

Albian calcareous nannofossils from the Gault Clay of Munday's Hill (Bedfordshire, England)

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ABSTRACT — Abundant and diverse Middle and Upper Albian nannofossil assemblages are present in the Gault Clay exposed at Munday's Hill, Bedfordshire, England. The section was deposited between the first appearance datums of *Tranolithus orionatus* and *Eiffellithus turrisieffeli*. This interval can be further subdivided, using the last appearance of *Braloweria boletiformis* and the first appearances of *Axopodorhabdus albianus*, *Owenia hilli* sp. nov. and *Eiffellithus monechiae* sp. nov.

The presence of *Braloweria boletiformis*, *Ceratolithina hamata* and *Gaarderella granulifera*, only at this and other north-west European localities, defines a unique endemic nannofloral province. Low latitude species are present throughout the studied section and first and last appearance datums of species are nearly synchronous, both at Munday's Hill and in other areas. This indicates continuous marine connections between Munday's Hill and low latitude areas through the Mid and Late Albian.

Abundance patterns of high latitude nannofossils, primarily *Repagulum parvidentatum* and *Seribiscutum primitivum*, suggest that relatively cold waters dominated in the Munday's Hill area near the base of the Middle Albian. The abundance of high latitude taxa gradually decreased towards the end of the Middle Albian, but temporarily increased at the base of the Upper Albian. The abundance of high latitude taxa was relatively low throughout the lower half of the Upper Albian and intermediate to low in the upper half of the Upper Albian.

Two new genera, *Braloweria* gen. nov. and *Owenia* gen. nov., and two new species, *Owenia hilli* sp. nov. and *Eiffellithus monechiae* sp. nov., are described.

INTRODUCTION

During the Mid and Late Albian, an epicontinental sea covered much of what is now north-west Europe. This sea was connected to the Tethys—Proto-Atlantic seas in the south and to the high northern latitudes via narrow passageways (Fig. 1). North-west Europe was during this time, intermittently influenced by water masses from both the south and the north due to regional transgressions and regressions and tectonic processes. Studies of ammonites (Owen, 1971, 1973) have shown that the north-west European faunas of the Middle and Upper Albian sometimes showed strong provincialism and sometimes varying degrees of influence of Tethyan or high latitude elements. Black (1972, 1973, 1975) described numerous calcareous nannofossil species from the Gault Clay (Middle and Upper Albian) of south-east England which have never been recorded elsewhere. Manivit (1976) suggested that these species formed a distinct nannofloral province restricted to north-west Europe.

This study aims to study the stratigraphic distribution of calcareous nannofossils present in the Gault Clay at Munday's Hill, Bedfordshire, England. Furthermore, to compare the results with nannofossils from other areas and to ammonite and foraminiferal faunas in order to trace palaeoceanographic variations in north-west Europe during the Middle and Upper Albian.

MATERIALS AND METHODS

A section of Gault Clay exposed in the Munday's Hill pit, near Leighton Buzzard (Grid ref. SP 939279), is chosen for this study (Fig. 1). The Munday's Hill pit contains well preserved and diverse nannofossil assemblages which show great variation through time. During the Mid and Late Albian, the area was connected to open marine seas to the south and north and was influenced by both low and high latitude waters. The section has previously been analysed for ammonite faunas (Owen, 1972) and details of the ammonite stratigraphy, to which the nannofossil samples are correlated, are presented in Fig. 2. For a full description of the Munday's Hill section,

see Owen (1972).

Thirty six samples were collected from the Middle Albian *Hoplites dentatus* ammonite Zone, to the Upper Albian *Mortoniceras inflatum* ammonite Zone. The very base of the *dentatus* Zone was not sampled, thus the lowermost Middle Albian is not represented. A stratigraphic break occurs in the middle of the section with part of the *Euhoplites loricatus*, all of the *E. lautus* and part of the *inflatum* ammonite Zones missing. The *Stoliczkaia dispar* ammonite Zone from the uppermost Albian is also missing. Details of the samples are presented in Appendix 1. Of the 36 samples, the lowermost (sample 11) was barren of nannofossils, but the remaining 35 samples contained abundant and diverse nannofloras. Diversity ranged from 39 to 54 species (Fig. 3). All assemblages showed signs of etching, with some overgrowth of secondary calcite in the higher samples examined. Roth and Krumbach (1986) considered dominance of the nannofossil assemblages by *Watznaueria barnesae* as a sign of poor preservation. In the samples studied, *W. barnesae* was very abundant only in samples 22, 33 and 34. Samples 33 and 34 did show low diversities, however, sample 22, contains 50 different species. The nannofossil content of the rock samples increases in the Upper Albian relative to the Middle Albian. Samples 27 - 29 are slightly less well preserved than the other samples.

The samples were prepared for examination in the light microscope using the methods described in Crux (1989). Visual abundance estimates of all species observed were made at X1562 magnification. Detailed abundance counts on selected species were made at X1000 magnification following a method described by Backman and Shackleton (1983). All specimens were counted in 25 fields of view with a diameter of 250µm. (A wide field lens was used.) These abundances are presented as number of specimens per square millimeter in the slide. Selected samples were also examined in the scanning electron microscope (SEM) using a centrifuge preparation technique described by Taylor and Hamilton (1982).

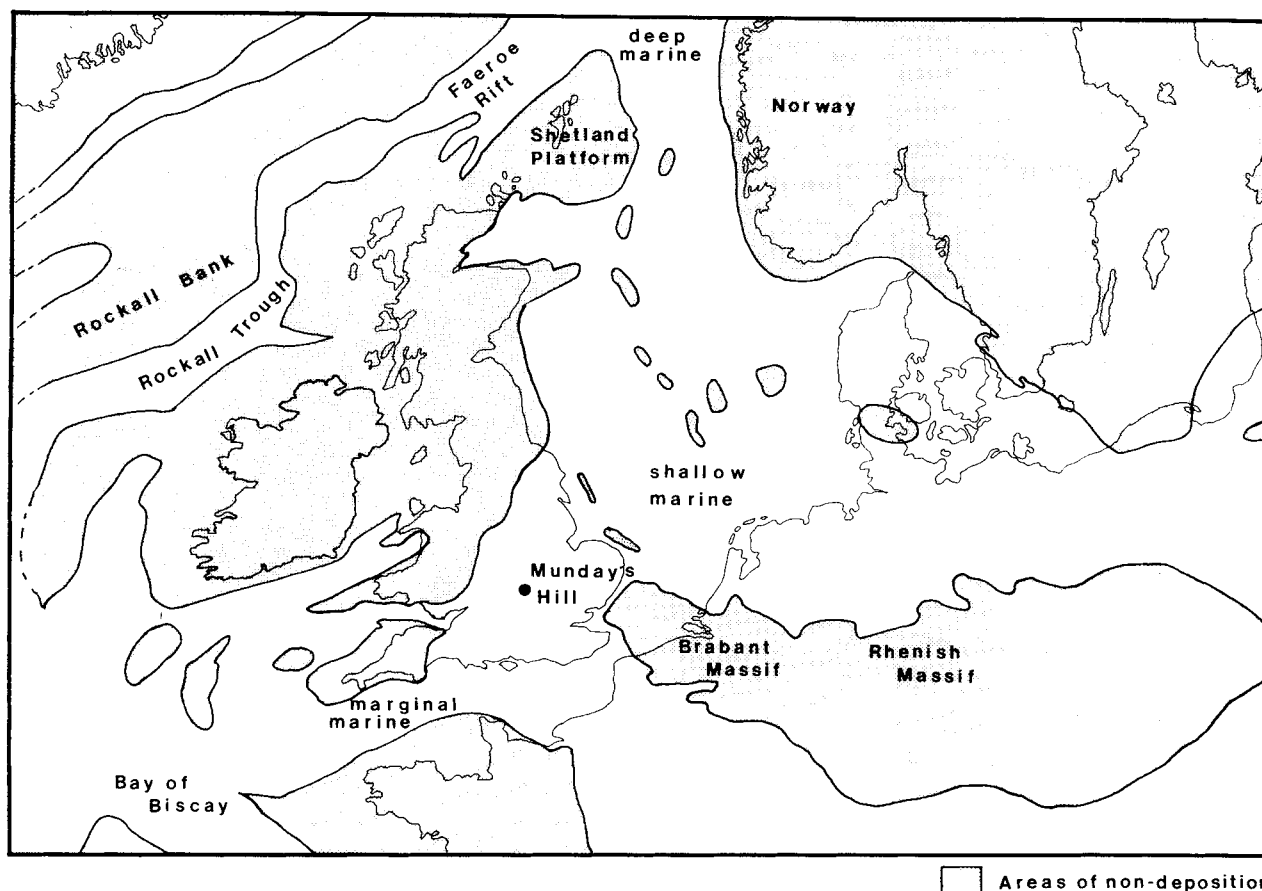


Fig. 1. Palaeogeographic and palaeoceanographic reconstruction of the Albian of north-west Europe. After Ziegler (1982).

NANNOFOSSIL BIOSTRATIGRAPHY

The whole of the stratigraphic interval exposed in Munday's Hill lies between the first appearance datums of the nannofossils *Tranolithus orionatus* and *Eiffellithus turriseiffeli*. This interval equates to the upper part of the *Prediscosphaera cretacea* Zone of Thierstein (1971), Zone 8b of Sissingh (1977) emend Perch-Nielsen (1979) and the *Prediscosphaera cretacea* to *Axopodorhabdus albianus* Zones NC 8-9 of Roth (1978). There is potential to further subdivide this time/rock interval using nannofossil datums of both a local and more cosmopolitan scale. In ascending order these are:

Last appearance datum (LAD) of *Braloweria boletiformis*

This species has never been recorded outside south-east England. Black (1972) reported it to have a LAD in Bed III (*niobe* Subzone) at Copt Point, Folkestone, 15ft above the base of the Gault Clay. He also recorded its occurrence in the basal beds of the Lower Gault in Cambridgeshire, Norfolk and Suffolk. This agrees with the present study where this LAD is recorded in sample 21, which was collected from near the *intermedius/niobe* Subzonal boundary.

Braloweria boletiformis is probably endemic to north-west Europe. Its LAD is a useful event in this area but is unlikely to be recorded elsewhere.

LAD of *Hayesites albiensis*

Hayesites albiensis has previously been recorded to co-occur with *E. turriseiffeli* by Roth and Thierstein (1972), Romein (1975),

Thierstein (1976), Manivit *et al.* (1977), Verbeek (1977), Noël (1980), Amedro *et al.* (1981), Taylor (1982), Watkins and Bowdler (1984) and Wiegand (1984). Manivit *et al.* (1977) defined the *Hayesites albiensis* Subzone as the interval where *E. turriseiffeli* and *H. albiensis* co-occur. In the present study, *H. albiensis* was found to have its LAD below the first occurrence of *Eiffellithus monechiae*, the ancestral species of *E. turriseiffeli*. *Hayesites albiensis* has a LAD in the *niobe* Subzone at Munday's Hill, which is earlier than recorded in most other studied sections. Some of the difference in this record may be due to the hiatus which results in the absence of part of the *niobe*, all of the *subdelaurei* to *daviesi* and part of the *cristatum* Subzones in the Munday's Hill section. Wise (1983) also recorded an early LAD for *H. albiensis* before the FAD of *E. turriseiffeli* in the high latitude South Atlantic DSDP Site 511. It thus appears that *H. albiensis* has a shorter stratigraphic range in high latitudes and is probably unreliable for biostratigraphical purposes in such areas.

FAD of *Axopodorhabdus albianus*

The FAD of *A. albianus* was used by Cepek and Hay (1969) and Roth (1978) as a zonal boundary. Roth (1978) recorded this event to lie between the FAD of *T. orionatus* and the FAD of *E. turriseiffeli*. This sequence of events was also recorded by Thierstein (1973, 1976), Manivit (1976), Amedro *et al.* (1981), Hojjatzadeh (1981), Taylor (1982) and Wise (1983). Perch-Nielsen (1985) questioned the reliability of the FAD of *A. albianus* as a biostratigraphical datum because of earlier stratigraphic records. Romein (1975), Hill (1976)

AGE	AMMONITE ZONE	AMMONITE SUBZONE	SAMPLE
UPPER ALBIAN	<i>S. dispar</i>	<i>M. perinflatum</i>	46
		<i>M. rostratum</i>	
	<i>M. inflatum</i>	<i>C. auritus</i>	31 30 27 26 23
		—	
		<i>H. varicosum</i>	
		<i>H. orbigny</i>	
		<i>D. cristatum</i>	
	<i>E. lautus</i>	<i>A. daviesi</i>	H i a t u s
		<i>E. nitidus</i>	
	<i>E. loricatus</i>	<i>E. meandrinus</i>	22 21 20 13
		<i>M. subdelaruei</i>	
		<i>D. niobe</i>	
		<i>A. intermedius</i>	
MIDDLE ALBIAN	<i>H. dentatus</i>	<i>H. spathi</i>	12
		<i>L. lyelli</i>	11

Fig. 2. Sample distribution compared to the ammonite zonal scheme of the north-west European province (Owen, 1984).

and Cepek (1982) all recorded the FAD of *A. albianus* before the FAD of *T. orionatus*. Cepek's (1982) samples may have been contaminated as he also records *Micula staurophora* in the Lower Albian. Hill's (1976) FAD of *T. orionatus* (*exiguus*) lies within the Upper Albian and thus this record is probably not its true first occurrence. Romein (1975) only found *A. albianus* in one sample below *T. orionatus*. In conclusion, it is more likely that the correct order of events is: the FAD of *T. orionatus* followed by the FAD of *A. albianus*.

The FAD of *A. albianus* lies within the *niobe* Subzone at Munday's Hill. This is slightly younger than its FAD recorded by Amedro *et al.* (1981) from Boulonnais in the *intermedius* Subzone, but slightly older than Black's (1972) record from Bed V at Copt Point (*nitidus* Subzone). The FAD of *A. albianus* thus appears to be a reliable cosmopolitan biostratigraphical datum.

FAD of *Owenia hilli*

The only previous record of this species is by Hill (1976) who recorded it in the Upper Albian of Texas under the name *Amphizygus brooksii* ssp. *nanus*. His observation of a FAD of this species at the base of the Upper Albian agrees with the findings of the present study, although at Munday's Hill, the base of the Upper Albian is absent due to a break in sedimentation. This species is rare in both Texas and England but its distinctive appearance may make it useful in future biostratigraphical studies.

FAD of *Corollithion signum*

Corollithion signum has been recorded in strata as old as the Early Albian (Bukry, 1969) and by several authors in the Middle Albian: Wise and Wind (1977), Perch-Nielsen (1979) and Roth (1983). Many authors don't record this species until the Upper Albian. These inconsistencies in the level of the FAD of *C. signum* are possibly caused by differences in taxonomic concepts. *Corollithion signum* probably evolved from *Corollithion achylosum* (Perch-Nielsen, 1985) through an intermediate form; *Corollithion protosignum*. The lineage involves the change from the circular *C. achylosum* to the hexagonal *C. signum*. This change is gradual and thus the FAD of *C. signum* is difficult to define precisely.

In the present study, the FAD of *C. signum* is recorded in the *cristatum* Subzone at Munday's Hill. The usefulness of this event as a biostratigraphical datum is limited by the inconsistency of identification between different authors and its rare occurrence in most areas.

Last common/abundant occurrence of *Repagulum parvidentatum*

This biostratigraphical datum was used by Jakubowski (1987) to define the top of his *R. parvidentatum* Zone (NLK 5) in the Middle Albian of the Moray Firth (North Sea, offshore UK).

At Munday's Hill, common/abundant *R. parvidentatum* occurs through the Middle Albian and into the base of the Upper Albian (*cristatum* Subzone). *Repagulum parvidentatum* is also common in sample 45 from the *varicosum*—*auritus* Subzones. It has been observed to be common/abundant when co-occurring with *E. turrisseiffelli* on the Mre-Trøndelag Platform offshore Norway (Crux, unpublished). It thus appears that the last common/abundant occurrence of *R. parvidentatum* is unreliable as a biostratigraphical event. It is diachronous and can repeat itself in the same area. A further problem is that Jakubowski (1987) did not define the terms common and abundant.

FAD of *Tegulalithus tessellatus*

The FAD of *T. tessellatus* is recorded in the *varicosum*—*auritus* Subzones of Munday's Hill. Other records of this species include Stradner, *et al.* (1968) from the Albian of Holland, Black (1973) from the Upper Albian of England, Thierstein (1973) from the Upper Aptian (*Lithastrinus septentrionalis*) and Roth (1983) from the Upper Aptian to Lower Albian of the western North Atlantic (*L.*

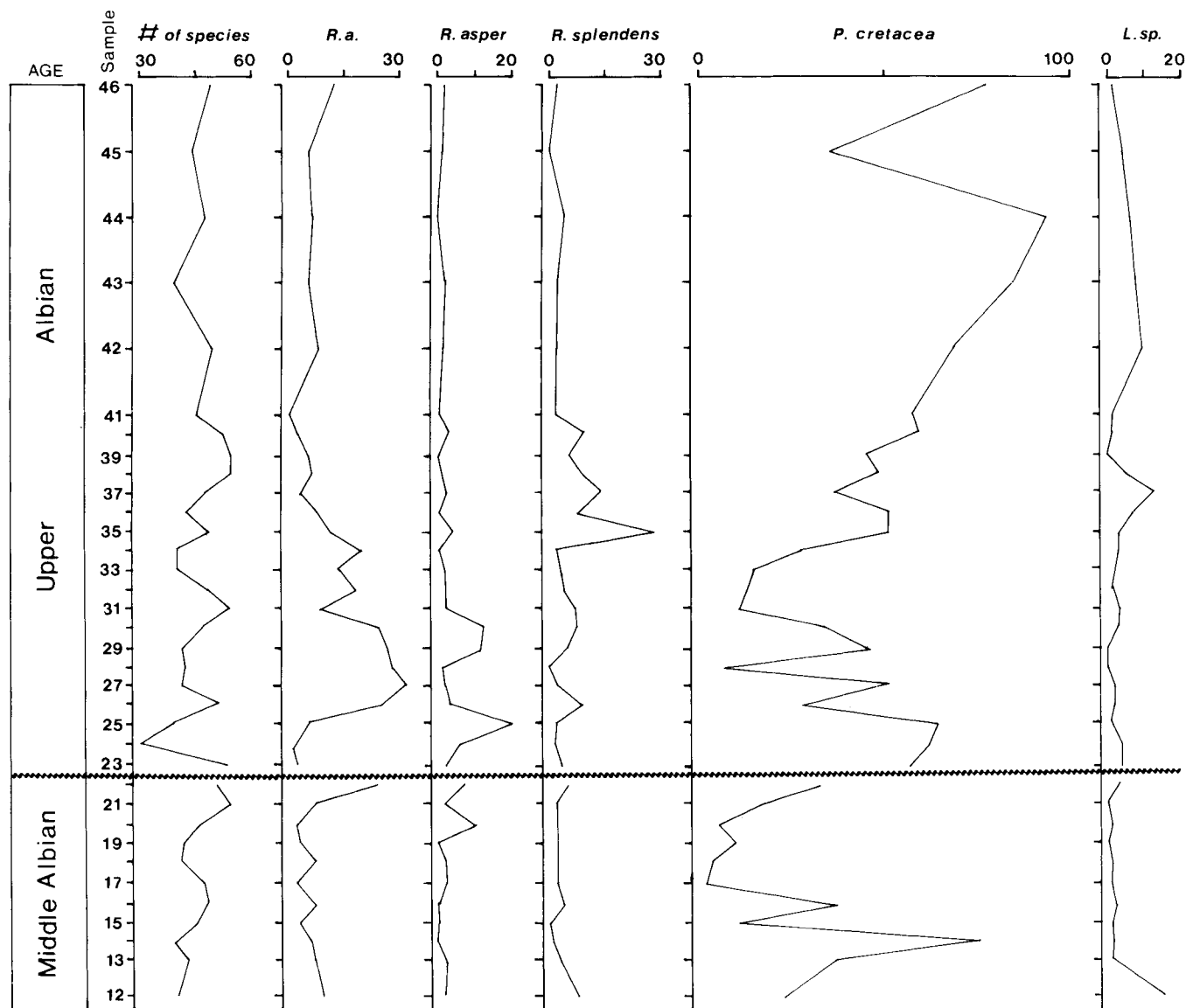


Fig. 3. Total numbers of species observed and abundance variations of *Rhagodiscus achlyostaurion* (*R. a.*), *Rhagodiscus asper*, *Rhagodiscus splendens*, *Prediscosphaera cretacea* and *Lithastrinus* sp. (*L. sp.*) in the studied samples.

septentrionalis). Roth's (1983) record is not illustrated and his range chart shows two occurrences of *L. septentrionalis*. It is probable that the higher record is of *T. tessellatus*, which many authors consider synonymous with *T. septentrionalis*. It appears that *T. tessellatus* has an earlier first occurrence outside north-west Europe than it does in the English Gault. The FAD of this species could be used as a local biostratigraphical event, but it is unreliable over great distances.

FAD of *Eiffellithus monechiae*

Opinions on the taxonomic divisions recognised in the early *Eiffellithus* species differ from author to author. Most authors agree that in the Upper Albian, species of *Eiffellithus*, with a central cross approximately aligned with the long and short axes of the elliptical coccolith (although often referred to as *Vekshinella angusta*), occur below the level of the first *E. turriseiffeli*. This sequence of events has

been documented by Hill (1976), Verbeek (1977), Perch-Nielsen (1979, 1985) and Hill and Bralower (1987).

In the Munday's Hill section, this first *Eiffellithus* species, *E. monechiae*, occurs in samples 45 and 46 from the *varicosum—auritus* Subzones. This biostratigraphical datum has been recorded from Tunisia, northern Europe and the USA. It therefore appears to be useful for inter-regional correlation

REGIONAL PALAEOGEOGRAPHY AND PALAEOOCEANOGRAPHICAL RECORD

The north-west European Mid and Late Albian epicontinental sea extended from south-east England across the North Sea, Denmark, northern Germany, Poland and into the USSR (Fig. 1). A shallow marine connection existed across north-east France to Tethys. Intermittent shallow marine connections may have existed along the

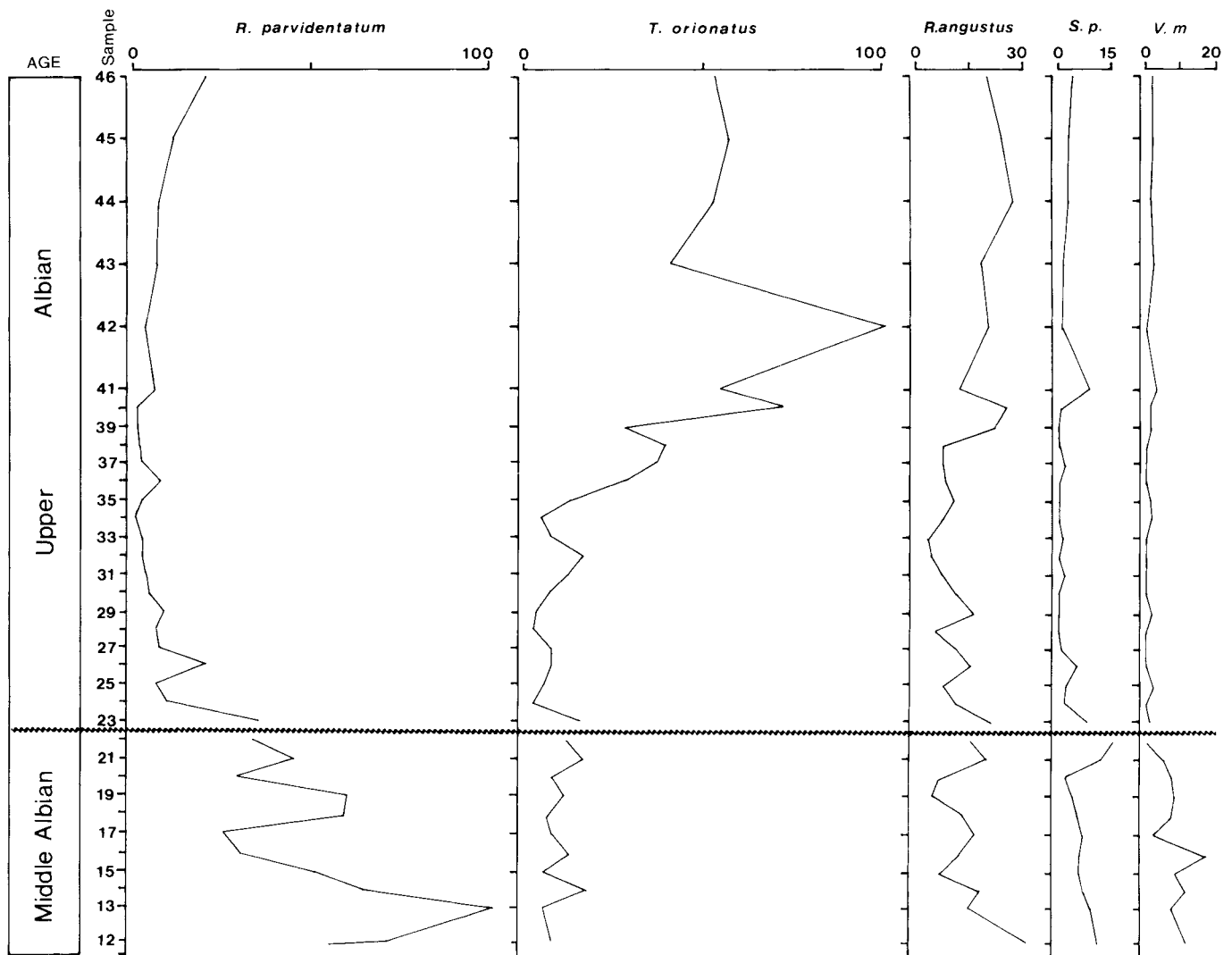


Fig. 4. Abundance variations of *Repagulum parvidentatum*, *Tranolithus orionatus*, *Rhagodiscus angustus*, *Seribiscutum primitivum* (*S. p.*) and *Stauroolithes matalosus* (*S. m.*) in the studied samples.

present day English Channel. These are shown on the generalised palaeogeographic maps for the Aptian-Albian and Albian of both Ziegler (1982) and Tyson and Funnell (1987). Owen's (1976) reconstruction of the Middle Albian shows no such connection. A narrow deep marine connection between the Shetland Platform and Norway linked this north-west European sea with Svalbard and east Greenland and possibly the Arctic Ocean. Another deep water connection is shown by Ziegler (1982) linking the proto-Atlantic with the northern North Sea along the Rockall Trough—Faroe Rift.

The extent of the north-west European epicontinental sea varied with the occurrence of regional transgressions and regressions. These also affected the marine connections with other areas. Owen (1976) reported an expansion of the area of marine deposition at the beginning of the Middle Albian. This transgression reached a maximum in the *intermedius* Subzone when the first Albian nannofossil bearing

marine clays were deposited at the Munday's Hill area. At the end of the Middle Albian, a short but widespread period of regression and erosion removed the uppermost Middle Albian sediments from Munday's Hill and much of north-west Europe. This regression has been linked to the onset of sea floor spreading in the Rockall Trough (Roberts *et al.*, 1981). Owen (1976) considered that these tectonic disturbances at the end of the Middle Albian opened an ephemeral connection between the Arctic and the European seas. Tectonic disturbances caused a further transgression in the *crisatum* Subzone at the beginning of the Late Albian. Marine connections were once again established with the Tethys—Proto-Atlantic area through the Polish Trough and the Paris Basin and presumably the Bay of Biscay and the Rockall Trough (Ziegler, 1982). The two transgressions discussed above can possibly be related to the global 3rd order cycles UZA-1.3 to UZA-1.4 and UZA-1.5 to the base of UZA-2.1 of coastal

[illegible]

Fig. 5. Stratigraphic distribution of nannofossil species in the Munday's Hill section. Description of abundances in Fig. 7.

[illegible]

Fig. 6. Stratigraphic distribution of nannofossil species in the Munday's Hill section. Description of abundances in Fig. 7.

[illegible]

Fig. 7. Stratigraphic distribution of nanofossil species in the Munday's Hill section. Very abundant >5 specimens/field of view, Abundant >1 specimen/field of view, Common >1 specimen/5 fields of view, Rare <1 specimen/field of view.

onlap change as described by Haq *et al.* (1988), although these correlations are tentative partly because of local tectonics and erosion. Haq *et al.* (1988) used sections in nearby northern France to define their cycles, so some relationship would be expected.

Owen (1971, 1973 and 1976) recognised a relationship between palaeogeography and the distribution of ammonite faunas during the Albian. He defined a Hoplitinid ammonite province in the Middle Albian European epicontinental sea. The hoplitinids were the predominant group of ammonites from the Anglo-Paris Basin eastwards to the USSR. The ammonite faunas show evidence for links with the Arctic north of Spitsbergen and east Greenland only during the *dentatus* Zone. Although marine connections with Tethys to the south existed, the hoplitinids remained in northern Europe. Typical Tethyan ammonites did occasionally migrate northwards, especially in the *lyelli* and the *subdelaueri* Subzones. Tectonic disturbance and renewed transgression at the beginning of the Late Albian allowed the Arctic—North American genus *Gastropolites* to enter and co-occur with the hoplitinid fauna in Spitsbergen, east Greenland and southern England. At the same time, in the *cristatum* Subzone, Tethyan ammonite genera entered from the south and persisted in the north-west European region throughout the Late Albian. A distinct Hoplitinid province was still present in the European area throughout the Late Albian.

Michael (1979) recognised a relationship between palaeogeography and the distribution of foraminifera. He identified

increases of warm water dextrally coiled benthic and planktonic foraminiferal faunas into the European sea at the base of the Middle Albian and during the Late Albian and Cenomanian. Michael (1979) also observed an increase in Tethyan planktonic and benthic foraminifera from the Middle to Upper Albian.

DISTRIBUTION OF PALAEOGEOGRAPHICAL AND PALAEOENVIRONMENTAL NANNOFOSSIL INDICATORS IN MUNDAY'S HILL

Our knowledge of the nannofloras that existed in north-west Europe prior to the transgression at the beginning of the Middle Albian is poor. Published accounts of Lower Albian nannofossils are from northern France (1 sample) (Stover, 1966), northern Germany, (Cepek, 1982, and Moray Firth (Jakubowski, 1987). Neither Stover (1966) or Jakubowski (1987) present detailed distribution charts. Cepek (1982) only studied the basal Lower Albian where he recorded 15 species. A number of studies have recently been published concerning the palaeobiogeography of nannofossils in the Lower and “middle” Cretaceous: Thierstein (1976), Wise and Wind (1977), Roth (1981), Roth and Bowdler (1981), Roth and Krumbach (1986), Kemper *et al.* (1987), Erba (1987) Erba *et al.* (1989), Mutterlose (1988, 1989), Applegate *et al.* (1989) and Crux (1989).

Nannofossil taxa with the environmental preferences suggested by these publications are summarised in Table 1. The distribution of all species recorded from the Munday's Hill section can be found in Figs 5 - 7.

Low latitude <i>R. achlyostaurion</i> (1) <i>H. albiensis</i> (1) <i>R. asper</i> (2, 3) <i>L. carniolensis</i> (3) <i>M. chiastius</i> <i>Z. erectus</i> (5) <i>R. infinitus</i> (4) <i>R. irregularis</i> (6, 7) <i>Nannoconus</i> spp. (3, 6, 7) <i>F. oblongus</i> (4) <i>R. splendens</i> (2) <i>H. trabeculatus</i> (4)	Endemic to NW Europe <i>C. bicornuta</i> (1) <i>B. boletiformis</i> (1) <i>C. cruxii</i> (1) <i>G. granulifera</i> (1) <i>C. hamata</i> (1)	High latitude <i>C. anfractus</i> (1) <i>C. anglicum</i> (1) <i>R. angustus</i> (1) <i>B. dissimilis</i> (4) <i>S. falklandensis</i> (4) <i>C. hayi</i> (1) <i>S. horticus</i> (8) <i>Lapideacassis</i> sp. (4) <i>Lithastrinus</i> spp. (9) <i>S. matalosus</i> (1) <i>T. orionatus</i> (10) <i>R. parvidentatum</i> (11, 12) <i>S. primitivum</i> (4, 5, 6, 7) <i>O. reinhardtii</i> (4) <i>Z. sisyphus</i> (8) <i>T. tessellatus</i> (1) <i>Z. noeliae</i> (2) <i>L. floralis</i> (2, 3)
Epicontinental/ continental margins <i>C. anglicum</i> (1) <i>Braarudosphaera</i> spp. (5) <i>Broinsonia</i> sp. (5) <i>Z. erectus</i> (5) <i>Nannoconus</i> spp. (5) <i>Z. noeliae</i> (5) <i>Z. elegans</i> (5)	High surface water fertility and unstable environments <i>Broinsonia</i> sp. (5) <i>Corollithion</i> spp. (5) <i>B. ellipticum</i> (5) <i>D. ignotus</i> (3) <i>Z. sisyphus</i> (8) <i>Zeugrhabdotus</i> spp. (3)	Oceanic <i>W. barnesae</i> (5)

TABLE 1. Summary of Environmental Indicator Nannofossil Species Considered in This Study. The following assumptions of taxonomic definitions have been made: *B. ellipticum* = *B. constans*, *O. reinhardtii* = *O. magnus*, *F. oblongus* = *F. biforaminis*. References: (1) This study, (2) Roth & Krumbach (1986), (3) Erba (1987), (4) Wise & Wind (1977), (5) Roth & Bowdler (1981), (6) Thierstein (1974), (7) Thierstein (1976), (8) Crux (1989), (9) Stradner (1963), (10) Roth (1983) (11) Wise (1983) (12) Erba (1989).

Results of abundance counts

Abundance counts were performed on ten taxa in order to evaluate their significance as palaeoenvironmental indicators (Figs. 3 and 4). The species were chosen because it was observed in the initial analysis that they significantly varied in abundance in different parts of the section, and that they were common enough to make abundance counts meaningful.

Rhagodiscus achlyostaurion, *R. asper* and *R. splendens* show a preference for conditions during the topmost *niobe* Subzone and during the *cristatum*, *orbigny* and the lower half of the *varicosum*—*auritus* Subzones, after a lowpoint in the lowermost *cristatum* Subzone. *Rhagodiscus asper* and *R. splendens* were previously suggested to prefer warm surface waters by Roth and Krumbach (1986). As *R. achlyostaurion* shows a similar distribution pattern to these two species, it appears that *R. achlyostaurion* may also prefer warm waters.

Repagulum parvidentatum, *S. primitivum* and *S. matalosus* have similar distribution patterns and show distinct preferences for conditions during the *spathi* to *niobe* Subzones. Amedro *et al.* (1981) recorded *S. primitivum* as common in the *E. turriseiffeli* Zone at Boulonnais, northern France. In the North Sea, Jakubowski (1987) found this species to be abundant up to a level just below the top of the Albian, although his record is based on oil company ditch cuttings samples which give less precise information. *Seribiscutum primitivum* co-occurs with *E. turriseiffeli* in core samples from the Mre-Trøndelag Platform (offshore Norway) where it comprises up to 5% of the nannofossil flora (Crux, unpublished) which confirms that *S. primitivum* is a high latitude species. *Repagulum parvidentatum* is known to prefer high latitudes which thus appear to be the case also for *S. matalosus*. *Lithastrinus* sp. and *T. orionatus* possibly prefer high latitudes, however, they show a slightly different abundance pattern to *R. parvidentatum* and *S. primitivum*, as they are most common in the upper part of the *varicosum*—*auritus* Subzones. *Tranolithus orionatus*, which has been reported as a high latitude species (Roth, 1983) is most abundant at the beginning of the cooling event in the upper Albian. However, *T. orionatus* evolved shortly before the base of the studied section, and its relatively low abundance in the middle Albian may reflect that this species was not yet established. Common for all the high latitude nannofossil species are low abundances in the *orbigny* through the lower half of the *varicosum*—*auritus* Subzones and higher abundances in the Middle Albian, in the *cristatum* Subzone and in the upper half of the *varicosum*—*auritus* Subzones. It appears that *R. angustus* has a weak preference for the conditions preferred by high latitude nannofossil species. The abundance pattern of *P. cretacea* is ambiguous to interpret and may indicate nutrient levels.

Low latitude and endemic species

Nannofossil taxa thought to prefer low latitudes occur in relatively low numbers throughout the Munday's Hill section. *Hayesites albiensis* appears to have a shorter stratigraphic range than in lower latitudes and *R. irregularis* is absent. *Rhagodiscus asper*, *R. splendens*, *Z. erectus*, *F. oblongus* and *Nannoconus* spp. are less common than they are reported to be in lower latitudes.

Braloweria boletiformis and *Ceratolithina hamata* have never been observed outside north-west Europe and appear to be endemic to this area. This may also be the case for *Gaarderella granulifera*, which outside north-west Europe has only been tentatively observed in the Pacific and Atlantic oceans (Roth, 1981, 1983). (See discussion

in Taxonomy). *Gaarderella granulifera* occurs in both the Middle and Upper Albian at Munday's Hill. It has also been recorded from the Middle and Upper Albian at Copt Point and localities in eastern England (Black, 1973). The only reported observations of *B. boletiformis* are restricted to the Middle Albian, where it also occurs at Munday's Hill. A closely related form, *Braloweria judithae*, was reported by Black (1972) from the Upper Albian of eastern England. *Ceratolithina hamata* is present in both the Middle and Upper Albian at Munday's Hill. It has previously been recorded from the Middle Albian of Germany (Martini, 1967), Middle Albian Copt Point (Perch-Nielsen, 1988) together with the closely related forms *C. cruxii* and *C. bicornuta* (Middle to Upper Albian) and from the Albian of an oil well onshore The Netherlands (Crux, unpublished).

High latitude nannofossil species

Nannofossils identified in previous studies to have high latitude preferences occur throughout the Munday's Hill section but their abundance vary at different levels, being most common in the *cristatum* Subzone and in the upper half of the *varicosum*—*auritus* Subzones (Figs. 5–7). *Biscutum dissimilis* and *S. falklandensis* were not observed. These species have only ever been recorded from the high latitudes of the southern hemisphere.

Environmental indicators

Most of the species identified in previous studies as being more common in epicontinental and continental margin seas, show little variation in their distribution through the Munday's Hill section (Figs. 5–7). The two most common species in this group are *B. ellipticum* and *Z. noeliae* which are slightly more abundant in the Upper Albian than in the Middle Albian. *Braarudosphaera* spp. and *Nannoconus* spp. are absent in the lower part of the Middle Albian at Munday's Hill.

No distinctive patterns are observed in the distribution of species previously found to indicate high fertility and unstable environments. *Watznaueria barnesae*, the only species whose high abundance has been identified as indicating oceanic conditions, is abundant throughout the section, becoming very abundant in two poorly preserved samples (33 and 34) and also in sample 22.

NANNOFLORAL DEVELOPMENT AND PALAEOCEANOGRAPHICAL IMPLICATIONS

The earliest stratigraphic records of *Crucicribrum anglicum* are from the Aptian and Lower to Middle Albian of the relatively shallow water, high latitude, Falkland Plateau and the marginal epicontinental seas of Texas and north-west Europe. It thus appears that this species evolved in shallow, high latitude seas and only occurred in low latitude deep water areas from the Late Albian to Cenomanian. This pattern would agree with other authors observations concerning the closely related genera *Broinsonia*, *Gartnerago* and *Kamptnerius*. These have been recognised to occur more abundantly in shallow shelf seas (Thierstein, 1976; Hartner *et al.*, 1981; Roth and Bowdler, 1981) and to occur earlier in high latitudes (*Kamptnerius magnificus* (Thierstein, 1976)).

A decrease in abundance of *R. parvidentatum* was noted by Jakubowski (1987) in the Moray Firth and by Erba *et al.* (1989) in the Middle Albian of southern England. Wise (1983) shows in his nannofossil distribution chart of DSDP Site 511 from the Falkland Plateau, a reduction in numbers of *R. parvidentatum* at the top of his *T. orionatus* Subzone. At the same level occurs the last *S. falklandensis*.

The record of the abundance decrease of *R. parvidentatum* by Erba *et al.* (1989) is stratigraphically earlier than observed in the present study. This would suggest that the abundance decrease of *R. parvidentatum* is diachronous, occurring later at Munday's Hill than in southern England. It is possible that the reduction in abundance of this cold water preferring species, occurred first at lower latitudes and moved diachronously towards higher latitudes in both hemispheres. Unfortunately, neither Wise's (1983) or Jakubowski's (1987) records are precisely dated by ammonites to give us further data on this. However, it is likely that this event indicates reduced influences of cold surface water masses. Erba *et al.* (1989) favoured a transgressive event displacing the Arctic watermasses of which *R. parvidentatum* was characteristic, to have caused its abundance decrease. In the Munday's Hill section, *R. parvidentatum* returns with increased abundances in the upper half of the *varicosum*—*auritus* Subzones, however, it does not become as common as in the Middle Albian. No return of *R. parvidentatum* during the Albian is noted in the southern hemisphere at DSDP Site 511.

Other species previously identified to have high latitude affinities also show some increase towards the top of the Munday's Hill section, in particular, *S. primitivum*, *S. horticus*, *Z. noeliae* and *T. tessellatus* in combination with species suggested in this study to prefer colder waters; *Lithastrinus* sp., *R. angustus* and *S. matalosus*. In the southern hemisphere, Wise (1983) reported *S. primitivum* to be common through the upper part of his *P. cretacea* Zone, becoming abundant just before the FAD of *E. turriseiffeli*. This abundant occurrence continues through the *E. turriseiffeli* Zone. A similar pattern was also recorded by Wise and Wind (1977) from the Falkland Plateau and by Thierstein (1974) at DSDP Site 258 in the high latitudes of the Indian Ocean. It thus appears that the advance of colder surface waters in the late *inflatum*—*dispar* Zone occurred in both the northern and southern hemispheres.

When marine sedimentation commenced at Munday's Hill in the *spathi* Subzone, the nannofloras were abundant and diverse. Forty species were present in the lowermost sample from the *spathi* Subzone, rising to 59 species in the *niobe* Subzone (Fig. 3). High total abundances and diversified nannofossil assemblages persisted throughout the studied section, suggesting that the Munday's Hill area continuously had marine connections with areas outside north-west Europe. The continuous presence, although in relatively low abundances, of species with low latitude affinities, indicates inflow of waters from the Tethys and proto-Atlantic seas. The approximately synchronous FAD's of *Axopodorhabdus albianus*, *Owenia hilli* and *Eiffellithus monechiae*, at Munday's Hill and at more southerly localities, supports this view.

The distribution of low latitude and endemic nannofossil species is similar to their ammonite counterparts. The species identified as being endemic to north-west Europe, could possibly also be present in the high latitude Boreal/Arctic as we know little about the nannofossils of these areas. However, they were not reported from the Moray Firth area (North Sea, offshore UK) by Jakubowski (1987) and have not been observed by the author in oil company wells offshore Norway. Furthermore, they do not have the bipolar distribution patterns of other high latitude nannofossil species. However, further studies outside north-west Europe are needed to definitely prove the existence of an endemic nannoflora, although these species were not reported in recent studies by Bralower (pers. comm.).

The nannofossil abundance patterns in north-west Europe suggest

that the relatively colder environment near the beginning of the Middle Albian gradually warmed up towards the regressive event at the end of the Middle Albian. In the Upper Albian, this general trend was temporarily interrupted in the lower *cristatum* Subzone, where high latitude species increase in abundance. Warmer conditions were established by the *orbigny* Subzone and persisted through the lower half of the *varicosum*—*auritus* Subzones. During the upper half of the *varicosum* - *auritus* Subzones, intermediate to cold surface waters may have prevailed.

This does not completely agree with Kemper (1987), who studied the distribution of pseudomorphs of glendardites and considered the Middle to Late Albian to be a period of climatic stability. The nannofossil abundance patterns show similarities to results obtained from foraminifera. Michael (1979) analysed the coiling direction of the foraminifera *Gavelinella* spp. (benthic) and *Hedbergella* (planktonic) through the Albian. During the Middle Albian 50 - 60 % were sinistrally coiled, indicating cold water conditions. However, a peak of dextrally coiled forms were found at the base of the Middle Albian. This is probably below the base of the Munday's Hill section. The number of sinistral forms dropped rapidly to 40% at the Middle to Upper Albian boundary, indicating somewhat warmer conditions. Higher in the Upper Albian, 50 % of the foraminifers were sinistrally coiled, before dropping to 35 % by the end of the Albian. Unfortunately, it is not possible to precisely correlate the foraminifer results to the nannofossils, as Michael (1979) did not relate his study against ammonite zones and subzones. His definitions of the Middle and Upper Albian may be different from those used in this study.

The decline in abundance of high latitude nannofossils observed through the uppermost *dentatus* to *loricatus* ammonite Zones, equates with the top of Haq *et al.*'s (1988) UZA-1.3 and the base of their UZA-1.4 coastal onlap cycles. The advance of high latitude species seen at the base of the *cristatum* Subzone lies near the base of Haq's *et al.*'s (1988) UZA-1.5 cycle, whereas the cooling interval observed in the uppermost *inflatum* Zone and into the *dispar* Zone corresponds with most of their UZA-2.1 cycle. No simple relationship appears to exist between the variations in high/low latitude nannofossil abundances in the Munday's Hill area and the sea level/transgressive-regressive cycles of Haq *et al.* (1988).

SYSTEMATICS

Taxonomic references not included in the reference list can be found in Perch-Nielsen (1985) and in the INA Newsletter.

Class Haptophyceae Christensen 1962
Order Prymnesiales Papenfuss 1955
Suborder Coccolithineae Kamptner 1928
Family *Biscutaceae* Reinhardt 1964
Genus *Crucibiscutum* Jakubowski 1986
Crucibiscutum hayi (Black 1971) Jakubowski 1986

Crucibiscutum salebrosum (Black 1971) Jakubowski 1986

Remarks. Large and small forms of *Crucibiscutum* have been divided into *C. hayi* and *C. salebrosum* respectively. Jakubowski (1987) used the extinction of *C. salebrosum* to define a zone within the Barremian of the Moray Firth. However, several authors have recorded this species from younger strata. In addition Crux (1989; Pl. 8.10, figs 29-30) recorded the large forms (*C. hayi*) from the Hauterivian. It thus appears that both forms range throughout most of the Lower Cretaceous and their division on size alone is of doubtful

value. The two forms were counted as one taxonomic unit in the present study.

Genus *Gaarderella* Black 1973

Gaarderella granulifera Black 1973
(Pl. 2, figs 20-21)

Remarks. Roth (1981) reported *G. cf. G. granulifera* from the Mid Pacific Mountains, and illustrated the species with a light micrograph (Roth (1981) Pl. 1, figs 5a, b). The illustrated specimen has a narrow rim with both the outer and inner parts brightly birefringent. In the specimens of this study, the rim is broader and only the inner part is observed to be bright (Pl. 2, fig. 20). In Roth's specimen, the birefringence pattern of the rim indicates that it is imbricate, however, Black (1973) described *G. granulifera* as having a non imbricate rim. Roth (1983) also recorded *G. granulifera* from the Aptian of DSDP Site 534 located on the Blake Bahama Basin, but did not illustrate the rare specimen recorded. In conclusion, the presence of *G. granulifera* in both the Atlantic and Pacific oceans are not verified.

Family *Calyptrorphaeraceae* Boudreaux and Hay 1969
Genus *Calculites* Prins and Sissingh in Sissingh 1977

Calculites sp. 1
(Pl. 1, fig. 4; Pl. 2, figs 5 and 6)

Description. Small elliptical holococcolith with a central perforation.
Remarks. No distal view of this species was seen in the scanning electron microscope (SEM). Its assignment to the genus *Calculites* is only tentative, it does not appear to fit into any other described genus of holococcolith.

Calculites sp. 2
(Pl. 2, Fig. 7)

Description. Small bright holococcolith which was only observed under the light microscope. It appears to have a single large central perforation. It differs from *Calculites* sp. 1 by possessing a distinctive extinction pattern between x-nicols which divides the rim into four unequal segments, two small and two large.

Remarks. Its assignment to *Calculites* is only tentative, it does not appear to fit into any other described genus of holococcolith.

Genus *Owenia* gen. nov.

Type species *Owenia hilli* n. sp.

Derivation of name. After H. G. Owen, ammonite specialist.

Diagnosis. Elliptical holococcolith with a narrow outer rim and broad inner rim. A central perforation is crossed by an arched bridge aligned with the short axis of the elliptical coccolith.

Remarks. *Owenia* differs from *Ottavianus* Risatti 1973 by lacking its 10-15 irregular rim elements. It differs from the genus *Ramsaya* Risatti 1973, whose outer rim is wider than the inner rim.

Owenia hilli sp. nov.

(Pl. 1, figs 3 and 6; Pl. 2, figs 1-4 and 8)

1976 *Amphizygus brooksii* ssp. nanus Bukry; Hill: 122, Pl. 1, figs 12-24.

Derivation of name. After M. E. Hill III, nannofossil specialist.

Diagnosis. As from the genus *Owenia*.

Holotype. Pl. 1, fig. 6.

Type locality and horizon. Munday's Hill near Leighton Buzzard, Bedfordshire, England. Grid ref. SP 939279. Upper Gault, *cristatum* Subzone, sample 23.

Dimensions. Length 2.9-3.5 μm ; width 2.0-2.1 μm , two specimens measured.

Remarks. The diagnosis of this species is similar to that of *Orastrum partium* Varol in Al Rifa'i et al. (1990). The two species differ in the construction of their bridges, *O. partium* is reported and illustrated as appearing to have a cross formed of four elements in X-nicol light. The bridge of *O. hilli* is composed of numerous crystals, which do not appear as a cross in X-nicol light.

Family *Ceratolithaceae* Norris 1965
Genus *Ceratolithina* Martini 1967

Ceratolithina hamata
(Pl. 1, fig. 5; Pl. 2, fig. 22)

Remarks. *Ceratolithina cruxii* Perch-Nielsen 1988 is included in the abundance estimates of *C. hamata* in Fig. 7.

Family *Crepidolithaceae* Black 1971
Genus *Braloweria* gen. nov.

Type species *Parhabdolithus boletiformis* Black 1972

Derivation of name. After T. J. Bralower, nannofossil specialist.

Diagnosis. Elliptical heterococcolith with a loxolith rim structure, the central areas is completely filled with a large single hollow spine composed of numerous laths of calcite. This spine may flare or taper distally.

Remarks. This genus differs from *Parhabdolithus* Deflandre 1952 in its rim structure. In *Braloweria*, the rim is of a loxolith structure

Explanation of Plate 1

Electron micrographs, bars in top left corner = 1 μm

Fig. 1. *Tegulolithus tessellatus*, plan view, sample 39.

Fig. 2. *Seribiscutum primitivum*, proximal view, sample 17.

Fig. 3. *Owenia hilli* n. sp., distal view, sample 39.

Fig. 4. *Calculites* sp. 1, proximal view, sample 39.

Fig. 5. *Ceratolithina hamata*, sample 23.

Fig. 6. *Owenia hilli* n. sp., distal view, sample 23.

Fig. 7. *Crucicribrum anglicum*, proximal view, sample 12.

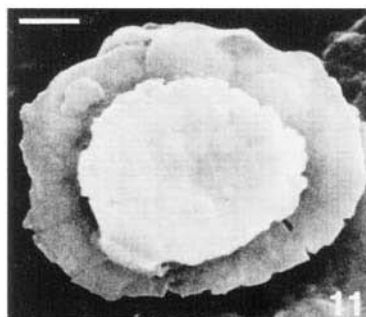
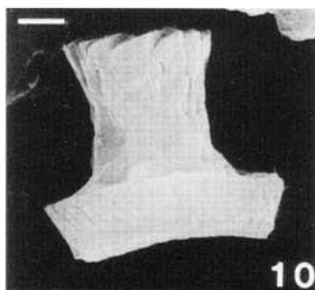
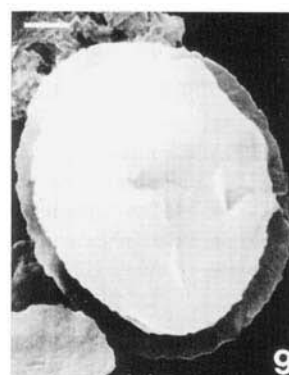
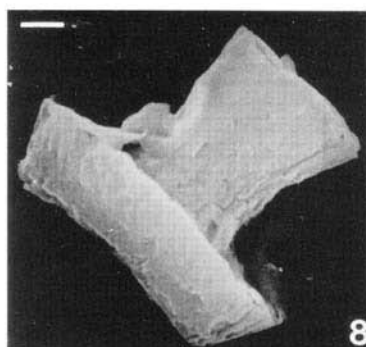
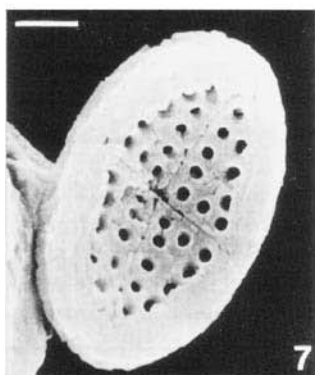
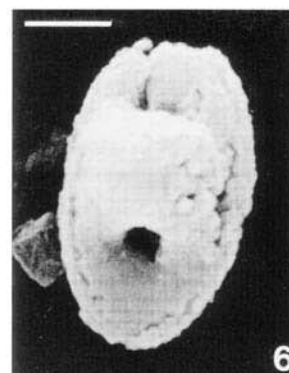
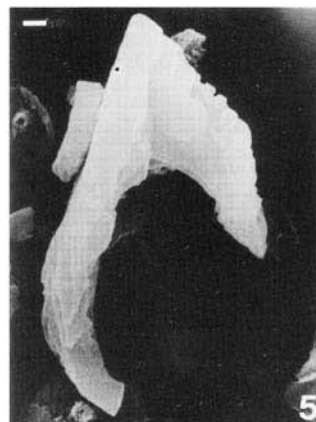
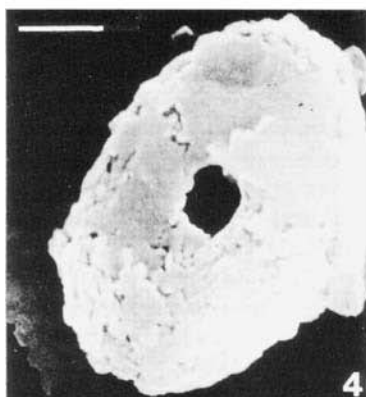
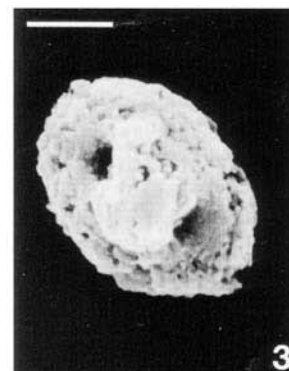
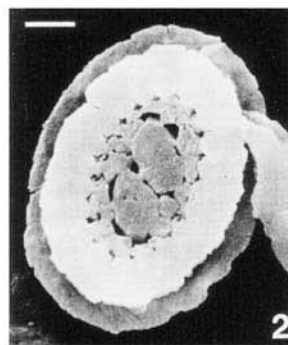
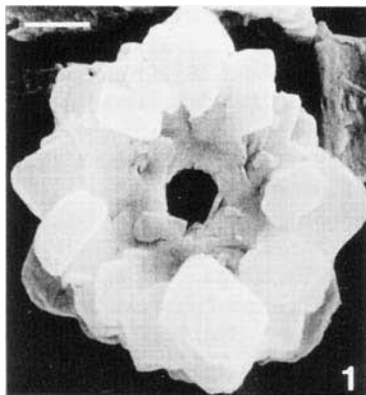
Fig. 8. *Braloweria boletiformis*, side view, sample 17.

Fig. 9. *Braloweria boletiformis*, distal view, sample 17.

Fig. 10. *Braloweria boletiformis*, side view, sample 17.

Fig. 11. *Braloweria boletiformis*, distal view, sample 17.

Fig. 12. *Repagulum parvidentatum*, distal view, sample 21.



while in *Parhabdolithus*, the rim is of a protolith structure sensu Bown (1987). *Braloweria* differs from *Rhagodiscus* Reinhardt 1967 by the regular construction of its central area which is completely filled by the spine.

Braloweria boletiformis (Black 1972) n. comb.
(Pl. 1, figs 8-11; Pl. 2, figs 13-18)

1972 *Parhabdolithus boletiformis* Black: 29-30, Pl. 3, figs 3, 4, Pl. 4, figs 1-3.

Remarks. Black (1972) considered the spines of *B. boletiformis* to be solid. In the present study, light microscope examinations suggest that they may be hollow (Pl. 2, figs 15-18).

Braloweria judithae (Black 1972) n. comb.

1972 *Parhabdolithus judithae* Black: 30-31, Pl. 3, figs 5, 6, Pl. 4, fig. 4.

Remarks. This species was not observed in the present study.

Genus *Crepidolithus* Noël 1965

Crepidolithus sp.

Remarks. This species, which was only seen under the light microscope in one sample, is similar to the Jurassic species *Crepidolithus crassus* (Deflandre in Deflandre and Fert 1954) Noël 1965. No other evidence for reworking of Jurassic nannofossils was seen, so it is assumed this species is in-situ and as yet undescribed.

Family *Eiffellithaceae* Reinhardt 1964
Genus *Chiastozygus* Gartner 1968

Chiastozygus sp.

Description. Small species of *Chiastozygus* with a thin central cross.

Remarks. This species was not seen in the SEM.

Genus *Eiffellithus* Reinhardt 1965

Eiffellithus monechiae sp. nov.

Not illustrated

non 1979 *Eiffellithus* sp. 1 Perch-Nielsen: 243

non 1979 *Eiffellithus* sp. 3 Perch-Nielsen: 243

1976 *Eiffellithus eximius* (Stover); Hill: 139, Pl. 6, figs 24-39 (non 19-23, 30-33)

1985 *Eiffellithus* sp. 1 Perch-Nielsen fig. 35.5 and 35.6 (non fig. 34)
1985 *Eiffellithus* sp. 3 Perch-Nielsen figs 35.7 and 35.8 (non fig. 34)
1987 *Eiffellithus eximius* (Stover): Hill and Bralower: 92-93, Pl. 1, figs 4-6, Pl. 2, figs 1-4 (non Pl. 1, figs 2, 3, 7 and 8).

Derivation of name. After S. Monechi, nannofossil specialist

Diagnosis. A species of *Eiffellithus* whose central cross is aligned within 20° of the major axes of the elliptical coccolith. The blocky plates of the central area are equal or greater in width than the rim, but do not totally fill the centre.

Holotype. Hill and Bralower, 1987, Pl. 2, fig. 3.

Type locality and horizon. Locality 6264 Hill (1976). North bank of Red River just E. of bridge of US highway 75 just below Texhoma Dam Oklahoma. Duck Creek Formation, Upper Albian.

Dimensions. Length 4.7 - 6 µm, width 3.4 - 4.6 µm, 3 specimens measured.

Remarks. *Eiffellithus monechiae* is differentiated from *E. eximius* by its stratigraphic range, Upper Albian to lowest Cenomanian, rather than the Turonian to Maastrichtian of *E. eximius*. It is also differentiated by a narrower cycle of blocky elements in the central area although this may vary considerably due to preservation.

Hill and Bralower (1987) grouped *E. monechiae* with *E. eximius* on the basis that they found *E. eximius* in the basal Turonian sediments and that they considered it probable that it was present throughout the Cenomanian in very low numbers and as yet undetected by them and other authors. I believe that *E. monechiae* evolved from *S. angustus* in the Late Albian and in turn *E. turriseiffeli* evolved from it. In the Turonian, *E. eximius* evolved from *E. turriseiffeli*. Thus the two forms, although morphologically similar, are different species. This is also a pragmatic approach as the first occurrences of both species are useful as biostratigraphical datums. *Staurolithites angustus* is differentiated from *E. monechiae* as the blocky elements in the central area are narrower than the outer rim. This definition may be difficult to apply in poorly preserved material where the elements are overgrown, but has worked in sections I have examined from north-west Europe.

Genus *Staurolithites* Caratini 1963

Staurolithites angustus (Stover 1966) n. comb.

1966 *Zygodolites angustus* Stover: 147, Pl. 3, figs 14, 15, Pl. 8, fig. 22.

1977 *Vekshinella angusta* (Stover) Verbeek: 96, Pl. 6, figs 11, 12.

Remarks. *Staurolithites* is the senior synonym of the genus *Vekshinella* Loeblich and Tappan 1963 although, many authors

Explanation of Plate 2

Light micrographs X2800

Figs 1, 2. *Owenia hilli* n. sp., x-nicols and bright field, sample 41.

Figs 3, 4. *Owenia hilli* n. sp., x-nicols and bright field, sample 23.

Figs 5, 6. *Calculites* sp. 1, x-nicols and bright field, sample 12.

Fig. 7. *Calculites* sp. 2, x-nicols, sample 23.

Figs 9, 10. *Lithastrinus* sp., x-nicols and bright field, sample 37.

Fig. 11. *Repagulum parvidentatum*, x-nicols, sample 12.

Fig. 12. *Seribiscutum primitivum*, x-nicols, sample 23.

Figs 13, 14. *Braloweria boletiformis*, x-nicols and bright field, sample 13.

Figs 15, 16. *Braloweria boletiformis*, x-nicols and bright field, sample 12.

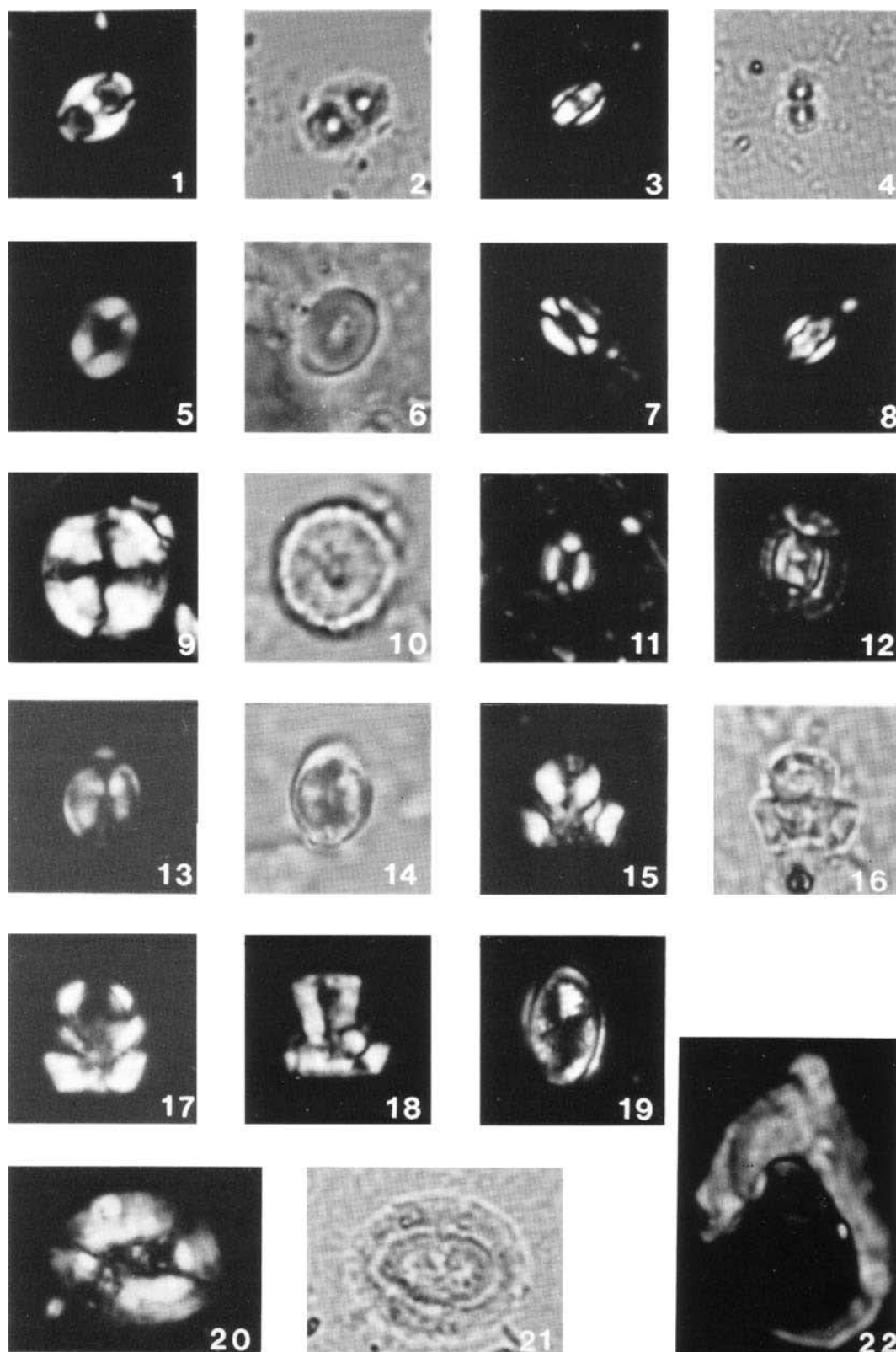
Fig. 17. *Braloweria boletiformis*, x-nicols, sample 14.

Fig. 18. *Braloweria boletiformis*, x-nicols, sample 19.

Fig. 19. *Crucicribrum anglicum*, x-nicols, sample 31.

Figs 20, 21. *Gaarderella granulifera*, x-nicols and bright field, sample 12.

Fig. 22. *Ceratolithina hamata*, x-nicols, sample 23.



(Bukry 1969) believe it is too poorly illustrated and defined to be useful and have used *Vagalapilla* Bukry (1969).

Family Polycyclolithaceae Forchheimer 1972

Genus *Lithastrinus* Stradner 1962

Lithastrinus orbiculatus (Forchheimer 1972) Crux in Crux *et al.* 1982

Remarks. *L. orbiculatus* is grouped with *L. floralis* in the light microscope abundance estimates presented in Fig. 6.

Lithastrinus sp.

(Pl. 2, figs 9-10)

Description. Large species of *Lithastrinus*, with 10 or more elements. It appears to be similar to *L. planus* but has more elements.

Genus *Tegulalithus* Crux 1986

Tegulalithus tessellatus (Stradner in Stradner *et al.*, 1968)

Crux 1986

(Pl. 1, fig. 1)

Remarks. *T. tessellatus* is differentiated from *T. septentrionalis* by having a much larger central perforation. The large wall forming elements seen in *T. septentrionalis* have not yet been observed in *T. tessellatus*.

Family Prediscosphaeraceae Rood, Hay and Barnard 1971

Genus *Prediscosphaera* Vekshina 1959

Prediscosphaera cretacea (Arkhangelsky 1912) Gartner 1968

Remarks. *Prediscosphaera cretacea* as used in this study also probably includes *Prediscosphaera columnata* (Stover 1966) Perch-Nielsen 1984. The two species can only be differentiated when their spines are preserved, which is infrequently, thus a more practical approach is to group them as one species.

CONCLUSIONS

The last occurrence of *Braloweria boletiformis* is a reliable biostratigraphic datum within south-east England. The first occurrences of *Axopodorhabdus albianus*, *Owenia hilli* and *Eiffellithus monechiae* appear to be reliable world-wide biostratigraphical datums. The last occurrence of common/abundant *Repagulum parvidentatum* is diachronous, occurring earlier in low latitudes. The last occurrence of *Hayesites albiensis* is also diachronous, occurring earlier in high latitudes. The first occurrence of *Corollithion signum* is an unreliable biostratigraphic event. This species evolves gradually from *Corollithion achylosum* and thus, its FAD is difficult to define consistently.

A nannofossil floral province, unique to north-west Europe, existed through both the Middle and Upper Albian. Three species, *B. boletiformis*, *Ceratolithina hamata* (and the closely related *C. bicornuta* and *C. cruxii*), and *Gaarderella granulifera*, appear to be endemic to north-west Europe.

The occurrence of low latitude nannofossil species throughout the Munday's Hill section, and the nearly synchronous first and last occurrences of species both at Munday's Hill and in other areas, indicates marine connections with the Tethys—Proto-Atlantic areas throughout the Middle and Upper Albian interval studied.

Decreasing abundances of high latitude nannofossil species, primarily *R. parvidentatum* and *S. primitivum*, through the Middle Albian suggest that a relatively cold environment near the base of the

Middle Albian gradually warmed up towards the regressive event at the end of the Middle Albian. This general trend was temporarily interrupted at the base of the Upper Albian (lower *cristatum* Subzone), when high latitude species increased in abundance. Low abundances of high latitude nannofossil species suggest that relatively warm surface water conditions were established by the *orbigny* Subzone and persisted through the lower half of the *varicosum*—*auritus* Subzones. These trends are supported by conclusions based on ammonite and foraminiferal data in previous studies.

This study suggests that *Rhagodiscus achlyostaurion* increases in abundance in warmer waters and that *Rhagodiscus angustus* shows a weak preference for colder conditions. Also, *Staurolithites matalosus* is a cold water preferring species.

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APPENDIX 1

Stratigraphic details of samples collected at Munday's Hill, Leighton Buzzard, Bedfordshire, England, Grid Ref. SP939279. Bed numbers from Owen (1972).

Sample No.	Bed	
11	1, base	<i>Corollithion achylosum</i> (Stover 1966) Thierstein 1971
12	1, top	<i>Rhagodiscus achlyostaurion</i> (Hill 1976) Doeven 1983
13	2 (ii)	<i>Braarudosphaera africana</i> Stradner 1961
14	2 (iii - iv)	<i>Axopodorhabdus albianus</i> (Black 1967) Wind and Wise in Wise and Wind 1977
15	2 (v), near	<i>Hayesites albiensis</i> Manivit 1971
base		<i>Bukryolithus ambiguus</i> Black 1971
16	2 (v)	<i>Calculites anfractus</i> (Jakubowski 1986) Varol and Jakubowski 1989
17	2 (v)	<i>Crucicribrum anglicum</i> Black 1973
18	2 (v)	<i>Cretarhabdus angustiforatus</i> (Black 1971) Bukry 1973
19	2 (v), near	<i>Rhagodiscus angustus</i> (Stradner 1963) Reinhardt 1971
top		<i>Staurolithites angustus</i> (Stover 1966) n. comb.
20	3 (ii) ?	<i>Rhagodiscus asper</i> (Stradner 1963) Reinhardt 1967
21	3 (iii)	<i>Watznaueria barnesae</i> (Black in Black and Barnes 1959) Perch-Nielsen 1968
22	3 (iv)	<i>Braarudosphaera bigelowii</i> (Gran and Braarud 1935) Deflandre 1947
23	3 (v)	<i>Watznaueria biporta</i> Bukry 1969
24	4 (i), near	<i>Braloweria boletiformis</i> (Black 1972) n. comb.
base		<i>Ceratolithina bicornuta</i> Perch-Nielsen 1988
25	4 (i), near top	<i>Broinsonia</i> Bukry 1969
26	4 (ii)	<i>Watznaueria britannica</i> (Stradner 1963) Reinhardt 1964
27	4 (iii)	<i>Reinhardtites brooksii</i> (Bukry 1969) Reinhardt 1971
28	4 (v), near	<i>Calculites Prins</i> and Sissingh in Sissingh 1977
base		<i>Lithraphidites carniolensis</i> Deflandre 1963
29	4 (v), near	<i>Microstaurus chistiatus</i> (Worsley 1971) Grün in Grün and Allemann 1975
top		<i>Chiastocyclus</i> sp. Gartner 1968
30	4 (ix)	<i>Haqius circumradiatus</i> (Stover 1966) Roth 1978
31	5	<i>Glaukolithus compactus</i> (Bukry 1969) Perch-Nielsen 1984
32 - 46	6	<i>Cretarhabdus conicus</i> Bramlette and Martini 1964
Samples 13 - 41 are approximately spaced every 30 cm.		<i>Tetrapodorhabdus coptensis</i> Black 1971
Samples 41 - 46 every 120 cm.		<i>Grantarhabdus coronadventis</i> (Reinhardt 1966) Grün in Grün and Allemann 1975
		<i>Cretarhabdus crenulatus</i> Bramlette and Martini 1964
		<i>Crepidolithus</i> sp. Noël 1965
		<i>Prediscosphaera cretacea</i> (Arkhangelsky 1912) Gartner 1968
		<i>Staurolithites crux</i> (Deflandre in Deflandre and Fert 1954) Caratini 1963
		<i>Ceratolithina cruxii</i> Perch-Nielsen 1988
		<i>Truncatoscapus</i> sp. cf. T. delftensis (Stradner and Adamiker 1966) Rood, Hay and Barnard 1971
		<i>Axopodorhabdus dietzmannii</i> (Reinhardt 1965) Wind and Wise 1983
		<i>Biscutum dissimilis</i> Wind and Wise in Wise and Wind 1977
		<i>Cribrosphaera ehrenbergii</i> Arkhangelsky 1912
		<i>Biscutum ellipticum</i> (Górka 1957) Grün in Grün and Allemann 1975
		<i>Nannoconus elongatus</i> Brönnimann 1955
		<i>Zeugrhabdotus embergeri</i> (Noël 1959) Perch-Nielsen 1984
		<i>Zeugrhabdotus erectus</i> (Deflandre in Deflandre and Fert 1954) Reinhardt 1965
		<i>Sollasites falklandensis</i> Wind and Wise in Wise and Wind 1977
		<i>Percivalia fenestrata</i> (Worsley 1971) Wise 1983
		<i>Scapholithus fossilis</i> Deflandre in Deflandre and Fert 1954
		<i>Tranolithus gabalus</i> Stover 1966
		<i>Gartnerago</i> Bukry 1969
		<i>Corollithion geometricum</i> (Górka 1957) Manivit 1971
		<i>Lapideacassis glans</i> Black 1971
		<i>Hemipodorhabdus gorkae</i> (Reinhardt 1969) Grün in Grün and

APPENDIX 2

Nannofossil species considered in this study.

Albian calcareous nannofossils

Allemann 1975
Gaarderella granulifera Black 1973
Ceratolithina hamata Martini 1967
Crucibiscutum hayi (Black 1971) Jakubowski 1986
Owenia hilli n. sp.
Sollasites horticus (Stradner *et al.* in Stradner and Adamiker 1966) Cepek and Hay 1969
Discorhabdus ignotus (Górka 1957) Perch-Nielsen 1968
Cretarhabdus inaequalis Crux 1987
Rhagodiscus infinitus (Worsley 1971) Applegate *et al.* in Covington and Wise 1987
Rucinolithus irregularis Thierstein in Roth and Thierstein 1972
Kamptnerius Deflandre 1959
Cylindralithus laffitei (Noël 1957) Black 1973
Lithastrinus sp. Stradner 1962
Chiasothygus litterarius (Górka 1957) Manivit 1971
Sollasites lowei (Bukry 1969) Roth 1970
Cretarhabdus madingleyensis (Black 1971) Crux 1989
Cyclagelosphaera margerelii Noël 1965
Lapideacassis mariae Black 1971
Staurolithites matalosus (Stover 1966) Cepek and Hay 1969
Grantarhabdus meddii Black 1971
Nannoconus minutus Bronnimann 1955
Eiffellithus monechiae n. sp.
Zeugrhabdotus noeliae Rood *et al.* 1971
Flabellites oblongus (Bukry 1969) Crux in Crux *et al.* 1982
Lithastrinus orbiculatus (Forchheimer 1972) Crux in Crux *et al.* 1982
Tranolithus orionatus (Reinhardt 1966) Perch-Nielsen 1968
Watznaueria ovata Bukry 1969
Repagulum parvidentatum (Deflandre in Deflandre and Fert 1954) Forchheimer 1972
Manivitella pemmatoidea (Deflandre in Manivit 1965) Thierstein 1971
Lithastrinus planus (Stover 1966) Crux in Crux *et al.* 1982
Lithastrinus sp. cf. *L. planus*
Gartnerago praeobliquum Jakubowski 1986
Seribiscutum primitivum (Thierstein 1974) Filewicz *et al.* in Wise and Wind 1977
Corollithion protosignum Worsley 1971
Octocyclus reinhardtii (Bukry 1969) Wind and Wise in Wise and Wind 1977
Corollithion rhombicum (Stradner and Adamiker 1966) Bukry 1969
Cyclagelosphaera rotaclypeata Bukry 1969
Crucibiscutum saleborosum (Black 1971) Jakubowski 1986
Tegulalithus septentrionalis (Stradner 1963) Crux 1986
Corollithion signum Stradner 1963
Zeugrhabdotus sisyphus (Gartner 1968) Crux 1989
Prediscosphaera spinosa (Bramlette and Martini 1964) Gartner 1968
Rhagodiscus splendens (Deflandre 1953) Verbeek 1977
Tegumentum striatum (Black 1971) Crux 1989
Cretarhabdus striatus (Stradner 1963) Black 1973
Viminites swinnertonii (Black 1971) Black 1975
Tegulalithus tessellatus (Stradner in Stradner *et al.* 1968) Crux 1986
Helicolithus trabeculatus (Górka 1957) Verbeek 1977
Nannoconus truittii Brönnimann 1955