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

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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 (Pa). 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 (Pla). 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

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; Suryk & 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.

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 subsequently 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 vexilliformis* forma α, *T. vexillifera* forma γ and *Cyclaster brunni*, while the C and D zones are distinguished by the echinoid *Tylocidaris vexillifera* forma β and the brachiopod *Terebratula lens* (Ødum 1926). Nielsen (1937) refined the Danian echinoid-based zonation and introduced the name *Tylocidaris oedumi* for the zonal marker *Ty-
locidaris vexillifera forma γ 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. brunnichi 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 zones (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 foraminifer 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. brunnichi and T. vexillifera zones were dominated by G. daubjergensis. In addition to this species, the T. brunnichi zone was also characterised by the first occurrence of Subbotina triloculinoideae (Globigerina triloculinoideae 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-
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 Hjerup 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 hornersstownensis* together with *Guembelia* 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 Hjerup 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

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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 bryozaon 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 Pu 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 daughjergensis is the dominant spiral PF (4–15%) followed by Eoglobigerina eobullooides and Globanomalina sp. A. Guembelitria 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 pseudobullooides (29%) and by a distinct reduction in the relative number of biserial PF (31%). Subbotina triloculinooides has its first appearance in the basal part of the overlying bryozaon 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 (Korsøeb). 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 triloculinoidea 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. Eoglabigerina ebulloides 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. ebulloides 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; Tourmakin & 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. Guembelitria 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, Globotruncan, Globigerinelloides) at the K-T boundary and the first appearance of Parvularugoglobigerina eugubina.
Fig. 6. Foraminiferal ranges and biostratigraphy of the Cerithium Limestone at Redvig (Korsnæs), 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 re-study 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.

**Pca. 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 (*Chilognomelina* spp. and *Heterohelix globulosa*), while *Globocunus 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 (Korsnæs): the 0–50 (657) cm interval above the base of the Cerithium Limestone; Højerup: the 10 (07)–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 (Pca) 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 (Pca) of Berggren & Miller (1988) corresponds to Zone P1a by Keller et al. (1993, 1995).

**P1. Parasubbotina pseudobulloides—Globocunus 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 *Præmorica 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 (Korsnæs) and Holtug quarry, and *Globocunus 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 (Korsnæs) and Holtug localities.

**Distribution and thickness.** Rødvig (Korsnæs): 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 than in the other localities. Alternatively, the compositional dissimilarities may reflect slight differences in taphonomy or depositional setting along the cliff.

Definition. Partial range of nominat 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 Pareularugoglobigerina eugubina Zone (Pø) sensu 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 Pø 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 Pø 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 Pø 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; Karoufi-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-
ern high latitudes. The *Heterohelix-Chilougembelina* 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* 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 μm) 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*α), while the uppermost part belongs to the overlying *P. pseudobulloides* Subzone (*P*1a). This pattern changes laterally towards the north (Fig. 7), where the *P*α 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 (*P*1a).

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*α 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; Schnitzius et al. 1992; Surlýk 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 Guembelitriidae Montanaro Gallitelli, 1957

Genus Guembelitria Cushman, 1933

Type species. Guembelitria cretacea Cushman, 1933.

Guembelitria cretacea Cushman, 1933
Fig. 8D

1933 Guembelitria cretacea n. sp. Cushman, p. 37, pl. 4, fig. 12a–b.
1999 Guembelitria 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 Guembelitria cretacea Cushman - Keller, pl. 4, figs 1–6.
2003 Guembelitria trifolia (Morozova) - Keller, pl. 2, fig. 13.

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 (Brønnimann, 1953) Fig. 8G–I.

1953 Globoconusa daubjergensis n. sp. Brønnimann, p. 340, text-fig. 1.
1970b Globoconusa daubjergensis (Brønnimann) - 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).
1999  *Globoconusa daubjergensis* (Brønnimann) - 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* (Brønnimann) - Keller, pl. 6, figs 2–3.

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


**Occurrence.** Rødvig (Korsnæs), Højerup, Sigerslev quarry, Mandehoved and 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 (Korsnæs) section.

**Material.** 3 specimens.

Family Heterohelicidae Cushman, 1927

Genus *Heterohelix* Ehrenberg, 1840

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

*Heterohelix globulosa* (Ehrenberg, 1840)

Fig. 8E(?–E)

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


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


**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 (Korsnæs), Højerup, Sigerslev quarry, Mandehoved and Holtug quarry.

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

Genus *Zeauguigerina* Finlay, 1939

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

*Zeauguigerina waiparaensis* (Jenkins, 1965)

Fig. 8C.

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

1999  *Zeauguigerina 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 (Korsnæs) and Holtug quarry.

**Material.** 4 specimens.

Family Chiloguembelinidae Reiss, 1963

Genus *Chiloguembelina* Loeblich & Tappan, 1956

**Type species.** *Guembelina midwayensis* Cushman, 1940.
Chiloquembelina morsei (Kline, 1943)  
Fig. 8A-B.

1943 Gümbelina morsei n. sp. Kline, p. 44, pl. 7, fig. 12.
1999 Chiloquembelina 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 globanomalinid wall structure, 5–76 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. 7, 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 varia (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, Hemleben, Berggren & Liu, 1992

Type species. G. pseudobulloides Plummer, 1926.

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

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

Occurrence. Rødvig (Korsnæb) and Højerup.

Material. 17.

Family Truncorotaloididae Loeblich & Tappan, 1961

Genus Praemurica Olsson, Hembleben, 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.

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