

# Planktonic foraminifers, biostratigraphy and the diachronous nature of the lowermost Danian Cerithium Limestone at Stevns Klint, Denmark

JAN A. RASMUSSEN, CLAUS HEINBERG & ECKART HÅKANSSON



Rasmussen, J.A., Heinberg, C. & Håkansson, E. 2005–12–31. Planktonic foraminifers, biostratigraphy and the diachronous nature of the lowermost Danian Cerithium Limestone at Stevns Klint, Denmark. *Bulletin of the Geological Society of Denmark*, Vol. 52, pp. 113–131. © 2005 by Geological Society of Denmark. ISSN 0011–6297. <https://doi.org/10.37570/bgds-2005-52-09>

New material comprising more than four thousand specimens of planktonic foraminifers from the lowermost Danian Cerithium Limestone at Stevns Klint, Denmark, reveal significant lateral biostratigraphic differences along the 14 km long cliff. The Cerithium Limestone at Rødvig (Korsnæb) in the southern part of Stevns Klint is dominated by foraminiferal assemblages indicative of the *Parvularugoglobigerina eugubina* Zone (P $\alpha$ ). This pattern changes laterally towards the north, where the *P. eugubina* Zone becomes gradually thinner. At the northernmost locality investigated, Holtug quarry, the Cerithium Limestone unit is characterised solely by assemblages of the succeeding *Parasubbotina pseudobulloides* Subzone (P1a). This indicates that the Cerithium Limestone is diachronous and becomes gradually younger from the southern part of Stevns Klint towards the northern part. The data indicate that a hiatus including all of the *P. eugubina* Zone is present at the Fish Clay – Cerithium Limestone transition in the northern part of the cliff, whereas such a hiatus cannot be demonstrated in the southern part.

**Keywords:** Planktonic foraminifers, foraminiferal biostratigraphy, Early Danian, Cerithium Limestone, Stevns Klint

Jan A. Rasmussen [janr@snm.ku.dk], Geological Museum, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark (Previous address: Dept. of Stratigraphy, Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark), Claus Heinberg, Dept. of Environment, Technology and Social Studies, Building 11.2, University Centre Roskilde, P.O. Box 260, DK-4000 Roskilde, Denmark and Eckart Håkansson, Geological Institute, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.

Early biostratigraphic studies of Maastrichtian–Danian boundary strata in Denmark were based on echinoids and other macrofossil groups (e.g. Rosenkrantz 1924, 1937; Ødum 1926; Nielsen 1937; Wind 1954), but during the past few decades microfossils such as foraminifers and dinoflagellate cysts together with nannofossils have proved to be powerful alternatives (e.g. Berggren 1960; Surlyk & Birkelund 1977; Hansen 1977; Perch-Nielsen 1979; Kjellström & Hansen 1981; Schmitz *et al.* 1992; Thomsen 1995; Håkansson & Thomsen 1999).

The objective of the present study is to enhance the biostratigraphic resolution of the basal Danian succession of Stevns Klint, eastern Denmark by means of planktonic foraminifers. Stevns Klint (Fig. 1) and the Fakse Limestone Quarry are the classic type localities for the Danian stage, and in addition

Stevns Klint displays the classic Maastrichtian–Danian boundary strata (Desor 1847).

At Stevns Klint, the lower Danian sediments are subdivided into three lithological units: the basal Danian Fish Clay that is a 0–25+ cm thick clay and marl unit (see description by Christensen *et al.* 1973); up to 80 cm of Cerithium Limestone, and more than 20 m bryozoan limestone (Fig. 2). Calcareous micro- and nannofossils are very rare within the Fish Clay, whereas palynomorphs are abundant. In contrast, the Cerithium Limestone and the bryozoan limestone units are relatively rich in calcareous plankton, while palynomorphs are rare (Hansen 1977, 1979; Brinkhuis *et al.* 1998). Previous studies have indicated a poorly preserved foraminiferal assemblage of very low density and diversity from the Cerithium Limestone (Bang 1971; Schmitz *et al.* 1992).

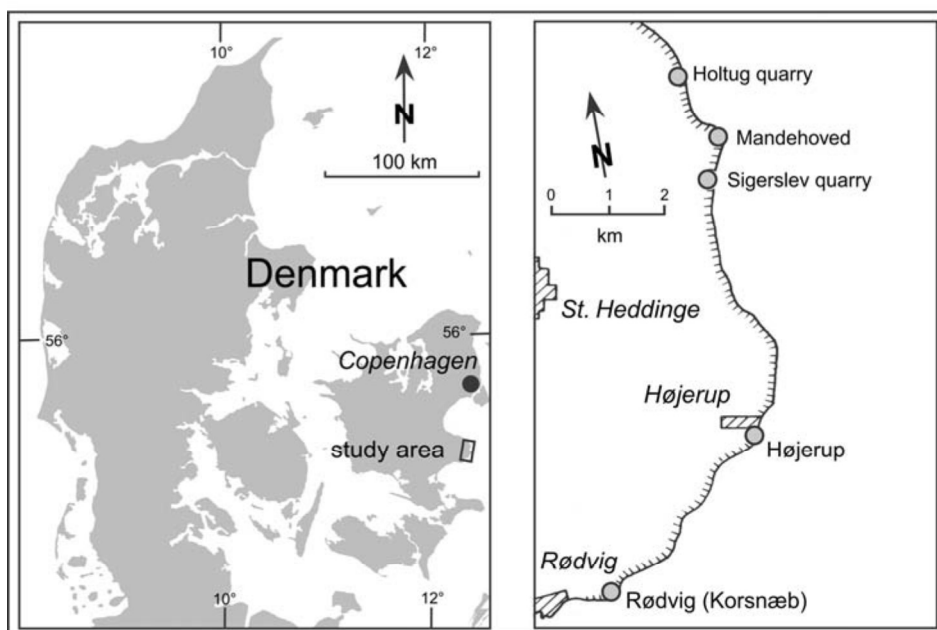


Fig. 1. Locality map.

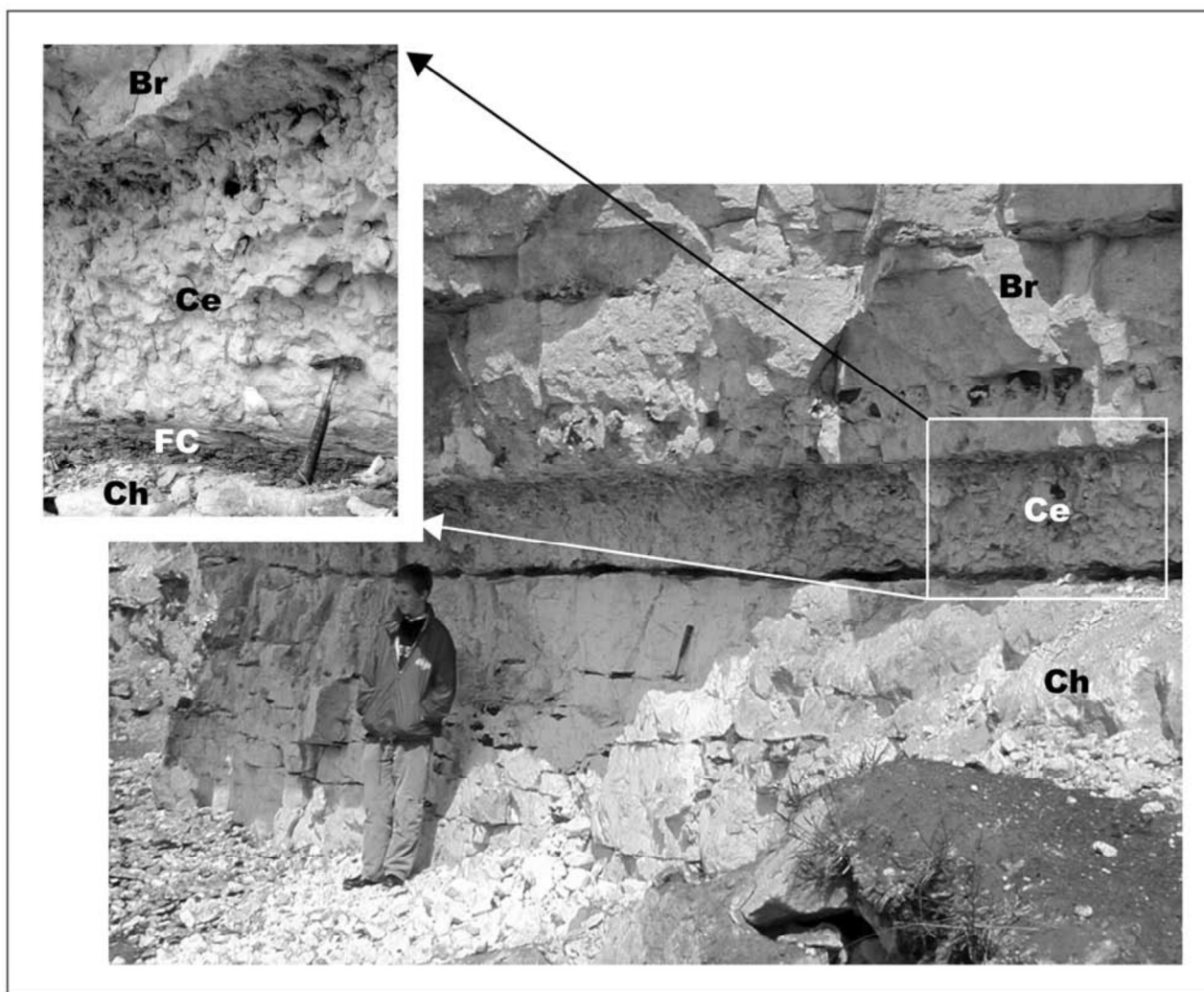


Fig. 2. Lithostratigraphic units of the Maastrichtian–Danian boundary at Stevns Klint (Rødvig at Korsnæb). Ch = Maastrichtian chalk; FC = Fish Clay; Ce = Cerithium Limestone; Br = bryozoan limestone.

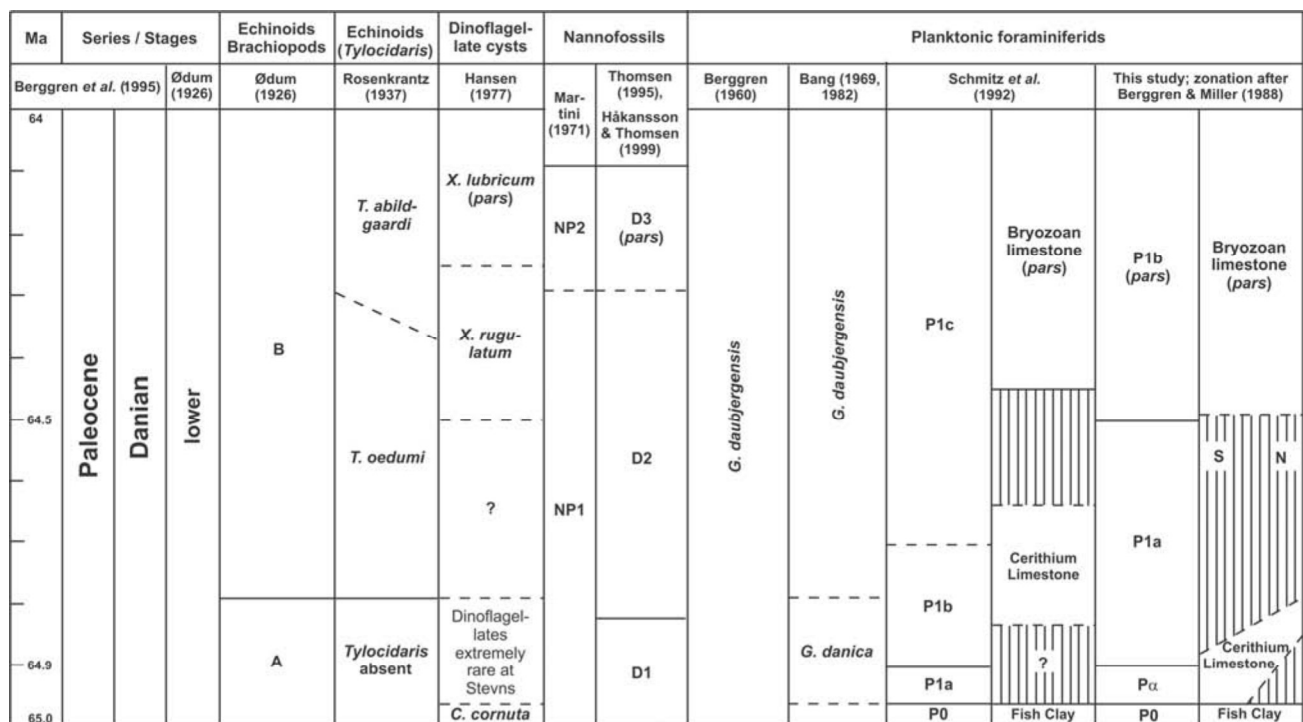


Fig. 3. Bio- and lithostratigraphy of the lower Danian strata of the eastern part of the Danish Basin.

Foraminifers from the Danian of Denmark were documented by Brotzen (1948), Brönniman (1953), Troelsen (1957), Berggren (1960, 1962), Hofker (1960), Bang (1969, 1971, 1979a, b, 1982), Hansen (1970a, 1970b), Schmitz *et al.* (1992), Keller *et al.* (1993), Stouge *et al.* (2000), Culver (2003), Rasmussen & Sheldon (2004). The dinoflagellate cyst biostratigraphy of the basal Danian strata was established by Hansen (1977, 1979), Kjellström & Hansen (1981), Hultberg (1986) and Hansen *et al.* (1986).

The aim of the present paper is to enhance the biostratigraphic resolution of the Cerithium Limestone and to document the spatial distribution of key zonal foraminifers at Stevns Klint.

## Localities and sample techniques

To investigate the bivalve fauna (Heinberg 2005, this volume) and biostratigraphy (planktonic foraminifers) of the Cerithium Limestone, sample series were collected from five selected Fish Clay basins representing most of the N–S range of this disjunctive unit. A total of 17 microfossil samples (25 splits) were investigated using a new preparation procedure (see Heinberg 2005, this volume), resulting in more than 4000 planktonic foraminifers. The samples were wet-sieved, and all of the 40–125 µm fraction was subse-

quently picked and analysed for microfossils. All sample levels are measured upward from the boundary between the Fish Clay and the Cerithium Limestone. Although preservation is poor, our investigations have revealed that an unexpectedly abundant assemblage of low diversity is indeed present in the Cerithium Limestone in the 40–125 µm fraction.

## Previous biostratigraphic work

The Danian succession of Denmark was subdivided into four zones by Ødum (1926) based on benthonic organisms (mainly echinoids and brachiopods). He distinguished between the 'Early Danian' biozones A and B and the 'Late Danian' biozones C and D (Fig. 3). Zone A corresponds to the Cerithium Limestone at Stevns Klint, zone B and C to the overlying bryozoan limestones and calcilutites, and Zone D was referred to the calcarenite-dominated uppermost part of the succession. Zones A and B are characterised by the echinoids *Tylocidaris vexillifera* forma  $\alpha$ , *T. vexillifera* forma  $\gamma$  and *Cyclaster bruennichi*, while the C and D zones are distinguished by the echinoid *Tylocidaris vexillifera* forma  $\beta$  and the brachiopod *Terebratulina lens* (Ødum 1926). Nielsen (1937) refined the Danian echinoid-based zonation and introduced the name *Tylocidaris oedumi* for the zonal marker *Ty-*

Locality	Rødvig (Korsnæb)							
Species	Samples							
	Rv-A 0-5 cm	Rv-B 5-18 cm	Rv-C 15-30 cm	Rv-D 27-38 cm	Rv-E 40-50 cm	Rv-F 65-75 cm	base of Bryozoan Limestone Rv-G	Hr-A 10-20 cm
<i>Eoglobigerina eobulloides</i>	8			6	5	17	5	
<i>Globanomalina</i> sp. A	3			3	18	13	1	1
<i>Globanomalina planocompressa</i>	1?							
<i>Globanomalina</i> cf. <i>compressa</i>							1	
<i>Globanomalina</i> sp.	1							
<i>Globigerinelloides</i> sp.								
<i>Globoconusa daubjergensis</i>	20	11	21	21	53	11	10	4
<i>Parasubbotina pseudobulloides</i>						30	8	
<i>Parasubbotina</i> aff. <i>pseudobulloides</i>	2							
<i>Praemurica taurica</i>	1				1	5		
<i>Subbotina triloculinoides</i>							1	
spiral planktonic indet.	6	1		1				
spiral planktonic total	42	12	23	31	77	76	26	5
spiral planktonic %	21	8	10	13	23	69	93	4
<i>Heterohelix</i> and <i>Chiloguembelina</i> spp. undiff.	140	128	168	201	258	34		132
<i>Zeuvingerina waiparaensis</i>		1	1					
biserial planktonic total	140	129	169	201	258	34	0	132
biserial planktonic %	72	89	87	85	75	31	0	92
<i>Guembelitra cretacea</i>	14	4	4	2	7		2	6
<i>Woodringina</i> spp.				3				
triserial planktonic total	14	4	4	5	7	0	2	6
triserial planktonic %	7	3	3	2	2	0	7	4
benthonic foraminifers	70	12	10	8	0	0	42	2
Total	266	157	206	245	342	110	72	145

Fig. 4. Actual number of foraminifers within each of the investigated samples. The sample ranges in the upper part of the diagram refer to their vertical range above the top of the Fish Clay.

*tylocidaris vexillifera* forma  $\gamma$  of Ødum (1926).

In a contemporary study, Rosenkrantz (1937) correlated the *T. oedumi* and *T. abildgaardi* zones at Stevns Klint with Ødum's Zone B, the *T. bruennichi* zone with Zone C, and the *T. vexillifera* zone with Zone D (Fig. 3). The lowermost part of the Danian, which is barren of *Tylocidaris*, was regarded as the oldest zone and correlated with Ødum's Zone A, which corresponds to the Cerithium Limestone. Rosenkrantz (1937) suggested that the overlying *T. oedumi* zone is c. 5 m thick at Stevns Klint. Hansen (1977) correlated the *Tylocidaris* zones with a newly established biostratigraphic zonation based on dinoflagellate cysts, which subdivided the Danian succession into four dinoflagellate cyst zonules (Fig. 3). He demonstrated that the *Tylocidaris* zones are facies dependent and diachronous becoming progressively younger towards the northwestern, deeper part of the Danish Basin.

Troelsen (1957) was the first to describe a succession of planktonic foraminiferal assemblages through the Danian stage of Denmark. Although his material was limited, a total of six samples from the entire Danian in Denmark, he reached some interesting conclusions. He adopted the *Tylocidaris*-based zonal scheme of Rosenkrantz (1937) and studied one sample from each of the four oldest zones, and two samples from the *Tylocidaris vexillifera* zone. The foraminiferal

composition changed considerably during the Danian, and '*Globigerina pseudobulloides*' sensu Troelsen (includes both *Parasubbotina pseudobulloides*, *Eoglobigerina eobulloides* and possibly *Globanomalina* sp. A according to the taxonomic interpretation of the present authors) dominates the basal Danian 'zone with no *Tylocidaris*', and the succeeding *T. oedumi* zone. The sample from the 'zone with no *Tylocidaris*' was collected north of Holtug quarry, and contained 32 specimens of planktonic foraminifers dominated by *P. pseudobulloides*. *Globoconusa daubjergensis* occurred very sporadically in the two lower zones (Troelsen 1957, fig. 24). The succeeding *T. abildgaardi* zone contained '*Globigerina pseudobulloides*' together with *G. daubjergensis*, while the overlying *T. bruennichi* and *T. vexillifera* zones were dominated by *G. daubjergensis*. In addition to this species, the *T. bruennichi* zone was also characterised by the first occurrence of *Subbotina triloculinoides* (*Globigerina triloculinoides* of Troelsen 1957), and the youngest Danian zone, the *T. vexillifera* zone by the first occurrence of *Globanomalina compressa* (*Globigerina compressa* of Troelsen 1957).

The same general development was documented by Berggren (1960, 1962), who undertook a more detailed study of the foraminiferal succession in the Danish Danian succession (Fig. 3). In his interpreta-



Højerup			Sigerslev quarry		Mandehoved	Holtug quarry			Total
Hr-B 20-30 cm	Hr-E 45-50 cm	base of Bryozoan Limestone Hr-G (a+b+c)	Si-A 3-12 cm	Si-B 17-25 cm	Mh-A 0-8 cm	Ht-A 0-10 cm	Ht-B 10-15 cm	Ht-E 40-60 cm	
	2	18	1	5	3	58	11	4	143
	1			12	7	4		1	64
									17
						1			1
						1			2
									1
1	24	38	6	77	112	557	149	88	1202
	5	29		5		17	5	7	107
		1				6	1		2
		16							15
1		4	1		2	21	25	3	17
2	32	106	8	99	124	665	191	103	67
2	31	90	5	46	51	71	53	67	1622
101	71	11	150	107	105	236	144	46	2032
101	71	11	150	107	105	236	146	46	4
94	69	9	91	49	44	25	41	30	2036
4		1	6	11	12	33	21	5	132
4	0	1	6	11	12	33	21	5	3
4	0	1	4	5	5	4	6	3	135
2	2	73	6	3	7	38	3	0	278
109	105	191	170	220	248	972	361	154	4071

tion, *S. triloculinoides* had its first occurrence already in the upper part of the *T. abildgaardi* zone and *G. compressa* in the middle part of the *T. bruennichi* zone. The biserial species, *Chiloguembelina morsei* and *C. midwayensis* were reported from most of the Danian succession. Berggren (1960, 1962) formalised the *G. daubjergensis* Zone for the Danian succession of Denmark and Sweden, and the *G. compressa* Subzone for the upper part of the succession, correlating with the upper part of the *T. bruennichi* zone and the *T. vexillifera* zone (Fig. 3).

Bang (1969, 1980, 1982) attempted a subdivision of the Danian succession in Denmark based on planktonic foraminifers. However, the zones were not described in detail, nor where they formally defined, but useful information may be extracted from the published range-charts (Bang 1969, fig. 4; Bang 1982, fig. B1). Three biozones, the *Eoglobigerina danica*, *Globoconusa daubjergensis* and *Subbotina triloculinoides* zones were recognised, including a total of seven foraminiferal zonules and assemblages.

A detailed study of the latest Maastrichtian and early Danian foraminifers from Højerup at Stevns Klint were presented by Schmitz *et al.* (1992). A small planktonic assemblage from a sample of the boundary layer between the Fish Clay and the Cerithium Limestone, 5–7 cm above the base of the Fish Clay

were isolated, but no absolute abundances were given (Schmitz *et al.* 1992, table 1). The sample contained rare *Eoglobigerina danica*, '*Globoconusa conusa*' and *Woodringina hornerstownensis* together with *Guembelina* spp., *Heterohelix* spp. (comparatively common) and three planktonic species, which originated already in the Cretaceous. The overlying sample from the middle of the Cerithium Limestone contained 28 planktonic specimens including the first occurrence of *Globoconusa daubjergensis* and '*Eoglobigerina*' *taurica*. *Parasubbotina pseudobulloides* is missing from the Cerithium Limestone according Schmitz *et al.* (1992, table 1); however, it is indicated to occur already from the 25 cm level within the middle part of the Cerithium Limestone in their range-chart (Schmitz *et al.* 1992, fig. 2).

## Foraminiferal assemblages

The present study includes samples from the Cerithium Limestone at five localities along Stevns Klint from Rødvig (at Korsnæb) in the south, through the Højerup region, Sigerslev quarry and Mandehoved to Holtug quarry in the northern part of the cliff (Fig. 1). The foraminiferal assemblage in the 40–125 µm

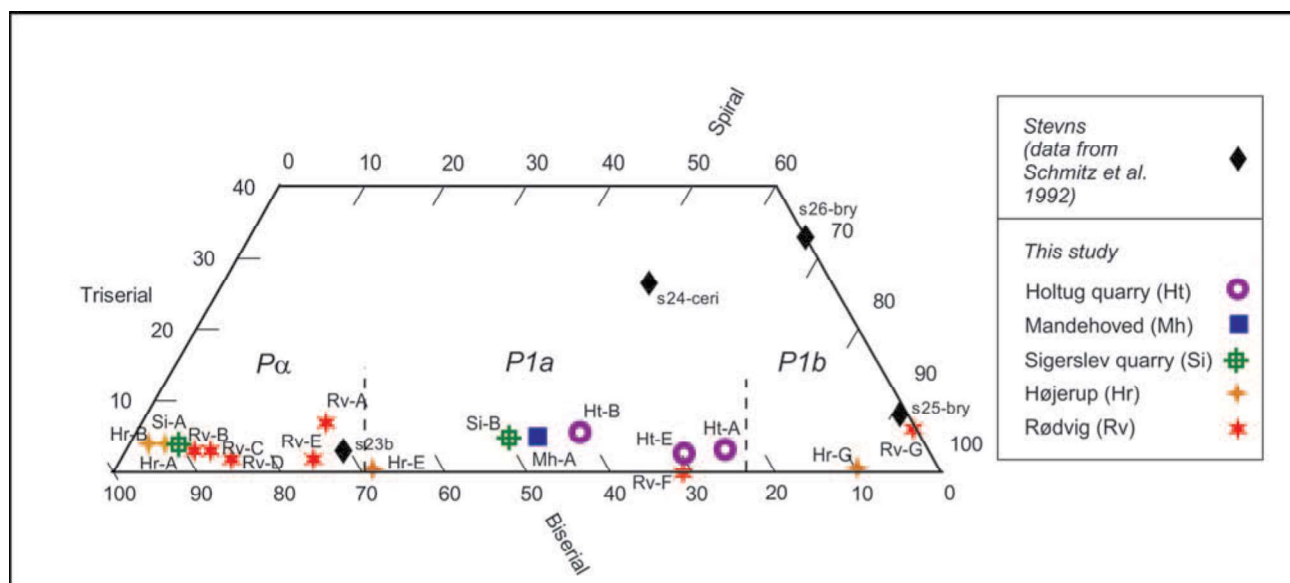


Fig. 5. Triangle Plot showing the relative distribution (percent) of triserial, biserial and trochospiral planktic foraminifers in the Cerithium Limestone at Stevns Klint. Data from Schmitz *et al.* (1992) are shown for comparison. Zonation after Berggren & Miller (1988).

fraction is completely dominated by calcitic planktonic taxa, and only limited assemblages of calcitic and aragonitic benthonic taxa were observed. The planktonic fraction of the total foraminiferal assemblage within the Cerithium Limestone varies from 74% (sample Rv-A) to 100% (Rv-E, 6, Ht-E) with an average of 96% (Fig. 4). In comparison, the planktonic content within the basal part of the overlying bryozoan limestone averages approximately 50% (Rv-G, Hr-G).

The average spiral : biserial : triserial ratio of the planktonic assemblage is 41% : 55% : 4% in the Cerithium Limestone, showing that foraminifers with biserial and spiral chamber arrangements are much more common than triserial taxa (Figs 4, 5). However, the average ratio of the P $\alpha$  Zone (19% : 77% : 4%) is significantly different from that of the P1a Zone (59% : 37% : 4%), making the ratio useful for regional correlation (Heinberg *et al.* 2001; Heinberg 2005, this volume). The diversity is generally low with a few dominating species.

## Rødvig (Korsnæb)

The succeeding description of the foraminiferal assemblages is solely concentrated on three main groups of planktonic foraminifers (PF): spiral, biserial and triserial morphotypes. The three groups have been shortened spiral PF, biserial PF and triserial PF in the following.

The lower five samples from the Fish Clay basin at Rødvig (Korsnæb) (Rv-A–Rv-E) were collected from the 0–50 cm interval above the base of the Cerithium Limestone. They are characterised by biserial PF comprising 71–89% of the total foraminiferal assemblage. Biserial PF includes both *Heterohelix* spp. and *Chiloguembelina* spp., but because of the generally poor preservation of the specimens from the Cerithium Limestone, it was only occasionally possible to distinguish between the two genera. As a result, *Heterohelix* and *Chiloguembelina* are listed together (Figs 4, 6).

*Globoconusa daubjergensis* is the dominant spiral PF (4–15%) followed by *Eoglobigerina eobulloides* and *Globanomalina* sp. A. *Guembelitra cretacea* is common in Rv-A (7% of the total planktic foraminiferal assemblage), but less so (2–3%) in the four overlying samples. The lowermost sample, Rv-A, contains a single, badly preserved specimen referred to *Globanomalina? planocompressa*.

The uppermost sample from the Cerithium Limestone at Rødvig (Korsnæb), Rv-F from the 65–75 cm interval, contains an assemblage characterised by the first appearance of *Parasubbotina pseudobulloides* (29%) and by a distinct reduction in the relative number of biserial PF (31%). *Subbotina triloculinoides* has its first appearance in the basal part of the overlying bryozoan limestone (Rv-G), where a single specimen was observed together with a single specimen of *Globanomalina cf. compressa*.

## Højerup

The basal sample from the Cerithium Limestone at Højerup (Hr-A, 10–20 cm) contains a foraminiferal assemblage similar to that of the lower to middle part of the Cerithium Limestone at Rødvig (Korsnæb). It comprises abundant biserial PF (*Chiloguembelina* spp. and *Heterohelix globulosa* constitute 92% of the total planktonic assemblage) together with rare *G. daubjergensis*, *Globanomalina* sp. A and *G. cretacea*. The overlying samples, Hr-B (20–30 cm) and Hr-E (45–50 cm) are characterised by the appearance of *P. pseudobulloides* and a relative increase in the number of *G. daubjergensis*. *Subbotina triloculinoides* has its first appearance in the basal sample of the overlying bryozoan limestone, where it comprises 8% of the foraminiferal assemblage.

## Sigerslev quarry

Two samples were studied. The lowermost sample (Si-A) from 3–12 cm above the base of the Cerithium Limestone is dominated by biserial PF (91% of the total planktonic assemblage) and contains only a limited number of spiral (5%, mainly *G. daubjergensis*) and triserial (4%) morphotypes. The overlying sample, Si-B from 17–25 cm, are characterised by a decrease in biserial PF (50%) and the appearance of *P. pseudobulloides* (2%). *G. daubjergensis* is by far the most common spiral PF representing 36% of the total planktonic foraminifers. *Eoglobigerina eobulloides* and *Globanomalina* sp. A are rare, while triserial PF (*G. cretacea*) comprises about 5% of the total planktonic assemblage.

## Mandehoved

One sample was studied from Mandehoved (Fig. 1). The sample (Mh-A) was collected from the lowermost 8 cm of the Cerithium Limestone. The spiral : biserial : triserial planktonic ratio is very similar to the one known from the upper sample at Sigerslev quarry (Si-B) and is represented by the following values; 51% : 44% : 5% (Figs. 4, 5). A notable difference is, however, that *P. pseudobulloides*, which occur in Si-B, is absent from Mh-A.

## Holtug quarry

Three samples were studied from Holtug: Ht-A from 0–10 cm above the base of the Cerithium Limestone, Ht-B from 10–15 cm and Ht-E from the uppermost part of the unit (40–60 cm). In contrast to the localities south of this, all of the Holtug samples are dominated by spiral PF. Ht-A is dominated by *G. daubjergensis* (60%), while *E. eobulloides* comprises 6% and *P. pseudobulloides* 2% of the total planktonic assemblage. Biserial PF represents 25% and triserial PF (*G. cretacea*) 4% of the planktonic assemblage. Ht-B contains a higher ratio of biserial PF (41%) but spiral PF are still the dominating constituent. *G. daubjergensis* comprises 42% of the total planktonic assemblage, and triserial PF (*G. cretacea*) 6%. The uppermost 20 cm of the Cerithium Limestone (sample Ht-E) is characterised by an increase in the number of *P. pseudobulloides* (6%) and *G. daubjergensis* (57%), while biserial morphotypes decrease to 30% of the total planktonic assemblage.

## Foraminiferal biostratigraphy of the Cerithium Limestone

Most of the published Danian foraminiferal zonations are based primarily on low and mid latitude assemblages (e.g. Blow 1979; Tourmakine & Luterbacher 1985; Berggren & Miller 1988; Keller 1988; Berggren & Norris 1997), but also collections from the North Sea and North Atlantic regions are occasionally included (King 1983, 1989; Gradstein *et al.* 1994). The latter three publications focused on the subdivision of the Cenozoic succession of the North Sea with only limited attention to the subdivision of the Danian.

The present study largely follows the zonation of Berggren & Miller (1988), who made a detailed description and definition of Danian (and Paleogene) foraminiferal biozones, which seems to be readily applicable to Stevns Klint. An exception is the P0 Zone (see below), which follows the definition of Keller (1988).

### P0. *Guembelitra cretacea* Partial Range Zone (*sensu* Keller 1988)

*Definition.* Partial range of the nominate species between the Last Appearance Datum of Cretaceous taxa (e.g. *Rugoglobigerina*, *Globotruncana*, *Globigerinelloides*) at the K-T boundary and the first appearance of *Parvularugoglobigerina eugubina*.

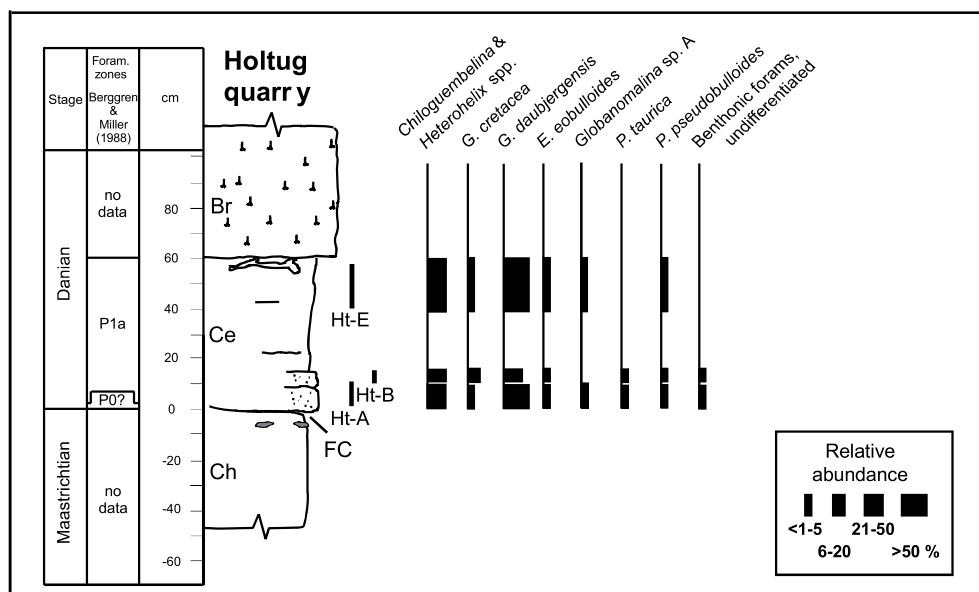
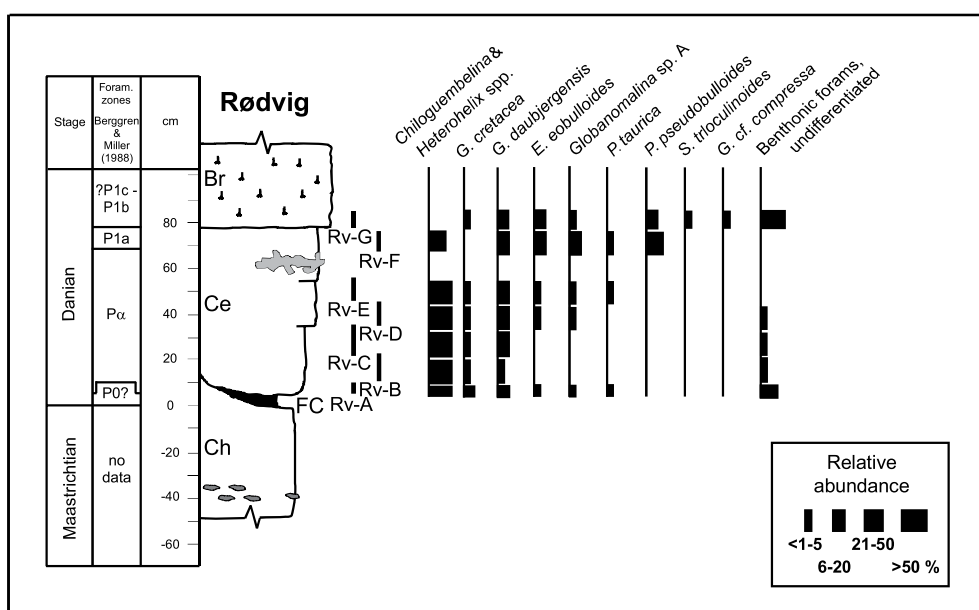
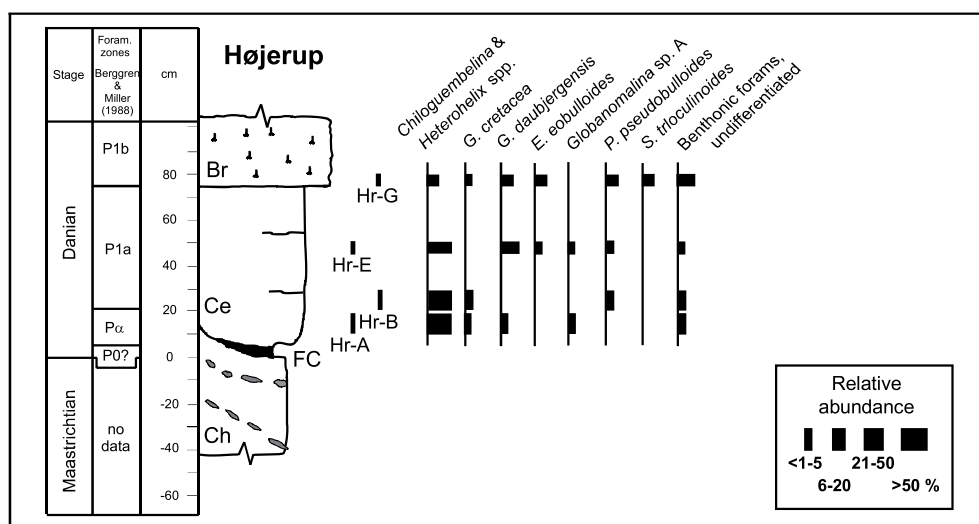


Fig. 6. Foraminiferal ranges and biostratigraphy of the Cerithium Limestone at Rødvig (Korsnæb), Højerup and Holtug quarry. The relative abundance of each taxonomic unit is indicated by the size of the bar. Abbreviations as in Fig. 2.



*Remarks.* Recent work on deep sea cores and a restudy of the El Kef stratotype section have revealed that the global significance of the P0 Zone may be questioned. Hence, it has been suggested that *P. eugubina* is more abundant in deep-sea sections compared with shallow-marine sections, leading to the assumption that the P0 Zone represents a shallow-marine biofacies (Norris *et al.* 1999). Zone P0 has not been recognised at Stevns Klint by means of foraminifers. The zone covers the black boundary clay at El Kef (Keller 1988) or only the very basal part of this (Norris *et al.* 1999). Although calcareous microplankton is virtually absent in the Fish Clay at Stevns Klint – possibly as a result of dissolution – it seems reasonable to assume that P0 corresponds with the Fish Clay interval at Stevns Klint.

### Pα. *Parvularugoglobigerina eugubina* Partial Range Zone

*Definition.* Interval from the first appearance of *Parvularugoglobigerina eugubina* to the first appearance of *Parasubbotina pseudobulloides sensu stricto* (modified from Berggren & Miller 1988).

*Characteristics.* At Stevns Klint, the zone is characterised by abundant biserial morphotypes (*Chiloguembelina* spp. and *Heterohelix globulosa*), while *Globoconusa daubjergensis*, although the most common spiral planktonic species, occurs only in small numbers. *Eoglobigerina eobulloides* and *Globanomalina* sp. A occur sporadically, while the nominate species *P. eugubina* is missing, probably due to the relatively shallow, subtidal palaeoenvironment (Norris *et al.* 1999).

*Distribution and thickness.* Rødvig (Korsnæb): the 0–50 (65?) cm interval above the base of the Cerithium Limestone; Højerup: the 10 (0?)–20 cm interval above the base of the Cerithium Limestone, and Sigerslev quarry: the 3–12 cm interval above the base of the Cerithium Limestone. The *P. eugubina* Zone (Pα) was not observed at Holtug quarry.

*Remarks.* The correlation with the *P. eugubina* Zone is based on circumstantial evidence. The absence of *Parasubbotina pseudobulloides sensu stricto* and the high percentage of biserial planktonic morphotypes, including the Cretaceous survivor species *Heterohelix globulosa* (see Heinberg 2005, this volume and Fig. 5 herein), indicate that this interval at Stevns is laterally equivalent to the *P. eugubina* Zone at Nye Kløv in northern Jutland, when compared with the data from Bang (1980) and Keller *et al.* (1993). Olsson *et al.* (1999) regarded *Parvularugoglobigerina longiapertura*

as a junior synonym of *P. eugubina* and this interpretation is followed here. The *P. eugubina* Zone (Pα) of Berggren & Miller (1988) corresponds to Zone P1a by Keller *et al.* (1993, 1995).

### P1. *Parasubbotina pseudobulloides*–*Globoconusa daubjergensis* Partial Range Zone (Berggren & Miller 1988)

*Definition.* Concurrent partial ranges of the nominate taxa between the first appearance of *Parasubbotina pseudobulloides* (base) and the first appearance of *Præmurica uncinata* (top) (Berggren & Miller 1988).

*Remarks.* The P1 Zone was subdivided into the three subzones P1a, P1b and P1c by Berggren & Miller (1988). See below for further details.

#### P1a. *Parasubbotina pseudobulloides* Partial Range Subzone (Berggren & Miller 1988)

*Definition.* Partial range of the nominate species between its first appearance (base) and that of *Subbotina triloculinoides* (top).

*Characteristics.* The *P. pseudobulloides* Subzone (P1a) is dominated by spiral planktonic foraminifers at Rødvig (Korsnæb) and Holtug quarry, and *Globoconusa daubjergensis* is usually the most common. Other characteristic spiral morphotypes include *Eoglobigerina eobulloides*, *Globanomalina* sp. A, and *P. pseudobulloides*. The P1a Subzone at Højerup and Sigerslev quarry contains a considerably higher percentage of biserial specimens than the Rødvig (Korsnæb) and Holtug localities.

*Distribution and thickness.* Rødvig (Korsnæb): the 65–75 cm interval above the base of the Cerithium Limestone; Højerup region: the 20–50 cm interval above the base of the Cerithium Limestone; Sigerslev quarry: the 17–25 cm interval above the base of the Cerithium Limestone, and Holtug quarry: all of the 60 cm thick Cerithium Limestone.

*Remarks.* It is not understood why the biserial planktonic foraminifers are much more common (69–94%) in the P1a Subzone at Højerup than at the other localities (25–49%). One possibility is that the P1a strata are slightly older there than in the other localities. Alternatively, the compositional dissimilarities may reflect slight differences in taphonomy or depositional setting along the cliff.

**P1b. *Subbotina triloculinoides* Partial Range Subzone (Berggren & Miller 1988, emend. Berggren *et al.* 1995)**

*Definition.* Partial range of nominate species from its first appearance (base) to the first appearance of *Globanomalina compressa* and/or *Praemurica inconstans* (top).

*Remarks.* The *S. triloculinoides* Subzone (P1b) characterises the lower part of the bryozoan limestone at Stevns Klint. This unit has not been investigated in detail here, but scattered spot samples have shown that P1b is represented at least at Rødvig (Korsnæb) and Højerup. Very small morphotypes of *Globanomalina* cf. *compressa*, which are characterised by a slightly more rounded periphery than *G. compressa sensu stricto* have their first appearance within the lower 2 m of the bryozoan limestone, at Rødvig (Korsnæb) already from just above the base of the unit.

## Discussion

The presence of a hiatus between the Fish Clay and the Cerithium Limestone at Stevns Klint was proposed by Schmitz *et al.* (1992) to span most or all of their Zone P1a (= *P. eugubina* Zone), or even as much as the entire interval from Zone P0 to within the lower part of P1c *sensu* Keller (1988) and Keller *et al.* (1993, 1995) (cf. Fig. 3). The latter interval correlates with the interval from Zone P0 to within the *P. pseudobulloides* Subzone (P1a) or *S. triloculinoides* Subzone (P1b) *sensu* Berggren & Miller (1988), but the correlation between the two zonal schemes is difficult due to different taxonomic interpretations.

The data presented here confirm the presence of a hiatus, corresponding approximately to the *P. eugubina* Zone, but only in the northern part of Stevns Klint. On the other hand, our data indicate that no hiatus exists in the southern part of Stevns Klint at Rødvig (Korsnæb). Schmitz *et al.* (1992) based their interpretations on a series of samples from south of Højerup Church, close to the locality 'Højerup' included in the present study. As discussed below, the assemblages from Højerup indicate that strata equivalent to the *P. eugubina* Zone do exist in the lower part of the section, and the hiatus at this site thus can not include more than part of the *P. eugubina* Zone. Furthermore, no sedimentological indication of a hiatus at this level has been found (Håkansson & Thomsen 1999).

The *Parvularugoglobigerina eugubina* Zone (P $\alpha$ ) *sen-*

*su* Liu & Olsson (1992) and Berggren *et al.* (1995) was defined by the total range of the nominate taxon. It corresponds to the P1a Zone of Keller *et al.* (1995). We failed – like Schmitz *et al.* (1992) – in finding *P. eugubina* in the Stevns Klint sections despite a considerably larger material. *P. eugubina* is a well known constituent from basal Danian assemblages at low palaeolatitudes such as Tunisia, Egypt, Spain, Italy, southern USA (e.g. Alabama, Texas), the southern Atlantic (e.g. DSDP site 528) and the northern Pacific Ocean (e.g. Luterbacher & Premoli Silva 1964; Blow 1979; Keller 1988, 2003; D'Hondt 1991; Canudo *et al.* 1991; McLeod 1995; Berggren & Norris 1997), but it is also described from intermediate and high latitudes such as Nye Kløv, Denmark (Bang 1980 [as 'New Genus L sp.']; Keller *et al.* 1993), where it occurs sparsely in the 0.2–1.2 m interval above the base of the Danian according to Keller *et al.* (1993). The Cerithium Limestone at Stevns Klint is generally interpreted as a more shallow water equivalent to the succession at Nye Kløv (Håkansson & Thomsen 1999; Heinberg 2005, this volume), and it is probable that the apparent lack of *P. eugubina* at Stevns Klint is due to palaeoenvironmental differences (Norris *et al.* 1999).

In view of the lack of the nominate species, the correlation with the *P. eugubina* Zone has been based on the following criteria: The initial appearance of *P. pseudobulloides* marks the top of P $\alpha$  as defined by Berggren & Miller (1988). Liu & Olsson (1992), Berggren *et al.* (1995) and Olsson *et al.* (1999) instead used the total range of *P. eugubina* to define the P $\alpha$  Zone. However, it was noted by Berggren *et al.* (1995) that the first appearance of *P. pseudobulloides* and the last appearance of *P. eugubina* were stratigraphically very close. Keller *et al.* (1995, 2002) indicated that *P. pseudobulloides* has its first appearance well below the last appearance of *P. eugubina*. The main reason for the difference between this interpretation and that of Berggren *et al.* (1995) and Olsson *et al.* (1999) is that the latter authors differentiated between an early morphotype, *Parasubbotina* aff. *pseudobulloides*, and *P. pseudobulloides sensu stricto*, while Keller *et al.* (1995, 2002) regarded them as representing varieties of one species. In the present study, we have used the initial appearance of *P. pseudobulloides* s.s. to mark the top of the P $\alpha$  Zone.

The first appearance of *Chiloguembelina* spp. is usually reported from levels within the *P. eugubina* Zone at low latitudes (e.g. Keller 1988; Liu & Olsson 1992) or even from very close to the base of this zone (D'Hondt 1991; Karoui-Yaakoub *et al.* 2002). Bang (1980) reported *Chiloguembelina* from the *P. eugubina* Zone at Nye Kløv, Denmark, showing that it occurs already from the lower part of the zone also at north-

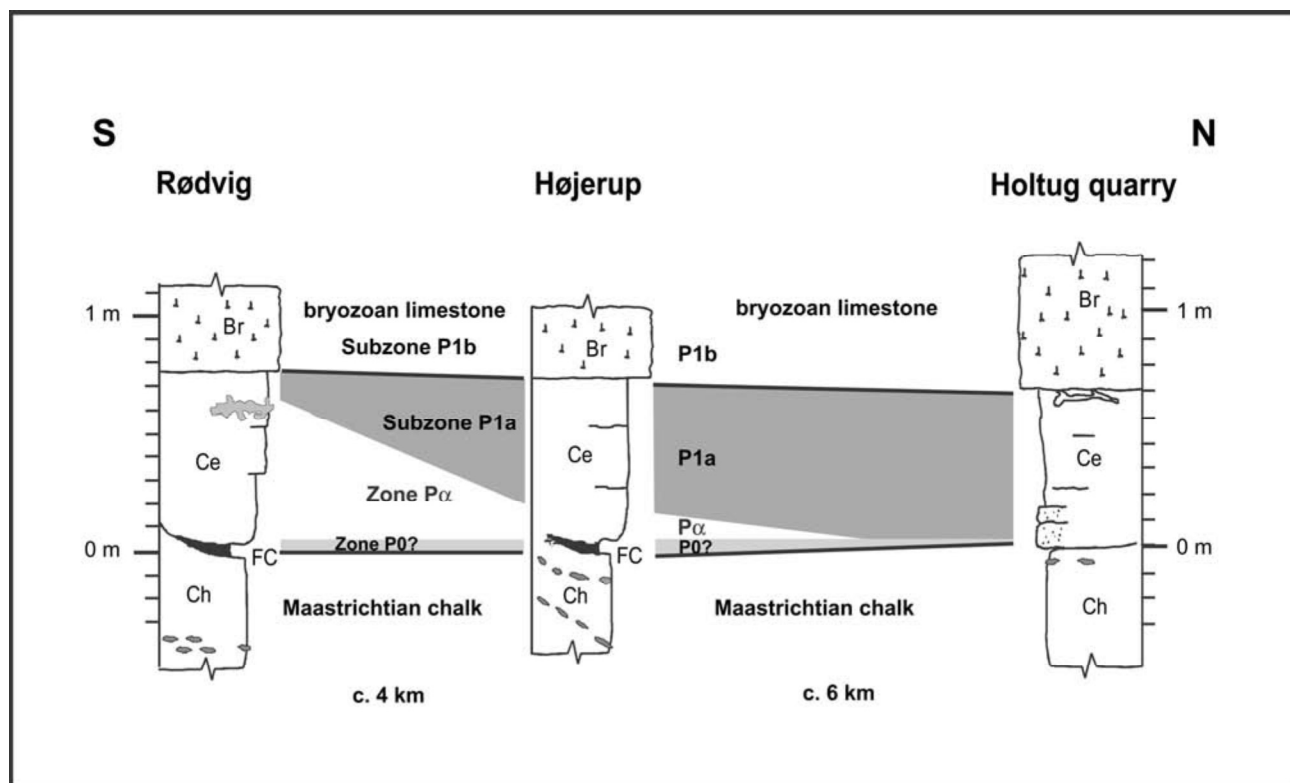


Fig. 7. Correlation between the Rødvig (Korsnæb), Højerup and Holtug quarry sections by use of planktonic foraminifers. Approximate distance between the localities is indicated in the lower part. Abbreviations as in Fig. 2; zonation after Berggren & Miller (1988).

ern high latitudes. The *Heterohelix-Chiloguembelina* ratio is apparently higher at Rødvig (Korsnæb) than at the more northern localities along Stevns Klint. This further indicates that an older part of the  $P\alpha$  Zone is preserved at Rødvig than further north at Stevns Klint, although reliable identification of many specimens is hampered due to the lack of morphological detail.

The ratio between biserial and spiral (e.g. Malmgren 1982; Haslett 1994) and biserial and triserial (e.g. Schmitz *et al.* 1992) planktonic foraminifers have proven to be valuable in palaeoenvironmental interpretations. Haslett (1994) showed that the biserial : spiral ratio was reduced to zero above the *P. eugubina* Zone at Bidart, south-west France. Heinberg *et al.* (2001) and Heinberg (2005, this volume) correlated the basal Danian beds at Nye Kløv, Jutland with the Stevns Klint succession in great detail using the spiral : serial (biserial and triserial) ratio in a strictly stratigraphic sense. The overall correlation concurs with the results encountered in the present paper (see also Fig. 5), suggesting that the main part of the Cerithium Limestone at Rødvig correlates with the *P. eugubina* Zone.

## Conclusion

Our study underlines the necessity to include very small specimens (40–125  $\mu\text{m}$ ) in studies of at least the basal Danian foraminiferal assemblages (Keller 2003). All of the Cerithium Limestone at Rødvig (Korsnæb), except the uppermost 10 cm, is referred to the *P. eugubina* Zone ( $P\alpha$ ), while the uppermost part belongs to the overlying *P. pseudobulloides* Subzone ( $P1a$ ). This pattern changes laterally towards the north (Fig. 7), where the  $P\alpha$  Zone becomes gradually thinner, and at the northernmost locality, Holtug quarry, the entire Cerithium Limestone unit is characterised by assemblages of the *P. pseudobulloides* Subzone ( $P1a$ ).

A hiatus exists between the basal Danian Fish Clay and the overlying Cerithium Limestone in the northern part of Stevns Klint comprising at least all of the  $P\alpha$  Zone, whereas the Fish Clay – Cerithium Limestone transition seems to be stratigraphically complete in the Fish Clay basins in the southern part of the cliff. Thus, the base of the Cerithium Limestone is diachronous and becomes gradually younger from the southern part of Stevns Klint towards the north.

Our biostratigraphic data are consistent with the

well-known, hardground associated hiatus between the Cerithium Limestone and the overlying bryozoan limestone (e.g. Rosenkrantz 1924; Schmitz *et al.* 1992; Surlyk 1997). Subsequent to the hardground formation, Subzone P1a was consistently eroded at the top all along Stevns Klint. However, the pronounced increase in thickness of this subzone from south to north is taken to indicate that also the top of the Cerithium Limestone may be diachronous (cf. Fig. 3).

## Palaeontological notes

The classification follows primarily that of Olsson *et al.* (1999).

Kingdom Protozoa Goldfuss, 1818  
Order Foraminiferida Eichwald, 1930  
Family Guembelitridae Montanaro Gallitelli, 1957

Genus *Guembelitra* Cushman, 1933

*Type species. Guembelitra cretacea* Cushman, 1933.

*Guembelitra cretacea* Cushman, 1933  
Fig. 8D

- 1933 *Guembelitra cretacea* n. sp. Cushman, p. 37, pl. 4, fig. 12a–b.
- 1999 *Guembelitra cretacea* Cushman - Olsson *et al.* pp. 79–80, fig. 31; pl. 8, figs 1–3; pl. 13, fig. 3; pl. 63, figs 1–12 (with additional synonymy).
- 2003 *Guembelitra cretacea* Cushman - Keller, pl. 4, figs 1–6.
- 2003 *Guembelitra trifolia* (Morozova) - Keller, pl. 2, fig. 13.
- 2003 *Guembelitra irregularis* Morozova - Keller, pl. 2, fig. 14.

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb), Højerup, Sigerslev quarry, Mandehoved, Holtug quarry.

*Material.* 132 specimens.

Genus *Globoconusa* Khalilov, 1956

*Type species. Globoconusa conusa* Khalilov, 1956.

*Globoconusa daubjergensis* (Brönnimann, 1953)  
Fig. 8G–I.

- 1953 *Globigerina daubjergensis* n. sp. Brönnimann, p. 340, text-fig. 1.
- 1970b *Globoconusa daubjergensis* (Brönnimann) - Hansen, pp. 343–344; pl. 1, figs 1–2; pl. 2, figs 1–2; pl. 3, figs 1–2; pl. 4, figs 1–2 (with additional synonymy).

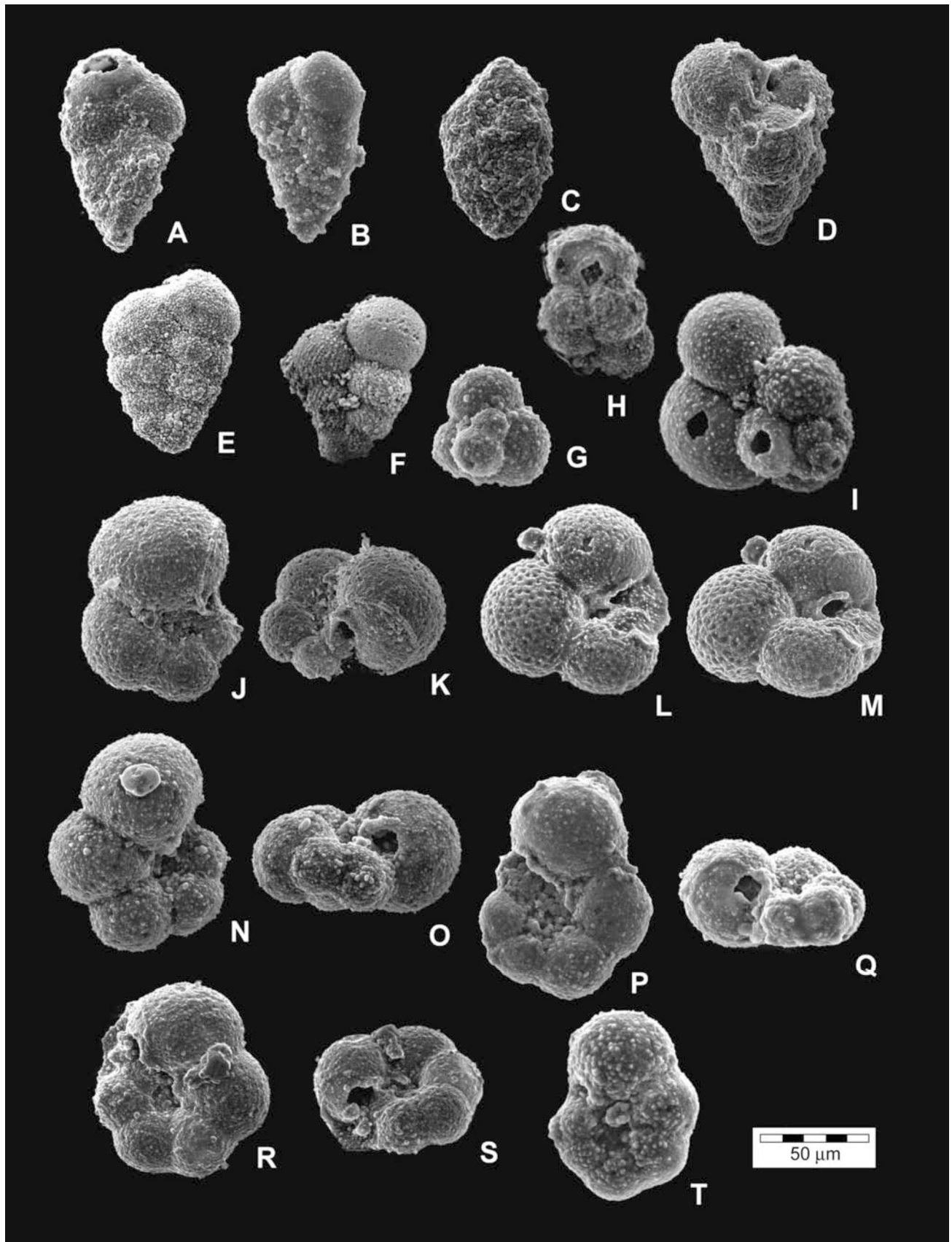
---

*Facing page:*

Fig. 8

A–B: *Chiloguembelina morsei* (Kline). A: sample Rv-B (Rødvig), *P. eugubina* Zone (Pα), MGUH 27502, B: sample Rv-E (Rødvig), *P. eugubina* Zone (Pα), MGUH 27503.  
C: *Zeauvigerina waiparaensis* (Jenkins), sample Rv-B (Rødvig), *P. eugubina* Zone (Pα), MGUH 27504.  
D: *Guembelitra cretacea* Cushman, sample Rv-B (Rødvig), *P. eugubina* Zone (Pα), MGUH 27505  
E: *Heterohelix globulosa* (Ehrenberg)?, sample Rv-C (Rødvig), *P. eugubina* Zone (Pα), MGUH 27506. Faint striae.  
F: *Heterohelix globulosa* (Ehrenberg), sample Rv-B (Rødvig), *P. eugubina* Zone (Pα), MGUH 27507. Distinct striae.  
G–I: *Globoconusa daubjergensis* (Brönnimann). G: sample Rv-E (Rødvig), *P. eugubina* Zone (Pα), MGUH 27508; H: sample Rv-C (Rødvig), *P. eugubina* Zone (Pα), MGUH 27509; I: sample Ht-E (Holtug quarry), *P. pseudobulloides* Subzone (P1a), MGUH 27510. Large, multi-chambered morphotype.  
J–M: *Eoglobigerina eobulloides* (Morozova). J: Sample Rv-D (Rødvig), *P. eugubina* Zone (Pα), MGUH 27511. Umbilical view. K: Same specimen as J in oblique view. L: Sample Ht-E (Holtug quarry), *P. pseudobulloides* Subzone (P1a), MGUH 27512. Umbilical view; M: Same specimen as L in oblique view.  
N, O: *Parasubbotina pseudobulloides* (Plummer). N: sample Ht-E (Holtug quarry), *P. pseudobulloides* Subzone (P1a), MGUH 27513. Umbilical view. O: sample Ht-E (Holtug quarry), *P. pseudobulloides* Subzone (P1a), MGUH 27514. Lateral view.  
P, Q: *Globanomalina* sp. A. P: sample Rv-F (Rødvig), *P. pseudobulloides* Subzone (P1a), MGUH 27515. Umbilical view; Q: sample Rv-F (Rødvig), *P. pseudobulloides* Subzone (P1a), MGUH 27516. Lateral view.  
R, S: ?*Globanomalina* sp. A. Sample Rv-D (Rødvig), *P. eugubina* Zone (Pα), MGUH 27517. Umbilical view, six chambers in last whorl; S: Same specimen as R in oblique view.  
T: *Praemurica taurica* (Morozova). Sample Rv-D (Rødvig), *P. eugubina* Zone (Pα), MGUH 27518. Umbilical view, six chambers in last whorl (last chamber broken).





1999 *Globoconusa daubjergensis* (Brönnimann) - Olsson *et al.*, pp. 80–81, fig. 32; pl. 8, figs 4–6; pl. 15, fig. 13–14; pl. 64, figs 1–12 (see additional synonymy).

2003 *Globoconusa daubjergensis* (Brönnimann) - Keller, pl. 6, figs 2–3.

?2003 *Parvularugoglobigerina extensa* (Blow) - Keller, pl. 6, fig. 1 (only).

*Remarks.* The interpretation of *Globoconusa daubjergensis* follows that of Hansen (1970b), who regarded *G. conusa* Khalilov, *G. kozlowskii* Brotzen & Pózaryska and *G. daubjergensis gigantea* Bang as junior synonyms of *G. daubjergensis* Brönnimann. See Hansen (1970b) for description.

*Occurrence.* Rødvig (Korsnæb), Højerup, Sigerslev quarry, Mandehoved, Holtug quarry.

*Material.* 1202 specimens.

Genus *Woodringina* Loeblich & Tappan, 1957

*Type species.* *Woodringina claytonensis* Loeblich & Tappan, 1957.

*Woodringina* sp. indet.  
Not illustrated

*Remarks.* Three badly preserved specimens of possible *Woodringina* were observed from the Rødvig (Korsnæb) section.

*Material.* 3 specimens.

Family Heterohelcidae Cushman, 1927

Genus *Heterohelix* Ehrenberg, 1840

*Type species.* *Textilaria americana* Ehrenberg, 1843.

*Heterohelix globulosa* (Ehrenberg, 1840)  
Fig. 8E(?)–F.

1840 *Textularia globulosa* n. sp. Ehrenberg, p. 135, pl. 4, figs 2b, 4b, 5b, 7b, 8b.

1991 *Heterohelix globulosa* (Ehrenberg) – Nederbragt, pp. 341–343, pl. 2, figs 1a–2b.

2003 *Heterohelix globulosa* (Ehrenberg) – Keller, pl. 3, fig. 2.

?2003 *Heterohelix striata* (Ehrenberg) – Keller, pl. 3, fig. 1.

*Remarks.* *Heterohelix* was discussed and revised by Nederbragt (1991). The generally bad preservation of the present material makes it difficult to distinguish *Heterohelix* from *Chiloguembelina*, and the two genera have been treated as one group in the present study.

*Occurrence.* *Heterohelix* and/or *Chiloguembelina* were observed from Rødvig (Korsnæb), Højerup, Sigerslev quarry, Mandehoved and Holtug quarry.

*Material.* 2032 specimens of *Heterohelix* and *Chiloguembelina* undifferentiated.

Genus *Zeauvigerina* Finlay, 1939

*Type species.* *Zeauvigerina zealandica* Finlay, 1939.

*Zeauvigerina waiparaensis* (Jenkins, 1965)  
Fig. 8C.

1965 *Chiloguembelina waiparaensis* n. sp. Jenkins, p. 1095, pl. 1, figs 1–6.

1999 *Zeauvigerina waiparaensis* (Jenkins) - Olsson *et al.* pp. 97–98, text-fig. 37; pl. 71, figs 1–18 (with additional synonymy).

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb) and Holtug quarry.

*Material.* 4 specimens.

Family Chiloguembelinidae Reiss, 1963

Genus *Chiloguembelina* Loeblich & Tappan, 1956

*Type species.* *Guembelina midwayensis* Cushman, 1940.

*Chiloguembelina morsei* (Kline, 1943)  
Fig. 8A–B.

- 1943 *Gümbelina morsei* n. sp. Kline, p. 44, pl. 7, fig. 12.  
1999 *Chiloguembelina morsei* (Kline) - Olsson *et al.* pp. 91–92, pl. 13, figs 14–15, pl. 69, figs 9–15 (with additional synonymy).

Remarks. See notes about ‘*Heterohelix*’ above.

Family Hedbergellidae Loeblich & Tappan, 1961

Genus *Globanomalina* Haque, 1956

Type species. *Globanomalina ovalis* Haque, 1956.

*Globanomalina* ?*planocompressa* (Shutskaya, 1965)  
Not illustrated

- ?1965 *Globorotalia planocompressa planocompressa* n. sp.  
Shutskaya, p. 179; pl. 1, fig. 6a–c.  
?1999 *Globanomalina planocompressa* (Shutskaya) -  
Olsson *et al.* pp. 44; pl. 36, figs 1–6 (with additional synonymy).

Remarks. A probable but broken specimen of *Globanomalina planocompressa* was observed from the lowermost sample at Rødvig (Korsnæb). See Olsson *et al.* (1999) for description.

Occurrence. Rødvig (Korsnæb).

Material. 1 specimen.

*Globanomalina* sp. A  
Fig. 8P–S

Remarks. *Globanomalina* sp. A has typically a globanomalinitid wall structure, 5–?6 chambers in the ultimate whorl of the low to medium trochospiral test. The specimens from the Cerithium Limestone are generally badly preserved and a proper description of the species awaits an investigation of supplementary material from other Danish localities. It is supposed that *Globanomalina* sp. A is synonymous with one of the morphotypes of ‘*Globigerina*’ *danica* ssp. 1

shown by Bang (1971, plate 1, fig. ?4, 6 (only)). *Globanomalina* sp. A, however, differs significantly from the morphotypes of ‘*Globigerina*’ *danica* Bang displayed initially by Bang (1969, plate 1, figs 1–3). The latter types share similarities with *Parasubbotina varianta* (Bang 1969, pl. 1, fig. 1a–c), *Eoglobigerina eobulloides* (Bang 1969, pl. 1, fig. 2a–c) and *Eoglobigerina edita* (Bang 1969, pl. 1, fig. 3a–c).

Occurrence. Rødvig (Korsnæb), Sigerslev quarry, Mandehoved and Holtug quarry.

Material. 64 specimens.

Family Globigerinidae Carpenter, Parker & Jones, 1862

Genus *Eoglobigerina* Morozova, 1959

Type species. *Globigerina* (*Eoglobigerina*) *eobulloides* Morozova, 1959.

*Eoglobigerina eobulloides* (Morozova, 1959)  
Fig. 8J–M

- 1959 *Globigerina* (*Eoglobigerina*) *eobulloides* n. sp.  
Morozova, p. 1115, text-fig. 1a–c.  
1999 *Eoglobigerina eobulloides* (Morozova) - Olsson  
*et al.* pp. 20–22; fig. 8; pl. 8, figs 10–12, pl. 19,  
figs 1–15 (with additional synonymy).  
2003 *Eoglobigerina eobulloides* (Morozova) - Keller, pl.  
6, fig. 15.

Remarks. See Olsson *et al.* (1999) for description.

Occurrence. Rødvig (Korsnæb), Højerup, Sigerslev quarry, Mandehoved and Holtug quarry.

Material. 143.

Genus *Parasubbotina* Olsson, Hembleben, Berggren & Liu, 1992

Type species. *Globigerina pseudobulloides* Plummer, 1926.

*Parasubbotina pseudobulloides* (Plummer, 1926)  
Fig. 8N, O

*Synonymy.*

1926 *Globigerina pseudobulloides* n. sp. Plummer, p. 133; pl. 8, fig. 9a–c.

1999 *Parasubbotina pseudobulloides* (Plummer, 1926) - Olsson *et al.* pp. 24–25; fig. 10; pl. 21, figs 1–15 (with additional synonymy).

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb), Højerup, Sigerslev quarry and Holtug quarry.

*Material.* 107.

*Parasubbotina* aff. *pseudobulloides* (Plummer, 1926)  
Not illustrated

aff. 1926 *Globigerina pseudobulloides* n. sp. Plummer, p. 133; pl. 8, fig. 9a–c.

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb).

*Material.* 2 specimens.

Genus *Subbotina* Brotzen & Pozaryska, 1961

*Type species.* *Globigerina triloculinoides* Plummer, 1926.

*Subbotina triloculinoides* (Plummer, 1926)  
Not illustrated

1926 *Globigerina triloculinoides* n. sp. Plummer, p. 134, pl. 8, fig. 10a–b.

1999 *Subbotina triloculinoides* (Plummer) - Olsson *et al.* pp. 31–32; fig. 12; pl. 9, figs 13–15; pl. 14, figs 15–16; pl. 27, figs 1–13 (with additional synonymy).

2003 *Subbotina triloculinoides* (Plummer) - Keller, pl. 6, figs 5–7.

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb) and Højerup.

*Material.* 17.

Family Truncorotaloididae Loeblich & Tappan, 1961

Genus *Praemurica* Olsson, Hemleben, Berggren & Liu, 1992

*Type species.* *Globigerina* (*Eoglobigerina*) *taurica* Morozova, 1961.

*Praemurica taurica* (Morozova, 1961)  
Fig. 8T

1961 *Globigerina* (*Eoglobigerina*) *taurica* n. sp. Morozova, p. 10; pl. 1, fig. 5a–c.

1999 *Praemurica taurica* (Morozova) - Olsson *et al.* pp. 75–76; fig. 29; pl. 10, figs 1–3; pl. 61, figs 1–15 (with additional synonymy).

*Remarks.* See Olsson *et al.* (1999) for description.

*Occurrence.* Rødvig (Korsnæb), Højerup and Holtug quarry.

*Material.* 15.

## Acknowledgements

We are indebted to Malcolm Hart and Finn Surlyk for their careful review and many helpful suggestions to improve the manuscript. We thank the Carlsberg Foundation for a grant in support of the present study. SEM help by Kurt Nielsen and palaeontological discussions with Hans Jørgen Hansen are greatly acknowledged. Anne-Grete Winding is warmly thanked for preparation of samples.

## References

- Bang, I. 1969. Planktonic foraminifera and biostratigraphy of the type Danian. In: Brönniman, P. & Renz, H.H. (eds): Proceedings of the First Conference on Planktonic Microfossils 1, 58–65. Geneva.
- Bang, I. 1971. Planktonic foraminifera of the lowermost Danian. In: Farinacci, A. (ed.): Proceedings of the Second Planktonic Conference, 17–24. Roma.
- Bang, I. 1979a: Foraminifera in the lowermost Danian of Denmark. In: Birkelund, T. & Bromley, R.G. (eds): Cretaceous–Tertiary Boundary Events, Symposium, Copenhagen, 114–118.
- Bang, I. 1979b: Foraminifera from the type sections of the eugubina Zone compared with those from Cretaceous/Tertiary boundary localities in Jylland, Denmark. In: Birkelund, T. & Bromley, R.G. (eds): Cretaceous–Tertiary Boundary Events, Symposium, Copenhagen, 127–130.
- Bang, I. 1980: Foraminifera from the type section of the eugubina zone compared with those from Cretaceous/Tertiary boundary localities in Jylland, Denmark. Danmarks Geologiske Undersøgelse Årbog 1979, 139–165.
- Bang, I. 1982: Biostratigraphic investigation of Danian in boreholes 505 and 515 Store Bælt, on the basis of planktonic foraminifera. In: Larsen, G., Baumann, J. & Tychsen, J. (eds): Danish Geotechnical Institute Bulletin 34, 51–70.
- Berggren, W.A. 1960: Biostratigraphy, planktonic Foraminifera and the Cretaceous–Tertiary boundary in Denmark and southern Sweden. 21st International Geological Congress, proceedings section 5, 181–192. Copenhagen.
- Berggren, W.A. 1962: Some planktonic foraminifera from the Maestrichtian and type Danian stages of southern Scandinavia. Stockholm Contributions in Geology 9, 1–106.
- Berggren, W.A., Kent, D.V., 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 stratigraphic correlation. Society for Sedimentary Geology Special Publication 54, 129–212.
- Berggren, W.A. & Miller, K.G. 1988: Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. Micropaleontology 34, 362–380.
- Berggren, W.A. & Norris, R.D. 1997: Biostratigraphy, phylogeny and systematics of Paleocene spiral planktic foraminifera. Micropaleontology 43 (Supplement 1), 1–116.
- Blow, W.H. 1979: The Cainozoic Globigerinida; a study of the morphology, taxonomy, evolutionary relationships and the stratigraphical distribution of some Globigerinida (mainly Globigerinacea). 1016 pp. E. J. Brill. Leiden, Netherlands.
- Brinkhuis, H., Bujak, J. P., Smit, J., Versteegh G.J.M. & Visscher, H., 1998: Dinoflagellate-based sea surface temperature reconstructions across the Cretaceous–Tertiary boundary. Palaeogeography, Palaeoclimatology, Palaeoecology 141, 67–83.
- Brotzen, F. (1948): The Swedish Paleocene and its foraminiferal fauna. Sveriges Geologiska Undersökning Serie C (1) 493, 140 pp.
- Brotzen, F. & Pozaryska, K. 1961: Foraminifères du Paléocène et de l'Eocène inférieur en Pologne septentrionale; remarques paléogéographiques. Revue de Micropaléontologie 4, 155–166.
- Brönniman, P. 1953: Note on planktonic foraminifera from Danian localities of Jutland, Denmark. Eclogae Geologicae Helvetiae 45, 339–341.
- Canudo, J.I., Keller, G. & Molina, E. 1991: Cretaceous/Tertiary boundary extinction pattern and faunal turnover at Agost and Caravaca, S.E. Spain. Marine Micropaleontology 17, 319–341.
- Carpenter, W.B., Parker, W.K. & Jones, T.R. 1862: Introduction to the Study of the Foraminifera. Royal Society Publications London, 1–139.
- Christensen, L., Frejerslev, S., Simonsen, A. & Thiede, J. 1973: Sedimentology and depositional environments of lower Danian fish clay from Stevns Klint, Denmark. Bulletin of the Geological Society of Denmark 22, 193–212.
- Culver, S.J., 2003: Benthic foraminifera across the Cretaceous–Tertiary (K-T) boundary: a review. Marine Micropaleontology 47, 177–226.
- Cushman, J.A. 1927: Some new genera of the foraminifera. Contributions from the Cushman Laboratory for Foraminiferal Research 3, 71–81.
- Cushman, J.A. 1933: Some new foraminiferal genera. Contributions from the Cushman Laboratory for Foraminiferal Research 9, 32–38.
- Cushman, J.A. 1940: Midway Foraminifera from Alabama. Contributions from the Cushman Laboratory for Foraminiferal Research 16, 51–73.
- Desor, E. 1847: Sur le terrain danien, nouvel étage de la craie. Bulletin de la Société géologique de France 2, 179–182.
- D'Hondt, S.L. 1991: Phylogenetic and stratigraphic analysis of earliest Paleocene biserial and triserial planktonic foraminifera. Journal of Foraminiferal Research 21, 168–181.
- Ehrenberg, C.G. 1840: Über die Bildung der Kreidefelsen und des Kreidemergels durch Übersichtbare Organismen. Königl. Akademie der Wissenschaften zu Berlin Physikalische Abhandlungen, 1838, 59–147 (in German).
- Ehrenberg, C.G. 1843: Verbreitung und Einfluss des mikroskopischen Lebens in Süd- und Nord-Amerika. Abhandlungen königlichen preussischen Akademie Wissenschaften zu Berlin (1843) 1, 291–446.
- Eichwald, C.E. von 1930: Zoologia specialis 2, 323 pp. D.E. Eichwaldus, Vilnia.
- Finlay, H.J. 1939: New Zealand Foraminifera: Key Species in Stratigraphy – No. 2. Transactions of the Royal Society of New Zealand 69, 309–329.
- Goldfuss, G.A. 1818: Über die Classification der Zoophyten. Oken's Isis, 1008–1013.
- Gradstein, F.M., Kaminski, M.A., Berggren, W.A., Kristiansen, I.L. & D'Iorio, M.A. 1994: Cenozoic biostratigraphy of the North Sea and Labrador Shelf. Micropaleontology 40, supplement, 1–152.
- Hansen, H.J. 1970a: Danian foraminifera from Nûgssuaq, West Greenland. Meddelelser om Grønland 193, 1–132.
- Hansen, H.J. 1970b: Biometric studies on the stratigraphic evolution of *Globoconusa daubjergensis* (Brönniman) from the Danian of Denmark. Bulletin of the Geological Society of Denmark 19, 341–360.
- Hansen, H.J., Gwondz, R., Hansen, J.M., Bromley, R.G. & Rasmussen, K.L. 1986: The diachronous C/T plankton extinction in the Danish Basin. In: Walliser, O. (ed.): Global bio-events, 381–384. Springer Verlag, Amsterdam.
- Hansen, J.M. 1977: Dinoflagellate stratigraphy and echinoid distribution in Upper Maastrichtian and Danian deposits from Denmark. Bulletin of the Geological Society of Denmark 26, 1–26.

- Hansen, J.M. 1979: A new dinoflagellate zone at the Maastrichtian / Danian boundary in Denmark. *Danmarks Geologiske Undersøgelse Årbog* 1978, 131–140.
- Haque, A.F.M.M. 1956: The Foraminifera of the Ranikot and the Laki of the Nammal Gorge, Salt Range. *Pakistan Geological Survey, Paleontologia Pakistanica* 1, 1–300.
- Haslett, S.K. 1994: Planktonic foraminiferal biostratigraphy and palaeoceanography of the Cretaceous–Tertiary boundary section at Bidart, southwest France. *Cretaceous Research* 15, 179–192.
- Heinberg, C. 2005: Morphotype biostratigraphy, diachronism, and bivalve recovery in the earliest Danian of Denmark. *Bulletin of the Geological Society of Denmark* 52, 81–95 (this volume).
- Heinberg, C., Rasmussen, J.A. & Håkansson, E. 2001: Planktic Foraminifera from the lowermost type Danian of Stevns Klint, Denmark. In: Harper, D.A.T. (ed.): Abstracts, 45th Annual Meeting of the Palaeontological Association December, 2001. Geological Museum, Copenhagen.
- Hofker, J. 1960: The foraminifera of the lower boundary of the Danish Danian. *Meddelelser fra Dansk Geologisk Forening* 14, 212–242.
- Hultberg, S. 1986: Danian dinoflagellate zonation, the C–T boundary and the stratigraphical position of the fish clay in southern Scandinavia. *Journal of Micropalaeontology* 5, 37–47.
- Håkansson, E. & Thomsen, E. 1999: Benthic extinction and recovery patterns at the K/T boundary in shallow water carbonates, Denmark. *Palaeogeography, Palaeoclimatology, Palaeoecology* 154, 67–85.
- Jenkins, D.G. 1965: Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand. *New Zealand Journal of Geology and Geophysics* 8, 1088–1126.
- Karoui-Yaakoub N., Zaghib-Turki D. & Keller G. 2002: The Cretaceous–Tertiary (K–T) mass extinction in planktic Foraminifera at Elles I and El Melah, Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 178, 233–255.
- Keller, G. 1988: Extinction, survivorship and evolution of planktic foraminifera across the Cretaceous/Tertiary boundary at El Kef, Tunisia. *Marine Micropaleontology* 13, 239–263.
- Keller, G. 2003: *Guembelitra* dominated late Maastrichtian planktic foraminiferal assemblages mimic early Danian in the Eastern Desert of Egypt. *Marine Micropaleontology* 47, 71–99.
- Keller, G., Barrera, E., Schmitz, B. & Mattson, E. 1993: Gradual mass extinction, species survivorship, and long-term environmental changes across the Cretaceous–Tertiary boundary in high latitudes. *Geological Society of America Bulletin* 105, 979–997.
- Keller, G., Li, L. & MacLeod, N. 1995: The Cretaceous/Tertiary boundary stratotype section at El Kef, Tunisia: how catastrophic was the mass extinction? *Palaeogeography, Palaeoclimatology, Palaeoecology* 119, 221–254.
- Keller, G., Adatte, T., Stinnesbeck, W., Luciani, V., Karoui-Yaakoub, N. & Zaghib-Turki, D. 2002: Paleocology of the Cretaceous–Tertiary mass extinction in planktonic foraminifera. *Palaeogeography, Palaeoclimatology, Palaeoecology* 178, 257–297.
- Khalilov, D.M. 1956: O pelagicheskoy faune foraminifer Paleogenoviykh otlozheniy Azerbaydzhana. *Trudy Instituta Geologii, Akademii Nauk Azerbaydzhanskoy SSR* 17, 234–255 (in Russian).
- King, C. 1983: Cainozoic micropalaeontological biostratigraphy of the North Sea. *Institute of Geological Sciences Report* 82-7, 1–40.
- King, C. 1989: Cenozoic of the North Sea. In: Jenkins, D.G. and Murray, J.W. (eds): *Stratigraphical atlas of fossil foraminifera*, 418–489. Ellis Horwood, Chichester.
- Kjellström, G. & Hansen, J.M. 1981: Dinoflagellate biostratigraphy of the Cretaceous–Tertiary boundary in southern Scandinavia. *Geologisk Föreningens i Stockholm Förhandlingar* 103, 271–278.
- Kline, V.H. 1943: Clay County fossils; Midway foraminifera and Ostracoda. *Mississippi State Geological Survey Bulletin* 53, 1–98.
- Liu, C.J. & Olsson, R.K. 1992: Evolutionary radiation of microperforate planktonic foraminifera following the K/T Mass Extinction Event. *Journal of Foraminiferal Research* 22, 328–346.
- Loeblich, A.R. & H. Tappan 1956: *Chiloguembelina*, a new Tertiary genus of the Heterohelidae (Foraminifera). *Journal of the Washington Academy of Sciences* 46, 340.
- Loeblich, A.R. & Tappan, H. 1957: *Woodringina*, a new foraminiferal genus (Heterohelidae) from the Paleocene of Alabama. *Journal of the Washington Academy of Sciences* 47, 39–40.
- Loeblich, A.R. & Tappan, H. 1961: Suprageneric classification of the Rhizopodea. *Journal of Paleontology* 35, 245–330.
- Luterbacher, H.P. & Premoli Silva, I. 1964: Biostratigrafia del limite Cretaceo–terziario nell’ Appennino centrale. *Revista Italiana di Paleontologia* 70, 67–117.
- MacLeod, N. 1995: Graphic correlation of high latitude Cretaceous–Tertiary boundary sequences at Nye Kløv (Denmark), ODP Site 690 (Weddell Sea), and ODP Site 738 (Kerguelen Plateau): Comparison with the El Kef (Tunisia) boundary stratotype. *Modern Geology* 19, 109–147.
- Malmgren, B. 1982: Biostratigraphy of planktic Foraminifera from the Maastrichtian white chalk of Sweden. *Geologiska Föreningens i Stockholm Förhandlingar* 103, 357–375.
- Martini, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (ed.): *Proceedings of the Second Planktonic Conference Roma 1970*. Edizioni Tecnoscienza Rome 2, 739–785.
- Montanaro Gallitelli, E., 1957: A revision of the foraminiferal family Heterohelidae. In: Loeblich, A.R. Jr., & collaborators (eds): *Studies in Foraminifera*, United States National Museum Bulletin 215, 133–154.
- Morozova, V.G. 1959: Stratigrafiya Datsko-Montskikh Otlozhenii Kryma Po Foraminiferam [Stratigraphy of the Danian–Montian deposits of the Crimea according to Foraminifera]. *Doklady Akademii Nauk SSSR* 124, 1113–1116 (in Russian).
- Morozova, V.G. 1961: Datsko-Montskie planktonnye foraminifery yuga SSSR [Danian–Montian Planktonic Foraminifera of the southern USSR]. *Paleontologicheskii Zhurnal* 2, 8–19 (in Russian).
- Nederbragt, A.J. 1991: Late Cretaceous biostratigraphy and development of Heterohelidae (planktic Foraminifera). *Micropaleontology* 37, 329–372.
- Nielsen, K.B. 1937: Faunaen i Ældre Danium ved Korporalskroen. *Meddelelser fra Dansk Geologisk Forening* 9, 117–126.
- Norris, R. D., Huber, B. T. & Self-Trail, J. 1999: Synchronicity of the K–T oceanic mass extinction and meteorite impact: Blake Nose, western North Atlantic. *Geology* 27, 419–422.

- Olsson, R.K., Hemleben, C., Berggren, W.A. & Liu, C. 1992: Wall texture classification of planktonic Foraminifera genera in the Lower Danian. *Journal of Foraminiferal Research* 22, 195–213.
- Olsson, R.K., Hemleben, C., Berggren, W.A. & Huber, B.T. 1999: Atlas of Paleocene planktonic foraminifera. *Smithsonian Contributions to Paleobiology* 85, 252 pp.
- Perch-Nielsen, K., 1979: Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark. In: Birkelund, T. & Bromley, R.G. (eds): *Cretaceous–Tertiary boundary events 1. The Maastrichtian and Danian of Denmark*, 115–135. University of Copenhagen.
- Plummer, H.J. 1926: Foraminifera of the Midway Formation in Texas. *University of Texas Bulletin* 2644, 206 pp.
- Rasmussen, J. & Sheldon, E. 2004: The Maastrichtian-Danian boundary of the TUBA-13 drill core, central Copenhagen, Denmark. In: Sheldon, E., Stouge, S. & Henderson, A. (eds): *The Micropalaeontological Society Calcareous Plankton Spring meeting (Joint Nannofossil and Foraminifera Group Meeting) Geocenter Copenhagen. Abstracts and Field Guide. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2004/50*, 58.
- Reiss, Z. 1963: Reclassification of perforate Foraminifera. *Bulletin of the Geological Survey of Israel* 35, 1–111.
- Rosenkrantz, A. 1924: Nye Iagttagelser over Cerithiumkalken i Stevns Klint med Bemærkninger om Grænsen mellem Kridt og Tertiær. *Meddelelser fra Dansk Geologisk Forening* 6, 28–31.
- Rosenkrantz, A. 1937: Bemærkninger om det østjællandske Daniens Stratigrafi og Tektonik. *Meddelelser fra Dansk Geologisk Forening* 9, 199–212.
- Schmitz, B., Keller, G. & Stenvall, O. 1992: Stable isotope and foraminiferal changes across the Cretaceous–Tertiary boundary of Stevns Klint, Denmark: Arguments for long-term oceanic instability before and after bolide-impact event. *Palaeogeography, Palaeoclimatology, Palaeoecology* 96, 233–260.
- Shutskaya, E.K. 1965: Filogeneticheskie vzaimootnoscheniya vidov gruppy *Globorotalia compressa* Plummer v datskom vekhe i paleotzenovoi epokhe [On the phylogenetic relations of the species of the *Globorotalia compressa* Plummer group during Danian time and the Paleocene epoch]. *Voprosy Mikropaleontologii, Akademiya Nauk SSSR* 9, 173–188 (in Russian).
- Stouge, S., Hjortkær, B.F., Rasmussen, J.A., Roncaglia, L. & Sheldon, E. 2000: Micro- and nannofossil biostratigraphy across the Danian/Selandian (Paleocene) Stage boundary at Gemmas Allé, Copenhagen, Denmark. *GFF* 122, 161–162.
- Surlyk, F. 1997: A cool-water carbonate ramp with bryozoan mounds: Late Cretaceous-Danian of the Danish Basin. In: James, N. P. & Clarke, J. D. A. (eds): *Cool-water carbonates. SEPM Special Publication* 56, 293–307.
- Surlyk, F. & Birkelund, T. 1977: An Integrated Stratigraphical Study of Fossil Assemblages from the Maastrichtian White Chalk of Northwestern Europe. In: Kaufmann, E. G. & Hazel, J. E. (eds): *Concepts and Methods of Biostratigraphy*, 257–281. Dowden; Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania.
- Thomsen, E. 1995: Kalk og kridt i den danske undergrund. In: Nielsen, O.B. (ed.): *Danmarks Geologi fra Kridt til i dag. Aarhus Geokompender* 1, 31–67. Aarhus.
- Tourmakine, M. & Luterbacher, H. 1985: Paleocene and Eocene planktic foraminifera. In: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds): *Plankton Stratigraphy*, 87–154. Cambridge University Press, Cambridge.
- Troelsen, J.C. 1957: Some planktonic foraminifera of the type Danian and their stratigraphic importance. *United States National Museum Bulletin* 215, 125–131.
- Wind, J. 1954: *Tylocidaris* Piggene som Ledeforsteninger i vort øvre Senon og Danien. *Meddelelser fra Dansk Geologisk Forening* 12, 481–490.
- Ødum, H. 1926: Studier over Daniet i Jylland og på Fyn. *Danmarks Geologiske Undersøgelse II Række* 45, 306 pp.