DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/38

Nannofossil biostratigraphy of the E-5X well, Danish Central Graben

Emma Sheldon, Jon R. Ineson & Paul Bown

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

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Contents

Introduction

Detailed nannofossil biostratigraphy of the cored upper Maastrichtian – Danian section of the E-5X 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 E-5X well was drilled in 1991 as an appraisal well on the Tyra-SE 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.

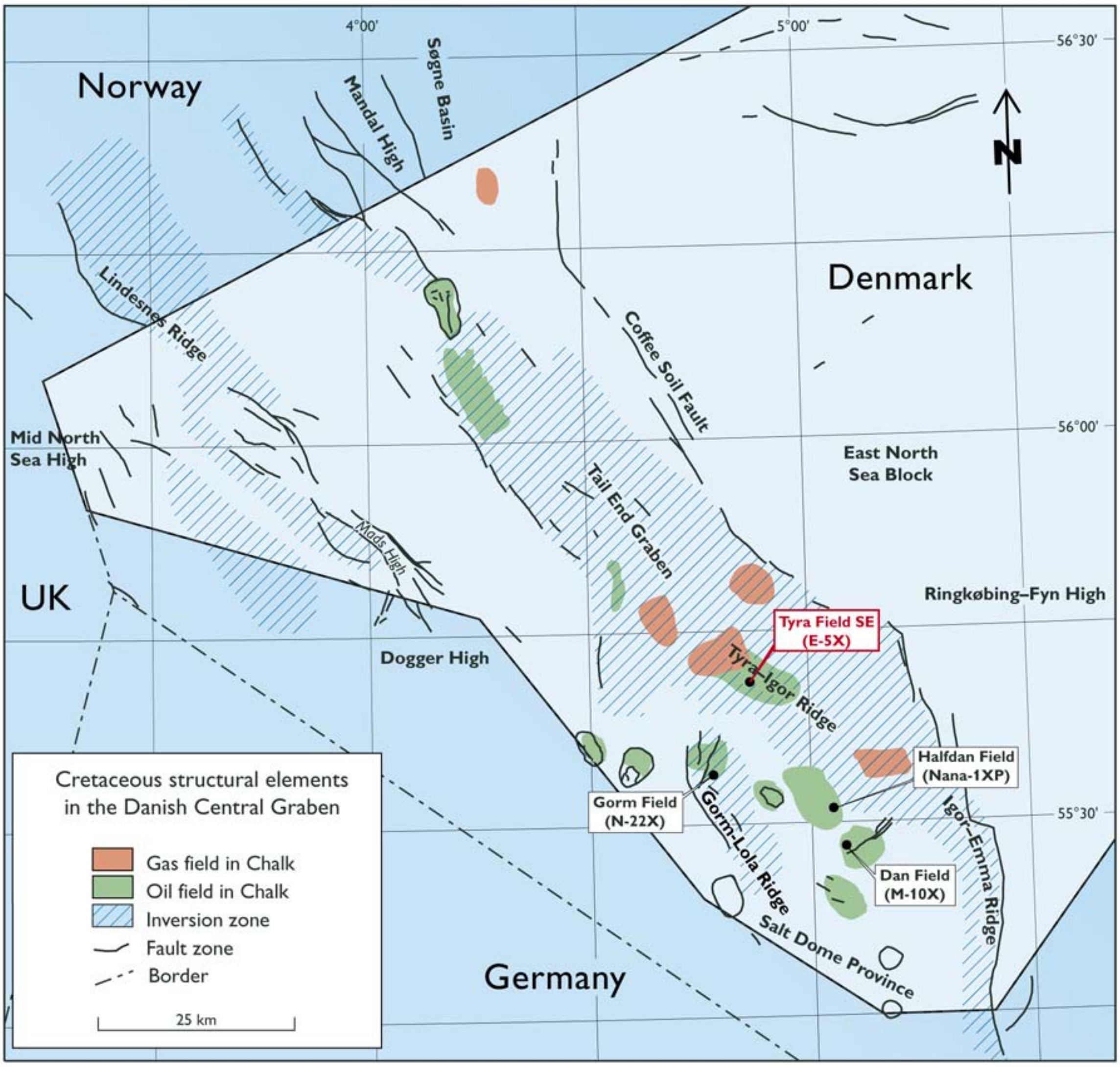


Figure 1. Location map, Danish Central Graben

Methods

62 samples were examined from the E-5X 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.

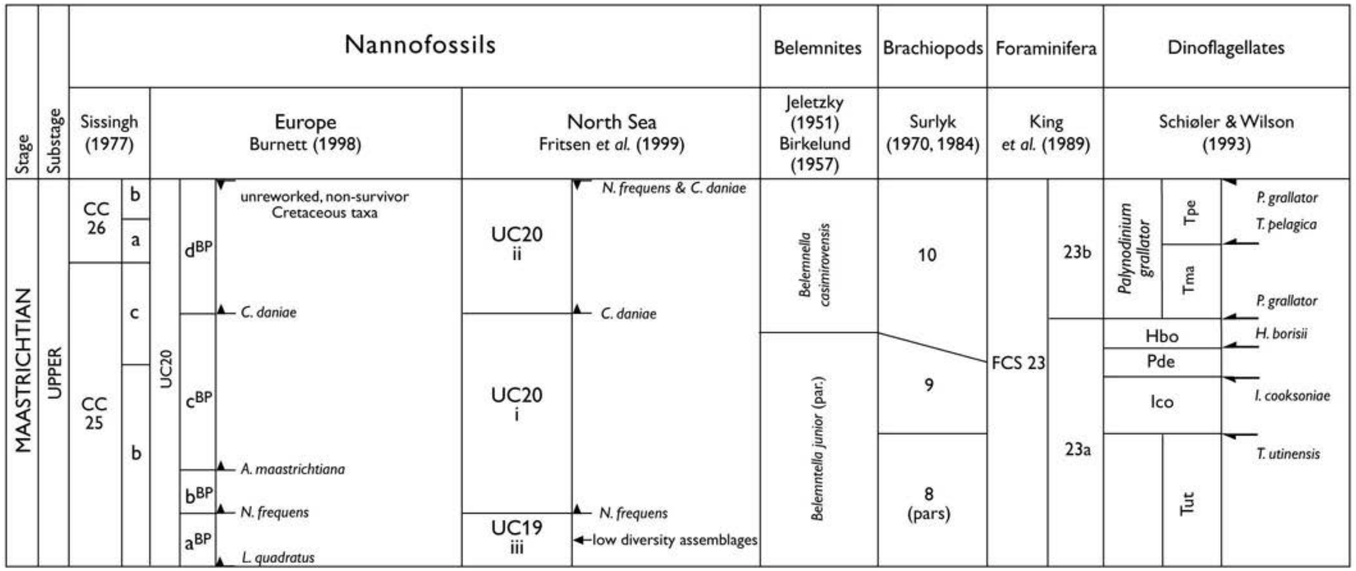
Terminology

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

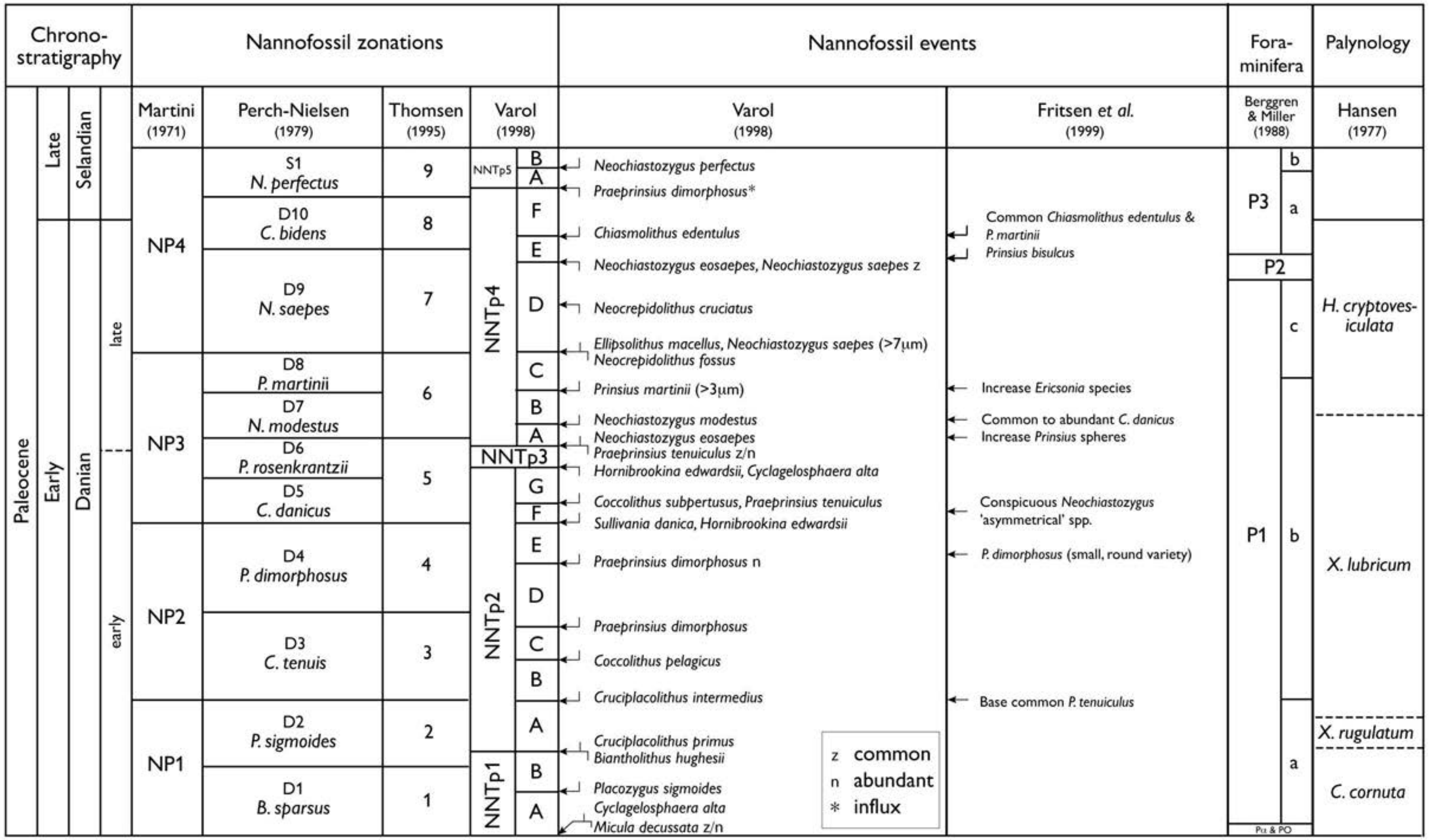
As core material was used in this study, caving is not an issue. Although reworking is potentially a complicating factor, the sedimentology indicates that pelagic settling and small-volume dilute density flows dominated the depositional system and significant ‘stratigraphic’ redeposition (i.e. by slumps, 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



* 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 E-5X well is divided into upper Maastrichtian nannofossil subzones UC20c^{BP} and UC20d^{BP} and Danian NNTp2E, NNTp2F–G and NNTp3 subzones (Enclosure 1, Table i).

	Base	Top	Thickness
NNTp3	6812.41´	6809.25´	3.16´ (minimum)
NNTp2F–G	6818.66´	6812.41´	6.25´
NNTp2E	6819.17´	6818.66´	0.51´
mixed interval	6820.00´	6819.17´	0.83´
UC20d^{BP}	6875.33´	6820.00´	55.33´
UC20c^{BP}	6975.17´	6875.33´	99.84´ (minimum)

Table i *Nannofossil subzone thickness in E-5X*

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 E-5X well is seen on Figures 5 & 6.

Tor Formation

Subzone UC20c^{BP}

6975.17´ (lowest sample examined) – 6875.33´ M.D.f.b.R.L. (Measured Depth, feet below Reference Level)

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

Floral characteristics

The common occurrence of *Nephrolithus frequens* (present throughout) in a high diversity and abundance nannofossil assemblage (including common to abundant *Arkhangelskiella cymbiformis*, common *Micula decussata*, *Lucianorhabdus cayeuxii*, *Kamptnerius magnificus*, *Placozygus* cf. *P. fibuliformis*, *Prediscosphaera cretacea* and *Prediscosphaera stoveri* and present *Biscutum* spp., *Chaistozygus amphipons*, *Cribrosphaerella ehrenbergii*, *Eiffelithus turriseiffelii*, *Prediscosphaera spinosa*, *Eiffelithus gorkae* and *Retecapsa crenulata*) with the absence of *C. daniae* assigns this interval to upper Maastrichtian subzone $UC20c^{BP}$. A single specimen of *Calculites obscurus* indicates minor reworking from the mid-Maastrichtian (Zone $UC19^{BP}$) at 6950.33´. Minor reworking from the Campanian is indicated at 6881.41´ by the presence of *Reinhardtites anthophorus*.

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 and 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. There were found to be fluctuations in the abundances of 'wide' forms but none as obvious and continuous as to suggest a biostratigraphic boundary. 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. It is concluded that this interval is assigned to subzone $UC20c^{BP}$. This subzone coincides with the upper part of subzone UC20i (Fritsen 1999).

Subzone $UC20d^{BP}$

6875.33´–6820.00´

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 an assemblage rich in calcareous nannofossils. Assignment to subzone UC20d^{BP} is indicated by the co-occurrence of common *N. frequens* (present throughout) with *C. daniae*. The assemblage comprises abundant *M. decussata* (especially in the uppermost part of the interval, probably associated with the hardground at the top of the Maastrichtian) *P. stoveri, A. cymbiformis*, common to abundant *L. cayeuxii*, common *P. cretacea, C. amphipons, E. turriseiffelii, K. magnificus and Placozygus* cf. *P. fibuliformis.* Species with lower abundances include *Ahmuellerella octoradiata*, *C. ehrenbergii*, *Munarinus* spp., *P. spinosa* and *Watznaueria barnesiae*.

Remarks

This subzone coincides with subzone UC20ii (Fritsen 1999). The Kjølby Gaard Marl equivalent (an important upper Maastrichtian marker bed) is found from 6833.00´–6834.17´ (Troelsen 1955, Sheldon *et al.* 2010).

Mixed interval

6820.00´–6819.17´

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 E-5X well.

Floral characteristics

6820.00´

This sample is dominated by *M. decussata* (a robust species associated with hardground levels, Sheldon et al. 2010) and *A. cymbiformis* with common *K. magnificus* and *C. ehrenbergii*. The presence of *N. frequens* and absence of *C. daniae* (along with a fairly diverse flora including *E. turriseiffelii*, *C. amphipons*, *A. octoradiata*, *P. stoveri*, *P. cretacea*, *R. crenulata* and *L. cayeuxii*) indicates that the Upper Cretaceous component of this sample could be assigned to subzone UC20c^{BP}. However, the presence of chalk from subzone UC20d^{BP} cannot be ruled out as *C. daniae* is often very rare and may have existed in numbers too low to be included in the 300 counts for each sample in this study. This sample from the ‘mixed zone’ is dominated by Upper Cretaceous forms and the only evidence of

Danian flora are very rare occurrences of *Prinsius dimorphosus* and *Zeugrhabdotus sigmoides* (Enclosure 1).

6819.50´

A patchy differential cementation was noted at this level with hardened matrix chalk and softer chalk, probably within *Thalassinoides* galleries (Ineson 2004). Two samples were thus taken at this level, one from a softer area of chalk and one from a hard region. They were analysed as two separate samples.

6819.50´ (soft chalk)

The mainly Upper Cretaceous nannofossil assemblage in this sample is dominated by *M. decussata.* Also showing high abundances are *A. cymbiformis*, and *C. ehrenbergii*. Common constituents include *E. turriseiffelii* and *P. cretacea*. The absence of the uppermost Maastrichtian marker species *C. daniae* and *N. frequens* suggest the Maastrichtian flora could be assigned to subzone $UC20b^{BP}$, $UC20a^{BP}$ or the upper part of zone $UC19^{BP}$ (UC19iii of Fritsen 1999). An alternative explanation is that *C. daniae* and *N. frequens* are in fact present at this level but in abundances too low to be seen in 300 counts. However, low numbers of Danian nannofossils (plus the high abundance of *Thoracosphaera* spp.) including *P. dimorphosus*, *Z. sigmoides*, *Cruciplacolithus asymmetricus* and *Cruciplacolithus intermedius* indicate that a Danian age (tentatively NNTp2D–E) for components of this sample cannot be discounted.

6819.50´ (hard chalk)

In this sample some nannofossil species exhibit similar trends and some show trends different to those in the soft chalk sample from the same depth. The abundance of *Thoracosphaera* spp. was negligible, whereas in the soft chalk, it was a dominant species. Similarly, *C. ehrenbergii* was present in the current sample, but was abundant in the soft chalk and *P. cretacea* was common in the soft chalk sample but was seen to be rare in the current sample. Also present in this sample (along with a high diversity assemblage including *K. magnificus*, *E. turriseiffelii*, *A. octoradiata*, *L. cayeuxii* and *W. barnesiae*) is *N. frequens*, indicating that this level could be assigned to subzones $UC20b^{BP}$–c^{BP} (UC20i of Fritsen 1999). Assignment to $UC20d^{BP}$ cannot be ruled out; *C. daniae* may be present but in numbers too low to be included in 300 counts. Apart from the abundance of *Thoracosphaera* spp., the sparse Danian flora did not differ markedly between the two samples; low numbers of *Chiasmolithus* spp. and *P. dimorphosus* also very tentatively indicate an age of NNTp2D–E for the Danian component of this ‘mixed’ sample.

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, Girgis 1993). This is the case with E-5X, 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

6819.17´–6818.66´

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

A rich nannofossil assemblage including abundant *P. dimorphosus*, *Cruciplacolithus primus* and *Thoracosphaera* spp., common *Coccolithus pelagicus*, *P. tenuiculus, C. asymmetricus*, *Cruciplacolithus tenuis*, *Markalius inversus* and *Z. sigmoides* and present *Biscutum* spp., *Chiasmolithus edwardsii*, *C. intermedius* and *Neocrepidolithus cohenii* (see remarks below). This assemblage, together with the absence of *C. danicus* and *H. edwardsii* (marker species for the overlying zone) assigns this interval to NNTp2E.
Rare reworking is present from the Upper Cretaceous.

Remarks

Varol (1998) indicates that the FO of common *P. tenuiculus* denotes the base of subzone NNTp2G. However, according to Fritsen (1999) it marks upper NNTp2E. The results in the present study fit best with the latter observation. NNTp2E coincides with upper Zone NP2 (Martini 1971).

Subzones NNTp2F–G

6818.66´–6812.41´

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 overlying NNTp2G are defined by the FO of *Coccolithus subpertsus* and/or the FO of *P. tenuiculus* (Varol 1998). However, the base of common *P. tenuiculus* is found in upper subzone NNTp2E (Fritsen 1999). The top of subzone NNTp2G is defined by the LO of *H. edwardsii* and/or *Cyclagelosphaera alta* (Varol 1998).

Floral characteristics

The co-occurrence of common *P. tenuiculus* and *C. danicus* in a fairly high diversity assemblage of nannofossils (including *C. pelagicus*, *C. asymmetricus*, *C. primus*, *M. inversus, Z. sigmoides* and *C. edwardsii* with abundant *P. dimorphosus* and *Thoracosphaera* spp.) assigns this interval to subzone NNTp2F. *H. edwardsii* (another marker species for NNTp2F) and *C. subpertusus* (the marker for the overlying subzone) were found in one sample at 6814.17´. Rare reworking is present from Upper Cretaceous Zone UC20^{BP}.

Remarks

NNTp2F and G coincide with lower to middle Zone NP3 (Martini 1971). *H. edwardsii* usually occurs consistently 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. 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.

Zone NNTp3

6812.41´–6809.25´ (uppermost sample examined)

Definition

The base of this subzone is based upon the LO of *H. edwardsii* and/or *C. alta* and the top on the LO of common to abundant *P. tenuiculus.*

Floral Characteristics

The samples from this interval are dominated by *Thoracosphaera* spp., *C. primus, C. edwardsii*, *C. pelagicus* and *P. dimorphosus* with *P. tenuiculus* and *Z. sigmoides*. Forms present in small numbers include *Neocrepidolithus neocrassus*, *Neocrepidolithus dirimosus*, *Cyclagelosphaera reinhardtii*, *C. asymmetricus*, *C. tenuis* and *M. inversus*.

Remarks

H. edwardsii and *Neochiastozygus* spp. (representative of older and younger subzones respectively) were not recognised in this interval. It is based upon this negative evidence that this interval is assigned to zone NNTp3. Zone NNTp3 is equivalent to the middle of NP3 (Martini, 1971).

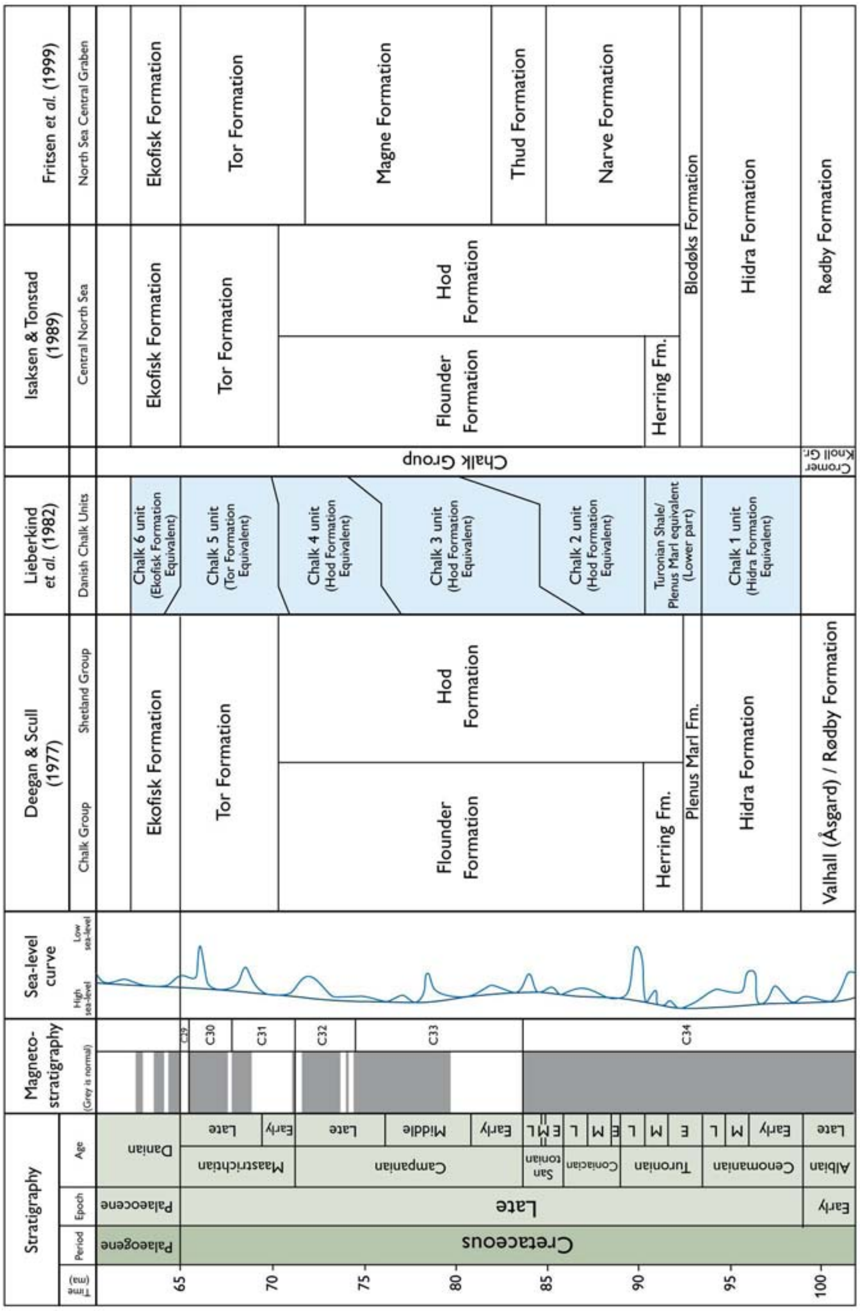


Figure 4. Upper Cretaceous lithostratigraphic correlation (sea level curve after Haq *et al.* 1988)

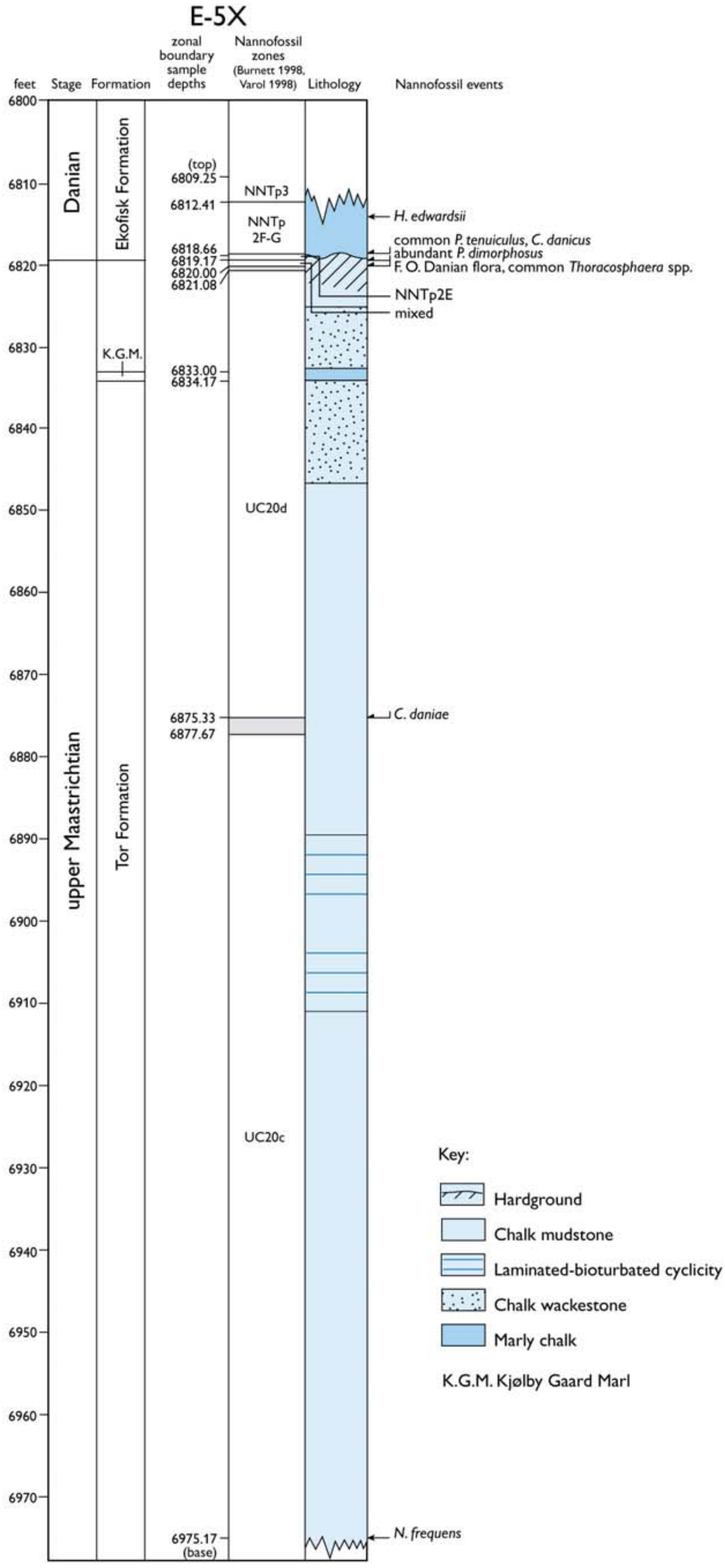


Figure 5. E-5X nannofossil biostratigraphy

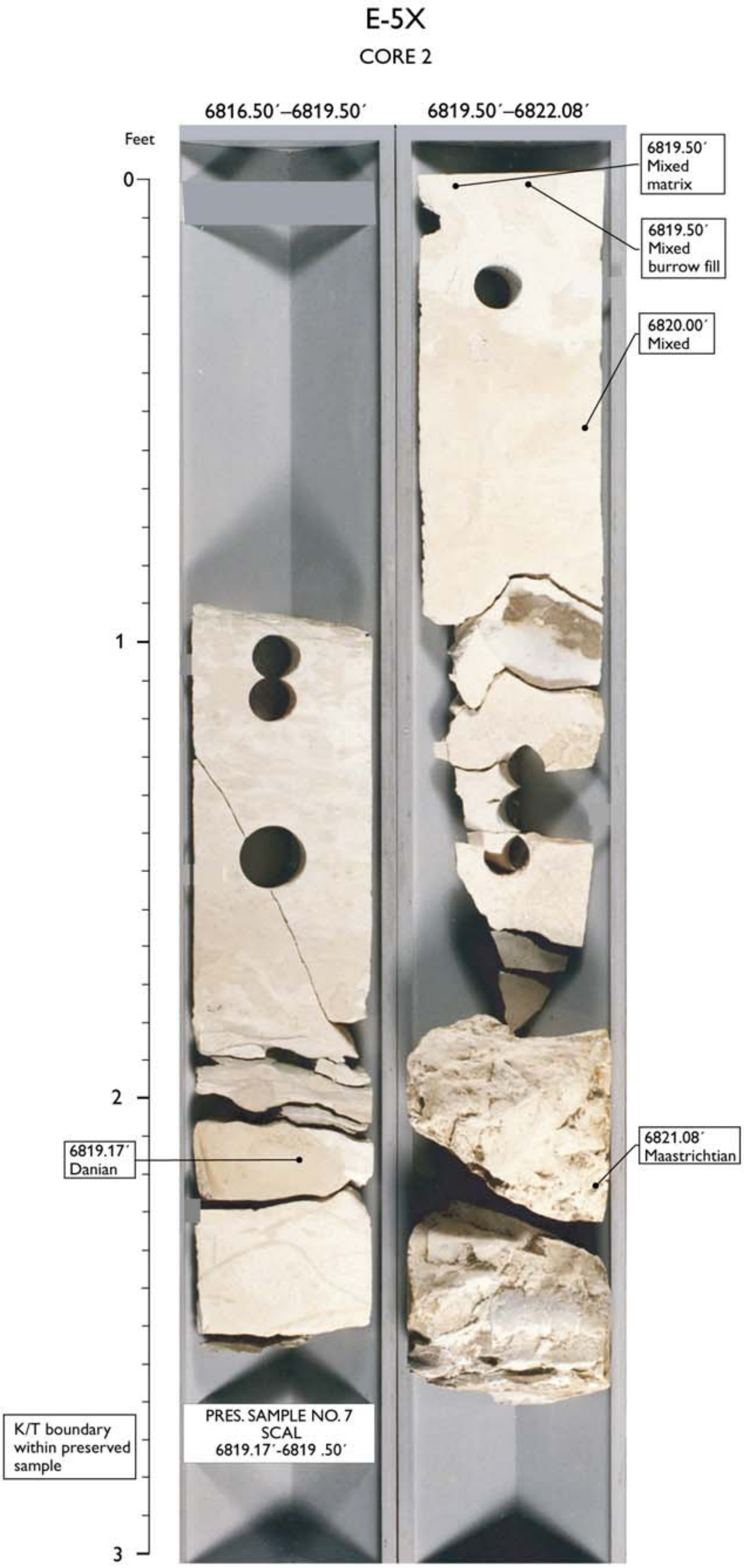


Figure 6. Photograph of the K/T boundary, E-5X

List of samples from E-5X (in feet)

6809.25	6847.83	6919.17
6812.41	6859.83	6920.75
6814.17	6863.33	6923.83
6817.58	6866.25	6926.17
6818.66	6869.33	6928.58
6818.92	6872.66	6932.41
6819.17	6875.33	6935.83
6819.50 (hard chalk)	6877.66	6938.33
6819.50 (soft chalk)	6881.41	6941.17
6820.00	6883.92	6943.25
6821.08	6887.25	6948.92
6823.33	6889.33	6950.41
6824.83	6890.66	6952.92
6826.66	6894.00	6956.83
6827.92	6897.92	6960.17
6830.00	6900.75	6963.17
6833.50	6903.75	6965.17
6836.83	6906.83	6968.58
6839.25	6910.25	6972.17
6841.92	6912.41	6975.17
6845.83	6916.33	

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