Journal of Micropalaeontology, **15**: 97–129. 0262-821X/96 $07.00 © 1996 British Micropalaeontological Society.

A proposed Albian To Lower Cenomanian nannofossil biozonation for England and the North Sea Basin

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ABSTRACT - Analysis of abundant, diverse and well-preserved Albian nannofloral assemblages from onshore English sections has enabled a high-resolution nannofloral zonation to be developed with the construction of sixteen zones. The results are correlated with the ammonite zonation.

Five new species, *Acaenolithus viriosus* sp. nov., *Staurolithites rotatus* sp. nov., *Staurolithites canthus* sp. nov., *Bownia glabra* sp. nov. and *Calculites percernis* sp. nov. are described. *J. Micropalaeontol.* **15**(2): 97–129, October 1996.

INTRODUCTION

Extensive sampling of Albian, ammonite-dated field localities from England (Fig. 1) together with additional localities in Germany, France and the southern North Sea Shell/Esso well, 49/25a-9, has provided an opportunity for a refined Albian nannofossil biozonation scheme to be developed.

Prior to 1987, calcareous nannofossil zonations of the Albian generally had low resolution, e.g. Thierstein (1976), Sissingh (1977) and Perch-Nielsen (1979). Many of the marker species used in these zonations (see Fig. 18) are based on localities in Tethyan areas. These species are often rare, entirely absent or have different age ranges in the Boreal Realm.

Jakubowski (1987) highlighted the immense potential of using calcareous nannofossils to date the Lower Cretaceous using released well sections mainly from the Moray Firth Basin. He erected six zones for the Albian using a combination of last appearance datums (LAD), first appearance datums (FAD) and semi-quantitative events. However, he did not have the benefit of macrofossil-dated material and hence his correlations with the ammonite zonation were speculative.

This study attempts to establish a scheme useful both for academic workers and for industrial purposes, in which LADs and acme datums are regularly used. A total of sixteen zones are defined for the Albian. This study establishes a link between macrofossil (MF) and nannofossil (NF) biostratigraphies, thus extending interdisciplinary correlations both geographically and biostratigraphically. The zonation was developed in conjunction with studies of North Sea wells and its applicability in this area has been proven, although detailed primary data (except for well 49/25a-9) cannot be documented here for commercial reasons.

METHODS

1. Sample preparation

For light microscope examination, the samples were prepared by placing a small amount of sediment directly onto a microscope slide. A pipette was used to place a drop of distilled water onto the sample and smeared out into a thin layer by using a clean picking brush (size 101). The smeared sample was dried on a hot plate and a coverslip was attached using a permanent mounting medium. The picking brush is placed in 10% HCl to remove any remaining residue.

2. Counting technique

Samples were examined with a light microscope at a magnification of 1000×. A transect of thirty fields of view is taken with all specimens counted. Some species, e.g. *Watznaueria barnesae,* are so profuse that only ten or, in some instances, five fields of view are counted. Its abundance is subsequently multiplied out to thirty fields of view.

The following relative abundance categories which are used extensively in industry are also utilized in the present study:

rare	: less than 1 specimen per 30 fields of view.
occasional	: 1–2 specimens per 30 fields of view.
common	: 3–10 specimens per 30 fields of view.
abundant	: 11–29 specimens per 30 fields of view.
influx	: individuals are a major component of assemblage – greater than 29 specimens per 30 fields of view.

MATERIAL STUDIED

The stratigraphic results presented here are based on data from several localities in England and northwest Europe together with knowledge gained from numerous exploration wells drilled throughout the North Sea. The localities studied are discussed briefly in the following sections. Nannofossils recovered in these sections are presented in range charts (Figs 2–16).

1. Folkestone area and Eastbourne
2. Cambridgeshire, Bedfordshire and Buckinghamshire
3. Yorkshire
4. Mt. Risou, southeast France
5. Vöhrum, Germany
6. Shell/Esso 49/25a-9

The locations of field samples studied from mainland UK

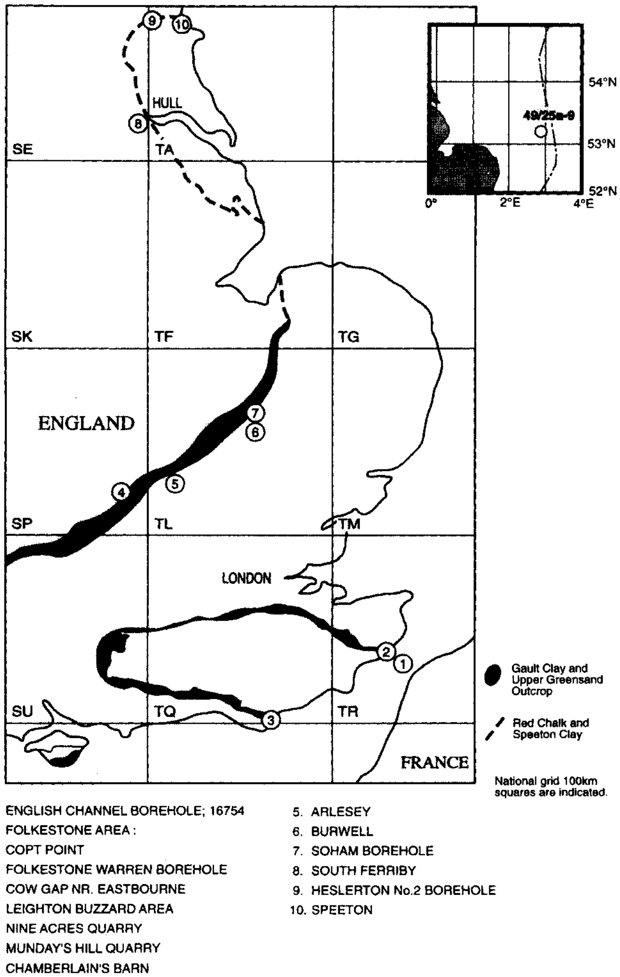


Fig. 1. Locations of the sections studied from mainland and offshore UK.

are indicated on Fig. 1. Precise locations are cited below relative to the UK national grid (e.g. TV 955 596). A chronostratigraphic synopsis of the studied localities is given in Fig. 17.

1. FOLKESTONE AREA AND EASTBOURNE

(a) Copt Point [TR 2414 3645]

The classic Gault Clay succession at Copt Point near Folkestone was used to establish a correlation between the ammonite-dated clays and the nannofloral assemblages (Fig. 2). The sediments are lithologically subdivided into Beds I–XIII, Price (1874), Jukes-Browne & Hill (1900). The bulk of Bed XIII, however, together with Bed XII and the upper part of Bed XI were not exposed due to slumping. This part of the sequence was sampled from the Folkestone Warren borehole.

(b) Folkestone Warren borehole [TR 24473 77813]

The Folkestone Warren borehole (Fig. 3) can be viewed at BGS, Keyworth (Reg. No. TR23NW No. 10). The nannofloral assemblages indicate a marked hiatus at the Bed X1/Bed X11 boundary. NF Zone NAL 12 rests directly upon NAL 9.

(c) English Channel borehole 16754

A more complete Albian/Cenomanian boundary succession, than that preserved at Folkestone, is documented from English Channel boreholes (Carter & Hart, 1977; Amédro, 1994). Four samples were analysed (Fig. 4) from this borehole (Zone 6a of Carter & Hart, 1977). Lithofacies data and foraminiferal assemblages suggest a Lower Cenomanian age for Zone 6a, although macrofossil information is sparse.

(d) Cow Gap near Eastbourne [TV 955 596]

This section (Fig. 5) was described by Price (1879). Additional macrofossil and lithological data were provided by A.S. Gale (pers. comm., 1994).

2. CAMBRIDGESHIRE, BEDFORDSHIRE AND BUCKINGHAMSHIRE

The Albian Gault Clay in East Anglia, Bedfordshire and Buckinghamshire consists of calcareous mudstones with rich nannofloras. The assemblages exhibit localized acmes of species that are rare elsewhere in England and in the central North Sea.

The Gault Clay is exposed in numerous quarries in the Leighton Buzzard area. The key outcrops studied are listed below.

(a) Chamberlain's Barn [SP 926 264]

This section (Fig. 9) was described by Lamplugh (1922) and Casey (1961). The most recent descriptions of the section are by Owen (1972) and Eyers (1992).

(b) Munday's Hill [SP 939 282]

Munday's Hill was described in detail by Owen (1972) and Eyers (1992). The nannofossil biostratigraphy of this section was documented by Crux (1991). A nannofloral chart is therefore not figured in this study although samples examined are documented in Appendix 2 together with NF zones and relevant discussion.

(c) Nine Acres Quarry [SP 939 278]

Nine Acres Quarry (Fig. 7) lies approximately 150 m southeast of the Munday's Hill section. A reduced sequence of ?*spathi* to *intermedius* MF Subzonal mudstones are exposed (Eyers, pers. comm., 1992).

(d) Arlesey [TL 186 354]

This section (Fig. 8) is described by Eyers (1992). Additional macrofossil data were supplied by H. G. Owen, pers. comm., 1994.

Chalk sedimentation was initiated earlier at Arlesey than at Folkestone. The NC1 marker, *Calculites anfractus* has a FAD approximately 3 m above the base Chalk at Arlesey whilst at Folkestone the FAD of *C. anfractus* is 2 m (pers. obs.) above the top of Bed X111 within glauconitic mudstones.

Two sections were studied in Cambridgeshire – (e) and (f).

(e) Burwell [TL 577 687]

The ammonite fauna and lithological subdivisions of the Burwell section (Fig. 10) are documented by Gallois & Morter (1982). Additional macrofossil information was supplied by J. Eyers (pers. comm., 1993).

The top of the *auritus* MF Subzone in East Anglia is often missing or highly condensed (J. Eyers, pers. comm., 1993). There is evidence of this hiatus at Burwell where *Eiffellithus monechiae* appears 10 cm below a phosphatic horizon. In Bedfordshire, however, the upper part of the *auritus* MF Subzone is locally more complete. At Munday's Hill at least 4 m of the latest *auritus* MF Subzone is present (top not seen) and here *Eiffellithus monechiae* eventually becomes common.

At Burwell, sediments of *rostratum* MF Subzone age lie unconformably upon the upper part of the *auritus* MF Subzone. The very pale grey mudstones of Bed 17 are intensely bioturbated throughout. This bed is, in parts, poorly exposed due to slumping. No younger Albian sediments are preserved at Burwell.

The presence of NF Zone NAL 11 indicates that Bed 17 has no lithological equivalent at Folkestone due to an erosional phase which is expressed in phosphatic nodules at the base of the 'Greensand Seam', Bed XII.

(f) Soham borehole [TL 593 745]

The Soham borehole (Fig. 6) can be viewed at BGS, Keyworth (Reg. TL57SE No. 1). Macrofossil determinations are based on Eyers (1992).

3. YORKSHIRE

(a) Speeton [TA 155 755]

The upper part of the Speeton Clay at Speeton (Fig. 12) and the overlying Red Chalk are almost devoid of ammonites. Lamplugh (1924) divided the clays into five subdivisions lettered A to E in descending sequence using the more abundant and better preserved belemnites. The A Beds are of Albian age and were subdivided A1 to A5 by Wright (1935).

The dark clays representing Bed A5 contain the belemnite *Neohibolites ewaldi* and were originally correlated with the Aptian Sutterby Marl of Lincolnshire by Spath (1924). The upper part of these beds, however, contain a Lower Albian ostracod assemblage (Kaye, 1964). This age assignment is supported by the palynological flora which contains *Kleithriasphaeridium simplicispinum* and lacks any Aptian markers (R. Davey, pers. comm., 1993).

The 'Greensand Streak', Bed A4, and the basal part of Bed A3 are non-calcareous and barren of calcareous nannofossils. Kaye (1964) postulated a Middle Albian age for these beds. The overlying sediments, however, yield Lower Albian nannofloral assemblages (NF Zone NAL 3) similar to those found in the *mammillatum* MF Zone at Chamberlain's Barn, Bedfordshire. Brown clays were also found yielding the Middle Albian markers, *Ceratolithina cruxii* and *Crucicribrum anglicum* (NF Zone NAL 4) associated with *Hamites* and *Hoplites* ammonites (A.S. Gale, pers. comm., 1996), but their exact level from within Bed A3 was not established. It should be noted that extensive slumping occurs at this level (P. Rawson, pers. comm., 1994). Due to slumping, Beds A2 and A1 were not sampled, although *Euhoplites* and *Mortoniceras* ammonites have previously been recovered from Bed A1 and indicate an Upper Albian age. The overlying Red Chalk (16.1m) is also regarded as Upper Albian. Further south, at South Ferriby, in proximity to the Market Weighton High the Red Chalk (= Hunstanton Formation) is only 2.5 m thick and, in part, forms a highly condensed lateral equivalent of the Red Chalk Formation at Speeton and the offshore southern UK Sector of the North Sea.

(b) Heslerton No. 2 borehole [SE 9199 7589]

This Heslerton No. 2 borehole can be viewed at BGS, Keyworth. Macrofossil data are limited from the interval studied in this borehole (P. Rawson, pers. comm., 1994). Nannofossil data (Fig. 11) suggests these sediments are equivalent to the top of Bed A5, Bed A4 and the base of Bed A3, as exposed at Speeton.

(c) South Ferriby, Humberside [SE 911 204]

The Carstone Formation at South Ferriby is considered to be of Lower Albian age based on the brachiopod fauna (Whitham, 1991). This formation, which consists of hard, iron- rich, pebbly sands, is non-calcareous and barren of nannofossils.

At Melton Bottoms [SE 970 270], just north of South Ferriby, the basal red marls of the Hunstanton Formation are considered to be of Middle Albian age (Whitham, 1991) based on a single whorl fragment of the ammonite *Dimorphoplites* cf. *hilli* Spath. The absence of Middle Albian NF zones at South Ferriby (Fig. 13) is possible evidence of a diachronous base to the Red Chalk particularly over the Market Weighton High. Sediments equivalent to the *auritus* MF Subzone are absent. This stratigraphic break is also present at the Heslerton No. 2 borehole (D. Rutledge, pers. comm., 1994) and possibly at Speeton (pers. obs.).

The upper part of the Hunstanton Formation at South Ferriby is equivalent to the majority of the Red Chalk at Speeton.

4. MT RISOU, SOUTHEAST FRANCE (ROSANS:1:25 000, LAMBERT ZONE II, 1937: 853.2-3239)

The section at Mt. Risou (Fig. 15) exposes a thick succession of marls and minor limestones across the Albian/Cenomanian boundary which have been accurately dated with ammonites (A.S. Gale, pers. comm., 1994).

This is the only location in the present study where common/abundant *Broinsonia enormis* have been found in Upper Albian dated sediments. A hiatus is present at this level in southern Britain.

The NF Zone NC1 nominate marker, *Calculites anfractus* is found at Mt. Risou. The FAD at this locality is stratigraphically higher than that seen further north in southern England, where *C. anfractus* is found associated with *Bownia glabra* and *Gartnerago chiasta*. It appears that *C. anfractus*, although not endemic to the Boreal Realm, as

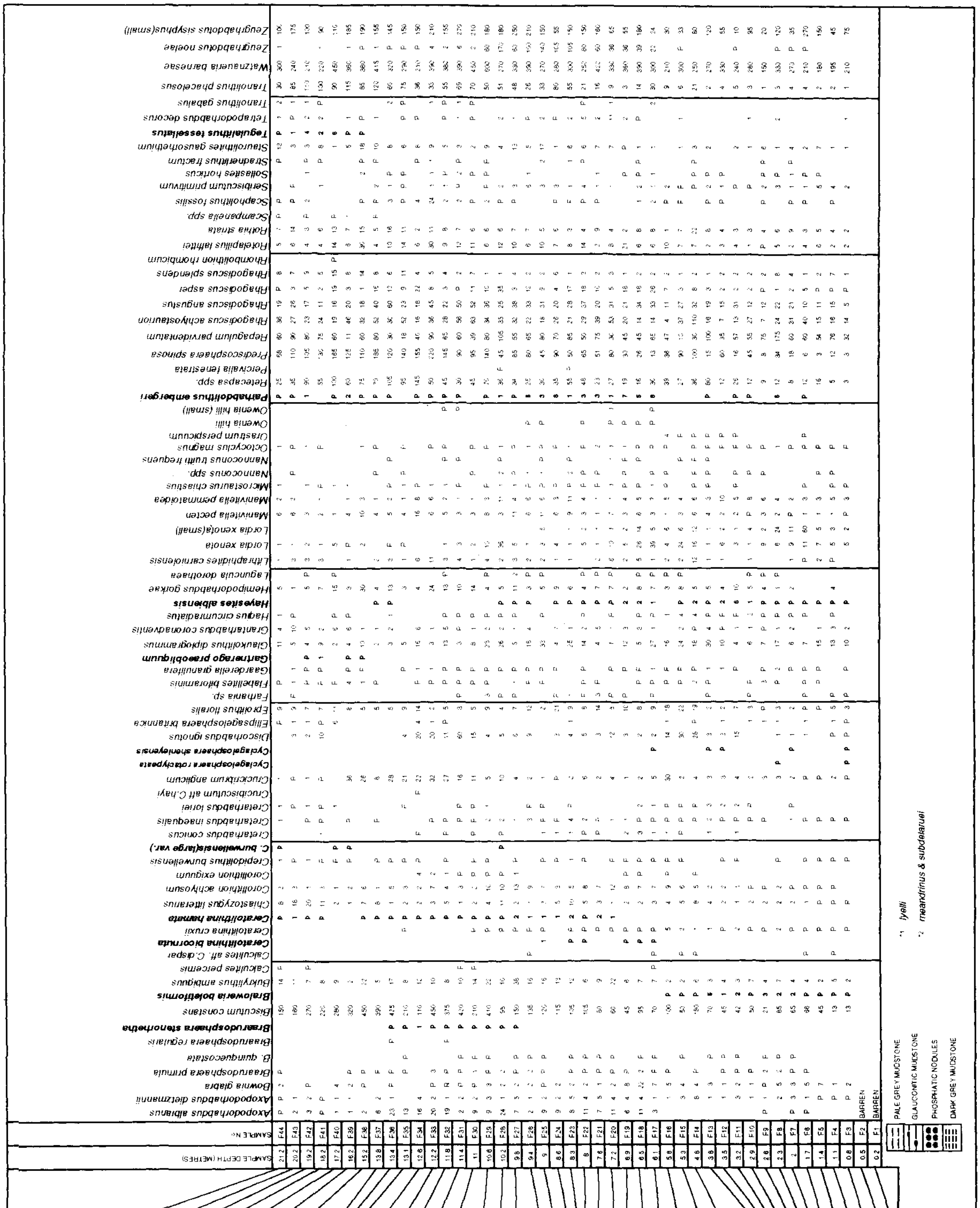


Fig. 2. Stratigraphic distribution of nannofossil species in the Copt Point section. Metre level of samples are with reference to base Bed 1. Abundance counts from 30 fields of view. Marker species in bold. Ammonite stratigraphy after Owen (1975); bed nomenclature after Jukes-Browne & Hill (1900).

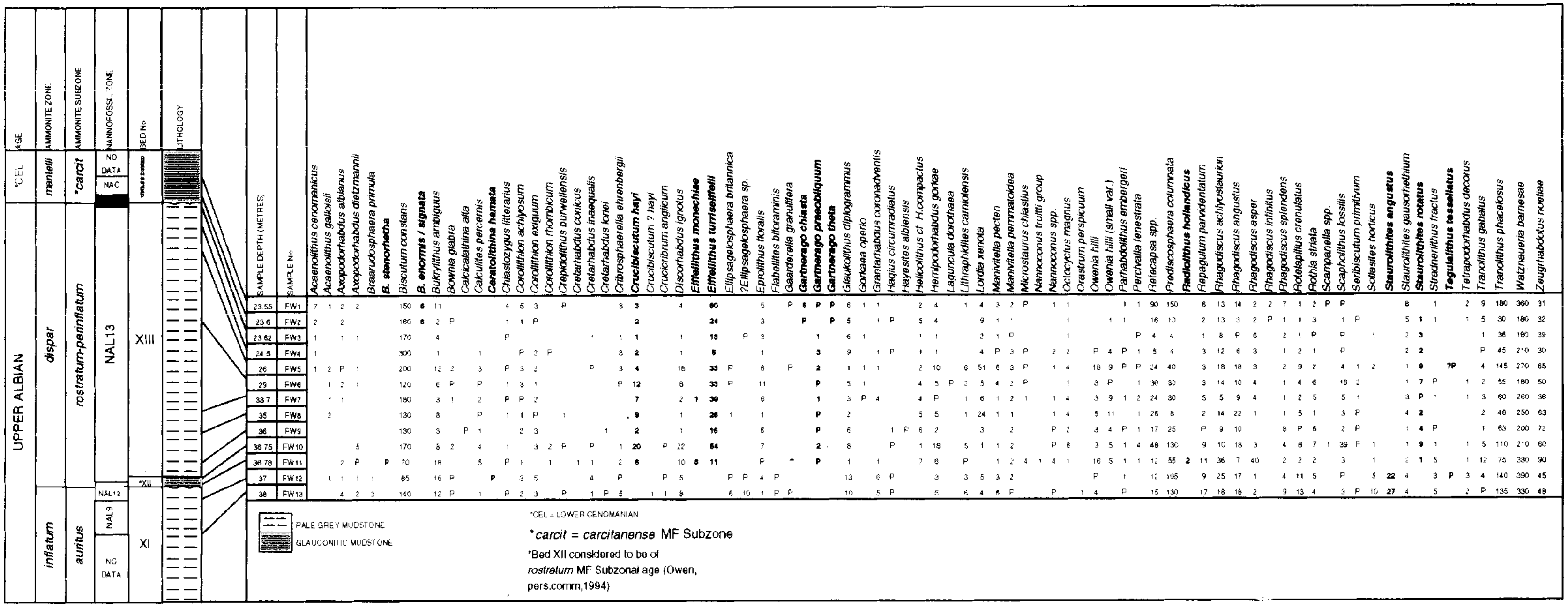


Fig. 3. Stratigraphic distribution of nannofossil species in the Folkstone Warren borehole, 23.55–38.00 m. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy based on correlation with Folkstone cliff section (Owen, 1975); bed nomenclature after Jukes-Browne & Hill (1900).

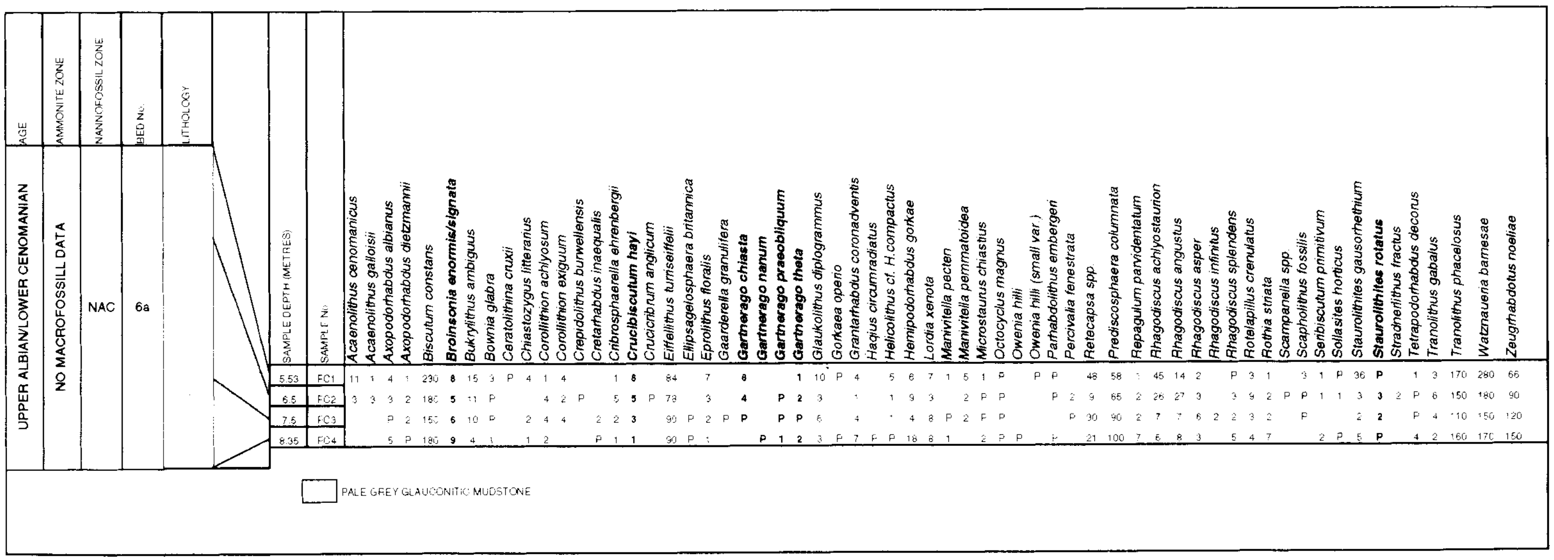


Fig. 4. Stratigraphic distribution of nannofossil species in the English Channel borehole, PM16754, 5.53–8.35 m . Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Bed nomenclature after Carter & Hart (1977).

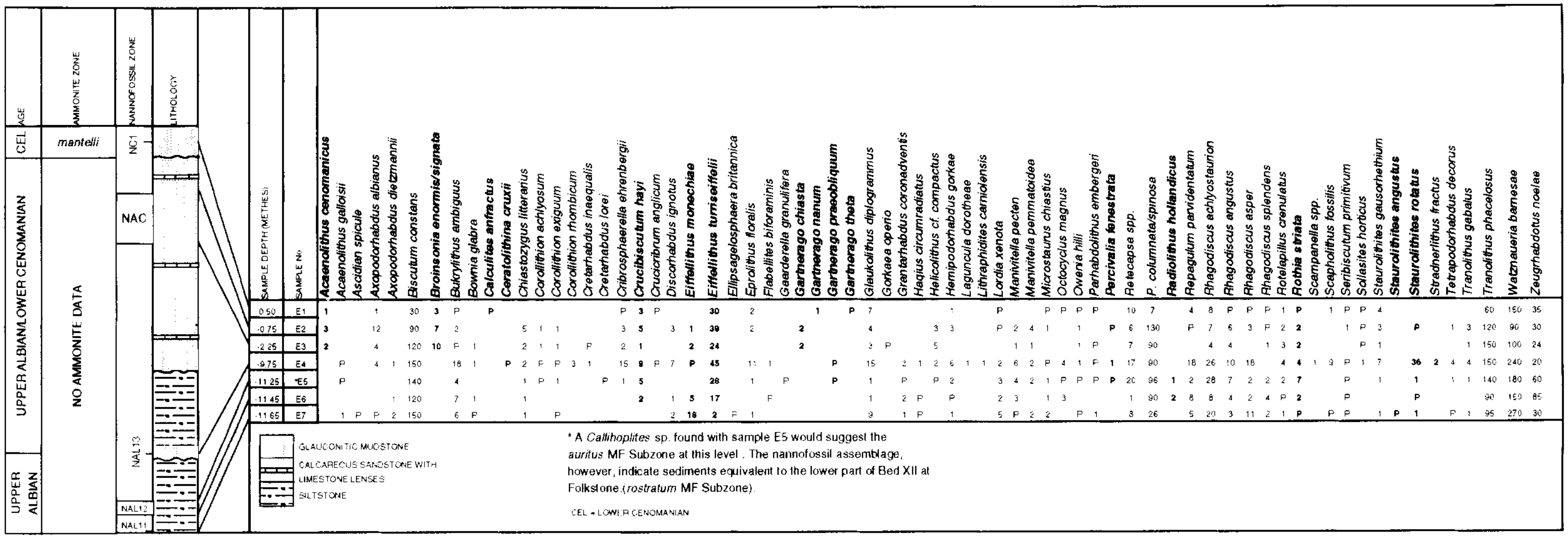


Fig. 5. Stratigraphic distribution of nannofossil species in the Cow Gap section. Metre level of samples are with reference to base glauconitic mudstone (*mantelli* MF Zone). Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Gale (pers. comm., 1994).

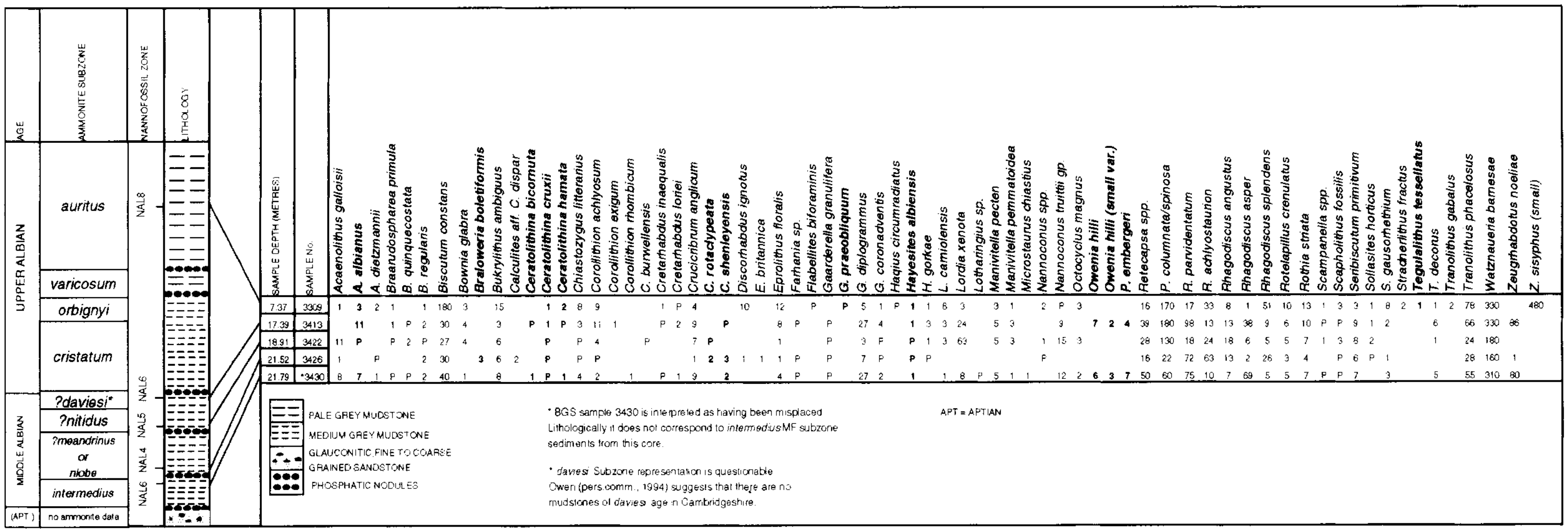


Fig. 6. Stratigraphic distribution of nannofossil species in the BGS Soham borehole, Cambridgeshire, 7.37–21.79 m. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Eyers (1992).

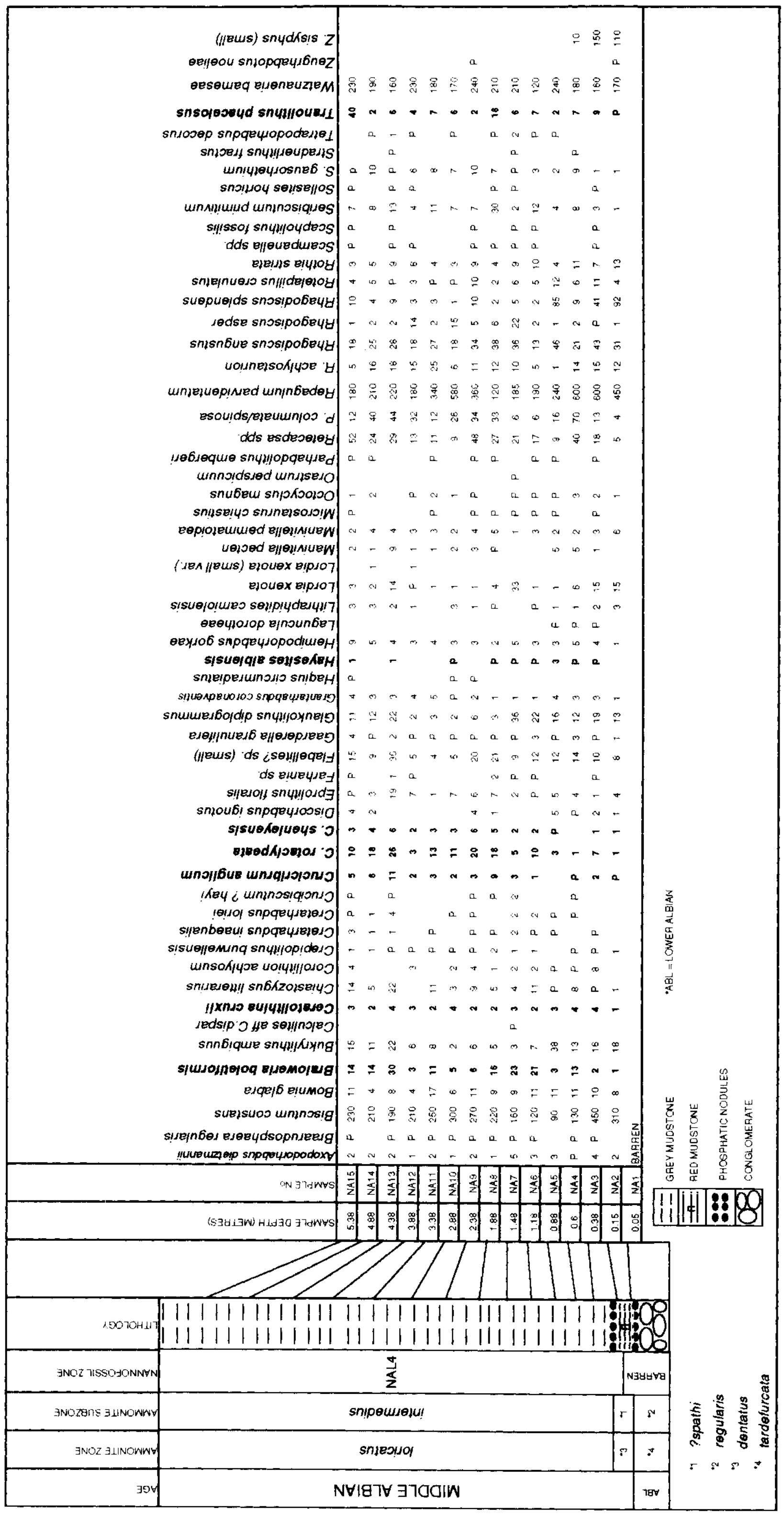


Fig. 7. Stratigraphic distribution of nannofossil species in the Nine Acres Pit section. Metre level of samples are with reference to base red mudstone. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Eyers (pers. comm., 1992).

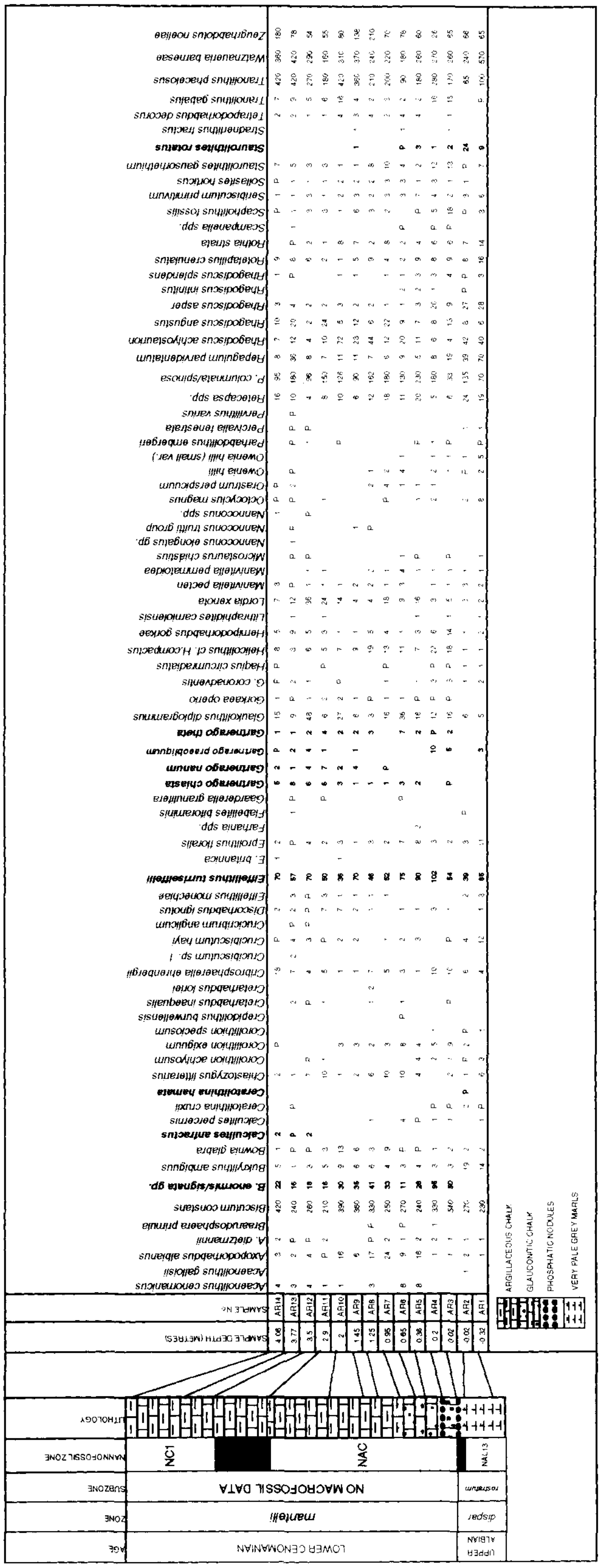


Fig. 8. Stratigraphic distribution of nannofossil species in the Arlesey section. Metre level of samples are with reference to base phosphatic nodules ('base' Cambridge Greensand). Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Owen (pers. comm., 1994) and Eyers (1992).

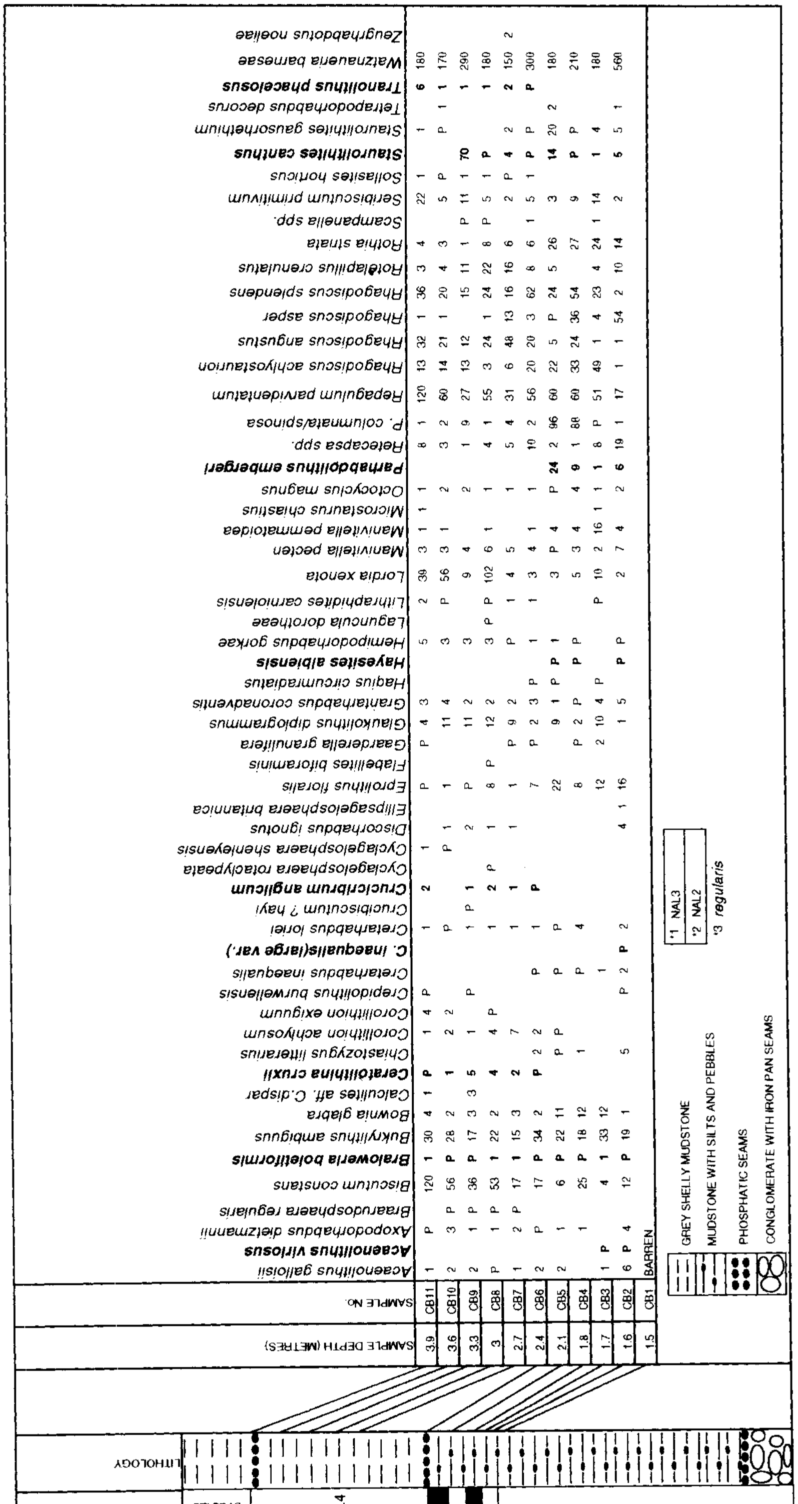


Fig. 9. Stratigraphic distribution of nannofossil species in the Chamberlain's Barn section. Metre level of samples are with reference to top iron pan seam/base mudstone. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Owen (1972) and Eyers (1992).

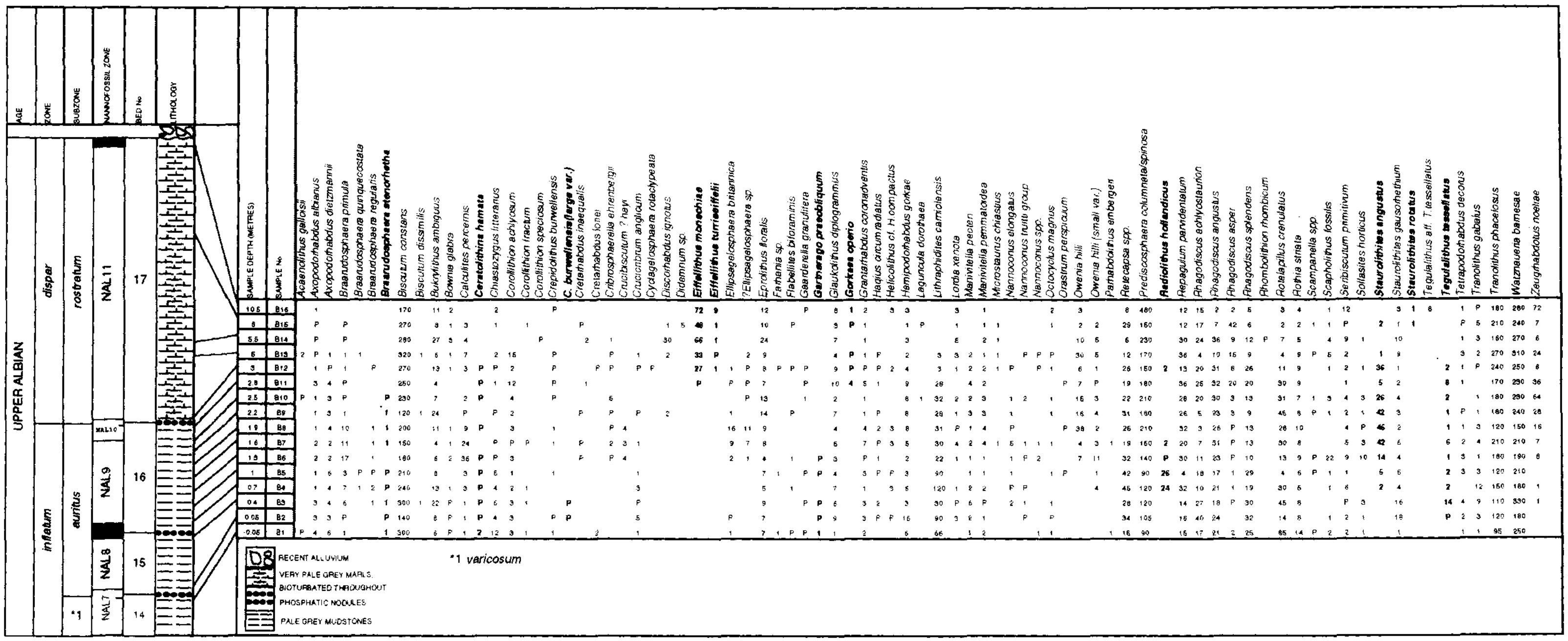
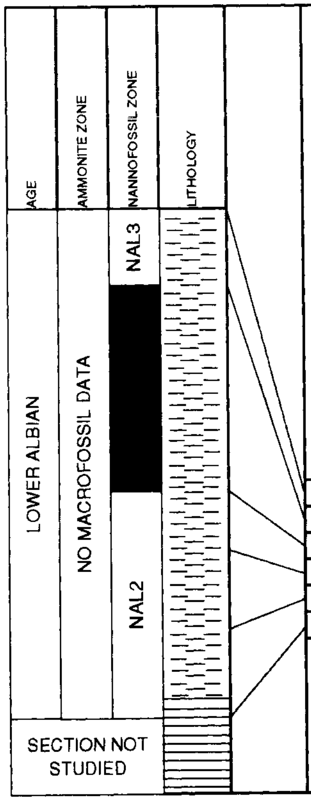


Fig. 10. Stratigraphic distribution of nannofossil species in the Burwell section. Metre level of samples are with reference to base Bed 15. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy and bed nomenclature after Gallois & Morter (1982).



Species	HB1 (3.6 m)	HB2 (3.9 m)	HB3 (4.35 m)	HB4 (4.5 m)	HB5 (4.6 m)	HB6 (4.7 m)
Acaenolithus galloisii	P	1	1	4	2	7
Acaenolithus viriosus			P	P	P	P
Axopodorhabdus dietzmannii	2	P	1		1	P
Biscutum constans	32	3	4	2	12	8
Braarudosphaera primula	3					
Braarudosphaera regularis	2					
Braloweria boletiformis	P		1			
Bukrylithus ambiguus	6	16	9	5	3	4
Bownia glabra	1	2	2	4	4	3
Calculites dispar	P					
Chiastozygus litterarius	1	P			P	
Corollithion achlyosum	5					
Crepidolithus burwellensis		P		P		
C. inaequalis(large var.)			1		1	
Cretarhabdus loriei	P	P	P	P	P	1
C. shenleyensis		1				
Eprolithus floralis	3	P	6	1	P	2
Flabellites biforaminis			P			
Gaarderella granulifera	P	P				
Glaukolithus diplogrammus	1	2	7		1	
Grantarhabdus coronadventis	P	P	P			P
Hayesites albiensis					P	
Hemipodorhabdus gorkae	1	P	1	1	2	1
Laguncula dorothaea		P				
Lithraphidites carniolensis						
Lordia xenota	7	4	3	P	P	2
Manivitella pecten	2		2	1		1
Microstaurus chiastius		P	P			P
Nannoconus truittii gp.	1					
Nannoconus spp.	2					
Octocyclus magnus	2	1	6	3		
Parhabdolithus embergeri	P	**20**	**3**	**14**	**17**	P
Retecapsa spp.	3		1	1	2	1
Prediscosphaera spinosa	3	7		P	1	P
Repagulum parvidentatum	90	85	30	65	10	15
Rhagodiscus achlyostaurion	36	20	2	2	P	P
Rhagodiscus angustus	6	8	1	2	2	5
Rhagodiscus asper	2	10	2	2	3	P
Rhagodiscus splendens	30	16	17	6	14	11
Rotelapillus laffittei	8		2	1		P
Rothia striata	P	18	9	2	3	1
Scampanella spp.	P					
Seribiscutum primitivum	1	6	7	P	P	P
Sollasites horticus						
Staurolithites canthus			5	P	P	
Staurolithites gausorhethium		26	11		P	P
Tetrapodorhabdus decorus			P		1	
Watznaueria barnesae	230	150	170	120	130	160

YELLOW / GREY CLAY
DARK GREY CLAY

Fig. 11. Stratigraphic distribution of nannofossil species in the Heslerton No. 2 borehole (3.6–4.7 m). Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold.

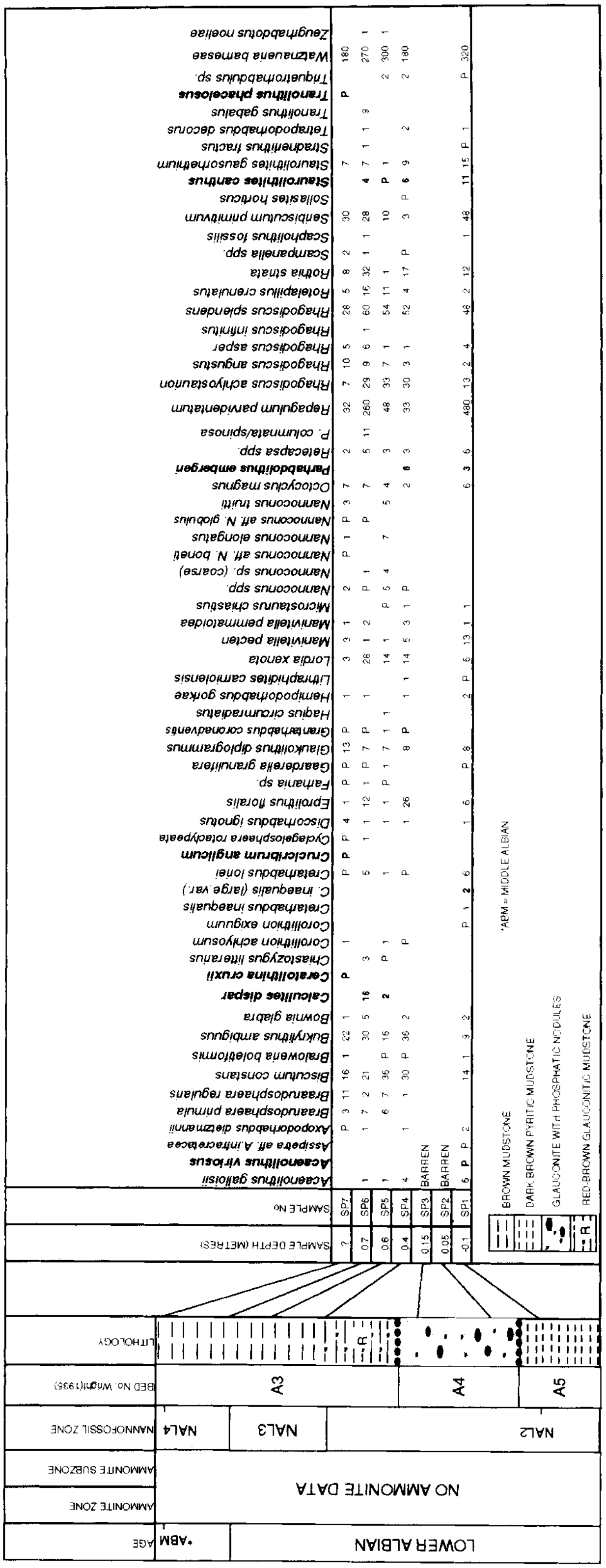


Fig. 12. Stratigraphic distribution of nannofossil species in the Speeton section. Metre level of samples are with reference to base Bed A4. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold.

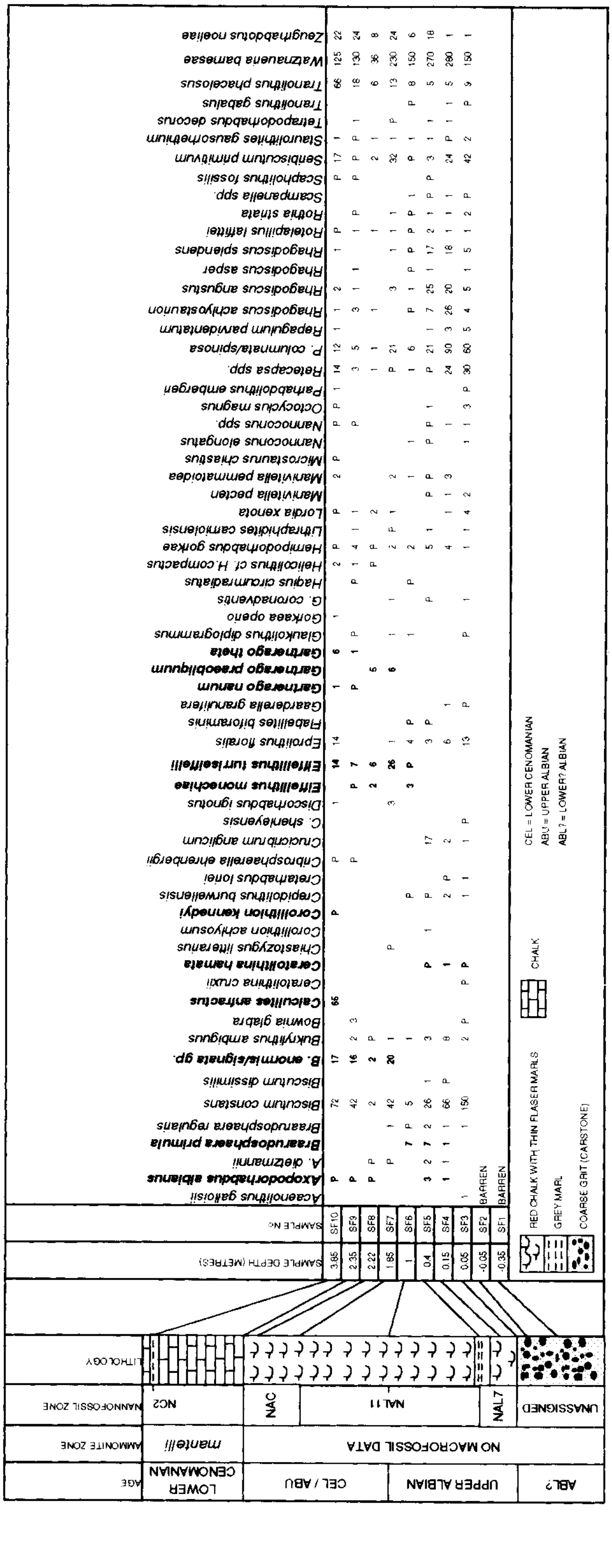
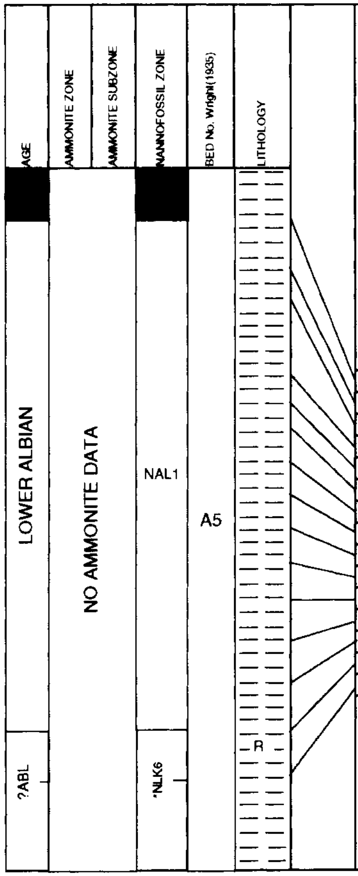


Fig. 13. Stratigraphic distribution of nannofossil species in the South Ferriby section. Metre level of samples are with reference to top Carstone. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Whitham (1991).



SAMPLE DEPTH (FEET)	SAMPLE No.	*Acaenolithus galloisii*	*Assipetra aff. A. infracretacea*	*A. dietzmannii*	*Braarudosphaera africana*	*Biscutum constans*	*Bukrylithus ambiguus*	*Calculites dispar*	*Corollithion achlyosum*	*Crepidolithus burwellensis*	*Cretarhabdus inaequalis*	*Crucicribrum? sp.*	*Crucibiscutum sp. 1*	*Cyclagelosphaera margerel*	*C. rotaclypeata*	*Discorhabdus ignotus*	*Eprolithus floralis*	*Glaukolithus diplogrammus*	*G. coronadventis*	*Hemipodorhabdus gorkae*	*Lordia xenota*	*Manivitella pecten*	*Manivitella pemmatoidea*	*Microstaurus chiastius*	*Nannoconus elongatus*
5800	CR1	BARREN																							
5804	CR2	P	1			6	2			P							P	4		1		P			
5808	CR3	2	3			3												3		1		1			
5812	CR4	3	6	2	P	18	1		P	P		1		1	1	1	2	24		1	2	P		P	
5816	CR5	24	3	2	P	28		P			P					P	1	16		1	2				
5820	CR6	26	3			118			4	P		P				P		30	P	11	5				
5822.6	CR7	26	1			18	1					P					P	14		4	1	P			
5826	CR8	33	P			42	1											5		1		P			
5830	CR9	60	4	1		5				P			P	1				9		P		P			
5834	CR10	14		1		3				P								3		P		1			
5838	CR11	27	1			6												10		3		3			
5842	CR12	87	4	P		7											5	18	P	5		3			P
5846	CR13	10	P		P	5											P			1	P	P			
5850	CR14	BARREN																							
5854	CR15		3	P		30	8			P						P		6	P	3	P		P		

SAMPLE DEPTH (FEET)	SAMPLE No.	*Nannoconus aff N. fragilis*	*Nannoconus aff. N. globulus*	*Nannoconus truittii gp.*	*Octocyclus magnus*	*Orastrum perspicuum*	*Parhabdolithus embergeri*	*Retecapsa spp.*	*Prediscosphaera spinosa*	*Repagulum parvidentatum*	***R. achlyostaurion***	*Rhagodiscus angustus*	***Rhagodiscus asper***	***Rhagodiscus splendens***	*Rotelapillus crenulatus*	*Rothia striata*	*Scampanella spp.*	*Scapholithus fossilis*	*Sollasites horticus*	*Staurolithites gausorhethium*	*Tetrapodorhabdus decorus*	*Tranolithus gabalus*	*Vekshinella sp.*	*Watznaueria barnesae*	*Zeugrhabdotus sisyphus (large var.)*
5800	CR1	BARREN																							
5804	CR2				4			7		102	11	3	3	11	P		P			1			3	180	1
5808	CR3				4			5		230	4	1	2	17	P								1	350	1
5812	CR4			1	3	2	1	13		102	25	2	6	22	P	P	P	P	2	1	P		8	360	
5816	CR5				5	22		9	7	150	34	9	3	32	2		P		P			P	7	290	
5820	CR6			P	4			5	2	86	19	7	5	16	8	P		1	3	1	P	P	12	180	
5822.6	CR7				4			5	P	63	16	5	5	6	1				1			P	22	240	
5826	CR8				P			2		42	45	1	8	2	P		P		2	1		1	18	270	
5830	CR9			P	3	P		6		42	5	2	5	10			P						9	300	1
5834	CR10				2			3	P	45	1	1	10	2			P						6	180	
5838	CR11				1			12		96	15	3	22	4			P						2	240	3
5842	CR12			1	1			12		57	82	4	8	6	2		P						17	310	2
5846	CR13				2			9		30	4	1	15		1								P	240	
5850	CR14	BARREN																							
5854	CR15	P	P	P	P		P	20		210	24	21	105	1	33	3	1			1		3		210	

DARK GREY MUDSTONE

R RED MUDSTONE

?ABL = ?LOWER ALBIAN

*NLK6 (Jakubowski, 1987)

Note:- Sample CR15 is considered Lower Albian in age due to the presence of *R. splendens* and *R. achlyostaurion*. In uppermost Aptian samples from Vöhrum these species were absent.

Fig. 14. Stratigraphic distribution of nannofossil species in Shell/Esso 49/25a-9 (Southern North Sea). Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold.

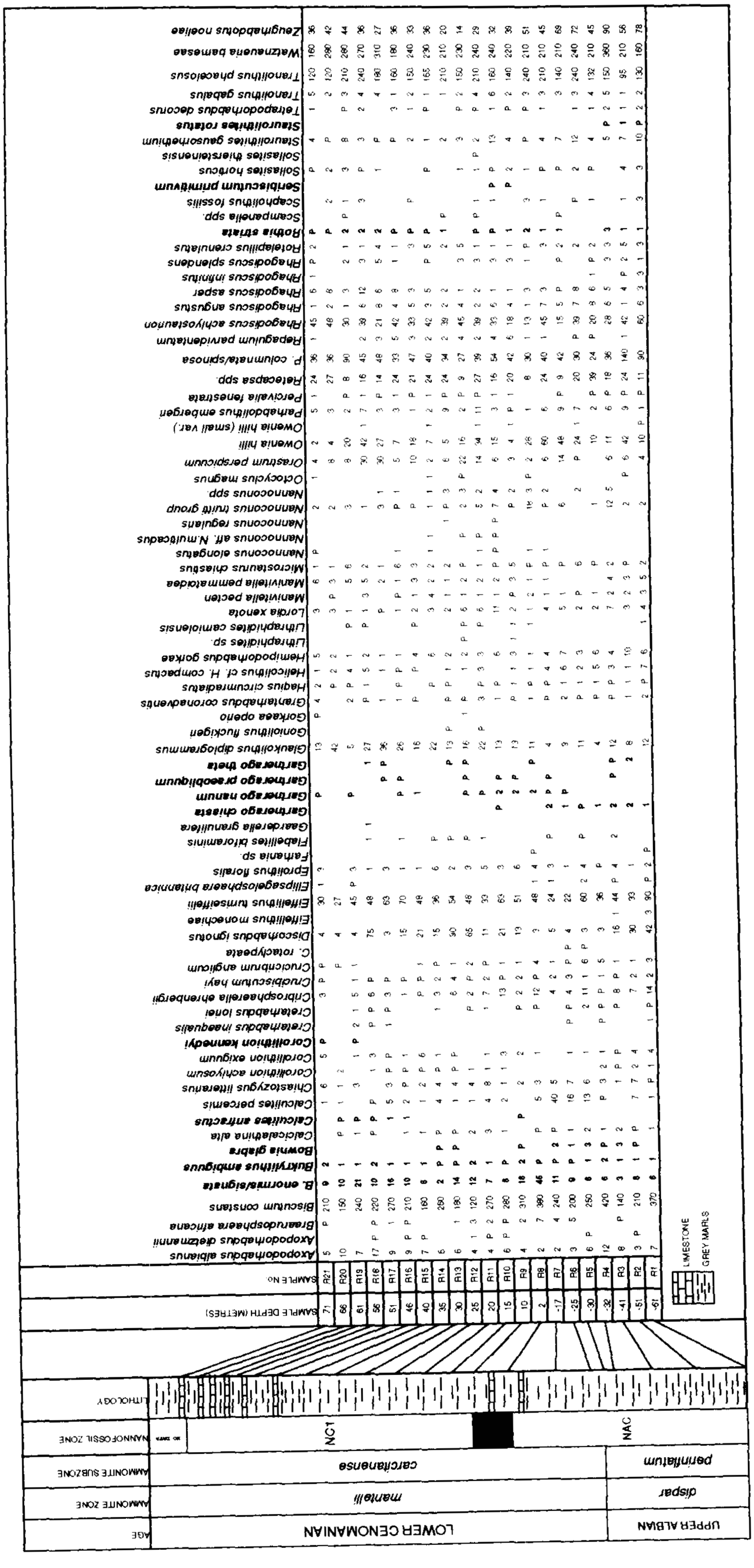


Fig. 15. Stratigraphic distribution of nannofossil species in the Mt Risou field section. Metre level of samples are with reference to base limestone bed. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in *bold*. Ammonite stratigraphy after Gale (pers. comm., 1994).

this study has proven, certainly preferred high latitudes. The isolated occurrence of *C. anfractus* within sample R9 may indicate an earlier cold water incursion from the north. This is supported by the presence of *Seribiscutum primitivum*, a form characteristic of Boreal Realm Albian nannofloral assemblages (Crux, 1991 and pers. obs.) but extremely rare at the Mt. Risou section.

5. VÖHRUM, NORTHWEST GERMANY Vö TK 25 HÄMELERWALD No. 3626 (re: 35 78 800, h: 58 00 000)

This locality (Fig. 16) exposes a succession of dark grey to black mudstones of Lowermost Albian to Uppermost Aptian age. A secondarily altered tuff is located at the Albian/Aptian boundary. The calcareous nannofossils of this section have been studied by Cepek (1982) and Mutterlöse (1989). The assemblages are of low abundance and diversity.

A detailed analysis of the sequence is given by Kemper & Zimmerle (1978) and Kemper (1982).

6. SHELL/ESSO SOUTHERN NORTH SEA WELL: 49/25a-9 (latitude 53° 12′ 37.760″N, longitude 02° 55′ 20.328″E)

This well (Fig. 14) is located approximately 20 km west of the UK/Netherlands median line in the UK southern North Sea.

ZONATION

The zonation outlined below was developed as a practical tool for subdividing the Albian to Lower Cenomanian of onshore sections, mainly from England and offshore material from throughout the North Sea Basin. Work was started with the aim of improving on the NF scheme of Jakubowski (1987) and constructing a scheme useful for both academic and industrial purposes. In this study, sixteen zones are defined for the Albian/Lower Cenomanian interval. They are correlated with the MF zones and compared with previous NF zonations in Fig. 18. A composite range chart of biostratigraphically useful species is presented in Fig. 19.

Bukrylithus ambiguus Interval Range NF Zone (NLK6, Jakubowski, 1987)

Definition: Interval from LAD of *Micrantholithus hoschulzii* to LAD of abundant *Rhagodiscus asper*.

Age: Lower Albian/Upper Aptian.

Remarks: In this study no change in nannofloral assemblages is identified over the Aptian/Albian boundary.

Abundant *R. asper* are found sporadically throughout the

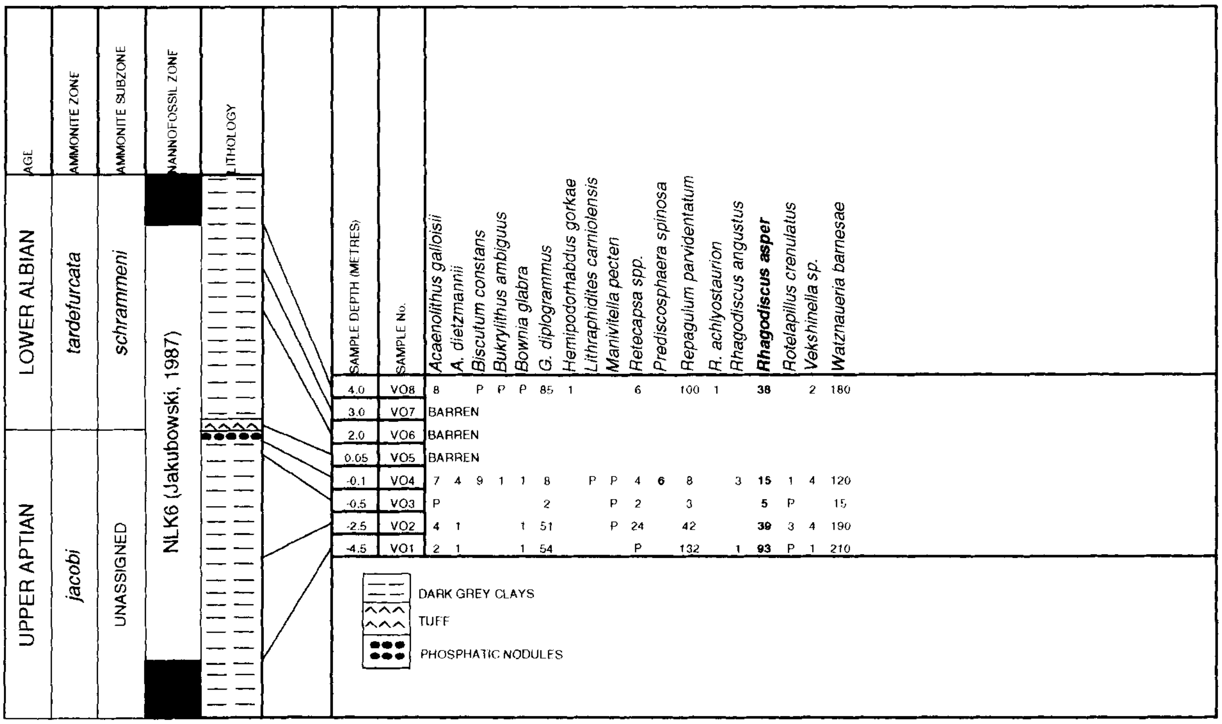
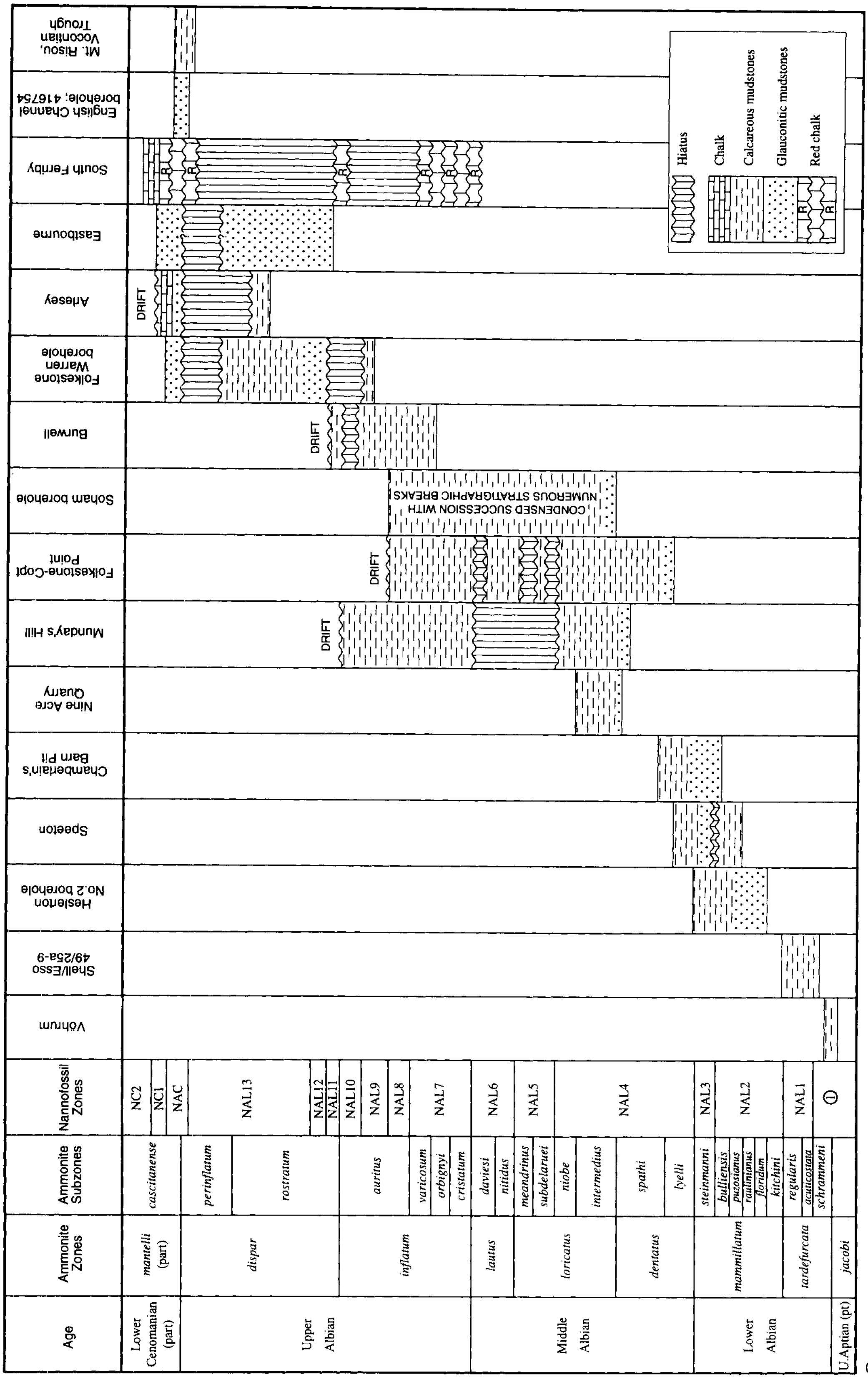


Fig. 16. Stratigraphic distribution of nannofossil species in the Vöhrum section. Metre level of samples are with reference to base tuff. Abundance counts from 30 fields of view. P refers to species present outside 30 fields of view. Marker species in bold. Ammonite stratigraphy after Kemper & Zimmerle (1978).



① NLK6 (Jakubowski, 1987)

Fig. 17. Stratigraphic sections studied.

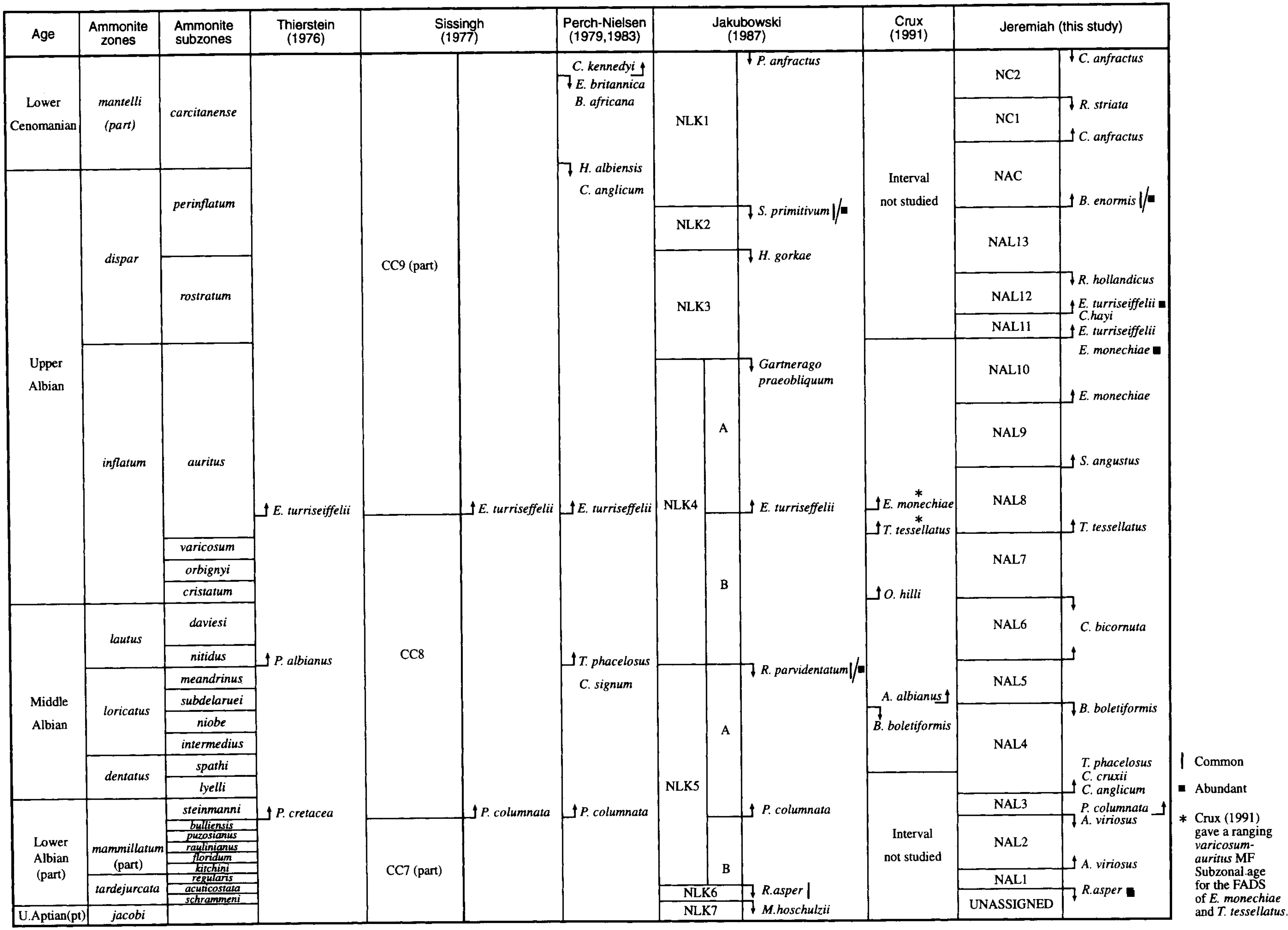


Fig. 18. Nannofossil zonation scheme of the present study compared with previous schemes.

Middle/Upper Albian. It is, however, only in basal Albian and older sediments that *R. asper* is a major component of assemblages. At Vöhrum, *R. asper* makes up between 15% and 30% of the total nannoflora when *Watznaueria barnesae* is discounted. This event is probably equivalent to the *Bukrylithus ambiguus* Zone (NLK 6) of Jakubowski (1987) based on the LAD of common *R. asper* (common occurrence was defined as 3 to 15 specimens per 30 fields of view, pers. comm., 1995).

Micrantholithus hoschulzii, the top Aptian marker of Jakubowski, 1987 (Zone NLK 7) is not identified from *jacobi* MF dated sediments at Vöhrum or numerous cored wells studied in the Moray Firth area (pers. obs.) and appears to have an intra Upper Aptian (*nutfieldiensis* MF Zone) LAD in the North Sea Basin (pers. obs.). Mutterlöse (1991) suggests an even earlier LAD for *M. hoschulzii* within the *drewi* MF Zone of Germany.

Repagulum parvidentatum Interval Range NF Zone (NAL 1)

Definition: Interval from LAD of abundant *Rhagodiscus asper* to FAD of *Acaenolithus viriosus*.

Age: Lower Albian, ?*tardefurcata* MF Zone.

Remarks: NF Zone NAL 1 is rarely identified in the central and northern North Sea as a result of non-calcareous lithologies. In the southern North Sea, however, calcareous mudstones are locally developed equivalent to the lower part of the A5 Beds at Speeton.

Acaenolithus viriosus Taxon Range NF Zone (NAL 2)

Definition: Total range of *Acaenolithus viriosus*.

Age: Lower Albian, *mammillatum* MF Zone.

Remarks: The FAD of *A. viriosus* could not be correlated with the MF Zonation due to limited onshore material studied over this interval. This event, however, is biostratigraphically restricted to an intra Lower Albian age based on the absence of *A. viriosus* from *schrammeni* MF dated mudstones at Vöhrum and uppermost *mammillatum* MF dated mudstones at Chamberlain's Barn.

Crucicribrum anglicum Partial Range Zone (NAL 3)

Definition: Interval from LAD of *Acaenolithus viriosus* to FAD of *Crucicribrum anglicum* (and *Ceratolithina cruxii*).

Age: Lower Albian, top *mammillatum* MF Zone (*steinmanni* MF Subzone).

Remarks: The FAD of *Prediscosphaera columnata* was used by Thierstein (1976), Sissingh (1977), Perch-Nielsen (1979, 1983) and Jakubowski (1987) as a zonal boundary. In the present study *P. columnata* was, however, found to be sporadic towards the base of its range in the uppermost Lower Albian at Speeton and Chamberlain's Barn. In the Tethyan Realm, however, the FAD of *P. columnata*, in the absence of other markers, is a useful approximation to the base of the Middle Albian. Under the light microscope no differentiation could be made between *P. spinosa* and *P. cf. stoveri*.

Braloweria boletiformis Partial Range NF Zone (NAL 4)

Definition: Interval from FAD of *Crucicribrum anglicum* (and *Ceratolithina cruxii*) to LAD of *Braloweria boletiformis*.

Age: Middle Albian, base of *lyelli* MF Subzone to top of *niobe* MF Subzone.

Remarks: *Axopodorhabdus albianus* has its FAD at the base of the *intermedius* MF Subzone both at Folkestone (Bed II) and at Mundays Hill (pers. obs.) but the occurrences are extremely rare and sporadic. These records, however, support the identification of *A. albianus* by Amédro *et al.* (1981) from coeval sediments at Boulonnais, France.

The FAD of *A. albianus* which was used by Cepek & Hay (1969), Thierstein (1976) and Roth (1978) as a zonal marker is not taken as a reliable datum in this study due to its extreme rarity at the base of its range. Records of *A. albianus* below the Middle Albian (Perch-Nielsen, 1985) are probably due to contamination or misidentification. The presence of *A. albianus* and *Ceratolithina hamata* in the *niobe* MF Subzone (Crux, 1991) is possibly due to mis-sampling over the *niobe/cristatum* stratigraphic break. *Hayesites albiensis* is inconsistently present and usually rare in the sections studied. The rare and intermittent occurrence limits any biostratigraphical usefulness. It however, appears to be more consistently present in localities from Kent than further north in Cambridgeshire and Bedfordshire. *Hayesites albiensis* was not identified from Yorkshire field sections or the North Sea Basin.

Braloweria boletiformis, however, is far more widespread than previously recognized. It is consistently present in the condensed Middle Albian successions of the North Sea Basin (pers. obs.) and may be recorded outside northwest Europe in future studies. This form has only previously been recorded from onshore material (Black, 1972; Crux, 1991).

Bownia glabra Interval Range NF Zone (NAL 5)

Definition: Interval from LAD of *Braloweria boletiformis* to FAD of *Ceratolithina bicornuta*.

Age: Middle Albian, base *subdelaruei* MF Subzone to top *meandrinus* MF Subzone.

Remarks: The *Bownia glabra* NF Zone yields no FADs in this study and the assemblages show only local changes in the relative abundance of some taxa. Sediments equivalent to NAL 5 are very restricted in occurrence due to the erosion of Middle Albian sediments during the *cristatum* MF Subzone (Owen, 1975). This NF biozone was not sampled at Folkestone due to the attenuated sequence present at this locality. Sediments equivalent to this NF zone are identified, however, within the Soham borehole. NAL 5 has not been identified in the North Sea Basin.

The LAD of a *Repagulum parvidentatum* influx is an easily recognized and consistent event occurring within the North Sea Basin. The datum was used by Jakubowski (1987) in the identification of his *Repagulum parvidentatum* Zone (NLK5).

This event, however, as recorded by Crux (1991) using abundance variations at Munday's Hill is unreliable in

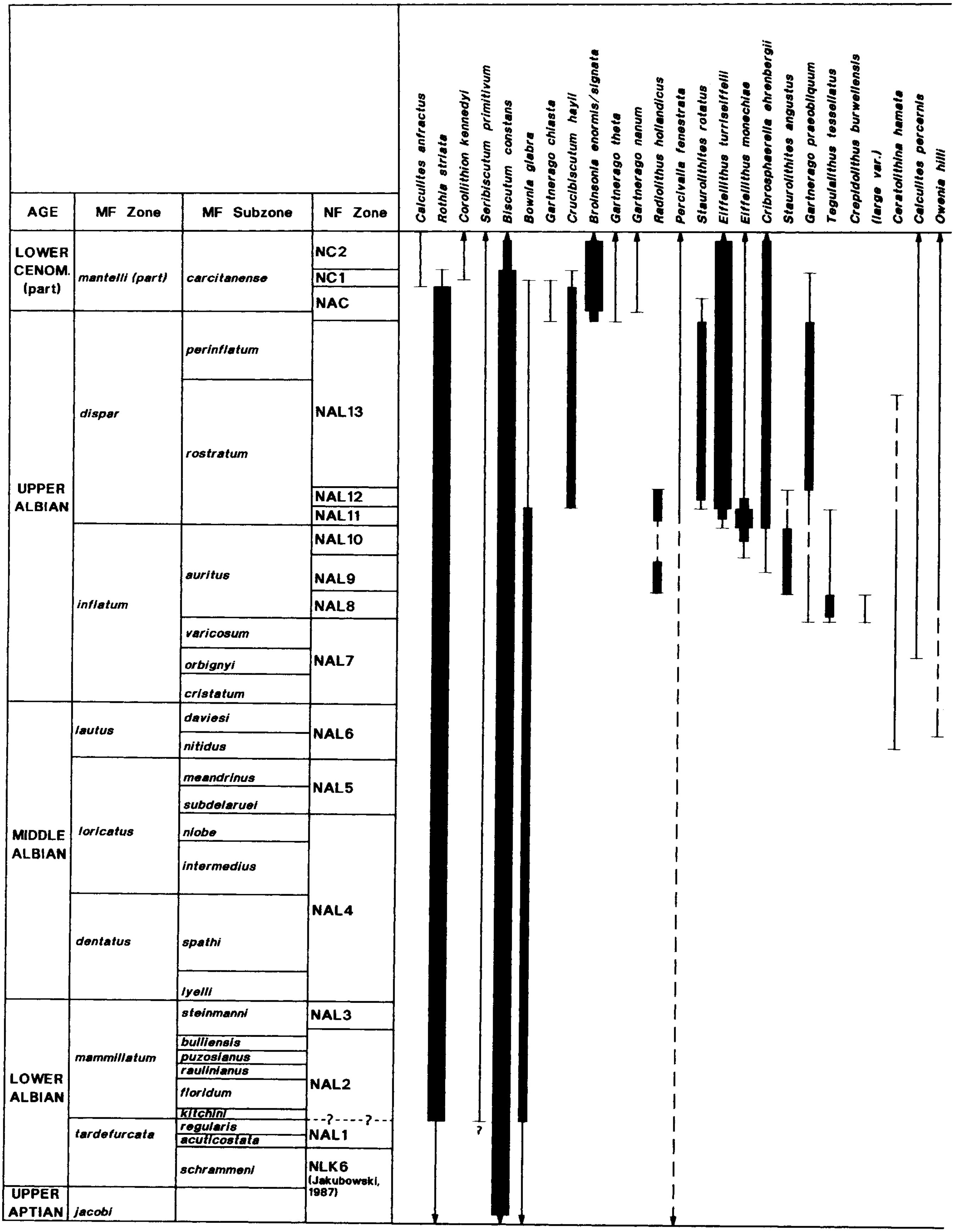


Fig. 19. Composite range chart of stratigraphically important calcareous nannofossils in England and the North Sea Basin: Albian to Lower Cenomanian.

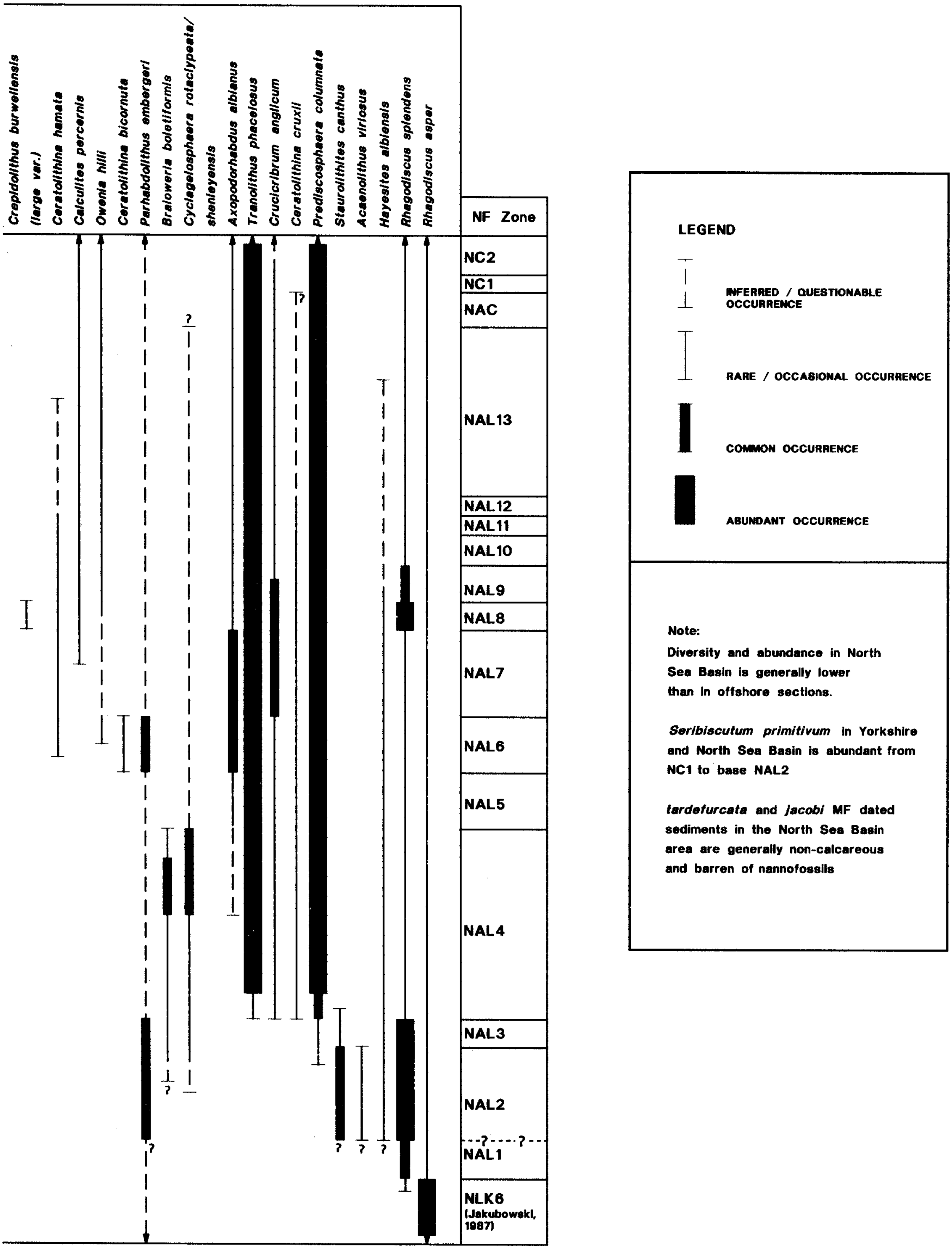


Fig. 19. (*Continued.*)

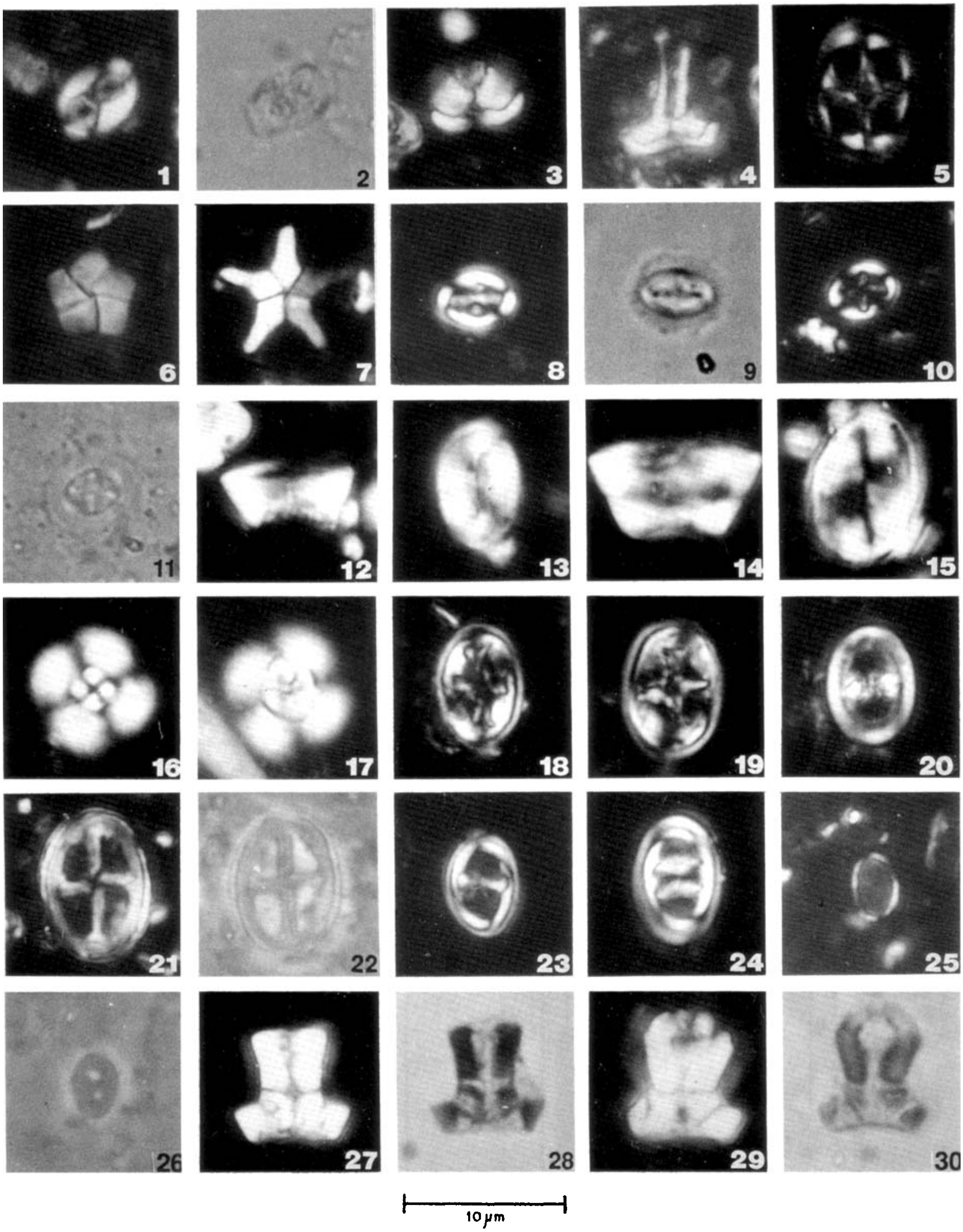

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Plate 1

onshore field sections where *R. parvidentatum* is also a major component of Upper Albian assemblages. This anomaly is possibly a reflection of the normally lower diversity and poorer preservation in offshore material.

Ceratolithina bicornuta **Taxon Range NF Zone (NAL 6)**
Definition: Total range of *Ceratolithina bicornuta*.
Age: Middle Albian, base *nitidus* MF Subzone to top *daviesi* MF Subzone.
Remarks: Perch-Nielsen (1988) recorded *C. bicornuta* from Bed VI (*nitidus* MF Subzone)–Bed VIII (*cristatum* MF Subzone) at Folkestone. Extensive searching at the type Gault Clay section and at other ammonite-dated sections has, as yet, failed to record this form from above the *daviesi* MF Subzone. The presence of *Ceratolithina hamata* in the *niobe* MF Subzone at Munday's Hill, Bedfordshire, as recorded by Crux (1991), is anomalous possibly due to mis-sampling over the *niobe/cristatum* stratigraphic break. Sediments equivalent to this NF biozone appear to be very restricted due to a short but widespread period of erosion in the *cristatum* MF Subzone (Owen, 1975). *Ceratolithina bicornuta* is rare in offshore wells possibly as a result of the condensed nature or absence of NAL 6 equivalent sediments. *Ceratolithina bicornuta* has, however, been observed (pers. obs.) in the South Halibut Basin (North Sea).

Ceratolithina hamata **Interval Range NF Zone (NAL 7)**
Definition: Interval from LAD of *Ceratolithina bicornuta* to FAD of *Tegulalithus tessellatus* (and *Gartnerago praeobliquum*).
Age: Upper Albian, base of *cristatum* MF Subzone to top *varicosum* MF Subzone.
Remarks: Due to the absence of the Middle Albian *lautus* MF Zone over much of the English Albian, the first occurrences of *Ceratolithina hamata* and *Axopodorhabdus albianus* are often found at the base of the Late Albian in the *cristatum* MF Subzone e.g. at Munday's Hill.

Crux (1991) considered the FAD of *Owenia hilli* as a potential biostratigraphical datum for the basal Upper Albian. In the present study, the FAD of *O. hilli* is recorded earlier within the *daviesi* MF Subzone.

Hayesites albiensis is confined to Albian sediments below (except for a single identification within the Folkestone borehole) the FAD of *Eiffellithus turriseiffelii* in this study Hill (1976) and Crux (1991). Many authors including Roth & Thierstein (1972), Verbeek (1977) and Manivit *et al.* (1977) used *H. albiensis* as a zonal marker co-occurring with *E. turriseiffelii*. *H. albiensis* is considered an unreliable biostratigraphic marker in this study.

Braarudosphaera stenorhetha appears in this NF zone in the southern North Sea where it is associated with common/abundant *Braarudospharea primula* and *Braarudosphaera quinquecostata*. The *Braarudosphaera* assemblage is particularly well developed in East Anglia, Yorkshire and in the southern North Sea. The common/abundant occurrence of the *Braarudosphaera* group in the *orbignyi* to *varicosum* MF Subzones is considered a localized event possibly due to palaeoenvironmental conditions. Hill (1976) recorded a similar event (*Braarudosphaera quinquecostata* Acme Zone) associated with *Eiffellithus turriseiffelii*.

Lambert (1986) grouped the separate species of *Braarudosphaera* under *B. africana*, based on the discovery of entire coccoliths in Albian laminated mudstones from Cameroon. The different architectural forms have not all been grouped under *B. africana* in the present study since they appear to have distinct stratigraphic ranges.

Tegulalithus tessellatus **Partial Range NF Zone (NAL 8)**
Definition: Interval from FAD of *Tegulalithus tessellatus* (and *Gartnerago praeobliquum*) to FAD of *Staurolithites angustus*.

Explanation of Plate 1

Figs 1–4. *Owenia hilli*. **Fig. 1,** crossed-nicols, SMH-10-06; **fig. 2,** bright field, same specimen, SMH-10-07. **Fig. 3,** crossed-nicols, partial side view, SMH-14-09. **Fig. 4,** crossed-nicols, side view, SMH-10-10. All specimens, *auritus* MF Subzone, Bed 6, Munday's Hill, Bedfordshire (NAL 9). **Fig. 5.** *Axopodorhabdus albianus*, crossed-nicols, SMH-13-08, *varicosum* MF Subzone, Bed X, Copt Point, near Folkestone, Kent (NAL 7). **Fig. 6.** *Braarudosphaera primula*, crossed-nicols, SMH-11-30, *varicosum* MF Subzone, Bed 5, Munday's Hill (NAL 7). **Fig. 7.** *Braarudosphaera stenorhetha*, crossed-nicols, SMH-08-05, *varicosum* MF Subzone, Bed 5, Munday's Hill (NAL 7). **Figs 8–9.** *Crucibiscutum hayi*. **Fig. 8,** crossed-nicols, SMH-16-24; **fig. 9,** bright field, same specimen, SMH-16-25, *mantelli* MF Zone, Folkestone Warren borehole, 36.75 m (NAC) . **Figs 10–11.** *Crucibiscutum* sp.1. **Fig. 10,** crossed-nicols, SMH-08-12; **fig. 11,** bright field, same specimen, SMH-08-13, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Figs 12–13.** *Crepidolithus burwellensis*. **Fig. 12,** crossed-nicols, SMH-12-20, *intermedius* MF Subzone, Nine Acres Quarry, Bedfordshire (NAL 4). **Fig. 13,** crossed-nicols, SMH-09-16, *orbignyi* MF Subzone, Bed IX, Copt Point (NAL 7). **Figs 14–15.** *Crepidolithus burwellensis* (large variety). **Fig. 14,** SMH-12-23 and **fig. 15,** SMH-11-35, crossed-nicols, both specimens from Block 15, UK central North Sea (NAL 8). **Fig. 16.** *Cyclagelosphaera rotaclypeata*, crossed-nicols, SMH-09-26, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Fig. 17.** *Cyclagelosphaera shenleyensis*, crossed-nicols, SMH-09-27, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Figs 18–19.** *Eiffellithus monechiae*. **Fig. 18,** crossed-nicols, SMH-12-32, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 10). **Fig. 19,** crossed-nicols, SMH-12-31, *rostratum* MF Subzone, Bed 17, Burwell, Cambridgeshire (NAL 11). **Fig. 20.** *Zeugrhabdotus noeliae*, crossed-nicols, SMH-06-03, *daviesi* MF Subzone, Bed VII, Copt Point (NAL 6). **Figs 21–22.** *Gartnerago praeobliquum*. **Fig. 21,** crossed-nicols, SMH-11-32; **fig. 22,** bright field, same specimen, SMH-11-31, *auritus* MF Subzone, Bed 15, Burwell (NAL 8). **Figs 23–24.** *Lordia xenota*. **Fig. 23,** crossed-nicols, SMH-11-22, *spathi* MF Subzone, Bed I, Copt Point (NAL 4). **Fig. 24,** crossed-nicols, SMH-11-18, *auritus* MF Subzone, Bed 16, Burwell (NAL 9). **Figs 25–26.** *Orastrum perspicuum*. **Fig. 25,** crossed-nicols, SMH-11-04; **fig. 26,** bright field, same specimen, SMH-11-05, *intermedius* MF Subzone, Bed II, Copt Point (NAL 4). Note the two perforations which were not described by Varol (1991) due to overgrowth in his material. **Figs 27–30.** *Braloweria boletiformis*. **Fig. 27,** crossed-nicols, SMH-12-17; **fig. 28,** bright field, same specimen, SMH-12-18, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Fig. 29,** crossed-nicols, SMH-10-20: **fig. 30,** bright field, same specimen, SMH-10-19, *intermedius* MF Subzone, Nine Acres Quarry (NAL 4).

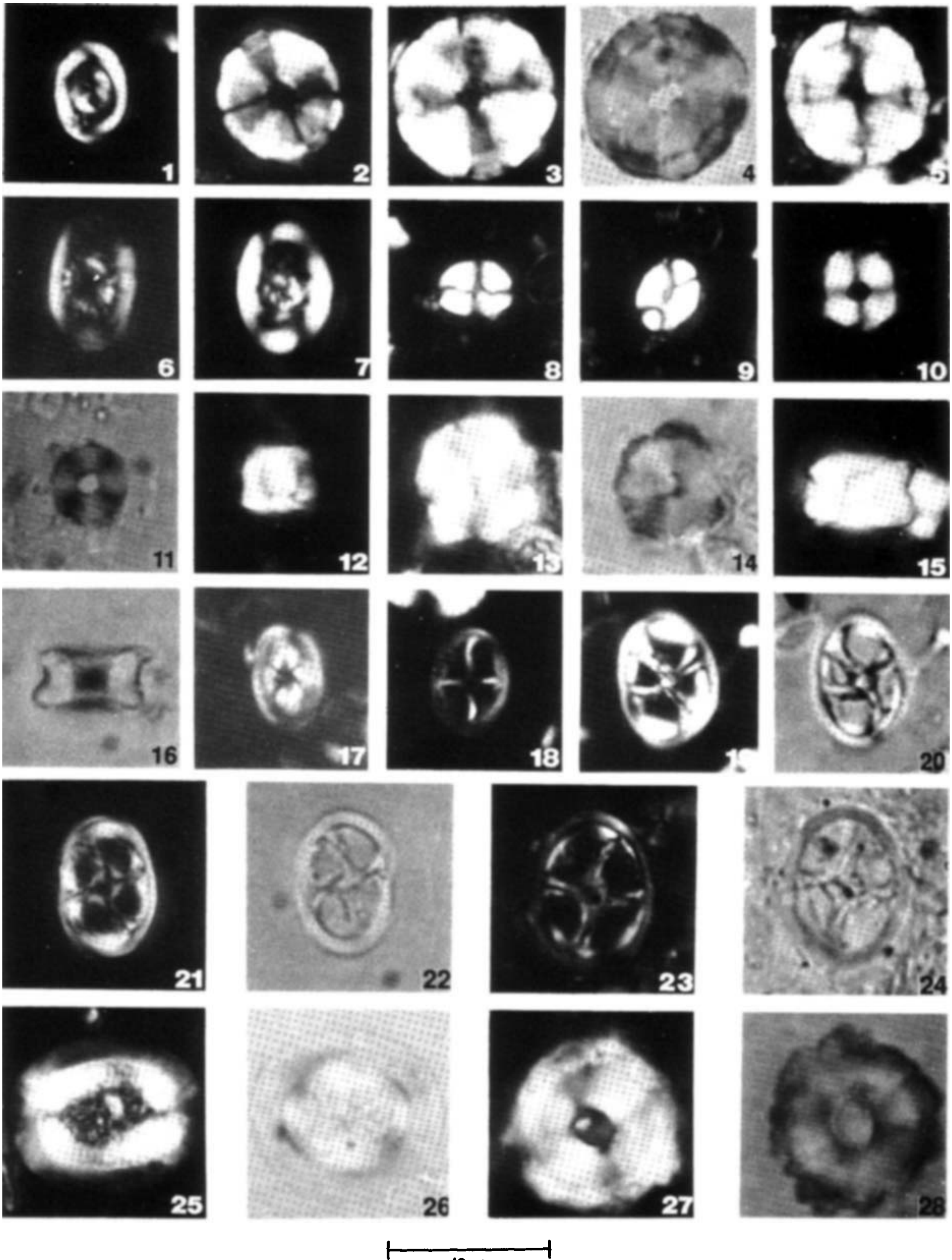
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Plate 2

Age: Upper Albian, *auritus* MF Subzone (lower part).
Remarks: *Tegulalithus tessellatus* is restricted to this NF biozone in the North Sea Basin but occurs sporadically in younger NF zones from onshore localities. The FAD of *T. tessellatus* is a reliable biostratigraphic event. This form appears at Folkestone towards the base of the *auritus* MF Subzone together with *Gartnerago praeobliquum*. This association also occurs at Munday's Hill, Burwell and at La Héve, northern France (pers. obs.), in reliably dated *auritus* MF Subzonal sediments (J. Eyers, pers. comm.,1993) and is locally present in sequences throughout the North Sea Basin.

***Staurolithites angustus* Partial Range NF Zone (NAL 9)**
Definition: Interval from FAD of *Staurolithites angustus* (and *Radiolithus hollandicus*) to FAD of *Eiffellithus monechiae.*
Age: Upper Albian, *auritus* MF Subzone.
Remarks: *Staurolithites angustus* appears to be a cosmopolitan form having been recorded in Tunisia and Spain (Verbeek, 1977), onshore Holland (Stradner *et al.*, 1968) and northern France (pers. obs.), below the FAD of *Eiffellithus turriseiffelii*. *Staurolithites angustus* as described by Stover (1966), has not been found to occur outside the Upper Albian in the present study. The LAD of *Braarudosphaera stenorhetha* within this NF zone appears to represent a localized event within the southern North Sea and England. Hill (1976) recorded *B. stenorhetha* from Oklahoma and Texas in younger Albian sediments associated with *Eiffellithus turriseiffelii.*

Eiffellithus monechiae Partial Range NF Zone (NAL 10)
Definition: Interval from FAD of *Eiffellithus monechiae* to FAD of *Eiffellithus turriseiffelii*.
Age: Upper Albian, *auritus* MF Subzone (upper part).
Remarks: A minor hiatus at the base of the *rostratum* MF Subzone has resulted in much of the upper part of the *auritus* MF Subzone being removed in Cambridgeshire (J. Eyers, pers. comm., 1993). This hiatus also occurs in the Folkestone section, with a non-sequence represented by phosphatic nodules at the base of the 'Greensand Seam' (Bed XII).

***Eiffellithus turriseiffelii* Partial Range NF Zone (NAL 11)**
Definition: Interval from FAD of *Eiffellithus turriseiffelii* to FAD of *Crucibiscutum hayi.*
Age: Upper Albian, *rostratum* MF Subzone (lower part).
Remarks: This NF zone contains a period of nannofloral diversification characterized by the rapid evolution of the *Eiffellithaceae*. This evolutionary lineage has previously been documented by many authors, e.g. Verbeek (1977) and Hill & Bralower (1987). A similar evolutionary trend exists between *Staurolithites angustus* and *Staurolithites rotatus* within this NF biozone, whereby the bars which were near parallel to the axes of the ellipse rotated to form large angles with the axes.

The FAD of *E. turriseiffelii* has been used as a zonal marker event by many authors, e.g. Roth (1973), Thierstein (1976), Sissingh (1977), Taylor (1982) and Jakubowski (1987).

The FAD of abundant *Eiffellithus monechiae* is an alternative marker for the base of NAL 11.

***Radiolithus hollandicus* Partial Range NF Zone (NAL 12)**
Definition: Interval from FAD of *Crucibiscutum hayi* to LAD of *Radiolithus hollandicus*.
Age: Upper Albian, *rostratum* MF Subzone.
Remarks: *Radiolithus hollandicus* occurs as distinct influxes at disparate stratigraphic levels and can be missed in field samples, sidewall cores or core samples. Its LAD in ditch cuttings, however, is a recognized correlatable event in North Sea wells.

Eiffellithus monechiae is subordinate to *E. turriseiffelii* within this biozone.

Crux (1991) identified *Crucibiscutum hayi* throughout the Middle to Upper Albian section at Munday's Hill, Bedfordshire. A review of these sediments, however, resulted in the identification of a variety of *Crucibiscutum* spp. from the Middle Albian which are not synonymous with

Explanation of Plate 2

Fig. 1. *Braloweria boletiformis*, crossed-nicols, SMH-13-29, *niobe* MF Subzone, Bed 3(iii), Munday's Hill, Bedfordshire (NAL 4). **Figs 2–4.** *Radiolithus hollandicus* (11 rayed form). **Fig. 2,** crossed-nicols, SMH-10-27, *auritus* MF Subzone, Bed 16, Burwell, Cambridgeshire (NAL 9). **Fig. 3,** crossed-nicols, SMH-12-09; **fig. 4,** bright field, same specimen, SMH-12-10, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 9). **Fig. 5.** *Radiolithus hollandicus* (12 rayed form), crossed-nicols, SMH-12-06, *auritus* MF Subzone, Bed 16, Burwell (NAL 9). **Fig. 6.** *Rhagodiscus splendens*, crossed-nicols SMH-15-23, *auritus* MF Subzone, Bed 16, Burwell (NAL 9). **Fig. 7.** *Rhagodiscus asper*, crossed-nicols, SMH-04-01, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Figs 8–9.** *Calculites percernis*. **Fig. 8,** crossed-nicols, SMH-12-05, holotype; **fig. 9,** crossed-nicols, SMH-12-04, same specimen, *auritus* MF Subzone, Bed 16, Burwell (NAL 9). **Figs 10–16, 27-28.** *Tegulalithus tessellatus*. **Fig. 10,** crossed-nicols, SMH-14-01; **fig. 11,** bright field, same specimen, SMH-14-02, *auritus* MF Subzone, Bed 15, Burwell (NAL 8). **Fig. 12,** crossed-nicols, SMH-14-07, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 8). **Fig. 13,** crossed-nicols, SMH-09-09; **fig. 14,** bright field, same specimen, SMH-09-08, *auritus* MF Subzone, Bed XI, Copt Point, Kent (NAL 8). **Fig. 15,** crossed-nicols, SMH-14-05; **fig. 16,** bright field, same specimen, SMH-14-06, *auritus* MF Subzone, Soham borehole, Cambridgeshire, sample No. 3309 (NAL 8). **Fig. 27,** crossed-nicols, SMH-09-12; **fig. 28,** bright field, same specimen, SMH-09-11, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 8). **Fig. 17.** *Bukrylithus ambiguus*, crossed-nicols, SMH-17-21, *niobe* MF Subzone, Bed III, Copt Point (NAL 4). **Fig. 18.** *Staurolithites gausorhethium*, crossed-nicols, SMH-09-22, *auritus* MF Subzone, Bed 16, Burwell (NAL 8). **Figs 19–20.** *Staurolithites rotatus*. **Fig. 19,** crossed-nicols, SMH-16-30, holotype; **fig. 20,** bright field, same specimen, SMH-16-31, *dispar* MF Zone, Bed XIII, Copt Point (NAL 13). **Figs 21–24.** *Staurolithites angustus*. **Fig. 21,** crossed-nicols, SMH-10-31; **fig. 22,** bright field, same specimen, SMH-10-30, *auritus* MF Subzone, Bed XI, East Wear Bay, Kent (NAL 9). **Fig. 23,** crossed-nicols, SMH-12-26; fig. 24, bright field, same specimen, SMH-12-27, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 9). **Figs 25–26.** *Gaarderella granulifera*. **Fig. 25,** crossed-nicols, SMH-11-20; **fig. 26,** bright field, same specimen, SMH-09-11, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4).

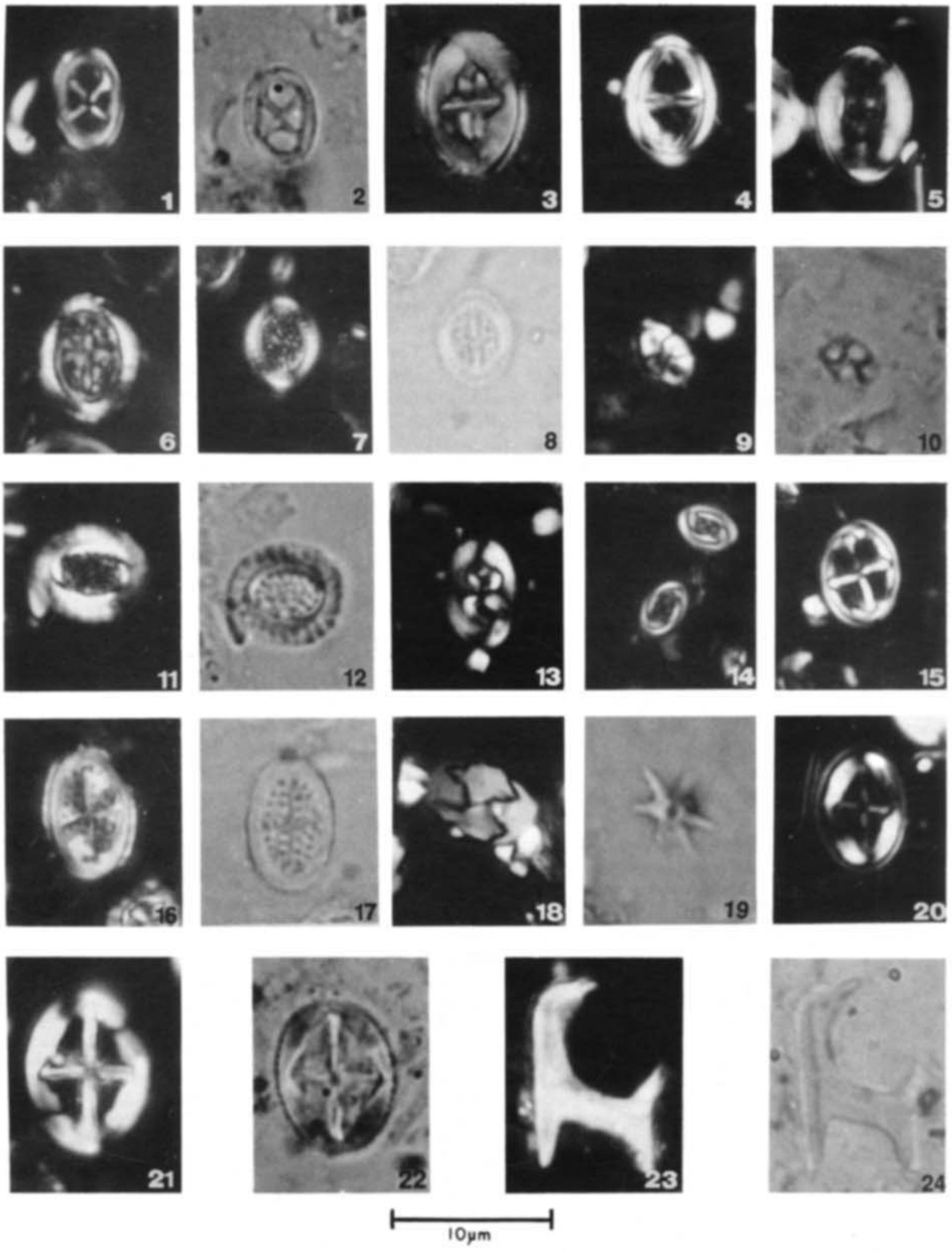

Plate 3

C. hayi s.s, e.g. *Crucibiscutum* sp. 1 (Pl. 1, Figs 10, 11). A form very similar to *C. hayi* is also present in Upper/Middle Aptian sediments from the North Sea Basin. This *Crucibiscutum* sp. is, however, probably more closely related to *Crucibiscutum salebrosum*. Electron microscopical analysis is needed to resolve the problem. In this study, *C. hayi s.s* does not appear until the *rostratum* MF Subzone.

This NF biozone equates in part to the *Gartnerago praeobliquum* NF Zone (NLK4) of Jakubowski (1987). This NF zone was defined as Middle to Upper Albian in age without any reference to ammonite-dated material.

***Gartnerago praeobliquum* Interval Range NF Zone (NAL 13)**

Definition: Interval from LAD of *Radiolithus hollandicus* to FAD of common/abundant *Broinsonia enormis*.

Age: Upper Albian, *rostratum-perinflatum* MF Subzones.

Remarks: This stratigraphic level has been correlated to a transgression within the *dispar* MF Zone (Eyers, 1992). In England, this sea-level rise is expressed by monotonous, very pale grey clays, with little evidence of breaks in sedimentation, unlike the underlying Gault Clay which is usually darker in colour and punctuated by numerous stratigraphic breaks.

The nannoflora within this NF biozone exhibit a degree of provincialism. *Crucibiscutum hayi, Cribrosphaerella ehrenbergii, Percivalia fenestrata* and *Staurolithites rotatus* are characteristic components of this NF zone in England and the southern North Sea but are rare in the central and northern North Sea.

***Broinsonia enormis* Partial Range NF Zone (NAC)**

Definition: Interval from FAD of common/abundant *Broinsonia enormis* to FAD of *Calculites anfractus*.

Age: Upper Albian, *perinflatum* MF Subzone – 'Lowermost' Cenomanian, *carcitanense* MF Subzone (lower part).

Remarks: In southern England NAC has only been found to correlate with macrofossil dated sediments of 'lowermost' Cenomanian age. A regional non-sequence is present at the Albian/Cenomanian boundary in northern France and southern Britain. An expanded ammonite dated equivalent of this NF biozone (Upper Albian to Lower Cenomanian) is preserved in the Vocontian Trough (A. S. Gale, pers. comm., 1994). A thick development of NAC dated sediments are also present in the Red Chalk of Speeton (pers. obs.). It is plausible that at Speeton, unlike in southern Britain, a complete Albian to Cenomanian boundary succession is present. Unfortunately, ammonite data are extremely sparse and the Cenomanian/Albian boundary is difficult to accurately locate (H. G. Owen, pers. comm., 1994).

The nannoflora at Mt. Risou does not exhibit any marked assemblage changes over the Albian/Cenomanian boundary. The FAD of *Gartnerago nanum* is of potential importance but further work is required to prove its value as a boundary marker. *Gartnerago chiasta* is present in the Vocontian Trough, England and southern North Sea but does not appear to have migrated any further north.

***Rothia striata* Partial Range NF Zone (NC 1)**

Definition: Interval from FAD of *Calculites anfractus* to LAD of *Rothia striata*.

Age: 'Lowermost' Cenomanian, *mantelli* MF Zone (lower part).

Remarks: This NF zone equates in part to the *Phanulithus anfractus* (NLK1), *Seribiscutum primitivum* (NLK 2), *Hemipodorhabdus gorkae* (NLK 3) and *Gartnerago praeobliquum* (NLK 4) NF Zones of Jakubowski (1987).

The LAD of abundant *Biscutum constans* approximates to the top of NC1 in the central North Sea. This event is, however, diachronous and found in younger sediments from onshore localities and in well sections from the North Viking Graben (Northern North Sea).

Seribiscutum primitivum is abundant at this stratigraphic level in the North Sea Basin and Yorkshire but is a minor component of nannofloral assemblages in southern Britain. At the Mt Risou section, *S. primitivum* is absent from the majority of samples analysed.

Explanation of Plate 3

Figs 1–2. *Gartnerago chiasta*. **Fig. 1,** crossed-nicols, SMH-16-27; **fig. 2,** bright field, same specimen, SMH-16-28, ?*mantelli* MF Zone, Wilstone Reservoir, near Tring, Buckinghamshire (NC 1). **Fig. 3.** *Gartnerago nanum*, crossed-nicols, SMH-06-11, Dutch southern North Sea, Upper Holland Marl, Well Q/7-2 (NAC). **Fig. 4.** *Gartnerago theta*, crossed-nicols, SMH-16-22, Dutch southern North Sea, Upper Holland Marl, Well Q/7-2 (NAC). **Fig. 5.** *Percivalia fenestrata*, crossed-nicols, SMH-02-01, *rostratum* MF Subzone, Arlesey, Bedfordshire (NAL 13). **Fig. 6.** *Cretarhabdus inaequalis* (large variety), crossed-nicols, SMH-16-12, Bed A5, *ewaldi* Marl, Speeton, Yorkshire (NAL 2). **Figs 7–8.** *Cretarhabdus inaequalis*. **Fig. 7,** crossed-nicols, SMH-11-13; **fig. 8,** bright field, same specimen, SMH-11-14, *orbignyi* MF Subzone, Bed IX, Copt Point, Kent (NAL 7). **Figs 9–10.** *Calculites dispar*. **Fig. 9,** crossed-nicols, SMH-17-08; **fig. 10,** bright field, same specimen, Bed A3, Speeton (NAL 3). Note the four perforations in this form were not originally described by Varol (1991), due to overgrowth in his material. **Figs 11–12.** *Cribrosphaerella ehrenbergii*. **Fig. 11,** crossed-nicols, SMH-16-32; **fig. 12,** bright field, same specimen, SMH-16-33, *rostratum-perinflatum* MF Subzones, Bed XIII, Copt Point (NAL 13). **Fig. 13.** *Rothia striata*, crossed-nicols, SMH-13-21, Hunstanton Formation, South Ferriby, Humberside (NAL 7). **Fig. 14.** ?*Lordia xenota* (small variety), crossed-nicols, SMH-11-17, *intermedius* MF Subzone, Bed I, Copt Point (NAL 4). **Fig. 15.** *Staurolithites canthus*, crossed-nicols, SMH-16-09, Bed A5, *ewaldi* Marl, Speeton, holotype (NAL 2). **Figs 16–17.** *Crucicribrum anglicum*. **Fig. 16,** crossed-nicols, SMH-12-01; **fig. 17,** bright field, same specimen, SMH-12-02, *varicosum* Subzone, Bed 5, Munday's Hill, Bedfordshire (NAL 7). **Fig. 18.** *Calculites anfractus*, crossed-nicols, SMH-04-36, ?*mantelli* MF Zone, Tring (NC 1). **Fig. 19.** *Hayesites albiensis*, bright field, SMH-07-19, *intermedius* MF Subzone, Nine Acres Quarry, Bedfordshire (NAL 4). **Fig. 20.** *Bownia glabra*, crossed-nicols, SMH-17-36, *daviesi* MF Subzone, Bed VII, Copt Point, holotype (NAL 6). **Figs 21–22.** *Acaenolithus viriosus*. **Fig. 21,** crossed-nicols, SMH-17-04, Bed A5, *ewaldi* Marl, Speeton, holotype (NAL 2). **Fig. 22,** bright field, SMH-17-05, Dutch southern North Sea, Middle Holland Shale Member, Well Q/16-2 (NAL 2). **Figs 23–24.** *Ceratolithina bicornuta*. **Fig. 23,** crossed-nicols, SMH-08-08; **fig. 24,** bright field, same specimen, SMH-08-07, *daviesi* MF Subzone, Bed VII, Copt Point (NAL 6).

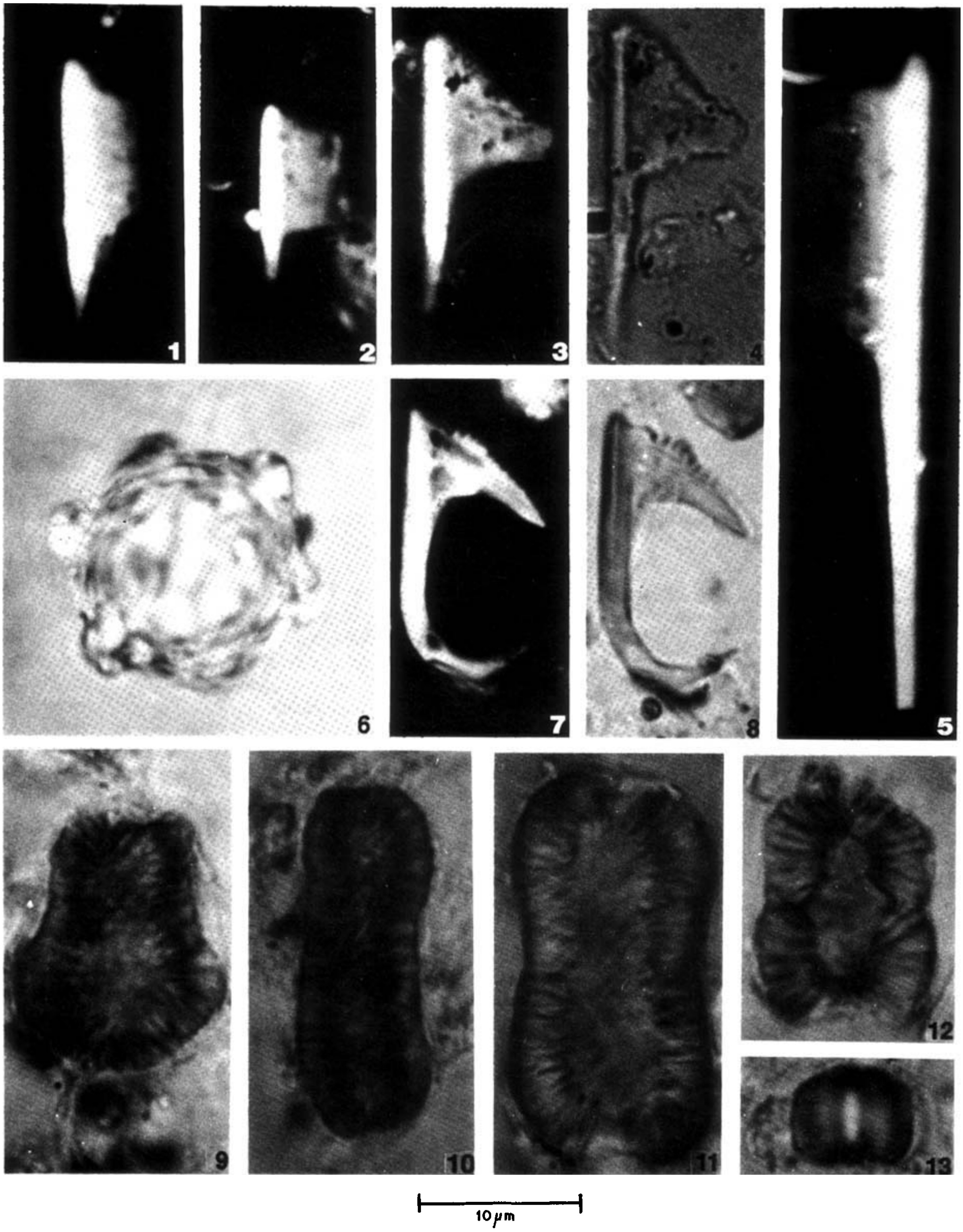

Plate 4

Calculites anfractus **Partial Range NF Zone (NC 2)**
Definition: Interval from LAD of *Rothia striata* to LAD of *Calculites anfractus.*
Age: Lower Cenomanian, *mantelli* MF Zone.

TAXONOMY

A detailed taxonomic section is not provided, although taxa referred to in this paper are listed alphabetically in Appendix 1. Taxonomic references not included in the reference list can be found in Perch-Nielsen (1985). New species and combinations are detailed below.

Genus **ACAENOLITHUS** Black, 1973
Acaenolithus viriosus sp. nov.
(Pl. 3, figs. 21–22)

Derivation of name: Latin *viriosus*, meaning robust.
Diagnosis: A large species of *Acaenolithus* with large central openings and a massive unstriated cross. The outline of the coccolith is elliptical with a rim built of two separate shields. The distal surface of the rim is fluted. The central opening is spanned by a robust cross along the principal axes of the ellipse. A short spine is present at the centre. On the proximal side, each arm of the cross appears to have a shallow central furrow.
Holotype: SMH-17-04 (Pl. 3, fig. 21).
Type locality and horizon: Speeton, Yorkshire, *ewaldi* Marl, Bed A_5 (Early Albian).
Dimensions: Mean length – 8.9 μm, 50 specimens measured. Maximum length – 11.8 μm. Smallest forms appear to grade into *A. galloisii* (mean length of 5.5 μm). Forms with a maximum length of greater than 8 μm are assigned to *A.viriosus*.
Remarks: *Acaenolithus viriosus* appears to be constructed similarly to *A. galloisii* when viewed under the light microscope. *Acaenolithus viriosus* is, however, much larger. A similar form to *A. viriosus*, although possessing a more elaborate rim structure, occurs in the Glauconitic Marl at Folkestone and is possibly synonymous to *A. cenomanicus* Black (1973).

Genus **BOWNIA** Varol, 1994
Bownia glabra sp. nov.
(Pl. 3, fig. 20)

1966 *Coccolithus matalosus* Stover: 139, pl. 2; pl. 8, fig. 10.
1973 *Vagalapilla matalosa* (Stover) Thierstein: 37–38, pl. 3, figs 15-18.
1994 *Bownia matalosa* (Stover) Varol & Girgis: 237, fig. 11, 1.
Derivation of name: Latin *glabra*, meaning smooth.
Diagnosis: The coccoliths are elliptical and consist of two closely-appressed zeugoid walls. The central opening is bridged by a narrow cross parallel to the principal axes of the ellipse with flaring, arrowhead-like ends. Under crossed-nicols, the inner cycle is highly birefringent and appears brighter than the rim.
Holotype: SMH-17-36 (Pl. 3, fig. 20).
Type locality and horizon: Speeton, Yorkshire, *ewaldi* Marl, Bed A_5 (Early Albian).
Dimensions: L: 6–8 μm (mean length 7.5 μm), 50 specimens measured.
Remarks: Stover's holotype, (Pl. 2, figs 1a–c) clearly exhibits a scalloped outer rim, similar to that of the *Arkhangelskiellaceae*, and is probably synonymous with *Broinsonia signata or Acaenolithus cenomanicus*.

Stover's paratype, (Pl. 2, figs 2a–b) has a zeugoid outer wall and is identifiable as *Bownia glabra.*

Genus **CALCULITES** Prins & Sissingh *in* Sissingh, 1977
Calculites percernis sp. nov.
(Pl. 2, figs. 8–9)

1976 *Biscutum supracretaceum* Hill: 124, Pl. 2, figs 1–9.
1991 *Calculites* sp. 1 Crux: 214, Pl. 1, fig. 4; Pl. 2, figs 5–6.
Derivation of name: Latin *percernis*, meaning easily visible.
Diagnosis: This holococcolith is composed of a narrow rim, a broad wall consisting of a limited number of calcite blocks and a central pore. Under crossed-nicols and with the axes of the ellipse aligned with the nicols, extinction gyres lie on the principal axes of the ellipse. With the axes rotated 45 degrees to the nicols, the gyres do not intersect but form arches about the acute ends of the ellipse.
Holotype: SMH-12-05 (Pl. 2, fig. 8).
Type locality and horizon: Burwell, Cambridgeshire, Bed 16 (Late Albian).
Dimensions: L: 3–5 μm (mean length 4.4 μm), 50 specimens measured.
Remarks: This small holococcolith is abundant at certain horizons within the *auritus* MF Subzone in Cambridgeshire and Bedfordshire and in the *dispar* MF Zone of the Vocontian Trough, France (pers. obs.).

Genus **CRUCIBISCUTUM** Jakubowski, 1986
Crucibiscutum sp. 1
(Pl. 1, figs 10–11)

Remarks: A species of *Crucibiscutum* with an asymmetrical cross.

Explanation of Plate 4

Figs 1–5. *Ceratolithina cruxii*. **Fig. 1,** crossed-nicols, SMH-11-09. **Fig. 2,** crossed-nicols, SMH-11-06. **Fig. 3,** crossed-nicols, SMH-09-17; **fig. 4,** bright field, same specimen, SMH-09-19. **Fig. 5,** crossed-nicols, SMH-11-07. All specimens, *intermedius* MF Subzone, Bed 2, Munday's Hill, Bedfordshire (NAL 4). **Fig. 6.** *Cyclagelosphaera shenleyensis* (coccosphere), bright field, SMH-11-29, *intermedius* MF Subzone, Bed 2, Munday's Hill (NAL 4). **Figs 7–8.** *Ceratolithina hamata*. **Fig. 7,** crossed-nicols, SMH-09-15; **fig. 8,** bright field, same specimen, SMH-09-14, *orbignyi* MF Subzone, Bed 4 (iii), Munday's Hill (NAL 7). **Fig. 9.** *Nannoconus aquitanicus*, bright field, SMH-08-15, *orbignyi* MF Subzone, Bed 4 (v), Munday's Hill (NAL 7). **Fig. 10.** *Nannoconus elongatus*, bright field, SMH-09-07, *auritus* MF Subzone, Soham borehole, Cambridgeshire (NAL 8). **Fig. 11.** *Nannoconus grandis*, bright field, SMH-08-21, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 8). **Fig. 12.** *Nannoconus* aff. *N. multicadus*, bright field, SMH-09-04, *auritus* MF Subzone, Bed 6, Munday's Hill (NAL 8). **Fig. 13.** *Nannoconus truitti*, bright field, SMH-09-05, *daviesi* MF Subzone, Soham borehole (NAL 6).

Genus **STAUROLITHITES** Caratini, 1963
Staurolithites canthus sp. nov.
(Pl. 3, fig. 15)

Derivation of name: Latin *canthus*, meaning cart-wheel.
Diagnosis: A species of *Staurolithites* whose central cross is slightly offset from the principal axes of the ellipse. The two cycles forming the rim can be seen with the light microscope between crossed-nicols. The inner cycle is bright and often appears segmented when rotated under crossed-nicols.
Holotype: SMH-16-09 (Pl. 1, fig. 15).
Type locality and horizon: Speeton, Yorkshire, *ewaldi* Marl, Bed A_5 (Early Albian).
Dimensions: L: 6–8 μm (mean length 7.2 μm), 50 specimens measured.

Staurolithites rotatus sp. nov.
(Pl. 2, figs 19-20)

Derivation of name: Latin *rotatus*, meaning to turn around.
Diagnosis: This form is elliptical with a narrow, single zeugoid wall. The large central opening is bridged by a spine-bearing cross which is often missing. Each bar of the cross consists of two parallel blocks. The bars, unlike in *Staurolithites angustus*, form a large angle with the long axis of the ellipse. *Staurolithites rotatus* exhibits a slight bifurcation at the ends of the cross.
Holotype: SMH-16-30 (Pl. 2, fig. 19).
Type locality and horizon: Folkestone, Kent, Bed XIII (Late Albian – *dispar* MF Zone)
Dimensions: L: 6.5–9 μm (mean length 8.5 μm), 50 specimens measured.
Remarks: An evolutionary trend is considered to exist between *S. angustus* through intermediate forms to *S. rotatus* where by a gradual rotation of the bars occurs, from almost parallel to the axes of the ellipse to a position midway between the axes of the ellipse. This gradual change has also been documented by Stover (1966) and Verbeek (1977), although they did not differentiate the two end members.

CONCLUSIONS

Extensive sampling of Albian to Lower Cenomanian, ammonite dated localities, mainly from England, has provided an opportunity to develop a high resolution nannofossil biozonation scheme. A total of sixteen zones are defined.

The *Repagulum parvidentatum* (NAL 1) and *Acaenolithus viriosus* (NAL 2) NF Zones are poorly represented in onshore English sections possibly due to unfavourable, high energy, shallow marine environments. Exceptions include Beds A5 to A3 at Speeton and the Chamberlain's Barn section, Bedfordshire, which confirms NAL 2 as Lower Albian in age. The *Bownia glabra* (NAL 5) and *Ceratolithina bicornuta* (NAL 6) NF Zones of Middle Albian age are poorly represented at English sections and in the North Sea Basin as a result of the regional Upper Albian *cristatum* MF erosive event.

A major unconformity is present at the Albian/Cenomanian boundary in southern England with the *dispar* MF Zone truncated to varying levels. A complete sequence across the boundary is present at Mt. Risou, southern France and possibly in the Red Chalk facies of Yorkshire and the southern North Sea Basin.

ACKNOWLEDGEMENTS

I would like to thank Dr. J. Eyers (Open University, Milton Keynes), Dr. H. G. Owen (Natural History Museum, London) and Dr. A. S. Gale (Natural History Museum, London) for help in collecting samples and helpful observations on ammonite stratigraphy. I would also like to thank Dr. J. A. Burnett (University College London), Mr M. Jakubowski (Natural History Museum, London), Dr. J. Crux (Caraças) and Dr. J. R. Young (Natural History Museum, London) for their constructive comments on an earlier draft of the paper. Mr N. Sharp (Shell U.K) is gratefully acknowledged for his help in constructing Figs 2–16. I thank Shell UK for permission to publish this paper.

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APPENDIX 1: Alphabetical list of species considered in this study

Acaenolithus cenomanicus Black, 1973
Acaenolithus galloisii Black, 1973
Acaenolithus viriosus n. sp.
Axopodorhabdus albianus (Black, 1967) Wind & Wise *in* Wise & Wind, 1977
Axopodorhabdus dietzmannii (Reinhardt, 1965) Wind & Wise, 1983
Biscutum constans (Górka, 1957) Black *in* Black & Barnes, 1959
Biscutum dissimilis Wind & Wise *in* Wise & Wind, 1977
Bownia glabra n. sp
Braarudosphaera africana Stradner, 1961
Braarudosphaera primula Black, 1973
Braarudosphaera quinquecostata Hill, 1976
Braarudosphaera regularis Black, 1973
Braarudosphaera stenorhetha Hill, 1976
Braloweria boletiformis (Black, 1972) Crux, 1991
Broinsonia enormis (Shumenko, 1968) Manivit, 1971
Bukrylithus ambiguus Black, 1971
Calcicalathina alta Perch-Nielsen, 1979
Calculites anfractus (Jakubowski, 1986) Varol & Jakubowski, 1989
Calculites dispar Varol *in* Al-Rifaiy *et al.*, 1990
Calculites percernis n. sp.
Ceratolithina bicornuta Perch-Nielsen, 1988
Ceratolithina cruxii Perch-Nielsen, 1988
Ceratolithina hamata Martini, 1967
Chiastozygus litterarius (Gorka, 1957) Manivit, 1971
Corollithion achlyosum (Stover, 1966) Thierstein, 1971
Corollithion exiguum Stradner, 1961
Corollithion kennedyi Crux, 1981
Corollithion rhombicum (Stradner & Adamiker, 1966) Bukry, 1969
Cretarhabdus inaequalis Crux, 1987
Cretarhabdus loriei Gartner, 1968
Crepidolithus burwellensis Black, 1972
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre *in* Piveteau, 1952
Crucibiscutum hayi (Black, 1971) Jakubowski, 1986
Crucibiscutum salebrosum (Black, 1971) Jakubowski, 1986
Crucibiscutum sp.1 n. sp.
Crucicribrum anglicum Black, 1973
Cyclagelosphaera rotaclypeata Bukry, 1969
Cyclagelosphaera shenleyensis Black, 1973
Discorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968
Eiffellithus monechiae Crux, 1991
Eiffellithus turriseiffelii (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965
Ellipsagelosphaera britannica (Stradner, 1963) Perch-Nielsen, 1968
Eprolithus floralis (Stradner, 1962) Stover, 1966
Eprolithus varolii Jakubowski, 1986
Farhania sp. Varol, 1992
Flabellites biforaminis Thierstein, 1973
Gaarderella granulifera Black, 1973
Gartnerago chiasta Varol, 1991
Gartnerago nanum Thierstein, 1974
Gartnerago praeobliquum Jakubowski, 1986
Gartnerago theta (Black, 1959), Jakubowski, 1986
Glaukolithus diplogrammus (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1964
Goniolithus fluckigeri Deflandre, 1957
Gorkaea operio Varol & Girgis, 1994
Grantarhabdus coronadventis (Reinhardt, 1966) Grün *in* Grün & Allemann, 1975
Haqius circumradiatus (Stover, 1966) Roth, 1978
Hayesites albiensis Manivit, 1971
Helicolithus cf. *compactus* (Bukry, 1969) Varol & Girgis, 1994
Hemipodorhabdus gorkae (Reinhardt, 1969) Grün *in* Grün & Allemann, 1975
Laguncula dorotheae Black, 1971
Lithraphidites carniolensis Deflandre, 1963
Lordia xenota (Stover, 1966) Varol & Girgis, 1994
Manivitella pecten Black, 1973
Manivitella pemmatoidea (Deflandre *in* Manivit, 1965) Thierstein, 1971
Micrantholithus hoschulzii (Reinhardt, 1966) Thierstein, 1971
Microstaurus chiastius (Worsley, 1971) Grün *in* Grün & Allemann, 1975
Nannoconus aquitanicus Deres & Achéritéguy, 1980
Nannoconus elongatus Brönnimann, 1955
Nannoconus grandis Deres & Achéritéguy, 1980
Nannoconus multicadus Deflandre & Deflandre, 1959
Nannoconus truitti Brönnimann, 1955
Octocyclus magnus Black, 1972
Orastrum perspicuum Varol *in* Al-Rifaiy *et al.*, 1990
Owenia hilli Crux, 1991
Parhabdolithus embergeri (Noël, 1965) Stradner, 1963
Percivalia fenestrata (Worsley, 1971) Wise, 1983
Pervilithus varius Crux, 1981
Prediscosphaera columnata (Stover, 1966) Perch-Nielsen, 1984
Prediscosphaera spinosa (Bramlette & Martini, 1964) Gartner, 1968
Prediscosphaera cf. *stoveri* Barrier, 1977
Radiolithus hollandicus Varol, 1992
Repagulum parvidentatum (Deflandre *in* Deflandre & Fert, 1954) Forchheimer, 1972

Rhagodiscus achlyostaurion (Hill, 1976) Doeven, 1983
Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971
Rhagodiscus asper (Stradner, 1963) Reinhardt, 1967
Rhagodiscus infinitus (Worsley, 1971) Applegate *et. al. in* Covington & Wise, 1987
Rhagodiscus splendens (Deflandre, 1953) Verbeek, 1977
Rhombolithion rhombicum (Stradner & Adamiker, 1966) Black, 1973
Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Rothia striata (Black, 1971) Varol & Girgis, 1994
Scampanella spp. Forchheimer & Stradner, 1973
Scapholithus fossilis Deflandre *in* Deflandre & Fert, 1954
Seribiscutum primitivum (Thierstein, 1974) Filewicz *et al. in* Wise & Wind, 1977
Sollasites horticus (Stradner *et al. in* Stradner & Adamiker, 1966)
Sollasites lowei (Bukry, 1969) Roth, 1970
Staurolithites angustus (Stover, 1966) Crux, 1991
Staurolithites canthus n. sp.
Staurolithites gausorhethium (Hill, 1966) Varol & Girgis, 1994
Staurolithites rotatus n. sp.
Stradnerlithus fractus (Black, 1973) Perch-Nielsen, 1984
Tegulalithus tessellatus (Stradner *in* Stradner *et al.*, 1968) Crux, 1986
Tetrapodorhabdus decorus (Deflandre *in* Deflandre & Fert, 1954) Wind & Wise *in* Wise & Wind, 1977
Tranolithus gabalus Stover, 1966
Tranolithus phacelosus Stover, 1966
Watznaueria barnesae (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968
Zeugrhabdotus sisyphus (Gartner, 1968) Crux, 1989
Zeugrhabdotus noeliae Rood *et al.*, 1971

APPENDIX 2: Stratigraphic details of samples collected at Munday's Hill

Stage	MF Subzone (Owen, 1972)	No. of samples viewed	NF Zone
Upper Albian	**auritus*	4	NAL 10
		4	NAL 9
		4	NAL 8
	varicosum	1	NAL 7
	orbignyi	1	NAL 7
	cristatum	1	NAL 7
stratigraphic break			
Middle Albian	*niobe*	1	NAL 4
	intermedius	7	NAL 4
	spathi	1	NAL 4

The nannofossil asssemblages from this locality are discussed by Crux, 1991.

Crux notes both *Ceratolithina hamata* and *Axopodorhabdus albianus* together with the absence of *Braloweria boletiformis* from the *niobe* MF Subzone (samples 21 and 22). This is in conflict with my results which indicate the FAD of *C. hamata* and consistent *A. albianus* within the *cristatum* MF Subzone at Munday's Hill. *Braloweria boletiformis* is present within the *niobe* MF Subzone at this locality.

* *auritus* MF Subzonal assignment (H. G. Owen, pers. comm., 1994)

Manuscript received May 1993
Manuscript accepted May 1996