DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/40

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G E U S

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# Introduction

Detailed nannofossil biostratigraphy of the the cored upper Maastrichtian – Danian section of the N-22X 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 N-22X well (also known as Deep Gorm) was drilled in 1987 as a deviated exploration well on the Gorm 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.

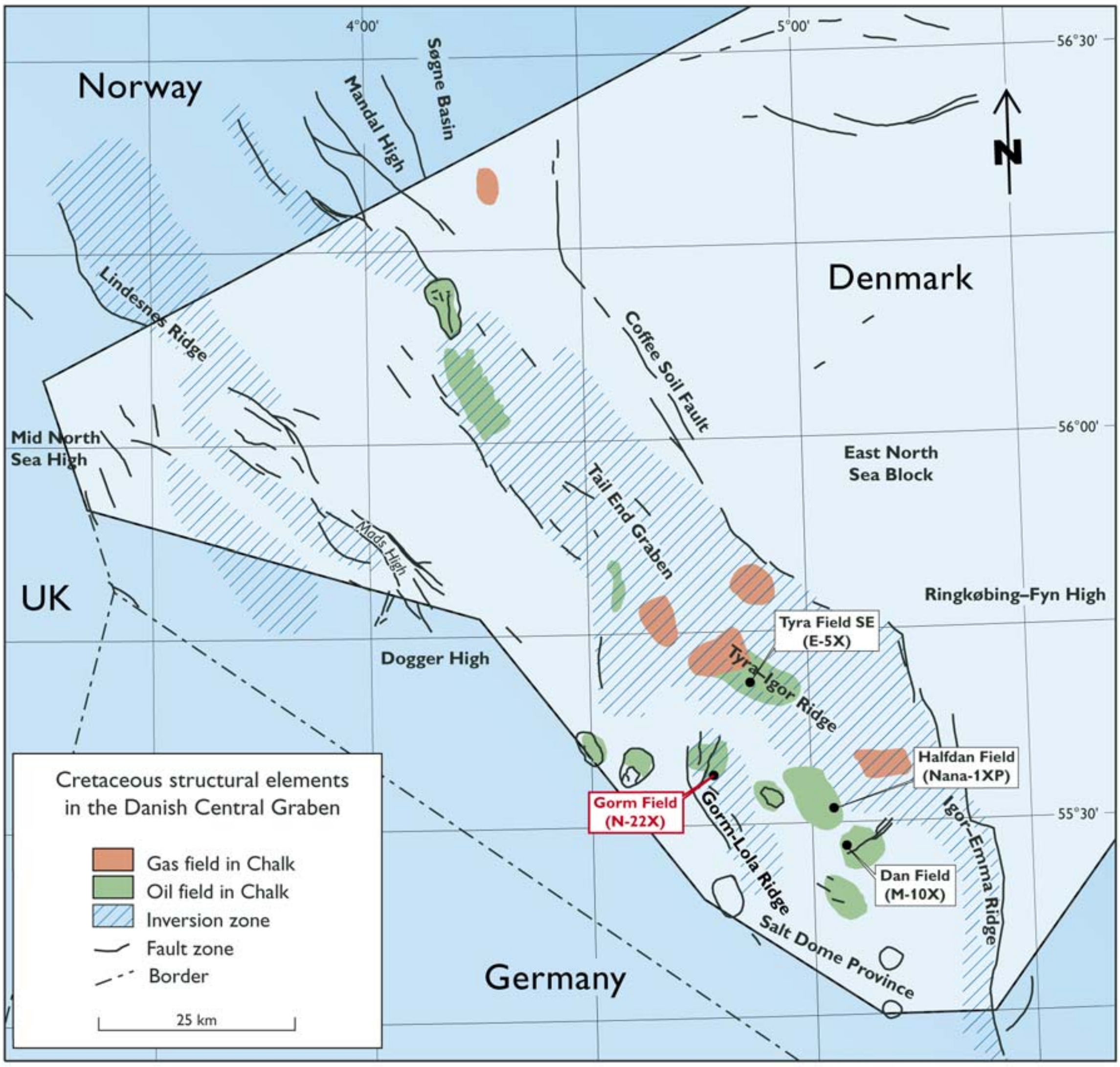



Figure 1. Location map, Danish Central Graben

# Methods

97 samples were examined from the N-22X 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

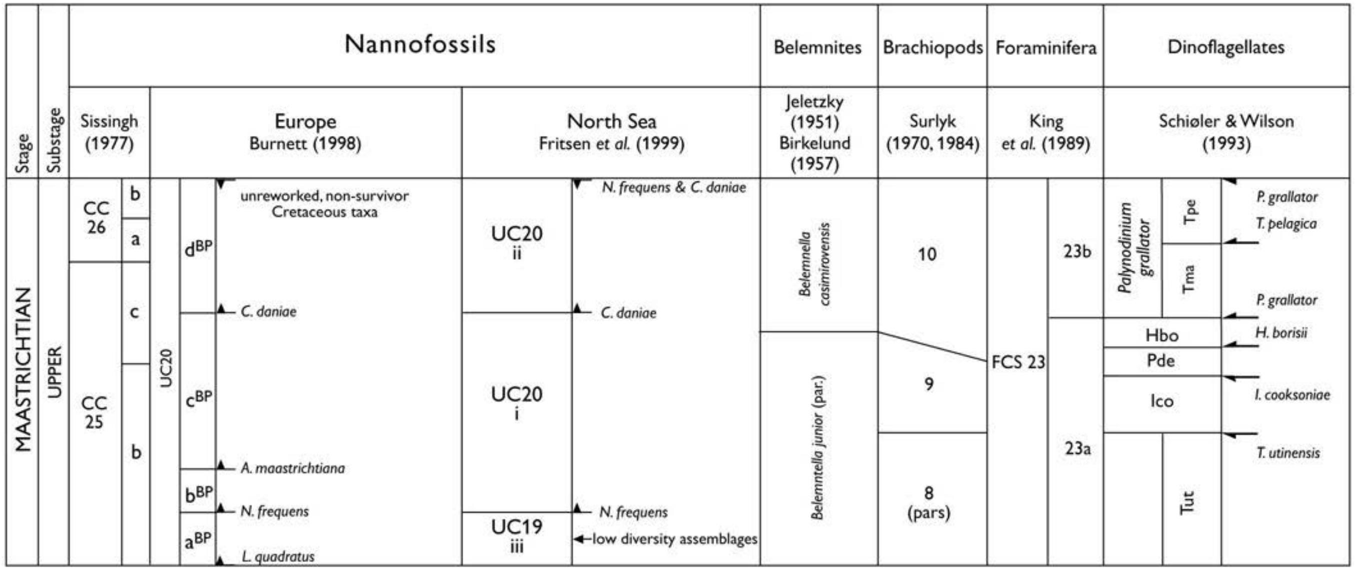
The nannofossil zonation schemes used in this study are applicable to the northern high latitudes and North Sea area. The $UC^{BP}$ scheme of Burnett (1998) is used for the Cretaceous, and the scheme of Varol (1998) is used for the Paleocene. Both schemes are modified using local observations from the 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.




* BP = ´Boreal Province´

Figure 2. Upper Maastrichtian multidisciplinary biostratigraphic correlation

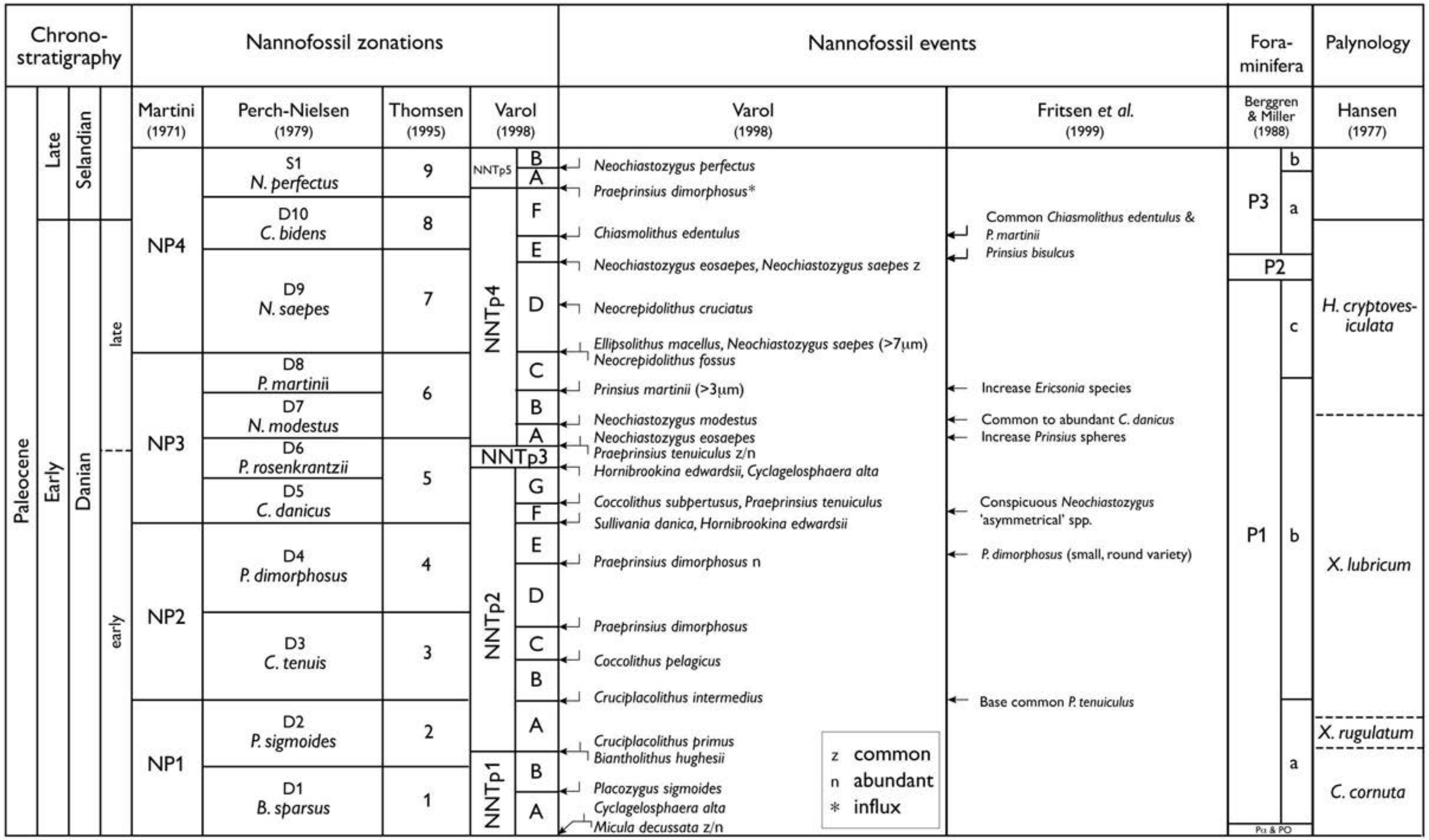



Figure 3. Danian multidisciplinary biostratigraphic correlation

# Biostratigraphy

On the basis of nannofossil assemblage analysis, the cored upper Maastrichtian – Danian section of the N-22X well is divided into upper Maastrichtian nannofossil subzones UC20b$^{BP}$, UC20c$^{BP}$ and UC20d$^{BP}$ and Danian NNTp2D, NNTp2E, NNTp2F–NNTp3 biozones (Enclosure 1, Table i).

| | Base | Top | Thickness |
|---|---|---|---|
| NNTp2F–NNTp3 | 7061.00´ | 7057.58´ | 3.42´ (minimum) |
| NNTp2E | 7066.83´ | 7061.00´ | 5.83´ |
| NNTp2D | 7071.33´ | 7066.83´ | 4.50´ |
| mixed interval | 7074.25´ | 7071.33´ | 2.92´ |
| UC20d$^{BP}$ | 7133.33´ | 7074.25´ | 59.08´ |
| UC20c$^{BP}$ | 7245.00´ | 7133.33´ | 111.67´ |
| UC20b$^{BP}$ | 7343.66´ | 7245.00´ | 98.66´ (minimum) |

***Table i** Nannofossil subzone thickness in N-22X*

## 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 N-22X well is seen on Figures 5 & 6.

## Tor Formation

### Subzone UC20b$^{BP}$

7343.66´ (lowest sample examined) – 7245.00´ 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*

A fairly diverse upper Maastrichtian assemblage including *Prediscosphaera cretacea*, *Kamptnerius magnificus*, *Cribrosphaerella ehrenbergii*, *Watznaueria barnesiae*, *Prediscosphaera stoveri*, *Placozygus* cf. *P. fibuliformis* and relatively low numbers of *Eiffelithus turriseiffelii* and *Retecapsa crenulata*. A relatively low abundance of 'wide' rimmed, 'large' forms of *Arkhangelskiella cymbiformis* exists in this subzone compared with the overlying interval (see discussion below); a characteristic of $UC20b^{BP}$ (Varol 1989). This interval is dominated by *Micula decussata* (as is the whole core) and to a lesser extent by *Lucianorhabdus cayeuxii*. *N. frequens* appears sporadically. Reworking from the mid-Maastrichtian is indicated by the presence of *Calculites obscurus* and *Biscutum magnum* (indicative of $UC19^{BP}$).

*Remarks*

According to Varol (1989), *A. maastrichtiana* is equivalent to the large to very large variety of *Arkhangelskiella* with a broad rim. The presence/absence of *A. maastrichtiana* defines the subdivision of subzones $UC20b^{BP}$ and $UC20c^{BP}$ (Burnett 1998). This species has not been identified with confidence in this study so the subdivision of these subzones is tentative. The subdivision in this study 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). In the present study, 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 a shift to higher numbers of the 'wide' rimmed varieties from 7245.00´ upwards. 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 also demonstrated an increase in number from 7245.00´ upwards. This is in agreement with the findings of Varol (1989). These results are consistent with those from the Nana-1XP well (Sheldon *et al.* 2012a) but in contrast to those in the M-10X well (Sheldon *et al.* 2012b).

By definition, *N. frequens* should be present throughout this interval (Burnett 1998), but in this well, it is present in several consecutive samples then seems to disappear for several samples. It is absent from the intervals 7342.33´–7318.66´, 7312.08´–7291.08´, 7288.50´–7281.42´ and 7276.00´–7272.00´ (Enclosure 1). Reworked nannofossils from the mid-Maastrichtian are present within some, though not all of these intervals/samples. Whether these absences of *N. frequens* are due to reworking of mid-Maastrichtian chalk into the upper Maastrichtian sediments, or are artefacts of diagenetic alteration, dominance by *M. decussata,* or due to palaeoenvironmental parameters, is discussed in (Sheldon 2006). The samples below 7318.66´ may to be assigned to a subzone older than $UC20b^{BP}$, however evidence to support assignment to an older subzone is sparse; *B. magnum* (indicative of UC19$^{BP}$) is present in one sample in the lower part of the well, but it is also present, possibly reworked into younger sediments which have been assigned to subzones UC20b$^{BP}$ and UC20c$^{BP}$. In addition, the marker fossil for UC20a$^{BP}$, *Lithraphidites quadratus* has not been identified in this study. This subzone coincides with the lower part of subzone UC20i (Fritsen 1999).

### Subzone UC20c$^{BP}$

7245.00´–7133.33´

*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*

This interval is characterised by similar assemblages to those described from the previous interval. Although dominated by *M. decussata* and *L. cayeuxii*, the flora in this section comprises common *P. cretacea* with fairly common *A. cymbiformis*, *C. ehrenbergii* and *K. magnificus*. Fluctuating numbers of other nannofossils characteristic of the Upper Cretaceous include *E. turriseiffelii*, *Placozygus* cf. *P. fibuliformis*, *P. stoveri* and *R. crenulata*. The absence of *C. daniae* and the continued presence of *N. frequens* (although sporadically), in this interval indicates a flora older than UC20d$^{BP}$ but younger than UC20a$^{BP}$. The presence of relatively high numbers of 'large' forms of *A. cymbiformis* with 'wide' rims from 7245.00´ upwards, assigns this interval to UC20c$^{BP}$ (see remarks from subzone UC20b$^{BP}$). Reworking from the mid-Maastrichtian is indicated by the occasional occurrence of *C. obscurus, Zeugrhabdotus bicrescenticus* and *B. magnum* and from the Campanian as indicated by *Orastrum campanensis, Monomarginatus quaternarius* and *Gorkaea obliqueclausus*. The LO of *Z. bicrescenticus* is a marker species for the top of UC19i (Fritsen 1999), but according to J. Lees (personal communication, 2005) it continues to the top of the Maastrichtian in some areas.

*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 numbers and in four intervals, 7263.25´–7218.08´ (UC20b$^{BP}$ pars), 7214.66´–7212.00´, 7208.66´–7188.42´ and 7181.83´–7161.25´, it appears to be completely absent (see remarks from UC20b$^{BP}$ and Enclosure 1).

**Subzone UC20d$^{BP}$**

7133.33´–7074.25´

*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*

*C. daniae* is present throughout this interval in low numbers. Together with the continued presence of *N. frequens*, this assigns the interval to subzone UC20d$^{BP}$. Other nannofossils characteristic of this subzone include *P. cretacea*, *A. cymbiformis*, *L. cayeuxii*, and *M. decussata* in large numbers. Also consistently present (although in relatively low abundance) are *C. ehrenbergii*, *P. stoveri*, *K. magnificus*, *E. turriseiffelii*, *Placozygus* cf. *P. fibuliformis* and *W. barnesiae,* amongst others.

*Remarks*

This subzone coincides with Subzone UC20ii (Fritsen 1999). The Kjølby Gaard Marl equivalent (an important upper Maastrichtian marker bed) has not been identified as a discrete unit in this well.

## Mixed interval

7074.25´–7071.33´

*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 biozone mixing at this level, each sample from this interval is described. Figure 6 depicts the K/T interval of the N-22X well.

*Floral characteristics*

7074.25´

Due to the nature of this sample (rare nannofossils), 10 traverses of the length of the slide were counted. *M. decussata* dominates the assemblage, while *Biscutum harrisonii* and *A. cymbiformis* are relatively common. The presence of *A. cymbiformis,* along with rare specimens of *K. magnificus*, *Chiastozygus amphipons*, *P. cretacea* and *C. ehrenbergii*, indicates the presence of upper Maastrichtian sediments. However, the presence of *Biscutum* spp., *Cyclagelosphaera* cf. *C. alta* and *Neocrepidolithus dirimosus* suggest a lower Paleocene influence. 'Survivor taxa' in this sample include *Braarudosphaera bigeloweii*, *Markalius inversus* and *Thoracosphaera* spp. The mixed Maastrichtian/Danian nannofloral assemblage suggests that either Danian sediments were burrowed into Maastrichtian chalk, or that Maastrichtian chalk has been reworked into Paleocene strata. As the marker species that subdivide the upper Maastrichtian were not found, it is not possible to date the Upper Cretaceous chalk component accurately. Likewise a limited Paleocene flora prevents accurate dating of the Danian, though earliest Danian subzone NNTp1A is probable (Sheldon 2006).

7072.66´

Due to scarcity of fossil specimens, 10 length traverses of the nannofossil slide were made. This sample contains a flora characteristic of both the Maastrichtian and the Danian. *M. decussata*, *A. cymbiformis, M. inversus*, *Thoracosphaera* spp., *N. dirimosus, Biscutum* spp. and *B. harrisonii* are fairly common. The upper Maastrichtian element is further represented by *K. magnificus*, *E. turriseiffelii*, *Ahmuellerella octoradiata* and *C. daniae* (the presence of *C. daniae* indicates subzone UC20d$^{BP}$) while a single specimen of *Zeugrhabdotus sigmoides* and *Cyclagelosphaera* cf. *C. alta* represent the Danian chalk (the presence of these two species and the absence of *Prinsius* spp. and *Cruciplacolithus/Chiasmolithus* spp. suggest the presence of lower Danian subzone NNTp1B, however, *Z. sigmoides* is also observed in the Maastrichtian.

7072.33´ (flint)

This sample is dominated by flint. 10 traverses along the length of the slide (due to scarceity of nannofossils) resulted in rare occurrences of *Coccolithus pelagicus, Cyclagelosphaera* cf*. C. alta, N. dirimosus, Cruciplacolithus primus, Prinsius dimorphosus,* and *Thoracosphaera* spp*.* indicating Danian material. In addition, rare specimens of *A. cymbiformis*, *C. ehrenbergii*, *K. magnificus* and *W. barnesiae* represent Upper Cretaceous sediments which cannot be assigned a subzone due to lack of marker species. The impoverished Paleocene assemblage appears to be NNTp2D in age, but due to the lack of fossil individuals this dating is only tentative.

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 unconformities are present (Perch-Nielsen, 1979a, b, 1985; van Heck & Prins 1987). This is the case in the Nana-1XP, M-10X and E-5X wells, with the hiatus apparently spanning NNTp1A–NNTp2D (Sheldon *et al.* 2012, a, b and c). The N-22X well however, seems to show slightly different characteristics, with evidence of subzones NNTp1A, NNTp1B and NNTp2D, but if these subzones are present, they are thin. If the intervening subzones are present, (although not recognised here), they must be very thin, or missing. The K/T boundary Fish-clay seen onshore Denmark (Surlyk & Håkansson 1999) is not known from the Central Graben area.

## Ekofisk Formation

### Subzone NNTp2D

7071.33´–7066.83´

*Definition*

The base of this subzone is defined by the FO of *P. dimorphosus* and the top by the FO of abundant *P. dimorphosus* (Varol 1998).

*Floral characteristics*

The assemblages are characterised by *Cruciplacolithus intermedius*, *C. primus*, *B. harrisonii*, *Neocrepidolithus* spp. and *Markalius* spp. in relatively equal proportions. More common are *Z. sigmoides*, *P. dimorphosus* and *Thoracosphaera* spp. That *P. dimorphosus* does not dominate the assemblages indicates assignment to subzone NNTp2D. Reworking from the Upper Cretaceous is indicated by specimens of *K. magnificus*, *L. cayeuxii*, *A. cymbiformis*, *W. barnesiae*, *C. ehrenbergii* and specifically from the upper Maastrichtian by *N. frequens*.

*Remarks*

The youngest subzone in the Nana-1XP, M-10X and E-5X wells (Sheldon *et al.* 2012 a, b and c) is dated as NNTp2E which is characterised by abundant *P. dimorphosus.* The assemblages in the lowest Danian samples of N-22X contain a similar flora to that found in NNTp2E, but *P. dimorphosus* is present in lower numbers and is not the dominant species. Therefore these samples have been assigned to the slightly older Danian subzone NNTp2D, inferring deposition/preservation of slightly older sediments in this part of the Gorm Field than in the M-10X, E-5X and Nana-1XP wells.

**Subzone NNTp2E**

7066.83´–7061.00´

*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 *Hornibrookina edwardsii* (Varol 1998). The base of common *Prinsius tenuiculus* is found in upper subzone NNTp2E (Fritsen 1999).

*Floral characteristics*

*P. dimorphosus* is abundant for the first time in this interval. In addition, *Z. sigmoides* and *Thoracosphaera* spp. are common, while *B. harrisonii*, *C. intermedius*, *N. dirimosus*, *Cruciplacolithus asymmetricus*, *C. primus* and *Markalius* spp. are present in low numbers. *P. tenuiculus* is rare. This assemblage (particularly the abundance of *P. dimorphosus*) indicates the presence of subzone NNTp2E. Reworking from the upper Maastrichtian is indicated by the presence of *K. magnificus*, *A. cymbiformis*, *P. cretacea*, *W. barnesiae*, *A. octoradiata* and *N. frequens*.

*Remarks*

The inception of rare *C. danicus* before that of common *P. tenuiculus* indicates the upper part of subzone NNTp2E (M. Hampton, personal communication, 2005). According to (Fritsen 1999), *P. tenuiculus* is found to be common for the first time in the uppermost part of subzone NNTp2E. Neither C. *danicus* nor common *P. tenuiculus* were found in this interval, but the presence of rare *P. tenuiculus* indicates assignment to lower subzone NNTp2E. NNTp2E coincides with upper Zone NP2 (Martini 1971).

**Subzone NNTp2F–Zone NNTp3**

7061.00´–7057.58´ (uppermost sample examined)

*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 the following subzone, NNTp2G, is defined by the FO of *Coccolithus subpertsus* and/or the FO of *P. tenuiculus.* The top of subzone NNTp2G is defined by the LO of *H. edwardsii* and/or *Cyclagelosphaera alta* (Varol 1998). However, the base of common *P. tenuiculus* is found in upper subzone NNTp2E (Fritsen 1999). The top of subzone NNTp2G and the base of Zone NNTp3 is defined on the LO of *H. edwardsii* and/or *C. alta*. The top of Zone NNTp3 is based upon the LO of common to abundant *P. tenuiculus* (Varol 1998).

*Floral characteristics*

These samples are dominated by *P. dimorphosus* and *P. tenuiculus* (with a ratio of approximately 60:40). In addition, *Thoracosphaera* spp., *Z. sigmoides*, *C. primus*, *C. intermedius* and *C. asymmetricus* are common to abundant, while *B. harrisonii*, *C. pelagicus*, *Markalius* spp. and *Neocrepidolithus* spp. continue to be present. Minor reworking from the Upper Cretaceous (the presence of *K. magnificus* and *A. cymbiformis*) is seen in the sample at 7061.00´.

*Remarks*

The presence (although rare) of *C. danicus* in the uppermost sample together with *P. tenuiculus* indicates the presence of subzone NNTp2G. The underlying sample, however, contains abundant *P. tenuiculus*, but does not appear to contain *C. danicus*. In addition, *H. edwardsii* (a marker species for subzones NNTp2F and G) has not been found in these samples. This evidence, along with the lack of *Neochiastozygus* spp., which defines younger levels, assigns this interval, tentatively, to NNTp2F–NNTp3. 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 of *C. alta* marks the top of subzone NNTp2G. In the North Sea area, however, these 3 'events' are not considered reliable (M. Hampton, personal communication, 2005); in this well, therefore, 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 this well might indicate the presence of a minor hiatus. NNTp2F and G coincide with lower part and NNTp3 with the middle of Zone NP3 (Martini 1971).

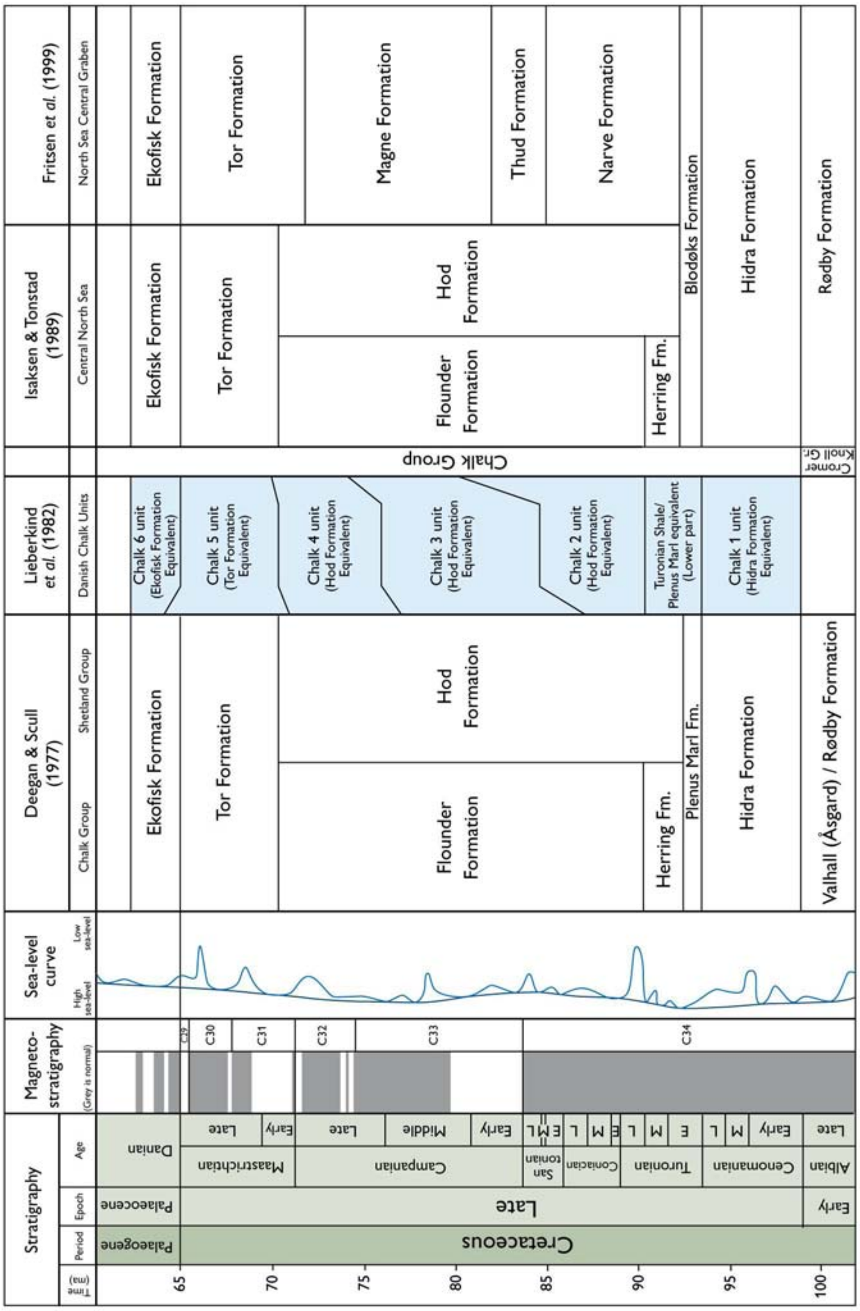



Figure 4. Upper Cretaceous lithostratigraphic correlation (sea level curve after Haq *et al.* 1988)

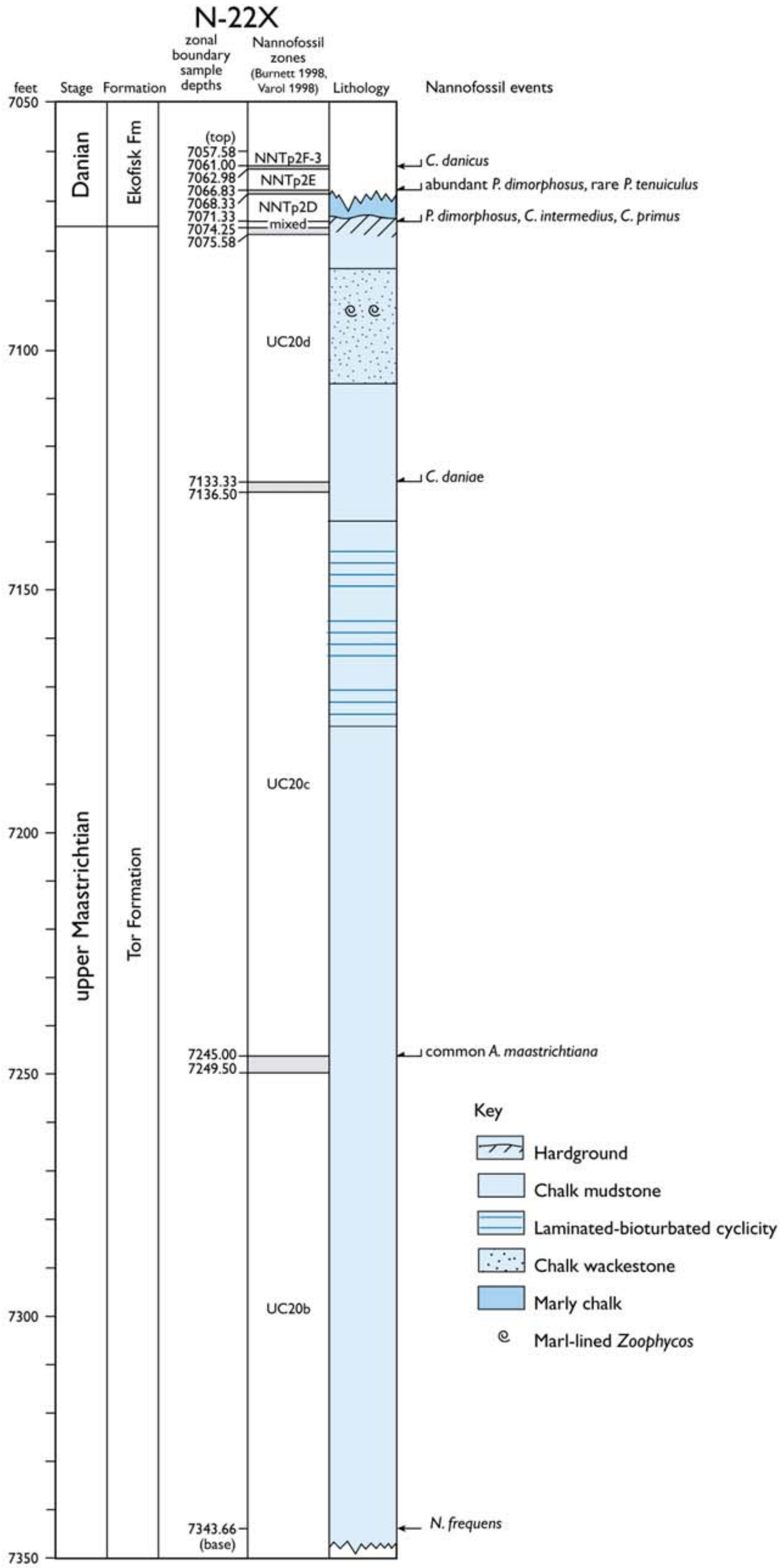



Figure 5. N-22X nannofossil biostratigraphy

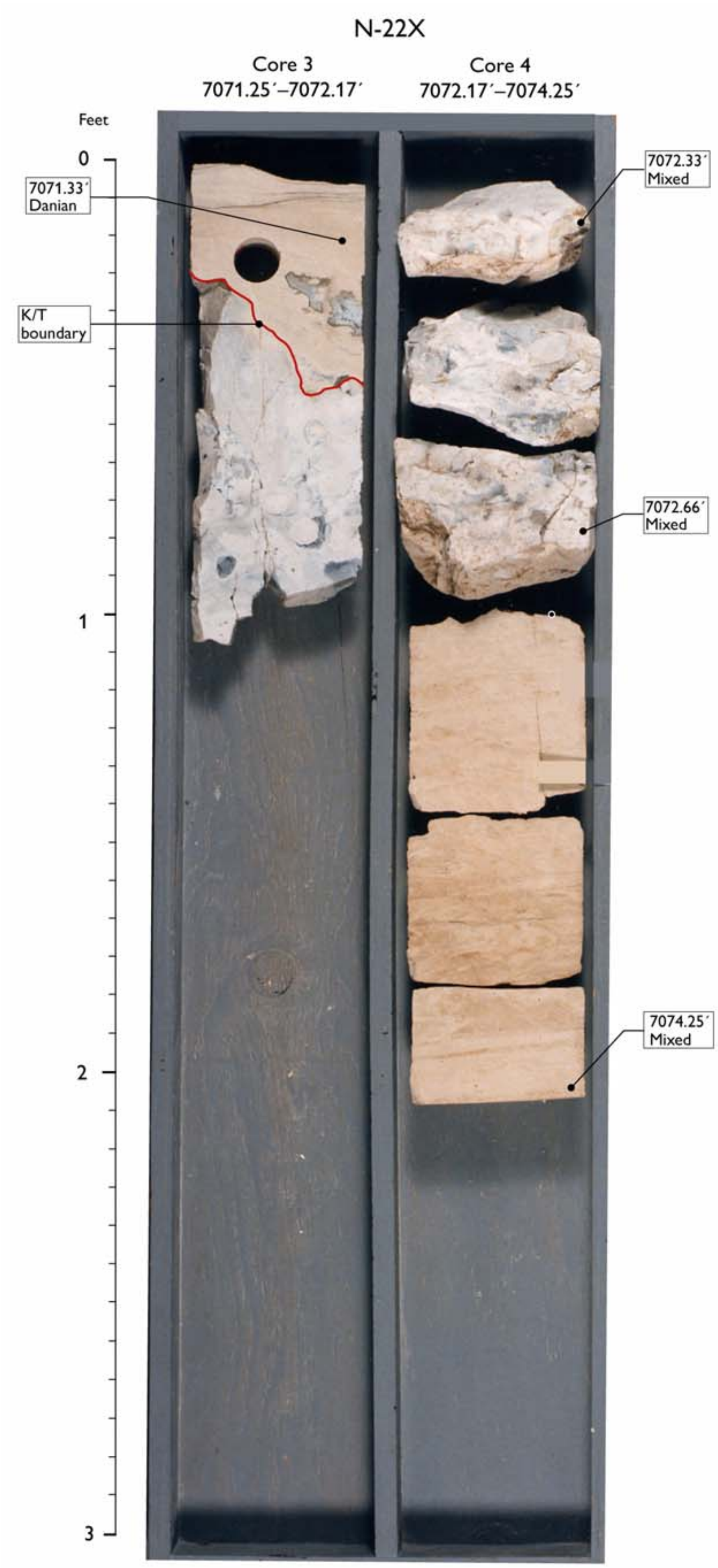



Figure 6. Photograph of the K/T boundary, N-22X

# List of samples from N-22X (in feet)

| | | |
|---|---|---|
| 7057.58 | 7153.75 | 7257.66 |
| 7061.00 | 7158.08 | 7259.75 |
| 7062.92 | 7161.25 | 7263.25 |
| 7065.08 | 7163.66 | 7265.92 |
| 7066.83 | 7166.17 | 7269.25 |
| 7068.33 | 7172.00 | 7272.00 |
| 7069.33 | 7176.50 | 7276.00 |
| 7070.75 | 7178.00 | 7279.08 |
| 7071.33 | 7181.83 | 7281.42 |
| 7072.33 | 7188.42 | 7284.33 |
| 7072.66 | 7190.08 | 7288.50 |
| 7074.25 | 7191.42 | 7291.08 |
| 7075.58 | 7194.33 | 7293.33 |
| 7076.58 | 7197.33 | 7296.00 |
| 7078.66 | 7199.92 | 7297.66 |
| 7081.00 | 7202.83 | 7301.00 |
| 7084.50 | 7205.33 | 7304.00 |
| 7087.00–089.25 | 7207.17 | 7308.17 |
| 7091.25 | 7208.66 | 7309.33 |
| 7094.17 | 7212.00 | 7312.08 |
| 7096.58 | 7214.66 | 7313.50 |
| 7098.25 | 7218.08 | 7316.50 |
| 7101.50 | 7221.83 | 7318.66 |
| 7105.08 | 7222.92 | 7321.33 |
| 7111.17 | 7228.75 | 7325.17 |
| 7114.66 | 7231.58 | 7327.92 |
| 7133.33 | 7235.50 | 7330.42 |
| 7136.50 | 7243.00 | 7333.42 |
| 7139.66 | 7245.00 | 7337.25 |
| 7142.42 | 7249.50 | 7340.33 |
| 7145.58 | 7251.83 | 7342.33 |
| 7148.66 | 7254.17 | 7343.66 |
| 7151.42 | | |

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