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Upper Campanian-Maastrichtian calcareous nannofossil biostratigraphy of the Stevns-1 borehole, Denmark

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Abstract The Stevns-1 borehole (Stevns Klint, eastern Denmark) penetrated lowermost Danian bryozoan limestone and Maastrichtian chalk before reaching a terminal depth of 456.1m in the Campanian/Maastrichtian boundary interval. The borehole, drilled as part of a project to study the Earth System in a Greenhouse World, provides the most complete and expanded section through the Maastrichtian in NW Europe. Consequently, it constitutes a significant biostratigraphic reference for this interval. This work presents the biostratigraphy of the borehole, underpinning palaeoecological research that is in progress.

Application of existing northern high-latitude calcareous nannofossil biozonation schemes to the biostratigraphic data has revealed some previously unsubstantiated/unreported nannofossil events. These include the extinction of *Helicolithus trabeculatus* and increase in abundance of *Prediscosphaera grandis* in the Upper Maastrichtian, and extinction of *Zeugrhabdotus praesigmoides* in the Campanian/Maastrichtian boundary interval. These may prove to be useful in further subdividing this interval, or of particular palaeoecological relevance. Additionally, some nannofossil events appear to contradict those of the established schemes, such as higher than expected extinctions of *Zeugrhabdotus bicrescenticus* and *Gartnerago segmentatum*, and the lower than expected extinction of *Calculites obscurus*. The significance of these, in biostratigraphic or palaeoecological terms, remains to be assessed.

Keywords Calcareous nannofossils, Maastrichtian, Campanian, Boreal Realm, Denmark

1. Introduction

A shallow borehole was drilled and cored, in 2005, through Lower Danian, Maastrichtian and Upper Campanian limestone and chalk at Stevns Klint, on the east coast of Sjælland, eastern Denmark (Figure 1). The operation took place under the auspices of the Cretaceous Research Centre (CRC), a collaboration of scientists from The Geological Survey of Denmark and Greenland (GEUS) and the Department of Geography and Geology, University of Copenhagen, and was funded by the Danish Natural Science Research Council (FNU). The project for which the borehole was drilled aimed to investigate the lithological composition, variation and cyclicity of the Maastrichtian part of the Chalk Group. The succession comprises ridge, drift, moat and valley systems formed by long-lasting bottom-currents (Lykke-Andersen & Surlyk, 2004; Surlyk & Lykke-Andersen, 2007). The Stevns-1 borehole (DGU 218.1938) was positioned on a palaeotopographic ridge. It was drilled from close to the base of the Danian Stevns Klint Formation into the Maastrichtian chalk of the Tor Formation below, with the intention of obtaining a complete core through the Maastrichtian (Surlyk *et al*., 2006). The succession in the area is expanded, compared with the equivalent succession in the chalks of the North Sea. Breaks in sedimentation are documented by firmgrounds, but hardgrounds are not present (S.L. Rasmussen, H.B. Madsen, pers. comms, 2008). The drilled interval represents the only completely cored section through the Upper Campanian-Maastrichtian of NW Europe, rendering it ideal as a biostratigraphic reference section (Stemmerik *et al*., 2006). Apart from providing a time-frame for current and future research (sedimentological logging, nannofossil palaeoecology, carbon, oxygen and strontium isotopes, trace elements, silica and diagenesis studies), the data derived from this cored interval is ideal for testing existing nannofossil zonation schemes, and this is the theme of the work presented here.

Several nannofossil biostratigraphic schemes have been developed from northern high-latitude Campanian and Maastrichtian sediments, primarily in response to hydrocarbon exploration in the North Sea (*e.g*. Sissingh, 1977, 1978; Perch-Nielsen, 1979; Crux, 1982). The 'NK' biozonation scheme (Mortimer, 1987) was based on successions in the Danish and southern Norwegian sectors of the North Sea, using core, sidewall core and ditch-cuttings samples. This has been superceded by the 'UC^{BP}' (Upper Cretaceous boreal province) nannofossil biozonation scheme of Burnett (1998), which was developed from the scheme of Burnett (1990), and was based on outcrop and well sections from Denmark, Germany, Holland, and the northern and southern UK. Network Stratigraphic Consulting Limited (hereafter NSCL) have since further refined the UC^{BP} scheme for more local use, using data from several hundred wells in the Norwegian and Danish sectors of the North Sea, to erect a number of subzones within the UC framework, particularly in $UC16^{BP}$ (Campanian/Maastrichtian boundary interval) and UC19-20 ^{BP} (Maastrichtian; Fritsen, 1999). Here, I present the results of the nannofossil biostratigraphic study of the Stevns-1 borehole. These results suggest further, potentially useful biostratigraphic events, and highlight some discrepancies relative to the established biozonations.

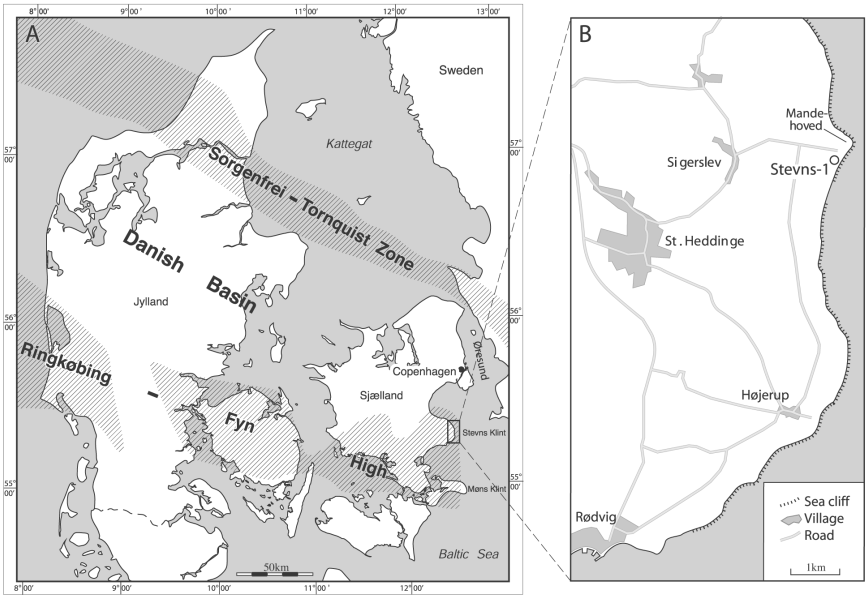


Figure 1: Maps illustrating the location of the Stevns-1 borehole, eastern Denmark. **A**) Regional geomorphology (after Stemmerik *et al*., 2006). **B**) Location (after Surlyk & Lykke-Andersen, 2007)

2. Materials and methods

The Stevns-1 borehole is situated near Mandehoved, close to the village of Højerup, eastern Sjælland, Denmark (Figure 1). The borehole was drilled early in 2005 by Faxe Kalk A/S and penetrated 456.1m of lowermost Danian, Maastrichtian and Campanian/Maastrichtian boundary interval sediments (Figure 2), with close to 100% recovery. The borehole was terminated in the Campanian/Maastrichtian boundary interval, belonging to nannofossil zone UC16a^{BP}. The Cretaceous/Tertiary boundary was picked using the gamma log (Figure 2).

A total of 83 samples were analysed, taken at approximately every 5m, except around (sub)zonal boundaries, where sampling density was, at times, higher. The succession roughly comprises Upper Campanian-lowermost Maastrichtian bioturbated chalk, succeeded by Lower Maastrichtian chalk and marl. The Upper Maastrichtian part comprises almost pure chalk with some intervals of flint-rich chalk and marly horizons (marly horizons can be seen on the gamma log: Figure 2). Bryozoans and other macrofossils increase towards the top of the Maastrichtian (Stemmerik *et al*., 2006). Nannofossil smear-slides were prepared from core plugs using the simple smear-slide technique described in Bown & Young (1998). The prepared slides were examined using a Leitz Laborlux 8 light-microscope, at 1250x magnification. All slides are stored at GEUS.

Due to the biostratigraphic nature of the study, basic presence/absence counting was employed. Particular care was taken to search for biostratigraphic marker-species, and obvious changes in assemblage composition were noted (Figure 3). A complete taxonomic list is found in Bown (1998). The 'NNTp' nannofossil zonation scheme of Varol (1998) was applied to the Danian, whereas the UC^{BP} scheme of Burnett (1998), with modifications by NSCL (Fritsen, 1999), was utilised for the Maastrichtian and Campanian (Figure 3). It should be noted that the Lower/Upper Maastrichtian boundary has not been formally defined, but that the nannofossil zones of Burnett (1998) have been calibrated with belemnite zones in Germany, so an approximation can be made based on the belemnite substage definitions. The base Maastrichtian *has* been formally defined and lies in nannofossil zone UC16 (Odin, 2001). However, the base cannot be precisely located in the boreal region because the sequence of nannofossil events in the boreal region is slightly different from that seen in the low-latitude boundary-stratotype section (Tercis, southern France), and also the nannofossil event that lies just above the boundary in Tercis is not present at all in the boreal region (last occurrence of *Uniplanarius trifidus*), because this is a lower-latitude-restricted taxon.

3. Biostratigraphic results

The biostratigraphic data are presented on the range-chart (Table 1). Rich and diverse nannofossil assemblages characterise most of the succession. Species richness, excluding reworked species, is 64 for the Maastrichtian and 71 for the Campanian/Maastrichtian boundary interval. The nannofossil preservation is, in general, relatively good, particularly when compared to Maastrichtian chalk from the Danish North Sea (Sheldon, 2006). This is probably due to the Stevns area only being buried to a depth of approximately 500m during post-Danian times (Japsen & Bidstrup, 1999), compared with 2–3km in the Central Graben. The nannofossil biostratigraphic breakdown is discussed below, following Burnett (1998), using first downhole occurrences (FDO) and last downhole occurrences (LDO) of key species (Figure 3). Selected zonal marker species are illustrated on Plate 1.

3.1 Danian (0-12.47m)

NNTp1B (0-12.47m): The assemblage comprises Danian and survivor nannofossils, including *Zeugrhabdotus sigmoides*, *Biscutum* spp., *Markalius inversus*, *Braarudosphaera bigelowii*, *Neocrepidolithus cohenii*, *Cyclagelosphaera reinhardtii* and some Upper Cretaceous reworked species. The presence of *Z. sigmoides*, which marks the base of subzone NNTp1B, suggests that the lowermost Danian (subzone NNTp1A) does not exist here, or was not sampled.

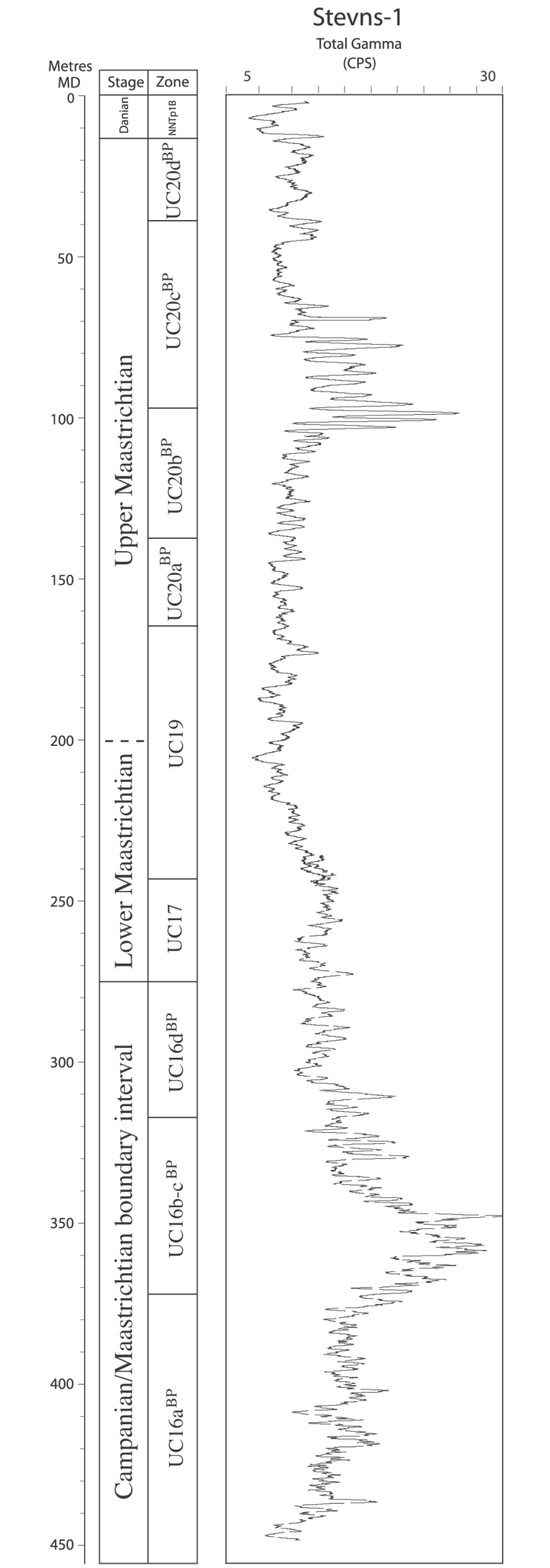


Figure 2: Stevns-1 depth profile, nannofossil zonation (UC^{BP} zonation of Burnett, 1998) and gamma log (after Stemmerik *et al*., 2006)

3.2 Maastrichtian (14.29-275.54m)

UC20d^{BP} (14.29-39.07m): The presence of *Cribrosphaerella daniae* indicates UC20d^{BP}. The FDO of *Gartnerago segmentatum* (= *Gartnerago obliquum* of some authors; Figure 3) is found within this subzone. *G. segmentatum* occurs more or less consistently from the base of the cored section to 56.57m, above which it occurs occasionally (Table 1). Reworking is occasionally present in the form of *Reinhardtites levis* and *Calculites obscurus* from the Lower Maastrichtian, and *Eiffellithus eximius* from the Campanian. These species are considered to be reworked, as they occur as rare specimens in an occasional sample (Table 1).

UC20c^{BP} (41.15-94.32m): Common *Arkhangelskiella maastrichtiana*, together with the absence of *C. daniae*, indicates UC20c^{BP}. The FDO of *Zeugrhabdotus bicrescenticus* (= *Zygodiscus compactus* of some authors) is found within this subzone (Figure 3). The FDO of *Helicolithus trabeculatus* occurs at 94.32m, and may have potential as a biostratigraphic indicator towards the base of this subzone (Table 1). Occasional reworking is represented by *Seribiscutum primitivum* and *R. levis*.

UC20b^{BP} (98.16-132.53m): The presence of *Nephrolithus frequens*, together with the absence of *C. daniae* and *A. maastrichtiana*, indicate that this interval belongs to UC20b^{BP}. *N. frequens* is not found in the interval from 118.5m to 123.10m in the Stevns-1 borehole. *N. frequens* is also absent from intervals within UC20b^{BP} in the Danish North Sea (Sheldon, 2006). Occasional reworking is represented by *R. levis*.

UC20a^{BP} (137.14-164.8m): This interval is assigned to UC20a^{BP} based on very rare occurrences of *Lithraphidites quadratus*. *Prediscosphaera grandis* increases in abundance from UC20a^{BP} downhole.

UC19 (174.24-243.09m): The FDO of *S. primitivum*, together with the absence of *L. quadratus*, mark the presence of UC19. It is noted that *Biscutum magnum* has its FDO close to that of *S. primitivum* (Table 1). Poorly-preserved specimens of *S. primitivum* (where the central-area is missing) can be difficult to differentiate from *B. magnum*. Occasional reworking is represented by *Tranolithus orionatus* and *R. levis*.

UC17 (252.31-275.54m): The FDOs of consistent *R. levis* and *T. orionatus* (marker-species for UC18 and UC17, respectively) almost coincide, indicating that UC18 is likely missing or condensed in this borehole. The FDO of *in situ C. obscurus* was noted at 275.54m. According to NSCL (Fritsen, 1999), this species is used as a marker for base UC19ii (Figure 3), equivalent to lower UC19 of Burnett (1998).

3.3 Campanian/Maastrichtian boundary interval (284.81-456.10m)

UC16d^{BP} (284.81-317.28m): UC16d^{BP} is characterised by the FDO of *Broinsonia parca constricta* and continued presence of the marker-species denoting UC19, UC18 and UC17. NSCL (Fritsen, 1999) use the FDO of *Reinhardtities*

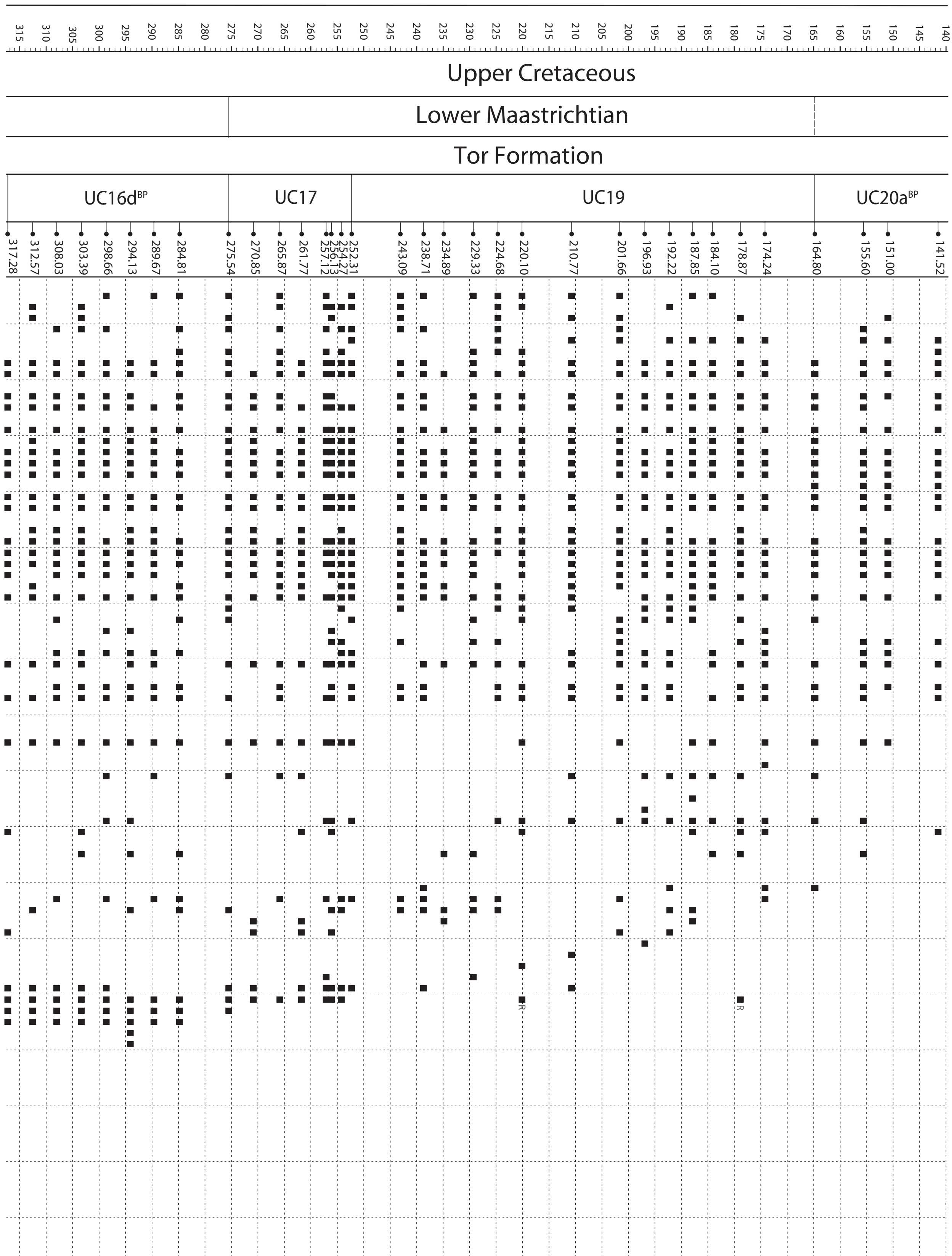
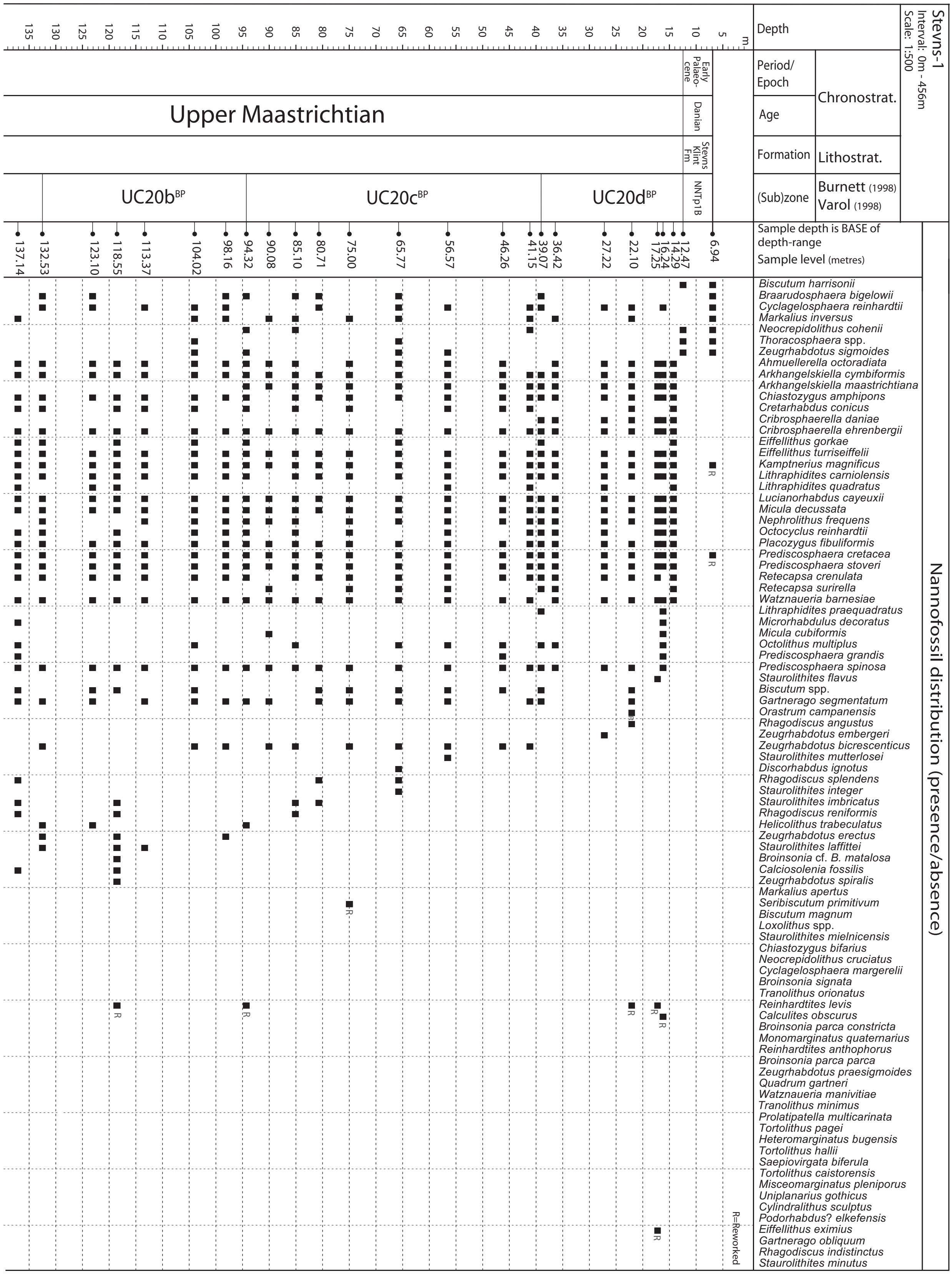


Table 1: Stevns-1 nannofossil distribution chart


Stevns-1
Interval: 0m - 456m
Scale: 1:500
Depth
Period/Epoch
Age
Chronostrat.
Formation
Lithostrat.
(Sub)zone
Burnett (1998)
Varol (1998)
Early Palaeo-cene
Danian
Stevns Klint Fm
NNTp1B
Upper Maastrichtian
UC20b^BP
UC20c^BP
UC20d^BP
Sample depth is BASE of depth-range
Sample level (metres)
137.14
132.53
123.10
118.55
113.37
104.02
98.16
94.32
90.08
85.10
80.71
75.00
65.77
56.57
46.26
41.15
39.07
36.42
27.22
22.10
17.25
16.24
14.29
12.47
6.94
Nannofossil distribution (presence/absence)
R=Reworked
Biscutum harrisonii
Braarudosphaera bigelowii
Cyclagelosphaera reinhardtii
Markalius inversus
Neocrepidolithus cohenii
Thoracosphaera spp.
Zeugrhabdotus sigmoides
Ahmuellerella octoradiata
Arkhangelskiella cymbiformis
Arkhangelskiella maastrichtiana
Chiastozygus amphipons
Cretarhabdus conicus
Cribrosphaerella daniae
Cribrosphaerella ehrenbergii
Eiffellithus gorkae
Eiffellithus turriseiffelii
Kamptnerius magnificus
Lithraphidites carniolensis
Lithraphidites quadratus
Lucianorhabdus cayeuxii
Micula decussata
Nephrolithus frequens
Octocyclus reinhardtii
Placozygus fibuliformis
Prediscosphaera cretacea
Prediscosphaera stoveri
Retecapsa crenulata
Retecapsa surirella
Watznaueria barnesiae
Lithraphidites praequadratus
Microrhabdulus decoratus
Micula cubiformis
Octolithus multiplus
Prediscosphaera grandis
Prediscosphaera spinosa
Staurolithites flavus
Biscutum spp.
Gartnerago segmentatum
Orastrum campanensis
Rhagodiscus angustus
Zeugrhabdotus embergeri
Zeugrhabdotus bicrescenticus
Staurolithites mutterlosei
Discorhabdus ignotus
Rhagodiscus splendens
Staurolithites integer
Staurolithites imbricatus
Rhagodiscus reniformis
Helicolithus trabeculatus
Zeugrhabdotus erectus
Staurolithites laffittei
Broinsonia cf. B. matalosa
Calciosolenia fossilis
Zeugrhabdotus spiralis
Markalius apertus
Seribiscutum primitivum
Biscutum magnum
Loxolithus spp.
Staurolithites mielnicensis
Chiastozygus bifarius
Neocrepidolithus cruciatus
Cyclagelosphaera margerelii
Broinsonia signata
Tranolithus orionatus
Reinhardtites levis
Calculites obscurus
Broinsonia parca constricta
Monomarginatus quaternarius
Reinhardtites anthophorus
Broinsonia parca parca
Zeugrhabdotus praesigmoides
Quadrum gartneri
Watznaueria manivitiae
Tranolithus minimus
Prolatipatella multicarinata
Tortolithus pagei
Heteromarginatus bugensis
Tortolithus hallii
Saepiovirgata biferula
Tortolithus caistorensis
Misceomarginatus pleniporus
Uniplanarius gothicus
Cylindralithus sculptus
Podorhabdus? elkefensis
Eiffellithus eximius
Gartnerago obliquum
Rhagodiscus indistinctus
Staurolithites minutus

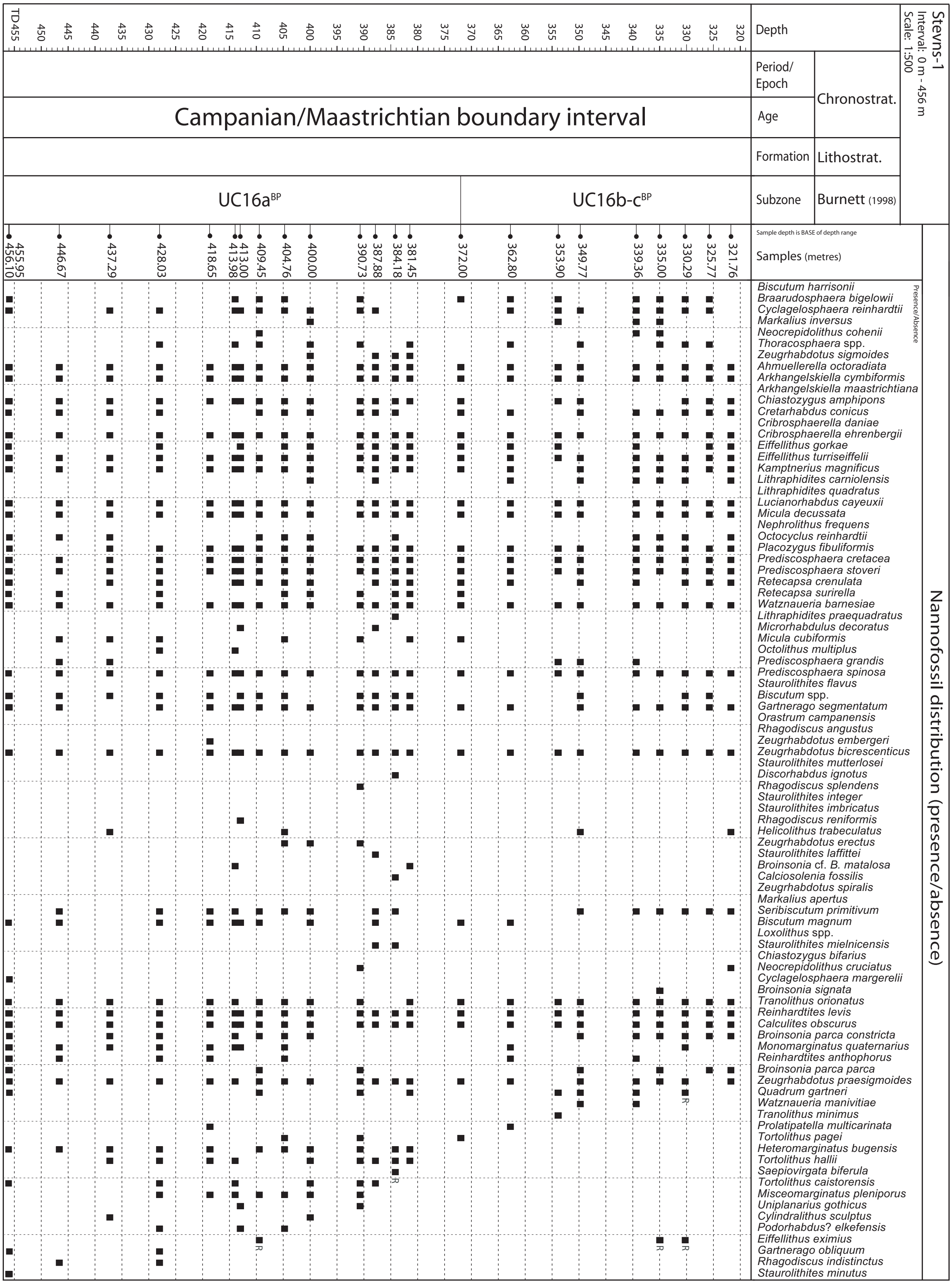


Table 1: Stevns-1 nannofossil distribution chart (continued from previous pages)

anthophorus as an intra-UC16d^{BP} marker, while Burnett (1998) utilises this bio-event as a marker for base UC16. *R. anthophorus* was found as a rare occurrence in one sample within UC16d^{BP} and is, therefore, not used as a marker here.

UC16b-c^{BP} (321.76-372.00m): By definition, the FDO of *Monomarginatus quaternarius* marks the base of UC16d^{BP} (Burnett, 1998). A single specimen of *M. quaternarius* was noted within UC16d^{BP}, at 294.13m. Due to identification difficulties and sporadic occurrences, this species is not considered to be a reliable marker in this study. The FDO of *Broinsonia parca parca* also coincides with the base of UC16d^{BP} (intra-UC16ii of NSCL; Figure 3), and is found at 321.76m. The FDO of *Zeugrhabdotus praesigmoides* coincides with the FDO of *B. parca parca* in this study. The base of UC16c^{BP} is defined by the FDO of *Tortolithus caistorensis*. This species is rare and its FDO occurs below that of *Heteromarginatus bugensis* (which marks the base of UC16b^{BP}) in the current study. *H. bugensis* likely preserves preferentially to *Tortolithus* spp. (J. Lees, pers. comm., 2008). The former species is therefore preferred as a marker to *Tortolithus* spp. It is not possible, consequently, to identify UC16b^{BP} in the Stevns-1 borehole. *Tortolithus pagei* has its FDO at 372.00m. Occasional reworking is represented by rare *Eiffellithus eximius*.

UC16a^{BP} (381.45-456.10m): The marker species for base UC16b^{BP} is *H. bugensis*, following the Burnett (1998) zonation. The FDO of *H. bugensis* also marks the base of NSCL's UC16ii (Figure 3). This species is found in the present study from 381.45m and downwards. Within this subzone (UC16a^{BP}), *Misceomarginatus pleniporus* and *M. quaternarius* occur downwards from 390.73m and 404.76m, respectively. *T. caistorensis* is found from 387.88m to the base of the core at 456.10m, and *Tortolithus hallii* has its FDO at the top of this subzone, at 381.45m. *Tortolithus* spp. may act as supplementary subzonal marker-species in the local Danish onshore area. *Reinhardtites levis*, *Lucianorhabdus cayeuxii* and *Calculites obscurus* become abundant in the lower part of this interval. Occasional occurrences of *E. eximius* and *Saepiovirgata biferula* within this subzone are considered to be reworked from UC15 or lower.

UC15: The FDO of *E. eximius* marks the base of UC16 (Figure 3). This species was found occasionally in UC20d^{BP}, UC16b-c^{BP} and UC16a^{BP} in this study, where it is considered to be reworked (Table 1). The FDO of *R. anthophorus* also marks the base of UC16 in the Burnett (1998) scheme. This species was noted within UC16a^{BP}, UC16b-c^{BP} and UC16d^{BP}, but identification can be problematic, and it is therefore not used as a marker here. It is concluded that UC15 may not have been penetrated in the Stevns-1 borehole.

4. Biostratigraphic discussion

The Stevns-1 borehole data presented here suggest some biostratigraphic events that differ from those used in the established biozonation schemes (Figure 3).

Specimens, interpreted as reworked, of *Reinhardtites levis* and *Eiffellithus eximius* are found, sporadically, above their known ranges in this borehole (Table 1). The Sorgenfrei-Tornquist Zone (Figure 1A) was associated with inversion and uplift during the Cretaceous, and was exposed (Vejbæk & Andersen, 2002; Surlyk & Lykke-Andersen, 2007). This probably accounts for the reworking found in the Stevns-1 borehole.

The FDOs of *Gartnerago segmentatum* and *Zeugrhabdotus bicrescenticus* occur in UC20d^{BP} and UC20c^{BP}, respectively, in this study, whereas NSCL use these bio-events to subdivide UC19. It cannot be ruled out that these species are reworked, but the distribution patterns seen on the range-chart (Table 1) suggest that this is not the case in the Stevns area; they occur, more often than not, in successive samples, and not necessarily in samples where clearly reworked specimens, such as *R. levis* and *E. eximius*, are found. It is not unusual that taxa appear sporadically towards the end of their range: *Z. bicrescenticus* is found consistently from the base of the core to 252.31m, followed by a gap of approximately 30m where it is not seen, followed by two intervals (220.01m to 151.00m and 104.02m to 41.15m) where it appears more or less consistently; Table 1).

The marker-species for UC20b^{BP}, *Nephrolithus frequens*, is not consistently present within this subzone, nor in UC20c^{BP}. Particular care should, therefore, be taken when assigning UC20^{BP} in the boreal region. It is inferred that the pattern that this high-latitude taxon demonstrates is a response to environmental perturbations, such as temperature variation, in the Danish Central Graben and Danish Basin (Sheldon, 2006).

The FDO of *Helicolithus trabeculatus* occurs within UC20c^{BP}. The use of *Lithraphidites quadratus* as a marker for UC20a^{BP} is relatively limited, as it is extremely rare in the North Sea (Sheldon, 2006; M. Hampton, pers. comm., 2007). This species is also difficult to distinguish from *Lithraphidites praequadratus* in poorly-preserved material. *Prediscosphaera grandis* increases in abundance downhole from UC20a^{BP}. The FDO of *Calculites obscurus* is found in UC17 in the Stevns-1 borehole, compared with UC19 in the NSCL scheme.

The FDOs of *R. levis* and *Tranolithus orionatus* almost coincide, indicating UC18 is either missing or condensed in this section. It was also noted that UC17 is relatively very thin in this well. The missing section is probably due to erosion of the sea-bed due to strong bottom-currents (Surlyk & Lykke-Andersen, 2007).

NSCL (Fritsen, 1999) divided UC16d^{BP} into UC16iii, the base of which is marked by the FDO of *Reinhardtities anthophorus*, and UC16ii (*pars*.; Figure 3). In the scheme of Burnett (1998), the FDO of *E. eximius* indicates the base of UC16, virtually coincident with the FDO of *R. anthophorus*. *R. anthophorus* was found as a rare occurrence in one sample within UC16d^{BP} in this study, and was first found consistently in UC16a^{BP}. Identification of *R. anthophorus* can be problematic, as in poorly-preserved ma-

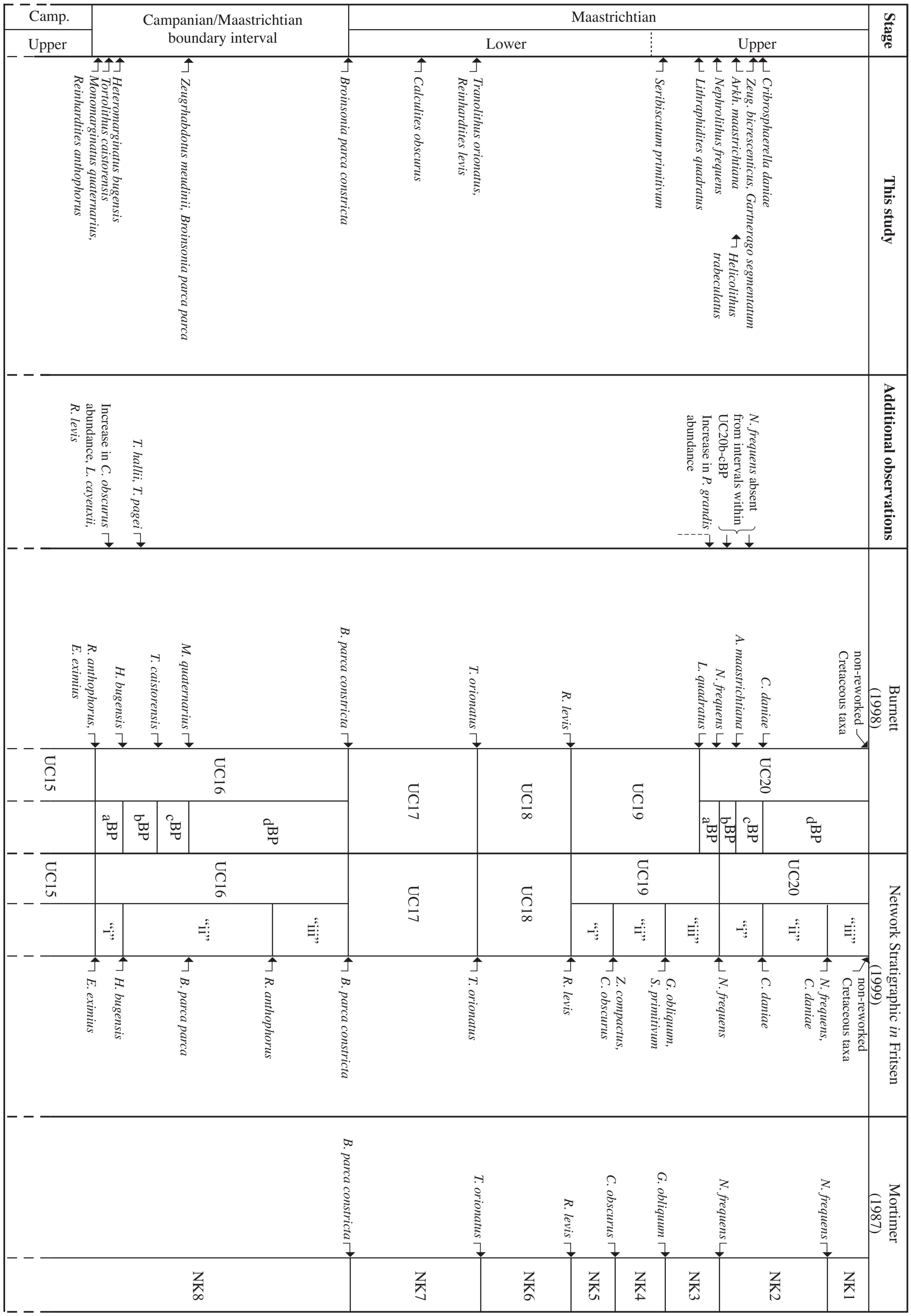


Figure 3: Summary of nannofossil data from this study compared with nannofossil events of the boreal biozonations. *NB* (1) The base Maastrichtian (following Odin, 2001) cannot be precisely placed; (2) *Gartnerago obliquum* and *Zygodiscus compactus* of Network Stratigraphic Consulting Ltd (NSCL, *in* Fritsen, 1999) are equivalent to *Gartnerago segmentatum* and *Zeugrabdotus bicrescenticus* (this and other studies). The level of the FDO of *H. bugensis*, according to NSCL, is redrawn to be compatible with that of Burnett (1998)

terial it is difficult to distinguish from *R. levis*; it is therefore not used as a marker here.

The FDO of *Monomarginatus quaternarius* defines the base of UC16d^{BP} (Burnett, 1998). This species is difficult to distinguish from *Misceomarginatus pleniporus* under the light-microscope (J. Lees, M. Hampton, pers. comms, 2007). A single specimen of *M. quaternarius* was recorded at 294.13m, within UC16d^{BP}, but does not appear again until 404.76m in UC16a^{BP}. Due to identification difficulties and its sporadic occurrence, this species is not considered to be a reliable marker here.

The FDO of *Broinsonia parca parca* also coincides with the base of UC16d^{BP} (intra-UC16ii of NSCL; Figure 3). In this borehole, the FDO of *B. parca parca* is at

321.76m and is used in preference over *M. quaternarius* to approximate the base of UC16d^{BP}. The FDO of *Zeugrhabdotus praesigmoides* also coincides with the FDO of *B. parca parca* in this study.

The base of UC16c^{BP} is defined by the FDO of *Tortolithus caistorensis*. The NSCL zonation scheme does not use *T. caistorensis* as a marker, as it is very rare and intermittent in North Sea sections. The base of UC16b^{BP} is defined by the FDO of *Heteromarginatus bugensis*. In this study the FDO of *H. bugensis* occurs above that of *T. caistorensis* (Table 1). *H. bugensis* likely preserves preferentially to *Tortolithus* spp. (J. Lees, pers. comm., 2008). The former species is therefore preferred as a marker to *Tortolithus* spp., meaning that the base of UC16c^{BP} cannot be correlated in this study (Figure 3). The interval between the FDO of *B. parca parca* and the FDO of *H. bugensis* is referred to UC16b-c^{BP}. The FDOs of *T. caistorensis*, *T. hallii* and *T. pageii* all occur close to the base of UC16b-c^{BP}. In this study, *T. hallii* is the most frequently-noted *Tortolithus* species. The FDO of *Tortolithus* spp. (not exclusively *T. caistorensis*) could be used as additional markers within the Campanian/Maastrichtian boundary interval. *R. levis*, *L. cayeuxii* and *C. obscurus* increase in abundance downwards in the lower part of this interval.

The observations in this study present some difficulties in applying only one of the established biozonation schemes (Figure 3). The relevant part of the UC^{BP} biozonation of Burnett (1998) was erected using sections from onshore northern Europe, from relatively high and intermediate latitudes, whilst NSCL's (Fritsen, 1999) and Mortimer's (1987) schemes were based on offshore material from the Norwegian and Danish sectors of the North Sea. Consequently, there may be some palaeobiogeographical differences between the schemes that have not yet been adequately highlighted. In addition, preservation can be quite variable within the chalk facies, and this can also account for apparent discrepancies. With these points in mind, both the schemes of Burnett (1998) and NSCL (1999) are equally applicable to the Stevns-1 data for the Campanian/Maastrichtian boundary interval and the lower part of the Lower Maastrichtian. In the Upper Maastrichtian, the Burnett (1998) scheme is more applicabale to the Stevns-1 data, although a number of additional events are recognised (Figure 3) that may prove useful in the Danish sector of the North Sea, or which may have local palaeoenvironmental significance in the Danish region.

5. Conclusions

A thick section (456.10m) of Maastrichtian and Campanian/Maastrichtian boundary interval chalk was penetrated by the Stevns-1 borehole and belongs to nannofossil subzones UC20d^{BP}-UC16a^{BP}. Thick Maastrichtian sections are rare in NW Europe, and the extensive thickness of the Stevns-1 core thus allows an expanded biostratigraphic breakdown. Established nannofossil biozonation schemes of Burnett (1998) and NSCL (*in* Fritsen, 1999) are both applicable to the present dataset, but additional bioevents are found. This dataset represents the results from a single section applicable to the Danish area and could be particularly useful in linking North Sea sections with onshore sections. Events of particular note are as follows:

1) The FDO of *Gartnerago segmentatum* occurs in UC20d^{BP}. The FDOs of *Zeugrhabdotus bicrescenticus* and *Helicolithus trabeculatus* occur in UC20c^{BP}.
2) The reliability of *Lithraphidites quadratus, Monomarginatus quaternarius*, *Reinhardtites anthophorus* and *Tortolithus caistorensis* as marker-species is questioned due to identification problems or scarcity.
3) *Prediscosphaera grandis* increases in abundance downhole from intra-UC20a^{BP}.
4) The FDO of *Calculites obscurus* occurs in UC17 in the Stevns-1 borehole, compared with UC19 in the NSCL scheme.
5) Together with the FDO of *Broinsonia parca parca,* the FDO of *Zeugrhabdotus praesigmoides* may act as a further marker for the base of UC16d^{BP}.
6) The FDO of *Tortolithus* spp. (*T. caistorensis*, *T. hallii* and *T. pagei*) occurs within UC16b-c^{BP} and may prove to be an additional marker for this interval.

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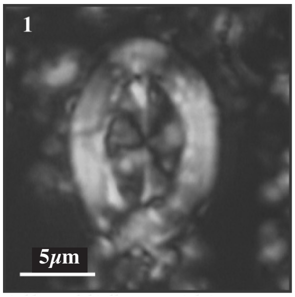
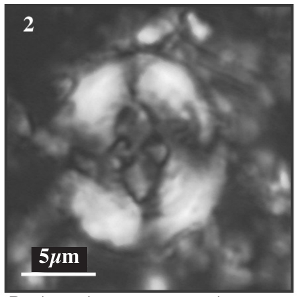
Plate 1

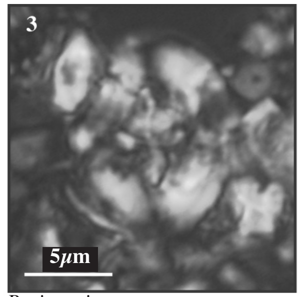
Selected light-micrographs of marker-taxa



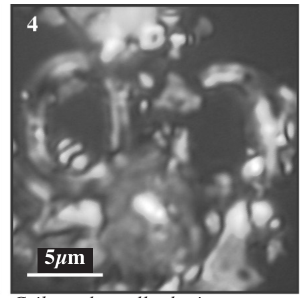
Arkhangelskiella maastrichtiana
Stevns-1, 36.42m



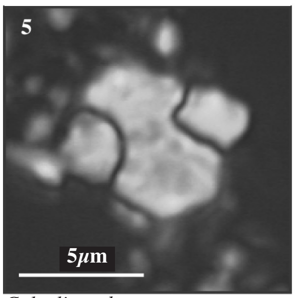
Broinsonia parca constricta
Stevns-1, 284.81m



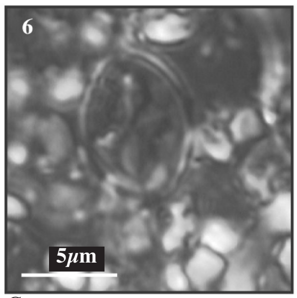
Broinsonia parca parca
Stevns-1, 335.06m



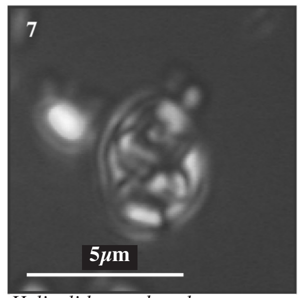
Cribrosphaerella daniae
Stevns-1, 14.29m



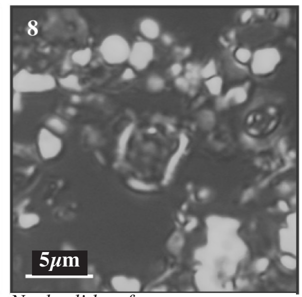
Calculites obscurus
Stevns-1, 284.81m



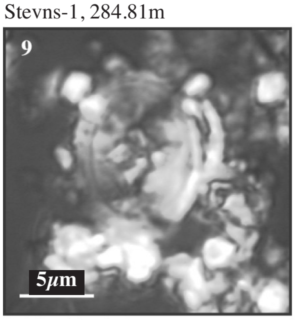
Gartnerago segmentatum
Stevns-1, 113.37m



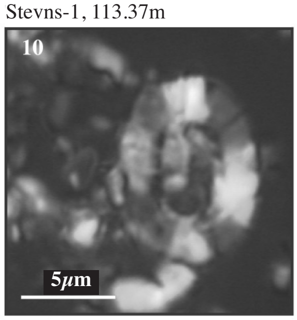
Helicolithus trabeculatus
Stevns-1, 174.24m



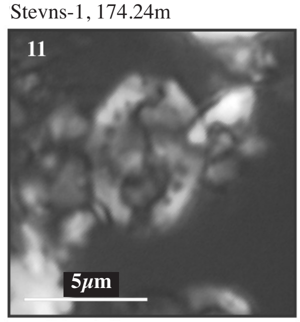
Nephrolithus frequens
Stevns-1, 39.07m



Reinhardtites levis
Stevns-1, 312.57m



Tortolithus caistorensis
Stevns-1, 390.73m



Tortolithus hallii
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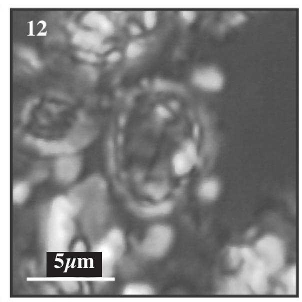
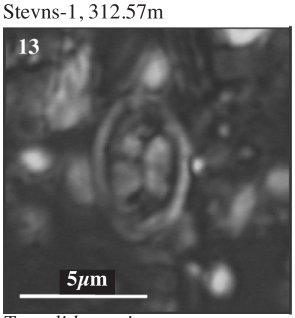
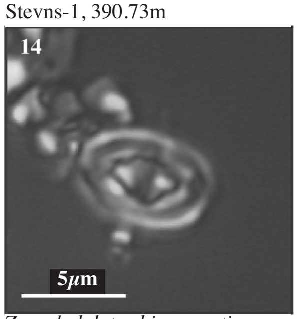


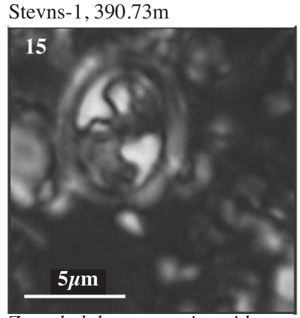
T. hallii
Stevns-1, 390.73m



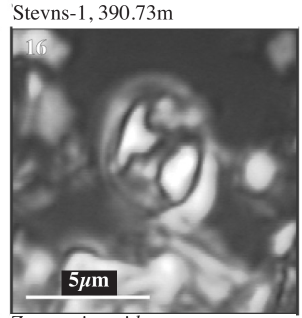
Tranolithus orionatus
Stevns-1, 335.06m



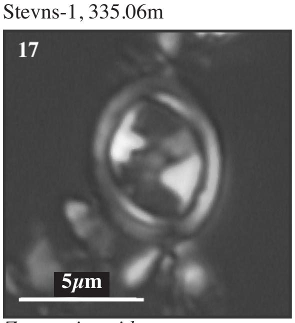
Zeugrhabdotus bicrescenticus
Stevns-1, 261.77m



Zeugrhabdotus praesigmoides
Stevns-1, 321.76m



Z. praesigmoides
Stevns-1, 321.76m



Z. praesigmoides
Stevns-1, 390.73m