DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/37

Nannofossil biostratigraphy of the M-10X well, Danish Central Graben

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GEUS

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G E U S

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Introduction

Detailed nannofossil biostratigraphy of the cored upper Maastrichtian – Danian section of the M-10X 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 M-10X well was drilled in 1982 as an appraisal well on the Dan 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.

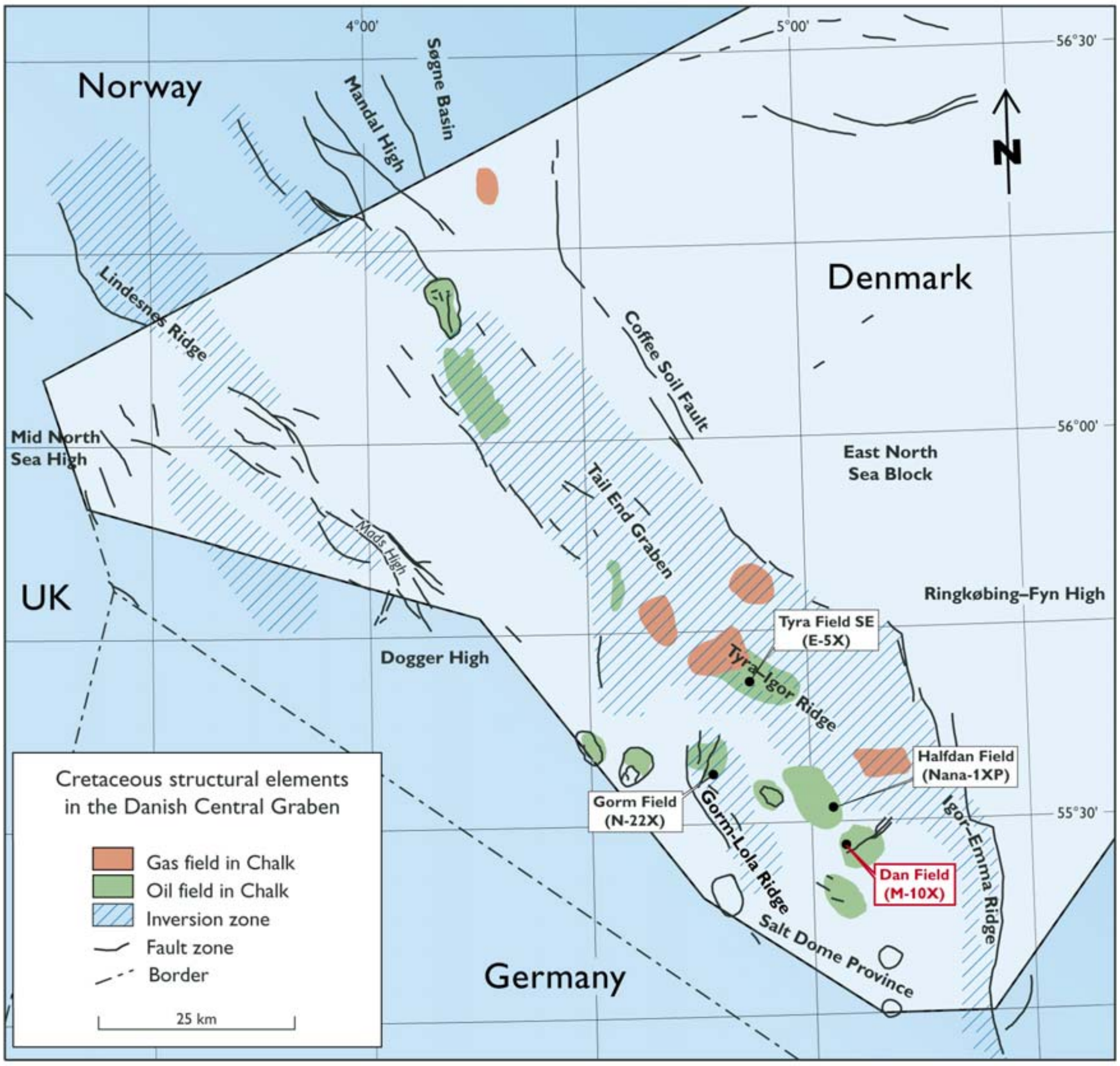


Figure 1. Location map, Danish Central Graben

Methods

104 samples were examined from the M-10X 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 zonation 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.

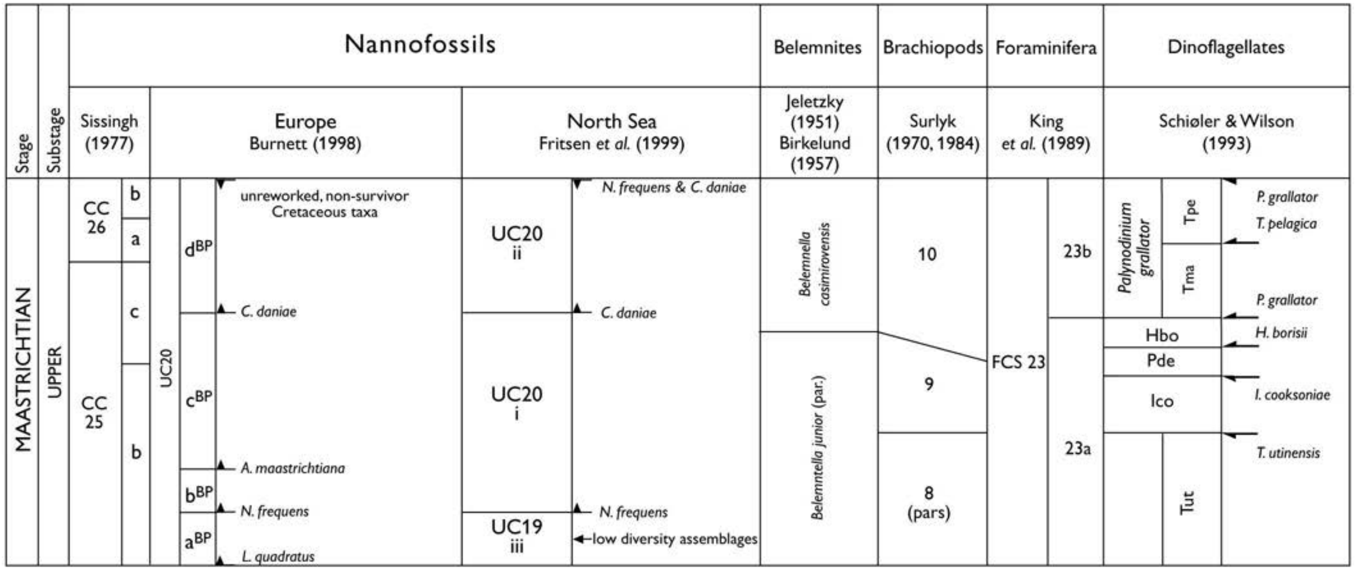
Terminology

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



* BP = ´Boreal Province´

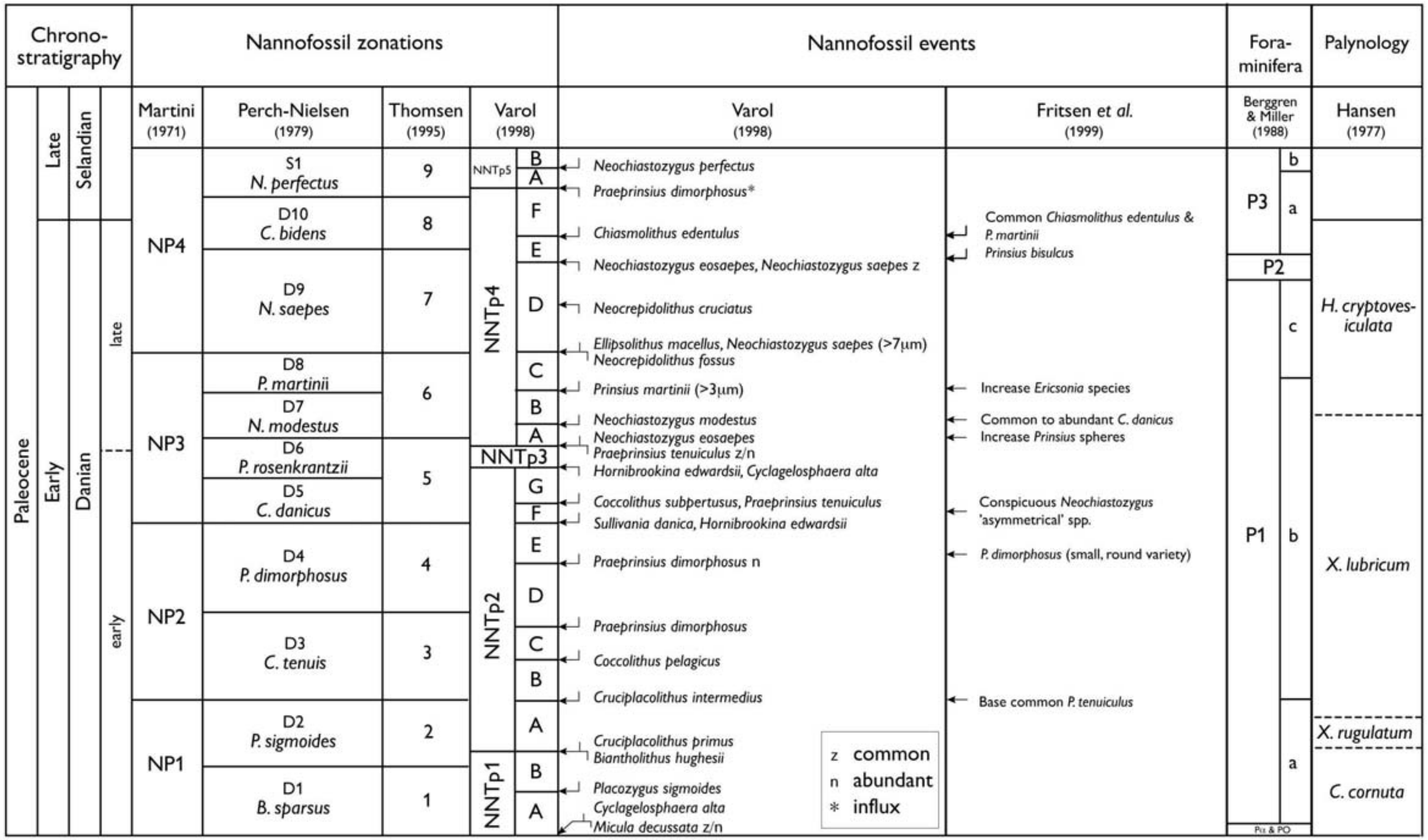


Figure 3. Danian multidisciplinary biostratigraphic correlation

Biostratigraphy

On the basis of nannofossil assemblage analysis, the cored upper Maastrichtian – Danian section of the M-10X well is divided into upper Maastrichtian nannofossil subzones $UC20b^{BP}$, $UC20c^{BP}$ and $UC20d^{BP}$ and Danian NNTp2E, NNTp2F–NNTp3 subzones (Enclosure 1, Table i).

	Base	Top	Thickness
NNTp2F–NNTp3	6436.33´	6433.58´	2.75´ (minimum)
NNTp2E	6439.00´	6436.33´	2.67´
mixed interval	6441.92´	6439.00´	2.92´
$UC20^{BP}$	6507.66´	6441.92´	65.74´
$UC20c^{BP}$	6648.50´	6507.66´	140.84´
$UC20b^{BP}$	6655.58´	6648.50´	7.08´ (minimum)

Table i *Nannofossil subzone thickness in M-10X*

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 M-10X well is seen on Figures 5 & 6.

Tor Formation

Subzone $UC20b^{BP}$

6655.58´ (lowest sample examined) – 6648.50’ 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 subzone comprises a rich nannofossil assemblage including *Arkhangelskiella cymbiformis*, *Micula decussata*, *Kamptnerius magnificus*, *Lucianorhabdus cayeuxii*, *Prediscosphaera cretacea*, *Prediscosphaera stoveri*, *Placozygus* cf. *P. fibuliformis* and fluctuating abundances of *N. frequens*. Large specimens of *A. cymbiformis* assigned to '*A. maastrichtiana*' are present, but only in low numbers in this subzone (see remarks below). Reworking from the mid-Maastrichtian is noted by the presence of *Calculites obscurus*.

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 subdivision in the present 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). 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 6648.50´ upwards. To be consistent with the study of Varol (1989), coccolith length was also taken into account, but once plotted, the large (length >10–18 microns) specimens showed neither a sudden, nor a gradual increase in number anywhere in the section.

Stratigraphically, the UC20b/c^{BP} boundary in M-10X, is in accordance with the stratigraphy from micropalaeontological (Lassen & Rasmussen 2004) palynological (Schiøler 2004) and isotope (Schovsbo & Buchardt 2004) investigations. This subzone coincides with the lower part of subzone UC20i (Fritsen 1999).

Subzone UC20c^{BP}

6648.50´–6507.66´

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

The nannofloral assemblage is very similar to that in the underlying interval. *C. daniae* is absent while *N. frequens* is present indicating the continuation of upper Maastrichtian sediments. As in the previous subzone, the assemblage comprises a high abundance and diversity of nannofossils, including *K. magnificus*, *Placozygus* cf. *P. fibuliformis*, *Cribrosphaerella ehrenbergii*, *Eiffelithus turriseiffelii*, *P. cretacea*, *P. stoveri*, *Ahmuellerella octoradiata* and *Watznaueria barnesiae*. The presence, in fairly high numbers, of '*A. maastrichtiana*' forms of *Arkhangelskiella* assigns this interval to subzone UC20c^{BP} (see remarks from subzone UC20b^{BP}). Reworking from the Cenomanian is noted by the presence of *Gartnerego theta* and from the Campanian or older by *Haquis circumradiatus*. Reworking from the Campanian is indicated by the occasional occurrence of *Orastrum campanensis* and *Monomarginatus* spp., from the mid-Maastrichtian by *C. obscurus* and the lower Maastrichtian by *Tranolithus orianatus.*

Remarks

This subzone coincides with the upper part of subzone UC20i (Fritsen 1999). By definition, *N. frequens* should be present throughout UC20c^{BP} (Burnett 1998), but as in the neighbouring Nana-1XP and N-22X wells (Sheldon *et al.* 2012 a, b) this species is found in several consecutive samples in M-10X, then appears to be absent for several samples before reappearing (Enclosure 1). This pattern occurs throughout UC20c^{BP} in M-10X. In the interval from the base of the core to 6641.00´, samples at 6634.41´, 6629.33´, 6623.00´ and the interval 6614.41´–6604.92´ it appears to be completely absent. It is possible, that these samples/intervals could represent reworking from the mid-Maastrichtian (although mid-Maastrichtian markers are not seen in these samples). Alternatively its absence could be due to environmental/diagenetic parameters (Sheldon 2006). The lower interval, where *N. frequens* is absent, could in theory be assigned to subzone UC20a^{BP} or UC19^{BP}. However, the presence of *Isabelidinium cooksoniae* (a dinoflagellate cyst) in a correlateable interval barren of *N. frequens* in Nana-1XP (P. Schiøler, personal communication, 2006) indicates that the sediments are younger than UC20a^{BP}. In addition, according to Burnett (1998) and (Fritsen 1999), Zone UC19 ^{BP} is characterised by low diversity assemblages.

Subzone UC20d^{BP}

6507.66´–6441.92´

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

This interval is characterised by high abundance and diversity assemblages typical of the upper Maastrichtian. The rich nannoflora is dominated by *M. decussata*, *L. cayeuxii* and *A. cymbiformis*. Other common species are *K. magnificus*, *E. turriseiffelii*, *C. ehrenbergii*, *Chiastozygus amphipons*, *P. cretacea* and *P. stoveri*. The co-occurrence of *N. frequens* and *C. daniae* assign this interval to subzone UC20d^{BP}. This interval is also characterised by the presence of other species present throughout the Upper Cretaceous e.g. *A. octoradiata, Placozygus* cf. *P. fibuliformis*, *W. barnesiae*, *Octocyclus reinhardtii*, *Retecapsa crenulata*, *Prediscosphaera grandis*, *Prediscosphaera spinosa,* and *Cretarhabdus conicus*. The presence of *Percivalia fenestrata* and *T. orionatus* indicates reworking from the Campanian and lower Maastrichtian respectively.

Remarks

Within UC20d^{BP}, *N. frequens* only appears to be missing from 6481.00'. Its absence could be due to palaeoenvironmental or diagenetic factors. This subzone coincides with subzone UC20ii (Fritsen 1999). The Kjølby Gaard Marl equivalent (an important upper Maastrichtian marker bed) is found from 6456.50´–6458.25´ (Troelsen 1955, Sheldon *et al.* 2010).

Mixed interval

6441.92´–6439.00´

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 M-10X well.

Floral characteristics

6441.92´

Although this sample is almost completely dominated by Upper Cretaceous flora, the common occurrence of the calcareous dinoflaggelate cyst *Thoracosphaera* spp. suggests the presence of Danian chalk. However, absence of Danian nannofossils renders it impossible to assign this sample to a particular Danian nannofossil zone. The Upper Cretaceous flora shows fairly high diversity (comprising abundant *M. decussata* and *A. cymbiformis,* common *L. cayeuxii* and lower abundances of *E. turriseiffelii*, *K. magnificus*, *C. amphipons, P.*

stoveri, *A. octoradiata* and *C. ehrenbergii*), but the lack of the upper Maastrichtian marker species *N. frequens* and *C. daniae* allows only a general Upper Cretaceous age to be assigned to this sample.

6440.50´

Just over half of the nannofossils counted in this sample are assigned to the middle Danian subzone NNTp2E (represented by common *Prinsius dimorphosus*, *Cruciplacolithus asymmetricus*, large specimens of *Zeugrhabdotus sigmoides* and abundant *Thoracosphaera* spp.) and 40% of the flora is assigned to the upper Maastrichtian subzone $UC20d^{BP}$. The Upper Cretaceous assemblage includes *C. ehrenbergii*, *A. cymbiformis, W. barnesiae*, *N. frequens*, *C. daniae*, *E. turriseiffelii, Placozygus* cf. *P. fibuliformis* and *Cretarhabdus conicus.* On the basis of biostratigraphic data alone, it cannot be determined whether this sample represents upper Maastrichtian ($UC20d^{BP}$) reworking within Danian chalk, or Danian forms introduced by burrowing into Maastrichtian chalk. Based on regional stratigraphy and sedimentological observations, the latter is deemed most likely (Ineson *et al*. 2004).

6439.33´

This sample is dominated by Danian flora, with 8% of the total flora assigned to the upper Maastrichtian. The Danian element comprises abundant *P. dimorphosus*, *Cruciplacolithus primus*, *Z. sigmoides* and *Thoracosphaera* spp., and present *C. asymmetricus*, *Cruciplacolithus intermedius, Coccolithus pelagicus* and *Biscutum* spp. The Danian assemblage is assigned to nannofossil subzone NNTp2E, due to the absence of *Chiasmolithus danicus*, a marker species for the overlying subzone NNTp2F. Upper Maastrichtian nannofossils are assigned to subzone $UC20d^{BP}$ and are represented by low numbers of *C. daniae*, *N. frequens*, *E. turriseiffelii*, *A. octoradiata*, *L. cayeuxii*, *P. stoveri, M. decussata* and *K. magnificus*. Although dominated by Danian forms, regional considerations indicate an origin as open burrow fills at the Maastrichtian hardground (Ineson *et al*. 2004).

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 M-10X, 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

6439.00´–6436.33´

Definition

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

Floral characteristics

This interval is characterised by high abundance and fairly high diversity nannofossil assemblages. The samples are particularly rich in *P. dimorphosus*, the calcareous dinoflagellate cyst *Thoracosphaera* spp. and *C. primus*. Other common to present constituents are *Chiasmolithus edwardsii*, *C. pelagicus*, *C. asymmetricus*, *C. intermedius, Z. sigmoides* and *Markalius inversus*. *Cruciplacolithuis tenuis*, *Neocrepidolithus dirimosus* and *Biscutum* spp. are found in low abundances. *P. tenuiculus* is seen for the first time in low numbers, increasing in abundance upwards within this subzone with decreasing stratigraphic age (see remarks below). This assemblage (along with the absence of *C. danicus*, the marker nannofossil for the overlying NNTp2F subzone) assigns this interval to the NNTp2E nannofossil subzone of Varol (1998). Minor reworking of Upper Cretaceous sediments (undifferentiated) into the Danian is indicated by rare occurrences of *W. barnesiae, A. cymbiformis,* and *K. magnificus*, and from the Campanian by rare *Monomarginatus quaternarius*.

Remarks

The sample from 6436.83´ contains fairly common *P. tenuiculus* (in the absence of *C. danicus*). Varol (1998) indicated that the FO common *P. tenuiculus* denotes the base of subzone NNTp2G, however, according to Fritsen (1999), *P. tenuiculus* is found to be common for the first time in the uppermost part of subzone NNTp2E. The results in the present study agree with the latter observation. This sample is therefore assigned to the upper part of subzone NNTp2E. NNTp2E coincides with upper Zone NP2 (Martini 1971).

Subzone NNTp2F–Zone NNTp3

6436.33´–6433.58´ (uppermost sample examined)

Definition

The base of subzone NNTp2F is defined by the FO of *C. danicus* and/or *H. edwardsii*. The top of NNTp2F (and base of subzone NNTp2G) is defined by the FO of *Coccolithus subpertsus* and/or the FO of *P. tenuiculus* (Varol 1998). 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 *Cyclagelosphaera alta*. The top of Zone NNTp3 is based upon the LO of common to abundant *P. tenuiculus* (Varol 1998).

Floral characteristics

C. danicus exists together with abundant *P. dimorphosus*, common to abundant *P. tenuiculus* and common *C. pelagicus* and *C. primus.* The remainder of the assemblage includes low numbers of *C. edwardsii*, *C. asymmetricus*, *M. inversus*, *Biscutum harrisonii*, *C. intermedius*, *Chiasmolithus inconspicuus, Z. sigmoides* and *Thoracosphaera* spp. Minor reworking of Upper Cretaceous sediments into this interval of the Danian is indicated by rare occurrences of *A. octoradiata*, *M. decussata, A. cymbiformis* and *K. magnificus*.

Remarks

NNTp2F and G coincide with lower to middle Zone NP3 (Martini 1971). *H. edwardsii* usually occurs in abundance when present in North Sea wells (M. Hampton, personal communication, 2005). The fact that it does not in this well could be due to a minor hiatus at this level due to the position of M-10X on a Late Cretaceous – Danian structural high. The biostratigraphic ranges of *C. alta* and *C. subpertusus* according to Varol (1998) are also questionable. Observations in the present study find these two species ranging at least to the middle Danian. They are therefore not considered to be reliable marker species. The uncertainty surrounding these ‘marker’ species prevents this interval from being divided into subzones NNTp2F and G.

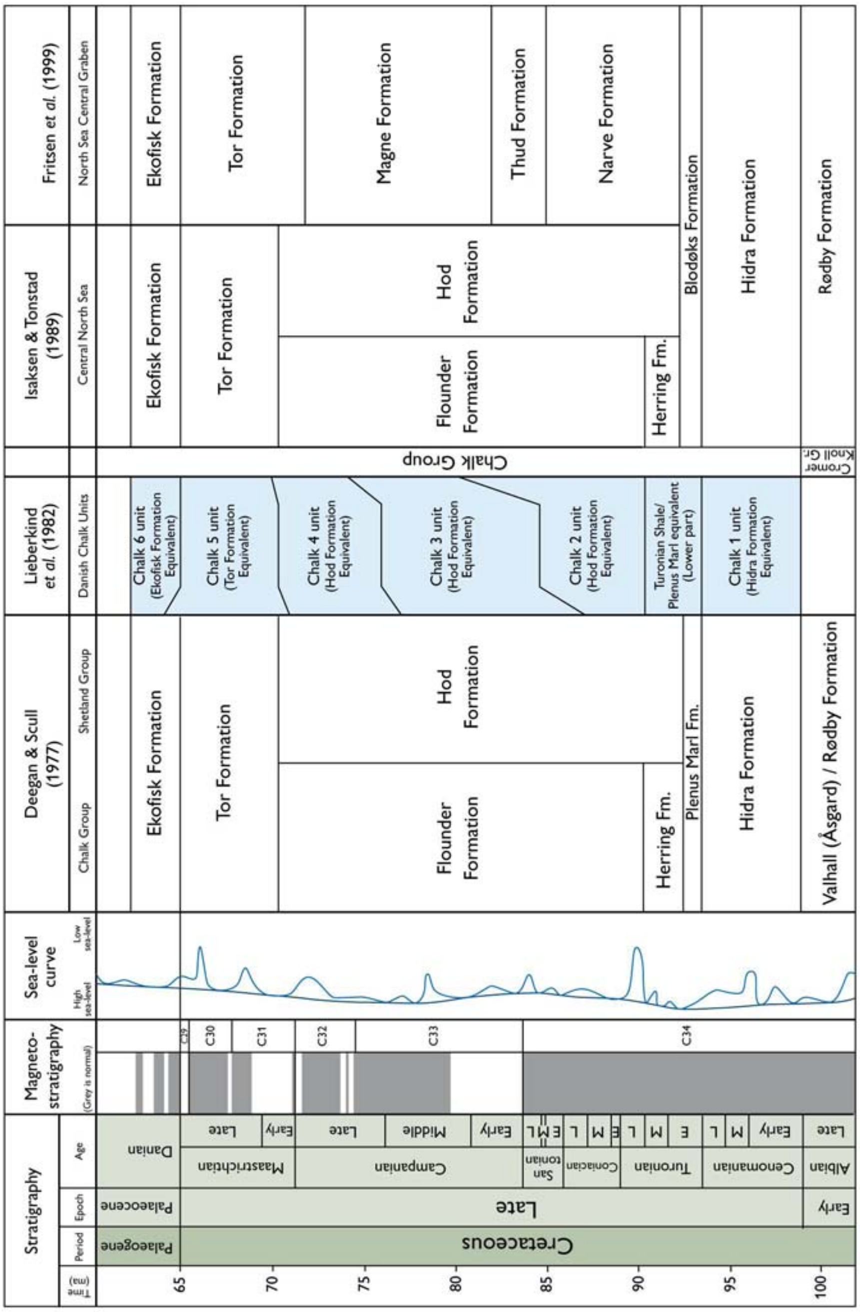


Figure 4. Upper Cretaceous lithostratigraphic correlation (sea level curve after Haq *et al.* 1988)

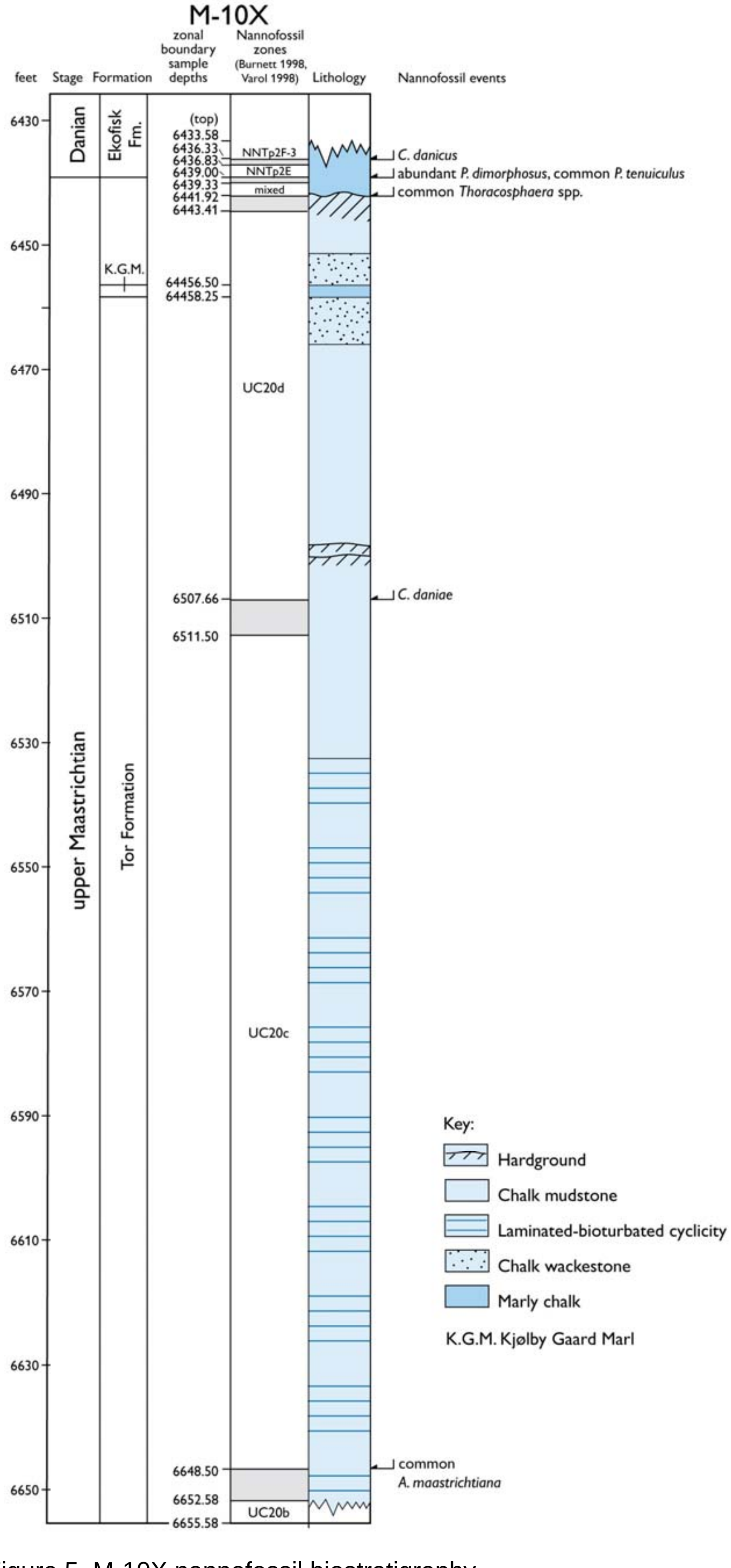


Figure 5. M-10X nannofossil biostratigraphy

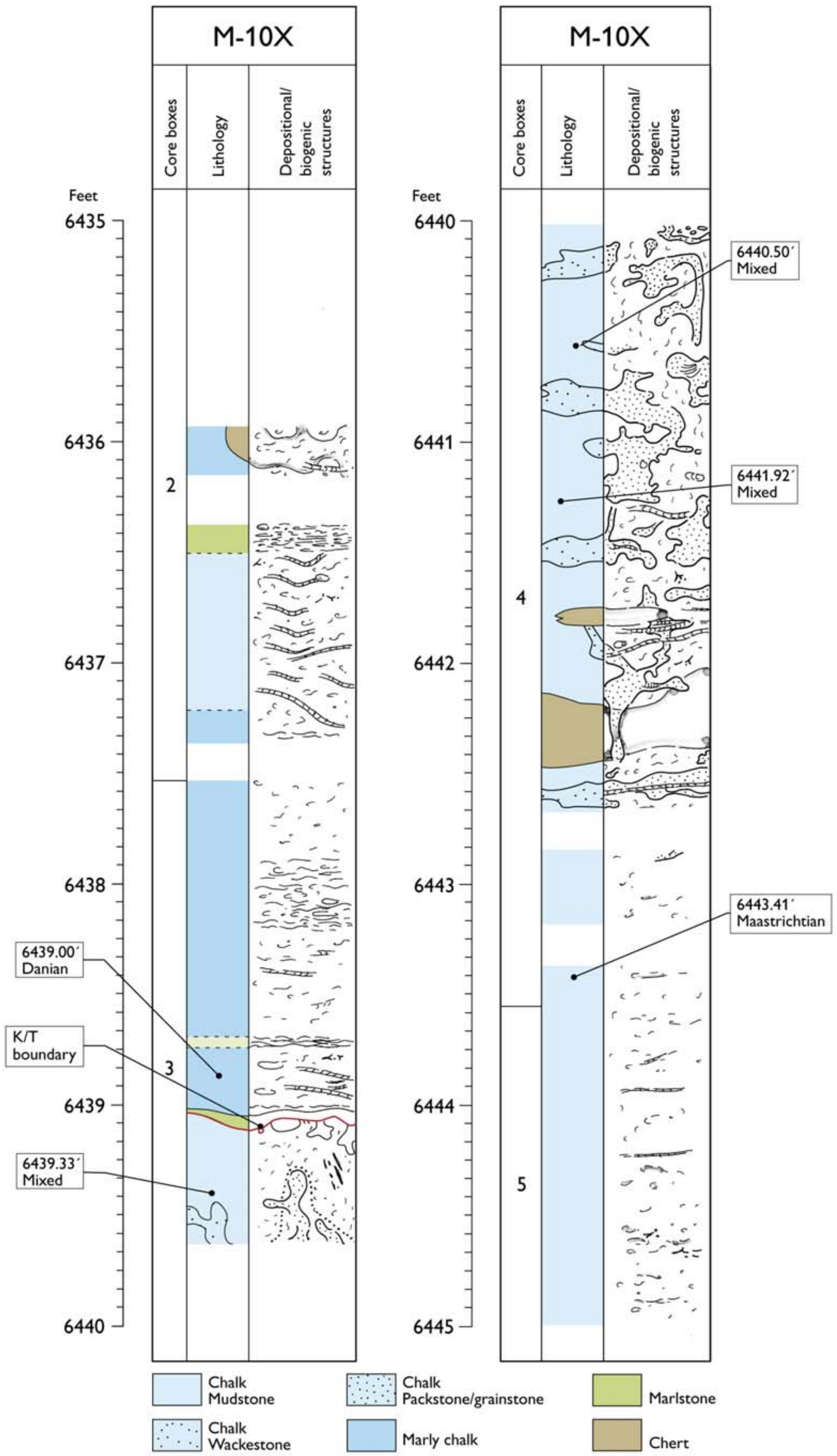


Figure 6. Figure of the K/T boundary, M-10X

List of samples from M-10X (in feet)

6433.58	6483.83	6557.58	6615.33
6434.58	6487.25	6560.75	6615.58
6436.33	6489.50	6563.41	6615.92
6436.83	6491.50	6564.66	6616.25
6438.17	6495.60	6568.25	6616.58
6438.83	6497.33	6571.17	6617.17
6439.00	6499.00	6573.66	6617.58
6439.33	6500.08	6577.08	6618.00
6440.50	6502.33	6579.83	6618.41
6441.92	6503.25	6582.58	6618.58
6443.41	6505.08	6586.25	6619.00
6444.83	6507.66	6590.00	6619.41
6446.50	6511.50	6592.00	6623.00
6448.17	6514.50	6598.50	6626.41
6449.50	6516.65	6601.58	6629.33
6451.83	6519.41	6604.92	6631.66
6454.33	6522.25	6608.08	6634.41
6456.75	6525.25	6610.00	6637.33
6458.17	6528.92	6611.58	6641.00
6460.00	6531.00	6612.33	6644.00
6463.00	6533.17	6612.66	6647.00
6465.25	6539.92	6613.08	6648.50
6467.66	6542.58	6613.50	6652.58
6472.33	6546.41	6614.08	6655.58
6475.17	6548.92	6614.41	
6477.00	6552.25	6614.58	
6481.00	6554.83	6615.00	

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