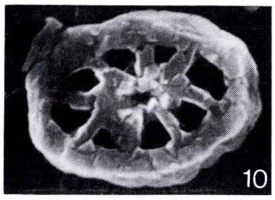
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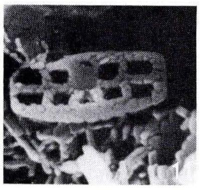
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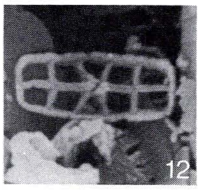
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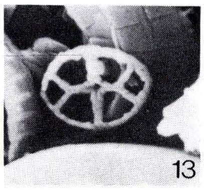
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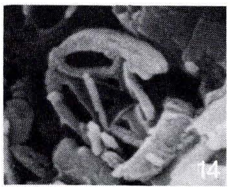
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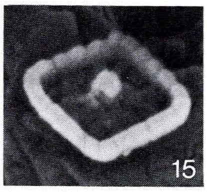
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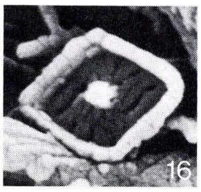
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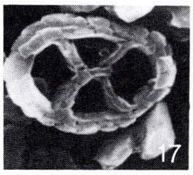
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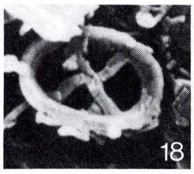
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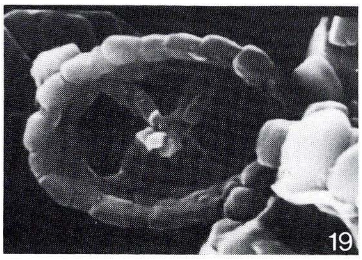
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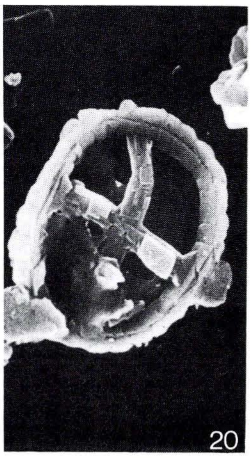
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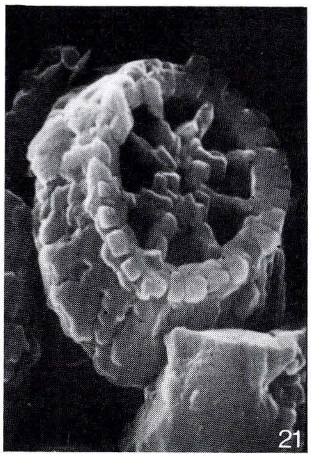
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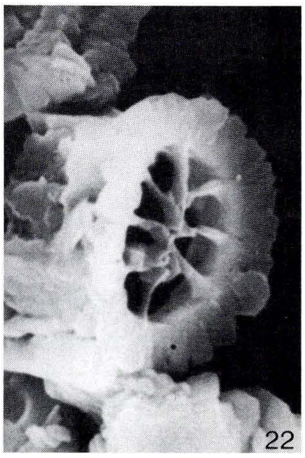
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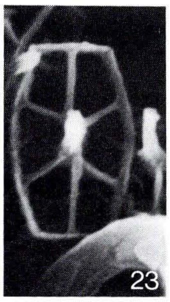
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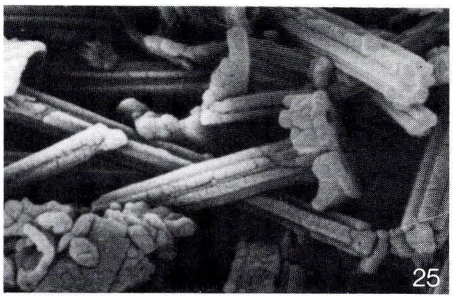
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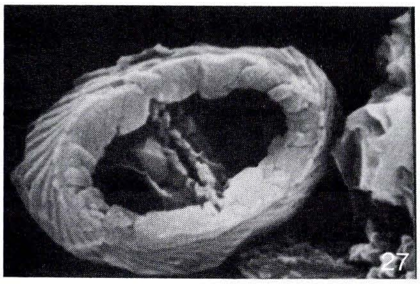
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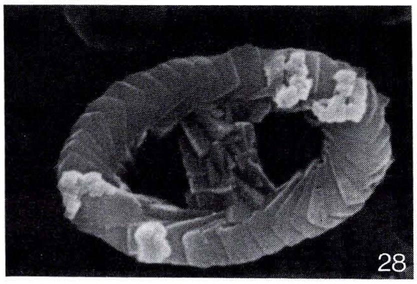
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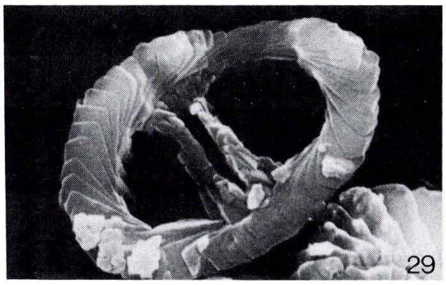
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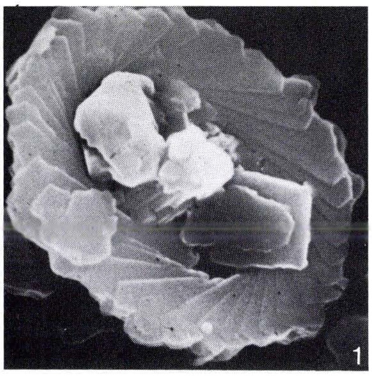
PLATE 18

Figs. 1–3. *Zeugrhabdotus sisyphus* (Gartner, 1968). Figs. 1–3, E-1 8119'.
Figs. 4–6. *Zeugrhabdothus embergeri* (Noël, 1959) Perch-Nielsen (1984). Figs. 4–6, I-1 9360'A.
Figs. 7,8. *Zeugrhabdotus elegans* (Gartner, 1968). Figs. 7,8, E-1 8233'8''.
Figs. 9–11. *Zeugrhabdotus reticulatus* (Black, 1971) Black (1973). Fig. 9, E-1 8208'5''. Fig. 10, E-1 8190'. Fig. 11, E-1 8180A.

Magnifications: × 7000.

PLATE 18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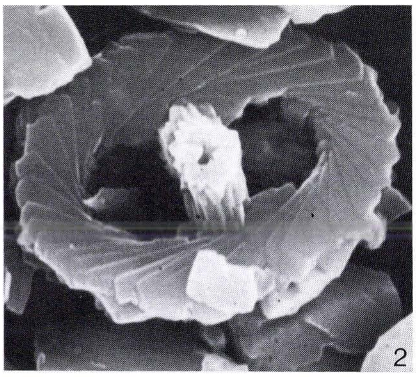
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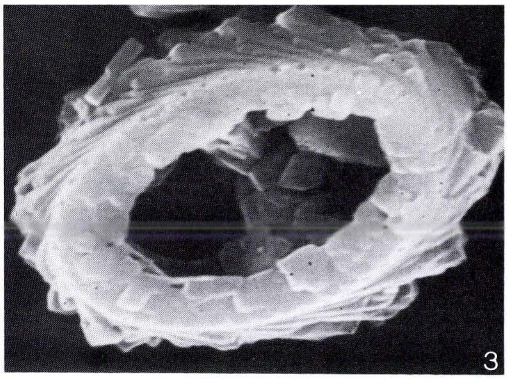
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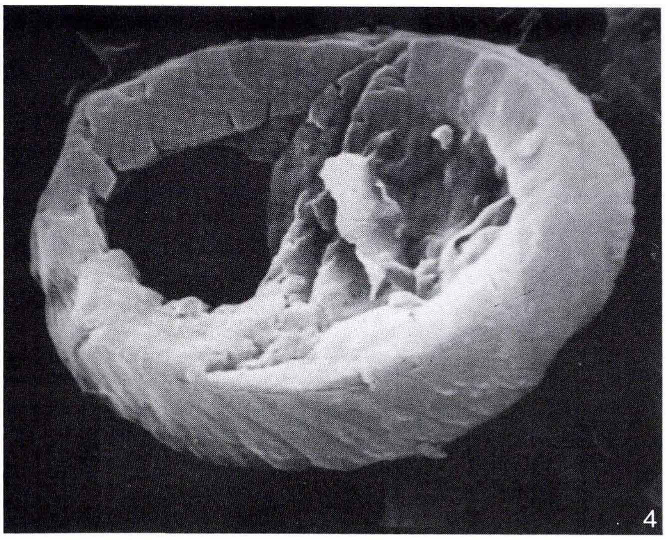
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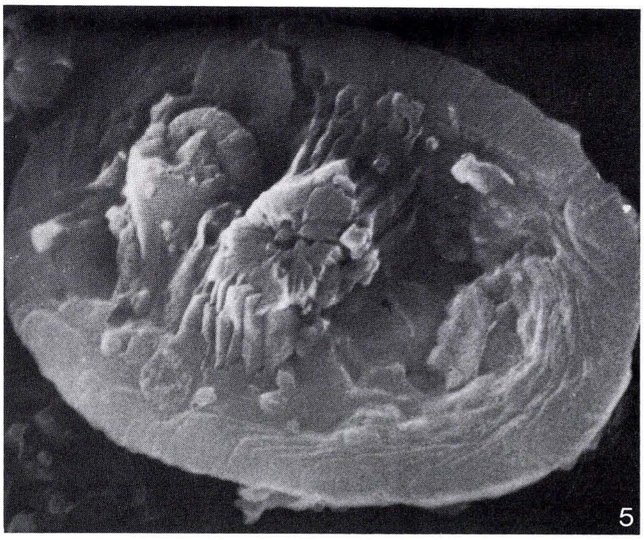
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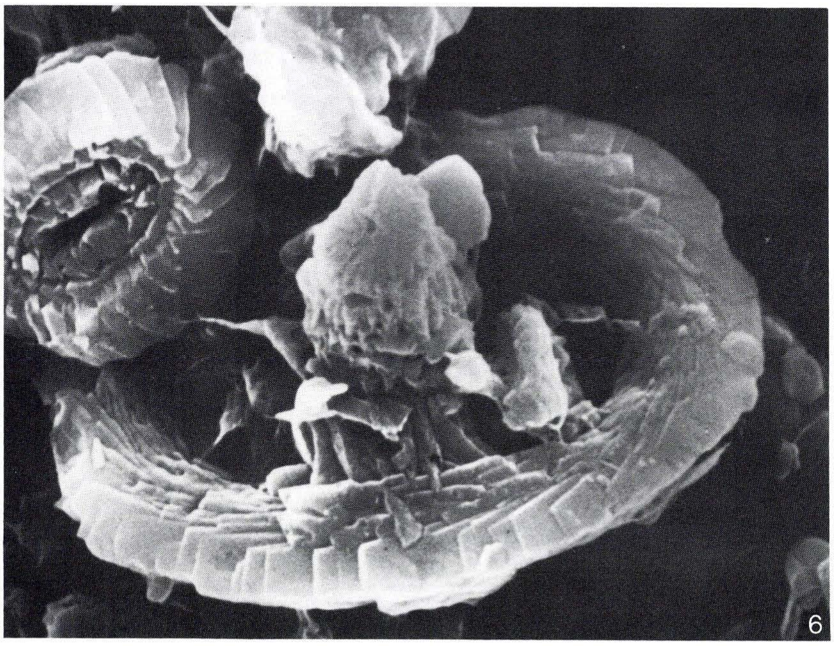
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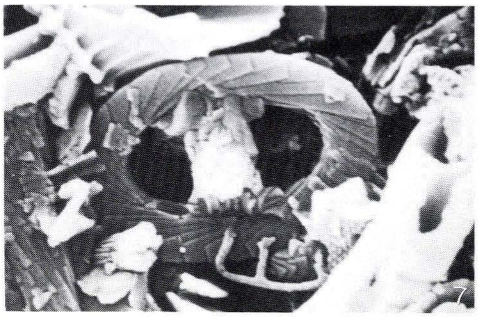
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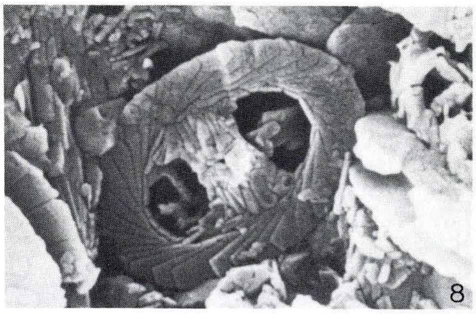
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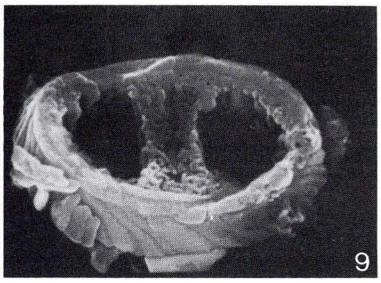
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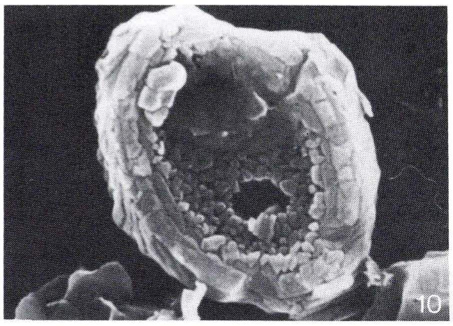
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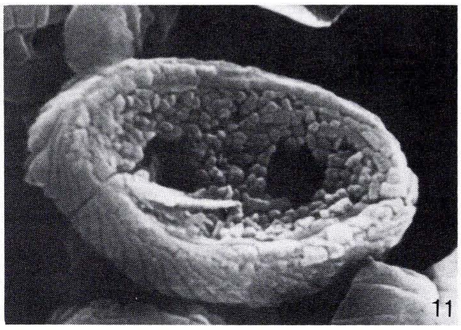
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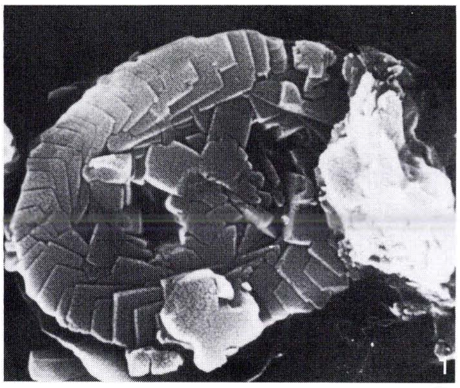
PLATE 19

Figs. 1,2. *Zeugrhabdotus reticulatus* (Black, 1971) Black (1973). E-1 8190'B.
Fig. 3. *Loxolithus armilla* (Black *in* Black & Barnes, 1959) Noël (1965). E-1 8180'A.
Figs. 4–12. *Zeugrhabdotus* spp. Figs. 4,8,9,10, E-1 8193'10''. Fig. 5, E-1 8180'A. Figs. 6,11,12, E-1 8119'. Fig. 7, E-1 8191'10''.
Fig. 13. *Zeugrhabdotus erectus* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1965). E-1 8119'.
Fig. 14. *Placozygus acanthus* Reinhardt (1965). I-1 9360'.
Figs. 15,16. *Placozygus* aff. *acanthus* Reinhardt (1965). Fig. 15, E-1 8232'8''. Fig. 16, E-1 8180'A.
Figs. 17,18. *Zeugrhabdotus bussonii* (Noël, 1965). E-1 8232'8''.
Fig. 19. *Tranolithus gabalus* Stover (1966). Adda-2 7750'.
Figs 20,21. *Repagulum parvidentum* (Deflandre *in* Deflandre & Fert, 1954) Forchheimer(1972). Fig 20. E-1 8170'A. Fig 21, Adda-2 7762'.
Figs. 22,23. *Noelithina*?. E-1 8232'8''.
Figs. 24–27. Unidentified species. E-1 8232'8''.

Magnifications: × 7000.

PLATE 19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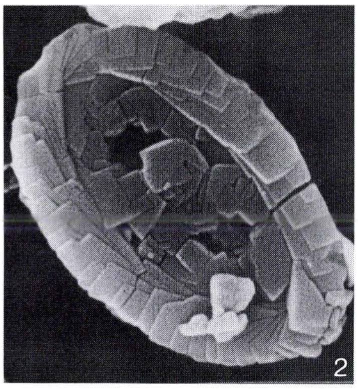
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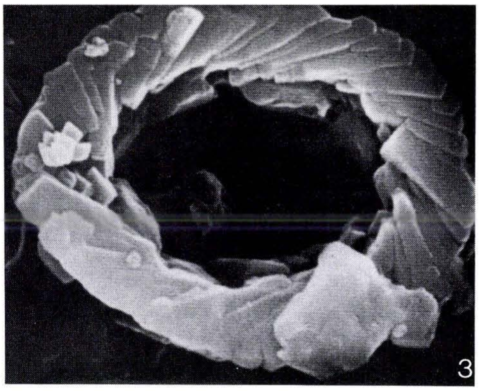
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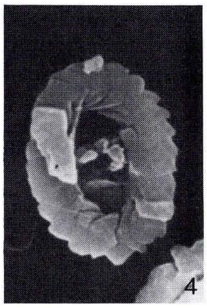
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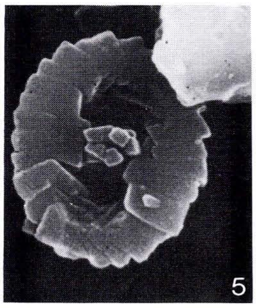
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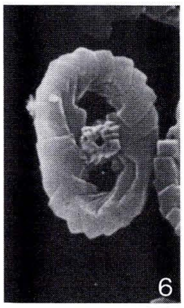
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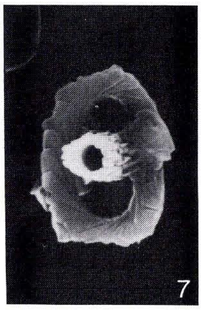
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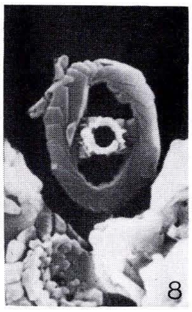
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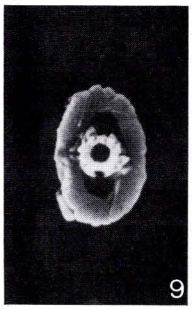
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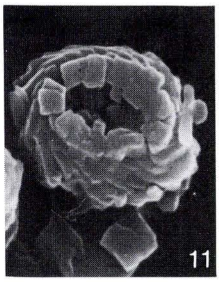
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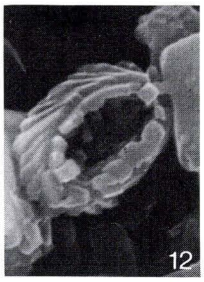
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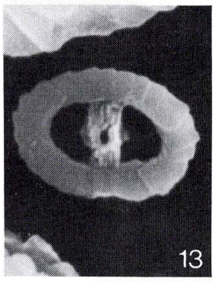
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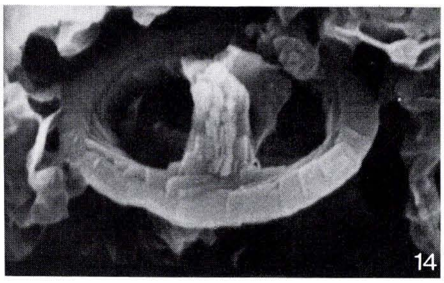
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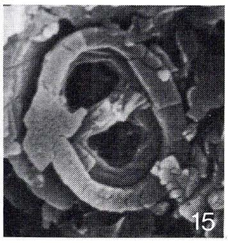
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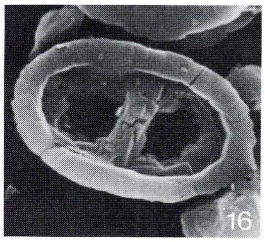
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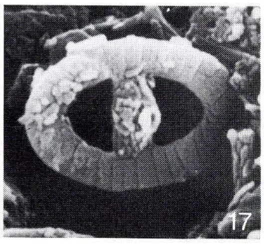
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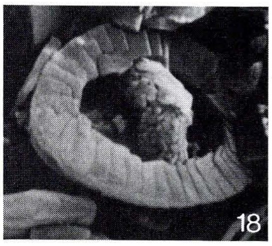
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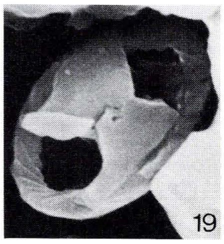
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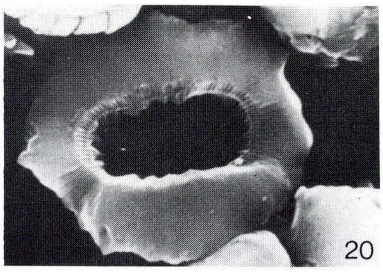
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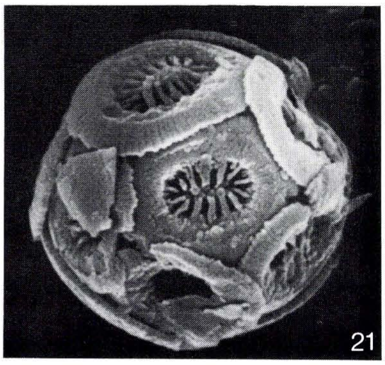
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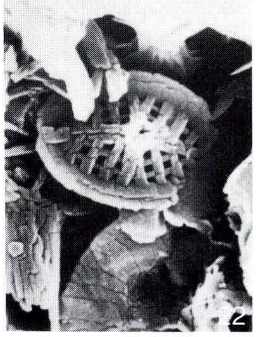
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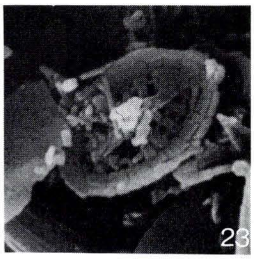
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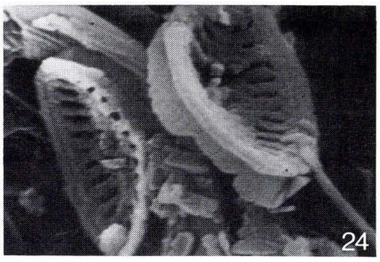
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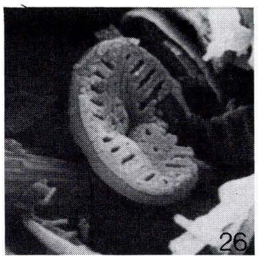
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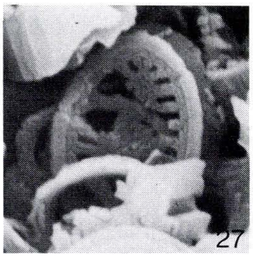
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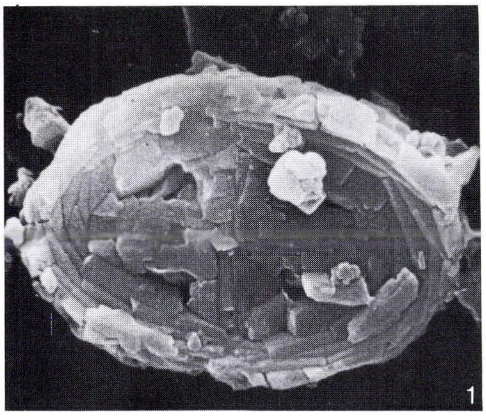
PLATE 20

Upper Albian to ?Cenomanian.
Figs. 1,2. *Cribicatillus robustus* Black (1973). Adda-2 7720'.
Fig. 3. *Chiastozygus bifarius* Bukry (1969). Adda-2 7720'.
Figs. 4,5. *Eiffellithus turriseiffelii* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt (1965). Adda-2 7720'.
Fig. 6. *Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Deflandre *in* Piveteau (1952). Adda-2 7720'.
Fig. 7. *Eprolithus apterior* Black (1973). Adda-2 7720'.
Figs. 8,9. *Prediscosphaera cretaceae* (Arkhangelsky, 1912) Gartner (1968). Adda-2 7720'.
Figs. 10,11. *Prediscosphaera spinosa* (Bramlette & Martini, 1964) Gartner (1968). Adda-2 7720'.
Figs. 12–14. *Nannoconus* sp.1. Adda-2 7720'.
Figs. 15–18. *Tranolithus phacelosus* Stover (1966). Figs. 15, Adda-2 7710'. Fig. 16–18, Adda-2 7720'.

Magnifications: × 7000 (Figs. 1–11, 15–18).
Magnifications: × 3500 (Figs. 12–14).

PLATE 20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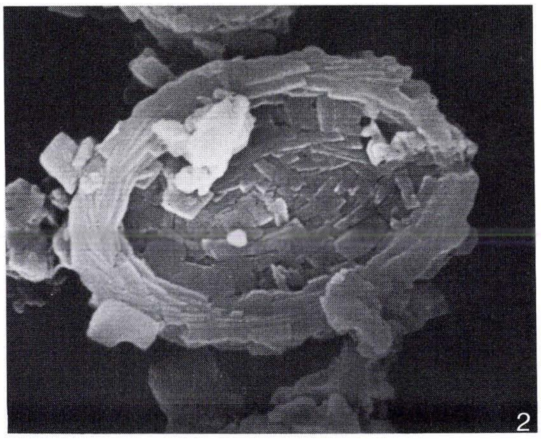
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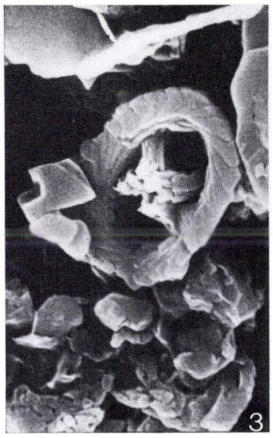
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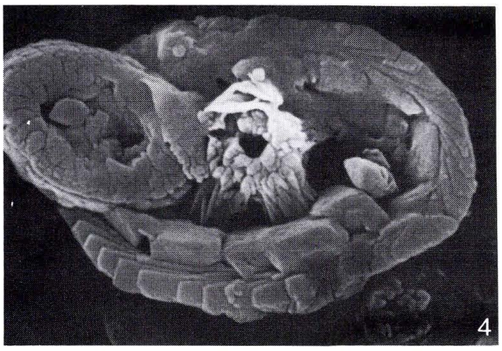
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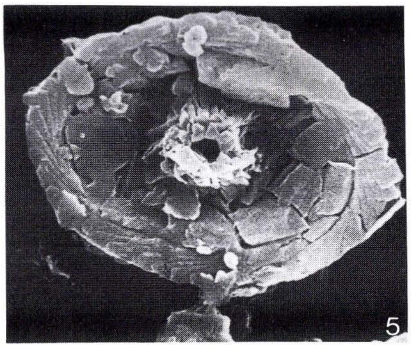
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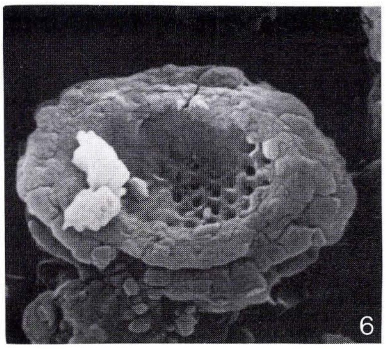
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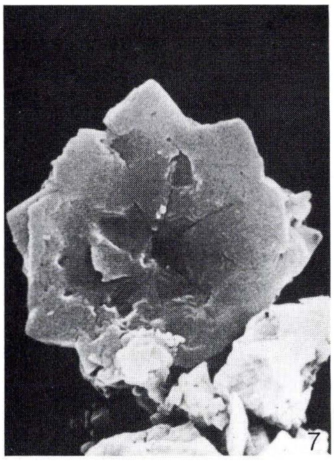
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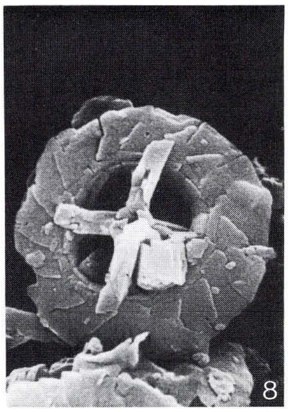
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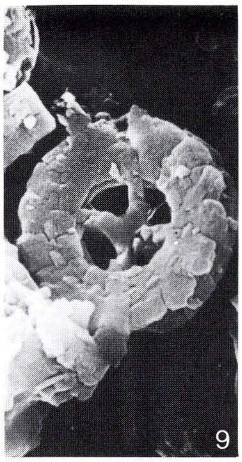
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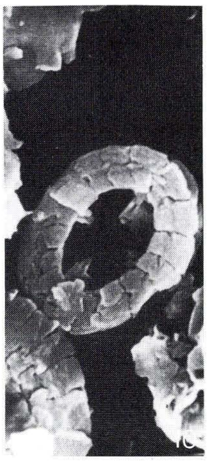
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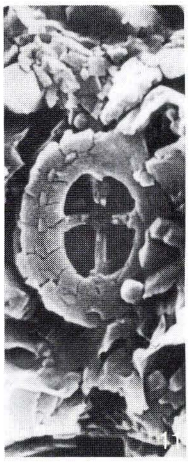
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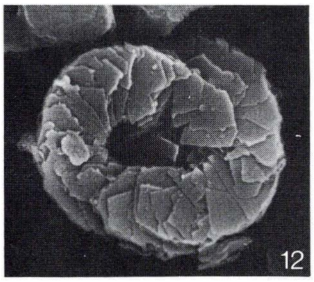
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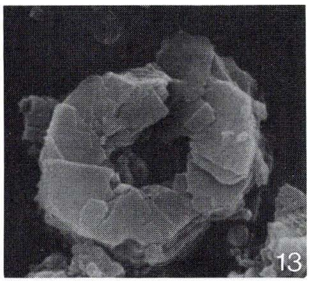
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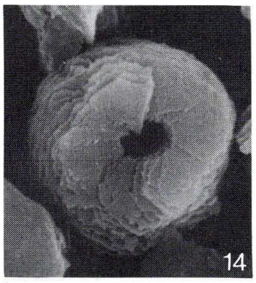
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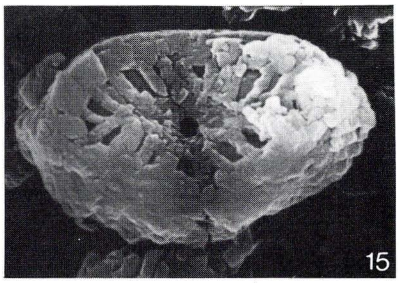
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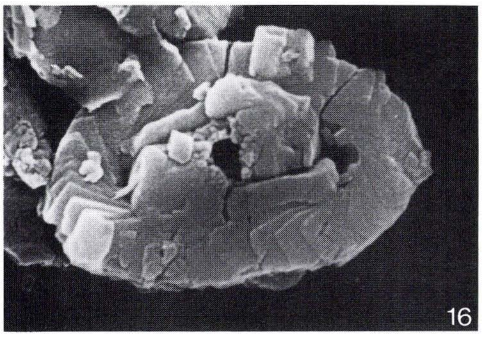
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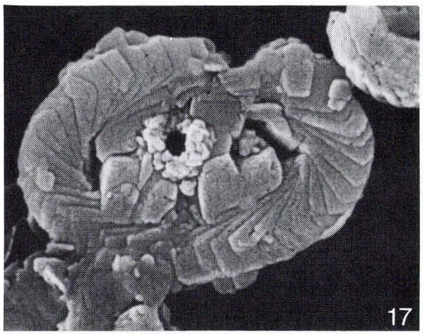
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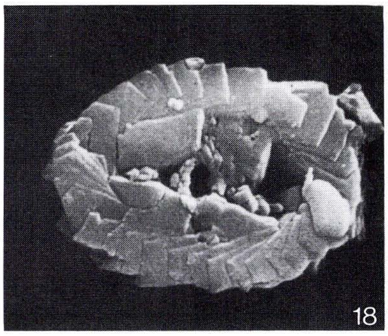
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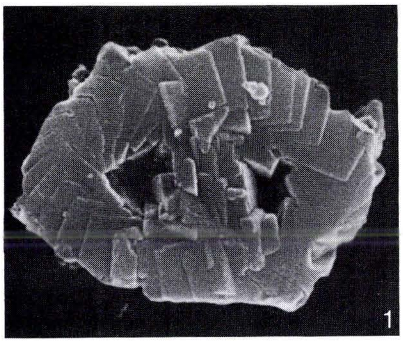
PLATE 21

Figs. 1–11. Upper Albian – ?Cenomanian.
Figs. 12–15. Inflexus marl (U. *nutfieldensis* ammonite zone) Gott, Sarstedt, Northwestern Germany.
Figs. 1–6. *Zeugrhabdotus compactus* (Bukry, 1969). Figs. 1,3,5, Adda-2 7710'. Figs. 2,4,6, Adda-2 7720'.
Figs. 7–11. *Zeugrhabdotus reticulatus* Black (1971) Adda-2 7720'.
Fig. 12. *Vagalapilla matalosa* (Stover, 1966) Thierstein (1973). Sarstedt.
Fig. 13. *Eprolithus varolii* Jakubowski (1986). Sarstedt.
Fig. 14. *Sollasites lowei* (Bukry, 1969) Roth (1970). Sarstedt.
Fig. 15. *Nannoconus* sp.l. Sarstedt.

Magnifications: × 7000 (Figs. 1–14).
Magnifications: × 3500 (Fig. 15).

PLATE 21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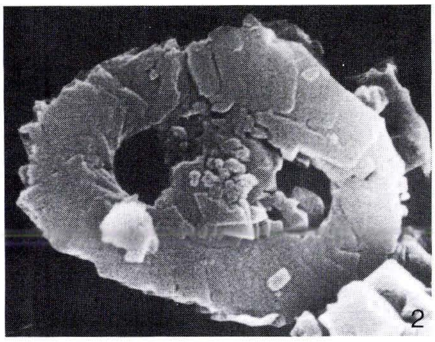
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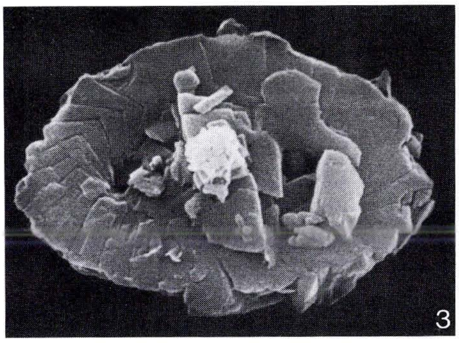
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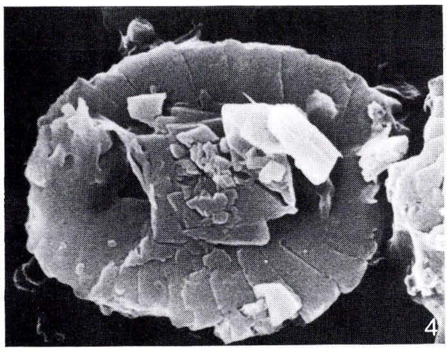
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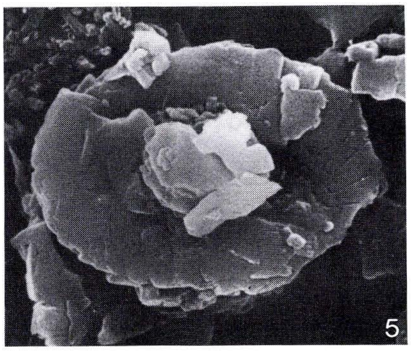
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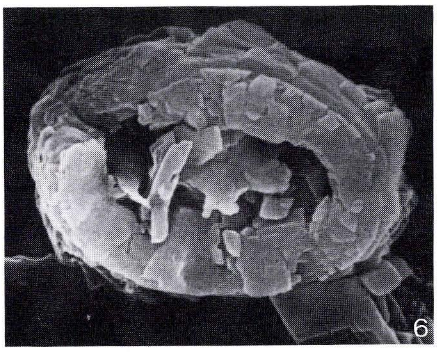
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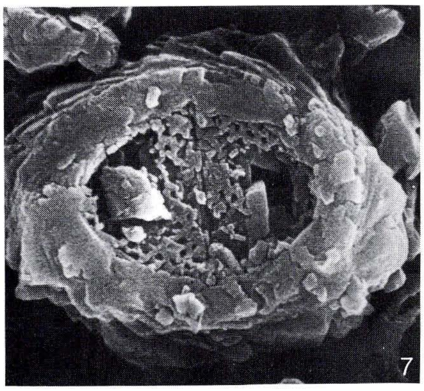
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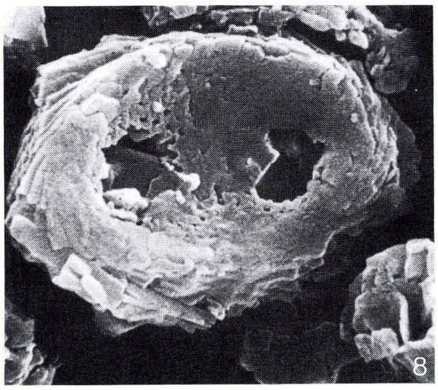
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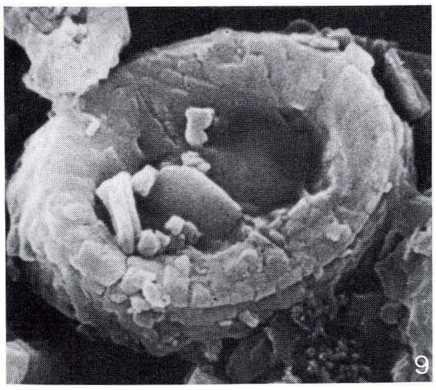
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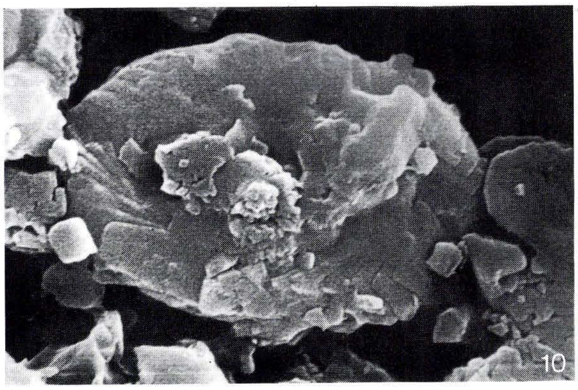
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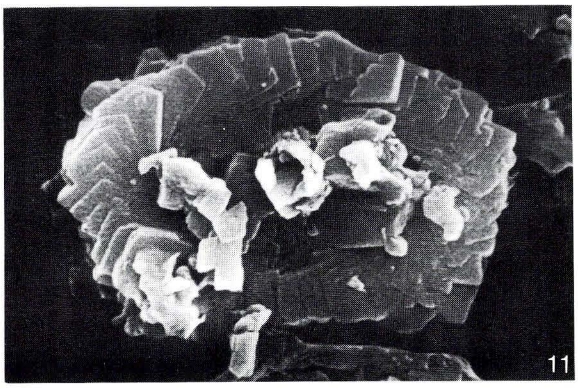
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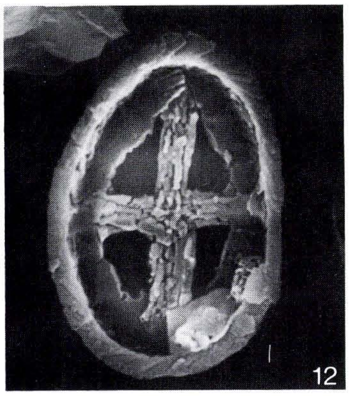
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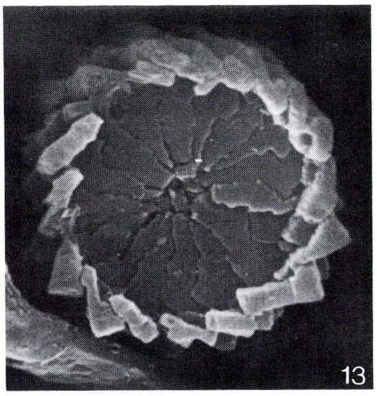
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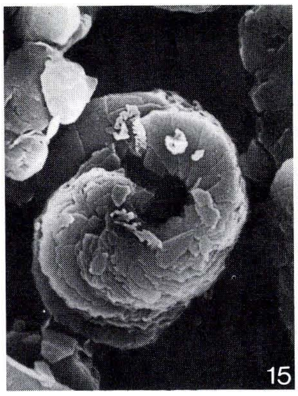
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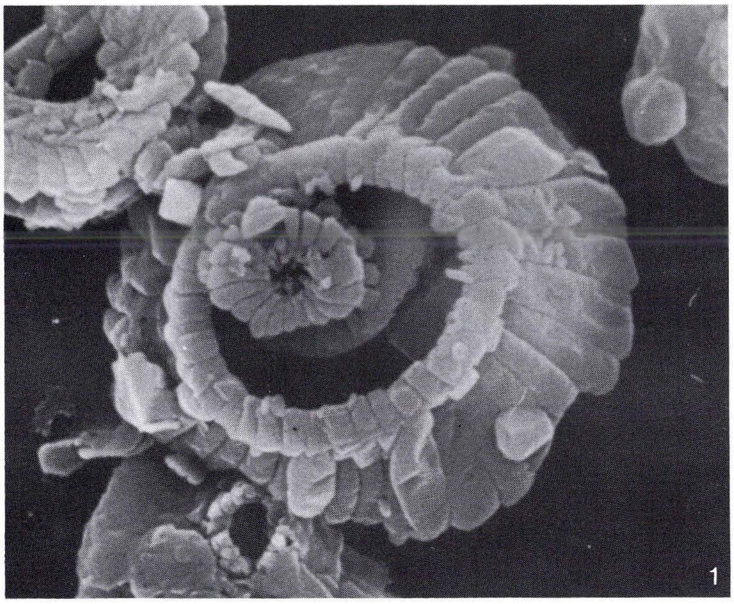
PLATE 22

Figs. 1–8. “Fischschiefer”, Helgoland (Lower Aptian).
Figs. 9–13, Rote *“ewaldi* Kreide”, Helgoland (Upper Aptian).
Fig. 1. *Pickelhaube furtiva* (Roth, 1983) Applegate, Covington & Wise (1987).
Figs. 2,3. *Prediscosphaera cf. stoveri* (Perch-Nielsen, 1968) Gartner (1968).
Figs. 4,14. *Rhagodiscus angustus* (Stradner, 1963) Reinhardt (1971).
Figs. 5–7,9,10. *Eprolithus apterior* Black (1973).
Figs. 8–11. *Chiastozygus platyrhethus* Hill (1976).
Figs. 12,13. *Acaenolithus* sp. 1.

Magnifications: × 7000.

PLATE 22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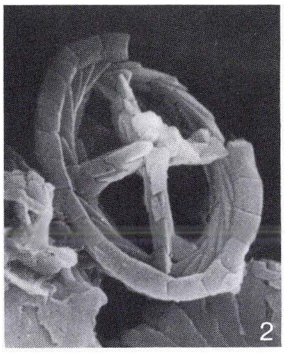
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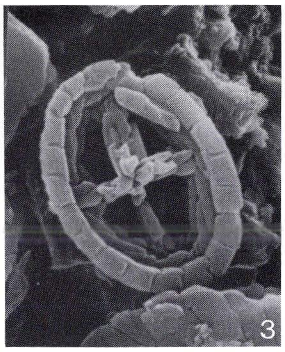
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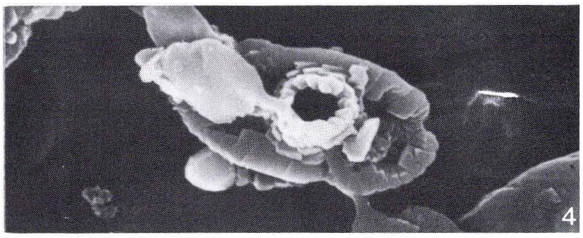
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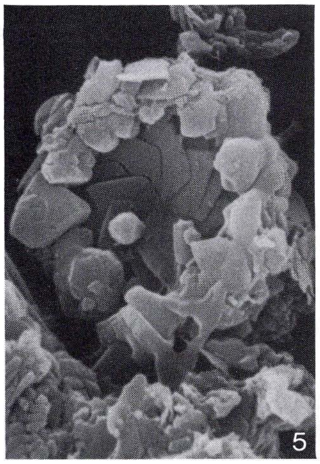
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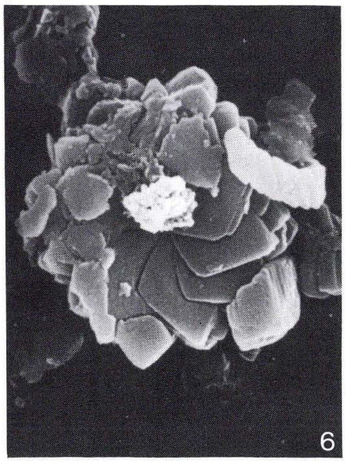
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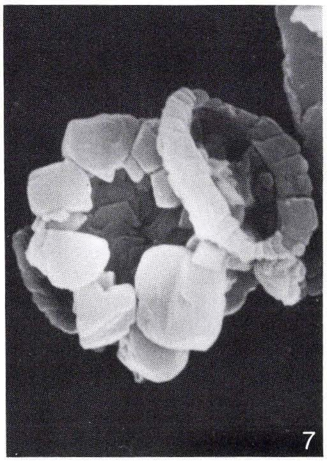
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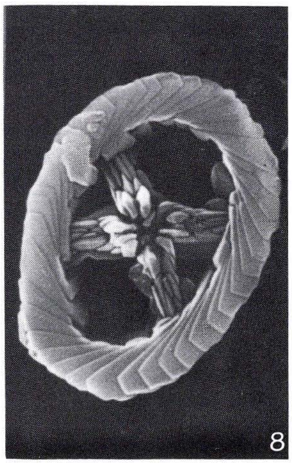
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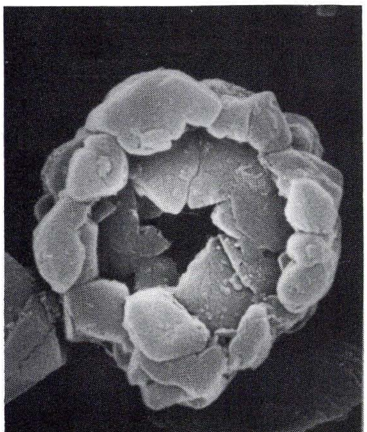
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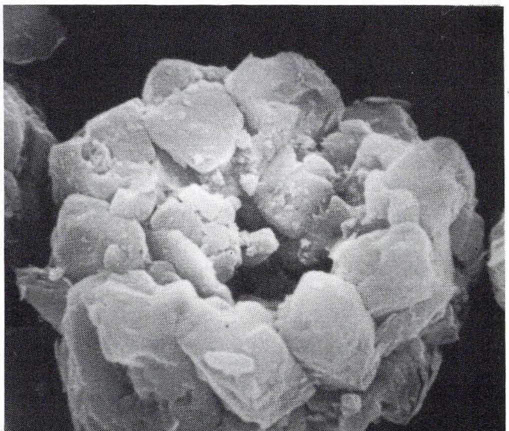
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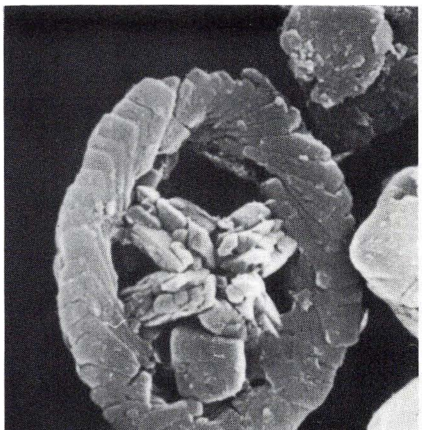
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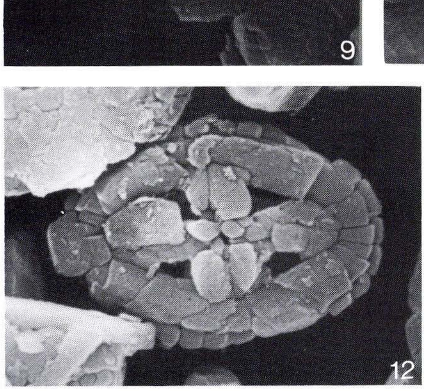
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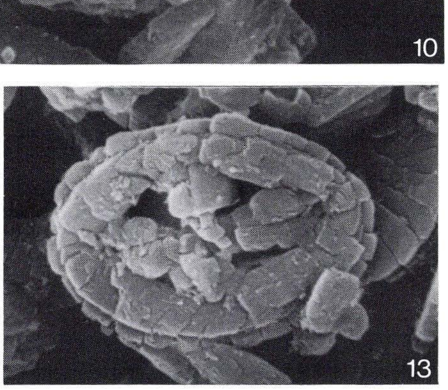
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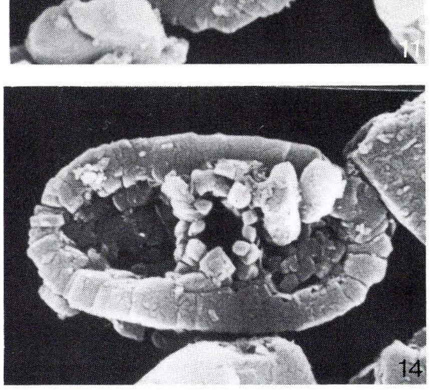
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This paper presents a biostratigraphical analysis of the Upper Hauterivian to Albian sequence in the Danish North Sea. The sequence is compared to the time-equivalent sections at Speeton (eastern England) and Helgoland (SE North Sea). The author shows that the sedimentary facies differs considerably between the central and marginal areas of the North Sea.

The calcareous nannofossils are fully illustrated by SEM photographs and many species are commented upon.

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