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A Proposed Lower Cretaceous Calcareous Nannofossil Zonation Scheme for the Moray Firth Area of the North Sea

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With 5 Figures and 3 Plates

North Sea
Moray Firth Basin
Calcareous nannofossils
Lower Cretaceous
Biostratigraphy
Zonation Scheme

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Zusammenfassung

Anhand von Untersuchungen an Bohrungen und Aufschlüssen wird eine Zonierung der Unterkreide des Moray Firth-Gebietes der Nordsee vorgeschlagen. Sie basiert auf dem Aussterben, der Entwicklung, der Vergesellschaftungen und der Häufigkeit der Arten. Durch die Anwendung von letztem Auftreten und Änderungen der Art-Häufigkeiten können vom Ryazan zum unteren Cenoman 19 Zonen definiert werden. Weitere 11 Subzonen werden durch entwicklungsgeschichtlich erstes Auftreten unterschieden. Die Zonen und Subzonen werden nützlichkeitshalber von oben nach unten durchnumeriert und kurz mit anderen Zonierungsschemata verglichen.

Abstract

A Lower Cretaceous nannofossil zonation for the Moray Firth area of the North Sea is proposed, based upon the examination of several wells and onshore exposures. The zonal subdivisions are based upon the extinction, evolution, association and abundance of taxa. Using extinction points and species abundances 19 zones can be recognised from the Ryazanian to the lower Cenomanian. A further 11 subzones are recognised using evolutionary appearances. Each of the zones and subzones has been coded for ease of use. A brief comparison with other zonation schemes has been undertaken.

1. Introduction

During the routine investigation of many released well sections within the Moray Firth Basin and other areas of the North Sea, it became evident that the Lower Cretaceous nannofossil assemblages were distinctly different to those seen in more southerly Tethyan areas. Many marker species used in zonation schemes based upon sections examined from the Tethys area were often either rare, absent or their ranges different in the North Sea. The sections also revealed that certain species and their high frequencies were endemic to the Boreal Realm and that others recorded in Tethys were rare. This obviously caused problems when attempting to use a Tethyan based zonation to date and correlate the well section. Only TAYLOR (1982) defines a zonation based upon the examination of only Boreal sections. However, her scheme could not be used because it primarily deals with evolutionary appearances which are difficult to determine in well sections where only ditch cuttings samples are available.

Therefore, an attempt has been made to establish a new Boreal zonation defined on extinctions, evolutionary appearances and acme events. As the zonation is designated primarily for the oil industry the zonal boundaries are based upon extinctions or to a lesser extent the acmes of selected species. Significant evolutionary appearances which can be identified in sidewall core and core samples or field samples have been given subzonal status. Each zone and subzone has been coded from the top of the section to the base which is more compatible with the oil industry. The samples were prepared using both smear and centrifuge techniques and were examined under the light microscope.

As mentioned above, the age ranges of many species are different to those in Tethyan areas. The precise ranges and significance of the species in the Boreal area have been established through the use of core and sidewall core material, by the examination of land sections in England (particularly Speeton and Nettleton) and north-west Germany and through discussion with colleagues also working on material from Boreal areas.

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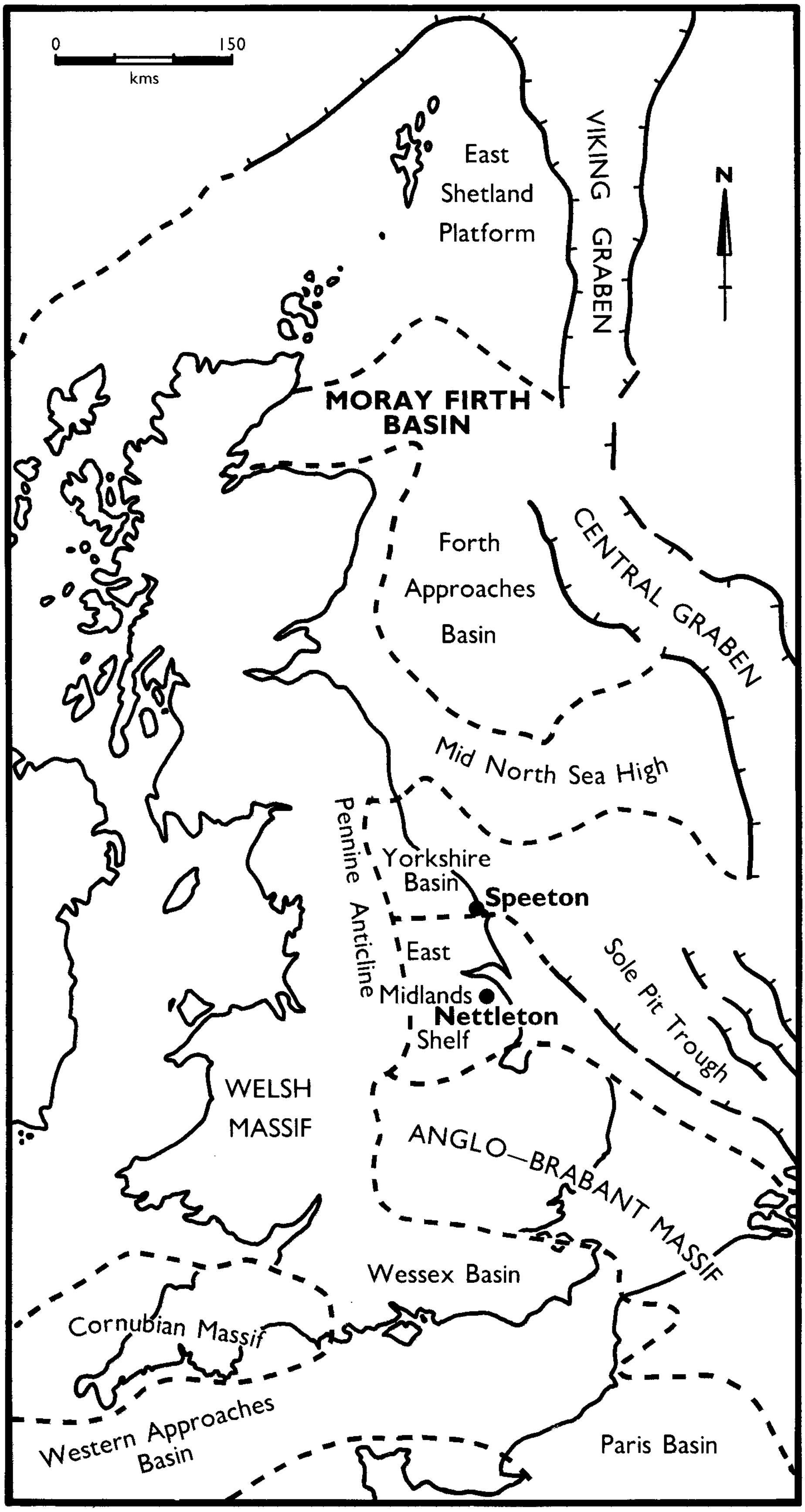

Fig. 1: The structural setting of Lower Cretaceous sediments and location of the Moray Firth Basin, Speeton and Nettleton (from RAWSON et al., 1978, fig. 2).

2. Depositional Environment and Stratigraphy of the Moray Firth Basin

The Moray Firth Basin is situated off the north-east coast of Scotland (see Fig. 1) and is of great significance to the oil industry as ten major fields have been discovered there so far.

Lower Cretaceous sediments deposited within the Moray Firth Basin are subdivided into two formations (see Fig. 2). The separation of Lower Cretaceous sediments in this study is an informal, unpublished scheme used by Robertson Research International Ltd (1985). The base of the Lower Cretaceous is characterised by anoxic black shales of the Kimmeridge Clay Formation which were deposited in a stratified water column following the isolation of the basin from cold oceanic bottom waters (during the Upper Jurassic) with an irregular marine topography impeding water circulation. During the Ryazanian the stratified water column began to dissipate and Kimmeridge Clay deposition ceased as the North Sea graben system opened up to colder Boreal waters which introduced well oxygenated conditions. Nutrients from these cold waters mixed with the existing surface water and resulted in the diverse and rich nannofloral assemblage seen in the uppermost Ryazanian.

During Valanginian to Barremian a constant subsidence of the basin occured together with a eustatic rise in sea level which produced a progressive transgression, although a minor regressive phase occurred during the upper Hauterivian and Barremian. In this shelf environment the limestones and calcareous shales of the Valhall A member were deposited. The top of the Valhall A member is marked by a very calcareous red shale or limestone which contains characteristic microfauna and nannofossil assemblages. The deposition of red shale or limestone during the lower Aptian occurred in a transgressive phase and the association of this lithology with the planktonic assemblage is indicative of Tethyan warmer water conditions.

The upper Aptian – Albian Valhall B member contains dark calcareous shales in the lower part passing into variecoloured calcareous shales and then argillaceous limestones. During the upper Aptian and lower Albian the dark calcareous shales were deposited under conditions in which a slight restriction of water circulation lowered the calcareous content of the shales. During this time the diversity of the nannofloral assemblages reaches its lowest point.

The reversion to normal open marine conditions with open circulation which occurred in the middle to upper Albian was marked by a considerable increase in diversity and total abundance of nannofossils, together with the deposition of argillaceous limestones and very calcareous shales. The Lower Cretaceous sea reached its maximum extent during the upper Albian. Sedimentation across the Lower Cretaceous/Upper Cretaceous boundary is thought to be continuous and is represented by a gradual change from argillaceous limestone to the more pure limestone of the Hidra Formation.

3. Biostratigraphy

3.1. Previous Studies

There have been several nannofossil zonations published for the Cretaceous, but only that of TAYLOR (1982) was solely for the Boreal Realm. Some of the more relevant zonation schemes are presented and compared in Fig. 3 and are discussed below.

In 1971 THIERSTEIN, WORSLEY and MANIVIT each introduced their Lower Cretaceous zonation schemes. WORSLEY identified six zones covering the Ryazanian to Cenomanian and introduced for the first time as marker species *Nannoconus steinmannii* and *Diadorhombus rectus* which have been used in later zonations. MANIVIT's study, which covered the Aptian to Cenomanian, also identified six zones. Only two of her datums have been used in this study, namely the evolutionary appearances of *Rhagodiscus angustus* and *Prediscosphaera columnata*. The *Prediscosphaera columnata* datum as used by MANIVIT, however, was placed within the Aptian which may be due to a different taxonomic concept since this datum is now regarded as occurring within the Albian.

Nine zones, ranging from the upper Tithonian to lower Cenomanian, were described by THIERSTEIN (1971) from continuous sections in south-west France and the west Atlantic. A number of zonal markers were introduced, namely: *Cretarhabdus crenulatus (= Retecapsa angustiforata), Calcicalathina oblongata, Microrhabdulus bollii (= Lithraphidites bollii), Chiastozygus litterarius, Lithastrinus floralis* (= *Eprolithus apertior* in this study), the correct position of *Prediscosphaera columnata*, and *Eiffellithus turriseiffelii*. Some of these datums have been used in the present study; these include *Retecapsa angustiforata, Eprolithus apertior* and *Eiffellithus turriseiffelii*. The remaining zonal markers were omitted for various reasons: *Calcicalathina oblongata* is rare in North Sea sections, *Lithraphidites bollii* is absent and there is often confusion over the identification of *Chiastozygus litterarius*. THIERSTEIN's (1971) zonation scheme was also used in his 1973 paper which included additional sections from Venezuela, Trinidad, Switzerland, Great Britain and the central Atlantic.

The next significant contribution was made by ROTH (1973) who defined nine zones from the central Pacific basin. His zonation used many of THIERSTEIN's (1971) datums but also introduced the use of *Tubodiscus jurapelagicus, Cruciellipsis cuvillieri* and *Lithraphidites alatus*. Only the *Cruciellipsis cuvillieri* datum has been used in the present study because *Tubodiscus jurapelagicus* was not recorded and *Lithraphidites alatus* was too rare.

The zonation of BUKRY (1974) was simply a combination of THIERSTEIN (1971) and ROTH (1973). Using core samples recovered from the Indian Ocean he was able to establish ten zones. In 1976 THIERSTEIN reviewed Mesozoic nannofossil biostratigraphy, based upon the examination of over 800 samples from all over the world covering the Liassic to Maastrichtian. Sixteen biohorizons for the Lower Cretaceous were presented, three of which were new, namely: *Lithraphidites carniolensis, Rucinolithus irregularis* and *Podorhabdus albianus (= Axopodorhabdus albianus)*. Only the *Lithraphidites carniolensis* datum has been used in this study because *Rucinolithus irregularis* was not recorded and *Axopodorhabdus albianus* was too sparse. SISSINGH's (1977) zonation was based upon the examination of Cretaceous well sections from the central and northern parts of the North Sea and onshore exposures in Tunisia, north France, north-west Germany and England and identified 9 zones. He introduced the markers *Cretarhabdus loriei* and *Speetonia colligata*, which enabled him to further subdivide THIERSTEIN's *Calcicalathina oblongata* zone, and *Crucibiscutum salebrosum* has been used but is extended into the lower Barrem-

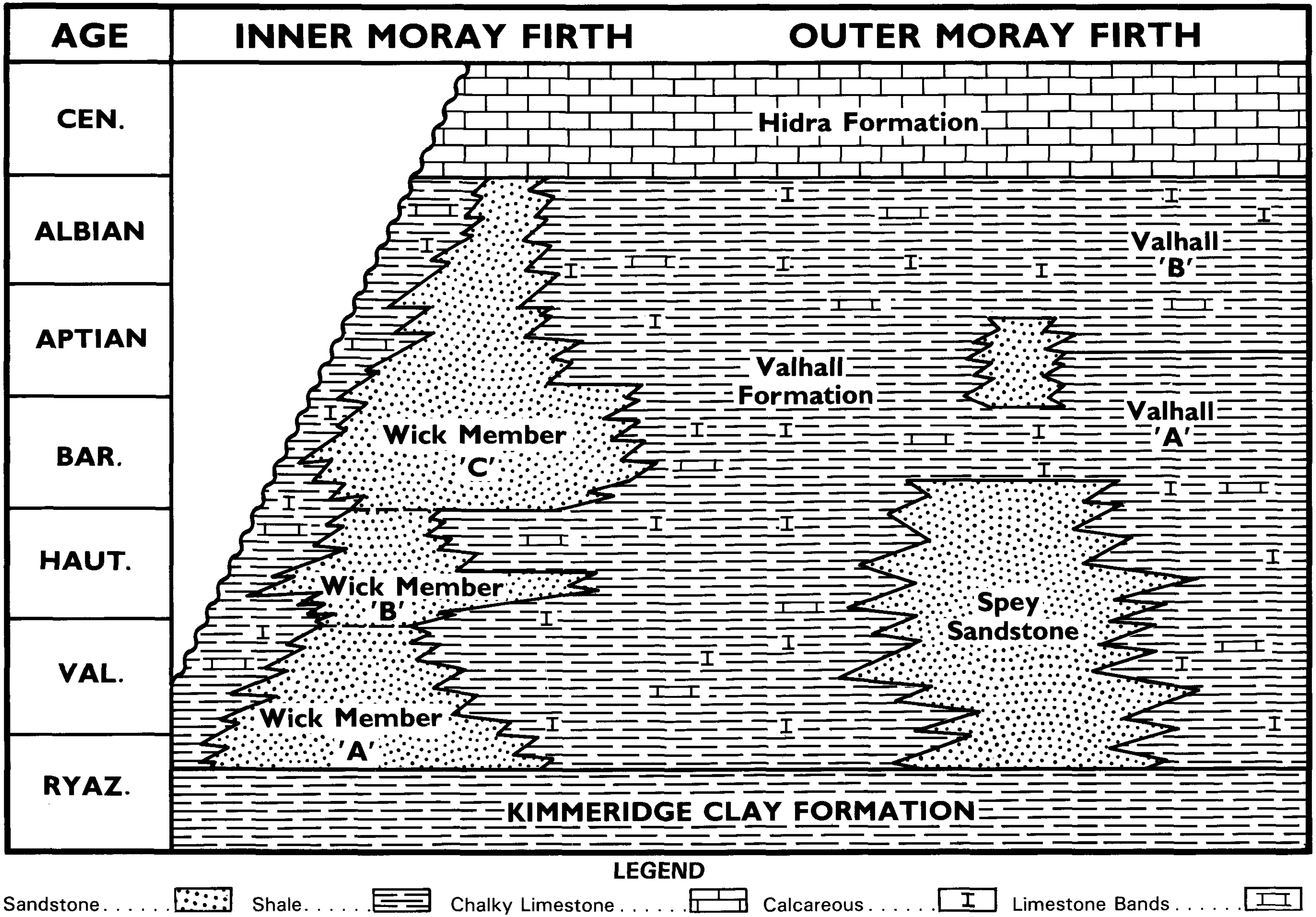

Fig. 2: A generalised lithostratigraphic succession for the Moray Firth Basin (from Robertson Research International Ltd., 1985).

AGE \ AUTHOR	MANIVIT 1971	THIERSTEIN 1971, 1973	ROTH 1973	BUKRY 1974	THIERSTEIN 1976	SISSINGH 1977	PERCH-NIELSEN 1979	TAYLOR 1982	THIS STUDY
CENOMANIAN	*S. orbiculo-fenestratus*	*E. turriseiffelii*	*L. alatus*	*L. alatus*		*M. decoratus* *E. turriseiffelii*			
ALBIAN	*S. matalosus* *C. rhombicum* *H. albiensis*	*E. turriseiffelii* *P. cretacea*	*E. turriseiffelii* *P. cretacea*	*E. turriseiffelii* *P. cretacea*	*L. alatus* *E. turriseiffelii* *P. albianus* *P. cretacea*	*E. turriseiffelii* *P. cretacea*	*E. britannica* *E. turriseiffelii* *T. phacelosus* *P. columnata*	*E. turriseiffelii* *P. cretacea*	NLK 1 NLK 2 NLK 3 NLK 4 A, B NLK 5 A, B
APTIAN	*P. angustus* *P. columnata*	*P. angustus* *C. litterarius*	*P. angustus*	*P. angustus* *C. litterarius*	*L. floralis* *P. angustus* *C. litterarius*	*C. litterarius*	*P. angustus* *E. floralis* *N. kamptneri* *N. steinmannii* *C. mexicana*	*P. angustus* *C. litterarius*	NLK 6 NLK 7 NLK 8 A, B NLK 9
BARREMIAN		*M. hoschulzii* *M. bollii*	*T. malticus*	*T. malticus* or *M. hoschulzii*	*N. colomii* *R. irregularis* *C. oblongata*	*M. hoschulzii* *L. bollii*	*C. oblongata*	*N. abundans*	NLK 10 NLK 11 NLK 12 NLK 13 NLK 14
HAUTERIVIAN		*M. bollii* *C. oblongata*	*C. cuvillieri*	*C. cuvillieri*	*C. cuvillieri* *L. bollii*	*L. bollii* *C. loriei*	*S. colligata* *C. cuvillieri* *C. striatus*	*C. striatus*	NLK 15 NLK 16 A, B NLK 17
VALANGINIAN		*C. oblongata* *C. crenulatus*	*T. jurapelagicus* *W. britannica*	*T. jurapelagicus* *W. britannica* or *C. crenulatus*	*R. angustiforata*	*C. oblongata* *C. crenulatus*	*M. speetonensis* *C. oblongata* *R. angustiforata*	*M. speetonensis* *C. salebrosus*	NLK 17 NLK 18
RYAZANIAN		*N. colomii*	*N. colomii*	*N. colomii*		*N. steinmannii*		*R. angustiforata*	NLK 19 A, B, C

Fig. 3: A comparison of Lower Cretaceous nannofossil zonation schemes.

ian. The *Speetonia colligata* datum has been emended in this study and is now placed in the Barremian, but the *Cretarhabdus loriei* datum has been omitted because the author found this species occurring in the Ryazanian at Speeton.

In 1979 PERCH-NIELSEN summarised and presented the then current knowledge on Cretaceous nannofossil biostratigraphy. She re-examined the Speeton section and introduced *Nannoconus borealis* and *Micrantholithus speetonensis* both of which are used in the present study as zonal markers. Finally in 1982 TAYLOR presented her Boreal zonation scheme, which included for the first time the zonal markers *Nannoconus abundans* and *Dodekopodorhabdus noelae.*

Only the marker species *Nannoconus abundans* has been used in this study. TAYLOR placed the evolutionary appearance of *Dodekopodorhabdus noelae* within the upper Hauterivian; however, it has been recorded much lower in the Ryazanian at Speeton in this study.

3.2. Proposed Zonation Scheme

Phanulithus anfractus Zone (NLK 1)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Phanulithus anfractus* and the first downhole occurrence of common/abundant *Seribiscutum primitivum.*

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: lower Cenomanian – upper Albian.

Remarks: This zone has also been recognised in the Central North Sea and the Dutch sector of the North Sea. The zone is characterised by common *Tranolithus phacelosus, Broinsonia enormis* and *Eiffellithus turriseiffelii.* In North Sea sections a distinctive log break is taken to mark the Albian/Cenomanian boundary. None of the documented nannofossil datums that occur around the boundary , namely the extinction of *Ellipsagelosphaera britannica* and the evolutionary appearance of *Lithraphidites alatus*, could be recognised with ease. Of interest, however, is the considerable increase in abundance of *Biscutum constans* which is often associated with the log break and may prove to be a valuable acme event for marking the boundary. It may therefore be possible to further restrict the age of this zone in the future.

Seribiscutum primitivum Zone (NLK 2)

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of common/abundant *Seribiscutum primitivum* and the extinction of *Hemipodorhabdus gorkae.*

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper Albian.

Remarks: The common occurrence of *Zygodiscus sisyphus* also characterises this zone, which is restricted in its distribution and has only been recorded in one other area, namely the central North Sea where the condensing of Lower Cretaceous sediments makes it difficult to subdivide the zone from NLK1 and NLK3 when analysing only ditch cutting's samples.

Hemipodorhabdus gorkae Zone (NLK 3)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Hemipodorhabdus gorkae* and the extinction of *Gartnerago praeobliquum.*

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper Albian.

Remarks: TAYLOR (1982) recorded the extinction level of *Hemipodorhabdus gorkae* as being close to the top of the Albian. *Tetrapodorhabdus decorus* has a similar extinction level to *Hemipodorhabdus gorkae* in the Moray Firth Basin although it is known to range higher in the other parts of the world. This zone is easily recognised throughout the North Sea.

Gartnerago praeobliquum Zone (NLK 4)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Gartnerago praeobliquum* and the first downhole occurrence of common/abundant *Repagulum parvidentatum.*

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper – middle Albian.

Remarks: The zone has also been recorded in the central North Sea, and can be split into two subzones which are missing in the Dutch sector of the North Sea due to a regional hiatus. *Tegumentum stradneri* has its extinction within the zone.

Eiffellithus turriseiffelii Subzone (NLK 4A)

Author: THIERSTEIN (1971) emend. JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Gartnerago praeobliquum* and the evolutionary appearance of *Eiffellithus turriseiffelii.*

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: THIERSTEIN (1971).

Age: upper Albian.

Watznaueria barnesae Subzone (NLK 4B)

Author: JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Eiffellithus turriseiffelii* and the first downhole occurrence of common/abundant *Repagulum parvidentatum.*

Definition upper boundary: THIERSTEIN (1971).

Definition lower boundary: JAKUBOWSKI (this study).

Age: upper – middle Albian.

AGE			ZONES/SUBZONES			
U. CRET.	Cenomanian	Lower				
U. CRET.	Cenomanian	Lower	NLK 1	*Phanulithus anfractus*		
LOWER CRETACEOUS	Albian	Upper	NLK 2	*Seribiscutum primitivum*		
LOWER CRETACEOUS	Albian	Upper	NLK 3	*Hemipodorhabdus gorkae*		
LOWER CRETACEOUS	Albian	Upper – Middle	NLK 4	*Gartnerago praeobliquum*	NLK 4A	*E. turriseiffelii*
LOWER CRETACEOUS	Albian	Middle	NLK 4	*Gartnerago praeobliquum*	NLK 4B	*W. barnesae*
LOWER CRETACEOUS	Albian	Middle – Lower	NLK 5	*Repagulum parvidentatum*	NLK 5A	*P. columnata*
LOWER CRETACEOUS	Albian	Lower	NLK 5	*Repagulum parvidentatum*	NLK 5B	*B. constans*
LOWER CRETACEOUS	Albian	Lower	NLK 6	*Bukrylithus ambiguus*		
LOWER CRETACEOUS	Aptian	Upper	NLK 7	*Micrantholithus obtusus*		
LOWER CRETACEOUS	Aptian	Upper	NLK 8	*Rhagodiscus asper*	NLK 8A	*E. apertior*
LOWER CRETACEOUS	Aptian	Lower	NLK 8	*Rhagodiscus asper*	NLK 8B	*E. varolii*
LOWER CRETACEOUS	Aptian	Lower	NLK 9	*Lithraphidites moray-firthensis*		
LOWER CRETACEOUS	Barremian	Upper	NLK 10	*Nannoconus abundans*		
LOWER CRETACEOUS	Barremian	Middle	NLK 11	*Nannoconus borealis*		
LOWER CRETACEOUS	Barremian	Middle – Lower	NLK 12	*Conusphaera rothii*		
LOWER CRETACEOUS	Barremian	Lower	NLK 13	*Crucibiscutum salebrosum*		
LOWER CRETACEOUS	Barremian	Lower	NLK 14	*Stradnerlithus comptus*		
LOWER CRETACEOUS	Hauterivian	Upper	NLK 15	*Lithastrinus septentrionalis*		
LOWER CRETACEOUS	Hauterivian	Upper	NLK 16	*Cruciellipsis cuvillieri*	NLK 16A	*S. colligata*
LOWER CRETACEOUS	Hauterivian	Upper – Lower	NLK 16	*Cruciellipsis cuvillieri*	NLK 16B	*C. margerelii*
LOWER CRETACEOUS	Hauterivian – Valanginian	Lower – Upper	NLK 17	*Corollithion silvaradion*		
LOWER CRETACEOUS	Valanginian	Lower	NLK 18	*Micrantholithus speetonensis*		
LOWER CRETACEOUS	Ryazanian	Upper	NLK 19	*Nannoconus steinmannii*	NLK19A	*S. arcuatus*
LOWER CRETACEOUS	Ryazanian	Upper	NLK 19	*Nannoconus steinmannii*	NLK19B	*R. angustiforata*
LOWER CRETACEOUS	Ryazanian	Upper – Lower	NLK 19	*Nannoconus steinmannii*	NLK19C	*L. carniolensis*

Fig. 4: Proposed Lower Cretaceous nannofossil zonation.

Repagulum parvidentatum **Zone (NLK 5)**

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of common/abundant *Repagulum parvidentatum* and the first downhole occurrence of common *Rhagodiscus asper*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: middle – lower Albian.

Remarks: This zone is recorded rarely in the central North Sea and Moray Firth Basin and is often missing in many areas due to a regional hiatus. It can be further subdivided using the evolutionary appearance of *Prediscosphaera columnata*. *Rhagodiscus splendens* and small sized forms of *Zygodiscus sisyphus* occur commonly within this zone.

Prediscosphaera columnata Subzone (NLK 5A)

Author: THIERSTEIN (1971), emend. JAKUBOWSKI (this study), non MANIVIT (1971).

Definition: The interval between the first downhole occurrence of common/abundant *Repagulum parvidentatum* and the evolutionary appearance of *Prediscosphaera columnata*.

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: THIERSTEIN (1971).

Age: middle – lower Albian.

Remarks: The evolutionary appearance of *Prediscosphaera columnata* is equivalent to the *Prediscosphaera cretacea* datum of THIERSTEIN (1971). This subzone differs from MANIVIT's (1971) *Prediscosphaera columnata* Zone which was defined as the interval between the evolutionary appearances of *Prediscosphaera columnata* and *Rhagodiscus angustus*.

Biscutum constans Subzone (NLK 5B)

Author: JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Prediscosphaera columnata* and the first downhole occurrence of common *Rhagodiscus asper*.

Definition upper boundary: THIERSTEIN (1971).

Definition lower boundary: JAKUBOWSKI (this study).

Age: lower Albian.

Bukrylithus ambiguus Zone (NLK 6)

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of common/abundant *Rhagodiscus asper* and the extinction of *Micrantholithus obtusus*, *Micrantholithus hoschulzii* and/or *Eprolithus varolii*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: lower Albian.

Remarks: This zone is mainly of local correlative value within the Moray Firth Basin but has also been recognised in the Central North Sea. It is characterised by common *Bukrylithus ambiguus*. As in Zone NLK5 this zone is often missing in many areas due to a regional hiatus.

Micrantholithus obtusus Zone (NLK 7)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Micrantholithus obtusus*, *Micrantholithus hoschulzii* and/or *Eprolithus varolii* and the first downhole occurrence of abundant *Rhagodiscus asper*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper Aptian.

Remarks: SISSINGH (1977) used *Micrantholithus hoschulzii* to define the top of his 7a Subzone of lower Aptian age, which PERCH-NIELSEN (1979) also followed. However, in this study and in TAYLOR (1982) *Micrantholithus hoschulzii* is recorded in the upper Aptian. In North Sea sections *Micrantholithus* spp. are rare in the Aptian but occur consistently in the Barremian.

Rhagodiscus asper Zone (NLK 8)

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of abundant *Rhagodiscus asper* and the extinction of common *Lithraphidites moray-firthensis*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper – lower Aptian.

Remarks: The first downhole occurrence of abundant *Rhagodiscus asper* together with its overwhelming dominance of the nannofloral assemblages within the Aptian is a characteristic and easily recognised event in the North Sea. This feature has also been recorded onshore in north-west Germany in the upper Aptian and is thought to reflect an influx of warm, Tethyan water. In the Dutch sector of the North Sea the event is also associated with a high Nannoconid population. The zone can be subdivided using the evolutionary appearances of *Rhagodiscus angustus* and/or *Eprolithus apertior*.

Eprolithus apertior Subzone (NLK 8A)

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of abundant *Rhagodiscus asper* and the evolutionary appearance of *Eprolithus apertior* or *Rhagodiscus angustus*.

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: MANIVIT (1971), THIERSTEIN (1971).

Age: upper Aptian.

Remarks: The evolutionary appearance of *Eprolithus apertior (= Lithastrinus floralis)* and *Rhagodiscus angustus* are well documented events worldwide; however, there is some controversy over the latter datum. PERCH-NIELSEN (1979) has recorded species similar to *Rhagodiscus angustus* in the Barremian, but does concede that the typical forms, which have a clearly visible granular centre and parallel sides, are not present below the upper Aptian. In this study the 9-rayed species of *Eprolithus* and *Lithastrinus* have been separated based on the presence or absence of a wide diaphragm. In the Aptian only species with a wide diaphragm are recorded and these are assigned to *Eprolithus apertior*. In some past zonations the *Eprolithus*/*Lithastrinus* group has not been separated and all 9-rayed forms were placed in *Lithastrinus floralis*.

Eprolithus varolii Subzone (NLK 8B)

Author: JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Eprolithus apertior* and *Rhagodiscus angustus* and the extinction of *Lithraphidites moray-firthensis*.

Definition upper boundary: MANIVIT (1971), THIERSTEIN (1971).

Definition lower boundary: JAKUBOWSKI (this study).

Age: lower Aptian.

Lithraphidites moray-firthensis Zone (NLK 9)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of common *Lithraphidites moray-firthensis* and the extinction of *Nannoconus abundans*.

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: TAYLOR (1982).

Age: lower Aptian – upper Barremian.

Remarks: This zone is of local correlative value and may often be difficult to detect in other areas of the North Sea due to condensing of lower Aptian sediments.

Nannoconus abundans Zone (NLK 10)

Author: TAYLOR (1982), emend. JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Nannoconus abundans* and the extinction of *Nannoconus borealis*.

Definition upper boundary: TAYLOR (1982).

Definition lower boundary: JAKUBOWSKI (this study).

Age: upper Barremian.

Remarks: This zone has been recognised throughout the North Sea and onshore at Speeton and in northwest Germany. The *Nannoconus abundans* Zone of TAYLOR (1982) which was defined as the interval between the evolutionary appearance and extinction of *Nannoconus abundans* has been emended by utilising the extinction level of *Nannoconus borealis*.

Nannoconus borealis Zone (NLK 11)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Nannoconus borealis* and the extinction of *Conusphaera rothii*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: middle Barremian.

Remarks: *Nannoconus borealis* was first described by PERCH-NIELSEN (1979) from Speeton. It is an easily recognised species and has a widespread occurrence throughout the North Sea.

Conusphaera rothii Zone (NLK 12)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Conusphaera rothii* and the extinction of *Crucibiscutum salebrosum*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: middle – lower Barremian.

Remarks: PERCH-NIELSEN (1979) records the extinction of *Conusphaera* spp. as occurring in the lower Aptian which is certainly the case in lower latitudes but in North Sea sections they become extinct near the middle/lower Barremian boundary, which correlation with palynological results would also suggest. The zone is recognisable in sections throughout the North Sea and is also characterised by an increase in abundance of *Nannoconus abundans* which may be related to greater Boreal cold water influence. It is worth noting that *Conusphaera mexicana* is not recorded in Boreal areas. For a full discussion of the difference between *Conusphaera rothii* and *Conusphaera mexicana* see JAKUBOWSKI (1986).

Crucibiscutum salebrosum Zone (NLK 13)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Crucibiscutum salebrosum* and the extinction of either *Lithastrinus septentrionalis* or *Speetonia colligata*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: lower Barremian.

Remarks: PRINS in PERCH-NIELSEN (1979) records *Crucibiscutum salebrosum* in the lower Aptian; however, this form may easily be confused with *Crucibiscutum hayi* which occurs commonly throughout the Aptian and also in the Albian. In this study *Crucibiscutum salebrosum* has not been recorded above the lower Barremian. TAYLOR (1982) also recorded the extinction level of *Crucibiscutum salebrosum* as lower Barremian. *Stradnerlithus comptus* becomes extinct towards the base of the zone and is a useful secondary marker. *Diazomatolithus lehmanii* has not been recorded from the Moray Firth Basin but is a reliable lower Barremian marker in other areas of the North Sea, particularly in the Dutch sector. *Calcicalathina oblongata* has its extinction in the upper part of the zone but this species is rare in North Sea sections.

Stradnerlithus comptus Zone (NLK 14)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinctions of *Lithastrinus septentrionalis* and/or *Speetonia colligata* and the first downhole occurrence of common/abundant *Lithastrinus septentrionalis*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: lower Barremian.

Remarks: Published literature records the extinction level of *Speetonia colligata* as upper Hauterivian; however, it has been recorded in this study, from the *variabilis* ammonite zone of lower Barremian age at Speeton. Another feature of the zone is the abundant occurrence of *Micrantholithus* spp. and *Braarudosphaera* spp. TAYLOR (1982) recorded this datum level in upper Hauterivian sediments which are now placed in the lower Barremian.

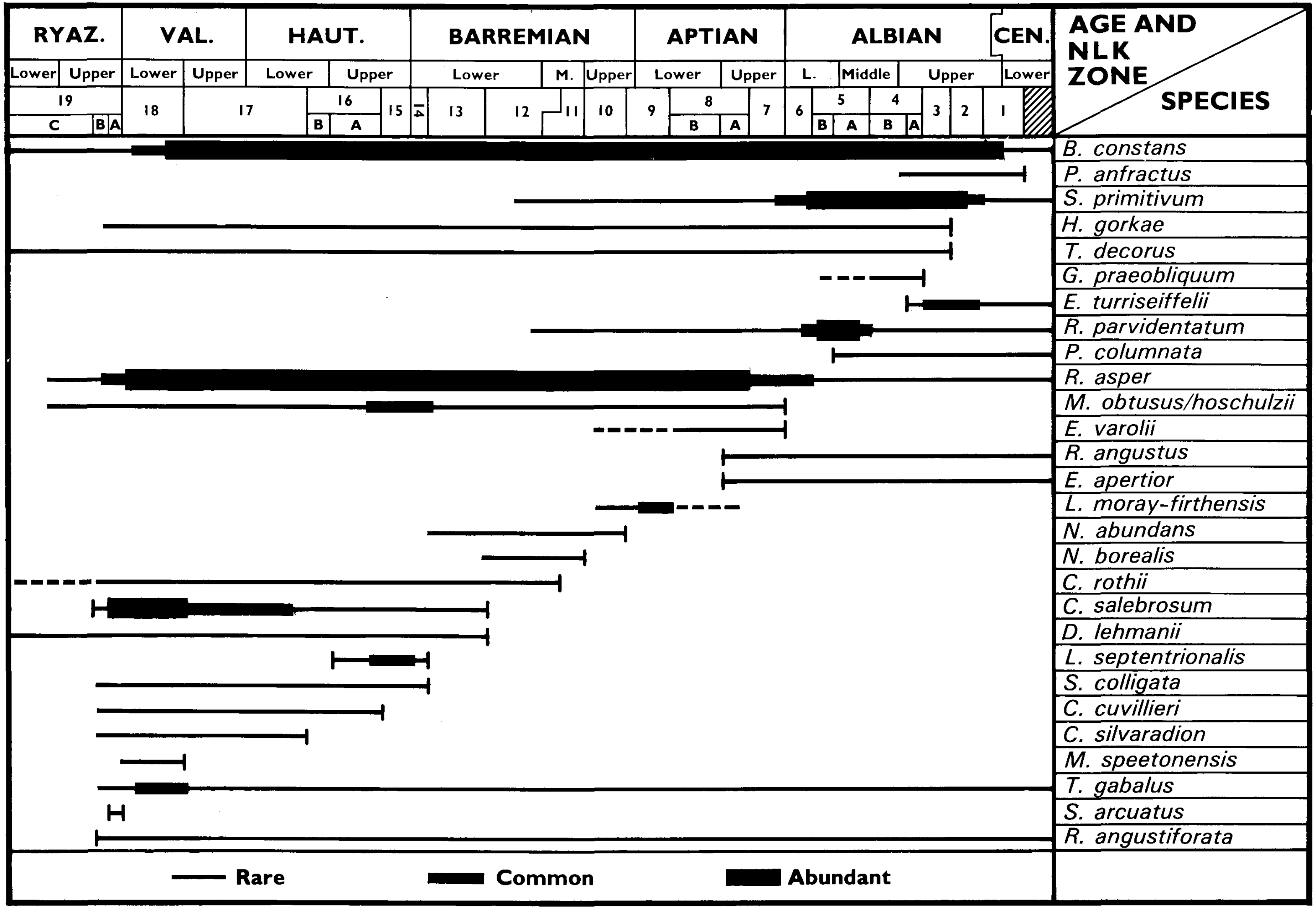

Fig. 5: Stratigraphical distribution of some important Lower Cretaceous marker species.

Lithastrinus septentrionalis Zone (NLK 15)

Author: JAKUBOWSKI (this study).

Definition: The interval between the first downhole occurrence of common/abundant *Lithastrinus septentrionalis* and the extinction of *Cruciellipsis cuvillieri.*

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: ROTH (1973).

Age: upper Hauterivian.

Remarks: This zone is easily recognised throughout the North Sea and onshore. *Lithastrinus septentrionalis* occurs in abundance in upper Hauterivian land sections at Nettleton, Speeton (J. CRUX, pers. comm.) and north-west Germany.

Cruciellipsis cuvillieri Zone (NLK 16)

Author: ROTH (1973), emend. JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Cruciellipsis cuvillieri* and the extinction of *Corollithion silvaradion.*

Definition upper boundary: ROTH (1973).

Definition lower boundary: JAKUBOWSKI (this study).

Age: upper – lower Hauterivian.

Remarks: The *Cruciellipsis cuvillieri* extinction datum was first recorded by ROTH (1973) who used it to mark the top of the *Cruciellipsis cuvillieri* Zone. Both PERCH-NIELSEN (1979) and SISSINGH (1977) placed the extinction of *Cruciellipsis cuvillieri* within the lower Hauterivian which is much lower than that indicated by ROTH (1973), BUKRY (1974) and THIERSTEIN (1976). PERCH-NIELSEN (1979) recorded it in the C4 bed at Speeton which is now placed within the upper Hauterivian *gottschei* ammonite Zone which therefore confirms the occurrence of *Cruciellipsis cuvillieri* within the upper Hauterivian. It occurs rarely in the Boreal region, its high abundance in the lower Hauterivian at Speeton being attributed to Tethyan influence. This zone can be further subdivided by using the evolutionary appearance of *Lithastrinus septentrionalis.*

Speetonia colligata Subzone (NLK 16A)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Cruciellipsis cuvillieri* and the evolutionary appearance of *Lithastrinus septentrionalis.*

Definition upper boundary: ROTH (1973).

Definition lower boundary: JAKUBOWSKI (this study).

Age: upper Hauterivian.

Remarks: TAYLOR (1981) recorded a single specimen of *Lithastrinus septentrionalis* from the lower Hauterivian *noricum* ammonite zone in north-west Germany. However, it was present in only one of the 18 samples analysed and has never been recorded by the author in any onshore lower Hauterivian sections; therefore TAYLOR's occurrence must be regarded as unreliable.

Cyclagelosphaera margerelii Subzone (NLK 16B)

Author: JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Lithastrinus septentrionalis* and the extinction of *Corollithion silvaradion.*

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: lower Hauterivian.

Corollithion silvaradion Zone (NLK 17)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Corollithion silvaradion* and the extinction of *Micrantholithus speetonensis.*

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: PERCH-NIELSEN (1979).

Age: lower Hauterivian – upper Valanginian.

Remarks: It has not been possible at this stage to separate the lower Hauterivian from the upper Valanginian. Good, marine, upper Valanginian onshore sequences are rare in north-west Germany and Great Britain and although it is probable that sequences of upper Valanginian age occur in the North Sea it is difficult to positively date them as such. Sidewall core and core samples would not solve this problem because there are no nannofossil species which have an evolutionary appearance at the base of the Hauterivian. *Chiastozygus striatus* has been recorded by the author in the lower Valanginian D3A bed at Speeton and *Cretarhabdus loriei* in the upper Ryazanian. PERCH-NIELSEN (1979) placed the extinction of *Micrantholithus speetonensis* within the upper Valanginian; however, the upper Valanginian at Speeton is either missing or very condensed. Beds D2E to D4A, the horizons in which PERCH-NIELSEN records *Micrantholithus speetonensis*, are in fact lower Valanginian. The zone is occasionally characterised by common *Cyclagelosphaera margerelii, Chiastozygus striatus* and *Crucibiscutum salebrosum.*

Micrantholithus speetonensis Zone (NLK 18)

Author: JAKUBOWSKI (this study), non TAYLOR (1982).

Definition: The interval between the extinction of *Micrantholithus speetonensis* and the extinction of *Sollasites arcuatus.*

Definition upper boundary: PERCH-NIELSEN (1979).

Definition lower boundary: JAKUBOWSKI (this study).

Age: lower Valanginian.

Remarks: The extinction level of *Micrantholithus speetonensis* is used in this study to mark the top of the lower Valanginian for the reasons mentioned above. The zone is also characterised by abundant *Tranolithus gabalus* and *Crucibiscutum salebrosum* and by *Micrantholithus brevis.* The zone differs from the *Micrantholithus speetonensis* Zone of TAYLOR (1982) which was defined as the interval between the evolutionary appearance of *Micrantholithus speetonensis* and the evolutionary appearance of *Chiastozygus striatus.*

Nannoconus steinmannii Zone (NLK 19)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction of *Sollasites arcuatus* and the evolutionary appearance of *Nannoconus steinmannii* and/or *Nannoconus colomii*.

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: WORSLEY (1971), not seen in this study.

Age: Ryazanian.

Remarks: The nannofloral assemblages in Zone NLK 19 are quite diverse and abundant. *Sollasites arcuatus* was first recorded by BLACK (1971) from the upper Ryazanian at Speeton and has a widespread occurrence in the North Sea. The assemblages are also characterised by large flat *Nannoconus* spp. and common *Discorhabdus ignotus*. Floods of *Parhabdolithus embergerii* have been recorded in beds of Ryazanian age onshore, a feature also seen by PERCH-NIELSEN (pers. comm.). The base of the zone was not recorded in this study. The zone can be further subdivided into three subzones.

Sollasites arcuatus Subzone (NLK 19A)

Author: JAKUBOWSKI (this study).

Definition: The interval between the extinction and the evolutionary appearance of *Sollasites arcuatus*.

Definition upper and lower boundary: JAKUBOWSKI (this study).

Age: upper Ryazanian.

Retecapsa angustiforata Subzone (NLK 19B)

Author: TAYLOR (1982), emend. JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Sollasites arcuatus* and the evolutionary appearance of *Retecapsa angustiforata*.

Definition upper boundary: JAKUBOWSKI (this study).

Definition lower boundary: THIERSTEIN (1971).

Age: upper Ryazanian.

Remarks: The evolutionary appearance datum of *Retecapsa angustiforata (= Cretarhabdus crenulatus)* is a correlatable event worldwide. The base of this zone, however, was not recorded in the Moray Firth Basin because of the development of the Kimmeridge Clay Formation during the upper to lower Ryazanian. This facies yields very poor nannofloral assemblages, and in this study all the Kimmeridge Clay samples analysed were either barren or contained only the solution resistant species *Watznaueria barnesae*.

Lithraphidites carniolensis Subzone (NLK 19C)

Author: JAKUBOWSKI (this study).

Definition: The interval between the evolutionary appearance of *Retecapsa angustiforata* and the evolutionary appearance of *Nannoconus steinmannii* and/or *Nannoconus colomii*.

Definition upper boundary: THIERSTEIN (1971).

Definition lower boundary: WORSLEY (1971).

Age: upper – lower Ryazanian.

Remarks: For the same reasons mentioned earlier, in Subzone NLK 19B, Subzone NLK 19C was not recorded in the study area.

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Appendix

Alphabetical List of Species

Axopodorhabdus albianus (BLACK, 1967) WIND & WISE in WISE & WIND, 1977
Biscutum constans (GORKA, 1957) BLACK in BLACK & BARNES, 1959
Broinsonia enormis (SCHUMENKO, 1968) MANIVIT, 1971
Bukrylithus ambiguus BLACK, 1971
Calcicalathina oblongata WORSLEY, 1971
Chiastozygus litterarius (GORKA, 1957) MANIVIT, 1971
Chiastozygus striatus BLACK, 1971
Conusphaera mexicana TREJO, 1969
Conusphaera rothii (THIERSTEIN, 1971) JAKUBOWSKI, 1986
Corollithion silvaradion FILEWICZ, WIND & WISE in WISE & WIND, 1977
Cretarhabdus loriei GARTNER, 1968
Crucibiscutum hayi (BLACK, 1971) JAKUBOWSKI, 1986
Crucibiscutum salebrosum (BLACK, 1971) JAKUBOWSKI, 1986
Cruciellipsis cuvillieri (MANIVIT, 1966) THIERSTEIN, 1971
Cyclagelosphaera margerelii NOEL, 1965
Diadorhombus rectus WORSLEY, 1971
Diazomatolithus lehmanii NOEL, 1965
Discorhabdus ignotus (GORKA, 1957) PERCH-NIELSEN, 1968
Dodekapodorhabdus noelae PERCH-NIELSEN, 1968
Eiffellithus turriseiffelii (DEFLANDRE in DEFLANDRE & FERT, 1954) REINHARDT, 1965
Ellipsagelosphaera britannica (STRADNER, 1963) PERCH-NIELSEN, 1968
Eprolithus apertior BLACK, 1973
Eprolithus varolii JAKUBOWSKI, 1986
Gartnerago praeobliquum JAKUBOWSKI, 1986
Hemipodorhabdus gorkae (REINHARDT, 1969) GRÜN & ALLEMANN, 1975
Lithastrinus septentrionalis STRADNER, 1963
Lithraphidites alatus THIERSTEIN in ROTH & THIERSTEIN, 1972
Lithraphidites bollii (THIERSTEIN, 1971) THIERSTEIN, 1973
Lithraphidites carniolensis DEFLANDRE, 1963
Lithraphidites moray-firthensis JAKUBOWSKI, 1986
Micrantholithus brevis JAKUBOWSKI, 1986
Micrantholithus hoschulzii (REINHARDT, 1966) THIERSTEIN, 1971
Micrantholithus obtusus STRADNER, 1963
Micrantholithus speetonensis PERCH-NIELSEN, 1979
Nannoconus abundans STRADNER & GRÜN, 1973
Nannoconus borealis PERCH-NIELSEN, 1979
Nannoconus colomii (DE LAPPARENT, 1931) KAMPTNER, 1938
Nannoconus steinmannii KAMPTNER, 1931
Parhabdolithus embergeri (NOEL, 1965) STRADNER, 1963
Phanulithus anfractus JAKUBOWSKI, 1986
Prediscosphaera columnata (STOVER, 1966) PERCH-NIELSEN, 1984
Repagulum parvidentatum (DEFLANDRE in DEFLANDRE & FERT, 1954) FORCHHEIMER, 1972
Retecapsa angustiforata BLACK, 1971

Rhagodiscus angustus (STRADNER, 1963) REINHARDT, 1971
Rhagodiscus asper (STRADNER, 1963) REINHARDT, 1963
Rhagodiscus splendens (DEFLANDRE in DEFLANDRE & FERT, 1954) VERBEEK, 1977
Rucinolithus irregularis THIERSTEIN in ROTH & THIERSTEIN, 1972
Seribiscutum primitivum (THIERSTEIN, 1974) FILEWICZ et al. in WISE & WIND, 1977
Sollasites arcuatus BLACK, 1971
Speetonia colligata BLACK, 1971
Stradnerlithus comptus BLACK, 1971
Tegumentum stradneri THIERSTEIN in ROTH & THIERSTEIN, 1972
Tetrapodorhabdus decorus (DEFLANDRE in DEFLANDRE & FERT, 1954) WIND & WISE in WISE & WIND, 1977
Tranolithus gabalus STOVER, 1966
Tranolithus phacelosus STOVER, 1966
Tubodiscus jurapelagicus (WORSLEY, 1971) ROTH, 1973
Watznaueria barnesae (BLACK in BLACK & BARNES, 1959) PERCH-NIELSEN, 1968
Zygodiscus sisyphus GARTNER, 1968

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Plate Descriptions

Following the name of each photographed species is the location from which the sample was obtained. In those cases where the samples were taken from well sections the name of the operator is given first (e.g. Sun Oil) followed by the block, quadrant and well number (e.g. 20/7-A1) and lastly the sample depth. The field samples are identified by their location (e.g. Nettleton) and the sample number (e.g. AF.1) The AF refers to the Acre Farm Quarry and WH. to Wood's Hill Quarry, which are both near Nettleton, Lincolnshire, England.

Plate 1

Fig. 1: *Repagulum parvidentatum* (DEFLANDRE), BP. 14/4-1, 1240 m, scanning electron micrograph of proximal side, × 7700.
Figs. 2– 3: *Lithraphidites moray-firthensis* JAKUBOWSKI, BP. 14/4-1, 1320 m, scanning electron micrograph of side view, × 7700.
Figs. 4– 5: *Repagulum parvidentatum* (DEFLANDRE), Sun Oil 20/7-A1, 7000′, × 2400.
Fig. 4: Phase contrast.
Fig. 5: Cross-polarized light.
Figs. 6– 7: *Lithraphidites moray-firthensis* JAKUBOWSKI, BP. 14/4-1, 1320 m, × 2400.
Fig. 6: Phase contrast.
Fig. 7: Cross-polarized light.
Figs. 8– 9: *Phanulithus anfractus* JAKUBOWSKI, Texaco 15/16-5, 11420′, × 2400.
Fig. 8: Phase contrast.
Fig. 9: Cross-polarized light.
Figs. 10–11: *Biscutum constans* (GORKA), B.P. 14/4-1, 1400 m, × 2400.
Fig. 10: Phase contrast.
Fig. 11: Cross-polarized light.
Figs. 12–13: *Seribiscutum primitivum* (THIERSTEIN), Sun Oil 20/7-A1, 6200′, × 2400.
Fig. 12: Phase contrast.
Fig. 13: Cross-polarized light.
Figs. 14–15: *Tetrapodorhabdus decorus* (DEFLANDRE), Sun Oil 20/7-A1, 6240′, × 2400.
Fig. 14: Phase contrast.
Fig. 15: Cross-polarized light.
Figs. 16–17: *Hemipodorhabdus gorkae* (REINHARDT), × 2400.
Fig. 16: Nettleton, WH.37; Phase contrast.
Fig. 17: Nettleton, AF.1; Phase contrast.
Figs. 18–19: *Tegumentum stradneri* THIERSTEIN, Sun Oil 20/7-A1, 6280′, × 2400.
Fig. 18: Phase contrast.
Fig. 19: Cross-polarized light.
Figs. 20–21: *Gartnerago praeobliquum* JAKUBOWSKI, Occidental 13/28-1, 4780′, × 2400.
Fig. 20: Phase contrast.
Fig. 21: Cross-polarized light.
Figs. 22–23: *Eiffellithus turriseiffelii* (DEFLANDRE), Sun Oil 20/7-A1, 6320′, × 2400.
Fig. 22: Phase contrast.
Fig. 23: Cross-polarized light.

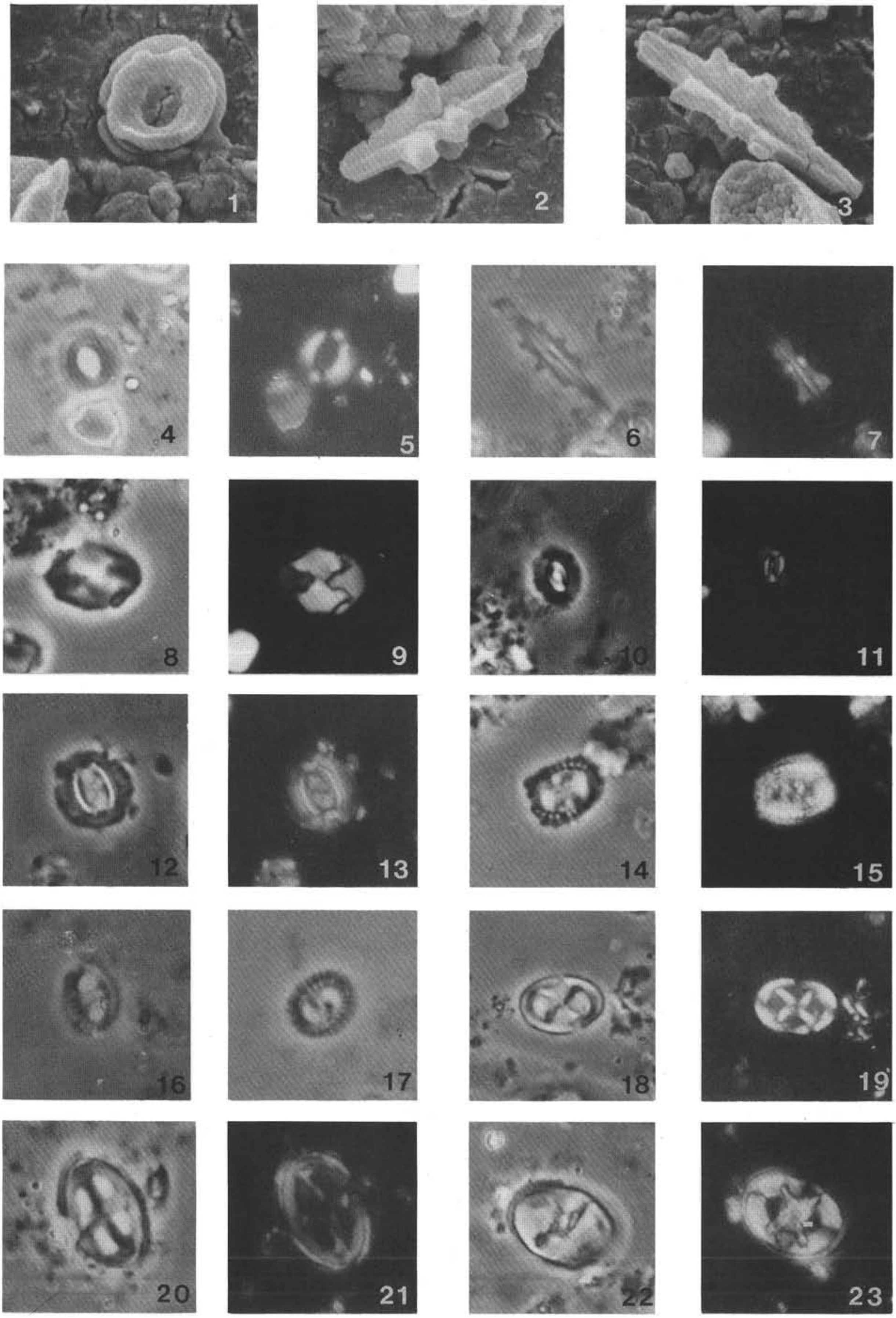
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Plate 2

Figs. 1– 2: *Prediscosphaera columnata* (STOVER), Sun Oil 20/7-A1, 6280′, × 2400.
Fig. 1: Phase contrast.
Fig. 2: Cross-polarized light.

Figs. 3– 4: *Speetonia colligata* BLACK, Nettleton AF.1, × 2400.
Fig. 3: Phase contrast.
Fig. 4: Cross-polarized light.

Figs. 5– 6: *Zygodiscus sisyphus* GARTNER, Sun Oil 20/7-A1, 6320′, × 2400.
Fig. 5: Phase contrast.
Fig. 6: Cross-polarized light.

Figs. 7– 8: *Cruciellipsis cuvillieri* (MANIVIT), Sun Oil 20/7-A1, 7720′, × 2400.
Fig. 7: Phase contrast.
Fig. 8: Cross-polarized light.

Figs. 9–10: *Rhagodiscus asper* (STRADNER), BP. 14/4-1, 1320 m, × 2400.
Fig. 9: Phase contrast.
Fig. 10: Cross-polarized light.

Figs. 11–12: *Rhagodiscus angustus* (STRADNER), Sun Oil 20/7-A1, 6280′, × 2400.
Fig. 11: Phase contrast.
Fig. 12: Cross-polarized light.

Figs. 13–14: *Nannoconus borealis* PERCH-NIELSEN, Occidental 14/18-1, 1380 m, × 2400.
Fig. 13: Phase contrast.
Fig. 14: Cross-polarized light.

Figs. 15–16: *Nannoconus abundans* STRADNER & GRÜN, Tenneco 20/6-1, 7150′, × 2400.
Fig. 15: Phase contrast.
Fig. 16: Cross-polarized light.

Figs. 17–18: *Conusphaera mexicana* TREJO, East Madagascar well, × 2400.
Fig. 17: Phase contrast.
Fig. 18: Cross-polarized light.

Figs. 19–20: *Conusphaera rothii* (THIERSTEIN), Tenneco 20/6-1, 7200′, × 2400.
Fig. 19: Phase contrast.
Fig. 20: Cross-polarized light.

Figs. 21–22: *Crucibiscutum salebrosum* (BLACK), Speeton, S.19, × 2400.
Fig. 21: Phase contrast.
Fig. 22: Cross-polarized light.

Figs. 23–24: *Stradnerlithus comptus* BLACK, Sun Oil 20/7-A1, 7680′, × 2400.
Fig. 23: Phase contrast.
Fig. 24: Cross-polarized light.

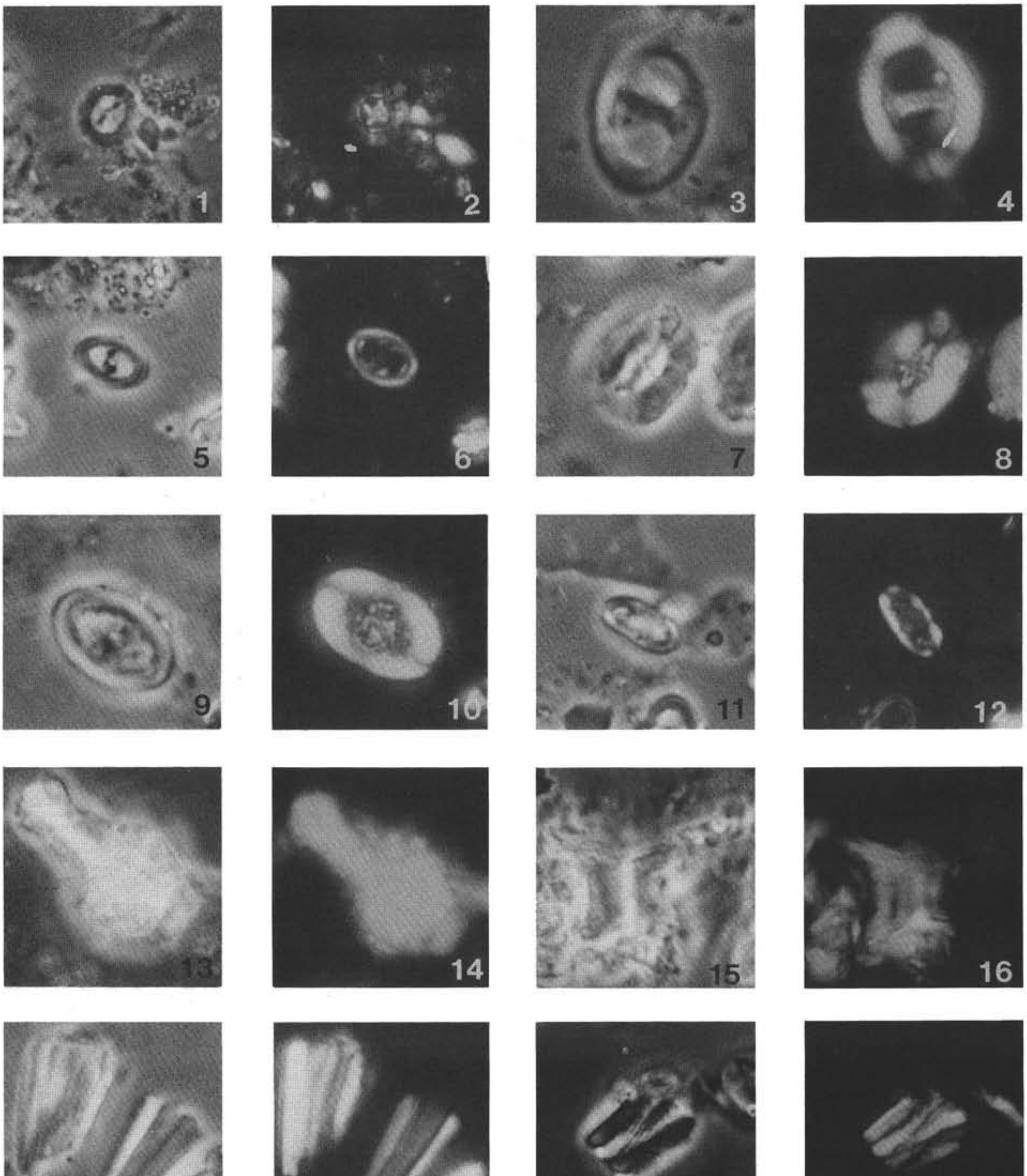
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Plate 3

Figs. 1– 2: *Eprolithus apertior* BLACK, Sun Oil 20/7-A1, 6280′, × 2400.
Fig. 1: Phase contrast.
Fig. 2: Cross-polarized light.

Fig. 3: *Micrantholithus obtusus* STRADNER, Nettleton, AF.1, × 2400, Phase contrast.

Fig. 4: *Micrantholithus hoschulzii* (REINHARDT), Nettleton, AF.1, × 2400, Phase contrast.

Figs. 5– 6: *Eprolithus varolii* JAKUBOWSKI, Sun Oil 20/7-A1, × 2400.
Fig. 5: Phase contrast.
Fig. 6: Cross-polarized light.

Figs. 7– 8: *Micrantholithus brevis* JAKUBOWSKI, BP. 14/4-1, 1685.5 m, ×2400.
Fig. 7: Phase contrast.
Fig. 8: Cross-polarized light.

Figs. 9–10: *Lithastrinus septentrionalis* STRADNER, Nettleton, WH.37, × 2400.
Fig. 9: Phase contrast.
Fig. 10: Cross-polarized light.

Figs. 11–12: *Micrantholithus speetonensis* PERCH-NIELSEN, BP. 14/4-1, 1660 m, × 2400.
Fig. 11: Phase contrast.
Fig. 12: Cross-polarized light.

Figs. 13–14: *Diazomatolithus lehmanii* NOEL, Nettleton, AF.2, × 2400.
Fig. 13: Phase contrast.
Fig. 14: Cross-polarized light.

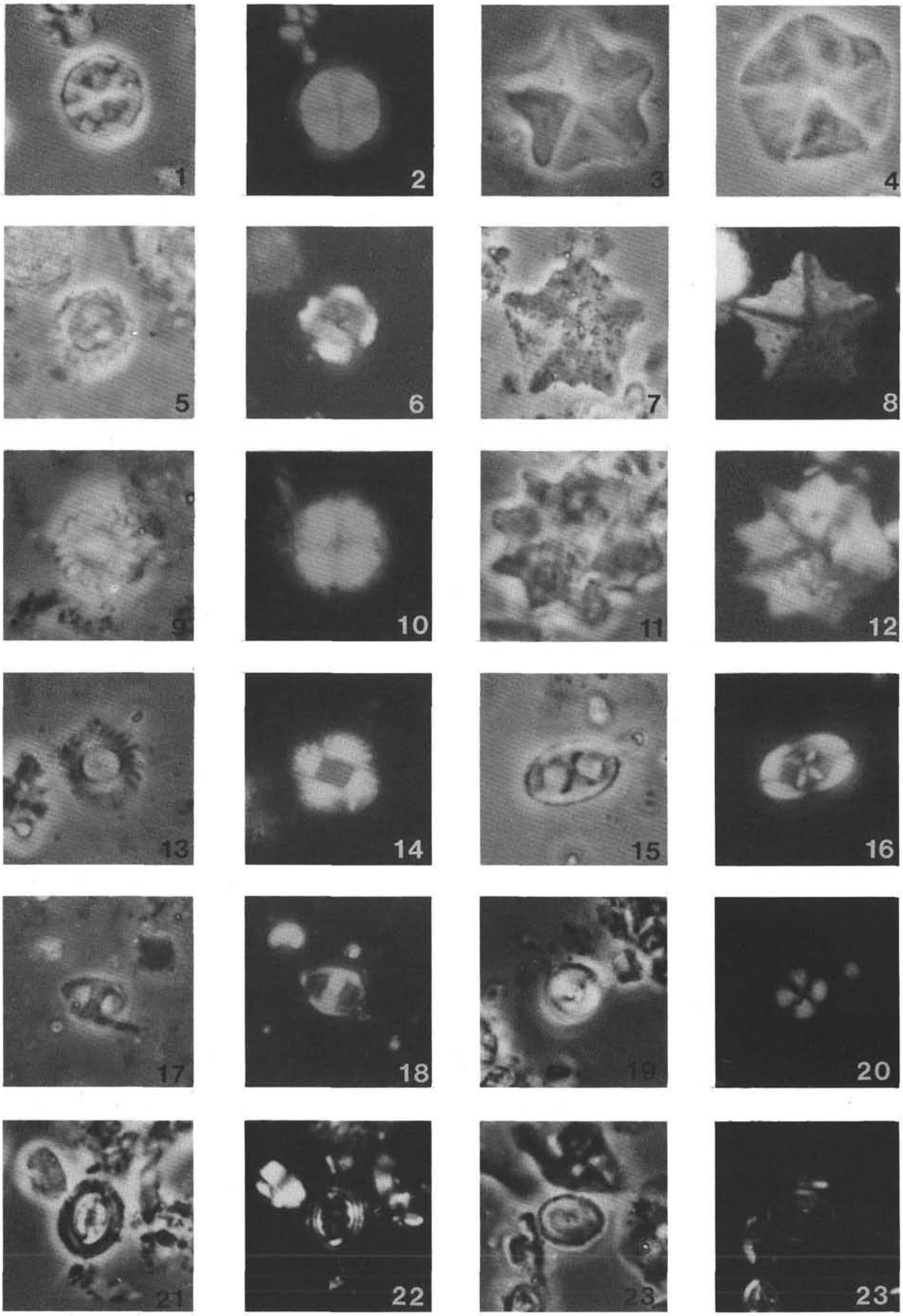
Figs. 15–16: *Chiastozygus striatus* BLACK, Nettleton, AF.2, × 2400.
Fig. 15: Phase contrast.
Fig. 16: Cross-polarized light.

Figs. 17–18: *Tranolithus gabalus* STOVER, BP. 14/4-1, 1660 m, × 2400.
Fig. 17: Phase contrast.
Fig. 18: Cross-polarized light.

Figs. 19–20: *Cyclagelosphaera margerelii* NOEL, Speeton, S.28, × 2400.
Fig. 19: Phase contrast.
Fig. 20: Cross-polarized light.

Figs. 21–22: *Sollasites arcuatus* BLACK, Tenneco 20/6-1, 6100′, × 2400.
Fig. 21: Phase contrast.
Fig. 22: Cross-polarized light.

Figs. 23: *Corollithion silvaradion* FILEWICZ, WIND & WISE, BP. 14/4-1, 1660 m, × 2400.
Fig. 23 (left): Phase contrast.
Fig. 23 (right): Cross-polarized light.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