

Calcareous nannofossil and foraminifer biostratigraphy of the Campanian–Maastrichtian chalk of the Femern Bælt (Denmark–Germany)

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A new study based on calcareous nannofossil and benthic and planktonic foraminifer biostratigraphy is presented for the upper Campanian – Maastrichtian chalk of the Femern Bælt (Denmark and Germany; Fig. 1). The results are consistent with recent studies of the Danish chalk for this interval, allowing correlation across the Danish Basin and forming the basis for correlation further afield within the Boreal Realm. Numerous studies have been carried out recently on the upper Campanian – Maastrichtian chalk of the Danish Basin, covering aspects such as sedimentology, depositional environment, macrofossil biostratigraphy, carbon isotope stratigraphy as well as nannofossil and dinoflagellate biostratigraphy. However, very few published studies on foraminifers exist across this interval in this area. The 09.A.006, 09.A.007 and 09.A.008 boreholes (Fig. 2) were drilled in 2009 in preparation for construction of a fixed link across the Femern Bælt, which will connect Denmark to Germany (Rambøll Arup JV 2011). The boreholes penetrated glacial till, Paleocene–Eocene clay and chalk (Sheldon *et al.* 2012). Here, for the first time, the Boreal foraminifer biostratigraphy of the late Campanian – Maastrichtian interval is investigated and presented alongside nannofossil biostratigraphy.



Fig. 1. Map of Denmark and northern Germany showing the location of the planned fixed road and rail link across Femern Bælt. L: Lolland, F: Fehmarn, FB: Femern Bælt.

Geological setting and palaeogeography

The Femern Bælt area is located to the south of the Ringkøbing–Fyn High and is part of the German Basin (Fig. 1). During the Late Cretaceous the Danish area was part of the extensive epicontinental sea where cool-water carbonate deposition dominated. The Maastrichtian chalk was deposited at depths of 100–250 m (Surlyk 1997). Chalk distribution patterns are affected in the Danish area by folding, salt diapirism, non-deposition and erosion, especially in the southern region (Lieberkind *et al.* 1982). In the Maastrichtian to Danian, the area was situated at 44°–46°N (Smith *et al.* 1994). In the upper Maastrichtian of this part of the Danish area, two main facies types dominate: (1) relatively deep water basinal sediments comprising coccolith and foraminifera-rich pelagic chalk, and (2) shallow marine chalk with high diversity faunas dominated by bryozoans, echinoids, bivalves and brachiopods (Surlyk 1997; Hart *et al.* 2004).

The upper Campanian – Maastrichtian chalk of onshore Denmark was until recently referred to the Tor Formation equivalent. The Tor Formation was established by Deegan & Scull (1977) as a Maastrichtian (locally upper Campanian) chalk unit in the Norwegian and Danish sectors of the North Sea. A new holostratigraphic analysis of the upper Cretaceous chalk of eastern Denmark resulted in a lithostratigraphic subdivision of the onshore chalk (Surlyk *et al.* 2013). However due to local facies variations this new subdivision cannot be applied to the chalk of the Femern Belt area with-

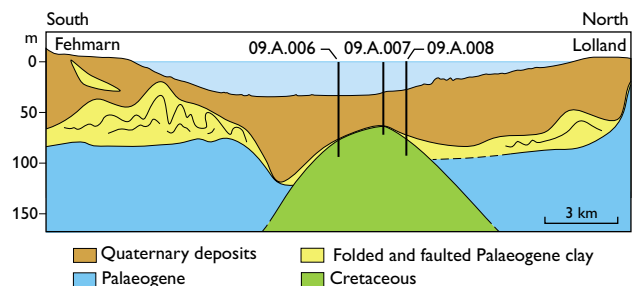


Fig. 2. Sketch south–north cross-section of the Femern Bælt area and the location of the boreholes (from Sheldon *et al.* 2012).

out sedimentological analysis and the term ‘Tor Formation equivalent’ is retained here.

Biostratigraphy

From the 09.A.008 and 09.A.006 boreholes nannofossils and foraminifers from the Campanian–Maastrichtian were analysed; from the 09.A.007 borehole nannofossils from the upper Maastrichtian were examined. The southern North Sea foraminifer zonation of King *et al.* (1989) and the Boreal nannofossil scheme of Burnett (1998) were applied (Fig. 3). Marker species are shown in Fig. 4 and biostratigraphic results on Fig. 5.

Nannofossil zones – The co-occurrence of *Orastrum campanensis* and *Eiffelithus eximius* indicates the presence of UC15d^{BP} at the base of core 09.A.008. Subzone UC15e^{BP} is absent. UC16^{BP} was defined by Burnett (1998) but recent studies of Danish Campanian–Maastrichtian chalks (Sheldon 2008; Thibault *et al.* 2012) question the reliability of the UC16^{BP} marker species in the Danish area. The top of UC16a^{BP} is defined by the last occurrence (LO) of *Heteromarginatus bugensis*. In the present study and in the Stevns-1 borehole, eastern Denmark, the LO of *H. bugensis* is below the LO of *Tortolitus caistorensis*

(marker for top UC16b^{BP}). Other studies (e.g. Fritsen *et al.* 1999) assign the LO of *H. bugensis* to the top of UC16c^{BP}. The top of UC16b^{BP} is defined by the LO of *T. caistorensis*, which is very rare in the Danish area. UC16a^{BP} and b are not easily subdivided in the Danish area and alternative markers are suggested for the top of UC16b^{BP}: the LO’s of *Tortolitus hallii* and *Tortolitus pagei* were successfully applied in the present study, positioned prior to the LOs of *Broinsonia parca parca* and *Zeugrhabdotus praesigmoides* (markers for the overlying UC16c^{BP}). The top of UC16c^{BP} is defined by the LO of *Monomarginatus quaternarius*. The LO of *B. parca parca* as a top UC16c^{BP} marker is a more reliable marker in this study. The LO of *Z. praesigmoides* as an additional top UC16c^{BP} marker is confirmed in this study. The top of subzone UC16d^{BP} is defined by the LO of *Broinsonia parca constricta*. The first occurrence (FO) of *Prediscosphaera mgayae* as an additional marker

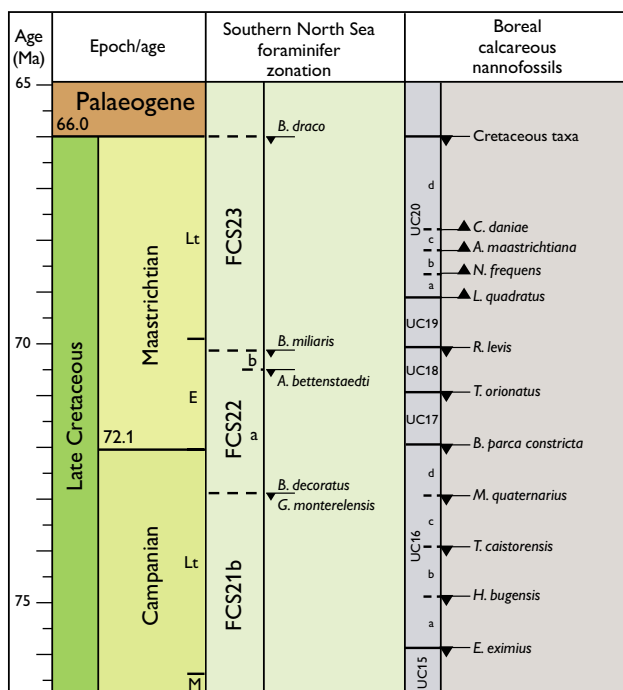


Fig. 3. Nannofossil and foraminifer zonations. The timescale is according to Gradstein *et al.* (2012). UC^{BP}: Upper Cretaceous Boreal Province nannofossil zones of Burnett (1998), FCS: Cretaceous southern North Sea Foraminifers, shelf facies, including chalk, zones of King *et al.* (1989). Nannofossil and foraminifer zonations correlated using Fritsen (1999).

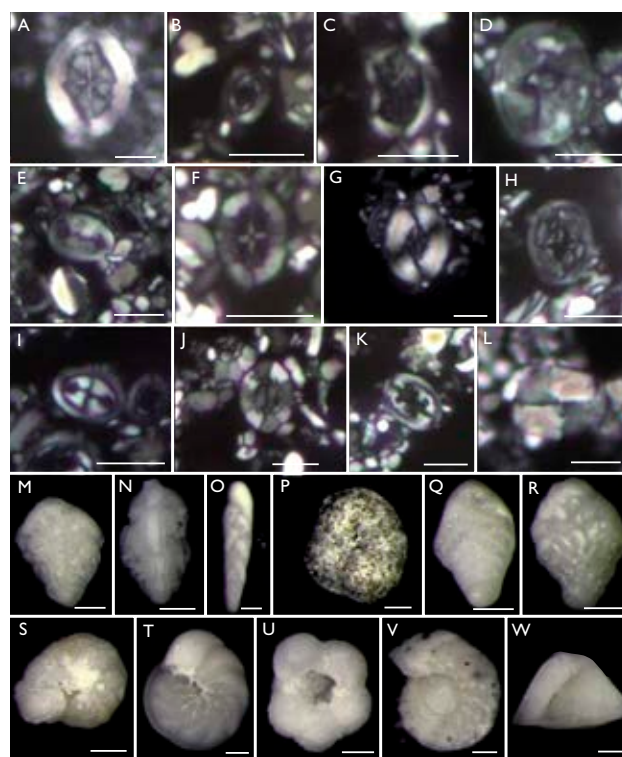


Fig. 4. Selected nannofossils and foraminifers from the Femern Belt. A: *Arkhangelskiella maastrichtiana*. B: *Prediscosphaera stoveri*. C: *Nephrolithus frequens*. D: *Reinhardtites levis*. E: *Tranolithus orionatus*. F: *Prediscosphaera mgayae*. G: *Broinsonia parca constricta*. H: *Monomarginatus quaternarius*. I: *Zeugrhabdotus praesigmoides*. J: *Tortolitus caistorensis*. K: *Heteromarginatus bugensis*. L: *Orastrum campanensis*. M: *Bolivinoidea draco*. N: *Pseudovigierina cristata*. O: *Brizalina incrassata*. P: *Hagenowella paleocena*. Q: *Bolivinoidea draco giganteus*. R: *Bolivinoidea decoratus*. S: *Stensioeina pommerana*. T: *Angulogavelinella bettenstaedti*. U: *Globotruncana arca*. V: *Gavelinella monterelensis*. W: *Globobulimina micheliana*. Scale bars, nannofossils: 5 µm, foraminifers: 0.1 mm.

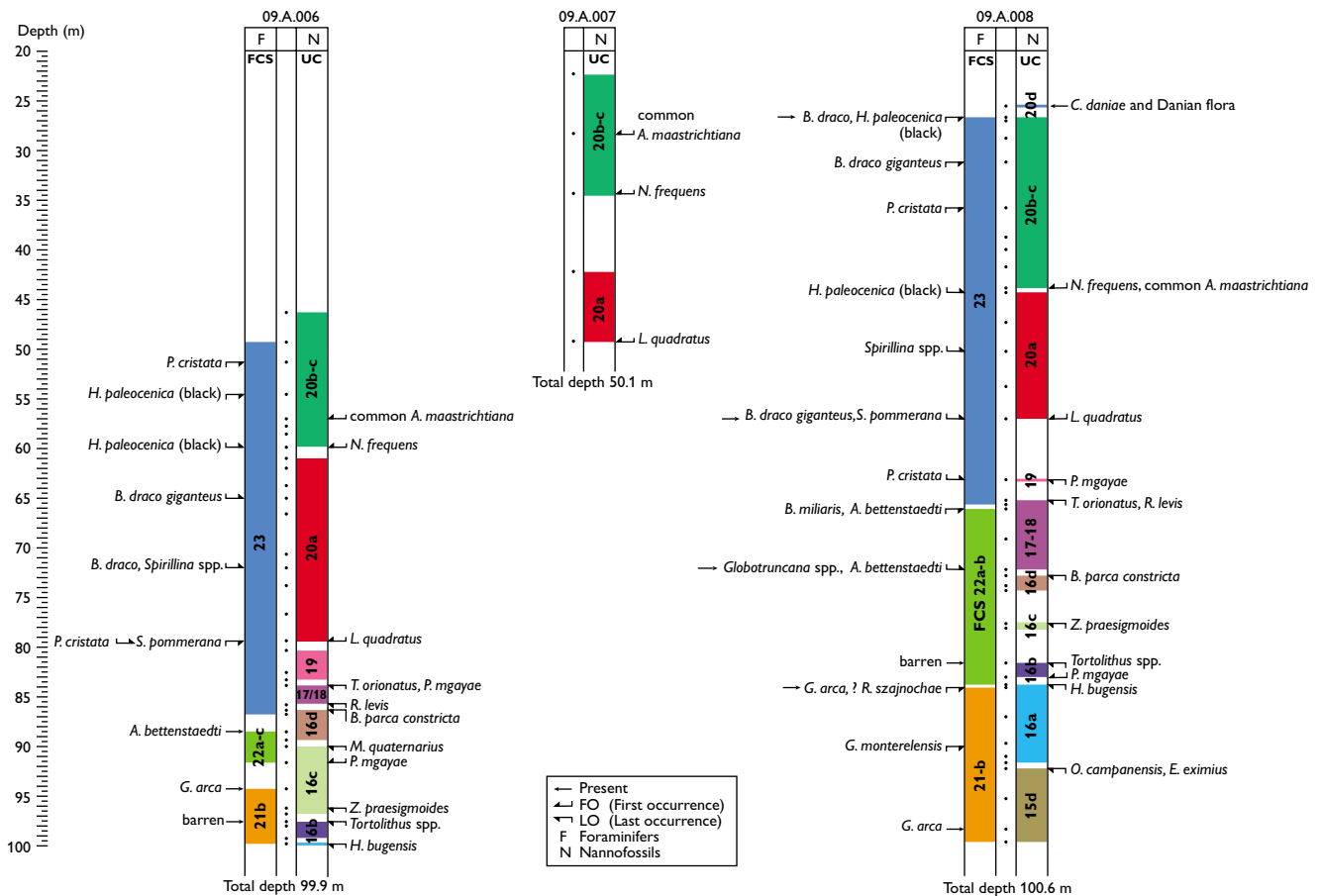


Fig. 5. Nannofossil and foraminifer biostratigraphic correlations of the three boreholes at the Femern Bælt.

in the middle of UC16d^{BP} (Thibaut *et al.* 2012) is confirmed in this study. The LO of *Tranolithus orionatus* marks the top of UC17^{BP}. In the present study, the LO of this species occurred after the LO of *Reinhardtites levis* (the LO of which marks the top of the overlying UC18^{BP}). In Stevns-1 these species also occur in the 'reverse' order. The LO of *R. levis* marks the top of UC18^{BP}, but in this study its LO is before that of *T. orionatus*. It is suggested that in the Danish area, UC17^{BP} and UC18^{BP} should be combined, using either the LO of *T. orionatus* or the LO of *R. levis* to mark the zone top. The LO of *P. mgayae* has been suggested as an additional marker for the top of this zone (Thibaut *et al.* 2012); this is confirmed in this study. UC19^{BP} comprises the interval from the LO of *Reinhardtites levis* to the FO of *Lithraphidites quadratus*. The FO of *L. quadratus* defines the base of UC20a^{BP}. The base of UC20b^{BP} is defined by the FO of *Nephrolithus frequens*. The base of UC20c^{BP} is defined by the FO of *Arkhangelskiella maastrichtiana*. The uncertainties surrounding the use of the FO of *A. maastrichtiana* as a marker are well-documented (e.g. Thibault 2010) and the two subzones are merged here. The first common occurrence of *A. maastrichtiana* is used to mark the base of UC20b-c^{BP} in

this study. The base of the *Prediscosphaera stoveri* acme within this combined subzone is also applied successfully in this study. The LO of *Helicolithus trabeculatus* was suggested as a supplementary marker for this level (Sheldon 2008) and is confirmed here. The FO of *Cribrosphaerella daniae* marks the base of UC20d^{BP}, the uppermost subzone of the Maastrichtian. The co-occurrence of *Chiasmolithus edentulus*, *Coccolithus pelagicus*, *Cyclagelosphaera alta* and *Neochiastozygus saepes* assigns the base of the overlying Danian in borehole 09.A.008 to the upper Danian subzone NNTp4F (Varol 1998). Lower – upper Danian subzones NNTp1A-4F are missing or were not sampled. Danian chalk in the Femern area was documented for the first time recently (Sheldon *et al.* 2012). Previously the southern limits of Danian deposits were thought to be farther to the north (Håkansson & Pedersen 1992).

Foraminifer zones – The top of FCS23 is defined by the LO of *Pseudotextularia elegans*. *Bolivinooides draco* (s.s.) is an index species. The top of subzone FCS23a is defined by the FO of *P. elegans*. *P. elegans* is not seen in the present study, but rare occurrences of *Bolivinooides draco* were noted, indicating the

presence of FCS23. In upper FCS23 the range of *Hagenowella paleocenica* and the FO of *Spirillina* spp. are additional markers in the present study. The LO of *Stensioeina pommerana* occurring towards the bottom of FCS23 (corresponding to the base of nannofossil subzone UC20a^{BP}) in this study may also prove useful. The range of *Pseudovigernina cristata* within FCS23 may prove to be another useful marker. The absence of *P. elegans* means that it is not possible to subdivide FCS23 in this study. The top of FCS22 is defined by the LO of *Bolivinooides miliaris*. FCS22 is divided into FCS22b, the top of which is defined by the LO of *B. miliaris*, and FCS22a, the top of which is defined by the LO of *Angulogavelinella bettenstaedti*. The LOs of *A. bettenstaedti* and *B. miliaris* occurred in the same sample suggesting the presence of only FCS22a, but the range of *A. bettenstaedti* within FCS22 could be useful. The top of FCS21 is defined by the LO (often a flood occurrence) of *Reussella szajnochae*. FCS21 is divided into FCS21b, the top of which is defined by the LO of *R. szajnochae*, and FCS21a, the top of which is defined by the LO of *Gavelinella usakensis*. *G. usakensis* was not found in the present study, indicating the presence only of FCS21b. The LO of *Globotruncana arca* at the top of FCS21 is an additional marker, as are the LOs of *Gavelinella monterelensis* and *Globorotalites micheliana* and FO of *Brizalina incrassata* at a slightly lower stratigraphic level.

Conclusions

The Campanian–Maastrichtian chalk of the Danish area has recently been studied intensively using calcareous nannofossils, applying the UC^{BP} scheme. The studies underline the need for an amendment of the UC scheme for the Danish area. The present study highlights the need to reconsider the subdivision of UC20b^{BP} and UC20c^{BP} based on the FO of *Arkhangelskiella maastrichtiana*. It is recommended for the Danish area to use the FO of common *A. maastrichtiana* to mark the base of UC20c^{BP}. It may also be practical to merge UC17^{BP} and UC18^{BP}. Additionally the subdivision of UC16^{BP} cannot be reliably applied in the Danish area. The Danian nannofossil assemblage in borehole 09.A.008 provides further evidence for the southerly encroachment of the Danian sea.

The foraminifer zonation of the Late Campanian – Maastrichtian is for the first time correlated with the nannofossil zonation based on the 09.A.006 and 09.A.008 cores (Fig. 5). In the absence of certain established FCS marker foraminifera for the North Sea chalk, new zonal markers, e.g. *Hagenowella paleocenica*, *Pseudovigernina cristata*, *Globotruncana*

arca, *Gavelinella monterelensis* and *Globorotalites micheliana* are used here in addition to conventional taxa for the Campanian–Maastrichtian chalk of Denmark, perhaps allowing correlation with the North Sea area, and further afield.

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