DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/87

High-resolution foraminiferal biostratigraphy of Upper Maastrichtian to basal Danian strata, Danish Central Graben

M-10X (Dan Field), E-5X (Tyra SE Field)

Susanne Lassen & Jan A. Rasmussen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/87

High-resolution foraminiferal biostratigraphy of Upper Maastrichtian to basal Danian strata, Danish Central Graben

M-10X (Dan Field), E-5X (Tyra SE Field)

A contribution to EFP-2001 (1313/01-0001)

Susanne Lassen & Jan A. Rasmussen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

Contents

Abstract

Benthic and planktic foraminiferids from the Upper Maastrichtian to Lower Danian part of the wells M-10X and E-5X were thoroughly analysed with the aim to establish a detailed biostratigraphic framework for the southern part of the Danish Central Graben area. The Upper Maastrichtian sediments correlate with Zone FCS23, which includes the subzones FCS23a and FCS23b. The faunal evidence show that the FCS23a Subzone extends to a lower stratigraphic level in M-10X than in E-5X.

Additional microfaunal events makes it possible to enhance the biostratigraphic resolution within the Upper Maastrichtian interval. The K-T boundary is characterised by a hard-ground, which marks the presence of a basal Danian hiatus in both wells. This hiatus spans the Danian zones P0 and Pα in M-10X, and P0, Pα and P1a in E5-X. The lower part of the overlying Danian sediments correlates with Subzone P1a and P1b in M-10X and Subzone P1b and P1c in E-5X.

Introduction

The Upper Cretaceous – Danian chalk deposits are among the most important reservoirs in the Danish Central Graben. Improved drilling and production techniques have raised new demands for a more refined stratigraphy and a better understanding of the controlling factors related to chalk sedimentation. In order to confront some of these questions, the EFP project "Genetic high-resolution stratigraphy of the Upper Maastrichtian", initiated in 2001, applied a multidisciplinary and high resolution approach. The disciplines involved are nannopalaeontology, palynology, micropalaeontology, stable isotope geochemistry and sedimentology.

The present study, which are based on qualitative and quantitative analyses of planktic and benthic foraminiferids, aims to provide new information on the surface and bottom water conditions during the latest Cretaceous time interval. The detection and description of different microfaunal palaeoecological events, adds both to a better understanding of the Maastrichtian depositional environments in the southern Danish Central Graben (Rasmussen & Lassen 2004, this study), and to the development of a more detailed biostratigraphic scheme for the region. The present paper focusses on the latter issue, presenting palaeontological analyses of the foraminiferal faunas from the two wells, M10-X and E-5X, situated in the Dan and Tyra SE fields in the Danish North Sea (Figure 1).

Geological setting

The Dan Field is situated in the Southern Salt Dome Province of the Danish Central Graben. The Dan Field developed over a diapiric structure, which explains the generally circular structure. Upper Maastrichtian and Danian chalk thicknesses are highest in the southern and western part of the Dan Field reaching around 105 and 45 m, respectively (Scholle *et al.* 1998). The Tyra SE Field is situated in the Central Graben approximately 30 km NW of the Dan Field in the Southern Compression Zone Province (Oakman & Partington 1998). In this area, the structures were initially formed by the inversion of a major Jurassic halfgraben.

The Maastrichtian–Danian chalks from the Central Graben form the uppermost part of the Chalk Group, a thick succession of pelagic carbonates, which were deposited during the Late Cretaceous (Cenomanian–Danian). The chalks from the Central Graben consist of very fine-grained calcium carbonate derived from mainly coccoliths (*c.* 72%), foraminiferids and fragments of other calcareous organisms (Münzberger, cited in Surlyk 1972). These primarily basinal chalks form the deepest facies in the Maastrichtian and Danian marine environment of the present-day Danish offshore and onshore areas, but it has been suggested that the palaeodepth probably never exceeded a few hundreds of metres (Surlyk & Håkansson 1999). The southern Central Graben area was part of a huge epeiric shelf sea, which covered most of the present northern European area. It is suggested that the study area was situated more than 300 km from the nearest shore during the Maastrichtian (see palaeogeographical map by Ziegler 1990).

Previous work

Koch (1977) published a detailed foraminiferal study of the calcareous Upper Cretaceous succession of northwest Germany (Fig. 2), and introduced three foraminiferid zones for the Late Maastrichtian interval. His work was later incorporated in the comprehensive biozonation schemes of the North Sea area presented by King *et al.* (1989). They correlated the three Late Maastrichtian zones from North Germany with two foraminiferid zones of the Central North Sea. Hart *et al.* (1989) established an onshore counterpart based on sections in southern England. A link between the Central North Sea biozonation and a new biozonation established in the more northern areas of the Norwegian Sea was proposed by Gradstein *et al.* (1999).

The Danian planktic faunas of the present study have been correlated with the zonation scheme of Berggren & Miller (1988) which is based on planktic foraminiferids (Fig. 3). These workers established three zones and three subzones for the Danian time interval. The zonation scheme was further revised by Berggren *et al.* (1995) and Olsson *et al.* (1999). However, because these revisions (especially for the Pα Zone) are more relevant for studies in the Early Danian subtropical and tropical areas than the Boreal region, it has been decided to focus on the scheme by Berggren & Miller (1988) in the biostratigraphic correlations. A valuable foraminiferal zonation covering the whole of the Cenozoic period of the North Sea was published by King *et al.* (1989). The scheme, however, is less detailed for the Danian interval, such that the Berggren & Miller (1988) chart allows for a more detailed biostratigraphic subdivision of this period.

Material and methods

A total of 103 and 36 samples were taken from the cored sections of M-10X and E-5X respectively (see Appendix I for sample lists). The samples were cleaned, crushed and approximately 50 g of disintegrated sample were washed through sieves with a mesh size larger than 63 μm. The residue was dried and gravity-separated by use of heavy liquid with a specific gravity of 1.8 g/cm^3. The 63–500 μm fraction was split down to a manageable random sub-sample, and the planktic and benthic foraminiferal faunas were counted quantitatively; a minimum of 100 specimens were identified and picked from the fraction between 63 μm and 500 μm when possible, although in few instances this number was unattainable.

The variable fossil abundance in the samples has only allowed for quantitative data analysis in a number of the analysed samples. Samples with less than 30 foraminiferal specimens have not been used for P/B (planktic/benthic) ratio and biofacies calculations and samples with less than 15 benthic specimens have not been used to calculate the epifaunal/infaunal ratio. Thus, 67 samples from M-10X and 3 samples from E-5X were excluded from calculation of the epifauna/infauna ratio. In particular, the very tightly sampled interval between 6619.41´ and 6612.33´ in M-10X was characterised by a very low abundance of benthic foraminiferids. The P/B ratio is markedly lower in E-5X than in M-10X, which explains why relatively more samples could be used for statistical treatment from this well.

There have been several uncertainties related to the micropalaeontological analysis. The main problem has been to isolate the microfauna from the rock samples by crushing and washing. Due to the very hard and often diagenetically altered material, it has not been possible to process the samples completely and thus no estimates of the total number of foraminiferids per gram sediment have been made.

Secondly, the strong diagenetic fingerprint on the studied interval has resulted in overgrown foraminiferal tests. Thus, the taxonomic features are often blurred and for that reason, determination of especially small overgrown specimens has been limited to genus level.

In general, the foraminiferid abundance and number of species per sample determines the uncertainty of each species in the sample. Thus, low abundance causes high uncertainty that is further increased if the number of species is high. The latter is often the case in the benthic faunas whereas in the almost mono-specific planktic faunas it can be neglected.

Microfossil biostratigraphy of E-5X and M-10X

The foraminiferid zonation of the North Sea chalk facies proposed by King *et al.* (1989) has been applied to the studied sections covering the Upper Cretaceous interval. Despite the fact that this zonation is based on last occurrences (LO) rather than first occurrences (FO), the comprehensive range-charts and faunal descriptions made the zonation scheme a useful framework for the present study. The Danian zonation is based on the biozonation scheme of Berggren & Miller (1988).

Zone FCS23 (*Pseudotextularia elegans* Zone) (King *et al.* 1989)

Original definition:
Base is defined by the last occurrence of *Bolivinoides miliaris*, and top is defined by the last occurrence of *P. elegans*.

Emended definition:
Biostratigraphic interval between the LO of *B. miliaris* (as in the original definition), and the LO of Cretaceous taxa (keeled globotruncanids, *Rugoglobigerina, Globigerinelloides*, among others).

Faunal characteristics:
M-10X: The planktic foraminiferal assemblage is dominated by *Heterohelix globulosa* throughout the interval. Associated species are *Guembelitria cretacea* and *H. monmouthensis.*

The composition of the benthic foraminiferal assemblage varies significantly through the zone with respect to total abundance as well as species composition. The most abundant species are *Pyramidina minuta, Cibicidoides* spp., *Gavelinella* spp., *Praebulimina laevis* and occasionally *Stensioeina* ex. *gr. beccariiformis.*

Samples with remarkably low concentrations of planktic foraminiferids were sporadically found through the zone (less than 14 planktic specimens were counted). Two specific samples were characterised by a total lack of planktic foraminiferids (6491.50´ and 6499.00´ feet) whereas both a high diversity and abundance typified the benthic foraminiferal fauna of the two samples. However, the total abundance of benthic foraminiferids in the M-10X samples is usually lower than the abundance of planktic foraminiferids. In general, the abundance of the planktic foraminiferal fauna is independent of the abundance of the benthic fauna.

E-5X: *H. globulosa* dominates the planktic foraminiferal fauna throughout the zone, together with *H. monmounthensis* and *Globigerinelloides multispina*, the latter two showing lower relative abundance. The total abundance of planktic foraminiferids is relatively high in all the studied samples (average 70%) in contrast to the more patchy abundance of the benthic foraminiferal fauna. The benthic foraminiferal fauna is diverse and displays a highly variable composition through the zone. The most common benthic taxa include *Cibicides,*

Cibicidoides, *Osangularia navarroana, Praebulimina laevis, Bolivinoides draco, Gyroidinoides nitidus* and *S.* ex. gr. *beccariformis.*

Thickness:
M-10X: 6655.58´ (lowest sample examined) – 6440.50´
E-5X: 6975.17´ (lowest sample examined) – 6824.83´

Remarks: The lack of *B. miliaris* suggests that Zone FCS22 (*Bolivinoides miliaris* Zone) is missing in the studied intervals of both M-10X and E-5X.

Subzone FCS23a (*Bolivinoides draco* Subzone) (King *et al.* 1989)

Original definition:
Base is defined by LO of *B. miliaris*, and top by FO of *P. elegans.*

Faunal characteristics:
M-10X: The planktic foraminiferal assemblage is highly dominated by the genus *Heterohelix*. Only a few additional species are present, i.e. *Guembelitria cretacea, H. monmouthensis* and *Laeviheterohelix glabrans.*

The benthic foraminiferal assemblage is poorly represented, being characterised by few and sporadic occurrences of many different species. Although they were never abundant, *Gavelinella* sp., *Pyramidina minuta*, and less commonly, *Cibicidoides* spp. were observed throughout the subzone, representing the most numerous benthic species in this subzone. The average number of benthic species is lower than in the overlying subzone, although they were observed in relatively high numbers in a few intermittent levels.

E-5X: As in M-10X, *Heterohelix* dominates the planktic foraminiferal faunas of E-5X. The pattern, however, is less pronounced than in M-10X. Instead, the abundance of *G. multispina*, *H. monmounthensis* and *G. cretacea* are higher than in M-10X. The most abundant species in the benthic assemblage are *O. navarroana, Cibicides succedens* and *B. draco.*

Thickness:
M-10X: 6655.58´ (lowermost sample examined) – 6528.92´
E-5X: 6975.17´ (lowermost sample examined) – 6889.33´

Remarks: Subzone FCS23a correlates with two zones of Koch (1977) from northern Germany, namely the *Gavelinella danica* Zone and the *Bolivinoides draco draco* Zone. These two zones are principally defined by the presence of *B. draco draco* (here *Bolivinoides draco*) and the appearance of *Gavelinella danica.* However, in the M-10X core, the presence of *B. draco* is restricted to three specimens in one sample below the *P. elegans* Subzone while *Gavelinella* danica has only been observed within the overlying *P. elegans* Subzone. Thus, it is not possible to further subdivide Subzone FCS23a in M-10X.

B. draco is more frequent in E-5X, but in this well *G. danica* only occurs in one sample (6963.17´). The interval in M-10X between 6647´and 6612.33´ that is characterised by high

P/B ratios was not found in E-5X. This suggests that the cored section in E-5X does not extend down into the lower part of FCS23a, as seen in M-10X.

Subzone FCS23b (*Pseudotextularia elegans* Subzone) (King *et al.* 1989)

Original definition:
Base defined by FO of *P. elegans*. Top is defined by LO of *P. elegans*.

Emended definition:
Biostratigraphic interval between the FO of P. elegans and the LO of Cretaceous taxa (keeled globotruncanids, *Rugoglobigerina, Globigerinelloides*, among others).

Faunal characteristics:
M10X: *P. elegans* occurs sporadically in low numbers through the subzone while *L. glabrans* appears only in the upper part. Only a few benthic species are restricted or mainly restricted to subzone FCS23b i.e. *Stensioeina pommerana, P. laevis, G. danica* and *Cibicidoides velascoensis*.

E-5X: The occurrence of *P. elegans* and *Globigerinelloides asperus* characterises this subzone. *Abathomphalus mayaroensis* and *Pseudoguembelina hariaensis* appears in small numbers in the uppermost part of the subzone. The benthic faunas in Subzone FCS23b show only minor differences from the underlying subzone, but *S. pommerana* is restricted to this subzone in E-5X.

Thickness:
M-10X: 6525.25′ – 6441.92′
E-5X: 6883.92′ – 6824.83′

Remarks: This subzone corresponds to the *P. elegans* Zone of Koch (1977). It should be noted that the zonal taxon *P. elegans* disappears below the top of the Zone in M-10X (above 6446.50′).

In the southern North Sea, *P. elegans* and *A. mayaroensis* display similar stratigraphic ranges in the Upper Maastrichtian (Hart *et al.*, 1989). However, *A. mayaroensis* is restricted to the uppermost part of the *P. elegans* Subzone in E-5X and is not found at all in M-10X.

Mixed Interval

Definition: This interval is added to the formal biostratigraphic scheme due to the lack of criteria to fulfil the definitions of the over- and underlying biostratigraphic zones.

Hence, this interval is defined by the presence of both Cretaceous and Danian species. The top of the Mixed Interval is the hardground surface capping the Uppers Maastrichtian Tor Formation (the "Maastrichtian hardground"). The complex mixed Maastrichtian – Danian fauna and flora is discussed in Ineson *et al.* (2004, this study).

Each of the samples within this zone is described separately below.

M-10X

Faunal characteristics:
6440.50´
The planktic foraminiferal fauna is dominated by *H. globulosa* together with *H. monmouthensis*. In addition to the Maastrichtian species, two Danian species appear, i.e., *Chiloguembelina morsei* and *Globoconusa daubjergensis*. The Danian component amounts to less than 10% of the total planktic fauna. No benthic foraminiferids were observed.

6439.41´
This sample is composed solely of a Danian planktic foraminiferal fauna dominated by *Heterohelix* and/or *Chiloguembelina*. The two genera are often partly covered by minute sediment grains, which makes it difficult or impossible to distinguish between them. Additional species are *Parasubbotina pseudobulloides*, *Parasubbotina* cf. *varianta, Subbotina trivialis* and *Eoglobigerina eobulloides.* The Danian assemblage in this sample is assigned to Subzone P1a. As in the underlying sample, no benthic foraminiferids were observed.

Thickness: 6440.50´ – 6439.41´

E-5X

Faunal characteristics:
6823.33´
The planktic foraminiferids in this sample consist of a mixture of Maastrichtian (*H. globulosa* and *P. elegans*) and Danian (*Subbotina triloculinoides* and *G. daubjergensis*) components. The Maastrichtian species comprise twice as much of the fauna as the Danian species.

6821.08´
Danian species dominate the planktic foraminiferal fauna, comprising more than 60%. The most abundant Danian species are *G. daubjergensis, P.* cf. *varianta* and *S. triloculinoides* whereas *H. globulosa* and *H. monmouthensis* form the Maastrichtian component.

6820.00´
This sample contains a pure Danian planktic foraminiferal fauna with a dominance of *G. daubjergensis*. Accompanying species are *E. eobulloides, P. pseudobulloides* and *P.* cf. *varianta*. The assemblage contains elements from the Danian subzones P1a and P1b.

Thickness: 6823.33´ - 6820.00´

Remarks: The Tor – Ekofisk boundary is placed at the level of a distinctive hardground surface in both wells. Evidence of extensive bioturbation related to the formation of this hardground has been recorded (Ineson *et al.*, 2004, this study). The mixture of Maastrichtian and Danian taxa in the levels below this boundary is suggested to have resulted from Danian fill of extensive open burrows systems within the top – Maastrichtian hardground.

Zone P1 (*Parasubbotina pseudobulloides – Globoconusa daubjergensis* Zone)

Original definition: Concurrent partial ranges of the nominate taxa between the initial appearance of *P. pseudobulloides* (base) and the initial appearance of *Morozovella uncinata* (Berggren & Miller 1988).

Faunal characteristics:
M-10X: The Danian planktic fauna is much more diverse than the Cretaceous survivor species and reworked species, with more species occurring in high numbers. The dominant species through the zone are mainly the group of *Heterohelix* spp./*C. morsei and P. pseudobulloides*. The abundance of planktic specimens is relatively high with the exception of the sample at 6439.33′ whereas the benthic abundance show the opposite pattern with a generally low level except at 6436.33′ and 6439.00′. *O. navarroana, Bolivinoides peterssoni* and *C. velascoensis* dominate the benthic fauna in these levels.

E-5X: The planktic foraminiferal fauna is characterised by *G. daubjergensis* and to a lesser extent *P.* cf. *varianta*. *Chiloguembelina* spp. is only found in low numbers in E-5X. The abundance and diversity of benthic foraminiferids is low with *O. navarroana* and *Cibicidoides* spp. as the most frequent taxa.

Thickness:
M-10X: 6439.33′ – 6433.58′ (uppermost sample examined)
E-5X: 6817.58′ – 6809.25′ (uppermost sample examined)

Remarks: The basal Danian zones P0 and Pα are not recognised due to the lack of *Parvularugoglobigerina eugubina* in both wells. Thus, the presence of a hiatus is suggested.

Subzone P1a (*Parasubbotina pseudobulloides* Subzone)

Original definition: Partial range of the nominate taxon between its initial appearance (base) and that of *Subbotina triloculinoides* (Berggren & Miller 1988).

Faunal characteristics:
The planktic fauna is rather homogenous comprising *Heterohelix* spp./*C. morsei, P. pseudobulloides, E. eobulloides, G. daubjergensis* and *P.* cf. *varianta*. The benthic fauna is characterised by low abundance and only one sample contained more than 30 individuals (at 6439.00′). The fauna in this sample is dominated by *O. navarroana, Bolivinoides peterssoni, S.* ex. gr. *beccariiformis* and *Cibicidoides velascoensis*.

Thickness:
M-10X: 6439.33′ – 6436.83′

Remarks: The zone was not observed in E-5X, although it cannot be excluded that it may occur between the 6820' and 6817.58′ samples.

Subzone P1b (*Subbotina triloculinoides* Subzone)

Original definition: Partial range of nominate taxon from its initial appearance (base) to the initial appearance of *Morozovella trinidadensis* (Berggren & Miller 1988).

Emended definition: Interval beween the FO of *Subbotina triloculinoides* and the FO of *Globanomalina compressa* (after Berggren 1969; high latitudes)

Faunal characteristics:
M-10X: The faunal compositions in Subzone P1b is very similar to the pattern in Subzone P1a except for the appearance of *Subbotina trivialis* at 6436.33´. The benthic fauna is also comparable with the underlying subzone. However, slight differences are seen with the appearance of *Brizalina incrassata* (possibly reworked), *Paralabamina lunata* and *Stilostomella* spp. The relative abundance of *S.* ex. gr. *beccariiformis* is lower than in Subzone P1a.

E-5X: *G. daubjergensis, P.* cf. *varianta* and *E. eobulloides* dominate the planktic foraminiferal fauna. The occurrence of *S. triloculinoides* assigns this level to Subzone P1b. The benthic foraminiferal fauna is comprised by *B. pettersoni, Cibicides* spp. and *O. navarroana.*

Thickness:
M-10X: 6436.33´ - 6433.58´ (uppermost sample examined)
E-5X: 6817.58´

Remarks: It is noted that *P.* cf. *varianta* occurs in Subzone P1a and P1b in M-10X and in P1b in E-5X although *P. varianta* sensu stricto initiates in the overlying Subzone P1c according to Olsson et al., (1999). It is possible that *P.* cf. *varianta* displays a wider stratigraphic range in this high latitude area than nearer to equator.

Subzone P1c (*Morozovella trinidadensis – Planorotalites compressus* Subzone)

Original definition: Concurrent partial range of the nominate taxa between the initial apperance of *M. trinidadensis* (base) and the initial appearance of *M. uncinata* (top) (Berggren & Miller 1988).

Emended definition: Interval between the FO of *Globanomalina compressa* and FO of *Praemurica uncinata* (after Berggren 1969; high latitudes).

Faunal characteristics:
G. daubjergensis dominates the planktic foraminiferal fauna, accompanied mainly by *P.* cf. *varianta* and *P. pseudobulloides*. The benthic foraminiferal fauna is mainly composed by *O. navarroana* and *Cibicides* spp.

Thickness:
E-5X: 6817.58´ – 6809.25´

Remarks: The P1c Subzone was not observed in M-10X, probably because of a lack of analysed samples from this interval.

Correlation of wells

The Upper Maastrichtian interval is represented in both wells comprising the two Subzones FCS23a and FCS23b. Both subzones are thicker in M-10X than in E-5X. Subzone FCS23a is 126.66′ thick (minimum) in M-10X and only 85.84′ (minimum) in E-5X whereas Subzone FCS23b is 83.33′ in M-10X and only 59.09′ in E-5X. The interval with very high P/B ratios (generally >90%) in M-10X (between 6647.00′ and 6612.33′) was not observed in E-5X, suggesting that this interval is missing in the latter well (see Appendix IIIa and Rasmussen & Lassen 2004, this study).

An unconformity separates the Maastrichtian deposits from the Danian, marked by the presence of a hardground. Evidence of extensive bioturbation related to the formation of the hardground is found and the mixture of Maastrichtian and Danian taxa in the interval named the Mixed Interval probably resulted from Danian fill of open burrow systems in the top – Maastrichtian hardground. This complex biostratigraphic interval is found in both wells and comprises 1.09′ and 3.33′ in M-10X and E-5X, respectively.

A lowermost Danian hiatus spanning the P0 and Pα zones is recorded from both wells. In addition, Subzone P1a is apparently also missing in E-5X (or it is situated within the 6820'–6817.58' interval) whereas M-10X comprises Subzone P1a (2.5′) and P1b (min 2.75′, last sample analysed). The latter Subzone is only represented in E-5X by one sample. Subzone P1c overlies subzone P1b in E-5X with a minimum thickness of 3.16′.

Additional biostratigraphic markers have been found based on the quantitative analyses of the foraminiferal faunas and these have been found useful for correlation between the two wells. Thus, three acmes of *P. elegans* occur within Subzone FCS23b. In M-10X, these acmes are found at the following levels: 6519.14′, 6481.00′ and 6446.50′. The corresponding levels in E-5X are: 6883.92′, 6847.83′, 6833.50′. In addition, two correlative acmes of *P. laevis* were observed in both wells. The lowermost was found just below the base of Subzone FCS23b in E-5X at 6897.92′ and just above Subzone FCS23a in M-10X at 6522.58′. The upper acme of *P. laevis* is within Subzone FCS23b between 6869.33′ and 6859.83′ in E-5X and between 6495.60′ and 6491.50′ in M-10X.

Correlation with other biostratigraphic zonations

Correlation with the zonation of Stenestad (1971)

Stenestad (1971) established a Late Cretaceous biozonation for the Danish onshore area based on both planktic and benthic foraminiferids from the Rønde-1 well in Jutland. The Upper Maastrichtian succession was subdivided into the *Pseudouvigerina cimbrica* (lowest), *Pseudouvigerina rugosa, Pseudotextularia elegans* and *Stensioeina esnehensis* (uppermost) zones. Of these zones, only the *P. elegans* is recognised with certainty in E-5X and M-10X. Stenestad (1971) regarded the *P. elegans* Zone as the interval between the first downhole occurrence of the nominate species and *Raceguembelina fructicosa*, and the level where *P. rugosa* is common. Although *P. rugosa* is much more uncommon in E-5X and M-10X than in Rønde-1, it is assumed that the *P. elegans* of Stenestad (1971) correlates roughly with FCS23b of the present study.

Correlation with the zonation of Malmgren (1981)

Malmgren (1981) erected a new Maastrichtian biozonation based on planktic foraminiferids from drill-cores in southern Sweden. He named the upper >200 m succession of Maastrichtian chalk the *Heterohelix striata – Globigerinelloides multispina* Zone, which was further subdivided into four subzones named (from the top) the *P. elegans – R. fructicosa* Subzone, *Rugoglobigerina rugosa* Subzone 1, *R. rugosa – R. rugosa* Interval Subzone and *Rugoglobigerina rugosa* Subzone 2. The lowermost subzone (*R. rugosa* Subzone 1) was defined by the dominance of *R. rugosa* together with a *Globigerinelloides/Heterohelix* ratio above 0.5. The overlying *R. rugosa – R. rugosa* Interval Subzone was characterised by the lack of *R. rugosa*, while the next following *R. rugosa* Subzone 1 was defined by the dominance of *R. rugosa* together with a *Globigerinelloides/Heterohelix* ratio below 0.5. The uppermost subzone (*P.elegans – R. fructicosa* Subzone) was characterised by the presence of the *P.elegans – R. fructicosa* complex.

R. rugosa was only found in one sample (from the Mixed Interval in M-10X) and thus *the R. rugosa* Subzone 1 is not present in the studied interval from E-5X and M-10X. The uppermost Maastrichtian *P. elegans – R. fructicosa* Subzone correlates with FSC23b in the present study based on the presence of *P. elegans*.

Four acmes of the *P. elegans – R. fructicosa* complex were identified within the *P. elegans – R. fructicosa* Subzone by Malmgren (1981). It is suggested that the three acmes of *P. elegans* distinguished in E-5X and M-10X correlate with three of the four acme events in the D-104 well reported by Malmgren (1981), but precise correlation between the two regions cannot be made from the present data.

Correlation with the zonation of Bergen & Sikora (1999)

Bergen & Sikora (1999) defined two zones (NCF2 and NCF1) for the late – early Maastrichtian succession within the southern Norwegian North Sea sector. The lower boundary of Zone NCF2 (*Rugoglobigerina pennyi* zone) was defined from the LO of *Globotruncana lapparenti* and/or *Globotruncana linneiana* and the top of the zone by the LO of *Globotruncana fornicata*. A further subdivision was made from LO of *Bolivinoides miliaris*. NCF2 correlate to the lower part of FCS23a (King *et al.*, 1989). The latter zone is defined in both wells of this study, though the species used for the zonation of the Norwegian area are not found in this study. Only a few keeled globotruncanid specimens were observed in the present study and only from E-5X.

The overlying zone, the *Pseudotextularia elegans* Zone (NCF1) was defined as the interval between the last appearance of the keeled *Globotruncana fornicata* and the last appearance of *Pseudotextularia elegans* and *Racemiguembelina fructicosa* with a further subdivision based on the last appearance of *Abathomphalus intermedia*. Zone NCF1 correlates with the upper part of FCS23a and all of FCS23b of King *et al.* (1989). *A. intermedia* and *G. fornicata* were not found in the present study, whereas *P. elegans* occurs in both wells and defines Subzone FCS23b. Thus, NCF1 correlates partly with Zone FCS23b of this study. Due to the general lack of the key globotruncanid species, further correlation is not possible.

Correlation with the zonation of Gradstein *et al.* (1999)

Gradstein *et al.* (1999) established a Cretaceous biozonation for the area offshore mid Norway based on optimum sequences of mainly foraminiferids. They established one zone for the Late Maastrichtian interval, the *Pseudotextularia elegans* Zone. The *P. elegans* Zone was defined on the presence of the nominate species. The zone was typified by a foraminiferal assemblage similar to that observed in the FCS23b Subzone of the present study (e.g. *P. elegans*, *B. incrassata*, *Heterohelix* and *Hedbergella* including *H. monmouthensis*) and correlates with this subzone.

An acme of *Rugoglobigerina rugosa* and/or *Globigerinelloides volutus* (between 50% and 90%) was reported from the lower part of the *Pseudotextularia elegans* Zone.

Dominance of *Globigerinelloides* (*G. multispina*) was found in one sample in E-5X (6897.92′) where it constitutes around 40% of the total planktic foraminiferal fauna. However, the occurrence in this well below Zone FCS23b and the different species question the correlation between the two acmes events.

References

Bergen, J.A. & Sikora, P.J. 1999: Microfossil diachronism in southern Norwegian North Sea chalks: Valhall and Hod fields. In: Jones, R.W. & Simmons, M.D. (Eds.), Biostratigraphy in Production and Development Geology. Geological Society Special Publication **152**, 85–111.

Berggren, W.A. 1969: Rates of evolution in some Cenozoic planktonic foraminifera. Micropaleontology 15, 351–365.

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

Berggren, W.A., Kent, D., Swisher, C.C. & 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 Stratigraphy Correlation. SEPM Spec. Publ. **54**, 129–212.

Gradstein , F.M., Kaminski, M.A. & Agterberg, F.P. 1999: Biostratigraphy and paleoceanography of the Cretaceous seaway between Norway and Greenland. Earth-Science Reviews **46**, 27–98.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., Graciansky, P.-C. De & Vail, P.R. 1998: Mesozoic and Cenozoic sequence chronostratigraphic framework of European Basins. In: Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., Graciansky, P.-C. De & Vail, P. R. (Eds), Mesozoic and Cenozoic sequence chronostratigraphic framework of European Basins. Society of Economic Paleontologists and Mineralogists Special Publication **60**, 1–13.

Hart, M.B., Bailey, H.W., Crittenden, S., Fletcher, B.N., Price, R.J. & Swiecicki, A. 1989: Cretaceous. In: Jenkins, D.G. & Murray, J.W. (Eds.), Stratigraphical atlas of fossil foraminifera. British Micropalaeontological Society Series. Ellis Horwood Limited, 273–371.

Ineson, J.R., Buchardt, B., Lassen, S., Rasmussen, J.A., Schovsbo, N.H., Schiøler, P. & Sheldon, E. 2004: Integrated Upper Maastrichtian stratigraphy, Danish Central Graben, Danmarks og Grønlands Geologiske Undersøgelse Rapport 2004/80.

King,C., Bailey, H.W., Burton, C.A. & King, D. 1989: Cretaceous of the North Sea. In: Jenkins, D.G. & Murray, J.W. (Eds.) Stratigraphical atlas of fossil foraminifera. British Micropalaeontological Society Series. Ellis Horwood Limited, 372–417.

Koch, W. 1977: Biostratigraphie in der Oberkreide und Taxonomie von Foraminiferen. Geol. Jb. **A 38**, 11–123, 17 plates.

Li, L., Keller, G. & Stinnesbeck, W. 1999: The Late Campanian and Maastrichtian in northwestern Tunisia: palaeoenvironmental inferences from lithology, macrofauna and benthic foraminifera. Cretaceous Research **20**, 231–252.

Malmgren, B. 1981: Biostratigraphy of planktiv Foraminifera from the Maastrichtian white chalk of Sweden. Geologiska Föreningens i Stockholm Förhandlingar, **103**, 357–375.

Oakman, C.D. & Partington, M.A. 1998: Cretaceous. In: Glennie, K.W. (Ed.), Petroleum Geology of the North Sea, Basic Concepts and Recent Advances. Blackwell Science, 294–349.

Olsson, R.K., Hemleben, C., Berggren, W.A., Huber, B.T. (Eds.), 1999: Atlas of Paleocene Planktonic Foraminifera. Smithsonian Contributions to Paleobiology No. **85**., 252 pp., 71 plates.

Rasmussen, J.A. & Lassen, S. 2004: Foraminiferal palaeoecology of the Upper Maastrichtian, Danish Central Graben. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2004/88.

Scholle, P.A., Albrechtsen, T. & Tirsgaard, H. 1998: Formation and diagenesis of bedding cycles in uppermost Cretaceous chalks of the Dan Field, Danish North Sea. Sedimentology **45**, 223–243.

Stenestad, E. 1971: Øvre Kridt i Rønde nr. 1 (307-1985 M). In: Rasmussen, L.B., Dinesen, A., Henriksen, S.E., Bang, I., Stenestad, E., Buch, A., Christensen, O.B., Michelsen, O. & Jacobsen, F.L. (Eds.), Dybdeboringen Rønde nr. 1 på Djursland. Resultaterne af de geologiske undersøgelser. Geological Survey of Denmark, III series **39**, 53–60.

Surlyk, F. 1972: Morphological adaptions and population structures of the Danish chalk brachiopods (Maastrichtian, Upper Cretaceous). Det Kongelige Danske Videnskabernes Selskab Biologiske Skrifter, **19** (2), 57 pp.

Surlyk, F. 1997: A cool-water carbonate ramp with bryozoan mounds: Late Cretaceous-Danian of t he Danish basin. In: James, N.P. & Clarke, J.A.D. (Eds.) Cool-water carbonates. SEPM Spec. Publ. **56**, 293–307.

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.

Ziegler, P.A. 1990: Geological Atlas of Western and Central Uerope. Geologcial Society, Bath (distributors), Shell International Petroleum Maatshappij BV, 239 pp.

Ødum, H. 1926: Studier over Daniet i Jylland og på Fyn. Danmarks Geologiske Undersøgelse Serie 2 **45**, 306 pp.

Figures

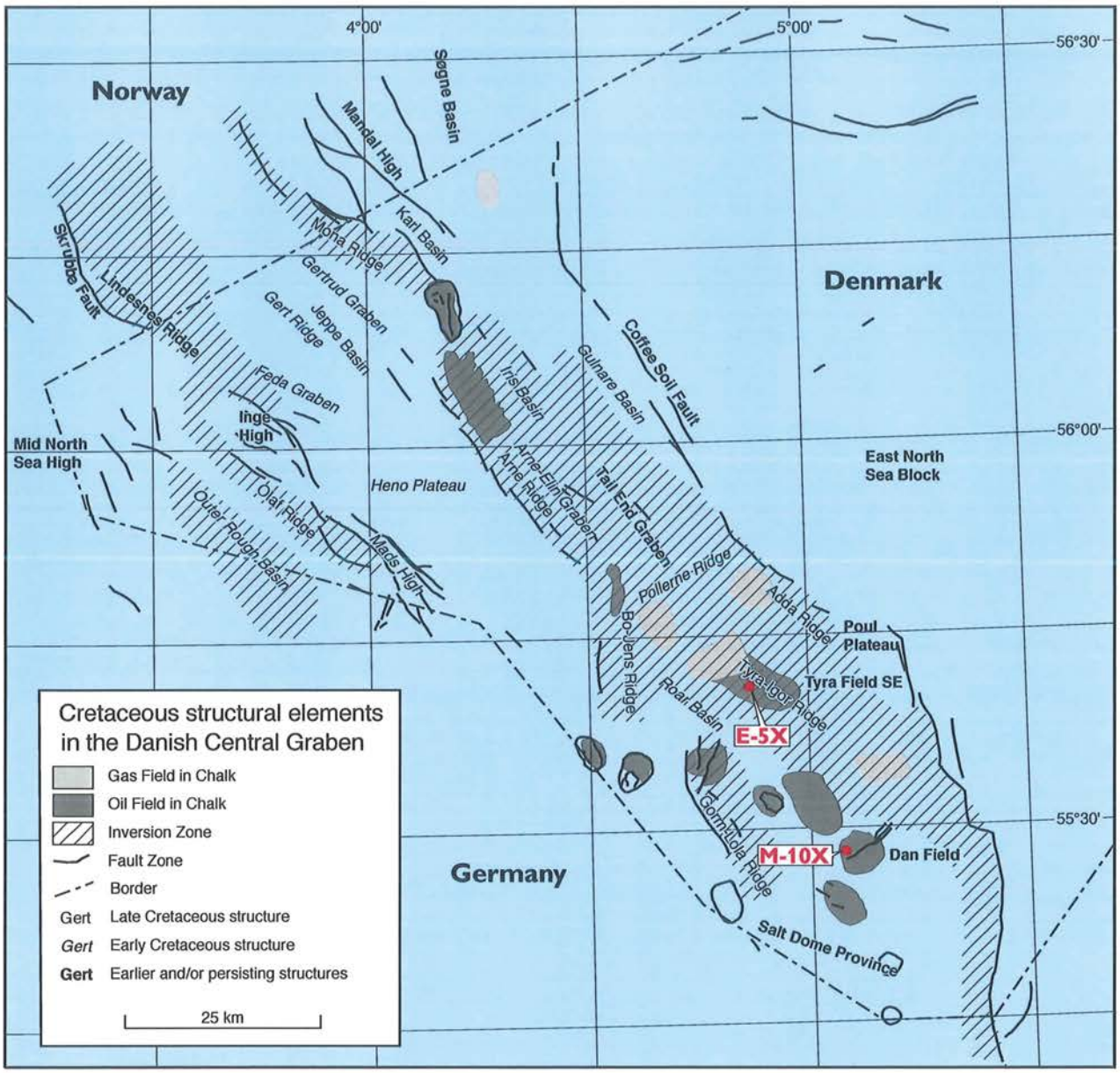

Figure 1: Location of the Dan and Tyra Fields in the Central Danish Graben. The positions of the two wells, M-10X and E -5X, are shown.

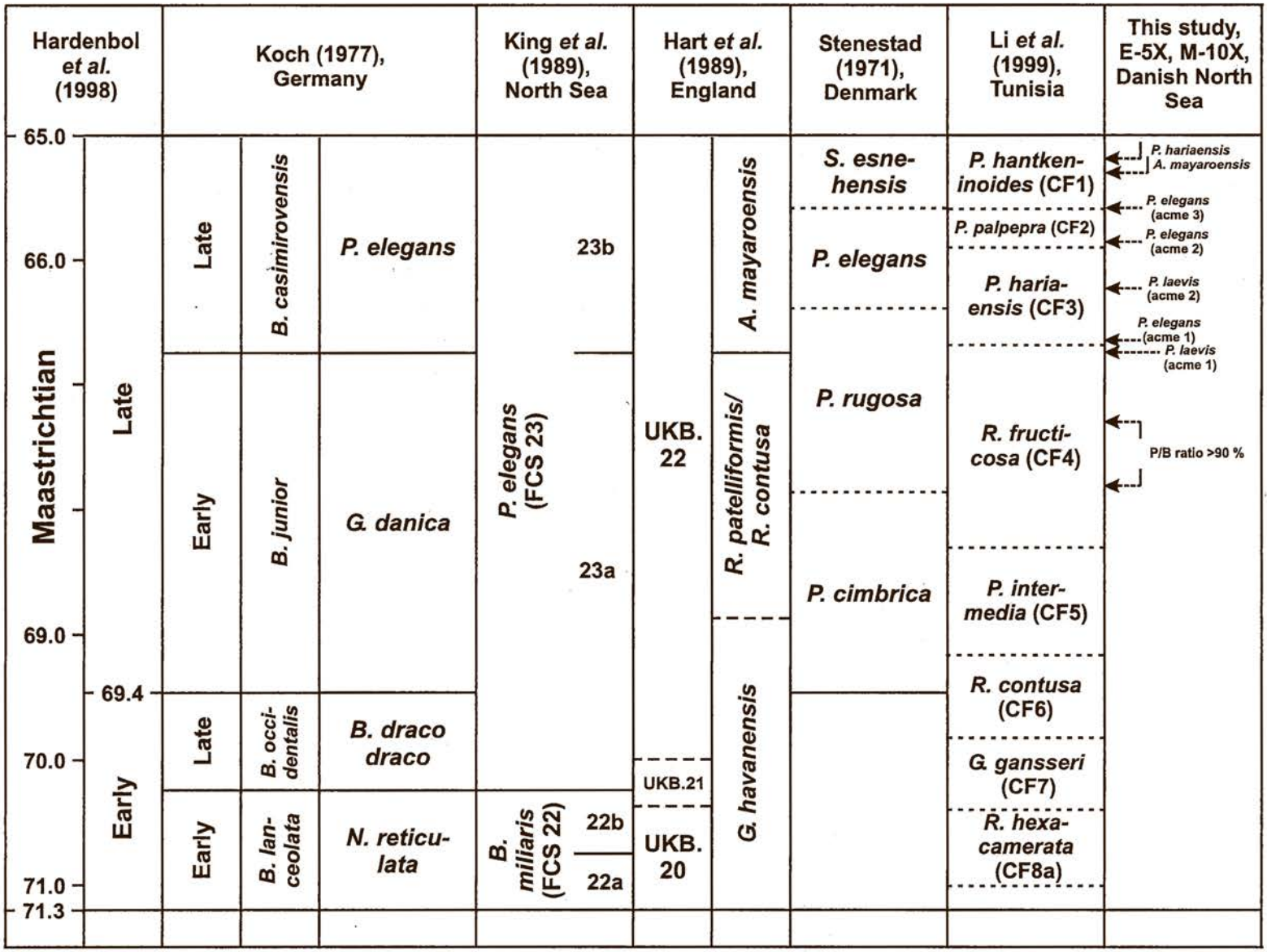

Fig. 2. Maastrichtian foraminiferal biostratigraphy and chronostratigraphy.

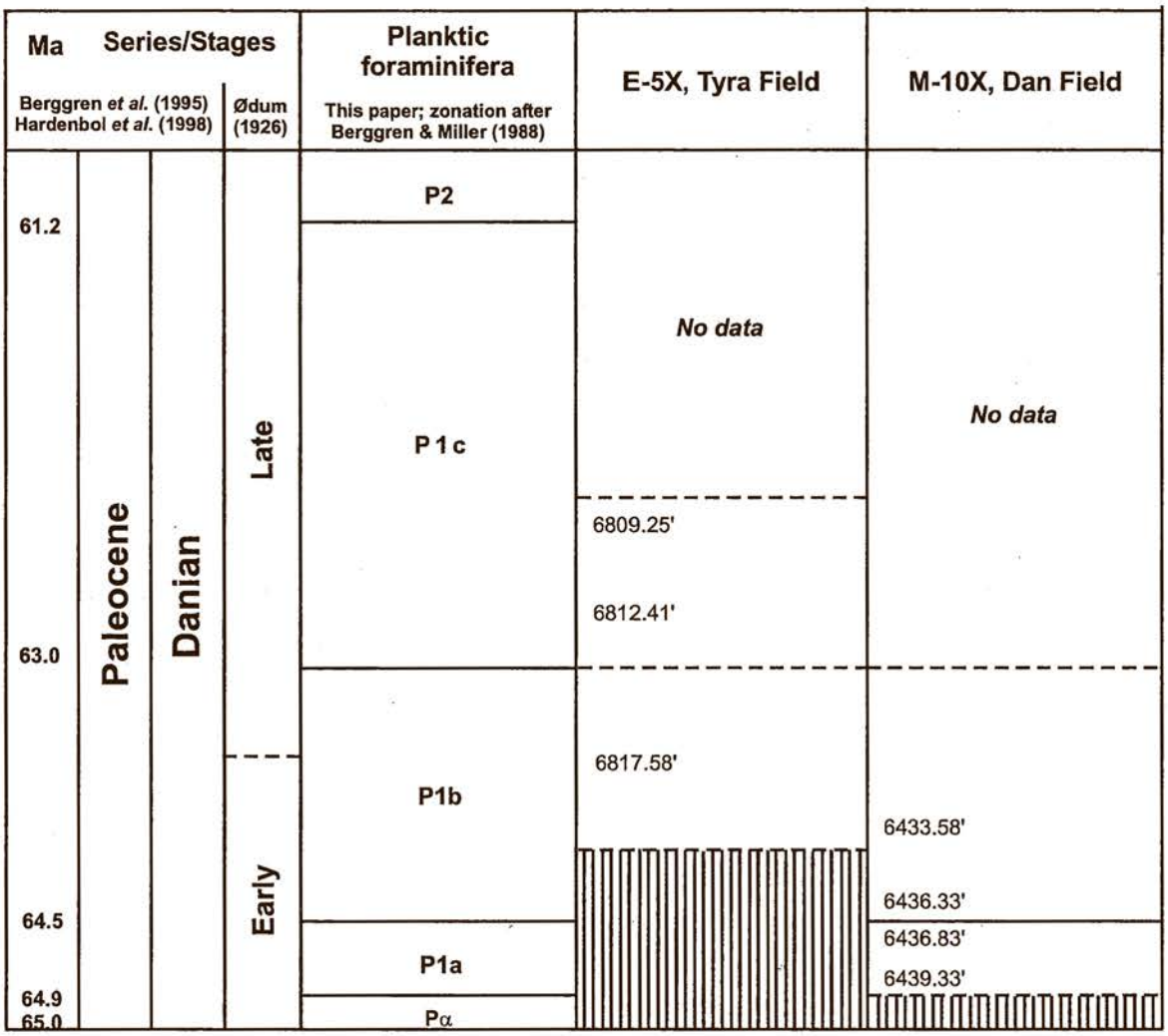

Fig. 3. Biostratigraphy and chronostratigraphy of the early Danian interval of E-5X and M-10X.

Appendix I: Sample lists

M-10X

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

6433.58	6511.50	6614.08
6434.58	6514.50	6614.41
6436.33	6516.65	6614.75
6436.83	6519.41	6615.00
6438.17	6522.25	6615.33
6438.83	6525.25	6615.58
6439.00	6528.92	6615.92
6439.33	6531.00	6616.25
6440.50	6533.17	6616.58
6441.92	6539.92	6617.17
6443.41	6542.58	6617.58
6444.83	6546.41	6618.00
6446.50	6552.25	6618.41
6448.17	6554.83	6618.58
6449.50	6557.58	6619.00
6451.83	6560.75	6619.41
6454.33	6563.41	6623.00
6456.75	6564.66	6626.41
6458.17	6568.25	6629.33
6460.00	6571.17	6631.66
6463.00	6573.66	6634.41
6465.25	6577.08	6637.33
6467.66	6579.83	6641.00
6472.33	6582.58	6644.00
6475.17	6586.25	6647.00
6477.00	6590.00	6648.50
6481.00	6592.17	6652.58
6483.83	6598.50	6655.58
6487.25	6601.58	
6489.50	6604.92	
6491.50	6608.08	
6495.60	6610.00	
6499.00	6611.58	
6502.33	6612.33	
6503.25	6612.66	
6505.08	6613.08	
6507.66	6613.50	

E-5X

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

6809.25
6812.41
6817.58
6820.00
6821.08
6823.33
6824.83
6826.66
6827.92
6830.00
6833.50
6836.83
6839.25
6841.92
6845.83
6847.83
6859.83
6863.33
6869.33
6875.33
6878.58
6881.41
6883.92
6889.33
6894.00
6897.92
6910.25
6916.33
6920.75
6926.58
6941.17
6950.41
6956.83
6963.17
6968.58
6975.17

Appendix II: Species lists

Benthic species

Agglutinated spp.
Alabamina ex gr. *Limbata*
Alabamina midwayensis
Alabamina cf. *midwayensis*
Ammodiscus cretaceus
Ammodiscus spp.
Angulogavelinella avnimelechi
Anomalinoides spp.
Aragonia aff. *ouezzanensis*
Aragonia velascoensis
Bathysiphon spp.
Bolivinoides draco
Bolivinoides cf. *draco*
Bolivinoides giganteus
Bolivinoides paleocenicus
Bolivinoides peterssoni
Bolivinoides spp.
Brizalina cf. *decurrens*
Brizalina decurrens
Brizalina incrassata
Brizalina cf. *incrassata*
Brizalina spp.
Brozenella acuta
Brozenella welleri
Bulimina? paleocenica
Calcareous benthic foraminifera indeterminata
Calcareous benthic foraminifera inderterminata trochospiral
Calcareous benthic indeteterminata epifaunal
Calccareous benthic indeterminata infaunal
Cibicides aff. *burlingtonensis*
Cibicides cf. *simplex*
Cibicides mariae
Cibicides spp.
Cibicides succedens
Cibicides cf. *succedens*
Cibicides velascoensis
Cibicides cf. *velascoensis*
Cibicidoides alleni
Cibicidoides cf. *alleni*
Cibicidoides involutus
Cibicidoides sp. A
Cibicidoides spp.
Coleites reticulosus

Coryphostoma limonense
Coryphostoma plaita
Coryphostoma spp.
Dentalina catenula
Dentalina alternata
Dentalina cf. *alternata*
Dentalina spp.
Dorothia spp.
Ellipsodimorphina divergens
Ellipsoidella gracillima
Eouvigerina hispida
Eouvigerina sculptura
Eouvigerina spp.
Eponides sp.
Eponides spp.
Fissurina laticarinata
Fissurina spp.
Frondicularia spp.
Fursenkoina tegulata
Gaudryina spp.
Gavelinella danica
Gavelinella cf. *danica*
Gavelinella laevigata
Gavelinella nacatochensis
Gavelinella pertusa
Gavelinella sp. A
Gavelinella spp.
Gavelinella whitei
Gavelinopsis bembix
Gen. et sp. indet. A
Globorotalites micheliniana
Globorotalites spp.
Globorotalites subconicus
Guttulina spp.
Guttulina trigonula
Gyroidinoides nitidus
Gyroidinoides octocamerata
Gyroidinoides sp. A
Gyroidinoides spp.
Karrerulina conversa
Lagena acuticosta
Lagena amphora
Lagena cf. *sulcatiformis*
Lagena geometrica
Lagena isabella
Lagena paucicostata
Lagena semiinterrupta

Lagena sphaerica
Lagena spp.
Lenticulina mundus
Lenticulina spp.
Lenticulina macrodiscus
Lenticulina spp.
Lenticulina triangularis
Lenticulina pseudocultrata
Lenticulina cf. *pseudocultrata*
Lenticulina cf. *velascoensis*
Lenticulina inhabilis
Lenticulina spp.
Loxostomum sp.
Melonis spp.
Neoflabellina reticulata
Neoflabellina rugosa
Neoflabellina spp.
"Nodosaria" sp.
Nodosaria spp.
Nonionella spp.
Nuttallinella spp.
Orbignyna spp.
Osangularia cf. *cordieriana*
Osangularia navarroana
Osangularia cf. *navarroana*
Osangularia spp.
Paralabamina lunata
Paralabamina sp. A
Planularia liebusi
Pleurostomella subnodosa
Praebulimina cf. *reussi*
Praebulimina laevis
Praebulimina spp.
Praebulimina? sp. A
Praebulimina? sp. B
Praebulimina? spp.
Pseudonodosaria proboscidea
Pseudonodosaria pseudoscripta
Pseudonodosaria spp.
Pseudouvigerina cimbrica
Pseudouvigerina cristata
Pseudouvigerina rugosa
Pullenia cretacea
Pullenia jarvisi
Pullenia quaternaria
Pullenia sp. A
Pullenia spp.

Pyramidina cimbrica
Pyramidina minuta
Pyramidina spp.
Pyrulina cylindroides
Pyrulina spp.
Pyrulinoides acuminatus
Quadrimorphina allomorphinoides
Reussoolina apiculata
Reussoolina simplex
Rhabdammina spp.
Rosalina spp.
Saracenaria cf. *triangularis*
Spiroplectammina spp.
Spirrilina spp.
Spirrillina subornata
Stensioeina ex. gr. *beccariformis*
Stensioeina pommerana
Stensioeina spp.
Stilostomella spp.
Tappanina selmensis
Vaginulina spp.
Vaginulina trilobata
Vaginulinopsis sp.

Planktic species
Eoglobigerina eobulloides
Globanomalina compressa
Globigerinelloides asperus
Globigerinelloides cf. *asperus*
Globigerinelloides multispina
Globoconusa daubjergensis
Globotruncana arca
Globotruncana spp.
Globotruncanella havanensis
Guembelitria cretacea
Hedbergella monmouthensis
Heterohelix complanata
Heterohelix dentata
Heterohelix globulosa
Heterohelix cf. *globulosa*
Heterohelix punctulata
Heterohelix spp.
Heterohelix spp./*Chiloguembelina morsei*
Laeviheterohelix glabrans
Parasubbotina pseudobulloides
Parasubbotina cf. *varianta*
Parvularugoglobigerina? spp.

Planktic foraminifera indeterminata
Planktic foraminifera trochospiral
Praemurica spp.
Praemurica taurica
Pseudoguembelina hariaensis
Pseudotextularia elegans
Racemiguembelina fructicosa
Rugoglobigerina rugosa
Rugoglobigerina spp.
Subbotina spp.
Subbotina triloculinoides
Subbotina trivialis
Subbotina cf. *trivialis*

Appendix III: Data sets

IIIa M-10X: Total abundance of planktic and benthic foraminiferids

IIIb E-5X: Total abundance of planktic and benthic foraminiferids

Appendix IIIa. Total abundance of planktic and benthic foraminifera in M-10X.

M-10X Sample depth (feet)	6433,58	6434,58	6436,33	6436,83	6438,17	6438,83	6439,00	6439,33	6440,50	6441,92	6443,41	6444,83	6446,50	6448,17	6449,50	6451,83	6454,33	6456,75	6458,17	6460,00	6463,00	6465,25	6467,66	6472,33	6475,17	6477,00	6481,00	6483,83	6487,25	6489,50	6491,50	6495,60	6499,00	6502,33	6503,25	6505,08	6507,66	6511,50	6514,50	6516,65	6519,14	6522,25	6525,25	6528,92	6531,00	6533,17	6539,92	6542,58	6546,41	6552,25	6554,83	6557,58	6560,75	6563,41	6564,66	6568,25	6571,17	6573,66	6577,08	6579,83	6582,58	6586,25	6590,00	6592,17	6598,50	6601,58	6604,92	6608,08	6610,00	6611,58	6612,33	6612,66	6613,08	6613,50	6614,08	6614,41	6614,75	6615,00	6615,33	6615,58	6615,92	6616,25	6616,58	6617,17	6617,58	6618,00	6618,41	6618,58	6619,00	6619,41	6623,00	6626,41	6628,33	6631,66	6634,41	6637,33	6641,00	6644,00	6647,00	6648,50	6652,58	6655,58
Agglutinated spp.			1																																						1																																																														
Alabamina midwayensis																		1		7				1		7					12		1																										1					1																									1												1		4
Alabamina cf. *midwayensis*																		1																	1																																						1																																		
Ammodiscus cretaceus			5				4																																																																																															
Angulogavelinella avnimelechi			2				2																									1																																																																							
Aragonia aff. *ouezzanensis*																																																																																															|1|							
Bathysiphon spp.			2				2																																																																																												
Bolivinoides draco													1														4		5		4	1	4																												3	5		2																																				1					
Bolivinoides cf. *draco*																														1											1									1				1																																																			
Bolivinoides petersoni		|12|		|24|																																																						|1|																																												
Bolivinoides spp.																																																														2																																														
Brizalina incrassata			6												2			3	1	4	1					1		1		7	2	6								13		1	1	3			2			8	1		4								1	4		13	3		1		1																	2											7			2	1		3		17
Brizalina spp.																							1																																																																													
Cibicides cf. *simplex*			1	2											6			2		11	6						3				2	4				1		1					2		2						1				1							6			12		3						6													1				1	1						7				1					1
Cibicides spp.			2				1								3	1		1	16								5	3	9		1		2				2	3		4				6										5												5									1												1																		
Cibicidoides velascoensis			12				9																				2						14	3					1				2										5				2								1																																											
Cibicidoides cf. *velascoensis*																												1																																																																														
Cibicidoides succedens		1	1				2																				5					5	10							4	1								1					2																																																							
Cibicidoides cf. *succedens*		1																		1									1																											1												5					2													1																			
Cibicidoides alleni			3																																								2				1																																1																			1									
Cibicidoides cf. *alleni*																																																		1																												1																										
Dentalina spp.							5																																																																																													
Dentalina cf. *alternata*																																	3																																																																						
Dorothea spp.			1																																																																																																		
Eponides spp.																																																														1																																									1				
Fissurina spp.																															2																							1																																																			
Gaudryina spp.			1																																																																																																	
Gavelinella danica							3							3															1							1			1		5		1								2																																																						
Gavelinella cf. *danica*						3												1				1		1		1																								7						1						1	1																																																
Gavelinella perfusa																			1																																																																																			
Gavelinella spp.		5			3	1										9	2	7			8	2		10			2	3	4	1	4	2	2			3	13			1	6			2		1	5	1	1	30	4		2	3		1	2				23	4		5	6		3	1	2		1		1		2	4		2	3				1		2			1		2			1	5	2	3		5		1		13				
Globorotalites michelinianus																																			1															1																								1																					1								
Guttulina sp.							2																									2											2									1													2																																	1				
Gyroidinoides octocamerata				2			4														1						2	2	2		1		5	3																3				2								2	2														1									3										1			1				1	1	5
Gyroidinoides spp.																			1	1																				1				1				1			1																																																					
Lagena cf. *sulcatiformis*																																																															1																																													
Lagena spp.																																			1								1										2													1																																											
Lenticulina pseudocultrata																		1										1																			2														2																																						1								
Lenticulina cf. *pseudocultrata*																											1							3																																																																						
Lenticulina cf. *velascoensis*																																																																																						1																			
Lenticulina inhabilis																											1					1														1																																																												1		1
Lenticulina spp.																			1									1	1		1		3		1		1	1		2			1	2						1				4	1								2	3		2															1							1																							
Melonis spp.																			1																																																																																			
Neoflabellina reticulata																																	2																																																																					
Neoflabellina spp.			1																																																																																																	
"*Nodosaria*" spp.																											3					1					1																									1			1																						1																				2
Nonionella spp.			1																																																																																																	
Nuttallinella spp.																																																										1			5																1																		1								
Osangularia navarroana			29				26										2	6					2			8	4	9		4		5				2	1				1	1				6			1			5								4	3				1		2						1			1																												
Osangularia cf. *navarroana*					1	1																																																																																															
Osangularia cf. *cordieriana*							4																					2																																																																										
Osangularia spp.																																																																	1																															2								
Paralabamina lunata			8				1																																																							5		1																																											
Planularia liebusi																																			1					1			1	1			1						2									1																																														5
Praebulimina laevis														1			2	8	3					2		27	17	2	1	8	23	40	1				1	1	17	1	3	6	4			3	2					12				2					2				1																														7									5
Praebulimina spp.			1																																														1				1							2			1																																								1		
Pseudouvigerina cimbrica					1															4			1							2																3						1	5							5				1	3			1																									3												
Pseudouvigerina cristata																																2																																																																					
Pullenia quaternaria			3				4																				1						2					1									1		1													8		4		1																																					3		8
Pullenia jarvisi			4				5																																																																																											
Pullenia sp. A													1																				1						1													2		1			1					1	1		2																																									1
Pullenia spp.																																					1																											1																1																							1
Pyramidina minuta		1		2						1				1		1	8	20	1					1	1	18	7	60	3	1	6	24	1	3	1	6	2	1		1		1	9			3			8			3		1	2		2				7		10	4		3	1			1	1	2		1		1				1	1	2	1	2							1	2		1								
Pyrulina spp.																																							|2|																							|5|																																							|3|	
Saracenaria cf. *triangularis*																																2																																																																					
Stensioeina pommerana																		2		1								5		2				2						3		1									1				1																																																			
Stensioeina ex gr. *beccariiformis*			1				11							1	1		2	2		1							5		2	1	1	12	5	1	1	1				8	1	3		1										17							1	7	18	1	33	9	16	1								1												1							5		1	1										67
Rhabdammina spp.							2																																																																																													
Stensioeina spp.							1												3								1																																																																										
Stilostomella spp.			6																																																																																											1				
Tappanina selmensis	1	3		1														1	10								3	1	2																		1																					1																																								
Vaginulina spp.																																																																																																1							
Vaginulina trilobata																																																														2																																													1
Trochospiral spp.																																																	|8|										|10|																																															
Benthic foraminifera indeterminata		4	8	2	11		2				1		3	2		3	4	8	5	5	4		2	1	1	12	9	6	1	4	2	14		2	7	3	4		3	1	9	4	13	12		14	3			3		13	7	3			1	2	4	26	10	6	15	6	7	2	6			1	2	5		5	1	1						1	3	7	2			1		7	2			9			2	18		1	1	18
epifaunal/(epifaunal+infaunal)*100		64	67		88		64						67				61	43	75	74			86			45	40	31		42	51	38		60		73	69		43		64	41	41			61			71			61	50							76	56		59	73	65	69																											77				53				83					66
Total benthic	1	24	122	9	19	2	115	0	0	2	1	0	17	14	11	9	31	77	24	38	7	1	16	6	2	111	51	106	8	42	74	0	14	15	13	39	17	3	64	12	21	21	51	12	2	76	7	4	66	8	0	87	21	5	4	6	5	4	6	100	74	3	107	36	38	15	10	4	0	3	8	9	4	9	6	6	2	3	1	1	2	5	13	12	3	0	2	3	1	20	5	6	2	44	0	3	5	36	0	14	2	138
Eoglobigerina eobulloides	2			12	2	1		7																																																																																															
Globigerinelloides asperus									1						1					1										1						1		2							3	9				1				3				2	1		4		4	1		2																						2		6			1				5			1	2	3						31
Globigerinelloides cf. *asperus*																																																																																																			1		
Globoconusa daubjergensis	3			6	10	8		1	2																																																																																														
Guembelitria cretacea	1			3		2			3	3	5	1	7		8	4	4	2	3	4	4	2	2		1									1		13		3	3	5	2		1			2			16			2		5						30			1	3	1	3		1	2	4	3	2	2	1	1	3		1	1			3		6	1	1	1	1	1	19		2	3	18			1	13	3			1
Hedbergella monmouthensis									15	16	1	2	11	1	5		12			14		3	5	11	1	10	6	10	1	1				2	3	3	1	5	11				6			8	2	2	15	14	1	3			2	3		2		6			2	6			3			2	1								3	2	1		3	1	8	4	4	4			2	6			4	4	1		1	3	2	9
Heterohelix cf. *globulosa*											6																																																																		17																										
Heterohelix complanata								1																																																																																														
Heterohelix dentata					1	4																																									1			3																																																						1
Heterohelix globulosa									53	125	98	29	234	115	103	104	207	118	98	188	89	98	216	200	8	216	64	228	9	19		8		107	31	232	13	208	158	103	59	13	209	17	40	145	109	17	235	186	10	161	57	99	13	83	15	121	14	220	80	47	47	159		110	12	11	109	73	104	103	102	114	136	122	93	82	147	112	106	103	219	116	96	103	97	95	93	241	100	208	102	210	99	177	106	350	109	8	22	60
Heterohelix spp.					10	3				6		3		11	19	5		10	12			9													6		1									8									3			2	18	3					4	32	7			10	20	18	30	7	8	15	21	13		3	15	1	10		18	7	6	5	7	10		8		13		10	1	5		7		2	
Heterohelix spp./*Chiloguembelina morsei* indiff.	6	45		26	30	17		80	8																																																																																													
Heterohelix glabrans										1	1			1	10			1	8									1																								6												2					4	5		2	4	4		1		1				1		1									3				6		7			
Parasubbotina cf. *varianta*	4	28			3	17		9																																																																																																
Parasubbotina pseudobulloides	2	48	24	7	33	11		12																																																																																															
Planktonic foraminifera indeterminata			11			13	4				1		1	3	1		1		2			2		1				1						1		1			1	4			5	4		12	1		31	8		2		2		1				6	5	6	8	10		6			3					1			6			6	1	5		1	2	5	1	4			4	3	2	10	4			7	1	1		9
Praemurica taurica		4	6	2	6			3																																																																																															
Pseudotextularia elegans													8		3		1		1	1				2		1	6													3	1	5		1																																										1																		
Rugoglobigerina rugosa									6																																																																																														4
Subbotina cf. *trivialis*																																																																																																									
Subbotina spp.																																																																																																										
Subbotina triloculinoides			4																																																																																																		
Subbotina trivialis		10	3	11	3	3		8																																																																																															
Plankt. Foram. inderterminata trochospiral	16	41	7	17	31		4	14	13	5					1																										1					1								1	1									7				1		1								1																							1	2				
Total planktonic	34	176	55	76	127	79	8	141	100	156	112	35	261	128	151	118	225	133	122	206	94	111	223	213	10	227	76	240	10	21	0	8	0	117	34	251	14	218	176	114	66	13	222	21	52	174	113	19	268	212	11	174	58	113	15	87	17	143	18	265	89	60	137	185	33	129	15	13	130	104	126	137	115	128	153	147	112	101	155	135	111	124	222	150	114	119	109	111	104	260	119	219	123	239	119	185	120	372	128	13	26	115
(Planktic/(benthic+planktic))*100	97	88	31	89	87	98	7	100	100	99	99	100	94	90	93	93	88	63	84	85	93	99	93	97	83	67	60	69	56	33	0	100	0	89	72	87	45	99	73	90	76	38	81	64	96	70	94	83	80	96	100	67	73	96	79	94	77	97	75	73	55	95	56	84	46	90	60	76	100	97	94	94	97	93	96	96	98	97	99	99	98	96	94	93	97	100	98	97	99	93	96	97	98	84	100	98	96	91	100	48	93	45
Total foraminifera	35	200	177	85	146	81	123	141	100	158	113	35	278	142	162	127	256	210	146	244	101	112	239	219	12	338	127	346	18	63	74	8	14	132	47	290	31	221	240	126	87	34	273	33	54	250	120	23	334	220	11	261	79	118	19	93	22	147	24	365	163	63	244	221	71	144	25	17	130	107	134	146	119	137	159	153	114	104	156	136	113	129	235	162	117	119	111	114	105	280	124	225	125	283	119	188	125	408	128	27	28	253
Caldsphere			2	1							1			1			2	36		6						24	11	9	6		12						3		2			2	15			10	3		2			31	1		1		2		1	21	18	2	11	2	4			1			1		8	1	1						11		6	5	9	1	1	1		32	2			9						very abundant		very abundant
Ostracod			1																																												1													1						1																																										
Radiolaria																																																								|1|																																																				|abundant| |rare

Appendix IIIb. Total abundance of planktic and benthic foraminiferids in E-5X.

E-5X Sample depth (feet)	6809,25	6812,41	6817,58	6820	6821,08	6823,33	6824,83	6826,66	6827,92	6830	6833,5	6836,83	6839,25	6841,92	6845,83	6847,83	6859,83	6863,33	6869,33	6875,33	6878,58	6881,41	6883,92	6889,33	6894	6897,92	6910,25	6916,33	6926,58	6941,17	6950,41	6956,83	6963,17	6975,17
Alabamina ex gr. Limbata	0																														1		
Anomalinoides spp.	1			1										1			3		1	1					1				1				
Aragonia velascoensis	1													1																			
Astacolus mundus																				2													
Astacolus spp.								1													1			1									
Bolivinoides draco							4	1							3	4	5	5	1		2						3		2			1	2
Bolivinoides giganteus					1																												
Bolivinoides paleocenicus	1																																
Bolivinoides petersoni			7									1																					
Brizalina cf. decurrens													1			1																	
Brizalina decurrens							3													1		1											
Brizalina incrassata					1	1	3	13	1	6	6	29	2		1	2	3	4	1				2	4	1	2	2		1				
Brizalina spp.			1														1													1			
Brozenella acuta																									1		1						
Brozenella wellen										3																				5			
Bulimina? paleocenica										2					1	1															2		
Cibicides aff. burlingtonensis																				1	1												
Cibicides mariae				1	1								1				1	4								1				1			
Cibicides cf. simplex			1		1		7		7	2	1			3			1		3	6					1		2	2					4
Cibicides succedens	1		2		1	1		1	1	3	4	9				1	2		1								2		6	14			3
Cibicides velascoensis							1																	2				2					2
Cibicides spp.										1																							
Cibicidoides alleni							2																										
Cibicidoides involutus										2																							
Cibicidoides sp. A							1																										
Cibicidoides spp.	5	1	4		1	2			1			4	3		1		3			1	2	2	3		1	9	1						
Coleites reticulosus																																	1
Coryphostoma limonense														1	1																		
Coryphostoma plaita																						3											
Coryphostoma spp.								1	1		1										1												1
Dentalina alternata																							1			2							
Dentalina catenula							1																										
Dentalina spp.			1				1			3			1	1			6					4	4	3	1	1	1	1		3			1	1
Ellipsoidella gracillima																		1															
Ellipsodimorphina divergens																						1											
Eouvigerina hispida					1																												
Eouvigerina sculptura					1		2	3	2																								
Eouvigerina spp.															1																		
Eponides sp.								3																									
Fissurina laticarinata																								1									
Fissurina spp.																							1										
Frondicularia spp.						1																											
Fursenkoina tegulata					1																												
Gavelinella cf. danica							1																									1	
Gavelinella laevigata																																	
Gavelinella nacatochensis									1																								
Gavelinella pertusa								2	2			1																					
Gavelinella whitei					1					7																							
Gavelinella sp. *A*							4																										
Gavelinella spp.												3												1				1				1	1
Gavelinopsis bembix																1																	
Globorotalites subconicus														1							2		1										
Globorotalites spp.																				1													
Guttulina spp.												2					1						1										
Guttulina trigonula															1																		
Gyroidinoides nitidus								2			8	2		3	4	3	3	6	4		1	1		1			1						1
Gyroidinoides octocamerata						1	2	1				2				1		2	1	1				2									
Gyroidinoides sp. A												1																					
Gyroidinoides spp.																							1			1					1		
Lagena acuticosta																		1	1														
Lagena amphora																															1		
Lagena geometrica													1																				
Lagena isabella																						1	1	2									
Lagena paucicostata												2																					
Lagena semiinterrupta								1																									
Lagena sphaerica					1															1	2												
Lagena spp.																						1					2						
Loxostomum sp.									1																								
Neoflabellina reticulata								2								2		1															
Neoflabellina rugosa																															1		
"Nodosaria" sp.							1																										
Nonionella spp.			1																														
Oridorsalis umbonatus																																	
Osangularia navarroana	7	3	4	2	12	2		3	2	11	2	11	4	5	12	1	7	6	6	2	4	1		1	5	1		5		2			1	5
Paralabamina lunata	1						4			2		1																					
Paralabamina sp. A													1						2														
Pleurostomella subnodosa							2					2																					
Praebulimina laevis						1	2	9	2	1	4	2	1	4	2	4	7	13	7		3	1	1	8		6	1	2	1	3	1			
Praebulimina cf. reussi						1	1	2								1	1				2		1										
Praebulimina spp.												1			1																		
Praebulimina? sp. A							1	3			2																						
Praebulimina? sp. B								1																									
Praebulimina? spp.							2																										
Pseudonodosaria proboscidea							1																										
Pseudonodosaria pseudoscripta					1			3	1	2	1		2	1		1		1		1			1										
Pseudonodosaria spp.	1				2																												
Pseudouvigerina cristata								1								1					1			1									
Pseudouvigerina rugosa																																	
Pullenia cretacea							1	1						1	1																		
Pullenia jarvisi				1			2							1	1		1		2		2		1		1						1	1
Pullenia spp.	1																								1								
Pyramidina cimbrica							1																1				1						
Pyramidina minuta							1			1		4	1	4			3	4	2				2								1		
Pyramidina spp.										1						1																	
Pyrulina cylindroides																		2	2	1										1			
Pyrulina spp.											1					1							1	3			1	1					
Pyrulinoides acuminatus																	1																
Quadrimorphina allomorphinoides					1				1				1					1	1		1	1		1									1
Reussoolina apiculata											1													2									
Reussoolina simplex																1	1																
Rosalina spp.													1																				
Robulus macrodiscus								1																									
Robulus spp.					1		1			1		5		1		1		4	1					2		1				1		1	
Saracenaria triangularis																				1													
Spirillina subornata							1																										
Spirillina spp.																				1													
Stensioeina ex gr. beccariformis					4		14	13	7	16			1					7	7				5				5				1	1	1
Stensioeina pommerana			1							5	1	1		1	2	2																	
Tappanina selmensis	2										1		2				3								1						1		
Vaginulinopsis sp.									1									2													1		
Gen. et sp. indet. A																															4		
Calcareous benthic indet. total	0	1	5	7	6	6	15	4	9	9	9	12	6	3	13	8	7	8	16	3	6	4	5	4	7	8	5	11	18	18	10	22	6	6
Calcareous benthic indet. Epifaunal			2	5	4	5	4	1	7	5	8	5	6	1	9	4	5	4	8	2	6	4	3	2	3	4	1	4	18	18	6	18	5	2
Calccareous benthic indet. Infaunal			3				3	2	2	4	1	2		1	2	1	1	1	1	1	1		1	1	3	2	2	2			1	4		1
Total calcareous benthic	**21**	**5**	**27**	**12**	**38**	**16**	**82**	**72**	**40**	**78**	**42**	**95**	**29**	**30**	**45**	**40**	**58**	**73**	**57**	**26**	**31**	**23**	**31**	**41**	**19**	**25**	**36**	**26**	**28**	**47**	**15**	**35**	**14**	**29**
Ammodiscus spp.								1																									
Bathysiphon spp.								1																2									
Karrerulina conversa					1																												
Orbignyna spp.																			1				1										
Rhabdammina spp.												1																					
Spiroplectammina spp.														1																			
Agglutinated indet								3															1										
Total agglutinated benthic	**0**				**1**			**5**			**1**		**1**						**1**				**2**	**2**			**1**						
(epifaunal/(epifaunal+infaunal))*10(	**71**		**54**		**72**	**80**	**57**	**41**	**70**	**74**	**57**	**50**	**59**	**55**	**65**	**43**	**44**	**49**	**68**	**62**	**53**	**35**	**47**	**30**	**61**	**39**	**62**	**71**	**86**	**85**	**67**	**77**		**73**
Total benthic	**21**	**5**	**27**	**12**	**39**	**16**	**82**	**77**	**40**	**78**	**42**	**96**	**29**	**31**	**45**	**40**	**58**	**73**	**58**	**26**	**31**	**23**	**33**	**43**	**19**	**25**	**37**	**26**	**28**	**47**	**15**	**35**	**14**	**29**
Abathomphalus mayaroensis								1	1?	1																							
Chiloguembelina spp.	3		5	3																													
Eoglobigerina edita					3																												
Eoglobigerina eobulloides			10	6	2																												
Globanomalina compressa	3	1																															
Globigerinelloides asperus										5				2	3	6	6	10	6	6	6	3	5										
Globigerinelloides multispina							5	7	1	6	3	3	4	7	18	19	14	16	8	16	15	13	14	5	1	16	5		13	7	2	7	1	3
Globoconusa daubjergensis	27	20	48	30	30	3																											
Globotruncana arca																		1															
Globotruncana spp.														1																			
Globotruncanella havanensis																					2		1										
Guembelitria cretacea	1						1	1	4		1	2	2	1	1	1			1	2	6	5	2		4		1?	3		1		2	2	
Hedbergella monmouthensis					7		8	12	11	10	7	9	9	15	7	17	14	7	8	10	10	20	22	6	5	12	5		3	10		13	2	7
Heterohelix dentata							2	2	2	2	6			1	1	1	1	1		2		5	8	13	2			1						
Heterohelix globulosa					18	10	52	40	63	51	40	28	113	94	54	52	55	43	71	104	136	89	61	106	75	8	56	31	40	92	76	113	20	30
Heterohelix punctulata												1									1	4								2				
Heterohelix spp.															2																		
Parasubbotina pseudobulloides	13		8	5	1																												
Parasubbotina cf. varianta	14	5	18	4	20																												
Parvularugoglobigerina? spp.		3																															
Praemurica spp.	2	2																															
Pseudoguembelina hariaensis					1	1	2																										
Pseudotextularia elegans							1		2	3	61	4			8	37		3			3		17										
Racemiguembelina fructicosa						1?																											
Rugoglobigerina spp.			1nw						1		1								1	1			7	3			1						4
Subbotina triloculinoides	4	2	3		5	2																											
Planktic indet.	17	3	12	2	4	8	10	6	10	2	3	5	6	5	6				3	3	6	11		6	7	1	5	3			7	4	4	7
Total planktic	**84**	**36**	**105**	**50**	**91**	**25**	**81**	**69**	**95**	**80**	**122**	**52**	**134**	**126**	**100**	**133**	**90**	**81**	**97**	**144**	**186**	**150**	**137**	**139**	**94**	**37**	**73**	**38**	**56**	**112**	**85**	**139**	**29**	**51**
Planktic / (benthic + planktic)*10(	**80**	**88**	**80**	**81**	**70**	**61**	**50**	**47**	**70**	**51**	**74**	**35**	**82**	**80**	**69**	**77**	**61**	**53**	**63**	**85**	**86**	**87**	**81**	**76**	**83**	**60**	**66**	**59**	**67**	**70**	**85**	**80**	**67**	**64**
Total foraminifera	**105**	**41**	**132**	**62**	**130**	**41**	**163**	**146**	**135**	**158**	**164**	**148**	**163**	**157**	**145**	**173**	**148**	**154**	**155**	**170**	**217**	**173**	**170**	**182**	**113**	**62**	**110**	**64**	**84**	**159**	**100**	**174**	**43**	**80**
Bivalve fragment											1																						
Calcispheres			1	2	9	9	1			6	1	18			1		2	9	3			2	1	1	14			7	11	8	11		
Cenodiscus / Cenosphaera																											28		2		16	2	
diatom indet.											1														1								
Inoceramus fragments														1																			
ostracod indet.					2	2					1			1									1	2									
radolaria indet.																							3										
sponge spicules										1	1	4			1		1							1									
dinoflagellate cyst															3																		