DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/39

Nannofossil biostratigraphy of the Nana-1XP well, Danish Central Graben

Emma Sheldon, Jon R. Ineson & Paul Bown

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

G E U S

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/39

Nannofossil biostratigraphy of the Nana-1XP well, Danish Central Graben

Emma Sheldon, Jon R. Ineson & Paul Bown

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

Contents

Introduction

Detailed nannofossil biostratigraphy of the cored upper Maastrichtian – Danian section of the Nana-1XP well was carried out as part of the PhD study 'Upper Maastrichtian – Danian nannofossils of the Danish Central Graben and the Danish Basin: a combined biostratigraphic – palaeoecological approach' (Sheldon 2006). The Nana-1XP well was drilled in 1999 as a vertical exploration well on the Halfdan Field in the Danish Sector of the North Sea (Figure 1). The following report presents a biostratigraphic breakdown of the cored chalk section of the well, based on nannofossils.

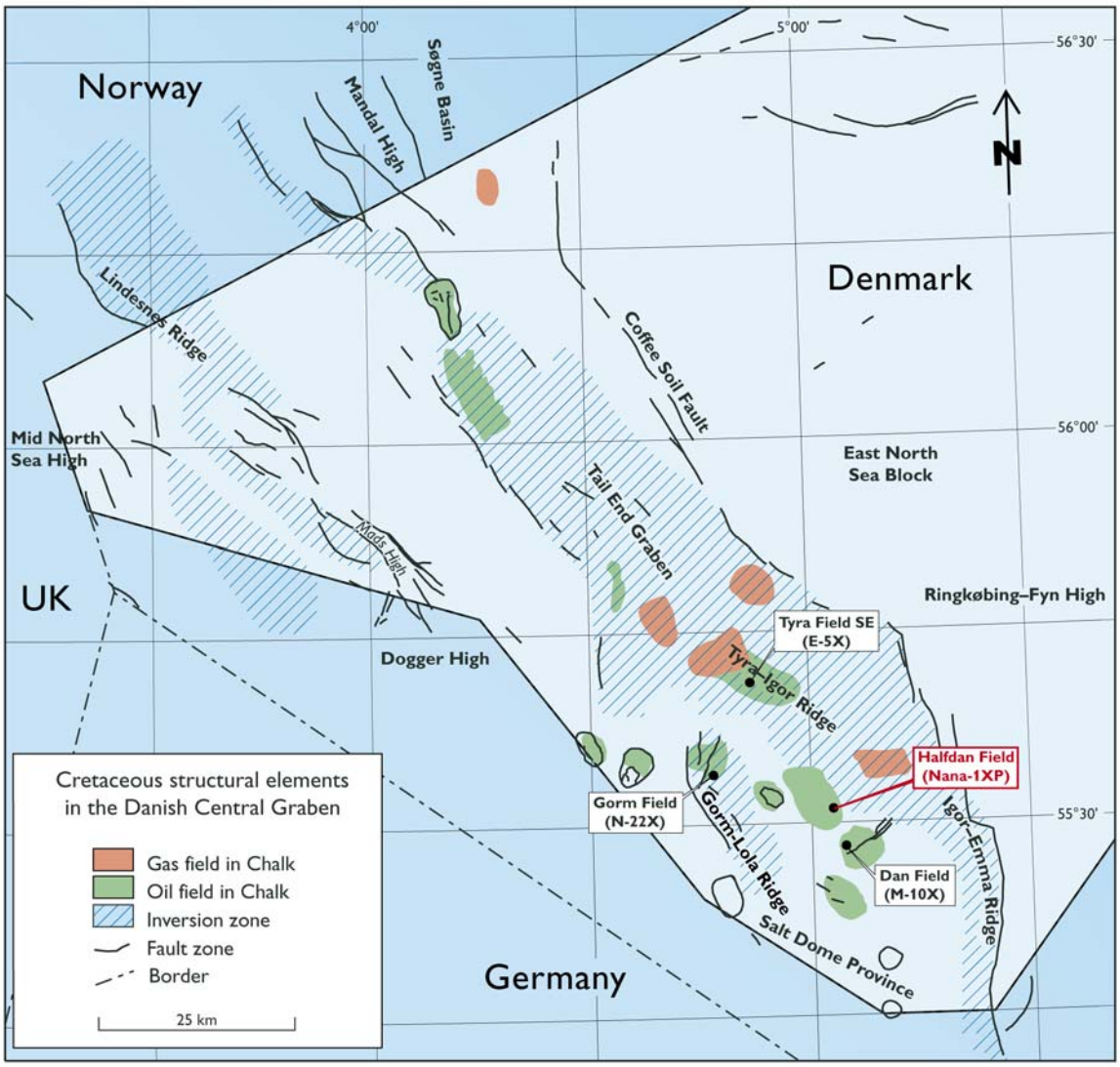

Figure 1. Location map, Danish Central Graben

Methods

110 samples were examined from the Nana-1XP well. Sampling was undertaken approximately every 3 feet, apart from at levels of particular interest, e.g. the K/T (Cretaceous-Tertiary) boundary where sampling was more closely spaced (every 5–6 inches). Samples were taken in clean, uniform chalk, away from clay partings and stylolitic horizons. In order to avoid zones of excessive diagenetic alteration (e.g. due to stylolitisation), care was taken where possible to sample in uniform pelagic chalk, away from solution horizons and mineralised fractures.

Nannofossil smear slides were prepared using the simple smear slide technique described in Bown & Young (1998). As the core was drilled in a major hydrocarbon reservoir level, core chips were often saturated in oil when they were processed: a mild detergent (washing-up liquid) was added to the suspension during preparation to disaggregate the chalk. The prepared slides were examined using a Leitz Labrolux 8 light microscope under x1250 magnification. All slides are stored at GEUS.

Simple relative abundance counting (Bown & Young 1998) was utilised in this study, i.e. a minimum of 300 specimens, which at the 95% confidence level provides representation of taxa present at 1% or greater. At important stratigraphic levels (i.e. close to zonal boundaries) extra counting was undertaken when necessary to check for the presence of key zonal marker taxa. Samples which upon initial examination appeared to be barren of nannofossils were subsequently examined for 10 length-traverses to obtain a rough species abundance. The quantitative data was recorded as a biostratigraphic range chart (Enclosure 1).

Nannofossil biozonation

The nannofossil zonation schemes used in this study are applicable to the northern high latitudes and North Sea area. The UC^{BP} scheme of Burnett (1998) is used for the Cretaceous, and the scheme of Varol (1998) is used for the Paleocene. Both schemes are modified using local observations from the Danish and Norwegian sectors of the North Sea (Fritsen 1999) (Figures 2 & 3). In this study, where cored intervals are assigned to a nannofossil zone or subzone, the ‘Interval Zone’ convention of Hedberg (1976) is followed. The timescale of Gradstein *et al.* (1994) is used for the Maastrichtian, and those of Berggren *et al.* (1995) and Haq *et al.* (1987) are used for the Danian.

Terminology

In this study the use of ‘FO’ (First evolutionary Occurrence) and ‘LO’ (Last evolutionary Occurrence) is used. Wells drilled in the Danish Central Graben are measured in imperial units (feet and inches). Danish Central Graben well data is supplied in well-site reports and on electrical logs as MD RT (Measured Depth below Rotary Table) or TVD SS (True Vertical Depth Sub Surface).

Reworking and caving

As core material was used in this study, caving is not an issue. Although reworking is potentially a complicating factor, the sedimentology indicates that pelagic settling and small-volume dilute density flows dominated the depositional system and significant ‘stratigraphic’ redeposition (i.e. by slumps, slides and debris flows) was rare or absent in this part of the Danish Central Graben (Ineson 2004). Although much of the chalk is thoroughly bioturbated, the scale of biogenic mixing is considered negligible with regard to the biozonation.

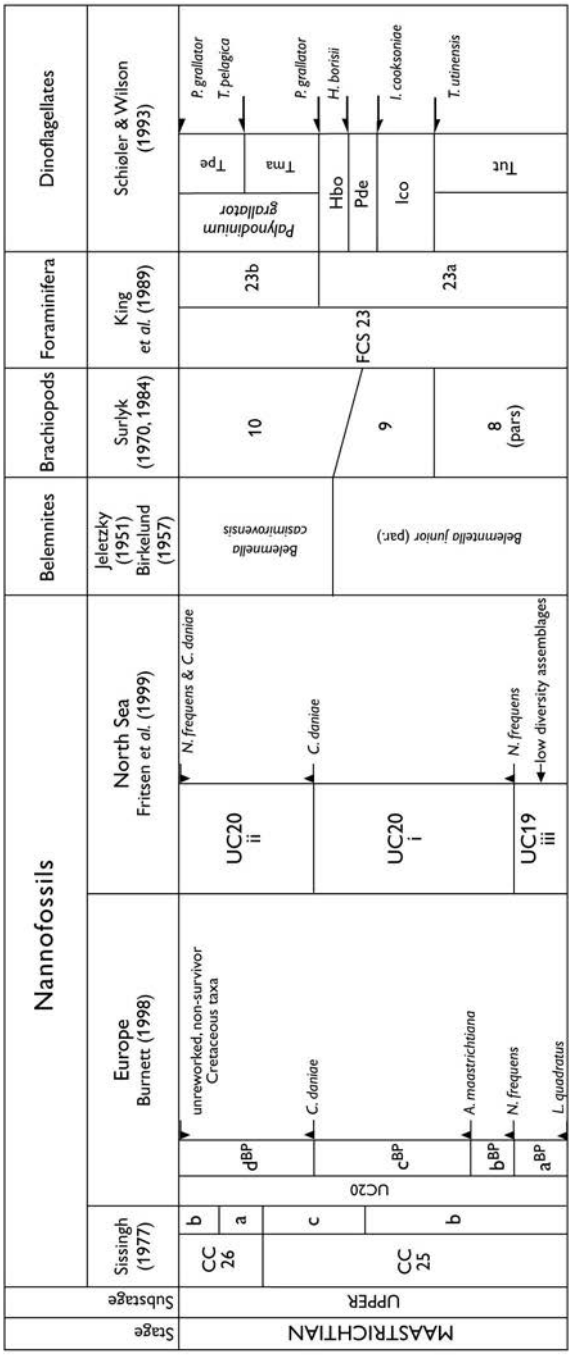

Figure 2. Upper Maastrichtian multidisciplinary biostratigraphic correlation

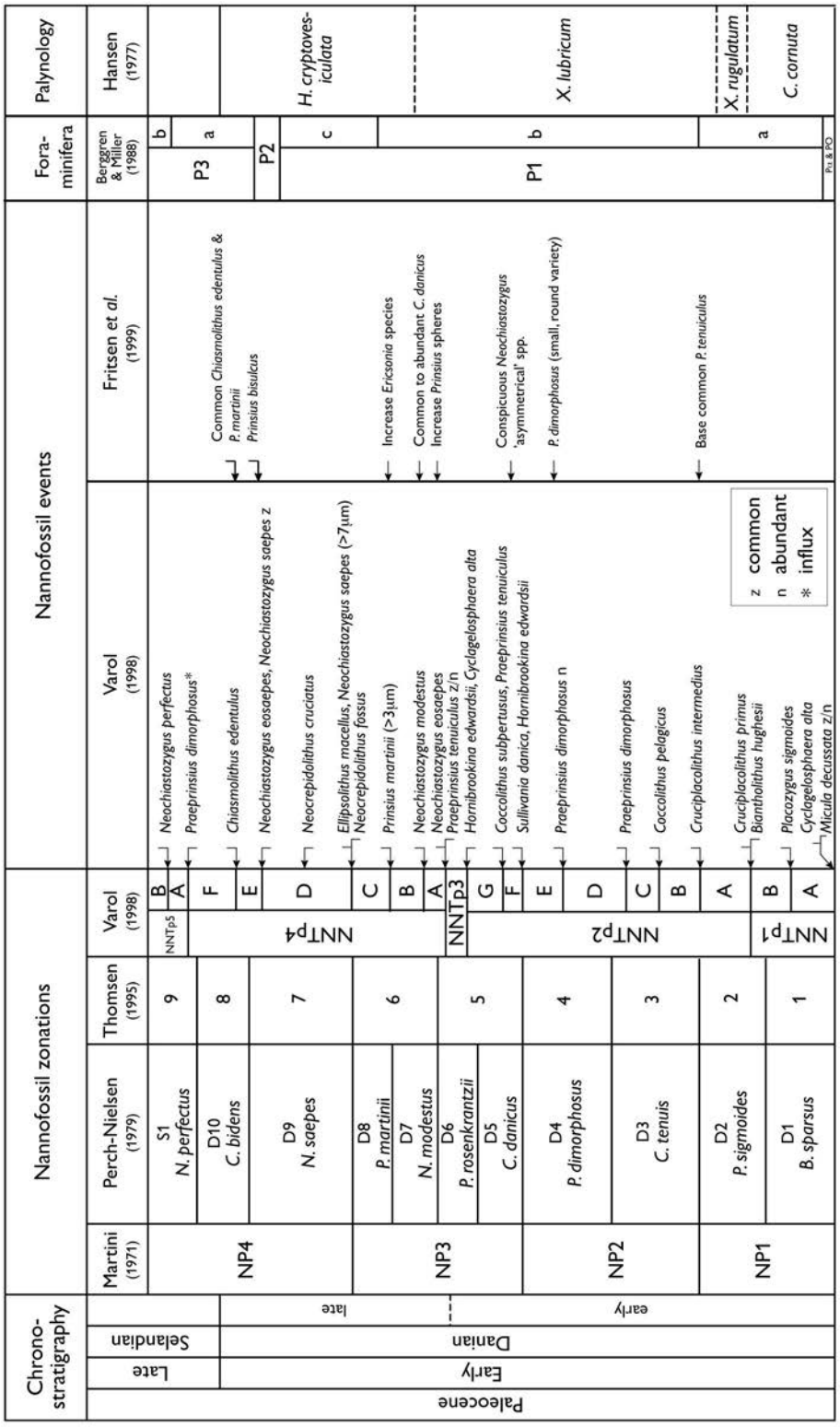

Figure 3. Danian multidisciplinary biostratigraphic correlation

Biostratigraphy

On the basis of nannofossil assemblage analysis, the cored upper Maastrichtian – Danian section of the Nana-1XP well is divided into upper Maastrichtian nannofossil subzones UC20b^{BP}, UC20c^{BP} and UC20d^{BP} and Danian NNTp2E, NNTp2F–G, NNTp3, NNTp4A, NNTp4B, NNTp4C, NNTp4D, NNTp4E and NNTp4F biozones (Enclosure 1, Table i).

	Base	Top	Thickness
NNTp4F	6928.00´	6918.17´	9.83´ (minimum)
NNTp4E	6945.17´	6928.00´	17.17 ´
NNTp4D	6958.92´	6945.17´	13.75´
NNTp4C	6967.00´	6958.92´	8.08´
NNTp4B	6981.00´	6967.00´	14.00´
NNTp4A	6984.42´	6981.00´	3.42´
NNTp3	6993.17´	6984.42´	8.75´
NNTp2F–G	6995.33´	6993.17´	2.16´
NNTp2E	7003.50´	6995.33´	8.17´
mixed interval	7005.58´	7003.50´	2.08´
UC20d^{BP}	7048.00´	7005.58´	42.42´
UC20c^{BP}	7176.00´	7048.00´	128.00´
UC20b^{BP}	7244.92´	7176.00´	68.92´ (minimum)

Table i *Nannofossil subzone thickness in Nana-1XP*

Lithostratigraphy

The cored section is referred lithologically to the Tor Formation (Maastrichtian) and the Ekofisk Formation (Danian), Figure 4. The following biostratigraphic breakdown is subdivided according to these broad lithological boundaries. The biostratigraphy and lithostratigraphy of the Nana-1XP well is seen on Figures 5 & 6.

Tor Formation

Subzone UC20b^{BP}

7244.92´ (lowest sample examined) – 7176.00´ M.D.f.b.R.L. (Measured Depth, feet below Reference Level)

Definition

The base of this subzone in the 'boreal' province is marked by the FO of *Nephrolithus frequens* and the top by the FO of *Arkhangelskiella maastrichtiana* (Burnett 1998).

Floral characteristics

This interval is characterised by a diverse and abundant nannofossil assemblage comprising common *Micula decussata*, *Prediscosphaera cretacea*, *Prediscosphaera stoveri*, *Arkhangelskiella cymbiformis* and *Lucianorhabdus cayeuxii*. Also fairly common are *Kamptnerius magnificus*, *Cribrosphaerella ehrenbergii*, *Placozygus* cf. *P. fibuliformis* and *Retecapsa crenulata*. *N. frequens* and *P. stoveri* are particularly common in the lower part of this interval. Consistently present, although in low numbers, are *Eiffelithus turriseiffelii*, *Chiastozygus amphipons*, *Watznaueria barnesiae* and *Biscutum* spp. Reworking in this interval is represented by rare specimens of *Calculites obscurus* (from the mid-Maastrichtian) and *Biscutum magnum* (indicative of UC19^{BP}). In addition, a single specimen at 7178.83´ of *Helicolithus turonicus* indicates reworking from the Turonian–Coniacian while a specimen of *Heteromarginatus bugensis* in the lowest sample examined indicates reworking from the Campanian.

Remarks

Subzones UC20b^{BP} and UC20c^{BP} are subdivided on the presence/absence of *A. maastrichtiana* (Burnett 1998). *A. maastrichtiana* is equivalent to the large to very large variety of *Arkhangelskiella* with a broad rim (Varol 1989). This species has not been identified with confidence in this study so the subdivision of these subzones is only tentative. The present subdivision is based upon a morphometric analysis carried out on specimens of *A. cymbiformis* in which the length and rim width of each specimen recorded was measured (Sheldon 2006). Specimens with rim widths of 2, 2½ and 3 microns were included in the 'wide' category and those with rim widths of less than 2 in the 'narrow' group. Using these definitions, there is an increase in abundance of the 'wide' rimmed varieties from 7176.00´ upwards. In order to be consistent with the study of Varol (1989), coccolith length was also taken into account. Once plotted, the large (length >10–18 microns) specimens demonstrated an increase in abundance from around 7176.00´ upwards. This is in agreement with the findings of Varol (1989). These results are consistent with findings from the N-22X well (Sheldon *et al.* 2012a), but in contrast to those from the E-5X and M-10X wells (Sheldon *et al.* 2012 b and c). In E-5X and M-10X, 'length' was the only parameter to demonstrate a

vaguely similar trend to that in Varol's study. This subzone coincides with the lower part of subzone UC20i (Fritsen 1999).

By definition, *N. frequens* should be present throughout this interval (Burnett 1998), but as in the M-10X and N-22X wells (Sheldon *et al.* 2012 c and a), this species is found in several consecutive samples in Nana-1XP, then appears to be absent for several samples before reappearing (Enclosure 1). This pattern occurs throughout this subzone. *N. frequens* is absent from 7207.50´–7196.58´, from 7185.92´ and from 7178.83´–7176.00´. The lowermost samples contain *N. frequens,* therefore subzone UC20b^{BP} is present to the base of this core. These absences of *N. frequens* may be due to reworking of mid-Maastrichtian chalk into the upper Maastrichtian (some samples, although not all, contain *C. obscurus*; a middle Maastrichtian marker, although occasional samples containing *N. frequens* also contain *C. obscurus*) or are perhaps artefacts of diagenetic alteration or due to palaeoenvironmental parameters (Sheldon 2006).

Subzone UC20c^{BP}

7176.00´–7048.00´

Definition

The base of subzone UC20c^{BP} of the 'boreal' province is marked by the FO of *A. maastrichtiana* and the top by the FO of *Cribrosphaerella daniae* (Burnett 1998).

Floral characteristics

A fairly diverse and abundant nannofloral assemblage characterises this interval. Particularly common are *L. cayeuxii*, *A. cymbiformis* and *P. cretacea* while *M. decussata* levels fluctuate. *K. magnificus*, *C. ehrenbergii*, *E. turriseiffelii*, *C. amphipons*, *Placozygus* cf. *P. fibuliformis*, *P. stoveri* and *N. frequens* continue to be present while *W. barnesiae*, *Biscutum* spp., *Ahmuellerella octoradiata*, *R. crenulata*, *Retecapsa surirella* and *Cretarhabdus conicus* are present in low numbers. The presence of relatively high numbers of 'large' forms of *A. cymbiformis* with 'wide' rims from 7176.00´ upwards, along with the continued presence of *N. frequens* and absence of *C. daniae* assigns this interval to UC20c^{BP} (see remarks from subzone UC20b^{BP}). Reworking in this interval is indicated by rare occurrences of *Biscutum magnum* and *Orastrum campanensis* from the Campanian, and *C. obscurus* from the mid-Maastrichtian.

Remarks

This subzone coincides with the upper part of subzone UC20i (Fritsen 1999). Within the UC20c^{BP} interval in this well, *N. frequens* fluctuates in abundance and in two intervals 7176.00´–7159.25´ and 7153.17´–7130.25´, and in sample 7127.08´ it appears to be completely absent (see remarks from UC20b^{BP} and Enclosure 1).

Subzone UC20d^{BP}

7048.00´–7005.58´

Definition

The base of subzone UC20d^{BP} of the 'boreal' province is defined by the FO of *C. daniae*, and the top by the LO of unreworked, non-survivor taxa (Burnett 1998).

Floral characteristics

The uppermost subzone of the Maastrichtian in this well is characterised by the co-occurrence of *C. daniae* and *N. frequens*. In addition the nannfossil assemblage comprises a relatively low diversity (especially towards the top of the Maastrichtian) assemblage dominated by *M. decussata* and to a lesser extent, *P. cretacea*, *L. cayeuxii* and *P. stoveri*. The high abundance of *M. decussata* is probably related to the hardground at the top of the Maastrichtian. The assemblage also includes *E. turriseiffelii*, *K. magnificus*, *R. surirella*, *A. octoradiata*, *R. crenulata*, *W. barnesiae*, *Prediscosphaera spinosa*, *C. ehrenbergii*, *Munarinus* spp. and *C. conicus*. Within this interval, rare specimens of *B. magnum* and *C. obscurus* indicate reworking from the mid-Maastrichtian.

Remarks

This subzone coincides with subzone UC20ii (Fritsen 1999). The Kjølby Gaard Marl equivalent (an important upper Maastrichtian marker bed) is found from 7016.50´–7017.00´ (Troelsen 1955, Sheldon *et al.* 2010).

Mixed interval

7005.58´–7003.50´

Definition

The Maastrichtian–Danian boundary is recognised as the top Tor hardground offshore, recognisable in core (Ineson 2004, Sheldon 2006) log and seismic. Due to extensive bio-

zone mixing at this level, each sample from this interval will be described. Figure 6 depicts the K/T interval of the Nana-1XP well.

Floral characteristics

7005.58´

M. decussata and *A. cymbiformis* dominate the assemblage in this sample. Also present, from the Maastrichtian, though in very low numbers, include *C. amphipons*, *K. magnificus*, *R. surirella*, *Placozygus* cf. *P. fibuliformis* and *C. daniae*; the last species assigning the Maastrichtian component of this sample to UC20d^{BP}. Rare *Coccolithus pelagicus*, *Thoracosphaera* spp. and *Zeugrhabdotus sigmoides* are the only indicators of a Danian flora, though *Z. sigmoides* is known from the Maastrichtian.

7005.00´

This sample is dominated by *M. decussata*, which is associated with the hardground at this level, with only rare specimens of *P. cretacea*, *C. amphipons*, *L. cayeuxii* and slightly more *A. cymbiformis*. *Thoracosphaera* spp. iss slightly more abundant than in the underlying sample. From the Danian *Cruciplacolithus intermedius*, *Markalius apertus*, *Coccolithus pelagicus* and *Prinsius dimorphosus* were present, along with *Hornibrookina edwardsii* (from subzones NNTp2F–G).

7004.41´

A Maastrichtian assemblage dominated by *M. decussata*, with abundant *A. cymbiformis* and common *L. cayeuxii*, *P. cretacea*, *C. ehrenbergii* and *K. magnificus*. One specimen of *Thoracosphaera* spp. was observed. The marker species *N. frequens* and *C. daniae* were not observed in this sample. The dominance of *M. decussata* is assumed to be an artefact of the hardground present at this level.

N.B. It was discovered that the piece of core that this sample was taken from had been slotted into the core box at the wrong stratigraphic position and originates from 7007.00´, at the base of core 3 (Figure 6). The totally Maastrichtian nannofloral assemblage described above, confirms that this piece of core is of Maastrichtian age and was eroneously placed in the ‘mixed interval’. For the purposes of this study, it has been decided to retain the original core depths.

Hiatus

In many Early Paleocene sections, including in the North Sea area, Zones NP1 and NP2 (Martini 1971), equivalent to NNTp1A–NNTp2E, are missing or thin, and intra-Danian un-

conformities are present (Perch-Nielsen 1979a, b, 1985; van Heck & Prins 1987; Outram 1999; Harrison 1999). This is the case in Nana-1XP, with the hiatus apparently spanning NNTp1A–NNTp2D. The K/T boundary Fish-clay seen onshore Denmark (Surlyk & Håkansson 1999) is not known from the Central Graben area.

Ekofisk Formation

Subzone NNTp2E

7003.5´–6995.33´

Definition

The base of this subzone is defined by the FO of abundant *P. dimorphosus*, while the top is marked by the FO of *Chiasmolithus danicus* and/or *H. edwardsii* (Varol 1998). The base of common *Prinsius tenuiculus* is found in upper subzone NNTp2E (Fritsen 1999).

Floral characteristics

P. dimorphosus and *Cruciplacoltihus primus* are abundant in this interval. Also common are *C. pelagicus*, *Thoracosphaera* spp. *Cruciplacolithus asymmetricus*, *Chiasmolithus edwardsii* and *Z. sigmoides.* In addition to *Markalius inversus*, *Cyclagelosphaera reinhardtii* and *Neocrepidolithus dirimosus*, amongst others, sample 6999.33´ contains rare *C. danicus* and common *P. tenuiculus*. Reworking from the Upper Cretaceous is represented by *C. amphipons*, *E. turriseiffelii* and *M. decussata*.

Remarks

According to Fritsen (1999), *P. tenuiculus* is found to be common for the first time in the uppermost part of subzone NNTp2E. Contrary to the findings of Varol (1998), the inception of rare *C. danicus* occurs before that of common *P. tenuiculus*, indicating the upper part of subzone NNTp2E. This sample is therefore assigned to the upper part of subzone NNTp2E. NNTp2E coincides with upper Zone NP2 (Martini 1971).

Subzones NNTp2F–G

6995.33´–6993.17´

Definition

The base of subzone NNTp2F is defined by the FO of *C. danicus* and/or *H. edwardsii*. The top of this subzone (and the base of NNTp2G) is defined by the FO of *Coccolithus subpert-*

sus and/or the FO of *P. tenuiculus* (Varol 1998). The top of NNTp2G is based on the LO of *H. edwardsii* and *Cyclagelosphaera alta* (Varol 1998). However, the base of common *P. tenuiculus* is found in upper subzone NNTp2E (Fritsen 1999).

Floral characteristics

This interval (comprising only 1 sample) is dominated by *Thoracosphaera* spp., *P. dimorphosus* and *P. tenuiculus*. Other common nannofossils are *C. edwardsii*, *Chiasmolithus*/*Cruciplacolithus* spp., *C. pelagicus* and *Z. sigmoides*. Of particular importance, a single occurrence of the marker species *H. edwardsii*, together with *C. danicus*, assigns this interval to subzones NNTp2F–G (undifferentiated).

Remarks

According to Varol (1998), the FO of *C. subpertusus* signals the base of subzone NNTp2G, as does the base of common *P. tenuiculus.* In addition to this, the LO *C. alta* marks the top of subzone NNTp2G. In the North Sea area, however, these 3 'events' are not observed as reliable (M. Hampton, personal communication, 2005), therefore in this well, these subzones are not differentiated. However, the presence of *H. edwardsii* is a good marker for this interval, and is often seen as a 'flood' off structure. That *H. edwardsii* was not seen in high abundances suggests that a minor hiatus might be placed here.

Zone NNTp3

6993.17´–6984.42´

Definition

The base of this zone is defined on the LO of *H. edwardsii* and *C. alta* (Varol 1998). The top is based on the LO of common to abundant *P. tenuiculus*.

Floral characteristics

P. dimorphosus and *P. tenuiculus* are common to abundant in this interval, whereas *Thoracosphaera* spp., *C. pelagicus*, *C. edwardsii*. *C. primus* and *Z. sigmoides* are common. Also present are *C. danicus*, *C. intermedius*, and *M. inversus,* amongst others. *H. edwardsii* is absent. In sample 6988.25´ one small specimen of *Neochiastozygus* spp. suggests that this sample is situated in the upper part of Zone NNTp3. Minor reworking from the Upper Cretaceous is represented by rare *L. cayeuxii*, *K. magnificus* and *A. cymbiformis*.

Remarks

Small *Neochiastozygus* spp. are found persistently within this zone (Varol 1998, Fritsen 1999). While the LO of *H. edwardsii* is considered to be a reliable 'event' marking the base of this zone, the LO of *C. alta* is not used in this study as it appears consistently to the top of the Danian and into the Selandian.

Subzone NNTp4A

6984.42´–6981.00´

Definition

The base of this subzone is defined by the LO of common to abundant *P. tenuiculus*. Also found at the base of this subzone is *Neochiastozygus eosaepes*. The top is defined by the FO of *Neochiastozygus modestus* (Varol 1998)

Floral characteristics

This interval is represented by a single sample at 6984.42´. *Thoracosphaera* spp. and *C. edwardsii* dominate this sample, along with common *Prinsius* spp., *C. pelagicus*, *M. inversus*, *C. danicus* and *Z. sigmoides*. The FO of *N. eosaepes* in this sample assigns it to subzone NNTp4A. Minor reworking from the Upper Cretaceous is indicated in this interval by the presence of *L. cayeuxii*, *M. decussata*, *A. cymbiformis* and *A. octoradiata*.

Remarks

Assignment of this interval to NNTp4A is tentative, based on a single specimen of the zonal marker *N. eosaepes* in conjunction with a lack of markers from the under and overlying subzones.

Subzone NNTp4B

6981.00´–6967.00´

Definition

The base of this subzone is defined by the FO of *N. modestus* and the top by the FO of *Prinsius martinii* (Varol 1998).

Floral characteristics

This interval is characterised by common to abundant *C. danicus*, *C. edwardsii*, *Thoracosphaera* spp., *C. primus*, '*Prinsius* spheres' and *C. pelagicus*, in addition to *Neocrepi-*

dolithus cruciatus, Octolithus multiplus, *Z. sigmoides* and *Biscutum* spp. Rare specimens of *Neochiastozygus saepes/modestus* (intermediate forms), *N. saepes/eosaepes* (intermediate forms) and *N. modestus* are present. Reworking from the Upper Cretaceous in this interval is indicated by the presence of *L. cayeuxii*, *M. decussata*, *A. cymbiformis*, *W. barnesiae*, *C. ehrenbergii* and *P. cretacea*.

Remarks

Fritsen (1999) note that *C. danicus* is found to be common to abundant within this interval, as are '*Prinsius* spheres'. Along with rare *N. modestus* and the absence of *P. martinii* (the marker for the overlying subzone), these events assign this interval to subzone NNTp4B.

Subzone NNTp4C

6967´–6958.92´

Definition

The base of this subzone is defined by the FO of *P. martinii* and the top by the FO of *N. saepes* (Varol 1998)

Floral characteristics

This interval is characterised by high abundance and diversity assemblages dominated by *Thoracosphaera* spp., *C. edwardsii*, *Chiasmolithus*/*Cruciplacolithus* spp., and *C*. *pelagicus*. Also common are *P. dimorphosus*, *C. danicus*, *C. primus*, and *Chiasmoltihus inconspicuus*. *P. martinii* first appears at 6967.00´ (defining the base of this subzone in this study) and becomes increasingly common up section. Also present are *O. multiplus*, *Z. sigmoides*, *Markalius* spp. and *Neochiastozygus* spp. Rare specimens of *W. barnesiae* are the only evidence of reworking in this interval.

Remarks

Neochiastozygus spp. are known to be common to abundant in Zone NNTp4 in parts of the North Sea area although in this study only rare specimens of this genus are seen. *C. danicus* is also observed to outnumber *C. inconspicuus* in this subzone (M. Hampton, personal communication, 2005), this is in agreement with subzone NNTp4C as observed in this study.

Subzone NNTp4D

6958.92´–6945.17´

Definition

The base of this subzone is defined by the FO of *N. saepes* and the top by the LO of *N. eosaepes* (Varol 1998).

Floral characteristics

The nannofloral assemblages in this interval are dominated by *C. pelagicus* and to a lesser extent by *C. edwardsii* and *Thoracosphaera* spp. Also common are *P. martinii*, *C. danicus*, *C. primus*, *Z. sigmoides*, *Chiasmolithus*/*Cruciplacolithu*s spp. and *C. inconspicuus*. *N. saepes* is present in small numbers throughout this interval and *Neocrepidolithus cruciatus* is present up until 6948.25´. Rare specimens of *W. barnesiae* are the only evidence of reworking in this interval.

Remarks

N. saepes, the first occurrence of which is thought to represent the base of this interval, is also present (often as forms intermediate to *N. eosaepes* and *N. modestus*) in the underlying interval. As discussed in Subzone NNTp4C, only rare occurrences of the *Neochiastozygus* genus are seen. Therefore these forms are only used tentatively as marker fossils in this well. Varol (1998) noted that *C. pelagicus* usually dominates the assemblages in this subzone; this seems to be the case in this well. According to Varol (1998), the LO of *N. cruciatus* is in the upper part of subzone NNTp4D; this is consistent with the findings in this well but is not a reliable event in the North Sea. Varol (1998) also records the FO common of *O. multiplus* in this interval. In this study, the notable increase in this species coincides with a notable increase in the abundance of *P. martinii*. In the greater Ekofisk Area (Southern Norwegian Central Graben), these two events coincide at a stratigraphically younger level (R. da Gama, personal communication, 2005) and are therefore assigned to the overlying subzone NNTp4E.

Subzone NNTp4E

6945.17´–6928.00´

Definition

The base of this subzone is defined by the LO of *N. eosaepes* and the top by the FO of *Chiasmolithus edentulus* (Varol 1998).

Floral characteristics

The high abundance and diversity assemblages in this interval are characterised by abundant *P. martinii*, *Z. sigmoides*, *C. pelagicus* and *O. multiplus*, and common *Thoracosphaera* spp. and *C. inconspicuus*. Other forms include *C. reinhardtii*, *N. saepes*, *N. modestus*, *C. primus*, rare *C. danicus* and *M. inversus*. Reworking from NNTp2F–G is indicated by the presence of *H. edwardsii* in sample 6931.00´.

Remarks

C. inconspicuus are thought to outnumber *C. danicus* in this interval (M. Hampton, personal communication, 2005); and as discussed for the underlying interval, commom *O. multiplus* and common *P. martinii* are seen to coincide in some areas of the North Sea in this subzone. These 'events' are in agreement with the patterns in this well. Reworking from lower in the Danian within this interval occurs in other areas of the North Sea (M. Hampton, personal communication, 2005).

Subzone NNTp4F

6928´–6918.17´ (last sample examined)

Definition

The base of this subzone is defined by the FO of *C. edentulus* and the top by the LO of an influx of *P. dimorphosus* (Varol 1998).

Floral characteristics

This interval is characterised by high abundance and diversity assemblages dominated by *C. pelagicus*, *O. multiplus*, *Z. sigmoides* and *P. martinii*. Also common are *Thoracosphaera* spp. *Chiasmolithus/Cruciplacolithus* spp., *C. primus* and *C. inconspicuus*. The presence for the first time of *C. edentulus* assigns this interval to subzone NNTp4F. Rare reworking (the presence of *A. cymbiformis* and *W. barnesiae*) is seen in the uppermost sample.

Remarks

O. multiplus is conspicuous in this interval in the Greater Ekofisk Area, Southern Norwegian Central Graben (R. da Gama, personal communication, 2005).

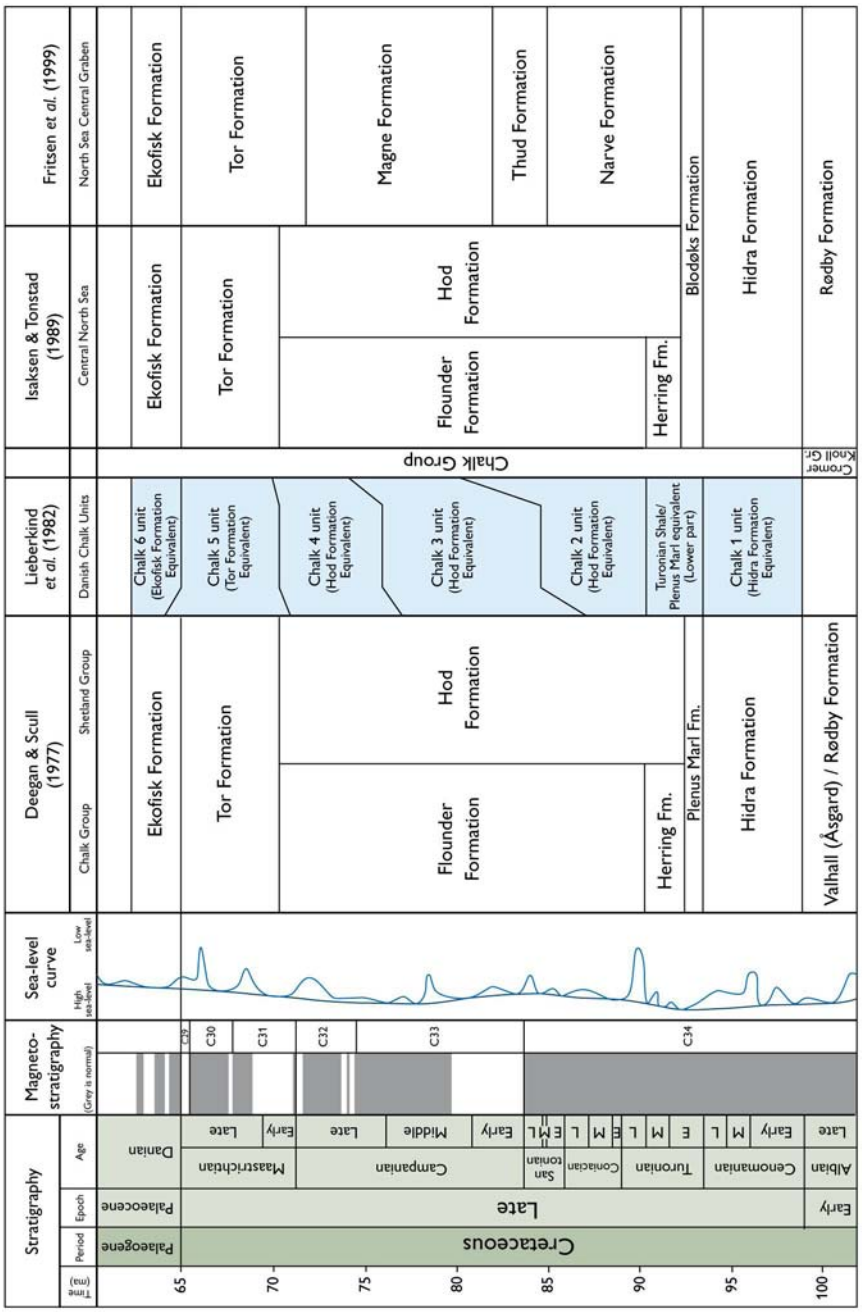

Figure 4. Upper Cretaceous lithostratigraphic correlation (sea level curve after Haq *et al.* 1988)

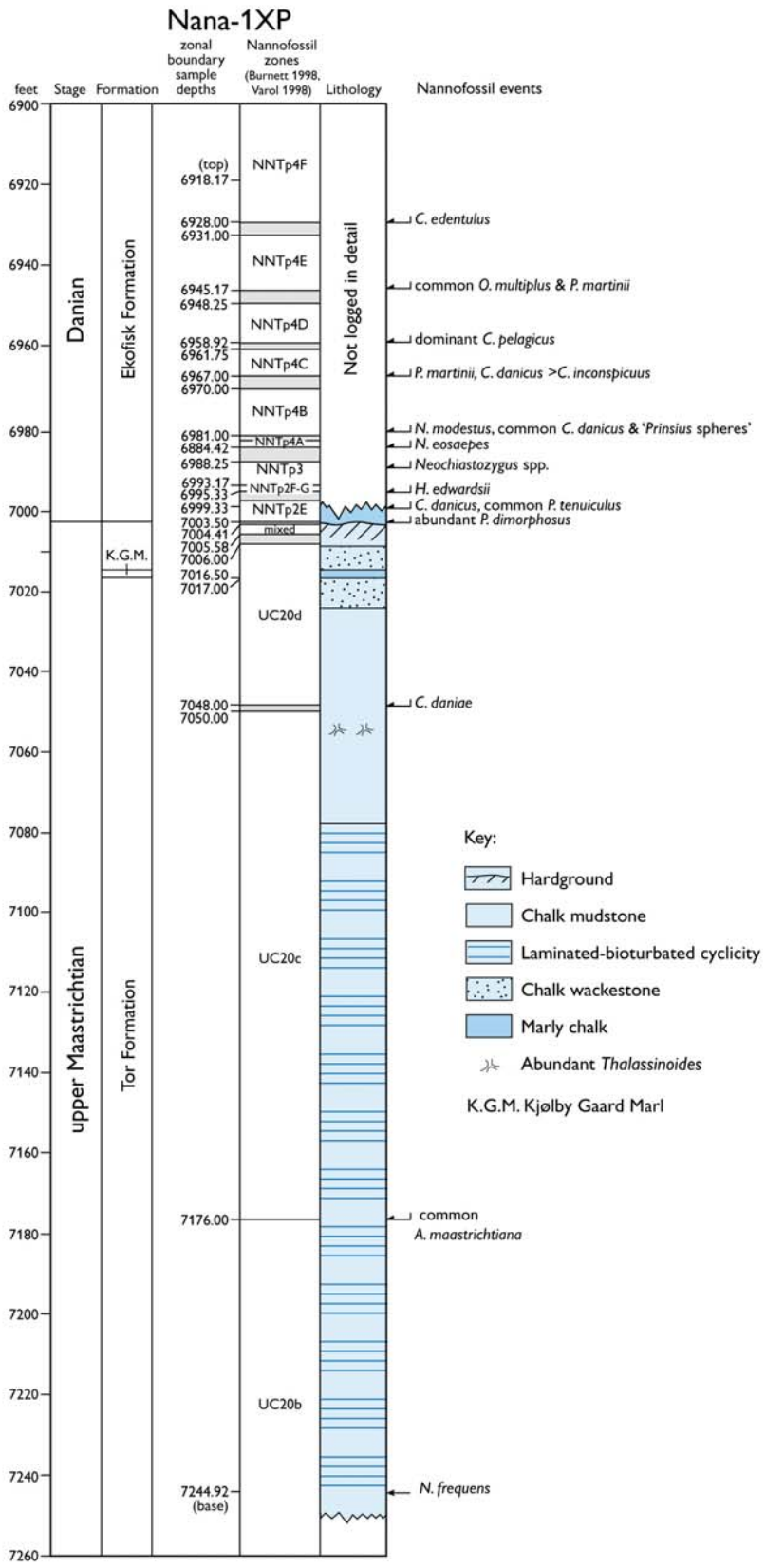

Figure 5. Nana-1XP nannofossil biostratigraphy

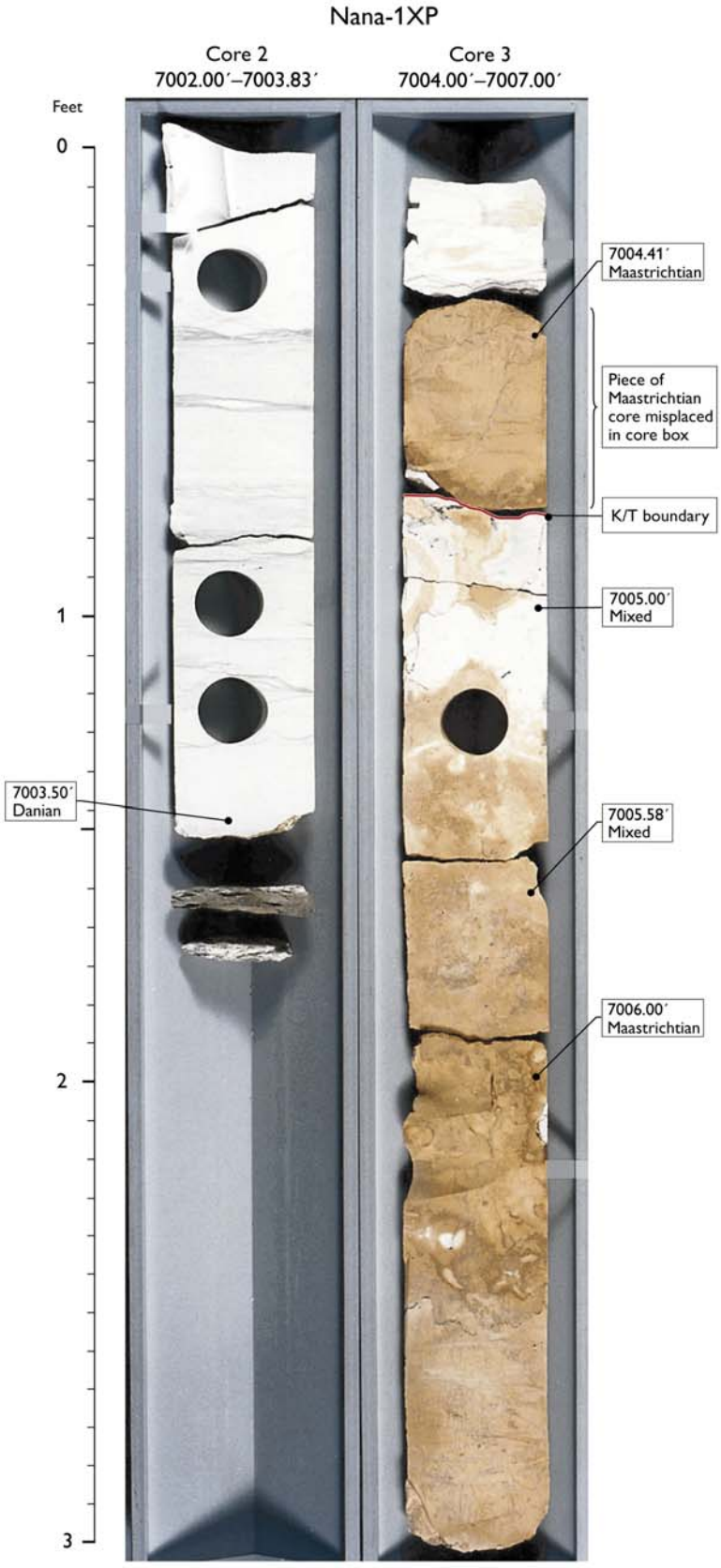

Figure 6. Photograph of the K/T boundary, Nana-1XP

List of samples from Nana-1XP (in feet)

6918.17	7022.92	7136.75	7238.75
6925.00	7025.92	7139.42	7240.83
6928.00	7028.00	7143.42	7244.92
6931.00	7030.00	7144.33	
6942.17	7033.00	7147.25	
6945.17	7035.50	7150.00	
6948.25	7037.50	7153.17	
6950.00	7042.92	7158.00	
6953.08	7046.42	7159.25	
6955.42	7048.00	7162.33	
6958.92	7050.00	7165.00	
6961.75	7053.00	7168.00	
6965.00	7066.58	7170.00	
6967.00	7069.00	7173.08	
6970.00	7072.17	7176.00	
6974.83	7076.58	7178.83	
6978.58	7079.50	7182.00	
6981.00	7082.92	7185.92	
6984.42	7085.25	7187.75	
6988.25	7088.17	7190.00	
6990.00	7091.17	7193.17	
6993.17	7094.08	7196.58	
6995.33	7096.92	7199.50	
6999.33	7100.00	7202.42	
7002.00	7103.00	7205.42	
7003.50	7106.25	7207.50	
7004.42	7110.00	7210.00	
7005.00	7113.00	7213.17	
7005.58	7115.92	7216.83	
7006.00	7118.83	7219.75	
7009.00	7121.33	7222.92	
7012.00	7124.42	7226.00	
7015.00	7127.08	7228.08	
7018.17	7130.25	7232.33	
7020.50	7133.33	7235.92	

References

Berggren, W.A. & Miller K.G. 1988: Paleogene tropical planktonic foraminiferal biostratigraphy and magnetostratigraphy. Micropalaeontology **34**, 362–380.

Berggren, W.A., Kent, D.V., Swisher, C.C., III, & Aubry, M.-P. 1995: A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.-P. & Hardenbol, J. (eds): Geochronology, Time Scales and Global Stratigraphic Correlation. Society of Economic Paleontologists and Mineralogists Special Publication **54**, 129–212.

Birkelund, T. 1957: Upper Cretaceous Belemnites from Denmark. Biologiske Skrifter. Det Kongelige danske Videnskabernes Selskab **9, 1,** 69 pp.

Bown, P. & Young, J. 1998: Techniques. In: Bown, P. R. (ed.): Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Series. Chapman & Hall/Kluwer Academic, 16–28.

Burnett, J.A. 1998: Upper Cretaceous. In: Bown, P. R. (ed.): Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Series. Chapman & Hall/Kluwer Academic, 132–199.

Deegan, C.E. & Scull, B.J. 1977: A proposed standard lithostratigraphical nomenclature for the Central and Northern North Sea. Report of the Institute of Geological Sciences **77/25**; Bulletin of the Norwegian Petroleum Directorate **1**.

Fritsen, A. (Ed.) 1999: A Joint Chalk Stratigraphic Framework. Volume 1. Joint Chalk Research Program Topic V. Norwegian Petroleum Directorate, 206 pp.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J. & Huang, Z. 1994: A Mesozoic timescale. Journal of Geophysical Research **99**, 24051–24074.

Hansen, J.M. 1977: Dinoflagellate stratigraphy and echinoid distribution in Upper Maastrichtian and Danian deposits from Denmark. Bulletin of the Geological Society of Denmark **26**, 1–26.

Haq, B. U., Hardenbol, J. & Vail, P.R. 1987: Chronology of fluctuating sea levels since the Triassic. Science **235**, 1156–1167.

Harrison, D.J. 1999: Mærsk Nana-1XP and -1X wells, Offshore Denmark. Biostratigraphy of the Interval 6918’ (core)-7247’4’’ (core) (Nana-1XP, Chalk Group) and 4110’-11755’TD (Nana-1X, Tertiary and Chalk Group). Unpublished well report prepared for Mærsk Olie og Gas AS, Robertson Research International Ltd., 19 pp.

Heck, S. E. van & Prins, B. 1987: A refined nannoplankton zonation for the Danian of the Central North Sea. Abhandlungen der Geologischen Bundesanstalt **39**, 285–303.

Hedberg, H.D. 1976: International Stratigraphic Guide. A guide to stratigraphic classification, terminology and procedure. (International Subcomission on Stratigraphic Classification of IUGS Commission on Stratigraphy). New York, John Wiley & Sons, 200 pp.

Ineson, J.R. 2004: Sedimentology of the Upper Maastrichtian chalk, Danish Central Graben. Danmarks og Grønlands Geologiske Undersøgelse Rapport **89**, 25 pp.

Isaksen, D. & Tonstad, K. 1989: A revised Cretaceous and Tertiary lithostratigraphic nomenclature for the Norwegian North Sea. Bulletin of Norwegian Petroleum Directorate **5**. 59 pp.

Jeletzky, A. J. 1951: Die Stratigraphie und Belemnitenfauna des Obercampan und Maastricht Westfalens, Nordwestdeutschlands und Dänemarks sowie einige allgemeine Gliederungsprobleme der jüngeren borealen Oberkreide Eurasiens. Beihefte zum Geologischen Jahrbuch **1**, 1–142.

King, C., Bailey, H. W., Burton, C. A. & King, A. D. 1989. Cretaceous of the North Sea. In: Jenkins, D. G. & Murray, J. W. (eds): Stratigraphic Atlas of Fossil Foraminifera. Chichester Ellis Horwood, 372–417.

Lieberkind, K., Bang, I., Mikkelsen, N. & Nygaard, E. 1982: Late Cretaceous and Danian limestone. In: Michelsen, O. (Ed.): Geology of the Danish Central Graben. Geological Survey of Denmark, Series B **8**, 49–62.

Martini, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (Ed.): Proceedings of the Second Planktonic Conference Roma. Edizioni Tecnoscienza, Rome **2**, 739–785.

Outram, R.A. 1999: Nana Field High Resolution Nannofossil Zonation. Nannofloral Analyses of Nana-1XP (Interval 6918' (core)-7247'4'' (core)). Unpublished well report prepared for Mærsk Olie og Gas AS, Robertson Research International Ltd., 7 pp.

Perch-Nielsen K. 1979a: Calcareous Nannofossil Zonation at the Cretaceous/Tertiary boundary in Denmark. In: Birkelund, T. & Bromley, R.G. (eds): Proceedings Cretaceous–Tertiary Boundary Events Symposium, Copenhagen **1**, 115–135.

Perch-Nielsen K. 1979b: Calcareous Nannofossils in Cretaceous/Tertiary boundary sections in Denmark. In: Birkelund, T. & Bromley, R.G. (eds): Proceedings Cretaceous–Tertiary Boundary Events Symposium, Copenhagen **1**, 120–126.

Perch-Nielsen K. 1985: Cenozoic calcareous nannofossils. In: Bolli, H. M., Saunders J. B. & Perch-Nielsen, K. (eds): Plankton Stratigraphy. Cambridge University Press, 427–554.

Schiøler, P. & Wilson, G. 1993: Maastrichtian dinoflagellate zonation in the Dan Field, Danish North Sea. Review of Palaeobotany and Palynology **78**, 321–351.

Sheldon, E., 2006. Upper Maastrichtian-Danian nannofossils of the Danish Central Graben and the Danish Basin: a combined biostratigraphic-palaeoecological approach. Unpublished Ph.D. Thesis, University College London, London.

Sheldon, E., Ineson, J & Bown, P. 2010: Late Maastrichtian warming in the Boreal Realm: Calcareous nannofossil evidence from Denmark. Palaeogeography, Palaeoclimatology, Palaeoecology 295, 55–75.

Sheldon, E., Ineson, J. & Bown, P. 2012a: Nannofossil biostratigraphy of the N-22X well, Danish Central Graben. Danmarks og Grønlands Geologiske Undersøgelse Rapport **40**, 22 pp.

Sheldon, E., Ineson, J. & Bown, P. 2012b: Nannofossil biostratigraphy of the E-5X well, Danish Central Graben. Danmarks og Grønlands Geologiske Undersøgelse Rapport **38**, 21 pp.

Sheldon, E., Ineson, J. & Bown, P. 2012c: Nannofossil biostratigraphy of the M-10X well, Danish Central Graben. Danmarks og Grønlands Geologiske Undersøgelse Rapport **37**, 21 pp.

Sissingh, W. 1977: Biostratigraphy of Cretaceous calcareous nannoplankton. Geologie en Mijnbouw 56, 37–65.

Surlyk, F. 1970: Die Stratigraphie des Maastricht von Dänemark und Norddeutschland aufgrund von Brachipoden. Newsletters in Stratigraphy **1, 2,** 7–66.

Surlyk, F. 1984: The Maastrichtian stage in NW Europe, and its brachiopod zonation. Bulletin of the Geological Society of Denmark **33**, 1–2.

Surlyk, F. & Håkansson, E. 1999: Maastrichtian and Danian strata in the southeastern part of the Danish Basin. In: Pedersen, G. K. & Clemmensen, L. B. (eds): Field Trip Guidebook. 19th Regional European Meeting of Sedimentology, Copenhagen, 29–58.

Thomsen, E. 1995: Kalk og Kridt I den danske underground. In: Nielsen, O.B. (Ed.): Danmarks Geologi fra Kridt til I dag. Aarhus, Aarhus Geokompendier **1**, 31–67.

Troelsen, J.C. 1955: Globotruncana contusa in the White Chalk of Denmark. Micropalaeontology **1**, 76–82.

Varol, O. 1989: Quantitative analysis of the *Arkhangelskiella cymbiformis* Group and Biostratigraphic usefulness in the North Sea. Journal of Micropalaeontology **8**, 131–134.

Varol, O. 1998: Palaeogene. In: Bown, P.R. (Ed.), Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Series, Chapman & Hall/Kluwer Academic, 200–224.