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Upper Cretaceous Calcareous Nannofossil Biostratigraphy of the Southern Norwegian and Danish North Sea Area

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With 8 Figures

North Sea
Calcareous Nannofossils
Late Cretaceous
Biostratigraphy

Contents

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Zusammenfassung

In dieser Arbeit wird ein Zonen-Subzonen Schema für kalkige Nannofossilien des Maastricht bis Cenoman (Ober-Kreide) vorgeschlagen. Die 19 Zonen und 10 Subzonen, die im südlichen norwegischen und im dänischen Nordseegebiet angewandt werden können, wurden anhand von detaillierten Untersuchungen an Kernen, Seitenkernen und Schlämmproben erarbeitet. Diese Zonierung wird als praktisches Schema zum Gebrauch durch die Erdöl-Industrie vorgeschlagen. Detaillierte Vergleiche mit den Arbeiten von SISSINGH (1977, 1978), PERCH-NIELSEN (1979a) und CRUX (1982) werden diskutiert.

Abstract

In this paper a calcareous nannofossil zonal / subzonal scheme spanning the Maastrichtian to Cenomanian (Upper Cretaceous) is proposed. The nineteen zones and ten subzones recognised for the Southern Norwegian and Danish North Sea Area have been derived from the extensive examination of core, sidewall core and, in particular, ditch cutting material. This zonation is proposed as a workable scheme for the oil industry. A detailed comparison with the works of SISSINGH (1977, 1978), PERCH-NIELSEN (1979a) and CRUX (1982) has been undertaken (as these are the most comparable schemes to the present study).

1. Introduction

Since the discovery of hydrocarbon bearing Upper Cretaceous strata in Amoco's 2/11–1 well (drilled on the southern flank of the Valhall field in 1969) much interest has been focussed on the Southern Norwegian and Danish North Sea Sectors. Shortly afterwards Phillips giant Ekofisk Chalk Field was discovered and to date at least 16 commercial hydrocarbon fields have been discovered in chalks of Late Cretaceous and Early Palaeocene age (Fig. 1).

The lack of age diagnostic planktonic foraminiferal taxa and their general poor preservation has hampered the solving of stratigraphic problems encountered in developing these North Sea Chalk Reservoirs. The potential biostratigraphic usefulness of calcareous nannofossils in the oil industry has only been recognised in relatively recent years following the publication of the comprehensive Tertiary zonation scheme of MARTINI (1971) which is now widely accepted. The Upper Cretaceous, however, is not so well subdivided and it became clear that a new biostratigraphic calcareous nannofossil scheme was needed to improve chronostratigraphic control for hydrocarbon exploration. The main objective of this paper is to introduce a workable Upper Cretaceous (Maastrichtian to Cenomanian) zonation scheme for the oil industry using calcareous nannofossils for the study area incorporating published nannofloral events where possible.

NB: For the purpose of this paper chronostratigraphic terms uppermost, upper, middle, lower and lowermost refer to rocks whereas the geochronologic terms latest, late, mid, early and earliest are used for stratigraphic units.

2. Geological Setting

The study area is located within the Southern Norwegian and Danish North Sea Sectors essentially centering around a Northwest–Southeast trending graben structure, (Fig. 1). The geological development of the graben was probably initiated before the Permian (OFSTAD, 1983). A more detailed account on the geological setting as well as tectonic history of the area, ist given by ZIEGLER (1978). It is, however, important to note that the thick Upper Permian evaporites deposited in the Central Graben area have greatly influenced the geological and structural evolution of the study area (OFSTAD, 1983). Salt movements, which were initiated in the Late Triassic, continued in the Cretaceous and Early Tertiary and were responsible both for the formation of most of the hydrocarbon traps and also the significant fracturing recorded in the area. The fracturing was very important as it provided conduits for hydrocarbon migration from the Upper Jurassic Kimmeridge Clay Formation source rock through the Lower Cretaceous sediments and into the Upper Cretaceous and Lower Palaeocene chalk reservoir rocks above.

3. Lithostratigraphy

The lithostratigraphic terminology used in this paper follows the schemes of DEEGAN & SCULL (1977) and HESJEDAL & HAMAR (1983). A generalised stratigraphy for the Upper Palaeocene to Middle Albian interval for the study area is shown in Fig. 2.

This study concentrates on the Chalk Group and in particular the Maastrichtian to Cenomanian interval. The Chalk Group is overlain by claystones of the Maureen Formation (Early Palaeocene age) and these are in turn succeeded by a shale sequence representing the Lista Formation and a shale/claystone and tuffaceous claystone sequence representing the Sele and Balder Formations respectively (which are all of Late Palaeocene age). The Chalk Group comprises the Hidra, Plenus Marl, Hod, Tor and Ekofisk Formations. The Ekofisk Formation, which is of Early Palaeocene age, consists of limestones which become increasingly more argillaceous towards their base. The Ekofisk/Tor Formation boundary can be represented by a dark grey coloured shale in some parts of the study area. This formation boundary coincides with that of the Tertiary/Late Cretaceous. The underlying Tor Formation con-

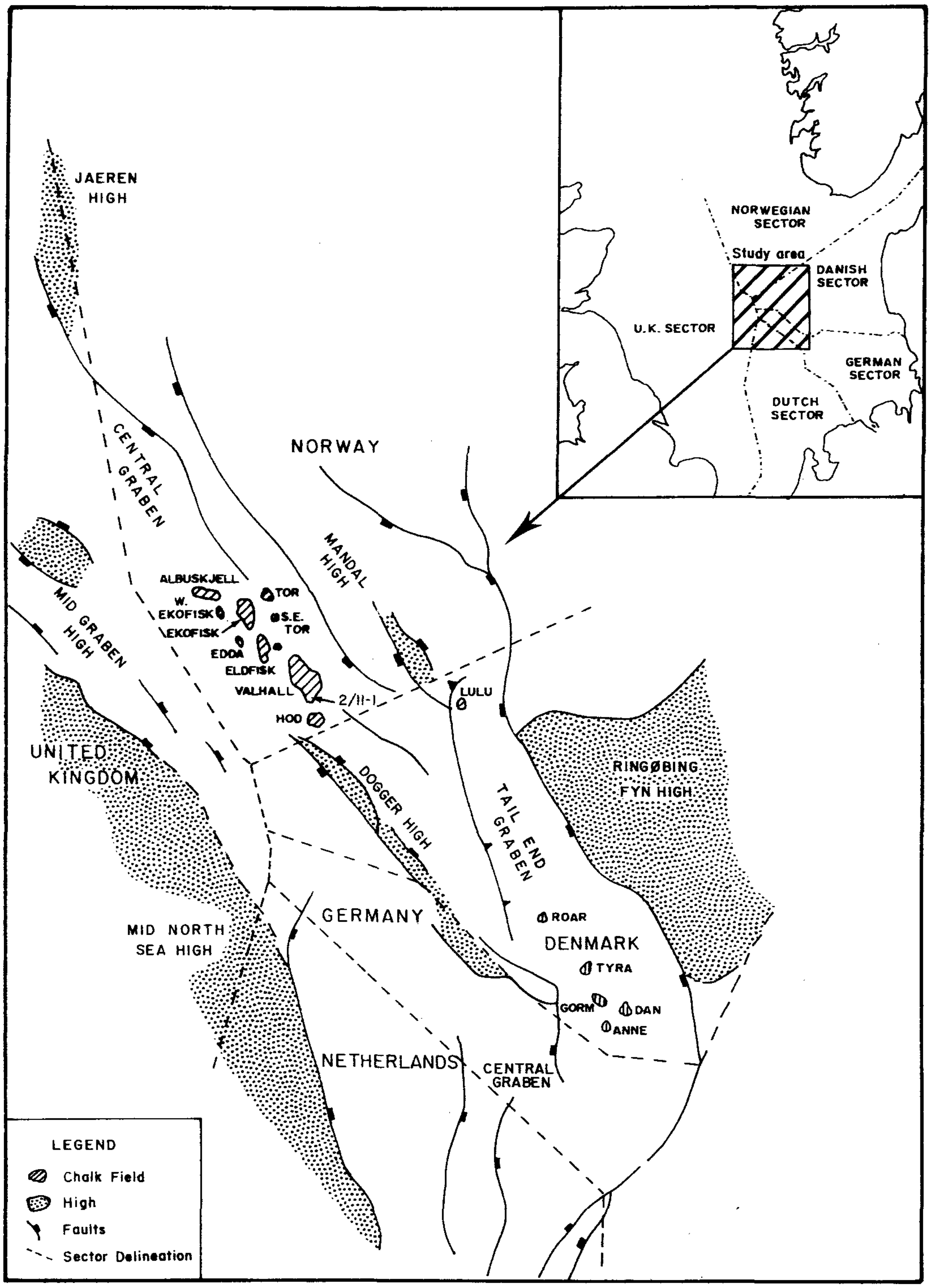


Fig. 1: Location map, showing the main structural elements for the study area.

sists of chalky limestones of Maastrichtian to late Campanian age. The Hod Formation underlies the Tor Formation and is predominantly early Campanian to Turonian in age. This Formation was initially subdivided into three units by HARDMAN & EYNON (1977) and subsequent authors have revised the definition of these units. For the purpose of this paper the subdivision follows the scheme developed by the author and used "in house" at Robertson Research International. In this scheme the Hod Formation is divided into three units, the Upper, Middle and Lower Hod. The Upper Hod is represented by chalky and quite clean limestones of early Campanian to Coniacian age and is of secondary importance as a reservoir. The underlying Middle Hod Unit consists of limestone/marl alternations and is Coniacian to Turonian in age. Finally the Lower Hod unit consists of quite pure chalky limestones (of secondary importance as a reservoir) but grades progressively into more argillaceous limestones towards the base of the Turonian. The Lower Hod culminates in the grey to greenish grey Plenus Marl Formation of late Cenomanian age. The underlying Hidra Formation of Cenomanian age consists of quite firm limestones which grade into the argillaceous limestones and calcareous clay-

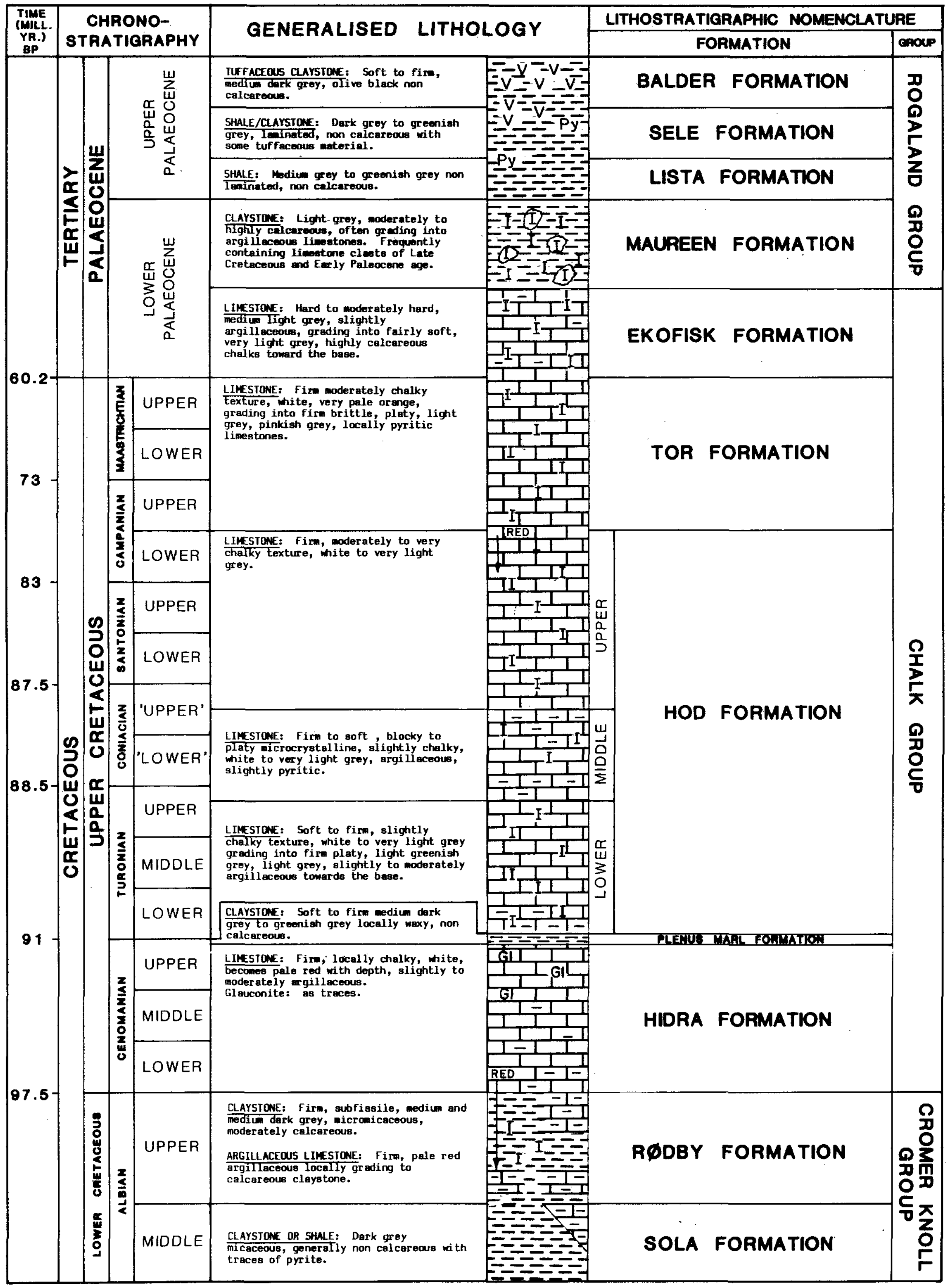


Fig. 2: Generalised stratigraphy for the Upper Paleocene to Middle Albian interval for the southern Norwegian and Danish central graben area. Lithostratigraphic nomenclature after DEEGEN & SCULL (1977) except for the Sola Formation which has been taken from HESJEDAL & HAMAR (1983).

stones of the Rødby Formation of late Albian age. The Hidra/Rødby Formation boundary coincides with the Upper/Lower Cretaceous boundary. The middle Albian ian to Aptian Sola Formation underlies the Rødby Formation and consists of non calcareous claystones or shales.

4. Method of Investigations

The investigations have been carried out using a Leitz Dialux 20 light microscope. Centrifuge and smear slides were prepared followig the standard techniques described by TAYLOR & HAMILTON (1982) using core, sidewall core and in particular ditch cuttings samples. The material examined and described in this paper is taken from released well sections and includes data from some of the Robertson Research International Limited multiclient reports in particular the report entitled "The Danish North Sea Area": The Stratigraphy and Petroleum Geochemistry of the Jurassic to Tertiary Sediments (1983), a report produced exclusively for the oil industry.

Since this paper is only a general review of the Upper Cretaceous calcareous nannofossil biostratigraphy from the study area and is predominantly based on ditch cuttings material, only stratigraphically significant abundances (i. e. acmes) are recorded. These acmes are readily recognisable in this type of sample as well as core and sidewall core material. The overall preservation of the nannofloral assemblages was noted but only characteristic nannofloral assemblage preservational horizons are documented (i. e. the very poorly preserved nannofloral assemblages characteristic of the middle to early Turonian age Lower Hod Unit).

5. Calcareous Nannofossil Biostratigraphy

5.1. Previous Studies in Upper Cretaceous Calcareous Nannofossil Zonation

Figure 3 illustrates diagrammatically the most important Upper Cretaceous calcareous nannofossil zonations proposed in the last twenty-two years. The following section reviews these schemes and where possible in context of the one proposed in the present study.

The first subdivision of the Upper Cretaceous utilizing calcareous nannofossils was presented by STRADNER (1963) using assemblage zones. Similar assemblage zonation schemes were proposed by STOVER (1966), REINHARDT (1966) and BUKRY (1969). However, it was not until 1969 that CEPEK & HAY introduced a zonation scheme for the Upper Cretaceous based on interval zones, using material from Kansas and Alabama. SMITH (1975) pointed out that on reviewing the scheme and trying to assign the zones to stages, that at least some of Coniacian and Santonian interval had not been included in the original study conducted by CEPEK & HAY (1969). Three of the zones proposed by these authors have been identified and used in an emended form in this study, namely the *Nephrolithus frequens* zone (Maastrichtian age in both studies), *Tetralithus pyramidus* (= *Quadrum gartneri* zone of this study, Turonian in both studies) and the *Staurolithites orbiculofenestrus* (= *Axopodorhabdus albianus* zone of this study, Cenomanian in both studies) zones. *Marthasterites furcatus* and *Kamptnerius magnificus* are the only other zonal marker species introduced by CEPEK & HAY (op. cit.) which were utilized in this study, although they have been assigned a subzonal status in the Turonian. This zonation scheme also used *Kamptnerius punctatus* (Campanian) as a zonal indicator which is considered a preservational morphotype of *Kamptnerius magnificus* by THIERSTEIN (1976). *Arkhangelskiella ethmopora* (Campanian) was also used as a zonal marker in this scheme but is considered to be a perforate morphotype of *Arkhangelskiella cymbiformis*.

Lithraphidites quadratus (Maastrichtian) was too inconsistently recorded to be a reliable zonal marker in the present study. Subsequent authors have used some of CEPEK & HAY's (1969) other zonal marker species in their schemes, such as *Tetralithus aculeus* (upper Campanian), subsequently used by MANIVIT (1971), VERBEEK (1976b), THIERSTEIN (1976), SISSINGH (1977), HAY (1977), PERCH-NIELSEN (1977, 1979a), ROTH (1978), PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984). This species was not recorded in the present study, neither was *Corollithion exiguum* (Turonian) which was used by MANIVIT (1971), ROTH (1973), BUKRY (1975), HAY (1977) as a zonal indicator. The other two marker species used by CEPEK & HAY (1969), *Chiastozygus cuneatus* (Turonian / Cenomanian) and *Chiastozygus initialis* (Maastrichtian – Upper Campanian) were not noted in the study area.

5.2. Historic reviews

Authors and correlations: BUKRY & BRAMLETTE (1970).

Study area: Leg 3 of the Deep Sea Drilling Project from the South Atlantic.

Age: Upper Cretaceous, Maastrichtian to Campanian interval.

Zones: 4 (3 of which were new).

Comments: Two zonal marker species used by these authors were found in the present study, namely *Lithraphidites quadratus* of Maastrichtian age which was rarely recorded and *Eiffellithus angustus* (= *Eiffellithus eximius* of this paper) of Campanian age which was found to have a very inconsistent top within the Campanian. SISSINGH (1977) recorded this species as extending to within the early Maastrichtian interval at the Dyr el Kef Section in W. Tunisia. The other zonal marker species used by BUKRY & BRAMLETTE (op. cit.) namely *Tetralithus murus* (= *Micula murus* of other authors) (late Maastrichtian) and *Tetralithus nitidus* (Maastrichtian – Campanian) were not found in the study area. The former species has been used by subsequent authors to mark the top zone of the Maastrichtian in tropical and subtropical regions.

*

Author and correlations: MANIVIT (1971, 1972).

Study Area: France (including the stage stratotypes).

Age: Tertiary-Cretaceous, Early Palaeocene to Aptian interval.

Zones: 15 of which 11 (1 of which was new) were for the Upper Cretaceous interval.

Comments: A number of zones identified in this scheme were originally definded by CEPEK & HAY (1969); MANIVIT however introduced the evolutionary appearance of *Gartnerago obliquus* to define the base of the zone of the same name of predominantly Cenomanian age. This zone has subsequently been used by THIERSTEIN (1974), VERBEEK (1976b, 1977),

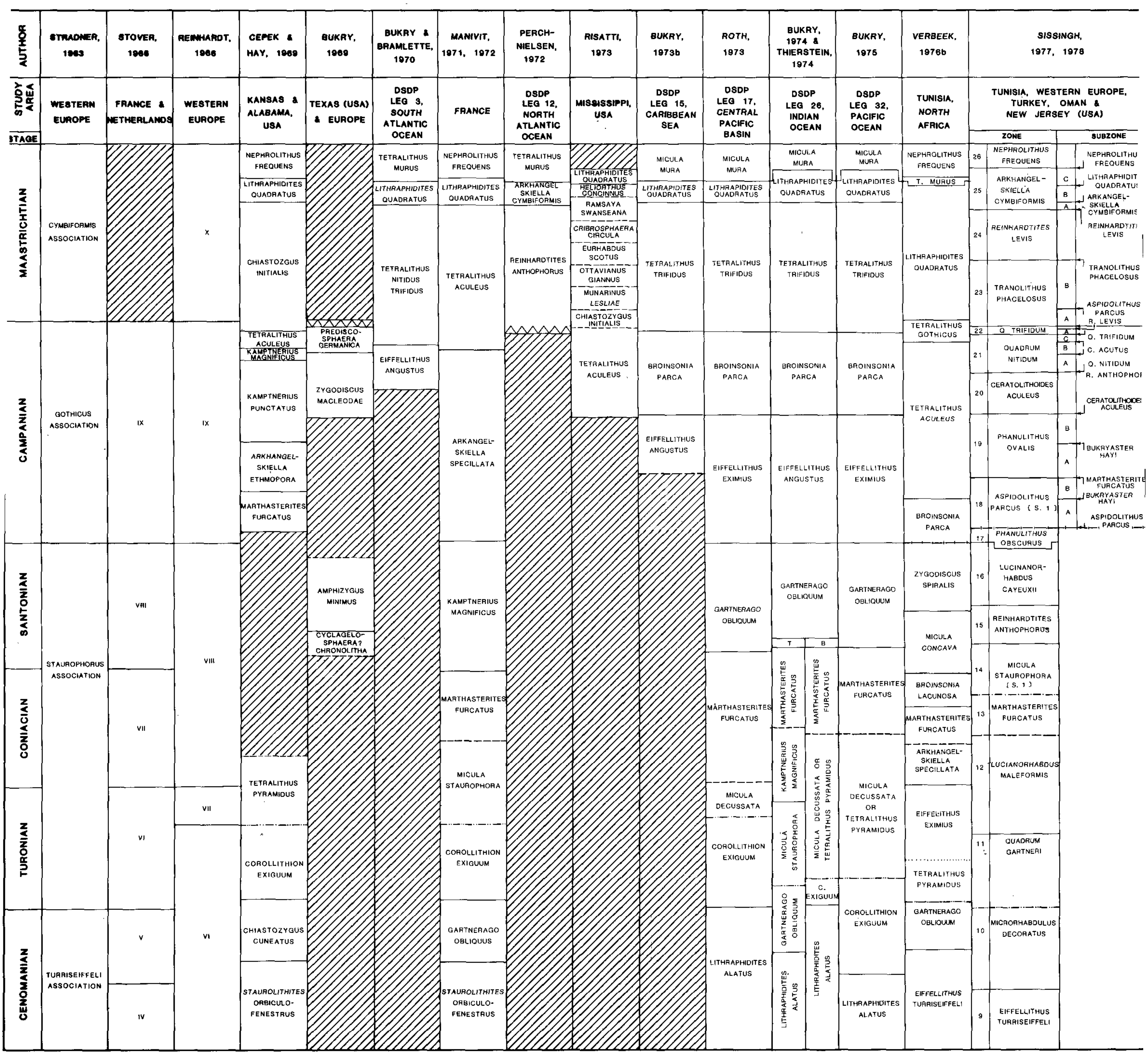
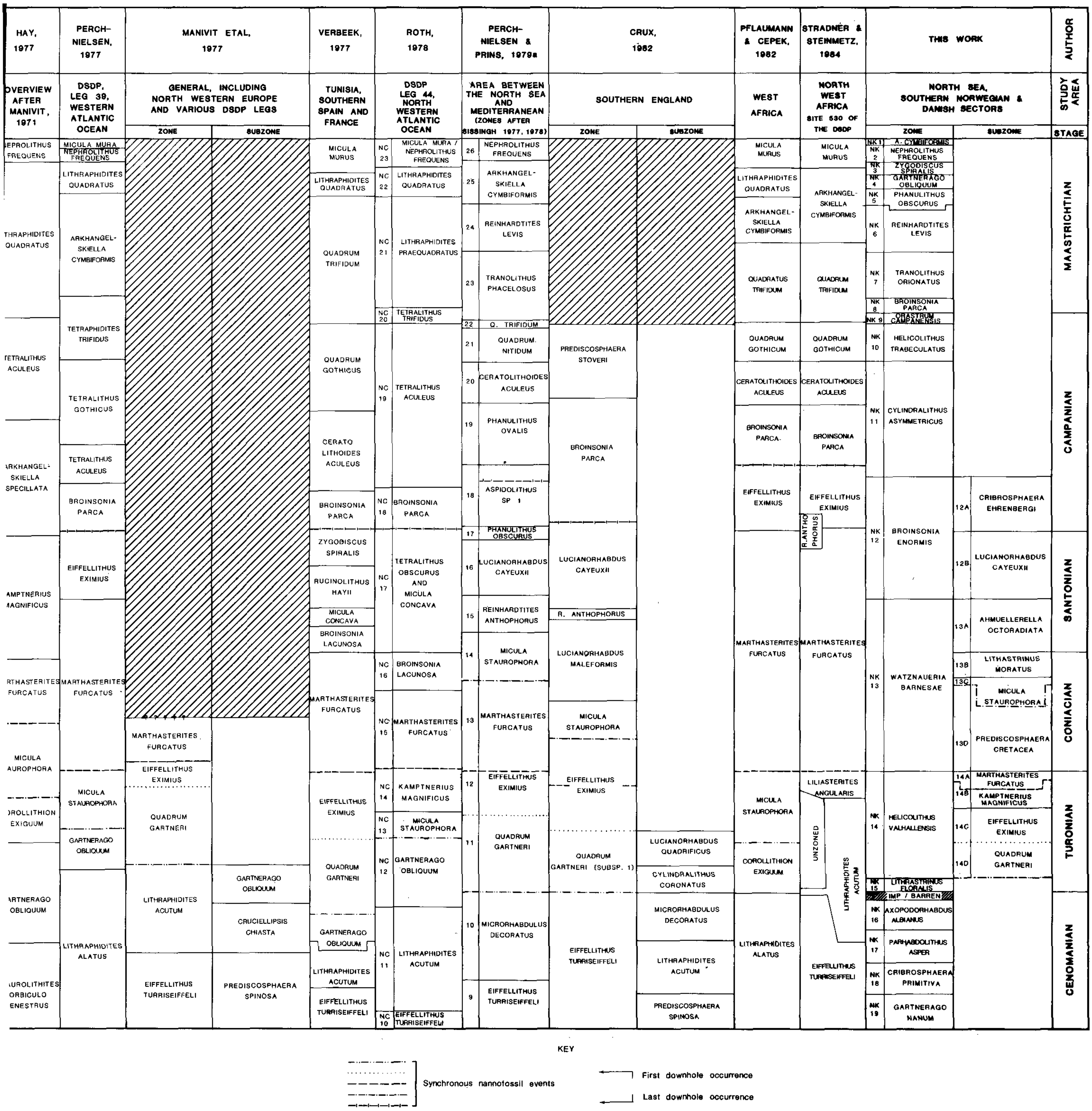


Fig. 3: Comparison of Upper Cretaceous calcareous nannofossil zonation schemes.

HAY (1977), PERCH-NIELSEN (1977) and ROTH (1978). The evolutionary appearance of *G. obliquum* was also noted by CRUX (1982), PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984) (?possibly) within the Cenomanian, although the former author mentions the difficulty as to whether to include rare small forms of *Garnterago* noted in the Cenomanian with this species and so did not use it as a zonal marker. The evolutionary appearance of this species has not been used in this study although the stratigraphic extinction has been used to define one of the zones of the same name in the Maastrichtian. MANIVIT also used *Kamptnerius magnificus* as zonal marker for the Santonian. CEPEK & HAY (1969) used the evolutionary appearance of this species to mark the base of their zone in the Campanian. The absence of Coniacian and Santonian age sediments in their study may explain this apparent discrepancy. A modified form of this zone was subsequently used by THIERSTEIN (1974) (Turonian/Coniacian), HAY (1977) (Santonian) and ROTH (1978) (Turonian). In the present study it has been used as a subzonal marker species in the Turonian. THIERSTEIN (1976) mentions that the first (last downhole) occurrence of *Kamptnerius magnificus* is



time-transgressive through at least 5 my. which may explain some of these age differences noted above.

*

Author and correlations: PERCH-NIELSEN (1972).

Study area :Leg 12 of the Deep Sea Drilling Project from the north Atlantic.

Age: Upper Cretaceous, Maastrichtian interval.

Zones: 3 (2 of which were new).

Comments: Two new zones were introduced by PERCH-NIELSEN namely the *Arkhangelskiella cymbiformis* and *Reinhardtites anthophorus* (?*R. levis* of SISSINGH, 1977) zones. If the top of the latter zone equates to the extinction level of *Reinhardtites levis* zone of SISSINGH (1977) then this zone has been recognised in the present study. The *Arkhangelskiella cymbiformis* zone has been recorded in the present study but has been used in emended form to mark the uppermost Maastrichtian zone. MARTINI (1976), SISSINGH (1977), PERCH-NIELSEN (1977) and STRADNER & STEINMETZ

(1984) have all used this zone but for different intervals of the Maastrichtian.

*

Author and correlations: RISATTI (1973).

Study area: Mississippi, U. S. A.

Age: Upper Cretaceous, Maastrichtian to Campanian interval.

Zones: 9 (6 of which were new).

Comments: Of the nine nannofloral zones recorded by the author, five were based on newly described species. None of these species have since been noted outside this area. The remaining three zones correspond to CEPEK & HAY's (1969) scheme.

*

Author and correlations: BUKRY (1973b).

Study area: Leg 15 of the Deep Sea Drilling Project from the Caribbean Sea.

Age: Upper Cretaceous, Maastrichtian to Campanian interval.

Zones: 5 (1 of which was new).

Comments: BUKRY introduced a *Broinsonia parca* zone (of Campanian age) and defined it as the interval between the evolutionary appearance of *Tetralithus trifidus* (= *Quadrum trifidum*) and the extinction of *Eiffellithus angustus* (= *E. eximius* of this paper). This zone has been used in emended form by VERBEEK (1976b, 1977), SISSINGH (1977), PERCH-NIELSEN (1977), ROTH (1978), PERCH-NIELSEN & (PRINS, 1979a), CRUX (1982), PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984). The *Broinsonia parca* zone was used in the present study but uses the stratigraphic extinction of the species following the findings of SISSINGH (1977), who used this event to subdivide his *Tranolithus phacelosus* partial range zone 23 of earliest Maastrichtian to latest Campanian age into two subzones (23b and 23a). The scheme was otherwise identical to that proposed by BUKRY & BRAMLETTE (1970).

*

Author and correlations: ROTH (1973).

Study area: Leg 17 of the Deep Sea Drilling Project from the Central Pacific Ocean.

Age: Upper Cretaceous, Maastrichtian to Cenomanian interval.

Zones: 10 (2 of which were new).

Comments: VERBEEK (1976b) indicated that the scheme of ROTH has one main disadvantage in being based partially on extinctions which means it is difficult to recognise in samples with reworked material, however, the use of extinctions when dealing with ditch cuttings material is standard practice in the oil industry. Many of the zones used by ROTH were proposed by earlier authors in particular BUKRY & BRAMLETTE (1970) and MANIVIT (1971) although this author defined two new zones; the *Gartnerago obliquum* and *Lithraphidites alatus* zones of Santonian and Cenomanian age respectively. The former is based on the interval between the evolutionary appearance of *Broinsonia parca* and the extinction of *Marthasterites furcatus* whereas the latter zone encompasses the interval between the evolutionary appearances of *Corollithion exiguum* and *Lithraphidites alatus* and has subsequently been used by BUKRY (1974), THIERSTEIN (1974) and PERCH-NIELSEN (1977). This species was only rarely recorded in the study area and therefore has not been used as zonal indicator.

*

Author and correlations: BUKRY (1974).

Study area: Leg 26 of the Deep Sea Drilling Project from the Indian Ocean.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 18 of which 10 were for the Upper Cretaceous interval.

Comments: The scheme was essentially based on the work of STRADNER, (1963), CEPEK & HAY (1969), ROTH (1973) and BUKRY (in press). However, THIERSTEIN (1974) produced a slightly modified zonation scheme for Santonian to Albian interval of this Leg (See Figure 3 for comparison).

*

Author and correlations: BUKRY (1975).

Study area: Leg 32 of the Deep Sea Drilling Project from the Pacific Ocean.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 18 of which 10 were for the Upper Cretaceous interval.

Comments: BUKRY essentially followed the scheme proposed by ROTH (1973) with some minor modifications.

*

Author and correlations: VERBEEK (1976b).

Study area: El Kef, Tunisia.

Age: Upper Cretaceous, Maastrichtian to Cenomanian interval.

Zones: 15 (of which 6 were new).

Comments: This scheme was based exclusively on evolutionary appearances. VERBEEK introduced *Tetralithus gothicus* (= *Quadrum gothicum*) as a zonal marker for the upper Campanian which has subsequently been used by PERCH-NIELSEN (1977), VERBEEK (1977), PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984). This species was not recorded in the present study. However, two of the zones introduced by VERBEEK have been used in emended form in the present study the *Zygodiscus spiralis* zone of Santonian age (Maastrichtian in the current study) and the *Eiffellithus eximius* zone (Turonian age in both studies). The latter zone has been used by PERCH-NIELSEN (& PRINS, 1979a) and CRUX (1982) for the Turonian and Turonian/Conician interval respectively. PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984), however, use a zone of this name in the lower Campanian.

*

Author and correlations: SISSINGH (1977).

Study area: Western Europe, Tunisia, Oman and New Jersey.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 26 of which 18 were for the Upper Cretaceous section (of which 9 were new) together with 14 subzones.

Comments: Three of SISSINGH's new zones have been adopted in the present study namely the *Reinhardtites levis* Zone 24, *Tranolithus phacelosus* (= *Tranolithus orionatus* of this study) Zone 23, both of early Maastrichtian age and the *Lucianorhabdus cayeuxii* Zone 16 of late Santonian age. A further three of his zones have been used on a subzonal status in emended form namely his *Micula staurophora* Zone 14 of Coniacian age, *Marthasterites furcatus* Zone 13 of Coniacian age (Turonian age in the current study) and *Tetralithus pyramidus* (= *Quadrum gartneri* of this study) Zone 11, both of Turonian age. Also his Subzone 23a, the top of which is defined on the extinction of *Aspidolithus* ex. gr. *parcus* (= *Broinsonia parca* of this study) was recognised in the present study but has been modified to zonal status. As mentioned by CRUX (1982), MANIVIT (1971) introduced the *Micula staurophora* zone but it differed from SISSINGH's in that she probably grouped *Quadrum gartneri* with *Micula staurophora*, hence the confusion in the literature regarding the evolutionary appearance of these two species. A more detailed comparison with SISSINGH's zonation scheme is included later in the paper.

*

Author and correlations: HAY (1977).

Study area: None just an overview.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 19 of which 10 were for the Upper Cretaceous interval.

Comments: In a general review of calcareous nannofossils HAY essentially utilised the scheme proposed by MANIVIT (1971) with some minor modifications.

*

Author and correlations: PERCH-NIELSEN (1977).

Study area: Leg 39 of the Deep Sea Drilling Project from the Western South Atlantic Ocean.

Age: Cretaceous, Maastrichtian to Albian interval.

Zones: 14 zones of which 13 were for the Upper Cretaceous interval.

Comments: PERCH-NIELSEN emended several zones, but essentially followed the schemes of MARTINI (1969, 1976), CEPEK & HAY (1969), BUKRY & BRAMLETTE (1970), PERCH-NIELSEN (1972) and ROTH (1973).

*

Author and correlations: MANIVIT et al. (1977).

Study area: North Western Europe and various DSDP Legs.

Age: Coniacian to Albian interval.

Zones: 5 (one of which was new) and 3 subzones.

Comments: Neither the new *Lithraphidites acutum* zone of early Turonian to Cenomanian age, or the *Gartnerago obliquum*, *Cruciellipsis chiastia* and *Prediscosphaera spinosa* subzones of early Turonian to late Albian age could be recognised in the present study. The *Lithraphidites acutum* zone has since been used by ROTH (1978) in emended form and STRADNER & STEINMETZ (1984). CRUX (1982) used the species *Lithraphidites acutum* and *Prediscosphaera spinosa* on a subzonal level but emended both.

*

Author and correlations: VERBEEK (1977).

Study area: Tunisia, Southern Spain and France.

Age: Cretaceous, Maastrichtian to Albian interval.

Zones: 17 of which 16 (including 1 new zone) were for the Upper Cretaceous interval

Comments: Although this zonation is similar to the one he introduced earlier (1976b) with some emendments, one new zone was proposed, the *Rucinolithus hayii* zone of middle Santonian age. This species, however, was not recognised in the present study.

*

Author and correlations: ROTH (1978).

Study area: Leg 44 of the Deep Sea Drilling Project from the North Western Atlantic Ocean.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 23 of which 13 (of which 2 were new) were for the Upper Cretaceous interval.

Comments: ROTH discussed the Cretaceous calcareous nannofossil biostratigraphy in relationship to the oceanic and classic European stages using the schemes of ROTH (1973), BUKRY (1975), THIERSTEIN (1976) and VERBEEK (1976). He proposed thirteen zones for the Upper Cretaceous and distinguished them by using the prefix NC and numbering them from 23 to 11 (youngest to oldest). Two new zones were introduced for the Upper Cretaceous namely the *Lithraphidites praequadratus* (NC 21 zone) of Maastrichtian age and the *Tetralithus obscurus* – *Micula concava* (NC 17 zone) of ?Santonian age. However the former species was not recorded in the present study and one of the latter zonal indicators *Tetralithus obscurus* (= *Phanulithus obscurus* of this paper) was found to have its last downhole occurrence at the Campanian / Santonian boundary which appears to be above ROTH's zone. *Micula concava* was not recorded in this study.

*

Authors and correlations: PERCH-NIELSEN (& PRINS, 1979a).

Study area: The area between the North Sea and the Mediterranean.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 26 of which 18 were for the Upper Cretaceous section together with 14 subzones.

Comments: These authors used the framework of the eighteen zones and fourteen subzones proposed by SISSINGH (1977) as the main basis of their zonation scheme but included some minor modifications and additional nannofloral events. This zonation scheme is also compared in some detail to the one proposed in this paper owing to its relevance to the North Sea Basin.

*

Author and correlations: CRUX (1982).

Study area: Southern England.

Age: Upper Cretaceous, Campanian to Cenomanian interval.

Zones: 9 (2 of which were new) and 5 subzones.

Comments: CRUX (1982) recognised two new zones, the upper Campanian *Prediscosphaera stoveri* zone, and an upper Coniacian to lower Santonian *Lucianorhabdus maleformis* zone, together with two new Turonian subzones; the *Lucianorhabdus quadrifidus* and *Cylindralithus coronatus* subzones, none of which were recognised in the present study. CRUX also emended several other zones and although all the zones and subzones identified were defined on evolutionary appearances several of the zones have been modified and included in the present scheme but on a subzonal level. Many of the species ranges definded by CRUX show great similarity to those recorded in this study. A detailed comparison of this work has, therefore, been undertaken, because of its relatively close proximity to the study area, particularly in respect to the studies conducted to date by other authors.

*

Authors and correlations: PFLAUMANN & CEPEK (1982).

Study area: North West African Continental Margin.

Age: Cretaceous, Maastrichtian to Berriasian interval.

Zones: 21 of which 9 were for the Upper Cretaceous interval.

Comments: PFLAUMANN & CEPEK produced a zonal scheme for the Upper Cretaceous consisting of nine zones essentially based on PERCH-NIELSEN's (1977) zonation scheme with some modifications.

*

Authors and correlations: STRADNER & STEINMETZ (1984).

Study area: Site 530 of the Deep Sea Drilling Project, Angola Basin.

Age: Cretaceous, Maastrichtian to Albian interval.

Zones: 11 (1 of which was new).

Comments: STRADNER & STEINMETZ adopted the zonation scheme used by PFLAUMANN & CEPEK (1982). However, they did introduce a new late Turonian zone, based on a new species, namely *Liliasterites angularis*. This species, however, was not recorded in the present study.

6. Constraints of the Study

In the preceeding section a review of the most important Upper Cretaceous calcareous nannofossil zonations proposed in the last twenty two years was presented. Although the information contained within these schemes has been used, the following problems also had to be taken into account.

6.1. Ditch Cuttings

Many of the samples examined in this study were ditch cuttings. The use of ditch cuttings renders age dating by evolutionary appearances impractical because of the problems of caving and drilling mud contamination. Since many Upper Cretaceous calcareous nannofossil zonation schemes rely on evolutionary appearances almost exclusively, it is very difficult to apply any of these schemes directly to the study area.

ROMEIN (1979) has noted that since calcareous nannofossils are easily reworked the use of stratigraphic tops of species for zonal boundaries is highly undesirable. However, in the oil industry this is the only practical method to date rocks from cuttings, although this limitation cannot be overlooked.

6.2. Type of Drilling

In suitably aged turbo drilled well sections nannofossils are often the only means to date the material. Since the nannofossils recovered from samples from this type of drilling are frequently fragments this renders identification difficult unless the species is both robust and readily identifiable. These two parameters characterise the forms chosen as zonal markers in this paper.

6.3. Diagnostic Species

Many of the diagnostic species used in previous zonation schemes were not recorded in the present study. Many of the forms which were recorded in this study were employed in previous schemes as zonal markers, on the basis of evolutionary appearances and not stratigraphic tops.

6.4. Preservation

In general the nannofloral assemblages from the Upper Cretaceous chalks of the study area are quite poorly preserved. As a direct result of this, only the more dissolution resistant and robust forms were noted consistently in most well sections. This renders the use of delicate and dissolution prone species impractical as zonal or subzonal markers in a study conducted on this type of material. On a more local scale where preservation is more suitable, they can be used to confirm age dating and provide additional biostratigraphic datums.

6.5. Geological Structure

Since many of the oil well sections analysed in the present study are drilled on structural highs, the material received from them is atypical (often with many stratigraphic breaks being recorded). If the structure was active during the Late Cretaceous this would have had an effect on both sedimentation rates and water depth. This in turn could have an effect on species distribution (particularly foraminifera). It is not known to what extent this may have effected calcareous nannofossil distribution. The calcareous nannofossil marker species therefore used in this study were forms that seem to have a cosmopolitan distribution in the study area and not forms whose absence in a well may be explained either by dissolution or environmental constraints.

7. Biozonation

The zonal markers have been chosen with the following parameters in mind. The species should have a well defined stratigraphic top, be readily recognisable with a light microscope, occur in reasonabley large numbers and be relatively dissolution resistant. Species with well defined evolutionary appearances have been used on a subzonal level where possible. The zonal scheme proposed in this study is based on the ranges of the most important biostratigraphic species shown in Figures 5, 6 and 7 and consists of nineteen zones and ten subzones. The nineteen zones are defined on eighteen stratigraphic or acme tops of species and one stratigraphic base. The zones are numbered 1–19 from youngest to oldest (for oil industry purposes), and the prefix NK has been added to each of these numbers (representing an abbreviation for Nannoplankton Cretaceous). The ten subzones proposed have been defined on seven evolutionary appearances, and four stratigraphic or acme tops, which in some cases coincide with acme or stratigraphic zonal tops. The suffix A, B, C and D has been added to the zonal number for subzonal recognition (Fig. 4). The use of evolutionary appearances to define most of the subzonal boundaries has an obvious disadvantage. When using ditch cutting material they are of secondary importance and can only be recognised and applied with confidence in core and sidewall core material. Throughout this paper the terms first downhole occurrence (= stratigraphic top or extinction) and last downhole occurrence (= stratigraphic base or evolutionary appearance) are used. The use and relative importance of these subzones will be discussed in more detail under the relevant sections. The reader is referred to the works of THIERSTEIN (1976), CRUX (1982), STRADNER & STEINMETZ (1984) and PERCH-NIELSEN (1985) for good light microscope photographs of all the important marker species used in this study for the Upper Cretaceous and PERCH-NIELSEN (1979b) for the Lower Palaeocene species.

The zones and subzones are defined below in reverse stratigraphic order from youngest to oldest. A comparison with the schemes of SISSINGH (1977) who included data from Maastrichtian age cores from the Danish North Sea sector, PERCH-NIELSEN (& PRINS, 1979a) who reviewed the calcareous nannofossils from the area between the North Sea and the Mediterranean and CRUX (1982), who examined the calcareous nannofossils from the Campanian to Cenomanian interval of Southern England is shown in Fig. 8. These three schemes are the most comparable both in terms of information, results and relative proximity to the study area.

Since the scheme proposed is for use in the oil industry it is convenient to subdivide and discuss it in sections corresponding to clearly defined lithological units as follows (see Figure 2):

1. Ekofisk Formation (lowermost part; earliest Palaeocene age)
2. Tor Formation (Maastrichtian – late Campanian age)
3. Hod Formation (early Campanian – early Turonian age)
4. Plenus Marl Formation (late Cenomanian age)
5. Hidra Formation (Cenomanian age)
6. Hidra / Rødby Formation boundary (early Cenomanian – late Albian age)

As the earliest Palaeocene has been examined, the zonation scheme starts with the lowermost zone of the Tertiary. This section should be read in conjunction with Figures 4, 5 and 8.

7.1. Tertiary

7.1.1. Ekofisk Formation (lowermost part; earliest Paleocene age)

The lower part of the Early Paleocene in the study area consists of argillaceous limestones (equivalent to the so called Ekofisk "tight zone") culminating, in certain areas, with a dark grey calcareous shale which marks the Lower Palaeocene/Upper Cretaceous, Ekofisk/Tor Formation boundary. This shale development is comparable to a similar horizon recognised in onshore Denmark where it is referred to as the "Fish Clay". The Danmarks Geologiske Undersoegelse (DGU) (MICHELSEN, 1982) regarded a similar dark grey shale found in the Danish sector to be of a younger age than the "Fish Clay". The results of the present study cast some doubt on this. One zone has been recognised in the present study and this equates with the basal part of the Ekofisk Formation. The distribution of the stratigraphically most important species recorded in this zone are shown in Fig. 5 and reference to the original taxonomic description of these species is given in Appendix I.

7.1.1.1. *Markalius inversus* Zone NP 1

Authors: MOHLER & HAY (1967) emended MARTINI (1970) (syn. *Markalius astroporus*). Equates with the *Zygodiscus sigmoides* (acme) subzone D 2 and *Biantholithus sparsus* subzone D 1 of PERCH-NIELSEN (1979b).

Definition: Interval from the last downhole occurrence of *Cruciplacolithus tenuis* (form with feet) to the extinction level of most Upper Cretaceous calcareous nannofossils.

Age: Earliest Palaeocene.

Lithostratigraphic Unit: Ekofisk Formation (lowermost part).

Last occurrences (bases): *Thoracosphaera operculata, Thoracosphaera* spp., *Markalius* spp. and *Biantholithus sparsus*.

Remarks: The zone is characteristically very thin corresponding well to the findings of PERCH-NIELSEN

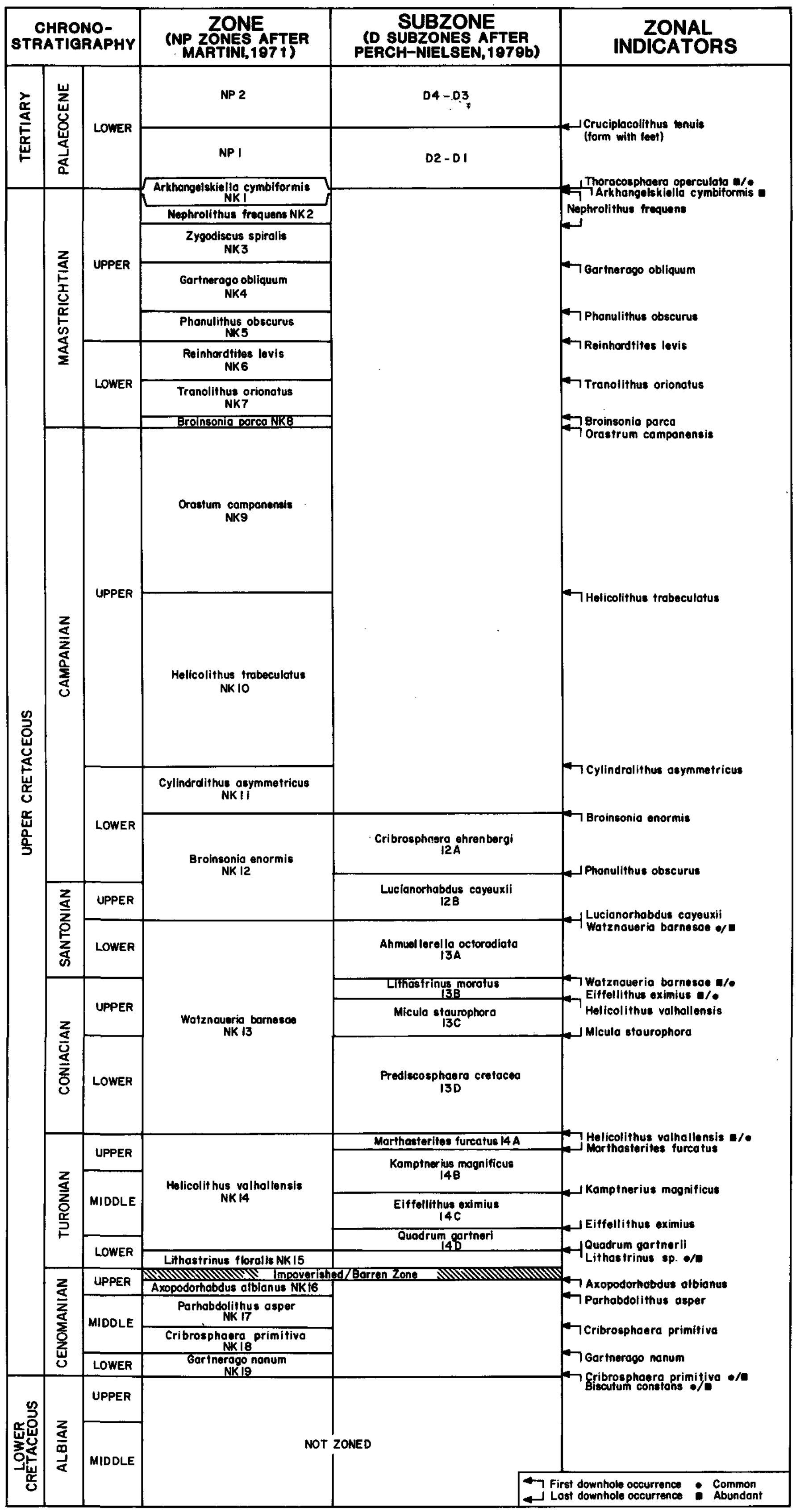


Fig. 4: Proposed Upper Cretaceous calcareous nannofossil zonation scheme for the study area.

(1979b) who reported this zone to be no more than 7 m thick and in some cases be locally absent from the study sections in Denmark. In general poorly preserved and quite impoverished nannofloral assemblages characterise the basal part of the Ekofisk Formation. Further Subdivision of the NP 1 zone into two subzones namely D 2 and D 1 was achieved by PERCH-NIELSEN (1979b), based on extensive work from onshore Danish sections. PERCH-NIELSEN (op. cit.) used a *Zygodiscus sigmoides* acme to delimit the D 1 / D 2 boundary. This acme was not noted in the study area, possibly because of environmental constraints (the Maastrichtian chalks of onshore Denmark are known to be from a more marginal setting (HARDMAN), 1982). These subzones may therefore, only be of "local" biostratigraphic use. PERCH-NIELSEN (1979b) also indicated that the nannofloral assemblages recorded in this zone consists almost exclusively of representatives of *Biscutum, Neocrepidolithus, Cyclagelosphaera* (mainly *Cyclagelosphaera reinhardtii*) *Zygodiscus sigmoides, Biantholithus sparsus, Thoracosphaera* spp., *Markalius* spp., and in some cases *Russellia multiplus*. In the present study the zone contains numerous specimens of *Markalius* spp. and *Thoracosphaera* spp., in particular *Thoracosphaera operculata* a species association which has been used to identify MARTINI's (1971) NP 1 zone. This latter species seems to have its last occurrence in the study area at the Tertiary/Cretaceous boundary. The restriction of *Thoracosphaera operculata* to the Tertiary agrees with the findings of PERCH-NIELSEN (1979b), whilst other authors have recorded it as ranging into the Maastrichtian. ROMEIN (1979) studied various Early Palaeocene sections in Denmark and recognised the *Biantholithus sparsus* zone at the base of the Tertiary. *Biantholithus sparsus*, however, was only very rarely recorded in the NP 1 zone in this study and is not considered to be consistent enough to warrant its use as a marker species in the present paper. Some Upper Cretaceous reworking is also recorded in this zone which may make it difficult

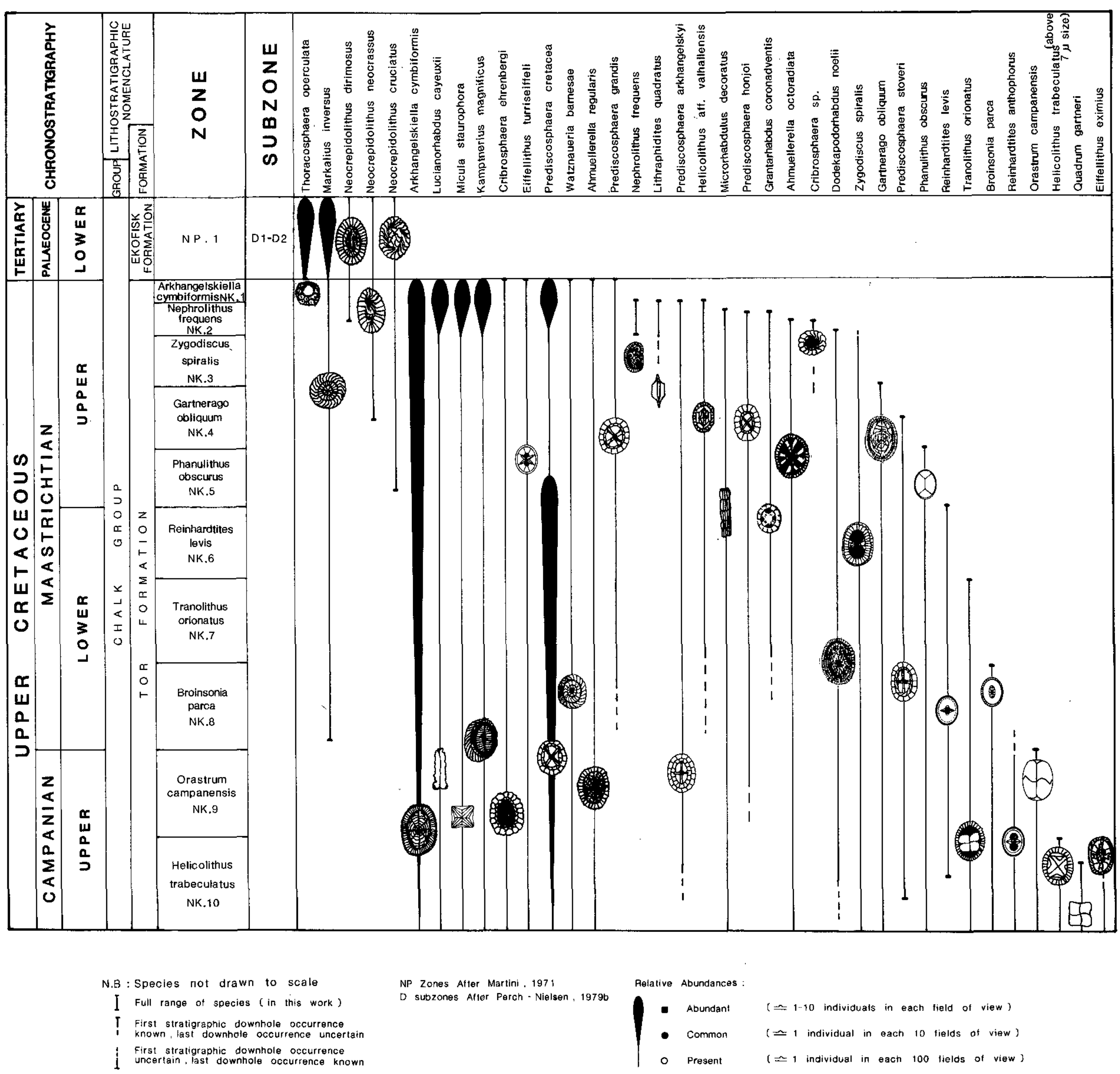


Fig. 5: Range chart showing distribution of selected important calcareous nannofossil species recorded in the lower Ekofisk and Tor Formations.

in recognising the Tertiary/Cretaceous boundary in ditch cuttings samples. The dominance of Thoracosphaerids in this zone, to the exclusion of *Braarudosphaera*, suggests that oceanic as opposed to neritic conditions prevailed after the Cretaceous/Tertiary boundary (suggested by HAQ & LOHMANN (1976) from quantitative analysis of Atlantic Early Palaeocene nannofloral assemblages). MÜLLER (1979) however, indicated that thoracospheres are more influenced by water temperature than water depth.

7.2. Late Cretaceous

7.2.1. Tor Formation (Maastrichtian – Late Campanian age)

The Tor Formation is one of the most important hydrocarbon reservoirs in the study area and can be divided into ten nannofloral zones (these are described and discussed below). The distribution of the stratigraphically most important and commonly recorded species in the Tor Formation is shown in Fig. 5. The distribution is given in reverse stratigraphic order, i. e. the order in which the species occur downhole in a well section. Detailed discussion of the taxonomy of each species is beyond the scope of this study and has already been discussed in detail by many previous authors. Appendix I, however, lists the references to the original taxonomic descriptions, and any subsequent emendments together with brief remarks.

7.2.1.1. *Arkhangelskiella cymbiformis* Partial Range Zone NK 1

Author: PERCH-NIELSEN (1972). MARTINI (1976) emended MORTIMER (this work). Equates possibly to the *Micula prinsii* zone (part) of PERCH-NIELSEN (1979b) and the *Nephrolithus frequens* taxon range zone (part) of CEPEK & HAY (1969) and SISSINGH (1977) (see remarks).

Definition: Interval from the extinction level of most Upper Cretaceous species to the first downhole occurrence of *Nephrolithus frequens*. In core and sidewall core material the last downhole occurrence of *Thoracosphaera operculata* can be used to mark the top of this zone, this is particularly useful when Upper Cretaceous reworking is present at the base of the Palaeocene.

Age: Latest Maastrichtian.

Lithostratigraphic Unit: Tor Formation (uppermost part).

First appearances (tops): *Arkhangelskiella cymbiformis* (common/abundant), *Lucianorhabdus cayeuxii* (common), *Micula staurophora* (common), *Kamptnerius magnificus* (common), *Prediscosphaera cretacea* (common), *Cribrosphaera ehrenbergii, Eiffellithus turriseifelii, Watznaueria barnesae, Ahmuellerella regularis* and *Prediscosphaera grandis*.
N. B.: *Neocrepidolithus cruciatus, Neocrepidolithus neocrassus, Neocrepidolithus dirimosus* and *Markalius inversus* cross the Tertiary/Cretaceous boundary in the study area since they have all been recorded in this NK 1 zone in core and sidewall core material.

Remarks: PERCH-NIELSEN (1972) introduced the *Arkhangelskiella cymbiformis* zone as the interval between the last downhole occurrences of *Tetralithus murus* or *Nephrolithus frequens* to the last downhole occurrence of *Reinhardtites anthophorus*. MARTINI (1976) subsequently emended this zone and defined it as the interval between first downhole occurrence of *Lithraphidites quadratus* to the first downhole occurrence of *Tetralithus trifidus*. PERCH-NIELSEN (1972), PFLAUMANN & CEPEK (1982) and STRADNER & STEINMETZ (1984) used it in the middle-early Maastrichtian interval. MARTINI (1976) and SISSINGH (1977) used an emended form of this zone for the late Maastrichtian section. In this paper it has been modified and used to mark the top zone in the Maastrichtian.
The absence in the present study of *Micula prinsii* (forms with distinct, long and sometimes bifurcated arms; the latest Maastrichtian zonal marker recorded by PERCH-NIELSEN, 1979b, in an onshore Danish Maastrichtian section) may be due to dissolution. Since HAKANSSON & HANSEN (1979b) (Pers. comm. PERCH-NIELSEN, 1979) note that *Micula prinsii* was only recorded at "Dania" (in one of the marl layers) among all the Danish boundary sequence examined by PERCH-NIELSEN. These authors indicate that *Micula prinsii* has probably suffered almost as severe dissolution here as in other Danish uppermost Maastrichtian sequences and it is clear that this form is unsatisfactory as a zonal marker when dealing with poorly preserved assemblages. The isolated occurrence at "Dania" however, does coincide with the unusually high standard of preservation noted at this locality by PERCH-NIELSEN (1979b). The absence of such dissolution controlled forms from the present study area might be expected since the latest Maastrichtian nannofloral assemblages are usually very poorly preserved, due in part to the development of hardgrounds, which severely effect nannofossil recovery.
The absence of *Nephrolithus frequens* from this uppermost zone of the Maastrichtian could also be explained by dissolution. THIERSTEIN (1981) recorded *Prediscosphaera cretacea* and *Cribrosphaera ehrenbergii*, which were both consistently recorded in this zone, as apparently more susceptible to dissolution than *Nephrolithus frequens* from experimental evidence. If this is true, then it may be assumed that its absence from the NK 1 zone may not be explained by dissolution. An alternative explanation is that this species could be ecologically controlled. SISSINGH (1977) recorded *Nephrolithus frequens* ranging to the Upper Cretaceous extinction horizon. ROMEIN (1979) noted that the *Nephrolithus frequens* zone was the highest zone recorded in the boreal region. It is, however, interesting to note that PERCH-NIELSEN (1979b) (Table 1) clearly shows the presence of the *Micula prinsii* zone above the *Nephrolithus frequens* zone based on studies from Denmark. The *Arkhangelskiella cymbiformis* zone has been defined as the topmost Maastrichtian zone in the study area and is possibly younger in age than the *Nephrolithus frequens* zone of SISSINGH (1977). It is often no more than 5 m in thickness.
Palaeoecologically the occurrence of common/abundant *Lucianorhabdus cayeuxii* in this zone, as suggested by THIERSTEIN (1976) is typical of boreal marginal conditions. PERCH-NIELSEN (1979a) indicates that *Arkhangelskiella cymbiformis* and *Kamptnerius magnificus* have a preference for marginal conditions. These two forms have a common/abundant distribution in the NK 1 zone. This, coupled with the large numbers of calcareous benthonic foraminifera, often recorded to-

wards the top of the Maastrichtian suggests that a shallowing of the water depth probably took place towards the end of the Maastrichtian in the study area. This shallowing may be reflected in some well sections with the development of a latest Maastrichtian age hardground which yields nannofloral assemblages containing the above species association dominance, together with common/abundant *Micula staurophora* (the relative abundance of which THIERSTEIN [1981] indicated is a good indicator of coccolith preservation).

7.2.1.2. *Nephrolithus frequens* Taxon-Range Zone NK 2

Authors: CEPEK & HAY (1969). Equates with Zone 26 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a).

Definition: The interval from the first to last downhole occurrence of *Nephrolithus frequens*.

Age: Latest Maastrichtian.

Lithostratigraphic Unit: Tor Formation (uppermost part).

First appearances (tops): *Nephrolithus frequens, Lithraphidites quadratus, Microrhabdulus decoratus , Prediscosphaera honjoi, Dodekapodorhabdus noeliae, Grantarhabdus coronadventis, Prediscosphaera arkhangelskyi, Ahmuellerella octoradiata* and *Zygodiscus spiralis*.

Last occurrences (bases): *Nephrolithus frequens* and *Neocrepidolithus dirimosus*.

Remarks: The absence of *Micula murus* from the study area, an important latest Maastrichtian marker species may be explained by its restriction to subtropical and tropical latitudes. PERCH-NIELSEN (1979a) indicated that the last downhole occurrence of *Ceratolithoides kamptneri* can be recognised in the *Nephrolithus frequens* zone, although, this species was not recorded in the present study. The occurrence of the total range of *Nephrolithus frequens* in the study area, which is considered by many authors to represent the top zone of Maastrichtian particularly for boreal areas (see remarks under zone NK 1) has been identified as the second zone within the Maastrichtian, although still in the uppermost part. SISSINGH (1977) notes the presence of this zone in late Maastrichtian age rocks from the Danish North Sea sector. PERCH-NIELSEN (1979b) and ROMEIN (1979) have both recognised this zone in onshore sections in Denmark, with the latter author defining it as the topmost zone of the Maastrichtian. The zone is rarely more than 20 m thick in the study area.

7.2.1.3. *Zygodiscus spiralis* Interval Range Zone NK 3

Author: MORTIMER (this work) (non VERBEEK, 1976b, 1977). Equates in part to Zone 25 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a).

Definition: Interval from the last downhole occurrence of *Nephrolithus frequens* to the first downhole occurrence of *Gartnerago obliquum*.

Age: Late Maastrichtian.

Lithostratigraphic Unit: Tor Formation (upper part).

Last occurrence (base): *Lithraphidites quadratus*.

Remarks: VERBEEK (1976b, 1977) introduced the *Zygodiscus spiralis* zone of Santonian age, defined as the interval between the last downhole occurrence of *Broinsonia parca* to the last downhole occurrence of *Zygodiscus spiralis*. In this paper the species name is used for the NK 3 interval zone of Maastrichtian age. This zone is considered to be late Maastrichtian in age but its exact relationship with the zones and subzones of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) is uncertain. The rare occurrence of *Lithraphidites quadratus* within this zone suggests that at least part of it equates to SISSINGH's (1977) 25c subzone. SISSINGH does note the recognition of subzones 25a and b in cores from the Danisch North Sea sector and Subzone 25c from the Netherlands.

In general the assemblages from this zone and the following *Gartnerago obliquum* partial range Zone NK 4 are poorly preserved and are characterised by their rather monotonous nature. This in itself can be used to identify general Maastrichtian age assemblages in the study area. The same is generally true for the foraminiferal assemblages over the upper part of the Maastrichtian. The NK 3 zone is of variable thickness.

7.2.1.4. *Gartnerago obliquum* Partial Range Zone NK 4

Author: MORTIMER (this work) (non MANIVIT, 1971 and ROTH, 1973). Equates in part to Zone 25 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a).

Definition: Interval from the first downhole occurrence of *Gartnerago obliquum* to first downhole occurrence of *Phanulithus obscurus*.

Age: Late Maastrichtian.

Lithostratigraphic Unit: Tor Formation (upper part).

First appearances (tops): *Gartnerago obliquum* and *Prediscosphaera stoveri*.

Last occurrence (base): *Neocrepidolithus neocrassus*.

Remarks: PERCH-NIELSEN (1979a, p. 237) noted the extinction of *Gartnerago obliquum* close to Zone 25/24 boundary of SISSINGH (1977). In this study it appears to have its first downhole occurrence between the outgoing of *Nephrolithus frequens* and the incoming *Phanulithus obscurus* and therefore has been used to delimit the top of the NK 4 zone in this scheme. MANIVIT (1971) introduced the *Gartnerago obliquum* zone of Turonian to Cenomanian age based on the evolutionary appearance of the nominate taxon. Subsequently ROTH (1973) used the species *Gartnerago obliquum* to name an interval zone between the evolutionary appearance of *Broinsonia parca* and the extinction of *Marthasterites furcatus* of Santonian age. *Prediscosphaera stoveri* was also found to have its extinction within this zone and may in the future be used to further subdivide the Upper Maastrichtian although its main limitation is that it is not always consistently recorded.

7.2.1.5. *Phanulithus obscurus* Partial Range Zone NK 5

Author: MORTIMER (this work) (non SISSINGH, 1977 and ROTH, 1978). Equates in part to Zone 25 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a).

Definition: Interval from the first downhole occurrence of *Phanulithus obscurus* to the first downhole occurrence of *Reinhardtites levis*.

Age: Late Maastrichtian.

Lithostratigraphic Unit: Tor Formation (upper part).

First appearance (top): *Phanulithus obscurus*.

Last occurrence (base): *Neocrepidolithus cruciatus*.

Remarks: SISSINGH (1977) noted the first downhole occurrence of *Calculites obscurus* (= *Phanulithus obscurus* of this study) at the top of Subzone 23a but also indicated that it had a questionable occurrence as high as his Subzone 25a. In the present study it was found to range into the upper Maastrichtian agreeing to some extent with the findings of SISSINGH (1977) and has been used as a zonal indicator. SISSINGH (1977) however, used *Calculites obscurus* as a zonal marker for the partial range zone of the same name of early Campanian age (earliest part), based on the first (regular) occurrence of *Calculites obscurus* (= first evolutionary appearance). ROTH (1978) introduced the *Tetralithus obscurus* (= *Phanulithus obscurus* of this study) or *Micula concava* zone to cover the Santonian interval of his study. In this study the extinction of *Phanulithus obscurus* is used to define the top of the zone of the same name although its stratigraphic base (last downhole occurrence) has also been used to define the Campanian / Santonian boundary (see Subzone 12A of this paper). SISSINGH (1977) noted the last downhole occurrence of *Arkhangelskiella cymbiformis* towards the base of his Zone 25 although he also recorded large forms of *Arkhangelskiella cymbiformis* to have an inferred range below this zone. In the present study this species was found to extend well below the Maastrichtian, this discrepancy is probably a result of individual authors species concept. In many well sections in this study the zone is quite thin.

7.2.1.6. *Reinhardtites levis* Partial Range Zone NK 6

Author: SISSINGH (1977) (= partial range Zone 24) and that of PERCH-NIELSEN (& PRINS, 1979a).

Definition: Interval from the first downhole occurrence of *Reinhardtites levis* to the first downhole occurrence of *Tranolithus phacelosus* (= *Tranolithus orionatus* of this paper).

Age: Early Maastrichtian.

Lithostratigraphic Unit: Tor Formation (middle part).

First appearance (top): *Reinhardtites levis*.

Remarks: SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) defined this zone on the same parameters as those used in this study to delimit Zone NK 6. PERCH-NIELSEN (1979a) mentions that the first downhole occurrence of *Reinhardtites levis* is a reliable event in the North Sea Basin, this was found to be true in the present study. In 1972, PERCH-NIELSEN defined a *Reinhardtites anthophorus* zone for the lower part of the Maastrichtian, SISSINGH (1977) questioned the identification of this form as possibly being *Reinhardtites levis*, which would concur with the findings of SISSINGH and those of the present study.

7.2.1.7. *Tranolithus orionatus* Partial Range Zone NK 7

Author: SISSINGH (1977) emended MORTIMER (this work). Equates in part to Zone 23 of SISSINGH (1977) PERCH-NIELSEN (& PRINS, 1979a).

Definition: Interval from the first downhole occurrence of *Tranolitus orionatus* (= *Tranolithus phacelosus* of SISSINGH, 1977) to the first downhole occurrence of *Broinsonia parca*.

Age: Early Maastrichtian.

Lithostratigraphic Unit: Tor Formation (middle part).

First appearance (top): *Tranolithus orionatus*.

Remarks: This zone is similar to that identified by SISSINGH (1977) as Zone 23 and PERCH-NIELSEN (& PRINS, 1979a), with the same marker species being used to define the top of the zone in both studies. However, PERCH-NIELSEN (& PRINS, 1979a) also noted an additional marker to delimit the upper boundary of this zone namely *Quadrum trifidum*. PERCH-NIELSEN in the same paper indicated that *Quadrum trifidum* has not been recorded from the North Sea area although CRUX (1982) reports the occurrence of *Quadrum trifidum* in Northern North Sea material. CRUX suggests that species such as *Quadrum trifidum* which are absent or rarely recorded in such areas follow distribution patterns which are controlled by factors other than simply water temperature.

7.2.1.8. *Broinsonia parca* Partial Range Zone NK 8

Author: SISSINGH (1977) (= partial range Subzone 23a [part] and Subzone 23b [part] of PERCH-NIELSEN [& PRINS, 1979a]) emended MORTIMER (this work).

Definition: Interval from the first downhole occurrence of *Broinsonia parca* to the first downhole occurrence of *Orastrum campanensis*.

Age: Earliest Maastrichtian.

Lithostratigraphic Unit: Tor Formation (middle part).

First appearance (top): *Broinsonia parca* (= *Aspidolithus parcus* of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a).

Last occurrences (bases): *Markalius inversus*, *Prediscosphaera grandis*, *Grantarhabdus coronadventis*.

Remarks: SISSINGH (1977) defined his 23a subzone as the interval between the extinction horizon of *Aspidolithus* ex. gr. *parcus* to the extinction level of *Reinhardtites anthophorus*. The NK 8 zone described in this study has emended this defintion. The extinction of *Orastrum campanensis* marks the base of the zone as *Reinhardtites anthophorus* was not recorded consistently in the study area.

PERCH-NIELSEN (& PRINS, 1979a) indicate that the first downhole occurrence of *Aspidolithus parcus* correlates with the Campanian/Maastrichtian boundary but these authors also noted that the boundary was not marked by a nannofossil event in THIERSTEIN (1976) and VERBEEK (1977) but indicates that SISSINGH (1977) correlates the first downhole occurrence of *Aspidolithus* ex gr. *parcus* with this boundary. SISSINGH however, showed *Aspidolithus* ex gr. *parcus* ranging into earliest Maastrichtian as do most other authors, a conclusion that has been followed in this study. This author also shows *Reinhardtites* sp. aff. *R. anthophorus* to occur within his Subzone 23a very close to the Maastrichtian/Campanian boundary. This species was not formally identified in the present study; neither was *Quadrum nitidum* which was shown by SISSINGH to have its extinction horizon at the 23b/23a boundary, although this species was shown to have a questionable occurrence as high as Subzone 25a. *Lucianorhabdus cayeuxii* is also shown to have its extinction at this boundary by SISSINGH, although this author notes that the extinction level of *Lucianorhabdus cayeuxii* is diachronous and can only be used on a local basis. SISSINGH noted its extinction at the end of the Maastrichtian in the North Sea Basin, a conclusion supported from evidence of this study.

In general the lower Maastrichtian interval is relatively thin in the study area. It is not uncommon for the lower Maastrichtian marker species to appear in rapid succession in some cases within 20 m of section. The early Maastrichtian nannofloral assemblages tend to be more diverse and better preserved than those noted from the overlying late Maastrichtian interval.

7.2.1.9. *Orastrum campanensis* Partial Range Zone NK 9

Author: MORTIMER (this work). Equates with Zone 23 (part) and Zone 22 (part) of SISSINGH (1977), Zones 23 and 22 (part) of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a) and the *Prediscosphaera stoveri* zone (part) of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Orastrum campanensis* to the first downhole occurrence of *Helicolithus trabeculatus* (above 7 micron size).

Age: Late Campanian.

Lithostratigraphic Unit: Tor Formation (lower part).

First appearance (top): *Orastrum campanensis*.

Last occurrence (base): *Prediscosphaera honjoi*.

Remarks: SISSINGH (1977) indicated that the Maastrichtian / Campanian boundary falls within the 23a subzone. PERCH-NIELSEN (& PRINS, 1979a) modified this slightly using the first downhole occurrence of *Aspidolithus parcus*, the marker species to delimit the top of the 23a subzone to coincide with the Maastrichtian / Campanian boundary. CRUX (1982) did not examine any material from above the upper Campanian so no direct comparison between his findings and those of SISSINGH (1977), PERCH-NIELSEN (& PRINS, 1979a) and this work can be made. In this paper the first downhole occurrence of *Orastrum campanensis* is taken to mark the Maastrichtian/Campanian boundary. SISSINGH (1977) noted the first downhole occurrence of *Reinhardtites anthophorus*, which marks the top of his Zone 22, to occur within the uppermost Campanian. This event was also recognised in this study but was not consistent enough to warrant its use as a zonal marker. PERCH-NIELSEN (& PRINS, 1979a) indicated that the first downhole occurrence of *Eiffellithus eximius* occurs at the top of Zone 22 of SISSINGH (1977). In the present study *Eiffellithus eximius* was found to often have its first downhole occurrence within the lowest part of late Campanian and can be used on a local basis to indicate the penetration of early Campanian age sediments in certain areas. PERCH-NIELSEN, (1979a) indicated that the last downhole occurrence of *Arkhangelskiella cymbiformis* occurs somewhere within the late Campanian, a conclusion which cannot be supported in this study as the form has been recorded in sediments of Santonian age.

7.2.1.10. *Helicolithus trabeculatus* Partial Range Zone NK 10

Author: MORTIMER (this work). Probably equates with Zones 22 (part) and 21 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Prediscosphaera stoveri* (part) zone of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Helicolithus trabeculatus* (above 7 micron size) to the first downhole occurrence of *Cylindralithus asymmetricus*.

Age: Late Campanian.

Lithostratigraphic Unit: Tor Formation (lower part).

First appearances (tops): *Helicolithus trabeculatus*, *Quadrum gartneri* and *Eiffellithus eximius*

Last occurrences (bases): *Prediscosphaera stoveri*, *Reinhardtites levis*, *Prediscosphaera arkhangelskyi* and *Dodekapodorhabdus noeliae*.

Remarks: It is difficult to equate accurately this zone to the zones and subzones defined by SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) for the lower part of the upper Campanian. This is because of the absence from the study area of marker species *Quadrum trifidum*, *Ceratolithoides arcuatus* and *Quadrum nitidum* which delimit their Zone 21 and Subzones 21c, 21b and 21a respectively. The evolutionary appearance of the latter species is used to mark the late/early Campanian boundary by SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a). The evolutionary appearance of *Reinhardtites levis* was used by SISSINGH (1977, 1978) to differentiate Zone 22 into 2 subzones (22b and 22a). *Reinhardtites levis* was noted to have its last downhole occurrence within the *Helicolithus trabeculatus* partial range NK 10 zone of this study. This event was recognised only in core and sidewall core material and therefore is of secondary importance.

Prediscosphaerea stoveri was also noted to have its last downhole occurrence in this zone. CRUX (1982) noted the evolutionary appearance of *Prediscosphaera stoveri* in the late Campanian of Southern England. CRUX however indicated that the level at which *Prediscosphaera stoveri* appears is uncertain in respect of SISSINGH's zonation scheme, but places it close to the Zone 20/19 boundary. PERCH-NIELSEN (1979a) located it within the middle of Zone 22 of SISSINGH (1977). CRUX (1982) also notes the evolutionary appearances of the following species in his late Campanian *Prediscosphaera stoveri* zone: *Heteromarginatus bugensis*, *Staurolithites ellipticus*, *Russellia multiplus*, *Discolithina polygonata* and *Orastrum campanensis*. None of these species, except *Orastrum campanensis* (which was found to range into the Santonian), were recorded in the present study. CRUX also records the first downhole occurrence of *Cylindralithus nudus* and *Pervilithus varius* within this zone. Neither of these two species were noted in the present study.

7.2.2. Hod Formation (Early Campanian – Early Turonian age)

The Hod Formation can be subdivided into three units, the Upper, Middle and Lower Hod Units. Parts of the Upper and Lower Hod Units are of secondary importance as hydrocarbon reservoirs. The Hod Formation can be subdivided into five zones and ten subzones. These are described and discussed below. Figure 6 shows the distribution of the most stratigraphically important and commonly recorded species in the Hod Formation.

7.2.2.1. *Cylindralithus asymmetricus* Partial Range Zone NK 11

Author: MORTIMER (this work). Probably equates with Zones 20, 19 and 18 (part) of SISSINGH (1977, 1978) and zones 20, 19, 18 (part) of SISSINGH (1977, 1978) as defined by PERCH-NIELSEN (& PRINS, 1979a) and the *Prediscosphaera stoveri* (part) and *Broinsonia parca* (part) zones of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Cylindralithus asymmetricus* to the first downhole occurrence of *Broinsonia enormis*.

Age: Early Campanian.

Lithostratigraphic Unit: Hod Formation (Upper Hod Unit [part]).

First appearance (top): *Cylindralithus asymmetricus* BUKRY.

Remarks: It is difficult to relate zone NK 11 to the zonal schemes of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) because of the lack of the diagnostic species used by these authors to define their zones and subzones. Top Zone 20 and 19, marker species *Quadrum nitidum* and *Ceratolithoides aculeus* respectively and the marker species to delimit the 19b / 19a boundary, *Bukryaster hayi* were all absent from the study area.
PERCH-NIELSEN (1979a) reported the absence of *Quadrum nitidum* and *Ceratolithoides aculeus* from the North Sea Basin. CRUX (1982) indicated that *Bukryaster hayi* was very rarely recovered in his study area and lists the other species as rare or absent.
The top of this zone often is marked by the appearance of *Cylindralithus* spp. *Micula staurophora* can be quite common in this zone and is probably related to the hardgrounds which may often develop over this interval. THIERSTEIN (1976) noted that the relative abundance of *Micula staurophora* in an assemblage is a good indicator of coccolith preservation, since this species is dissolution resistant.

7.2.2.2. *Broinsonia enormis* Partial Range Zone NK 12

Author: MORTIMER (this work). Probably equates to Zones 18 (part), 17 and 16 of SISSINGH (1977) and Zones 18 (part), 17 and 16 of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a), the *Broinsonia parca* (part) and *Lucianorhabdus cayeuxii* (part) zones of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Broinsonia enormis* to the first downhole occurrence of *Watznaueria barnesae* (common / abundant) or the last downhole occurrence of *Lucianorhabdus cayeuxii*.

Age: Early Campanian – Late Santonian.

Lithostratigraphic Unit: Hod Formation (Upper Hod Unit [part]).
For details on first and last downhole occurrences of species in this zone, refer to the relevant subzone descriptions of this zone and Fig. 6.

Discussion: This zone straddles the Campanian/Santonian boundary. In general quite diverse and moderately preserved nannofloral assemblages were sometimes noted in the lower Campanian. On penetration of the Santonian however, impoverished and poorly preserved nannofloral assemblages are recorded probably due to the hard nature of the limestone lithologies of this interval. The Campanian/Santonian boundary is not marked by any distinctive nannofloral event in the study area, although the last downhole occurrence of *Phanulithus obscurus*, which SISSINGH (1977) equated with this boundary, has been used in the present study. This zone can be subdivided into 2 subzones delimited by the last downhole occurrence of *Phanulithus obscurus*.

7.2.2.2.1. *Cribrosphaera ehrenbergii* Interval Range Subzone NK 12A

Author: MORTIMER (this work). Equates with Zones 18 (part) and 17 of SISSINGH (1977), Zone 18 (part) of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a); the *Broinsonia parca* (part) and *Lucianorhabdus cayeuxii* (part) zones of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Broinsonia enormis* to the last downhole occurrence of *Phanulithus obscurus*.

Age: Early Campanian.

Lithostratigraphic Unit: Hod Formation (Upper Hod Unit [part]).

First appearance (top): *Broinsonia enormis*.

Last occurrences (bases): *Broinsonia parca* and *Ahmuellerella regularis*.

Remarks: Within this subzone the last downhole occurrence of *Broinsonia parca* was noted. This suggests that the Zone 18/17 boundary of SISSINGH (1977) which is identified on the last downhole occurrence of *Aspidolithus* ex gr. *parcus* (= Broinsonia parca of this study) occurs within this subzone. PERCH-NIELSEN (& PRINS, 1979a) modified the boundary to coincide with the Campanian/Santonian boundary based on the last downhole occurrence of *Aspidolithus* sp. 1 (after PRINS, 1978). This resulted in the inclusion of Zone 17 of SISSINGH (1978) within the upper Santonian. PERCH-NIELSEN (& PRINS, 1979a) also note the last downhole occurrences of *Bukryaster hayi, Staurolithites mielnicensis, Parhabdolithus reniformis* and the first downhole occurrences of *Microrhabdulus belgicus, Reinhardtites biperforatus, Tranolithus gabalus, Bukryaster hayi* and *Zygodiscus noelae* within the lower part of the *Broinsonia parca* zone, which equates in part with NK 12A subzone. None of these species if recorded in the present study, were noted to have their first or last downhole occurrences within this subzone. CRUX (1982) also recorded the last (first downhole) occurrences of various species of *Nannoconus* within the middle to early Campanian. This event was not recognised in the present study and, as noted by various authors their occurrence is sometimes taken to indicate near shore conditions or Te-

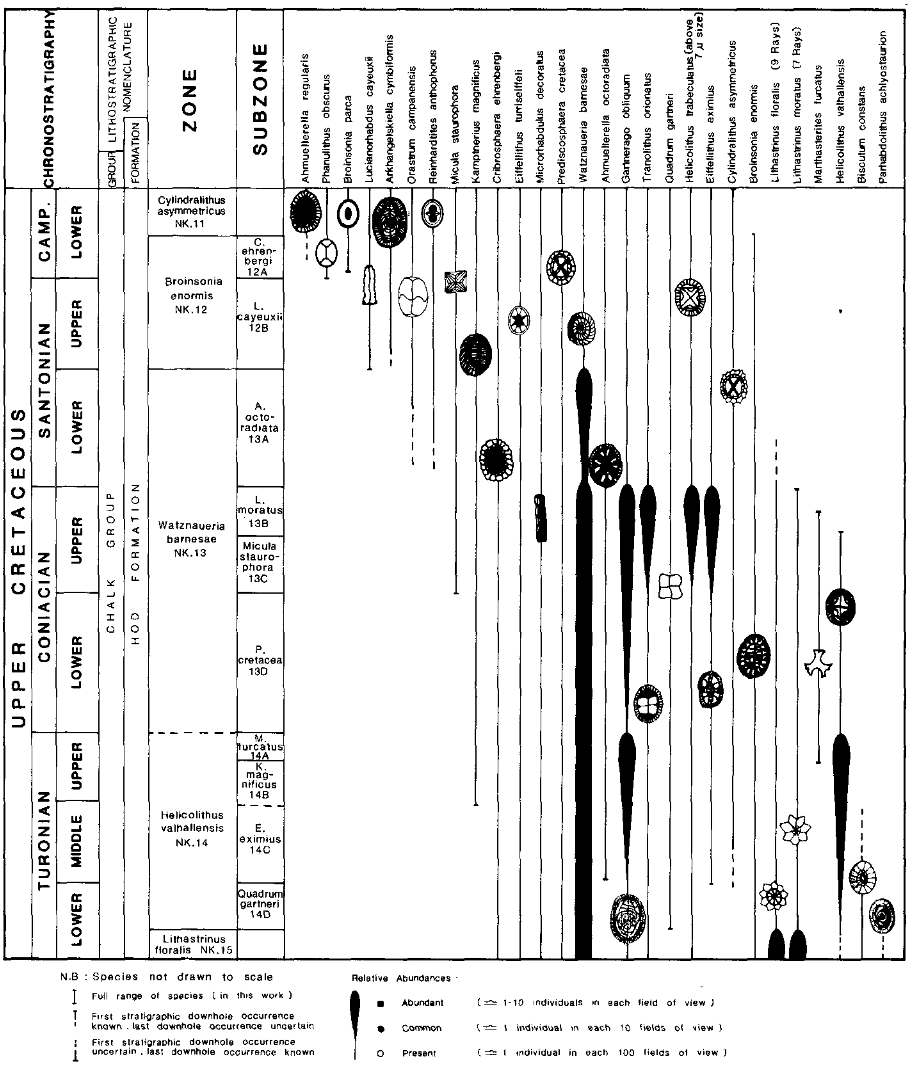


Fig. 6: Range chart showing distribution of selected important calcareous nannofossil species recorded in the Hod Formation.

thyan influence (which may in itself explain their absence). The base of this subzone is defined on the last downhole occurrence of *Phanulithus obscurus* following SISSINGH (1977), although, this event was correlated to the upper Santonian by PERCH-NIELSEN (& PRINS, 1979a). CRUX (1982) did not recognise this event and indicated that *Phanulithus obscurus* was difficult to separate from *Phanulithus ovalis* in material which had undergone overgrowth cementation and suggested that the last downhole occurrence of this species might be as low as the Turonian. For the purpose of this study the last downhole occurrence of *Phanulithus obscurus* is taken to approximate the boundary between the Campanian and Santonian as suggested by SISSINGH (1977).

7.2.2.2.2. *Lucianorhabdus cayeuxii* Partial Range Subzone NK 12B

Author: SISSINGH (1977). Equates with Zone 16 of SISSINGH (1977) as defined by PERCH-NIELSEN & PRINS (1979a) and the *Lucianorhabdus cayeuxii* zone (part) of CRUX (1982).

Definition: Interval from the last downhole occurrence of *Phanulithus obscurus* to the last downhole occurrence of *Lucianorhabdus cayeuxii*.

Age: Late Santonian.

Lithostratigraphic Unit: Hod Formation (Upper Hod Unit [part]).

Last occurrences (bases): *Lucianorhabdus cayeuxii* and *Arkhangelskiella cymbiformis*.

Remarks: SISSINGH (1977) indicated that his Zone 16 is solely of late Santonian age, with its upper limit corresponding to the Campanian/Santonian boundary. PERCH-NIELSEN (& PRINS, 1979a, p. 227) correlate this boundary to the 17/18 boundary of SISSINGH (1977), a boundary which is delimited by the last downhole occurrence of *Aspidolithus* sp. 1 (after PRINS, 1977).

CRUX's (1982) *Lucianorhabdus cayeuxii* zone straddles the Campanian/Santonian boundary and utilises the last downhole occurrence of *Broinsonia parca* to mark the top within the lower Campanian. For the purpose of this paper the findings of SISSINGH (1977) seem to be most applicable to the present study. PERCH-NIELSEN (& PRINS, 1979a) noted the first downhole occurrence of *Lithastrinus floralis* at the boundary between Zones 17 and 16 of SISSINGH (1977). In the present study this species was recorded towards the base of this subzone. CRUX (1982) noted the first downhole occurrence of *Lithastrinus floralis* within the upper Santonian which is similar to the findings of PERCH-NIELSEN (&

PRINS, 1979a) and also *Actinosphaera deflandrei*, this latter species was not recorded in the present study. He also attached importance to *Rucinolithus* sp. (an 8-rayed form whose rays radiate with only slight inclination and imbrication). This species appeared to have a last downhole occurrence within the upper Santonian. *Cylindralithus* sp. CRUX (1982) (a species defined as having no central cross with a complex rim and flaring distal cylinder, composed of several overlapping cycles of irregular elements) has its last downhole occurrence towards the base of his *Lucianorhabdus cayeuxii* zone. CRUX (1982) noted that this species can be difficult to distinguish from *Cylindralithus biarcus* under the light microscope. These latter three species were not observed in the present study. This author (1982) also indicated the last downhole occurrence of *Arkhangelskiella cymbiformis* within the Santonian, an observation confirmed in the present study and mentioned that the occurrence of *Arkhangelskiella cymbiformis* in much older sediments than previously recorded can be explained by inclusion of forms usually distinguished as *Arkhangelskiella specillata* in *Arkhangelskiella cymbiformis*. CRUX regarded these two species as preservational morphotypes, a conclusion supported by this study. The nannofloral assemblages recorded from this zone tend to be very poorly preserved.

7.2.2.3. *Watznaueria barnesae* Assemblage Zone NK 13

Author: MORTIMER (this work). Equates to Zones 15, 14, 13 and 12 (part) of SISSINGH (1977), Zones 15, 14, 13 of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a); the *Lucianorhabdus cayeuxii* (part) *Reinhardtites anthophorus, Lucianorhabdus maleformis, Micula staurophora* and *Eiffellithus eximius* (part) zones of CRUX (1982).

Definition: Interval from the first downhole occurrence of common/abundant *Watznaueria barnesae* or the last downhole occurrence of *Lucianorhabdus cayeuxii* to the first downhole occurrence of common/abundant *helicolithus valhallensis* (MORTIMER n. sp. in prep. see brief notes in Taxonomy, Appendix I).

Age: Early Santonian – Conacian.

Lithostratigraphic Unit: Hod Formation (Upper [part] and Middle [part] Hod Units).
For information on the various first and last downhole occurrences of the species in this zone, refer to the individual subzone sections.

Discussion: The Santonian part of this zone is marked by very impoverished and poorly preserved nannofloral assemblages (due in part to the relatively hard nature of the limestone lithologies of the Upper Hod Unit). The top of this zone is marked by a noticeable and distinctive increase in the numbers of *Watznaueria barnesae* which coincides closely, in suitable sections, with the last downhole occurrence of *Lucianorhabdus cayeuxii* and is taken to approximate the upper/lower Santonian boundary for the purpose of this study. The Coniacian/Santonian boundary is marked by a distinctive nannofloral break in the study area and the North Sea Basin in general.
Below the boundary moderately preserved and relatively rich nannofloral assemblages which are dominated by *Watznaueria barnesae* and to a lesser extent *Eiffellithus eximius, Gartnerago obliquum* and *Tranolithus orionatus* are recorded. A distinctive foraminiferal change is also noted at this boundary with assemblages dominated by *Globotruncana* spp. This contrasts with the very sparse and poorly preserved nannofloral assemblages noted in the overlying Santonian interval. The marked change at this boundary may reflect a change in environmental conditions. HATTNER et al. (1980) indicated that the dominance of such species as *Gartnerago obliquum* is more characteristic of nearshore assemblages, suggesting a shallowing of water depth over this interval. The abundance of *Watznaueria barnesae* is also almost certainly related to environmental parameters. NK 13 Zone can be subdivided into four subzones; these are described and discussed below, although most of them are of secondary importance because they are defined on stratigraphic bases. This assemblage zone is of very variable thickness in the study area.

7.2.2.3.1. *Ahmuellerella octoradiata* Interval Range Subzone NK 13A

Author: MORTIMER (this work). Equates to Zones 15 and 14 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Lucianorhabdus cayeuxii* (part) *Reinhardtites anthophorus* and *Lucianorhabdus maleformis* (part) zones of CRUX (1982).

Definition: Interval from the first downhole occurrence of common/abundant *Watznaueria barnesae* to the first downhole occurrence of common/abundant *Eiffellithus eximius*.

Age: Early Santonian.

Lithostratigraphic Unit: Hod Formation (Upper Hod Unit [part]).

First appearance (top): *Lithastrinus floralis*.

Last occurrence (bases): *Reinhardtites anthophorus* and *Orastrum campanensis*.

Remarks: SISSINGH (1977) noted the last downhole occurrence of *Reinhardtites anthophorus* which he used to define the base of the zone of the same name as did PERCH-NIELSEN (& PRINS, 1979a) and CRUX (1982) which all equate in part to subzone NK 13A. PERCH-NIELSEN (& PRINS, 1979a) recognised additional marker species to delimit the base of SISSINGH's Zone 15 namely *Lithastrinus grillii* and *Micula concava*. Neither of these species were recorded in the present study. CRUX (1982) noted the last downhole occurrence of *Reinhardtites minimus* and *Ahmuellerella regularis* within the lower Santonian. In the present study *Ahmuellerella regularis* was found to have its last downhole occurrence within the Campanian, and *Reinhardtites minimus* was only rarely recorded in the study area. CRUX (1982) also indicated the last downhole occurrence of *Lucianorhabdus cayeuxii* below that noted by SISSINGH (1977). In this paper the last downhole occurrence of *Lucianorhabdus cayeuxii* is taken to approximate to the late/early Santonian boundary following the findings of SISSINGH (1977).
CRUX (1982) indicated that his *Lucianorhabdus maleformis* zone is of early Santonian – late Coniacian age although, on p. 108 table 5.3. the *Lucianorhabdus maleformis* zone appears to be restricted to the lower Santonian which contradicts his original statement about the age of the zone (page 94). In view of this it is difficult to equate this zone to Subzone NK 13A. For the purpose of this paper it is taken as it appears in the text.

7.2.2.3.2. *Lithastrinus moratus* Interval Range Subzone NK 13B

Author: MORTIMER (this work). Equates with Zone 14 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Lucianorhabdus maleformis* zone (part) of CRUX (1982).

Definition: Interval between the appearance of common/abundant *Eiffellithus eximius* to the first downhole occurrence of *Helicolithus valhallensis* (MORTIMER n. sp. in prep. see Appendix I, Taxonomy for brief description).

Age: Late Coniacian.

Lithostratigraphic Unit: Hod Formation (Upper [part] to Middle [part] Hod Units).

First appearances (tops): *Lithastrinus moratus* and *Marthasterites furcatus*.

Remarks: CRUX (1982) noted the first downhole occurrence of *Marthasterites furcatus* and *Quadrum gartneri* subsp. 2 towards the top of the Coniacian. This latter species was diagnosed by CRUX (1982) as a subspecies of *Quadrum gartneri* which is composed of two layers each consisting of four blocks of calcite separated by sutures, the blocks are distorted rectangles in plan view and are arranged in an approximate square. In this study *Marthasterites furcatus* occurs towards the top of the upper Coniacian which agrees with the findings of CRUX. The species is known to occur in younger sediments elsewhere; SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) show this event as occurring within the early Campanian at the top of Zone 18 of these authors. In the study area *Marthasterites furcatus* can be used to indicate the penetration of Coniacian age sediments. One explanation for the relatively restricted occurrence of this species in the North Sea Basin could be because of the generally higher argillaceous content of the Coniacian and uppermost Turonian chalks. These in turn yield better preserved and richer nannofloral assemblages compared to the Santonian and late Turonian age chalks above and below. CRUX's *Quadrum gartneri* subsp. 2 has only an inferred range in the latest Coniacian, and was not distinguished from *Quadrum gartneri* in this study.

7.2.2.3.3. *Micula staurophora* Partial Range Subzone NK 13C

Author: SISSINGH (1977), emended MORTIMER (this paper) (non MANIVIT, 1971). Equates with Zone 14 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a); the *Lucianorhabdus maleformis* zone (part) of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Helicolithus valhallensis* (MORTIMER n. sp in prep. see Taxonomy in Appendix I for brief description) to the last downhole occurrence of *Micula staurophora*.

Age: Late Coniacian.

Lithostratigraphic Unit: Hod Formation (Middle Hod Unit [part]).

First appearance (top): *Helicolithus valhallensis* (MORTIMER n. sp in prep.).

Last occurrence (base): *Micula staurophora*.

Remarks: MANIVIT (1971) and THIERSTEIN (1976) used *Micula staurophora* to define a zone of the same name which ranged well into the Turonian. This is almost certainly due to the grouping of specimens of *Quadrum gartneri* with *Micula staurophora*, which would explain this apparent discrepancy. SISSINGH (1977) defined his Zone 14 as the interval between the last downhole occurrence of *Reinhardtites anthophorus* and the last downhole occurrence of *Micula* ex gr. *staurophora* of late Coniacian to early Santonian age. PERCH-NIELSEN (& PRINS, 1979a) and SISSINGH (1977) identified the same zone and placed the lower boundary at the late/early Coniacian boundary. CRUX (1982) however, defined his *Micula staurophora* zone as the interval between the last downhole occurrence of *Lucianorhabdus maleformis* and *Micula staurophora* of middle Coniacian age and showed it equating to Zone 13 (part) of SISSINGH (1977) which makes exact comparisons difficult. For the purpose of this paper the base of Subzone NK 13C is approximated to the late/early Coniacian boundary.

7.2.2.3.4. *Prediscosphaera cretacea* Interval Range Subzone NK 13D

Author: MORTIMER (this paper) (non THIERSTEIN 1971 and 1973). Equates with Zones 13 and 12 (part) of SISSINGH (1977); Zone 13 of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a); the *Micula staurophora* zone (part) and *Eiffelithus eximius* zone of CRUX (1982).

Definition: Interval between the last downhole occurrence of *Micula staurophora* to the first downhole appearance of common/abundant *Helicolithus valhallensis* (MORTIMER n. sp in prep. see Appendix I on Taxonomy for brief description).

Age: Early Coniacian.

Lithostratigraphic Unit: Hod Formation (Middle Hod Unit [part]).

Remarks: PERCH-NIELSEN (& PRINS, 1979a) note the last downhole occurrence of *Lithastrinus septenarius* as occurring within Zone 13 of SISSINGH (1977). However, this species was not recorded in the present study. CRUX (1982) records the last downhole occurrences of *Lithastrinus grilli* and *Lucianorhabdus arcuatus* towards the top of the *Micula staurophora* zone which equates in part with Subzone NK 13D, although neither of these species were recorded in the present study (see Remarks under Subzone NK 14A for further discussion of the earliest Coniacian to latest Turonian interval).

7.2.2.4. *Helicolithus valhallensis* Assemblage Zone NK 14

Author: MORTIMER (this paper). Equates to Zones 12 (part) and 11 (part) of SISSINGH (1978) and Zones 12 and 11 (part) of SISSINGH (1977) as indicated by PERCH-NIELSEN (& PRINS, 1979a); the *Eiffellithus eximius* (part) and *Quadrum gartneri* subsp. 1 (part) Zones and *Lucianorhabdus quadrifidus* and *Cylindralithus coronatus* (part) subzones of CRUX (1982).

Definition: The interval from the first downhole occurrence of abundant/common *Helicolithus valhallensis* (MORTIMER in prep.) to the first downhole appearance of common/abundant *Lithastrinus* spp.

Age: Turonian.

Lithostratigraphic Unit: Hod Formation (Middle [part] and Lower Hod Units).

For information on the first and last occurrences of species in this zone, refer to the relevant subzone descriptions and Fig. 6.

Discussion: The Coniacian/Turonian boundary appears to be located within a section comprising relatively argillaceous chalks. This is based on the distinctive increase in number of *Helicolithus valhallensis* which occurs within this unit and for the purpose of this paper is taken to approximate with this boundary. The exact dating of this event is difficult because of the almost complete lack of foraminiferal control and in part nannofloral data over this interval. From extrapolation of available nannofloral data above and below this event an approximate age can be assigned to this feature. *Micula staurophora* occurs above this event in the study area and has a reported last downhole occurrence within the Coniacian. SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) used it to define their late/early Coniacian boundary. CRUX (1982) placed the same event within the middle Coniacian, and indicates that sediments of definite Coniacian age occur above this event (probably of the lower part based on the work of the authors mentioned above). *Marthasterites furcatus* appeared to have a last downhole occurrence just below (approx. 10 m) this feature in the study area. This species was used by SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) to approximate the Coniacian/Turonian boundary. CRUX (op. cit.) indicated that *Marthasterites furcatus* although rare in his study was recorded within the Turonian of Southern England. If this latter line of evidence is followed the *Helicolithus valhallensis* event must lie in quite close proximity to the Coniacian/Turonian boundary. Even if the evidence of SISSINGH (1977) and PERCH-NIELSEN (1979a) is followed then this event is still close to the boundary. It must be emphasised that the approximation of this feature to this boundary is important since otherwise no clear distinction between Coniacian and Turonian age sediments would be possible, both in the study area and the North Sea Chalk province in general. Nannofloral preservation and recovery deteriorates markedly on penetration of the Lower Hod Unit, due to the very clean and relatively hard nature of the chalks which characterise this unit. This has resulted in great difficulty in confidently further subdividing the Turonian interval on the basis of calcareous nannofossils. Towards the base of the Lower Hod Unit, however, a marked increase in the argillaceous content of the chalks is recognised (resulting in a slight improvement in nannofloral recovery and preservation). Four subzones can be recognised covering the NK 14 zone. These are described and discussed below. They are however, of secondary importance since they utilise stratigraphic bases of species.

7.2.2.4.1. *Marthasterites furcatus* Concurrent Range Subzone NK 14A

Authors: CEPEK & HAY (1969) emended MORTIMER (this paper). Equates Zone 12 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a); the *Eiffellithus eximius* zone (part) of CRUX (1982).

Definition: Interval from the first downhole occurrence of common/abundant *Helicolithus valhallensis* (MORTIMER in prep.) to the last downhole occurrence of *Marthasterites furcatus*.

Age: Late Turonian.

Lithostratigraphic Unit: Hod Formation (Middle Hod Unit [part]).

Last occurrence (base): *Marthasterites furcatus*.

Remark: The *Marthasterites furcatus* zone was introduced by CEPEK & HAY ()1969) who defined it as the interval from the last downhole occurrence of *Arkhangelskiella ethmopora* to the last downhole occurrence of *Marthasterites furcatus* of Campanian age. SMITH (1975) indicated that a stratigraphical interval covering at least part of the Santonian to Coniacian interval was not covered in their study. Since then numerous revisions to the position of the upper boundary of this zone have been put forward including MANIVIT (1971), ROTH (1973), BUKRY (1975), VERBEEK (1976) and HAY (1977) all utilising different species to define the upper limit of this zone. SISSINGH (1977), PERCH-NIELSEN (& PRINS, 1979a) defined their *Marthasterites furcatus* Zone 13 as the interval between the last downhole occurrence of *Micula* ex gr. *staurophora* to the last downhole occurrence of *Marthasterites furcatus* of early Coniacian age. PERCH-NIELSEN (& PRINS 1979a) correleated the base of this zone to the Coniacian/Turonian boundary. This correlation agrees with the studies of THIERSTEIN (1976), VERBEEK (1976), PERCH-NIELSEN (1977), ROTH (1978), CEPEK & PFLAUMANN (1982) and STRADNER & STEINMETZ (1984), all of whom accept that this well documented worldwide event approximates to the stage boundary. In contrast, STRADNER (1963) and CRUX (1982) reported *Marthasterites furcatus* from within Turonian age sediments. According to STRADNER & STEINMETZ (1984, p. 570) the forms attributed to *Marthasterites furcatus* should in fact be included in the older genus *Liliasterites*. However, CRUX's photograph on pl. 22, pl. 5.5. Fig. 13 is clearly *Marthasterites furcatus*, thus the conclusion of this author, that the form ranges into the upper Turonian has been followed in the present study. The main limitation for use of this species is that it is being used as a stratigraphic base and its upper occurrence is apparently partly if not wholly controlled by the lithological nature of the chalk. For localised use, however, it appears to be a useful correlative event. CRUX (1982) indicated that his *Eiffellithus eximius* zone encompassed the lower Coniacian to middle Turonian section (based on the interval between the last downhole occurrence of *Micula staurophora* to the last downhole occurrence of *Eiffellithus eximius*. CRUX recorded the first downhole occurrence of *Cylindralithus coronatus* within the upper part of this zone, although THIERSTEIN (1976) noted that this species is easily destroyed by dissolution (which may explain its absence from the study area).

7.2.2.4.2. *Kamptnerius magnificus* Partial Range Subzone NK 14B

Author: ROTH (1978). Probably equates to Zone 12 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Eiffellithus eximius* zone (part) of CRUX (1982).

Definition: Interval from the last downhole occurrence of *Marthasterites furcatus* to the last downhole occurrence of *Kamptnerius magnificus*.

Age: Late – Middle Turonian.

Lithostratigraphic Unit: Hod Formation (Middle Hod Unit [part]).

Last occurrence (base): *Kamptnerius magnificus.*

Remarks: SISSINGH (1977) used the last downhole occurrence of *Lucianorhabdus maleformis* to define the base of his Zone 12 which straddles the Coniacian/Turonian boundary. PERCH-NIELSEN (& PRINS, 1979a) used the last downhole occurrence of *Eiffelithus eximius* to define the lower limit of SISSINGH's Zone 12, as did CRUX (1982) to define his *Eiffellithus eximius* zone. CRUX also recognised a number of species which have their last downhole occurrence within the upper Turonian i. e. *Reinhardtites biperforatus, Marthasterites furcatus, Quadrum gartneri* subsp. 2 and *Phanulithus obscurus*. In the present study only *Marthasterites furcatus* was found to have its last downhole occurrence close to the Turonian/Coniacian boundary. No subdivision of *Quadrum gartneri* into subspecies was attempted and the last downhole occurrences of *Reinhardtites biperforatus* and *Phanulithus obscurus* were not observed within the Turonian of the study area. The use of the last downhole occurrence of *Kamptnerius magnificus* for delimiting the base of the subzone of the same name was found to be fairly reliable in the study area. However, CRUX (1982) indicated that *Kamptnerius magnificus* has a last downhole occurrence within his *Quadrum gartneri* subsp. 1 zone of middle to early Turonian age. It is, therefore, quite likely that the presence of *Kamptnerius magnificus* may be controlled by lithology (i. e.it is absent in the hard limestones of the Lower Hod Unit (upper part) which would make this species use as a marker species very unreliable on a regional level. The occurrences of the hard platy limestones of the Lower Hod Unit however, are widespread in the study area and it is felt that this form can be used on a relatively local basis in the absence of any other species to mark the second subzone of the Turonian. THIERSTEIN (1976) noted that the first occurrence of *Kamptnerius magnificus* is time-transgressive through at least 5 my. and that it preferred cooler water temperatures which may explain this apparent discrepancy in the range of this species noted by various authors.

7.2.2.4.3. *Eiffellithus eximius* Partial Range Subzone NK 14C

Author: VERBEEK (1976) emended MORTIMER (this work, non ROTH, 1973). Probably equates with Zones 11 (part) and 12 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Eiffellithus eximius* (part) and *Quadrum gartneri* subsp. 1 (part) zones and *Lucianorhabdus quadrifidus* subzone (part) of CRUX (1982).

Definition: Interval from the last downhole occurrence of *Kamptnerius magnificus* to the last downhole occurrence of *Eiffellithus eximius.*

Last appearance (base): *Ahmuellerella octoradiata.*

Age: Middle Turonian.

Lithostratigraphic Unit: Hod Formation (Lower Hod Unit [part]).

Remarks: Very impoverished and poorly preserved nannofloral assemblages were recorded from this subzone. The use of stratigraphic bases to define the upper and lower boundaries of this subzone is unsatisfactory for purpose of the oil industry but no other age diagnostic taxa were recorded within the Lower Hod Unit. CRUX (1982) noted that *Parhabdolithus achlyostaurion, Axopodorhabdus dietzmannii, Staurolithites crux, Helicolithus bifarius, Tranolithus salillum, Flabellites oblonga* and *Corollithion signum* all have their first downhole occurrences within the lower part of his *Eiffellithus eximius* zone (which equates in part to Subzone NK 14C of this study). None of these species were found to have first downhole occurrences within this zone, which can probably be explained partly by the unsuitable nature of the lithology for good nannofloral recovery. *Parhabdolithus achlyostaurion* and *Axopodorhabdus dietzmannii* were found to have their first downhole occurrences lower in the section and *Tranolithus salillum* was felt to be a very unreliable marker. *Helicolithus bifarius, Corollithion signum* and *Staurolithites crux* were only rarely recorded in the study and hence no biostratigraphic significance was attached to them.

7.2.2.4.4. *Quadrum gartneri* Partial Range Subzone NK 14D

Authors: CEPEK & HAY (1969) (*Tetralithus pyramidus*), emended MANIVIT et al. (1977). Equates to Zone 11 (part) of SISSINGH (1978) and Zone 11 of SISSINGH (1977) as defined by PERCH-NIELSEN (& PRINS, 1979a); the *Quadrum gartneri* subsp. 1 zone (part), the *Lucianorhabdus quadrifidus* (part) and *Cylindralithus coronatus* (part) subzones of CRUX (1982).

Definition: Interval from the last downhole occurrence of *Eiffellithus eximius* to the last downhole occurrence of *Quadrum gartneri* and / or the first downhole occurrence of common/abundant *Lithastrinus* spp.

Age: Early Turonian.

Lithostratigraphic Unit: Hod Formation (Lower Hod Unit [part]).

Last occurrence (base): *Quadrum gartneri.*

Remarks: SISSINGH (1977) indicated that his *Tetralithus pyramidus* (= *Quadrum gartneri* of this study) zone may range into the late Cenomanian (latest part), although he considered that the zone was essentially early Turonian in age (a view that has been followed in the present study). PERCH-NIELSEN (& PRINS, 1979a) and CRUX (1982, p. 92) clearly showed the last downhole occurrence of his *Quadrum gartneri* subsp. 1 (defined as early forms whose elements in plan view show a distorted square shape so that the corners of the cube radiate outwards) delimits the Turonian/Cenomanian boundary. This author also noted that *Helicolithus anceps, Kamptnerius magnificus, Ahmuellerella octoradiata* and *Lucianorhabdus quadrifidus* all have their first downhole occurrences and *Octocyclus reinhardtii* its first downhole occurrence within the *Quadrum gartneri* subsp. 1 zone. *Lucianorhabdus quadrifidus* was not recorded and *Kamptnerius magnificus, Ahmuellerella octoradiata* and *Helicolithus anceps* were found to have higher last downhole occurrences in the Turonian than reported by CRUX.

7.2.2.5. *Lithastrinus* spp. Assemblage Zone NK 15

Author: MORTIMER (this work) (also see remarks).

Definition: The interval from the first downhole occurrence of common/abundant *Lithastrinus* spp. including *Lithastrinus floralis* (9 rays), *Lithastrinus moratus* (7 rays) and *Lithastrinus* sp. (8 rays) to the appearance of generally non calcareous dark to greenish grey shales of the Plenus Marl Formation.

Age: Early Turonian.

Lithostratigraphic Unit: Hod Formation (Lower Hod Unit [part]).

First appearance (top): *Parhabdolithus achlyostaurion*.

Last occurrence (base): *Helicolithus valhallensis* (MORTIMER in prep.).

Remarks: Difficulties have arisen in accurately equating zone NK 15 to the zonal schemes of SISSINGH (1977), PERCH-NIELSEN (& PRINS, 1979a) and CRUX (1982) (see remarks also in NK 14D). Since the stratigraphic position of this zone is just above the Plenus Marl Formation (the definition of which for the purpose of this paper follows that of the Geological Society London Special Report No. 9 on the Cretaceous) its recognition is considered to indicate penetration of earliest Turonian sediments. It may be considered to possibly equate to the basal part of Zone 11 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and CRUX's *Quadrum gartneri* subsp. 1 zone. The occurrence of this zone at the base of the Turonian is almost certainly related to environmental and / or lithological constraints, i. e. the increase in argillaceous content of the Lower Hod Formation over this interval. CRUX (1982) noted that the first downhole occurrence of *Octocyclus reinhardtii* is within the Early Turonian. This species was found to have its first downhole occurrence within the Late Cenomanian in this study. *Helicolithus valhallensis* has its last downhole occurrence towards the base of this subzone and *Parhabdolithus achlyostaurion* has its first downhole occurrence within this subzone in the study area.

7.2.3. Plenus Marl Formation (Late Cenomanian age)

The Cenomanian/Turonian boundary for the purpose of this paper is taken to coincide with the lithological boundary between the Hod and Plenus Marl Formations. This conclusion follows the Geological Society of London Special Report No. 9 on the Cretaceous which places the Cenomanian/Turonian boundary just above the Plenus Marl at the top of the *gracile* ammonite zone based on studies from both onshore and offshore

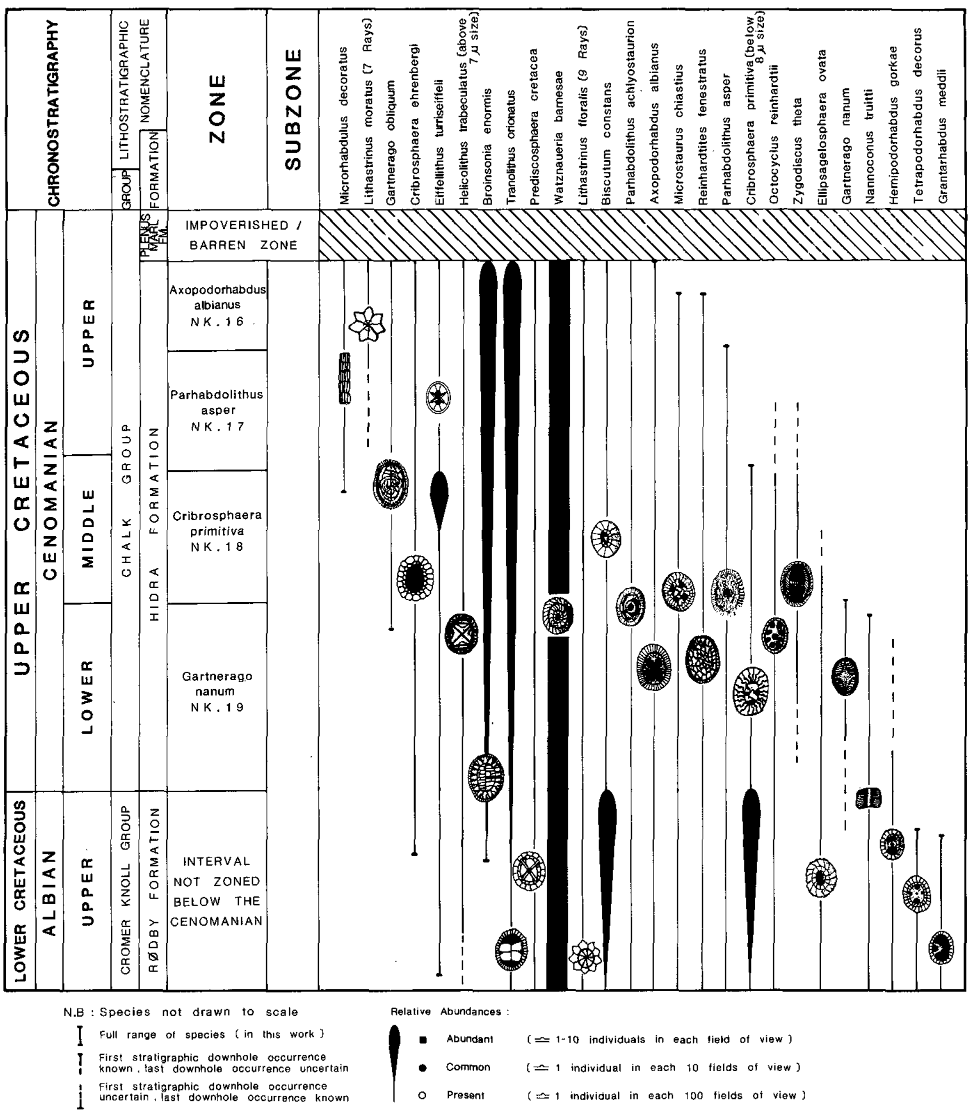


Fig. 7: Range chart showing distribution of selected important calcareous nannofossil species recorded in the Plenus Marl, Hidra and Rødby Formations.

British Isles. This formation is recognised as corresponding to the Barren/Impoverished zone described below and illustrated in Fig. 7.

7.2.3.1. Barren / Impoverished Zone

Author: MORTIMER (this work). Equates to Zone 10 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a), the *Eiffellithus turriseiffeli* zone (part) and *Microrhabdulus decoratus* subzone (part) of CRUX (1982).

Definition: Interval between the outgoing of common/abundant *Lithastrinus* spp. and the first downhole occurrence of *Axopodorhabdus albianus*.

Age: Late Cenomanian.

Lithostratigraphic Unit: Plenus Marl Formation.

Remarks: This zone is characteristically barren of calcareous nannofossils or occasionally yields very impoverished nannofloral assemblages containing only dissolution resistant species such as *Watznaueria barnesae*. The present author has recorded moderately diverse nannofloral assemblages from the Plenus Marl of Lincolnshire (paper in prep.). CRUX (1982) noted *Axopodorhabdus albianus, Microstaurus chiastius* and *Cretarhabdus striatus* as having extinctions close to the Turonian / Cenomanian boundary in Southern England. Two of these species were recorded in the present study as having their first downhole occurrence within the fossiliferous Upper Cenomanian interval immediately below the Plenus Marl Formation. *Cretarhabdus striatus* was only very rarely recorded in the present study and therefore was not used as a marker form. This zone has not been assigned a prefix NK or a number since its presence and thickness is solely governed by the thickness of a lithological unit. It is easily recognised from the "vipers tongue" like response on the gamma logs, and characteristically separates the Hod from Hidra Chalk Formations. Even though it does not contain any age diagnostic nannofossils, the Plenus Marl Formation is assigned a late Cenomanian age by direct comparison with onshore sections and the occurrence of well documented earliest Turonian age marker nannofossils just above it.

7.2.4. Hidra Formation (Cenomanian age)

The Hidra Formation represents the lowest unit of the Chalk Group and has no reservoir potential in the study area. This formation can be subdivided into 4 nannofloral zones. The distribution of the stratigraphically most important and commonly recorded species in this Formation are shown in Figure 7.

7.2.4.1. *Axopodorhabdus albianus* Partial Range Zone NK 16

Authors: CEPEK & HAY (1969) emended MORTIMER (this paper, non ROTH 1978). Equates with Zone 10 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a), the *Eiffellithus turriseiffelii* zone (part) and *Microrhabdulus decoratus* subzone (part) of CRUX (1982).

Definition: Interval from the first downhole appearance of *Axopodorhabdus albianus* to the first downhole appearance of *Parhabdolithus asper*.

Age: Late Cenomanian.

Lithostratigraphic Unit: Hidra Formation (upper part).

First appearances (tops): *Microstaurus chiastius, Reinhardtites fenestratus* and *Axopodorhabdus albianus*.

Remarks: ROTH (1978) introduced the *Axopodorhabdus albianus* NC 9 zone defined as the interval between the last downhole occurrence of *Eiffellithus turriseiffelii* to the last downhole occurrence of *Axopodorhabdus albianus* of Albian age. In the present study the extinction of *Axopodorhabdus albianus* has been employed to define the top of the zone of the same name of late Cenomanian age. The nannofloral assemblages within this zone are dominated by *Tranolithus orionatus* and *Broinsonia enormis*, a species association which on a local basis can be used to indicate the penetration of late Cenomanian age deposits in the absence of any of the characteristic marker species for delimiting this zone. The abundance of the latter species may suggest a shallowing during the deposition of the Hidra Formation (HATTNER et al. [1980] noted an increase in the relative abundance of *Broinsonia* in nearshore nannofloral assemblages). CRUX (1982) showed the first downhole occurrence of *Microstaurus chiastius, Cretarhabdus striatus, Lithraphidites acutum* and the last downhole occurrence of *Zygodiscus minimus* within the upper part of his *Eiffellithus turriseiffelii* zone (which corresponds in part to the NK 16 zone of this study). *Microstaurus chiastius*, and *Axopodorhabdus albianus* were found to have first downhole occurrences within this zone. *Cretarhabdus striatus* and *Lithraphidites acutum* were only rarely recorded in the study area and the last downhole occurrence of *Zygodiscus minimus* was not recognised. *Reinhardtites fenestratus* was noted to have its first downhole occurrence within this zone.

7.2.4.2. *Parhabdolithus asper* Partial Range Zone NK 17

Author: MORTIMER (this work). Probably equates with Zone 10 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) and the *Eiffellithus turriseiffelii* zone (part), the *Microrhabdulus decoratus* (part) and *Lithraphidites acutum* (part) subzones of CRUX (1982).

Definition: Interval from the first downhole occurrence of *Parhabdolithus asper* to the first downhole appearance of *Cribrosphaera primitiva* (below 8 micron size).

Age: Upper to Middle Cenomanian.

Lithostratigraphic Unit: Hidra Formation (upper part).

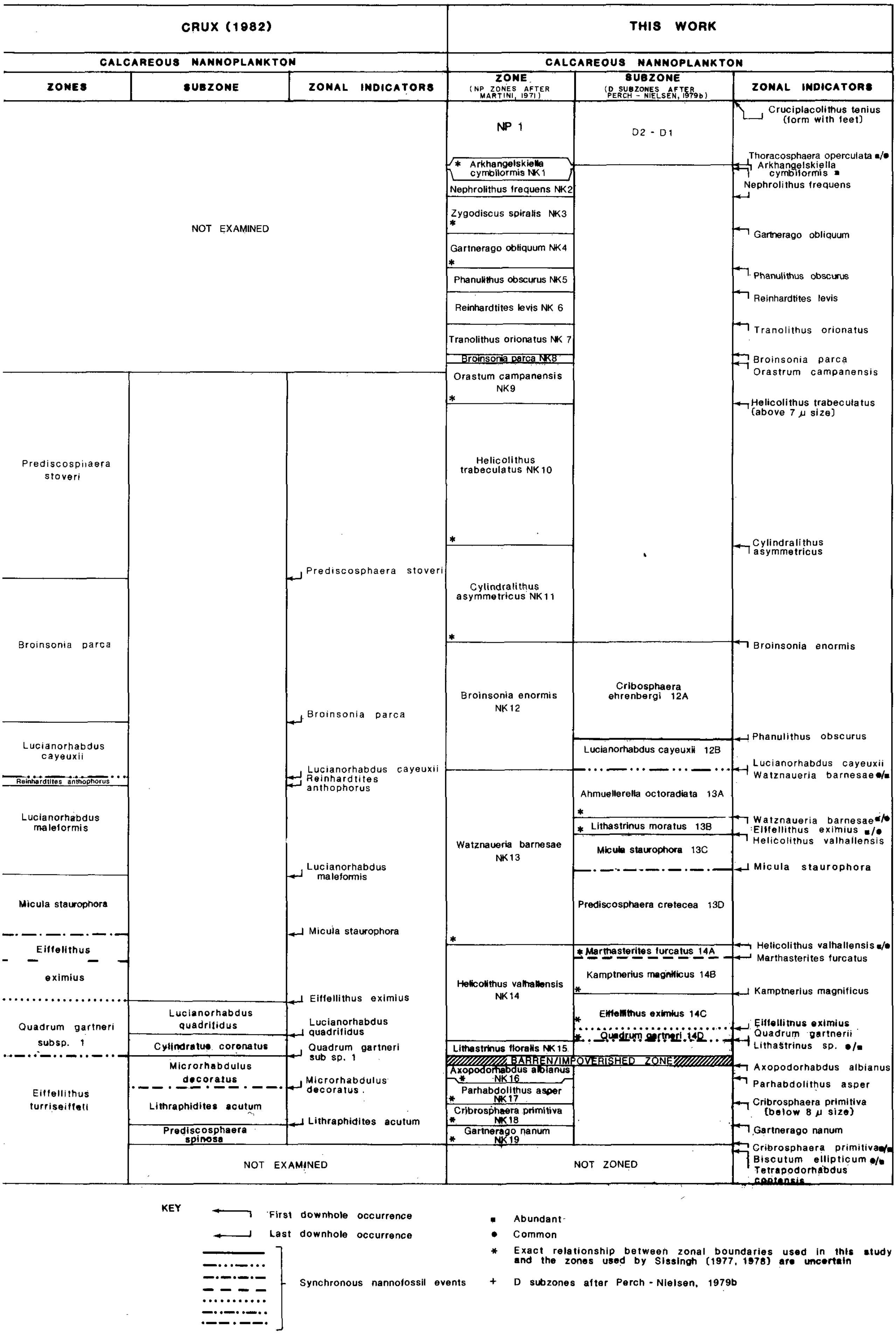
First appearances (tops): *Parhabdolithus asper, Zygodiscus theta* and *Octocyclus reinhardtii*.

Last occurrence (base): *Lithastrinus moratus*.

Remarks: PERCH-NIELSEN (& PRINS, 1979a) recognised the first downhole occurrence of *Gartnerago nanum* and *Cruciellipsis chiastia* (= *Microstaurus chiastius* of this study) towards the top of SISSINGH's Zone 10 (which would probably relate to horizons within the NK 17 zone of this study). CRUX (1982) and the present author recognise the occurrence of *Gartnerago nanum* towards the base of the Cenomanian and *Cruciellipsis chiastia* was found to have its extinction in the NK 16 zone. PERCH-NIELSEN (& PRINS, 1979a) also note the last downhole occurrence of *Ahmuellerella octoradiata, Microrhabdulus decoratus, Lithraphidites acutum* and *Corollithion exiguum* within SISSINGH's Zone 10. The exact re-

Chrono-stratigraphy			Sissingh (1977, 1978) Calcareous Nannoplankton Zone			Zonal indicators	Perch-Nielsen and Prins (1979a) / Perch-Nielsen (1979b) Calcareous Nannoplankton Zones after Sissingh (1977) & Martini (1971)	Zonal indicators
Tertiary	Palaeocene	Lower	Not examined				NP 1 D2	FIRST CRUCIPLACOLITHUS TENUIS
							NP 1 D1	FIRST BIANTHOLITHUS SPARSUS LAST NEPHROLITHUS FREQUENS
Upper Cretaceous	Maastrichtian	Upper	26		Nephrolithus frequens	LAST NEPHROLITHUS FREQUENS FIRST NEPHROLITHUS FREQUENS	26	FIRST NEPHROLITHUS FREQUENS
			25	C	Arkhangelskiella cymbiformis	FIRST LITHRAPHIDITES QUADRATUS	25	FIRST LITHRAPHIDITES QUADRATUS
				B		FIRST ARKHANGELSKIELLA CYMBIFORMIS		FIRST ARKHANGELSKIELLA CYMBIFORMIS
				A		LAST REINHARDTITES LEVIS		LAST REINHARDTITES LEVIS
		Lower	24		Reinhardtites levis	LAST TRANOLITHUS PHACELOSUS	24	LAST TRANOLITHUS PHACELOSUS
			23	B	Tranolithus phacelosus	LAST ASPIDOLITHUS PARCUS	23	LAST ASPIDOLITHUS PARCUS
	Campanian	Upper		A		LAST REINHARDTITES ANTHOPHORUS		LAST REINHARDTITES ANTHOPHORUS
			22	B	Quadrum trifidum	FIRST REINHARDTITES LEVIS	22	FIRST REINHARDTITES LEVIS
				A		FIRST QUADRUM TRIFIDUM		FIRST QUADRUM TRIFIDUM
			21	C	Quadrum nitidum	LAST CERATOLITHOIDES ARCUATUS	21	LAST CERATOLITHOIDES ARCUATUS
				B		FIRST CERATOLITHOIDES ARCUATUS		FIRST CERATOLITHOIDES ARCUATUS
				A		FIRST QUADRUM NITIDUM		FIRST QUADRUM NITIDUM
		Lower	20		Ceratolithoides aculeus	FIRST CERATOLITHOIDES ACULEUS	20	FIRST CERATOLITHOIDES ACULEUS
			19	B	Phanulithus ovalis	LAST BUKRYASTER HAYI	19	LAST BUKRYASTER HAYI
				A		LAST MARTHASTERITES FURCATUS		LAST MARTHASTERITES FURCATUS
			18	B	Broinsonia parca (s. 1)	FIRST BUKRYASTER HAYI	18	FIRST BUKRYASTER HAYI
				A		FIRST BROINSONIA PARCA (S. 1)		FIRST ASPIDOLITHUS SP. 1
			17		Phanulithus obscurus	FIRST PHANULITHUS OBSCURUS	17	FIRST PHANULITHUS OBSCURUS
	Santonian	Upper	16		Lucianorhabdus cayeuxii	FIRST LUCIANORHABDUS CAYEUXII	16	FIRST LUCIANORHABDUS CAYEUXII
		Lower	15		Reinhardtites anthophorus	FIRST REINHARDTITES ANTHOPHORUS	15	FIRST REINHARDTITES ANTHOPHORUS
	Coniacian	Upper	14		Micula staurophora (s. 1)	FIRST MICULA STAUROPHORA (s. 1)	14	FIRST MICULA DECUSSATA
		Lower	13		Marthasterites furcatus	FIRST MARTHASTERITES FURCATUS	13	FIRST MARTHASTERITES FURCATUS
	Turonian	Upper	12		Lucianorhabdus maleformis	FIRST LUCIANORHABDUS MALEFORMIS	12	FIRST EIFFELLITHUS EXIMUS
		Middle Lower	11		Quadrum gartneri	FIRST QUADRUM GARTNERI	11	FIRST QUADRUM GARTNERI
	Cenomanian	Upper Middle	10		Microrhabdulus decoratus	FIRST MICRORHABDULUS DECORATUS	10	FIRST MICRORHABDULUS DECORATUS
		Lower	9		Eiffellithus turriseiffeli	FIRST EIFFELLITHUS TURRISEIFFELI	9	FIRST EIFFELLITHUS TURRISEIFFELI
Lower Cret.	Albian	Upper						

Fig. 8: Comparison of the Upper Cretaceous schemes used by SISSINGH (1977, 1978), PERCH-NIELSEN (& PRINS, 1979a), CRUX (1982) and this work.
Correction: In the last column (zonal indicators) *Biscutum ellipticum* must read *Biscutum constans*.


CRUX (1982)
THIS WORK
CALCAREOUS NANNOPLANKTON
CALCAREOUS NANNOPLANKTON
ZONES
SUBZONE
ZONAL INDICATORS
ZONE (NP ZONES AFTER MARTINI, 1971)
SUBZONE (D SUBZONES AFTER PERCH - NIELSEN, 1979b)
ZONAL INDICATORS
NOT EXAMINED
NP 1
D2 - D1
Cruciplacolithus tenius (form with feet)
Thoracosphaera operculata ■/●
* Arkhangelskiella cymbiformis NK1
Arkhangelskiella cymbiformis ■
Nephrolithus frequens NK2
Nephrolithus frequens
Zygodiscus spiralis NK3
Gartnerago obliquum NK4
Gartnerago obliquum
Phanulithus obscurus NK5
Phanulithus obscurus
Reinhardtites levis NK 6
Reinhardtites levis
Tranolithus orionatus NK 7
Tranolithus orionatus
Broinsonia parca NK8
Broinsonia parca
Orastrum campanensis
Orastum campanensis NK9
Helicolithus trabeculatus (above 7 µ size)
Helicolithus trabeculatus NK10
Prediscosphaera stoveri
Cylindralithus asymmetricus
Prediscosphaera stoveri
Cylindralithus asymmetricus NK11
Broinsonia parca
Broinsonia enormis
Broinsonia enormis NK12
Cribosphaera ehrenbergi 12A
Broinsonia parca
Lucianorhabdus cayeuxii
Phanulithus obscurus
Lucianorhabdus cayeuxii 12B
Reinhardtites anthophorus
Lucianorhabdus cayeuxii
Reinhardtites anthophorus
Lucianorhabdus cayeuxii
Watznaueria barnesae ●/■
Ahmuellerella octoradiata 13A
Lucianorhabdus maleformis
Watznaueria barnesae ■/●
Eiffellithus eximius ■/●
Helicolithus valhallensis
Lithastrinus moratus 13B
Watznaueria barnesae NK13
Micula staurophora 13C
Lucianorhabdus maleformis
Micula staurophora
Micula staurophora
Prediscosphaera cretecea 13D
Micula staurophora
Eiffellithus eximius
Helicolithus valhallensis ■/●
Marthasterites furcatus 14A
Marthasterites furcatus
Kamptnerius magnificus 14B
Helicolithus valhallensis NK14
Kamptnerius magnificus
Eiffellithus eximius
Lucianorhabdus quadrifidus
Eiffellithus eximius 14C
Eiffellithus eximius
Quadrum gartneri subsp. 1
Lucianorhabdus quadrifidus
Quadrum gartneri
Quadrum gartneri 14D
Cylindratus coronatus
Quadrum gartneri sub sp. 1
Lithastrinus floralis NK15
Lithastrinus sp. ●/■
BARREN/IMPOVERISHED ZONE
Microrhabdulus decoratus
Axopodorhabdus albianus NK16
Axopodorhabdus albianus
Eiffellithus turriseiffeli
Microrhabdulus decoratus
Parhabdolithus asper NK17
Parhabdolithus asper
Lithraphidites acutum
Cribrosphaera primitiva NK18
Cribrosphaera primitiva (below 8 µ size)
Lithraphidites acutum
Gartnerago nanum NK19
Gartnerago nanum
Prediscosphaera spinosa
Cribrosphaera primitiva ●/■
NOT EXAMINED
NOT ZONED
Biscutum ellipticum ●/■
Tetrapodorhabdus coptensis
KEY
First downhole occurrence
Last downhole occurrence
Synchronous nannofossil events
■ Abundant
● Common
* Exact relationship between zonal boundaries used in this study and the zones used by Sissingh (1977, 1978) are uncertain
+ D subzones after Perch - Nielsen, 1979b

lationship of these events with respect to the NK 17 zone of this paper is uncertain, since *Corollithion exiguum* was absent from this study, *Lithraphidites acutum* was only rarely recorded and *Ahmuellerella octoradiata* was found not to range below the Turonian. CRUX (1982) showed the first downhole occurrence of *Parhabdolithus angustus* and last downhole occurrences of *Cylindralithus coronatus* and *Microrhabdulus decoratus* within the Late Cenomanian, which would equate with the interval covering the NK 16 and NK 17 (part) zones of this paper. *Cylindralithus coronatus* was not recorded in this study (perhaps because it is very prone to dissolution). *Microrhabdus decoratus* was found to have its last downhole occurrence in the NK 18 zone and *Parhabdolithus angustus* appeared to have a first downhole appearance higher in the Upper Cretaceous.

7.2.4.3. *Cribrosphaera primitiva* Partial Range Zone NK 18

Author: MORTIMER (this work). Equates with Zones 10 (part) and 9 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a); the *Eiffellithus turriseifellii* zone (part) and the *Lithraphidites acutum* subzone (part) of CRUX (1982).

Definition: Interval from the first downhole appearance of *Cribrosphaera primitiva* (below 8 micron size) to the first downhole appearance of *Gartnerago nanum*.

Age: Middle Cenomanian.

Lithostratigraphic Unit: Hidra Formation (part).

First appearances (tops): *Cribrosphaera primitiva* (below 8 micron size) and *Ellipsagellosphaera ovata*.

Last occurrence (base): *Microrhabdulus decoratus*.

Remarks: CRUX (1982) showed Zone 10 of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) to range well within his *Lithraphidites acutum* subzone of middle Cenomanian age (which equates in part with the NK 18 zone of this paper). CRUX also noted the first downhole occurrences of *Corollithion kennedyi, Lithraphidites pseudoquadratus* and *Lithraphidites alatus* together with the last downhole occurrence of *Cylindralithus biarcus* in the middle Cenomanian. None of these events were recognised in the present study. CRUX (op. cit.) also listed the first downhole occurrence of *Gartnerago nanum* and *Parhabdolithus asper* within the middle Cenomanian. Both of these events were recognised in the present study but were found to have lower and higher occurrences respectively compared to these findings. Only rare occurrences of *Lithraphidites acutum* and *Lithraphidites alatus* were recorded in this zone. PERCH-NIELSEN (& PRINS, 1979a) noted the last downhole occurrences of *Microrhabdulus decoratus, Lithraphidites acutum* and *Corollithion exiguum* at the base of zone 10 which probably equates to some point within NK 18 Zone. The last downhole occurrence of *Microrhabdulus decoratus* noted by SISSINGH (1977), which he equates to the late/early Cenomanian boundary, also probably occurs within this zone: The exact relationship of these events to zone NK 18 of the present study is uncertain.

7.2.4.4. *Gartnerago nanum* Partial Range Zone NK 19

Author: MORTIMER (this work). Equates with the Zone 9 (part) of SISSINGH (1977) and PERCH-NIELSEN (& PRINS, 1979a) the *Eiffellithus turriseiffelii* zone (part), *Prediscosphaera spinosa* (part) subzone of CRUX (1982).

Definition: Interval between the first downhole occurrence of *Gartnerago nanum* to the first downhole occurrence of common/abundant *Cribrosphaera primitva* and/or *Biscutum constans*.

Age: Early Cenomanian.

Lithostratigraphic Unit: Hidra Formation (lower part).

First appearances (tops): *Gartnerago nanum, Hemipodorhabdus gorkae, Nannoconus truitti*.

Last occurrences (bases): *Gartnerago obliquum* and *Zygodiscus theta*.

Remarks: The first downhole occurrence of *Gartnerago nanum* is taken to approximate with the middle/early Cenomanian boundary for the purpose of this paper. This form is shown by CRUX (1982) to have its first downhole occurrence close to the middle/early Cenomanian boundary. This generalisation has been made because it is a form that is consistently recorded in the study area. PERCH-NIELSEN (& PRINS, 1979a) noted the last downhole occurrence of *Corollithion completum* and the first downhole occurrence of *Braarudosphaera africana* and *Ellipsagelosphaera keftalrempti* within the early Cenomanian. None of these events were recognised in the present study. CRUX (1982) indicated the last downhole occurrence of *Corollithion kennedyi, Gartnerago obliquum, Pervilithus varius* and *Lithraphidites acutum*, and the first downhole occurrence of *Ellipsagelosphaera forbesii, Parhabdolithus infinitus* and *Zygodiscus erectus* within the early Cenomanian. Only the last downhole occurrence of *Gartnerago obliquum* and first downhole appearance of *Parhabdolithus infinitus* were noted to occur within the early Cenomanian in this study, the other species being absent or very rare.

7.2.5. Upper / Lower Cretaceous Boundary, Cenomanian / Albian and Hidra Formation / Rødby Formation Boundaries

Detailed descriptions and defining zones for the Lower Cretaceous is beyond the scope of the present study. Most wells drilled in the chalk hydrocarbon fields terminate (T. D.) within the Hidra Formation or topmost Cromer Knoll Group. The uppermost Albian calcareous nannofossils noted from the study area will, however, be considered. The distribution of the stratigraphically most important and commonly occurring calcareous nannofossils is shown diagrammatically in Figure 7.

Discussion: PERCH-NIELSEN (1979a) noted problems in recognising the Albian/Cenomanian boundary due to the correlation of coccolith stratigraphy with the stratotypes, but indicated the first downhole occurrences of *Hayesites albiensis, Braarudosphaera quinquecostata, Braarudosphaera regularis* and *Braarudosphaera stenorhetha* to occur near to this horizon. However, none of these species were recorded in the present study. THIERSTEIN (1976) indicated that the last downhole occurrence of *Lithraphidites alatus*, which was only rarely found in this study, marked the Cenomanian/Albian boundary, but VERBEEK (1977) has recorded this species below the last downhole occurrence of *Eiffellithus turriseiffelii* (Late Albian). CRUX (1982) did not examine Albian age deposits but indicated, the *Eiffel-*

lithus turriseiffelii zone ranging into the upper Albian, based on the studies of THIERSTEIN (1971), SISSINGH (1977) and MANIVIT et al. (1977). Similarly, TAYLOR (1982) recognised the base of the *Eiffellithus turriseiffelii* zone within the upper Albian, but was unable to define the upper limit of this boundary since the study of Cenomanian age deposits was beyond the scope of her study.

In the present study the Upper/Lower Cretaceous boundary, which coincides with the Hidra/Rødby Formation boundary, is marked by an abundant first downhole occurrence of *Biscutum constans* and/or *Cribrosphaera primitiva*. These events are almost certainly related in some way to the lilthological change from chalky limestones of the Hidra Formation to the argillaceous limestones and calcareous claystones of the Rødby Formation of Late Albian age. It is interesting to note that the foraminiferal assemblages recorded at this boundary are dominated by hedbergellids, a group whose distribution pattern is linked to the proximity to the shoreline. If their presence is governed by lithology then this event will be diachronous, although they have been recognised consistently in the study area and dated accurately by palynological means. The recognition of these two events is dependent on sampling and thickness of the Upper Albian section, which can be quite condensed in the study area. The subsequent first downhole appearances of *Tetrapodorhabdus coptensis* and *Grantarhabdus meddii* appear to be the next biostratigraphically important nannofossil events in the Upper Albian of the study area.

8. Conclusions

❶ The scheme presented in the preceeding sections was designed for use in the oil industry.

❷ The main basis for the scheme is the use of stratigraphic (first downhole occurrences) and acme tops of species for zonal subdivision of the Upper Cretaceous. Stratigraphic bases of species (last downhole occurrences) are used for subzonal markers and are of secondary importance.

❸ The scheme has been found to work in the study area and hopefully will be developed and modified further to include other areas of the North Sea Basin when more well material is released.

❹ Difficulty has arisen in correlating this scheme with other disciplines particularly macrofossils. In the case of foraminifera direct correlation is hampered by the poor preservation, and lack of many age diagnostic planktonic forms. Palynology is not routinely carried out in chalk sections because the nature of the lithology is not conducive to good palynomorph recovery. Preliminary studies in the Northern North Sea in the more argillaceous Shetland Group indicate that greater integration between the three disciplines will probably be achieved.

❺ The use of species acme tops over the Santonian to Turonian interval proved the only reliable method to subdivide this section on the basis of calcareous nannofossils. Palynology has often used acmes and influxes of various species to subdivide certain parts of the Mesozoic and Cenozoic. The application of this method in nannofossil biostratigraphy has only recently been undertaken and in this study has proved to be very useful. It is hoped that this method will be more extensively used in industry, although with the limitation that these acmes or influxes may be influenced by environmental constraints (and may, therefore, be diachronous on a regional scale, although on a local (Block) or field scale they may be extremely useful). The two acme tops used in this study to define the tops of the *Watznaueria barnesae* NK 13 and *Helicolithus valhallensis* NK 14 Zones, have been recognised throughout most of the North Sea Basin.

❻ Some species have been found to have reduced stratigraphic ranges compared to those previously reported, due probably to preservation or environmental factors. They may, however, be used on a local basis.

❼ In certain parts of the scheme, the events are approximated to the stage boundaries, particularly where there is no direct comparison with other disciplines.

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Appendix 1
Taxonomy

This appendix lists the 56 most important calcareous nannofossils recorded in this study, in downhole stratigraphic order. Reference is made to the original description together with any subsequent emendments. Brief remarks are made where applicable.

○ *Thoracosphaera operculata* BRAMLETTE & MARTINI 1964. BRAMLETTE and MARTINI 1964 p. 305; pl. 5, figs. 3–7.

○ *Markalius inversus* (DEFLANDRE, in DEFLANDRE & FERT 1954) BRAMLETTE & MARTINI 1964. DEFLANDRE (1954) p. 150; pl. 9, figs. 4–5 (not figs. 6–7). BRAMLETTE & MARTINI (1964) p. 302; pl. 2, figs. 4–9; pl. 7, figs. 2a–b.

○ *Neocrepidolithus dirimosus* (PERCH-NIELSEN 1979b) PERCH-NIELSEN 1981. PERCH-NIELSEN (1979b) p. 124; pl. 2, figs. 16–18, 23, 24. PERCH-NIELSEN (1981) fig. 1 plate 6.

○ *Neocrepidolithus neocrassus* (PERCH-NIELSEN 1968) ROMEIN 1979. PERCH-NIELSEN (1968) p. 36; pl. 2, fig. 9, text-fig. 11. ROMEIN (1979) p. 183; pl. 1, fig. 6.

○ *Neocrepidolithus cruciatus* (PERCH-NIELSEN 1979b) PERCH-NIELSEN 1981. PERCH-NIELSEN (1979b) p. 124; pl. 2, figs. 11–13, 25, 26.
Remarks: ROMEIN (1979) introduced the genus *Neocrepidolithus* to distinguish it from the Jurassic genus *Crepidolithus* NOËL 1968 by the imbrication of the elements in the wall.

○ *Arkhangelskiella cymbiformis* VEKSHINA 1959. VEKSHINA (1959) p. 66; pl. 2, figs. 3a–6.
Remarks: *Arkhangelskiella cymbiformis* is used in this study to include all normally perforate species which some authors would assign to *Arkhangelskiella specillata* VEKSHINA 1959 because they cannot be distinguished from one another due to preservational constraints in particular overgrowth cementation.

○ *Lucianorhabdus cayeuxii* DEFLANDRE 1959. DEFLANDRE (1959) p. 142; pl. 4, figs. 11–25.
Remarks: *Lucianorhabdus cayeuxii* was the only species of *Lucianorhabdus* to be consistently recognised in the study area.

○ *Micula staurophora* (GARDET 1955) STRADNER 1963. GARDET (1955) p. 534; pl. 10, fig. 96. BRAMLETTE & MARTINI (1964) p. 318; pl. 6, figs. 7–11.
Remarks: *Micula staurophora* is used in preference to *Micula decussata* VEKSHINA 1959 in this study.

○ *Kamptnerius magnificus* DEFLANDRE 1959. DEFLANDRE (1959) p. 135; pl. 1, figs. 1–4.
Remarks: See THIERSTEIN (1976) for list of synonyms of this species (THIERSTEIN [op. cit.] included *Kamptnerius punctatus* STRADNER 1963 in this list). This form has been recognised in the Northern North Sea in well preserved material generally in the absence of *K. magnificus*. In the study area no perforate forms were recorded due to preservational constraints and because of this *K. magnificus* is taken to include all these normally perforate forms.

○ *Cribrosphaera ehrenbergii* ARKHANGELSKY 1912. ARKHANGELSKY (1912) p. 142; pl. 6, figs. 19, 20. GARTNER (1968) p. 40; pl. 1, figs. 14, 15; pl. 3, fig. 2; pl. 6, fig. 7; pl. 12, fig. 2; pl. 15, fig. 11.
Remarks: There appears to be extensive variation in outline shape of *Cribrosphaera ehrenbergii* ranging from elliptical to circular in the forms recorded in this study. However, shape is not considered to be a viable criterion to subdivide this species. Since only light microscope studies were carried out, the species *Cribrosphaera ehrenbergii* includes all these variously shaped forms.

○ *Eiffellithus turriseiffelii* (DEFLANDRE in DEFLANDRE and FERT 1954) REINHARDT 1965. DEFLANDRE & FERT (1954) p. 149; text-fig. 65, pl. 8, figs. 15–16. REINHARDT (1965) p. 32.
Remarks: PERCH-NIELSEN (1979a) fig. 12 illustrated several species which appear to be very similar to *Eiffellithus turriseiffelii* but are distinguished from one another on differences in structure. In most cases, particularly when the spine is missing, it is very difficult to subdivide them. They are for the purpose of this study all included in *Eiffellithus turriseiffelii* except where distinct differences can be identified.

○ *Prediscosphaera cretacea* (ARKHANGELSKY 1912) GARTNER 1968. ARKHANGELSKY (1912) p. 410; pl. 6, figs. 12, 13. GARTNER (1968) p. 19; pl. 2, figs. 10–12; pl. 3, fig. 8; pl. 4, figs. 19–24; pl. 6, figs. 14, 15; pl. 9, figs. 1–4; pl. 12, figs. 1; pl. 14, figs. 20–22; pl. 18, fig. 8; pl. 22, figs. 1–3; pl. 23, figs. 4–6; pl. 25, figs. 12–14; pl. 26, fig. 2.
Remarks: The various subspecies of *Prediscosphaera cretacea* have all been grouped together since they are not preserved (well enough) to be able to recognise the subtle differences used to differentiate them under the light microscope.

○ *Watznaueria barnesae* (BLACK 1959) PERCH-NIELSEN 1968. BLACK (1959) p. 325; pl. 9, figs. 1, 2. PERCH-NIELSEN (1968) p. 69; fig. 32, pl. 22, figs. 1–7; pl. 23, figs. 1, 4, 5, 16.

○ *Ahmuellerella regularis* (GORKA 1957) BUKRY 1969. VERBEEK 1977. GORKA (1957) p. 246; pl. 2, fig. 4. GARTNER (1968) p. 23; pl. 3, fig. 12; pl. 5, figs. 17–18; pl. 6, figs. 17–18; pl. 12, fig. 11.

○ *Prediscosphaera grandis* PERCH-NIELSEN (1979a) PERCH-NIELSEN (1968) (1979a). BRAMLETTE & MARTINI (1964) p. 30; pl. 2, figs. 13–16. PERCH-NIELSEN (1968) pl. 13, figs. 1, 5, 6; pl. 14, fig. 2. PERCH-NIELSEN (1979a) p. 267; pl. 2, fig. 8.

○ *Nephrolithus frequens* (GORKA 1957) REINHARDT & GORKA 1967. GORKA (1957) p. 282; pl. 5, fig. 7. REINHARDT & GORKA (1967) pl. 32, figs. 5–12.

○ *Lithraphidites quadratus* BRAMLETTE & MARTINI 1964. BRAMLETTE & MARTINI (1964) p. 310; p. 106, figs. 16, 17; pl. 7, fig. 8.

○ *Prediscosphaera arkhangelskyi* (REINHARDT 1965) PERCH-NIELSEN 1984. REINHARDT (1965) p. 30–40; pls. 1–3, text-figs. 1–6. PERCH-NIELSEN (1984) p. 43.

○ *Microrhabdulus decoratus* DEFLANDRE 1959. DEFLANDRE (1959) p. 140; pl. 4, figs. 1–5.

○ *Prediscosphaera honjoi* BUKRY 1969. BUKRY (1969) p. 39; pl. 18, figs. 4–6.

○ *Grantarhabdus coronadventis* (REINHARDT 1966a) GRÜN in GRÜN & ALLEMANN 1975. REINHARDT (1966a) p. 26; pl. 23, fig. 29, 30. GRÜN in GRÜN & ALLEMANN (1975) p. 184.

○ *Ahmuellerella octoradiata* (GORKA 1957) REINHARDT 1966. GORKA (1957) p. 259; pl. 4, fig. 10. REINHARDT (1966) p. 24; pl. 22, figs. 3, 4.

○ *Dodekapodorhabdus noeliae*. PERCH-NIELSEN 1968. PERCH-NIELSEN (1968) p. 47; pl. 8, figs. 1–5; pl. 9, fig. 1–7.

○ *Zygodiscus spiralis* BRAMLETTE & MARTINI 1964. BRAMLETTE & MARTINI (1964) p. 303; pl. 14, figs. 6–8.

○ *Gartnerago obliquum* (STRADNER 1963) THIERSTEIN 1974. STRADNER (1963) p. 10; pl. 1, fig. 2. THIERSTEIN (1974) p. 640; pl. 5, fig. 1–9; pl. 6, figs. 1–10; pl. 7, figs. 1–10.

○ *Prediscosphaera stoveri* (PERCH-NIELSEN 1968) WIND & WISE 1976. PERCH-NIELSEN (1968) p. 66; pl. 6, figs. 11–13. WIND & WISE (1976) p. 305; pl. 42, fig. 3.

○ *Phanulithus obscurus* (DEFLANDRE, 1959) WIND & WISE 1976. DEFLANDRE (1959) p. 138; pl. 3, figs. 26–29. WIND & WISE (1976) p. 304; pl. 31, fig. 5; pl. 33, figs. 2–6; pl. 34, figs. 2, 4; Pl. 36, fig. 6.

○ *Reinhardtites levis* PRINS & SISSINGH 1977. PRINS & SISSINGH (1977) p. 61; pl. 1, figs. 1–3.

○ *Tranolithus orionatus* (REINHARDT 1966a) REINHARDT 1966b. REINHARDT (1966a) p. 42; pl. 23, figs. 22, 31–33. REINHARDT (1966b) p. 522.

○ *Broinsonia parca* (STRADNER 1963) BUKRY 1969. STRADNER (1963) p. 10; pl. 1, figs. 3, 3a. BUKRY (1969) p. 23; pl. 3, figs. 3–10.

○ *Reinhardtites anthophorus* (DEFLANDRE 1959) PERCH-NIELSEN 1968, SISSINGH 1977. DEFLANDRE (1959) p. 137; pl. 1, figs. 21, 22. PERCH-NIELSEN (1968) (pars) p. 38; pl. 5, figs. 1, 5, 6 (non text-figs. 13, 14, pl. 5, figs. 2–4, 7, 8). SISSINGH (1977) p. 61; pl. 1, figs. 5a–d.

○ *Orastrum campanensis* (CEPEK 1970) WIND & WISE 1976. CEPEK (1970) p. 246–247; pl. 25, figs. 1, 2.

○ *Helicolithus trabeculatus* (GORKA 1957) VERBEEK 1977. GORKA (1957) p. 277; pl. 3, fig. 9. REINHARDT & GORKA (1967) p. 250; pl. 31, figs. 19, 23; pl. 32, fig. 1; text fig. 5.

○ *Quadrum gartneri* PRINS & PERCH-NIELSEN 1977. PRINS & PERCH-NIELSEN (1977) p. 177; pl. 1, figs. 9–10.

○ *Eiffellithus eximius* (STOVER 1966) PERCH-NIELSEN 1968. STOVER (1966) p. 138; pl. 2, fig. 15, 16; pl. 8, fig. 15. PERCH-NIELSEN (1968) p. 30; pl. 3, figs. 8–10.

○ *Cylindralithus asymmetricus* BUKRY 1969. BUKRY (1969) p. 42; pl. 19, figs. 9–12.

○ *Broinsonia enormis* (SHUMENKO 1968) MANIVIT 1971. SHUMENKO (1968) p. 33; pl. 1, fig. 3. MANIVIT (1971) p. 105–106; pl. 1, figs. 18–20.

○ *Lithastrinus floralis* STRADNER 1962. STRADNER (1962) p. 370–372; pl. 2, figs. 7–11.

○ *Lithastrinus moratus* STOVER 1966. STOVER (1966) p. 149; pl. 7, fig. 20.

○ *Marthasterites furcatus* (DEFLANDRE in DEFLANDRE & FERT 1954) DEFLANDRE 1959. DEFLANDRE & FERT (1954) p. 168; pl. 13, fig. 14. DEFLANDRE (1959) p. 139; pl. 2, figs. 3–12; pl. 3, figs. 1, 5.

○ *Helicolithus valhallensis* MORTIMER new species (MORTIMER in prep.).
Remarks: A species of *Helicolithus* in which the cross bars are subaxially aligned.

○ *Biscutum constans* (GORKA 1957) BLACK in BLACK & BARNES 1959. GORKA (1957) p. 279; pl. 4, fig. 7. BLACK & BARNES (1959) p. 325; pl. 10, fig. 1.

○ *Parhabdolithus achlyostaurion* HILL (1976). HILL (1976) p. 145–146; pl. 9, figs. 24–29.

○ *Axopodorhabdus albianus* (BLACK 1965) BLACK 1967, WIND & WISE 1976. BLACK (1965) p. 133; fig. 10. BLACK (1967) p. 143–144. WIND & WISE (1976) p. 297.

○ *Microstaurus chiastius* (WORSLEY 1971) GRÜN in GRÜN & ALLEMANN 1975. WORSLEY (1971) pl. 310; pl. 1, figs. 42–44. GRÜN in GRÜN & ALLEMANN (1975) p. 181; text-fig. 22; pl. V, figs. 1–4.

○ *Reinhardtites fenestratus* (WORSLEY 1971) THIERSTEIN in ROTH & THIERSTEIN 1972. WORSLEY (1971) p. 1305; pl. 1, figs. 33–35. ROTH & THIERSTEIN (1972) p. 437; pl. 8, figs. 1–12.

○ *Parhabdolithus asper* (STRADNER 1963) MANIVIT 1971. STRADNER (1963) p. 177; pl. 2, figs. 4–5. MANIVIT (1971) p. 87; pl. 23, figs. 4–7.

○ *Cribrosphaera primitiva* THIERSTEIN 1974. THIERSTEIN (1974) p. 637; pl. 1, figs. 1–13.

- ○ *Octocyclus reinhardtii* (BUKRY 1969) WIND & WISE 1976. BUKRY (1969) p. 38; pl. 16, fig. 7. WIND & WISE (1976) p. 302; pl. 57, fig. 6; pl. 58, figs. 1, 2.
- ○ *Zygodiscus theta* (BLACK in BLACK & BARNES 1959) BUKRY 1969. BLACK & BARNES (1959) p. 327; pl. 12, fig. 1. BUKRY (1969) p. 62; pl. 36, figs. 7, 8.
- ○ *Ellipsagelosphaera ovata* (BUKRY 1969) BLACK 1973. BUKRY (1969) (partim) p. 33; pl. 11, fig. 11 (non fig. 12). BLACK (1973) p. 71; pl. 26, figs. 10-12.
- ○ *Gartnerago nanum* THIERSTEIN, 1974. THIERSTEIN (1974) p. 637; pl. 2, figs. 1–13.
- ○ *Nannoconus truitti* BRÖNNIMANN 1955. BRÖNNIMANN (1955) p. 38; pl. 2, figs. 2–5, 7; text-figs. 2f–j.
- ○ *Hemipodorhabdus gorkae* (REINHARDT 1969) GRÜN in GRÜN & ALLEMANN 1975. REINHARDT (1969) p. 933; pl. 1, figs. 1–2. GRÜN & ALLEMANN (1975) p. 171–172.
- ○ *Tetrapodorhabdus coptensis* BLACK 1971. BLACK (1971) p. 411; pl. 31, fig. 7.
- ○ *Grantarhabdus meddii* BLACK 1971. BLACK (1971) p. 403; pl. 33, fig. 7.

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