Lower Cretaceous

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5.1 INTRODUCTION

Lower Cretaceous nannofossil biostratigraphy has a research history spanning the last 40 years, from Brönnimann (1955), whose nannoconid biostratigraphy of Cuba was one of the first applied nannofossil studies, through to the last ten years which has seen an immense amount of research, much of which has been directed at sections and industrial applications in the North Sea Basin and adjacent areas.

The first refined biostratigraphic zonation was developed by Thierstein (1971, 1973) based on low-latitude sample material, primarily the stage-stratotype and parastratotype sections of SE France. The marker-species utilized in this, and the subsequent but comparable zonations of Sissingh (1977) and Roth (1978), were predominantly large and distinctive tethyan taxa, essentially limiting biostratigraphic application to low latitudes or more strictly, western Tethys and the proto-Atlantic Ocean regions.

Perch-Nielsen (1979a) recognized the geographic limitations of these zonations, and using data from Speeton (NE England) and the North Sea Basin, inserted a number of important boreal events into the tethyan-based schemes. Since then, a progression of boreal Lower Cretaceous studies, both industry- and university-based, have described many new boreal nannofossil taxa and developed successively refined zonations, largely based upon Speeton, North Sea borehole data, and sections in northern Germany. Much of the impetus for this research has come from hydrocarbon exploration and development, with an unprecedented amount of data having been provided for this area.

Other valuable contributions have come from DSDP and ODP research from all of the world’s oceans, providing new information concerning palaeobiogeography and global correlation. There has also been some re-evaluation of southern European tethyan sections, which have provided calibration to the geomagnetic polarity time-scale.

Nannofossil biostratigraphy in the Lower Cretaceous now provides a resolution which is closely comparable to that of cephalopods, but more significant is the potential value of the group for global correlation in both epeiric and oceanic sediments. In addition, great advances are also being made in the fields of palaeobiogeography and palaeoceanography, which for the first time have used nannofossils as indicators of Cretaceous ocean environments.

5.2 IMPORTANT REFERENCES

Early biostratigraphic studies include Thierstein (1971, 1973), Sissingh (1977, 1978) and Roth (1978). The CC zones of Sissingh (1977) and NC zones of Roth (1978) have subsequently been widely applied although they have been substantially subdivided in recent years by Perch-Nielsen (1979a, 1985a), Bralower (1987), Applegate and Bergen (1988) and Bralower et al. (1989, 1993).

Lower Cretaceous calcareous nannofossils are now known from a wide geographic area including North America (Hill, 1976; Bralower, 1990), the N Atlantic Ocean (Wind and Cepek, 1979; Roth, 1983; Covington and Wise, 1987; Applegate and Bergen, 1988; Bralower et al., 1989), S Atlantic Ocean (Wise and Wind, 1977),
Indian Ocean (Mutterlose, 1992a; Bown, 1992b; Bralower, 1992), Pacific Ocean (Cepek, 1981; Roth, 1981; Erba and Covington, 1992) and Southern Ocean (Mutterlose and Wise, 1990) and recently from previously unstudied continental areas, including Papua New Guinea (Howe, 1995) and South America (Bown and Ellison, 1995; Mostajo et al., 1995).


Important re-evaluations of southern European tethyan sections are provided by Bralower et al. (1989), Bralower (1987), Bergen (1994) and Cecca et al. (1994).

Palaeoceanographic studies have provided many new ideas on the palaeoecology and palaeobiogeography of Early Cretaceous nannoplankton, including observations on bipolar and tropical/subtropical distributions (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Mutterlose, 1992a, b, 1996), indices of high surface-water fertility (Erba et al., 1992; Erba, 1992), and even the dynamics of subannual nannoplankton blooms (Thomsen, 1989a, b).

5.3 LOWER CRETAEOUS NANNOFOSSIL SUCCESION

The earliest Cretaceous nannofossil succession was a continuation of the Tithonian evolutionary radiation, which introduced several new nannolith and coccolith families as well as new taxa within established Jurassic families. Provincialism became less pronounced as the new groups became more widely distributed, but remained significant throughout the Early Cretaceous. The general trend through the interval was one of steady diversity increase.

The Tithonian radiation was characterized by the appearance of the new nannolith groups, Conusphaera, Nannoconaceae (Nannoconus), Microrhabdulaceae (Lithraphidites), Polycyclolithaceae (Polycostella) and Braarudosphaeraceae (Micrantholithus), all of which appeared cryptogenically. The timing of these appearances was originally thought to have been in the earliest Cretaceous, but recent studies of complete and well-preserved N Atlantic DSDP sites have shown that most were in the latest Tithonian (Bralower et al., 1989).

Many of the Jurassic families which had undergone high species-level extinctions in the Late Jurassic were also re-established during this radiation, although the timings of these events are still uncertain. The Cretarhabdaceae, in particular, diversified rapidly, having been rare and poorly-represented through most of the Jurassic.

The genus Watznaueria continued to dominate assemblages but the prevailing Jurassic species, W. britannica, was superseded by W. fossacincta and W. barnesae.

Following the Tithonian radiation, Neocomian assemblages were relatively stable, the commonest components including Watznaueria barnesae, W. fossacincta, Micrantholithus obtusus/hoschulzii, Rhagodiscus asper, Diazoomatolithus lehmani, and the simple murolith genera Zeugrhabdotus and Staurolithites. Low-latitude assemblages are characterized by abundant Nannoconus, although restricted acmes of this genus have also been recorded in higher latitudes (Mutterlose, 1989, 1992b). A low-magnitude and temporally-extended taxonomic turnover occurred at the Barremian/Aptian boundary, during which a number of new groups became established, including Eprolithus, Flabellites and Hayestites, whilst nannoconids declined, with the extinction of boreal species and a pronounced global nannoconid reduction in the Early Aptian (‘nannoconid crisis’ of Erba, 1994). By Late Aptian–Albian times, assemblages were significantly different to those of the Neocomian: Micrantholithus was replaced by rarer but closely-related Braarudosphaera; Rhagodiscus asper became rarer but was joined by new species of the same genus, particularly R. achlyostaurion; and a number of important new groups had appeared including Prediscosphaera and early representatives of the Arkhangelskiales (Acaenolithus, Brinsonia, Crucicribrum, Gartnerago), both of which went on to become characteristic components of Late Cretaceous nannofloras.
5.4 BIOSTRATIGRAPHY

The most refined biostratigraphic zonation schemes for the Lower Cretaceous have resulted from intense study of the NW European area, and therefore much of the following section will be concerned with data from this area. The most recent boreal zonations will provide the biostratigraphic framework and will be described in some detail. Later parts of the chapter will discuss the potential for worldwide correlation of these schemes, and correlation charts incorporate data from southern Europe and the ocean basins.

Research from the North Sea Basin and adjacent areas has produced a large amount of stratigraphic data including critical, macrofossil-dated outcrop material. Nannofossil biostratigraphic resolution down to ammonite-zone level is now achievable through much of the Lower Cretaceous, without recourse to any specific nannofossil zonation. While such a 'bioevent' approach is flexible, it is also desirable to have the framework zonation scheme against which other events may be calibrated. Additionally, it has become apparent that in certain intervals, e.g. the Upper Hauterivian and Lower Barremian, the sequence of nannofossil events is more rigorously defined than the cephalopod zones recognized onshore. Thus, while separate ammonite zonal terminologies are applied in Germany and England (e.g. discofalcatus AZ = marginatus and variabilis AZs), these strata are more easily and precisely correlated using nannofossils.

The boreal zonation presented below and in the biostratigraphic charts (Figs 5.1 and 5.2) is primarily drawn from Rutledge and Bown (in prep.) which represents the latest reappraisal of the Ryazanian–Aptian boreal nannofossil biostratigraphy based largely on Speeton and North Sea sections. However, this essentially represents a refinement of previous zonations, particularly those of Jakubowski (1987) and Crux (1989). The Albian zones are largely based upon well-established events but also include data from Crux (1991b) and Jeremiah (1996). Although these zonal schemes were developed in the North Sea Basin area, many of the events are much more widely applicable, and allow correlation with low latitude (—tethyan) and southern high-latitude zonations, as shown in Figs 5.1 and 5.2. The stratigraphic ranges of selected Lower Cretaceous nannofossil taxa are shown in Fig. 5.4. Marker species and principal assemblage components are illustrated in Plates 5.1 to 5.15.

Abundance terminology used in this chapter is as follows:

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<thead>
<tr>
<th>Term</th>
<th>Frequency</th>
<th>% of assemb.</th>
<th>#/FOV</th>
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<tbody>
<tr>
<td>Rare</td>
<td>0</td>
<td>&lt;1%</td>
<td>—</td>
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<tr>
<td>Frequent/Few</td>
<td>1–5</td>
<td>c.1%</td>
<td>&lt;1</td>
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<tr>
<td>Common</td>
<td>6–60</td>
<td>2–20%</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Abundant</td>
<td>&gt;60</td>
<td>&gt;20%</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Rare is used where one or several specimens, respectively, were recorded outside the standard 300 specimen count. The term acme is used for intervals of exceptional abundance (common/abundant) of a consistently present species.

BC1 Retepapsa angustiforata Zone


Definition. FO of Retepapsa angustiforata to the FO of Sollasites arcuatus.

Range. Ryazanian.

Remarks. The FO of R. angustiforata recorded in the Lower Berriasian of Tethys (Bergen, 1994) provides a convenient datum for the definition of a lower boundary. This zone is rarely encountered in the North Sea area, due to non-calcareous facies, and a regional unconformity between the Valhall Formation/Speeton Clay Formation and the underlying Kimmeridge Clay Formation.

BC2 Sollasites arcuatus Zone


Definition. Total range of Sollasites arcuatus.

Range. Upper Ryazanian (albidum AZ pars).

Remarks. S. arcuatus may be rare within this zone, which is otherwise characterized by frequent/common Sollasites spp. and Crucibiscutum salebrosum.

BC3 Crucibiscutum salebrosum Zone


Definition. LO of Sollasites arcuatus to the FO of Micrantholithus speetonensis.

Range. Uppermost Ryazanian (albidum AZ) to Lower Valanginian (Paratollia spp. AZ).

Remarks. Dominated by C. salebrosum, with conspicuous Kokia spp. and, in the upper part, Triquetrorhabdulus shetlandensis. Micrantholithus
Fig. 5.1 Neocomian nannofossil biostratigraphy. Boreal BC zones after Rutledge and Bown (in prep.); all events are calibrated to the boreal cephalopod zonation scheme. Tethyan NC zones after Roth (1978, 1983) with subdivisions after Bralower et al. (1989). Most events are calibrated against ammonite zones (predominantly using Bergen, 1984). The magnetostratigraphic scale is not well calibrated with the cephalopod stratigraphy and is included as a guide only, based on Bralower (1987), Bralower et al. (1989) and Cecce et al. (1994).

<table>
<thead>
<tr>
<th>BOREAL NF BIOSTRATIGRAPHY</th>
<th>BOREAL AMM. ZONES</th>
<th>STAGE</th>
<th>TETHYAN NF BIOSTRATIGRAPHY</th>
<th>TETHYAN AMM. ZONES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BC Zones</strong></td>
<td><strong>Secondary events</strong></td>
<td><strong>Zonal events</strong></td>
<td><strong>England</strong></td>
<td><strong>N Germany</strong></td>
</tr>
<tr>
<td>BC11 pars</td>
<td>S. collaris</td>
<td>Z. noetia acme</td>
<td>marginatus</td>
<td>discoloculatus (pars)</td>
</tr>
<tr>
<td>BC11b pars</td>
<td>re-entry. C. marginis</td>
<td>T. septentrionalis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC10</td>
<td>T. veryse</td>
<td>C. ciliifer</td>
<td>T. septentrionalis</td>
<td></td>
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<tr>
<td>BC9</td>
<td>C. archica</td>
<td>C. salibrom</td>
<td>T. septentrionalis</td>
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<tr>
<td>BC8c</td>
<td>R. globulus</td>
<td>Z. scutula</td>
<td>T. septentrionalis</td>
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<tr>
<td>BC8b</td>
<td>S. silvaricus</td>
<td>C. margarita acme</td>
<td></td>
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<tr>
<td>BC8a</td>
<td>T. octofoma</td>
<td>E. antiquus</td>
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<td>BC7</td>
<td>E. antiquus</td>
<td>T. shetlandensis</td>
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<td>BC6</td>
<td>E. striatus</td>
<td>Z. diapogonsum</td>
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<td>BC5</td>
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<tr>
<td>BC4b</td>
<td>M. speoetonia</td>
<td>E. windi</td>
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<tr>
<td>BC4a</td>
<td>C. ciliifer</td>
<td>S. collaris infrus</td>
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<tr>
<td>BC4b</td>
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<tr>
<td>BC3b</td>
<td>N. parvulum</td>
<td>T. shetlandensis</td>
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<td>BC3</td>
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</tr>
<tr>
<td>BC2</td>
<td>Z. embergeri infrus</td>
<td>S. arcuatus</td>
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<tr>
<td>BC1</td>
<td>R. angustiforata</td>
<td>K. borealis</td>
<td></td>
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</tbody>
</table>

Lower Cretaceous
brevis, the precursor of M. speetonensis, is a rare element of this and the underlying zone, and it is important that the definitions of these species are strictly applied.

**BC3a Subzone**  
**Author.** Rutledge and Bown (in prep.).  
**Definition.** LO of Sollasites arcuatus to the FO of Triquetrorhabdulus shetlandensis.  
**Range.** Uppermost Ryazanian and ?lowermost Valanginian (upper albidum AZ and possibly lower Paratollia spp. AZ).  
**Remarks.** *C. salebrosum* is the dominant taxon. *Kokia curvata, Kokia borealis* and *Nannoconus oviformis* are conspicuous elements, while *Sollasites* spp. are rare. *K. borealis* and *N. oviformis* have their LOs in this subzone (Perch-Nielsen, 1988).

**BC3b Subzone**  
**Author.** Rutledge and Bown (in prep.).  
**Definition.** FO of *Triquetrorhabdulus shetlandensis* to the FO of *Micrantholithus speetonensis*.  
**Range.** Lower Valanginian (Paratollia spp. AZ).  
**Remarks.** Dominated by *C. salebrosum*, with conspicuous *T. shetlandensis* and *K. curvata*. The latter species has only been recorded in the northern North Sea and Barents Sea, and may not have ranged into the southern North Sea.

**BC4 Micrantholithus speetonensis Zone**  
**Author.** (Taylor, 1982) Crux (1989, M. speetonensis Zone).  
**Definition.** The total range of *Micrantholithus speetonensis*.  
**Range.** Lower Valanginian (Paratollia spp. to Polyptychites spp. AZs).  
**Remarks.** This zone is subdivided using the FO of *Eiffellithus windii*, an important, interregionally correlatable event which is, however, difficult to precisely identify in the boreal area due to condensed Valanginian sections.

**BC4a Subzone**  
**Author.** Rutledge and Bown (in prep.).  
**Definition.** FO of *Micrantholithus speetonensis* to the FO of *Eiffellithus windii*.  
**Range.** Lower Valanginian (upper Paratollia spp. to lower Polyptychites spp. AZs).  
**Remarks.** Assemblages are dominated by *C. salebrosum*, with conspicuous *M. speetonensis*, *T. shetlandensis* and *Cyclagelosphaera brezae*. *Crucilliopsis cuvillieri* and *Speetonia colligata* are first recorded in boreal sections within this interval (the latter species commonly).

**BC4b Subzone**  
**Author.** Rutledge and Bown (in prep.).  
**Definition.** FO of *Eiffellithus windii* to the LO of *Micrantholithus speetonensis*.  
**Range.** Lower Valanginian (upper Polyptychites spp. AZ) to lowermost Upper Valanginian (?basal Dichotomites spp. AZ).  
**Remarks.** Due to regional unconformities and barren intervals, this interval has not yet been confidently identified in the boreal area.

**BC5 Triquetrorhabdulus shetlandensis Zone**  
**Author.** Rutledge and Bown (in prep.).  
**Definition.** LO of *Micrantholithus speetonensis* to the LO of *Triquetrorhabdulus shetlandensis*.  
**Range.** Upper Valanginian (?and lowermost Hauterivian (Dichotomites spp. to ?lowermost amblygonium AZs).  
**Remarks.** *E. windii* is the dominant form of *Eiffellithus* in the middle-upper Valanginian, and is largely superseded by *Eiffellithus striatus* (= 'Tegumentum tripes' in Mutterlose, 1991) in the uppermost Valanginian, but exact placement of the FO of *E. striatus* is presently problematical. *M. speetonensis* has been recorded from the hollwedensis AZ (lower Upper Valanginian) of Central Poland (Mutterlose, 1993), slightly later than most boreal records.

**BC6 Conusphaera rothii Zone**  
**Author.** (Mutterlose, 1991) Rutledge and Bown (in prep.).  
**Definition.** LO of *Triquetrorhabdulus shetlandensis* to the FO of *Eprolithus? antiquus*.  
**Range.** Lower Hauterivian (amblygonium AZ) (but possibly ranges lower, i.e. uppermost Hauterivian).  
**Remarks.** The base of this zone is also marked by the FO of *Conusphaera rothii*, although this
probably represents a first consistent occurrence in the boreal area, having been recorded sporadically from the Ryazanian (Crux, pers. obs.). Also characterized by common *C. margerelii*, frequent *E. striatus* and less frequent *E. windii*. *C. brezae* and *Stradnerlithus silvaradius* may be conspicuous.

**BC7 Eprolithus? antiquus Zone**


**Definition.** Total range of *Eprolithus? antiquus*.

**Range.** Lower Hauterivian (upper amblygonium to lower regale AZs).

**Remarks.** Abundant to common *C. margerelii*, with frequent/common *C. salebrosum*, frequent *E. striatus* and subordinate *E. windii*. *E.? antiquus* is rare to common. This zone is characterized by tethyan influences in the boreal area. *C. cuvillieri* and *Calcitalathina oblongata*, in particular, may be frequent.

**BC8 Cyclagelosphaera margerelii Zone**

**Author.** (Mutterlose, 1991) Rutledge and Bown (in prep.).

**Definition.** LO of *Eprolithus? antiquus* to the FO of *Tegulalithus septentrionalis*.

**Range.** Lower to lower Upper Hauterivian (regale to speetonensis AZs).

**Remarks.** *E. striatus* is a frequent and conspicuous element throughout, while *C. salebrosum* is frequent/common. *C. margerelii* is common in the lower part, and the top of this long-term acme is a useful subzonal event. *Perissocyclus plethotretus*, *Perissocyclus tayloriae*, *Rucinolithus windleyae* and *Zeugrhabdotus scutula* first appear towards the top of the zone. There appear to be no extinctions during this interval, other than the premature, regional (boreal) disappearances of *Helenea quadrata*, *C. oblongata* and *S. silvaradius*.

Jakubowski (1987) and Crux (1989) both subdivided this interval using the LO of *S. silvaradius*, however, this species is extremely rare in all but the basal Hauterivian of Germany (Crux, 1989; Mutterlose, 1991). In any case, Bergen (1994) recorded this species into the Upper Hauterivian of France and DSDP Site 534, and it was originally described from the Aptian of the Falkland Plateau (Wise and Wind, 1977). This interval is therefore subdivided using alternative bioevents; the top of a *C. margerelii* acme, and a number of approximately synchronous FOs.

**BC8a Subzone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** LO of *Eprolithus? antiquus* to the last consistent occurrence of common (~10%) *Cyclagelosphaera margerelii*.

**Range.** Lower Hauterivian (regale AZ pars).

**Remarks.** Common *C. margerelii*, with frequent *E. striatus*, rare *E. windii* and variable abundances of *C. salebrosum*. *C. cuvillieri* is relatively frequent.

*C. margerelii* is common throughout the Upper Valanginian (Mutterlose, 1991) and much of the Lower Hauterivian, and the top of this acme is utilized here. However, additional acmes of *C. margerelii* are recorded in the Upper Hauterivian and 'middle' Barremian, but it is relatively rare in the intervening strata. These acme events seem to be correlatable on a basin-wide scale (certainly between England and Germany, and within the North Sea).

**BC8b Subzone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** Last consistent occurrence of common *Cyclagelosphaera margerelii* to the FO of *Perissocyclus plethotretus* (and/or *P. tayloriae* and/or *Z. scutula*).

**Range.** Lower to lower Upper Hauterivian (upper regale to uppermost inversum AZs).

**Remarks.** *E. striatus* is a frequent and conspicuous element, along with *C. salebrosum*. *C. margerelii* is much reduced in abundance compared to the underlying subzone (~3%). *R. windleyae* first appears towards the top of this interval. The three FOs given to mark the top of this zone cannot yet be satisfactorily sequenced, but are sufficiently close to be complimentary. The FO of *P. plethotretus* is given precedence, since this species seems the most widely-distributed within the boreal area. A strict species concept must be applied: *P. plethotretus* is used herein for large, birefringent-strutted forms only.

**BC8c Subzone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** FO of *Perissocyclus plethotretus* (and/or *P. tayloriae* and/or *Z. scutula*) to the FO of *Tegulalithus septentrionalis*.

**Range.** Lower Upper Hauterivian (uppermost inversum to lower speetonensis/staffi AZs).

**Remarks.** Frequent/common *C. salebrosum*, fre-
quent *E. striatus*, with rare to frequent (but conspicuous) *P. plethotretus*, *P. tayloriae* and *Z. scutula*. *Assipetra infracretacea* is frequent/common throughout.

**BC9 Eiffellithus striatus Zone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** FO of *Tegulalithus septentrionalis* to the LO of *Eiffellithus striatus*.

**Range.** Upper Hauterivian (speetonensis/staffi AZ pars).

**Remarks.** *T. septentrionalis* is frequent/common throughout, and its sudden *en masse* appearance is an excellent datum. There is a dramatic reduction in the abundance of *C. salebrosum* within the lower part which may represent the extinction of this species; later, rare records are probably reworked or belong to another, similar species (*Crucibiscutum ?pinnatus* or *Crucibiscutum hayi*). The LO of *C. cuvillieri* was recorded within this interval, but this species is extremely rare in its upper range and may extend into BC10 (Bralower, 1991). *E. striatus* is frequent throughout its range and its LO provides a reliable datum that is correlatable worldwide. *C. margerelii* has a brief acme around the extinction level of *E. striatus*.

**BC10 Tegulalithus septentrionalis Zone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** LO of *Eiffellithus striatus* to the LO of *Tegulalithus septentrionalis*.

**Range.** Upper Hauterivian (upper speetonensis/staffi AZs).

**Remarks.** *Micrantholithus* spp. become common towards the top. *Clepsilithus maculosus* reappears just below the LO of *T. septentrionalis*, after a long absence from the boreal area. The highest occurrence of *Tubodiscus verenae* was recorded in this zone; this species is rare at boreal latitudes, and of no real biostratigraphic potential, but these late occurrences are significant because the species’ LO has previously been used to mark the top of the Valanginian.

*T. septentrionalis* is frequent/common throughout its range and its LO is abrupt. Previous records of *T. septentrionalis* in the Lower Barremian (Jakubowski, 1987; Crux, 1989; Mutterlose, 1991) are interpreted here as reworking. Records of ‘middle’ Barremian *T. septentrionalis* (Mutterlose and Harding, 1987; Crux, 1989) are thought to represent observations of the light-microscopically similar *Nannoconus pseudoseptentrionalis*.

**BC11 Clepsilithus maculosus Zone**

**Author.** (Crux, 1989, S. comptus Zone) Rutledge and Bown (in prep.).

**Definition.** LO of *Tegulalithus septentrionalis* to the LO of *Clepsilithus maculosus*.

**Range.** Upper Hauterivian to lowermost Barremian (upper gottschei to basal variabilis AZs).

**Remarks.** *C. maculosus* is entirely absent from North Sea ‘middle’ Hauterivian sections but occurs consistently, and often frequently, throughout this zone. *P. plethotretus* and *Z. scutula* are conspicuous throughout. *Micrantholithus* is abundant towards the base of the interval. The diminutive *Zeugrhabdotus noeliae* is abundant throughout the lower half of this zone; this long-term acme appears to be correlatable basin-wide, and is used to subdivide the interval.

**BC11a Subzone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** LO of *Tegulalithus septentrionalis* to the last consistent occurrence of abundant (>20%) *Zeugrhabdotus noeliae*, within the range of *Clepsilithus maculosus*.

**Range.** Upper Hauterivian (upper gottschei AZ).

**Remarks.** *Z. noeliae* is dominant, constituting 20–50% (generally 30–40%) of assemblages, with >15 individuals in an average FOV. *C. maculosus* is a conspicuous component but never common. *Z. noeliae* declines suddenly at the top of this zone; it is still frequent/common throughout the remainder of the range of *C. maculosus*, but does not dominate assemblages (constituting <15%, generally much less). This acme event may not be easily recognizable in ditch-cutting material, since *Z. noeliae* is occasionally abundant in the overlying zone; the *Micrantholithus* spp. acme (also noted by Jakubowski, 1987) may be a more easily utilized event.

**BC11b Subzone**

**Author.** Rutledge and Bown (in prep.).

**Definition.** Last consistent occurrence of abundant (>20%) *Zeugrhabdotus noeliae* to the LO of *Clepsilithus maculosus*.

**Range.** Upper Upper Hauterivian (marginatus AZ) to lowermost Barremian (basal variabilis AZ).
Fig. 5.2 Barremian-Albian nannofossil biostratigraphy. Boreal BC zones after Rutledge and Bown (in prep.). Albian events also based on Crux (1991), Burnett in Gale et al. (1996) and Jeremiah (1996). Most events are calibrated to the boreal cephalopod zones. See also Fig. 5.1 caption.
Remarks. As for BC11a, but Z. noeliae and Micrantholithus spp. are much depleted, although both may be frequent/common. Rhagodiscus asper and Watznaueria spp. are the dominant taxa. Rhagodiscus pseudoangustus is occasionally frequent.

BC12 Cretarhabdus inaequalis Zone

Author. (Crux, 1989) Rutledge and Bown (in prep.).

Definition. LO of Clepsilithus maculosus to the FO of Nannoconus abundans.

Range. Lower Barremian (variabilis AZ pars).

Remarks. Dominated by Watznaueria spp., R. asper and Biscutum constans. C. inaequalis, R. pseudoangustus and Tegumentum stradneri (small variety) are often frequent and characteristic of this interval. P. plethotretus and Z. scutula occur throughout. Rhabdophidites parallellus is unusually common. Tethyan species of Nannoconus (N. globulus, N. kamptneri, N. steinmannii) are frequent within the paler horizons of boreal, rhythmically-bedded sediments. Nannoconus inornatus becomes common in the upper part, just prior to the inception of N. abundans (these events are synchronous at Speeton due to condensation). Assipetra terebrodentarius appears towards the top, providing a reliable secondary datum.

BC13 Nannoconus abundans Zone

Author. (Crux, 1989) Rutledge and Bown (in prep.).

Definition. FO of Nannoconus abundans to the FO of Nannoconus borealis (or the LO of Rhagodiscus pseudoangustus).

Range. Lower Barremian (rarocinctum AZ).

Remarks. N. inornatus is common, and the dominant nannoconid, but fully-developed N. abundans is also conspicuous. R. pseudoangustus is a frequent and conspicuous element, and its LO is close to the top of the zone. Small forms of Crucibiscutum are last recorded here, but are rare and inconspicuous. A. infracretacea and A. terebrodentarius are frequent/common; the latter species is especially characteristic. As in BC12, R. parallelus is unusually common. C. margerelii becomes common in the upper part, marking the base of another major ('middle' Barremian) acme.

Several previous authors (Taylor, 1982; Thomsen, 1987) have included short, flangeless nannoconids (here assigned to N. inornatus) in N. abundans, thus giving this species an anomalously early FO.

BC14 Nannoconus borealis Zone

Author. (Crux, 1989, C. conicus Zone) Rutledge and Bown (in prep.).

Definition. FO of Nannoconus borealis (or the LO of Rhagodiscus pseudoangustus) to the first consistent occurrence of frequent/common Zeugrhabdotus scutula.

Range. Lower Barremian (fissicostatum AZ to basal elegans AZ/Aulacotethus spp. Bel. Zone).

Remarks. Boreal assemblages are often of low diversity and dominated by a few conspicuous elements, e.g. R. asper, C. margerelii, Micrantholithus spp. and Nannoconus spp.. Both N. inornatus and N. abundans are frequent/common throughout; the latter is generally dominant. N. borealis is more sporadic in its occurrence but very conspicuous and occasionally common.

BC15 Zeugrhabdotus scutula Zone

Author. Rutledge and Bown (in prep.).

Definition. Interval during which Zeugrhabdotus scutula is consistently frequent/common (2–15%), in the presence of other characteristic Barremian forms (notably N. abundans and N. borealis).

Range. Upper Lower to lower Upper Barremian (elegans to ?innexum AZs).

Remarks. The FO of N. pseudoseptentrionalis also approximates the base of this zone. Acaenolithus? sp.1 (= ?Vagalapilla matalosa) first appears in the middle of this interval. The regional (boreal) LO of Diazomatolithus lehmanii is also recorded here.

This and the following four zones have been further subdivided by Gallagher (pers. obs. and herein) based on high-resolution stratigraphic studies of the Valhall and Sola formations from the Britannia Field (Moray Firth Basin). The subdivision is based upon discrete LOs together with acme/influx abundance events. The ability to correlate some of these events away from this sub-basin of the North Sea is uncertain at present and the subzones are therefore presented informally (Fig. 5.3).

BC16 Acaenolithus? sp. Zone

Author. Rutledge and Bown (in prep.).

Definition. Last consistent occurrence of frequent/common (2–15% of assemblage) Zeugrhabdotus scutula to the LO of Nannoconus borealis.

Range. Upper Barremian (?innexum to ?bidenta-
Fig. 5.3 High-resolution subdivision of BC zones 15-20 (Barremian-Aptian), based on analysis of the Valhall Formation, Britannia Field (Moray Firth Basin). Subzonal status is informal. Ammonite zones are inferred.
BC17 Biscutum constans Zone
Author. Rutledge and Bown (in prep.).
Definition. LO of *Nannoconus borealis* to the FO of *Rhogodiscus gallagheri* and/or the re-entry of frequent *Watznaueria britannica*.
Range. Upper Barremian (bidentatum AZ).
Remarks. Evidence for the existence of this zone is scant due to non-exposure of this interval at Speeton, and to the rarity of ammonites in the German sections. The LO of *C. rothii* occurs within this zone, but the event may be difficult to apply due to its discontinuous occurrence. *N. borealis* also has a discontinuous range, but would seem to be consistently present in the Upper Barremian.

BC18 Watznaueria britannica Zone
Author. Rutledge and Bown (in prep.).
Definition. FO of *Rhogodiscus gallagheri* (or the re-entry of frequent *Watznaueria britannica*) to the FO of *Farhania varolii*.
Range. Lower Aptian (fissicostatus to forbesi AZs).
Remarks. *R. gallagheri* has previously been included within the species concept of *R. angustus* (Thomsen, 1987; Mutterlose, 1991). It has been recorded from the Lower Aptian of the North Sea and adjacent areas (e.g. Skegness Clay and basal Atherfield Clay) by Rutledge and Bown (in prep.). The FO of *R. gallagheri* coincides approximately with an influx of *W. britannica* (a predominantly Jurassic species that is very rare in the Neocomian). Gallagher (pers. obs. and Fig. 5.3) has observed two closely-spaced but discrete *W. britannica* influx events at this level.

R. gallagheri increases in abundance through the zone becoming frequent/common. Small forms of *Acaenolithus*? (3–4μm) are often frequent. *Flabellites oblongus* and *Hayesites irregularis* are first recorded here in boreal sections but may have earlier FOs in tethyan sections.

The LO of *N. abundans* was recorded within this zone by Rutledge and Bown (in prep.) although this species has been used as a uppermost Barremian datum by others (Taylor, 1982; Jakubowski, 1987; Mutterlose, 1991) and is used to subdivide BC17 by Gallagher (herein Fig. 5.3).

BC19 Farhania varolii Zone
Author. Rutledge and Bown (in prep.).
Definition. FO of *Farhania varolii* to the FO of *Lithraphidites moray-firthensis*.
Range. Lower Aptian (upper forbesi to ?lower deshayesi AZs).
Remarks. Abundant *B. constans*, with frequent *R. gallagheri*, *F. varolii*, and *F. oblongus*. *W. britannica* declines in abundance to its normal, background level (rare) early in this zone. Influxes of *Repagulum parvidentatum* and *Zeugrhabdotus xenotus* have also been recorded in boreal sections (Rutledge and Bown, in prep.). *Lithraphidites* cf. *L. pseudoquadratus*, the likely precursor of *L. moray-firthensis*, may be fairly frequent.

*F. varolii* is a distinctive and dissolution-resistant species, with a wide geographic distribution. Previous records of *Lithastrinus septentrionalis* from low-latitude Aptian sections (Thierstein, 1973; Roth, 1983) almost certainly belong to this species.

BC20 Lithraphidites moray-firthensis Zone
Author. Rutledge and Bown (in prep.).
Definition. Total range of *Lithraphidites moray-firthensis*.
Range. Lower Aptian (?deshayesi AZ).
Remarks. Frequent *L. moray-firthensis*, with *F. varolii* and *R. parvidentatum*. Jakubowski (1987) recorded *L. moray-firthensis* rarely in the Upper Aptian, and hence used the last common occurrence of the species as a datum. However, this species has never been described from Upper Aptian outcrop material, and is probably restricted to the Lower Aptian (?deshayesi AZ).

BC21 Rhagodiscus asper Zone
Author. (Jakubowski, 1987) Rutledge and Bown (in prep.).
Definition. Last consistent occurrence of *Lithraphidites moray-firthensis* to the LO of *Farhania varolii*.
Range. Upper Lower Aptian to Upper Aptian (?bowerbanki to jacobi AZs).
Remarks. *R. asper* is abundant (~20–50%) throughout, but declines in abundance towards the top of the zone. *R. parvidentatum* is frequent/common, particularly towards the top. *Nannoconus* spp. (especially *N. truitti* and *N. quadrangularis*) may be frequent. *Braarudosphaera* spp.
especially *B. africana*). *Radiolithus orbiculatus/planus* and *Eprolithus* *floralis* are also characteristic; these species have their FOs near the base (possibly in the underlying zone). *Crucibiscutum* cf. *C. salebrosum* may be frequent towards the top of the zone. *Micrantholithus* spp. become rare, and may disappear entirely towards the top of this interval. *F. varolii* is rare but consistently present.

Jakubowski (1987) subdivided this interval using the LO of ‘common’ *R. asper* but utilized the LO of ‘frequent/common’ *R. asper*, above the LO of *F. varolii*, to define another zonal boundary. Jeremiah (1996) utilizes the last consistent occurrence of a ‘high relative abundance’ of *R. asper* to define an uppermost Aptian or Lower Albian zonal boundary. However the placement of this abundance-decline event relative to the LO of *F. varolii* remains uncertain. The presently available onshore data suggests that a major decline in the abundance of *R. asper* (from >20% to ~5%) occurs within the nutfieldiensis AZ, prior to the LO of *F. varolii* (jacobi AZ).

**BC22 Repagulum parvidentatum Zone**

**Author.** (Jakubowski, 1987) Rutledge and Bown (in prep.).

**Definition.** LO of *Farhania varolii* to the FO of *Prediscosphaera columnata*.

**Range.** Uppermost Aptian (jacobi AZ) to Lower Albian (precise level uncertain).

**Remarks.** *R. asper* is much reduced in abundance relative to BC21. *R. parvidentatum* is frequent/common. *Acaenolithus viriosus* and *Seribiscutum primitivum* first appear here; the former species is almost restricted to this interval (having its LO shortly above the FO of *P. columnata*), while the latter is particularly common, upon its appearance. The first consistent occurrence of *Rhagodiscus splendens* lies within this interval; earlier, generally rare, records of this species may be aberrant specimens of *R. asper* or *R. fenestratus*.

**BC23 Prediscosphaera columnata Zone**

**Author.** Equivalent to the CC8a Subzone of Perch-Nielsen (1979a).

**Definition.** FO of *Prediscosphaera columnata* to the FO of *Tranolithus orionatus*.

**Range.** ?Aptian/Albian boundary interval to Middle Albian (?dentatus AZ).

**Remarks.** A small, elliptical species of *Prediscosphaera*, *P. cf. P. spinosa*, precedes the FO of *P. columnata* but the precise timing of these events has yet to be satisfactorily established in boundary stratotype sections. The differentiation of these two distinct species must be recognized in order to preserve the integrity of this zonal datum.

**BC24 Tranolithus orionatus Zone**

**Author.** Equivalent to the NC8C Subzone of Bralower *et al.* (1993).

**Definition.** FO of *Tranolithus orionatus* to the FO of *Axopodorhabdus albianus*.

**Range.** Middle Albian (?dentatus to loricatus AZs).

**Remarks.** The upper boundary of this zone is also approximated by the LO of *Braloweria boletiformis*.

**BC25 Axopodorhabdus albianus albianus Zone**

**Author.** Equivalent to the NC9A Subzone of Bralower *et al.* (1993).

**Definition.** FO of *Axopodorhabdus albianus* to the FO of *Eiffellithus monechiae*.

**Range.** Middle to Upper Albian (lautus to inflatum AZs).

**BC25a Subzone**

**Author.** Defined herein.

**Definition.** FO of *Axopodorhabdus albianus* to the LO of *Ceratolithina bicornuta*.

**Range.** Upper Middle Albian (lautus to lowermost Upper Albian (lower inflatum AZ).

**Remarks.** *C. bicornuta* is a distinctive nannolith which has been recorded from S England (Perch-Nielsen, 1988) and the Indian Ocean (Burnett, 1997a). In both areas it appears to have a restricted stratigraphic range, which in S England corresponds to the lautus-inflatum AZs. The subzone includes, and is approximately equivalent to, the total range of *C. bicornuta*.

**BC25b Subzone**

**Author.** Defined herein.

**Definition.** LO of *Ceratolithina bicornuta* to the FO of *Eiffellithus monechiae*.

**Range.** Upper Albian (inflatum AZ).

**BC26 Eiffellithus monechiae Zone**

**Author.** Equivalent to the NC9B Subzone of Bralower *et al.* (1993).

**Definition.** FO of *Eiffellithus monechiae* to the FO of *Eiffellithus turriseiffelli*. Lower Cretaceous 97
**Fig. 5.4** Stratigraphic ranges of selected Lower Cretaceous taxa.
Lower Cretaceous  99

<table>
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<tr>
<th>Stratigraphic Ranges of Selected Nannofossil Taxa</th>
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<td>BC 3 (b)</td>
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<td>BC 2 (a)</td>
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</tbody>
</table>

### Endemic (Boreal) Nannocnoids

- R. galilaei
- R. angustus
- F. vanoli
- R. spornula
- S. milleactum
- A. vulnus
- R. columnis
- T. abnosis
- C. rubra
- G. andersonii
- E. monophaei
- C. aractis

### Predominantly Tethyan Taxa

- A. albicans
- C. bioculata
- N. clioniaspis
- T. abnosis
- C. rubra
- G. andersonii
- E. monophaei
- C. aractis

- Abundant
- Common
- Rare, but consistently present
- Rare, sporadic occurrences
- Low-latitude range

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*Z. scalaris*

*U. pseudokoschkae*

*H. abderites*

*C. pseudocycla*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*

*H. baltica*

*C. delicata*

*S. longiuncula*
Range. Upper Albian (upper inflatum AZ).

**BC27 Eiffellithus turriseiffelii Zone**

**Author.** Equivalent to the NC10A Subzone of Bralower et al. (1993).

**Definition.** FO of Eiffellithus turriseiffelii to the FO of Corollithion kennedyi.

**Range.** Upper Albian (upper inflatum AZ) to Lower Cenomanian.

**Subzones BC27a–c/UC0a–c**

See Chapter 6, p. 139 and Fig. 5.2.

### 5.5 GLOBAL CORRELATION

The standard Lower Cretaceous stages are defined in SE France by means of ammonite biostratigraphy, and correlation of the Neocomian stages with more northerly, boreal areas has always been problematical due to faunal provincialism. Mixing of ammonite faunas through certain intervals, e.g. Valanginian and Hauterivian, has allowed limited calibration of the regional zonations, however, the correlation of stage and substage boundaries remains difficult.

Nannofossil zonation schemes applied to the Neocomian of boreal and tethyan areas have seemed virtually irreconcilable, utilizing entirely different suites of marker-species. While it is clear that some of the most easily-utilized markers in each realm have restricted geographic distributions, improved documentation of sections in the tethyan area (Applegate and Bergen, 1988; Bergen, 1994) and the boreal area (Rutledge and Bown, in prep.) has revealed the potential for direct interregional correlation. Following Thierstein (1971, 1973), tethyan zonations have relied heavily on two species, *C. oblongata* and *Lithraphidites bollii*, to subdivide the Neocomian. These highly restricted (?stenothermal) species only rarely reached boreal latitudes, if at all, and are also relatively long-ranging, so brief influxes into boreal areas are of little use in correlation. Fortunately, some of the most useful boreal markers are very short-ranging (e.g. *M. speetonensis*, *E.? antiquus*, *T. septentrionalis*), and even limited occurrences in tethyan sections are potentially useful for correlation. Bergen (1994) has recently documented two such 'boreal' species, *M. speetonensis* and *E.? antiquus*, in tethyan sections and several others are also known to be present there, e.g. *T. shetlandensis* has been observed frequently with *M. speetonensis* in a Lower Valanginian sample from Angles, SE France (Rutledge, pers. obs.); and *T. septentrionalis* is known to occur in the western North Atlantic (Roth, 1983), California (Bralower, 1990), Indonesia (Varol, 1991), and SE France (S. Gardin, pers. comm. 1994). This latter species is an extremely useful marker, with a total range of comparable duration to an ammonite zone.

Taxonomic improvements, with the application of more-restricted species concepts, have shown that many other species are common to both realms. Thus, *E. windii*, *E. striatus*, *Zeugrhabdotus diplogrammus*, *Z. trivectis*, *Z. scutula* and *A. terebrodentarius* have been previously overlooked or masked by broad species concepts, yet they are potentially useful interregional markers. In addition, improved documentation of the ranges of *C. cuvillieri* and *S. colligata*, which have previously been used as markers in both boreal and tethyan areas, has provided further interregional datums.

The Aptian is problematical, not because of a lack of potential datums, but due to a lack of complete, nannofossiliferous sections in which to calibrate the many FOs within this interval. *H. irregularis*, which is widely used as a basal Aptian marker at low-latitudes (e.g. Bergen, 1994) is rare and sporadic in boreal sections, and its FO is probably not a reliable datum. It is interesting that the markers which Jakubowski (1987) used to zone the Aptian of the North Sea (*L. morayfirthensis*, *F. varolii*) have not been recorded from the tethyan stratotypes, even though *F. varolii* is now known to be widely distributed (Varol, 1992). These species have probably been overlooked, or grouped with similar forms, in the less well-preserved tethyan material.

The Albian stage is known from many of the ocean basins, and all the zonal marker-species are cosmopolitan. Therefore, global correlation using nannofossils is readily achievable at a relatively high stratigraphic resolution, and is well demonstrated by Bralower (1992) and Bralower et al. (1993), who presented around 20 widely recognizable bioevents through this interval.

Thus, although further work is required, particularly the confirmation of stratigraphic ranges of newly described species and the testing of the geographic range of acme events, there is great
potential for interregional correlation using nannofossils.

5.6 MAGNETOBIOCHRONOLOGY

Calibration of nannofossil bioevents with the geomagnetic polarity time-scale has been undertaken almost exclusively on sections from the tethyan region and the Atlantic Ocean, e.g. Bralower (1987), Channell et al. (1987), Ogg and Steiner (1988), Bralower et al. (1989), Channell and Erba (1992) and Cecca et al. (1994). As yet, magnetostratigraphic studies on boreal sections have failed to provide satisfactory results.

5.7 BIOGEOGRAPHY

One of the most significant advances in Cretaceous nannopalaeontology in recent years has been the recognition of considerable palaeobiogeographic differentiation throughout this time interval. This has come about largely as a result of industrial biostratigraphy in the North Sea Basin together with DSDP/ODP research, particularly the drilling of sections in the southern hemisphere (Indian and Southern Oceans).

Early Cretaceous nannoplankton provincialism is generally recognized by limited endemism at species and, rarely, generic level, together with considerable abundance variations of cosmopolitan assemblage components. The number of endemic taxa varies somewhat through the Cretaceous but a consistent feature is the presence of species which apparently display bipolar distribution. This feature may actually represent high abundances at high latitudes and very rare occurrences in lower latitudes. By analogy with modern nannoplankton, these distributions are most likely primarily controlled by the nutrient and temperature characteristics of surface-waters, and comprise broadly parallel latitudinal regions.

Lower Cretaceous nannoplankton distributions broadly define three major provinces: northern high-latitude (Boreal), subtropical-tropical (Tethyan) and southern high-latitude (Austral), although these may be further subdivided, and transitional zones are recognized. Particularly well-defined provincialism is observed in the Tithonian-Berriasian time-interval but long-ranging species, such as C. salebrosum, S. primitivum and R. parvidentatum, consistently display bipolar distributions for most of the time-interval under discussion.

North Sea Basin research has produced a large number of new nannofossil species, many of which have been interpreted as endemic 'boreal' taxa, although this may simply reflect the intensity of research, with many of these taxa having been overlooked or undifferentiated in earlier, low-latitude studies. A number of recent studies in low latitudes have, in fact, begun to extend the ranges of some of these taxa, although they may be rare and stratigraphically restricted in these areas. Similarly, Southern Ocean DSDP/ODP sites have yielded a number of new taxa and these have been interpreted as 'austral' taxa, although more precise constraints on the palaeobiogeographies of these taxa await further research. However, despite some doubt about the precise distributions of some of these new taxa, it is almost certain that some are truly high-latitude-endemic, or at least only found commonly at these latitudes. These studies have also recognized the paucity or sporadic occurrence of other taxa which have been consistently utilized in low-latitude biostratigraphies, and these have been labelled low-latitude or 'tethyan' taxa. Again there have been problems with a number of these species, in that many appear to have much wider geographic distributions than first thought but only through restricted stratigraphic intervals. However, a number of these 'tethyan' taxa are clearly virtually cosmopolitan, e.g. C. cuvillieri and S. colligata.

5.8 ATLAS OF SPECIES

Most Lower Cretaceous calcareous nannofossils are illustrated in Plates 5.1–5.15. Taxa are listed according to the classification of Bown and Young (1997). EMs are not uniformly enlarged but magnifications are given in plate captions. LMs are uniformly enlarged at x2300. Stratigraphic information is given as stages (L=Lower, U=Upper) and ammonite zones (in brackets), where possible; question marks indicate a degree of uncertainty. Photographs are identified by a UCL number (film and frame). The majority of photographs come from the research of Drs Paul Bown, Jason Crux, Dave Rutledge and Rosanna Taylor.
Plate 5.1

Order EIFFELLITHALES Rood et al., 1971

FAMILY CHIASTOZYGACEAE Rood et al., 1973 emend. Varol and Girgis, 1994


Fig. 2. Bukrylithus ambiguus Black, 1971a. Distal view, Speeton (UK), L. Barremian, JC-99-17, x7384. Range: Berriasian – ?Campanian.

Fig. 3. Chiastozygus litterarius (Górka, 1957) Manivit, 1971. Distal view, Copt Point (UK), U. Albian (inflatum), UCL-1029-4, x4312. Range: U. Barremian – Maastrichtian.

Fig. 4. Chiastozygus ?tenuis Black, 1971a. Distal view, Speeton (UK), U. Hauterivian (marginatus), UCL-525-3, x4719.


Fig. 7. Diadorhombus rectus Worsley, 1971. Distal view, DSDP Site 534 (N Atlantic Ocean), Hauterivian, UCL-1744-6, x6970. Range: U. Berriasian (boissieri) – ?Aptian.

Fig. 8. Loxolithus armilla (Black in Black and Barnes, 1959) Noël, 1965. Distal view, BGS Borehole 81/43 (North Sea), L. Barremian, UCL-4079-13, x7000. Range: L. Hauterivian – Maastrichtian.


Fig. 11. Staurolithites crux (Deflandre and Fert, 1954) Caratini, 1963. Distal view, Speeton (UK), U. Hauterivian (marginatus), UCL-525-13, x5600.


Fig. 15. Zeugrhabdotus noeliae Rood et al., 1971. Distal view, Gr. Lafferde (N Germany), Barremian, UCL-468-9, x9710. Range: Jurassic – Santonian.


Family EIFFELLITHACEAE Reinhardt, 1965


Plate 5.2

Family EIFFELLITHACEAE Reinhardt, 1965

Fig. 2. *Tegumentum stradneri* Thierstein *in* Roth and Thierstein, 1972. Distal view, BGS Borehole 81/43 (North Sea), U. Hauterivian (gottschei), UCL-4067-16, x5156. Range: Valanginian – Maastrichtian.

Family RHAGODISCACEAE Hay, 1977


Fig. 10. *Rhagodiscus cepkeii* (Crux, 1987b) Rutledge and Bown comb. nov.. Distal view, BGS Borehole 81/43 (North Sea), L. Barremian (variabilis), UCL-4068-32, x7437. Range: ?L. Barremian (variabilis).

Basionym: *Chiasstozygus cepkeii* Crux, 1987b (*INA Newsletter, 9* (I), p. 30, pl. 1, figs 1–3, 6, 18-20, holotype fig. 1)


Order STEPHANOLITHIALES Bown and Young, 1997
?Family PARHABDOLITHACEAE Bown, 1987
Fig. 15. *'Parhabdolithus' stubbingsii* Black, 1971a. Proximal oblique view, BGS Borehole 81/43 (North Sea), U. Hauterivian (gottsc-ei), UCL-4076-12, x4687. Range: L. Hauterivian – L. Barremian.

Family STEPHANOLITHIALES Black, 1968
Figs 16–17. *Rotelapillus laffittei* (Noel, 1957) Noel, 1973. Distal (16) and proximal (17) views. Fig. 16, DSDP Site 547B (Atlantic Ocean), U. Valanginian/Hauterivian, UCL-1729-12, x6000. Fig. 17, Otto Gott (N Germany), Barremian, UCL-540-18, x6534. Range: U. Tithonian – Maastrichtian.

Fig. 18. *Stradnerlithus geometricus* (Górka, 1957) Bown and Cooper, 1989a. Distal view, Speeton (UK), U. Hauterivian, JC-101-24, x10000.


Fig. 20. *Scapholithus fossilis* Deflandre *in* Deflandre and Fert, 1954. Distal view, Hohenegglenson (N Germany), U. Barremian, UCL-439-9, x1820. Range: L. Hauterivian – ?present day.
**Plate 5.3**

Order PODORHABDALES Rood et al., 1971 emend. Bown, 1987

Family AXOPODORHABDACEAE Bown and Young, 1997


Fig. 4. *Perissocyclus noeliae* Black, 1971a. Distal view, Speeton (UK), L. Barremian, UCL-3699-7, x5275.


Figs 6–7. *Perissocyclus tayloriae* Crux, 1989. Distal (6) and side (7) views. 6, Otto Gott (N Germany, Aptian, JC-90-15, x6700; 7, Speeton (UK), L. Barremian, JC-100-14, x5870.

Fig. 8. *Tetrapodorhabdus coptensis* Black, 1971a. Distal view, Speeton (UK), L. Barremian (variabilis), UCL-521-6, x6000. Range: Berriasian? – Maastrichtian.

Family BISCUTACEAE Black, 1971a


Fig. 11. *Crucibiscutum hayi* (Black, 1973) Jakubowski, 1986. Distal view, BGS Borehole 81/43 (North Sea), L. Barremian (variabilis), UCL-4068-23, x7109. Range: Albian – Cenomanian.


Family CRETARHABDACEAE Thierstein, 1973

Fig. 18. *Cretarhabdus concin us* Bramlette and Martini, 1964. Distal view, BGS Borehole 81/43 (North Sea), L. Barremian (variabilis), UCL-4069-15, x4120. Range: Kimmeridgian (eudoxus) – Maastrichtian.


Fig. 3. *Helenea chiastia* Worsley, 1971. Distal view, Speeton (UK), U. Hauterivian (marginatus), UCL-525-5, x5127. Range: Tithonian – L. Turonian (devonense).


Family PREDISCOSPHAERACEAE Rood *et al.*, 1971


Family TUBODISCACEAE Bown and Rutledge in Bown and Young, 1997


Plate 5.5

Order WATZNAUERIALES Bown, 1987
Family WATZNAUERIACEAE Rood et al., 1971
Fig. 1. Cyclagelosphaera argoensis Bown, 1992b. Distal view, DSDP Site 261 (Indian Ocean), U. Tithonian, UCL-2999-33, x3536. Range: Tithonian – Maastrichtian.

Fig. 2. Cyclagelosphaera margerelii Noël, 1965. Coccosphere, BGS Borehole 81/43 (North Sea), U. Valanginian (Dichotomites spp.), UCL-4073-20, x3650. Range: U. Bajocian (parkinsoni) – L. Paleocene.


Fig. 5. Watznaueria barnesae (Black in Black and Barnes, 1959) Perch-Nielsen, 1968. Coccosphere, Speeton (UK), U. Hauterivian (marginatus), UCL-525-8, x3009. Range: L. Bajocian (laeviuscula) – Maastrichtian.


Order ARKHANGELSKIALES Bown and Hampton in Bown and Young, 1987
Family KAMPTNERIACEAE Bown and Hampton in Bown and Young, 1987
Fig. 9. Crucicribrum anglicum Black, 1973. Distal view, Folkestone (UK), U. Albian (inflatum), UCL-1029-2, x4800. Range: M. Albian (dentatus) – Cenomanian.


UNCERTAIN HETEROCOCCOLITHS


HOLOCOCCOLITHS – Family CALYPTROSPHAERACEAE Boudreaux and Hay, 1969
Fig. 16. Isocrystallithus compactus Verbeek, 1976b (= Owenia hillii Crux, 1991b). Distal view, Munday’s Hill (UK), U. Albian (inflatum), x8975. Range: M. Albian (laevus) – U. Cenomanian (guerangeri).

NANNOLITHS
Family BRAARUDOSPHAERACEAE Deflandre, 1947a

Fig. 18. Micrantholithus hoschulzii (Reinhardt, 1966) Thierstein, 1971. BGS Borehole 81/43 (North Sea), L. Barremian (variabilis), UCL-4079-19, x3187. Range: Berriasian – U. Aptian.

Fig. 19. Micrantholithus obtusus Stradner, 1963. DSDP Site 398D (Atlantic Ocean), Barremian, UCL-718-18, x2761. Range: Berriasian – U. Aptian.

Fig. 20. Micrantholithus sp. Djebel Oust (Tunisia), Barremian, UCL-482-25, x4541.
Family NANNOCONACEAE Deflandre, 1959

Fig. 1. *Nannoconus abundans* Stradner and Grün, 1973. Side view, UCL-4069-29, x3808. Range: Barremian (rarocintum – bidentatum)/?L. Aptian.


Fig. 4. *Nannoconus circularis* Deres and Achéritégy, 1980. DSDP Site 398D (Atlantic Ocean), Barremian, UCL-714-19, x3127. Range: Barremian – U. Aptian.

Fig. 5. *Nannoconus inornatus* Rutledge and Bown, 1996. Oblique view, BGS Borehole 81/43 (North Sea), L. Barremian (variabilis), UCL-4079-17, x4266. Range: U. Hauterivian – Barremian.

Fig. 6. *Nannoconus sp. (discs)* sensu Crux, 1989.


Family POLYCYCLOLITHACEAE Forchheimer, 1972 emend. Varol, 1992


Uncertain polycycloliths


Family LAPIDEACASSACEAE Bown and Young, 1997


Family MICRORHABDULACEAE Deflandre, 1963

Fig. 18. *Lithraphidites carniolensis* Deflandre, 1963. DSDP Site 547B (Atlantic Ocean), Valanginian, UCL-1700-I, x1700. Range: L. Berrisian (?jacobi) – Maastrichtian.

INCERTAE SEDIS NANNOLITHS


Plate 5.7

Order EIFFELLITHALES Rood et al., 1971

Family CHIASTOZYGACEAE Rood et al., 1973 emend. Varol and Girgis, 1994

Fig. 1. Braloweria boletiformis (Black, 1972) Crux, 1991b. Side view XPL, Munday's Hill (UK), M. Albian (loricus), JC-119-6.

Fig. 2. Bukrylithus ambiguus Black, 1971a. XPL (large specimen), Folkestone (UK), U. Albian (dispar), UCL-568-27.

Fig. 3. Chiastozygus litterarius (Górka, 1957) Manivit, 1971. XPL, Folkestone (UK), M. Albian (lautus), UCL-568-27.


Figs 6–7. Chiastozygus sp. 1. XPL (6) and PC (7), BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5690-30/31.

Figs 8–9. Clepsilithus maculosus Rutledge and Bown, 1996. XPL (8) and PC (9), BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5690-16/17.

Fig. 10. Diadorrhombus rectus Worsley, 1971. XPL, DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5702-29.

Fig. 11. Loxolithus armilla (Black in Black and Barnes, 1959) Noël, 1965. XPL, BGS Borehole 81/43 (North Sea), L. Barremian, UCL-5691-7.

Fig. 12. Rhabdophidites parallellus (Wind and Cepek, 1979) Lambert, 1987. XPL, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5568-32.

Fig. 13. Staurolithites crux (Deflandre and Fert, 1954) Caratini, 1963. XPL, BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5690-15.


Figs 21–22. Staurolithites sp. 1. XPL (21) and PC (22) (specimen displays a bicyclic XPL image but two cycles are not visible in the PC image), DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5569-26/27.

Figs 23–24. Staurolithites sp. 2. XPL (23) and PC (24), Folkestone (UK), M. Albian (lautus), UCL-5688-25/24.

Fig. 25. Tranolithus gabalus Stover, 1966. PC, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5569-9. Range: L. Valanginian (Paratollia)? – Maastrichtian.


Family CHIASTOZYGACEAE Rood et al., 1973 emend. Varol and Girgis, 1994

Fig. 5. Zeugrhabdotus embergeri (Noél, 1959) Perch-Nielsen, 1984. XPL, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5569-33.


Figs 8–10. Zeugrhabdotus xenotus (Stover, 1966) Burnett in Gale et al. 1996. XPL (8 at 45°, 9 at 0°) and PC (10), Folkestone (UK), M. Albian (laetus), UCL-5688-22/21/23. Range: L. Valanginian (campylotoxus) – Cenomanian.

Family EIFFELLITHACEAE Reinhardt, 1965
Fig. 11. Diloma galiciense Bergen, 1994. XPL, BGS Borehole 81/43 (North Sea), L. Barremian, UCL-4065-7.


Fig. 15 and 17. Eiffellithus (Rothia) striatus (Black, 1971a) Applegate and Bergen, 1988. XPL, Speeton (UK), L. Hauterivian (ambygonium–noricum), UCL-5689-31.

Fig. 16. Eiffellithus (Rothia) turriseiffelii (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965. PC (15) and XPL (17), Folkestone (UK), U. Albian (dispar), UCL-5671-1/2. Range: U. Albian (inflatum) – U. Maastrichtian.

Fig. 18. Eiffellithus (Rothia) windii Applegate and Bergen, 1988. XPL, DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5702-1.


Figs 26–27. Tegumentum stradneri Thierstein in Roth and Thierstein, 1972. XPL (26) and PC (27), Folkestone (UK), U. Albian (dispar), UCL-5670-14/15.

Family RHAGODISCACEAE Hay, 1977
Family RHAGODISCACEAE Hay, 1977


Order STEPHANOLITHIALES Bown and Young, 1997

?Family PARHABDOLITHACEAE Bown, 1987
Fig. 22. ‘Parhabdolithus’ stubbingsii Black, 1971a. XPL side view, BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5691-28.

Family STEPHANOLITHACEAE Black, 1968


Fig. 30. *Scapholithus fossilis* Deflandre in Deflandre and Fert, 1954. XPL and PC (right inset), DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5702-18; Folkestone (UK), U. Albain (dispar), UCL-5670-4.
Plate 5.10

Order PODORHABDALES Rood et al., 1971 emend. Bown, 1987
Family AXOPODORHABDACEAE Bown and Young, 1997


Figs 18–19. *Perissocyclus tayloriae* Crux, 1989. XPL (18) and PC (19), BGS Borehole 81/43 (North Sea), L. Barremian, UCL-5691-6/5.

Fig. 20. *Tetrapodorhabdus coptensis* Black, 1971a. PC, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5569-12/13.

Family BISCUTACEAE Black, 1971a


Fig. 25. *Crucibiscutum salebrosum* (Black, 1971a) Jakubowski, 1986. XPL, North Sea Borehole, Ryazanian, UCL-5690-6.


Plate 5.11

Family BISCUTACEAE Black, 1971a


Family CRETARHABDACEAE Thierstein, 1973
Fig. 6. *Cretarhabdus conicus* Bramlette and Martini, 1964. XPL, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5568-8.

Fig. 7. *Cretarhabdus inaequalis* Crux, 1987b. XPL, BGS Borehole 81/43 (North Sea), L. Barremian, UCL-5691-37.


Figs 16–18. *Helenea chiastia* Worsley, 1971. XPL at 0° low focus (16), XPL at ~45° high focus (17) and PC (18), DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5669-18/19.


Fig. 28. *Retecapsa surirella* (Deflandre and Fert, 1954) Grün *in* Grün and Allemann, 1975. DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5668-18.

Figs 29–30. *Spectonia colligata* Black, 1971a. XPL at 0° (29) and ~45° (30), Speeton (UK), L. Hauterivian (amblygonium–noricum), UCL-5689-33/34.
Family PREDISCOSPHAERACEAE Rood et al., 1971


Family TUBODISCACEAE Bown and Rutledge, 1997
Fig. 4. *Manivitella pemmatoidea* (Deflandre in Manivit, 1965) Thierstein, 1971. PC, DSDP Site 603B (N Atlantic Ocean), Aptian, UCL-5569-6.


Order WATZNAUERIALES Bown, 1987
Family WATZNAUERIACEAE Rood et al., 1971

Fig. 13. *Diazomatolithus lehmani* Noël, 1965. XPL, Bulgaria, Hauterivian, UCL-5691-12.


Fig. 16. *Watznaueria biporta* Bukry, 1969. XPL, Folkestone (UK), U. Albian (inflatum), UCL-5688-8.

Order ARKHANGELSKIALES Bown and Hampton in Bown and Young, 1997
Family ARKHANGELSKIELLACEAE Bukry, 1969 emend. Bown and Hampton, 1997 in Bown and Young, 1997


Figs 23–25. *Broinsonia sp. 1*. XPL (23 at 0°, 24 at ~45°), Folkestone (UK), M. Albian (lautus), UCL-5688-30/31/32.

Family KAMPTNERIACEAE Bown and Hampton in Bown and Young, 1997


UNCERTAIN HETEROCOCCOLITHS
Plate 5.13

**UNCERTAIN HETEROCOCCOLITHS**

Figs 1–2. *Haquius ellipticus* (Grün in Grün and Allemann, 1975) Bown, 1992b. XPL (1) and PC (2), DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5702-19/20.


Figs 4–5. *Laguncula montrougeana* Burnett, 1998. XPL, side view, low focus (4) and high focus (5), DSDP Site 259 (E Indian Ocean), L.?M. Albian (CC8a), UCL-3737-8/12.


Figs 8–10. *Repagulum parvidellatum* (Deflandre and Fert, 1954) Forchheimer, 1972. XPL (8, 10 – birefringence is exaggerated in photograph, this species has an inconspicuous LM image which is nevertheless distinctive once recognized) and PC (9), Folkestone (UK), U. Albian (dispar), UCL-5670-18/5671-8/7.

**HOLOCOCCOLITHS**

Family *CALYPTROSPHAERACEAE* Boudreaux and Hay, 1969


Fig. 26–28 *Calculites?* sp. 2. XPL (26, 27) and PC (28, same specimen as 27), BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-4071-31/24/25. Range: ?Hauterivian.

Fig. 29–30. *Holococcolith indet.*. XPL (29) and PC (30), DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5702-14/13.
Calcareous nanofossil biostratigraphy

Plate 5.14

NANNOLITHS

Family BRAARUDOSPHAERACEAE Deflandre, 1947a
Fig. 1. Braarudosphaera africana Stradner, 1961. XPL, Tunisia, U. Aptian, UCL-5701-8.


Fig. 4. Micrantholithus hoschulzii (Reinhardt, 1966) Thierstein, 1971. XPL, BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5690-24.

Figs 5–6. Micrantholithus obtusus Stradner, 1963. XPL (5) and PC (6), Speeton (UK), L. Barremian (fissicostatum), UCL-5689-27/28.

Fig. 7. Micrantholithus speetonensis Perch-Nielsen, 1979. XPL, Speeton (UK), U. Valanginian (Polyptychites), UCL-5005-1. Range: Valanginian (Paratollia – hollwedensis).

Fig. 9. Trapezopentus sarmatus Wind and Cepek, 1979. PC (8) and XPL (9), DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5701-18/20. Range: ?U. Valanginian.

Family EOCONUSPHAERACEAE Krystan-Tollmann, 1988a

Family NANNONANNOACEAE Deflandre, 1959


Fig. 24. Epriolithus? antiquus Perch-Nielsen, 1979a. XPL, Speeton (UK), L. Hauterivian (amblygonium–noricum), UCL-5689-29.

Fig. 20. Nannoconus pseudoseptentrionalis Rutledge and Bown, 1996. Top view, Speeton (UK), L. Barremian (elegans), UCL-5689-8.

Figs 21–22. Nannoconus steinmannii Kampptner, 1931 ssp. steinmannii. XPL (21) and PC (22), DSDP Site 397 (E Atlantic Ocean), U. Valanginian, UCL-5701-15/16.

Family POLYCYCLOLITHACEAE Forchheimer, 1972 emend. Varol, 1992
Fig. 23. Epriolithus? antiquus Perch-Nielsen, 1979a. XPL, Speeton (UK), L. Hauterivian (amblygonium–noricum), UCL-5689-29.


Uncertain polycycloliths
Fig. 1. *Assipetra infracretacea* (Thierstein, 1973) Roth, 1973. Upper specimen (lower specimen is *Watznaueria barnesae*) XPL, BGS Borehole 81/43 (North Sea), U. Hauterivian, UCL-5691-35.


Family LAPIDEACASSACEAE Bown and Young, 1997


Family MICRORHABDULACEAE Deflandre, 1963


**INCERTAE SEDIS NANNOLITHS**


Fig. 27. *Kokia borealis* Perch-Nielsen, 1988. IKU Core 7B (N North Sea/offshore mid-Norway), L. Valanginian, UCL-3724-10.

Fig. 22. *Kokia curvata* Perch-Nielsen, 1988. IKU Core 7B (N North Sea/offshore mid Norway), L. Valanginian, UCL-3724-16. Range: Ryazanian – L. Valanginian.
