A Foraminiferal Biostratigraphy of the Campanian and Maastrichtian Chalks of the United Kingdom.

Volume 2.

by

Anthony Swiecicki, B.Sc.


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CONTENTS

Volume 2.

Chapter 6: Zonal Scheme ... ... ... ... ... ... 1

6.1. Introduction ... ... ... ... 1

6.2. Planktonic Zonal Scheme ... ... ... ... 4

6.3. Benthonic Zonal Scheme ... ... ... ... 7

6.4. Comparison of Foraminiferal Zonal Schemes ... ... ... ... 16

Chapter 7: Stratigraphic Conclusions ... ... ... ... ... 21

7.1. Introduction ... ... ... ... ... 21

7.2. Southern England ... ... ... ... 21

1) Scratchell's Bay ... ... ... ... ... 21

2) Alum Bay ... ... ... ... ... 24

3) Studland Bay ... ... ... ... ... 26

7.3. Norfolk ... ... ... ... ... 26

1) Wells-next-the-Sea ... ... ... ... 26

2) Stiffkey Hall Farm ... ... ... ... 26

3) Alderford Common Pit ... ... ... ... 29

4) Bawburgh Pit ... ... ... ... ... 29

5) Cleyn ... ... ... ... ... ... 29

6) Weybourne Hope - Old Hythe Gap ... ... 29

7) Keswick Quarry ... ... ... ... ... 32

8) Eaton Golf Course ... ... ... ... 32

9) Catton Grove ... ... ... ... ... 34

10) Sheringham ... ... ... ... ... 34

11) Caistor St. Edmunds ... ... ... ... 36

12) Arminghall Pit ... ... ... ... ... 36

13) Frettenham Quarry ... ... ... ... 36

14) Whitlingham Pit ... ... ... ... 39
<table>
<thead>
<tr>
<th>Number</th>
<th>Location/Feature</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>15)</td>
<td>Postwick Riverbank</td>
<td>39</td>
</tr>
<tr>
<td>16)</td>
<td>Overstrand Hotel Lower Mass</td>
<td>39</td>
</tr>
<tr>
<td>17)</td>
<td>Overstrand Minor Mass</td>
<td>44</td>
</tr>
<tr>
<td>18)</td>
<td>Overstrand Hotel Upper Mass</td>
<td>45</td>
</tr>
<tr>
<td>19)</td>
<td>Sidestrand Western Mass</td>
<td>45</td>
</tr>
<tr>
<td>20)</td>
<td>Sidestrand Sponge Beds</td>
<td>46</td>
</tr>
<tr>
<td>21)</td>
<td>Trimingham (Little Marl Point)</td>
<td>48</td>
</tr>
<tr>
<td>22)</td>
<td>Marl Point (Trimingham)</td>
<td>48</td>
</tr>
<tr>
<td>7.4.</td>
<td>North Sea Basin</td>
<td>48</td>
</tr>
<tr>
<td>1)</td>
<td>Well 44/2-1</td>
<td>48</td>
</tr>
<tr>
<td>2)</td>
<td>Well 29/25-1</td>
<td>51</td>
</tr>
<tr>
<td>7.5.</td>
<td>Conclusions</td>
<td>53</td>
</tr>
</tbody>
</table>

Chapter 8: Palaeoecology

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Introduction</td>
</tr>
<tr>
<td>8.2. Salinity</td>
</tr>
<tr>
<td>8.3. Temperature</td>
</tr>
<tr>
<td>8.4. Surface Currents</td>
</tr>
<tr>
<td>8.5. Depth</td>
</tr>
<tr>
<td>8.6. Bottom Conditions</td>
</tr>
<tr>
<td>8.7. Sedimentation Rates</td>
</tr>
<tr>
<td>8.8. Faunal Diversity</td>
</tr>
</tbody>
</table>

Chapter 9: Conclusions

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

References

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

Plates

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Figure</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>6:1</td>
</tr>
<tr>
<td>6:2</td>
</tr>
<tr>
<td>7:1</td>
</tr>
<tr>
<td>7:2</td>
</tr>
<tr>
<td>7:3</td>
</tr>
<tr>
<td>7:4</td>
</tr>
<tr>
<td>7:5</td>
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<tr>
<td>7:6</td>
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<td>7:7</td>
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<td>7:8</td>
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<td>7:9</td>
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<td>7:10</td>
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<td>7:12</td>
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<td>7:13</td>
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<td>7:14</td>
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<td>7:15</td>
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<td>7:16</td>
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</tr>
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<td>7:19</td>
</tr>
<tr>
<td>7:20</td>
</tr>
<tr>
<td>7:21</td>
</tr>
<tr>
<td>7:22</td>
</tr>
<tr>
<td>7:23</td>
</tr>
</tbody>
</table>
Figure

7:24 Biozonation: Shell/Esso 44/2-1 ...
7:25 Biozonation: Shell/Esso 29/25-1 ...
7:26 Correlation of studied sections: Norfolk ...
7:27 Stratigraphic correlation of studied sections ...

8:1 Palaeoecological summary: 1) Isotopic Palaeotemperatures.
   2) Planktonic/Benthonic ratios.
   3) Eustatic sea level changes.
8:2 Latitudinal distribution of Campanian/Maastrichtian Planktonic Foraminifera ...
8:3 Palaeogeography of the North Atlantic region (Campanian)...

Page
49
52
55
56
59
62
65
1. Foraminiferal distribution: Scratchell's Bay, Isle of Wight.
2. Foraminiferal distribution: Alum Bay, Isle of Wight.
   Studland Bay, Dorset.
   Stiffkey Hall Farm, Norfolk.
   Alderford Common, Norfolk.
   Bawburgh Pit, Norfolk.
4. Foraminiferal distribution: Cley, Norfolk.
   Weybourne, Norfolk.
   Keswick Quarry, Norfolk.
   Catton Grove, Norfolk.
   Arninghall Pit, Norfolk.
   Caistor St. Edmunds, Norfolk.
   Sheringham, Norfolk.
   Whitlingham Pit, Norfolk.
   Postwick Riverbank, Norfolk.
   Overstrand Minor Mass, Norfolk.
   Overstrand Upper Mass, Norfolk.
   Sidestrand, Norfolk.
   Trimingham, Norfolk.
6.1. Introduction

To date, there has been no published foraminiferal zonation of the Campanian and Maastrichtian chalk of the United Kingdom. Williams-Mitchell (1948), Barnard and Banner (1953) and McGugan (1957) have published microfaunal range charts for the strata under consideration, though they all referred ranges to previously defined macrofaunal zones. Barr (1962, 1966a) documented both planktonic and Bolivinoides index forms from a number of spot samples in Norfolk and the Isle of Wight. Once again however, the foraminiferal ranges were related directly to Rowe's (1908) macro-zonal divisions, the placing of which is known to be erroneous (Brydone 1914, 1918; Rawson et al. 1978).

In order to avoid problems associated with the recognition, and subsequent revision of macrofossil zones, the present author has related the proposed biozonal scheme directly to reference sections as recommended by Holland et al. (1978), whilst at the same time noting any suggested macrofaunal schemes for the same successions. It is felt that many of the previous microfaunal studies have failed to take adequate advantage of one of the most useful features of foraminifera: their great abundance.

Foraminifera can be obtained from virtually every level within the Campanian and Maastrichtian chalk of the United Kingdom, generally in considerable numbers, thus offering potentially great stratigraphic resolution. Whilst in practice the effects of bioturbation place limits on the stratigraphic resolution, the present author has attempted to fully utilize this potential by analysis of over 700 samples collected.
on a bed-by-bed basis, with reference to 'local rock units', which "provide a stable objective reference" (Laffitte et al 1972) for the proposed zonal scheme. In practical terms, a sample interval of approximately 1 metre has been used throughout to reduce the influence of bioturbation.

To be of stratigraphic value, it is generally considered that fossil organisms should possess the following attributes:

1). Preservable and readily identifiable hard parts.
2). Widespread distribution.
3). Rapid migration.
4). Abundance.

These attributes are readily met by the planktonic foraminifera and their value for long distance correlation in the Upper Cretaceous has long been recognised and discussed. In the Upper Cretaceous of England however, the low diversity and long-ranging nature of the planktonic fauna, has allowed only a broad correlation to be made with the well documented Upper Cretaceous planktonic foraminiferal zones recognised in Tethyan regions. A planktonic foraminiferal biozonation is here presented which allows broad interregional correlations.

It has become readily apparent over the last twenty years that within the Upper Cretaceous several species of benthonic foraminifera also possess many of the attributes of good biostratigraphic index forms. Most noteworthy amongst these, are several members of the genus *Bolivinoides*, whose biostratigraphic utility has been shown to be comparable with that of the planktonic foraminifera on a world-wide scale. Members of the genus *Bolivinoides* have been found to be extremely abundant throughout the Campanian and Maastrichtian of the
United Kingdom as noted by Barr (1966a), who first recognised their great biostratigraphic value in England. After extensive study of this genus on a bed-by-bed basis, the present author has been able to accurately delimit their stratigraphic ranges which in turn has enabled the establishment of a multiple phylozonation scheme comprising 7 biozones of proven interregional value.

Within this biozonal scheme, changes in the accompanying benthonic foraminiferal assemblages permit the recognition of a more detailed biostratigraphy and a sequence of 15 assemblage sub-biozones has been established. Whilst an assemblage biozone primarily has environmental significance (van Hinte, 1969b), a substantial biostratigraphic component is also present in the proposed scheme, in that it contains elements of several phylogenetic lineages which are highly reliable biostratigraphic indicators, as they "directly reflect the irreversible evolution of life on earth" (van Hinte, 1969b). It should, in addition, be noted that within the widespread "normal" chalk facies of the Upper Cretaceous, variations of several palaeoenvironmental factors, such as substrate and depth, may be assumed to have been at a minimum. Thus, while the proposed assemblage sub-biozones are primarily of value in local correlations, it might well be that faunal comparisons with other areas may indicate that they may also have a regional value. The proposed scheme has been integrated on a bed-by-bed basis with the Bolivinoides and planktonic foraminiferal biozones to enable the foregoing hypothesis to be rigorously tested.

The resulting biozonal scheme is thus of a tripartite nature, with the recognition of 4 planktonic foraminiferal biozones, 7 Bolivinoides biozones and 15 assemblage sub-biozones. The Campanian stage is considered to represent a total time span of 11 million years (Obradovich and Cobban, 1975). and within this age, 10 assemblage biozones have been recognised, resulting in an average
biozone duration of 1.2 Ma. The Maastrichtian is considered to represent a time span of 5 million years (van Hinte, 1976) within which 5 assemblage sub-biozones with a resulting average duration of 1 Ma have been recognised.

Where applicable, notes on the recognition of biozones in offshore material have been provided in the zonal descriptions.

6.2. Planktonic Zonal Scheme

As previously noted, palaeoecological controls on the regional distribution of planktonic foraminifera resulted in restricted local ranges, low faunal diversity and low abundance of planktonic foraminifera throughout much of Campanian and Maastrichtian times in England. This has permitted the recognition of only 4 biozones which are, however, of value for inter-regional correlation. These are shown in Text fig. 6:1.

1) **Archaeoglobigerina cretacea/Rugoglobigerina pilula** concurrent range Biozone - Lower and Middle Campanian.

Type section: Scratchell's Bay, Isle of Wight (P 242 (basal Campanian) - M 16)

Thickness: 100m. (minimum)

This zone is characterized by the presence of the two zonal indices together with moderately abundant *Heterohelix striata*, *Globigerinelloides aspera*, *Globotruncanana bulloides bulloides*, *G. linneiana* and *G. fornicata*, together with rare *Globigerinelloides multispina*. The latter species has not been recorded from strata of Santonian age. It may be recognised in offshore material principally by the marked downhole increase in abundance of *G. bulloides bulloides* and *G. linneiana*, together with the first downhole occurrence of *R. (?) pilula*. 
Fig. 8:1 Planktonic Foraminiferal Biozonation.
2) *Globotruncana rugosa* Total range Biozone - Upper Campanian.
Type section: Scratchell's Bay/Alum Bay, Isle of Wight
(M 16 - top section (pars))

Thickness: 134m. (min.)

The boundary between this and the preceding zone is marked in the type section by a drastic reduction in the abundance of planktonic foraminifera; this may however, be of local significance only. This biozone is characterized by the incoming of the zonal index and the absence of *R. pilula*, *G. bulloides bulloides* and *G. linneiana* are relatively rare in this zone. In the higher levels *G. area*, *G. bulloides austenensis*, *G. plummerae*, *G. hilli*, *G. ventricosa*, *Globigerinelloides cf. bollii* and *Heterohelix complanata* all make their first appearance. This zone is of Upper Campanian age and is nowhere totally exposed in the United Kingdom, thus the thickness given is a minimum only.


Type section: This zone is only patchily exposed onshore along the North Norfolk coast and thus no type section has been designated.

Thickness: Unknown.

The base of this zone is marked by the first appearance of *G. havanensis*. *Rugoglobigerina rugosa* occurs abundantly throughout this biozone, whilst *R. milamensis*, *G. area* and *Hedbergella (?) monmouthensis* occur sporadically.
4) *Abathomphalus mavaroensis* Total Range Biozone - upper Upper Maastrichtian.

Type section: not designated

Thickness: Unknown.

This zone is characterized by the distinct latest Maastrichtian planktonic assemblage of *A. mavaroensis*, *G. contusa patelliformis* and *Pseudotextularia elegans*. It has only been encountered in material from the North Sea, where the nature of the samples precludes the recognition of the base of this zone.

6.3. **Benthonic Zonal Scheme**

The proposed biozonation scheme is diagrammatically represented in Text fig. 6:2. The following notes are a brief description only therefore.

1) Biozone Bl: *Bolivinoides strigillatus* Total Range Biozone - Upper Santonian to Lower Campanian.

Type section: Scratchell's Bay, Isle of Wight (F 242 - M 28)

Thickness: 40m. (min.)

The base of this biozone has not been found in the present study. This zone is approximately co-extensive with the macrofossil zones of *Marsupites testudinarius* and *Offaster pilula*.

a) Sub-Biozone i). Assemblage biozone - Upper Santonian.

Type section: not designated.

Thickness: unknown.

Only the uppermost beds of this sub-biozone have been examined, and thus no attempt has been made to designate a type section. It is apparently co-extensive, in part at least, with the macrofossil zone of
Fig. 6:2 Benthonic Foraminiferal Biozonation.
M. testudinarius and may be most readily recognised by the relative abundance of Stensioina exsulpta exsulpta and S. granulata perfecta. The former is apparently restricted to this sub-biozone.


Type section: Scratchell's Bay, Isle of Wight (M 67-M 51)

Thickness: 17m.

This sub-biozone may be most readily distinguished by the presence of Neoflabellina rugosa and the absence of S. exsulpta exsulpta. The dominant faunal elements of this zone include Reussella kelleri, Gavelinella cristata, Globorotalites micheliniana, Loxostomum eveli, and Eouvigerina aculeata; Gavelinella stelligera and G. lorneiana may also be present in some abundance, whilst S. granulata incondita, S. exsulpta gracilis, Bolivinoides strigillatus and Eouvigerina sp. A occur in low numbers in the type section, though more abundantly in Norfolk and the North Sea. All these species range into the overlying sub-biozone.

a) Sub-Biozone iii). Assemblage biozone - upper Lower Campanian.

Type section: Scratchell's Bay, Isle of Wight (M 50-M 28)

Thickness: 23m.

This sub-biozone is marked by an increase in faunal abundance and diversity. Though the dominant faunal composition remains unchanged the following rare species all have their first appearances near the base of this sub-biozone: Bolivinoides culverensis, Pyramidina rudita, Pseudouvirgerina plummerae, Osangularia cordieriana, Stensioina pommerana and the planktonic species Globigerinelloides multispina, whilst Pyramidina trigona and Gavelinella stelligera become noticeably more abundant.
2) Biozone B2: *Bolivinoides culverensis* Phylozone - Middle Campanian.

Type section: Scratchell's Bay, Isle of Wight (F 192-M 16)

Thickness: 59m.

Though occurring sporadically in the preceding biozone, the index species only becomes a dominant faunal element at the base of biozone B2. This biozone is approximately co-extensive with the macrofossil zone of *Gonioteuthis quadrata*.

a) Sub-Biozone i). Assemblage biozone - lower Middle Campanian.

Type section: Scratchell's Bay, Isle of Wight (F 192-F 176)

Thickness: 13m.

The base of this sub-biozone is marked by the virtual extinction of *B. strigillatus*, *R. kelleri*, *E. sp. A*, *O. sanugularia whitei* and *C. cristata*, and by the appearance in abundance of *B. culverensis*, *Gavelinella usskensis*, *O. cordieriana* and *S. pommerana*.

b) Sub-Biozone ii). Assemblage biozone - mid-Middle Campanian.

Type section: Scratchell's Bay, Isle of Wight (M 23-F 160)

Thickness: 17m.

The base of this sub-biozone is marked by the first appearance of *B. pustulatus*. *C. lorneiana* is locally absent throughout almost the whole of this sub-biozone in the type section which also shows a marked decline in the abundance of planktonic foraminifera. *G. trochus* and *G. involuta* make their first appearance at the base of this biozone whilst *E. paleata* appears to be virtually restricted to it.

c) Sub-Biozone iii). Assemblage biozone - upper Middle Campanian.

Type section: Scratchell's Bay, Isle of Wight (F 158-M 16)

Thickness: 29m.

This sub-biozone is characterized by the appearance of *Pullenia*
quaternaria as a rare but persistent component of the fauna. The decline in abundance of planktonic foraminifera first noticed in the type section within the preceding sub-biozone is continued, and Planorbulina cf. retae makes its first appearance. Towards the top transitional forms between B. culverensis and B. decoratus begin to appear.

The top of biozone B2 is marked by the extinction, or at least drastic reduction, of many of the most characteristic faunal elements of the Lower and Middle Campanian, including B. culverensis, G. stelligera, S. exsulpta gracilis and S. granulata inconspita.

3) Biozone B3: Partial Phylozone Bolivinoides decoratus — Upper Campanian (part)

Type section: Scratchell's Bay, Isle of Wight (M 15-F 1 part)
Thickness: 131.5m. (min.)

The upper levels of this biozone are not preserved on the Isle of Wight and may only be seen in scattered outcrops in Norfolk. This zone is defined as comprising that part of the consecutive range of B. decoratus subsequent to the extinction of B. culverensis and prior to the first appearance of B. draco miliaris.

a) Sub-Biozone 1. Assemblage biozone — lower Upper Campanian.

Type section: Scratchell's Bay/Alum Bay, Isle of Wight
(M 15-F 29)

Thickness: 90m. approx.

The base of this assemblage sub-biozone is marked by the first appearance of G. voltziana, G. monterelensis and B. decoratus, whilst G. elementiana s.l first appears close to this level. G. trochus becomes markedly more abundant in this sub-biozone. B. laevigatus praelaevigatus is a noteworthy component of the fauna at this level.
b) Sub-Biozone ii). Assemblage biozone - mid-Upper Campanian.
Type section: Alum Bay, Isle of Wight (F 29-F 15)
Thickness: 21m.

This assemblage biozone is characterized by the absence of *G. usakensis* and the marked increase in abundance of *Praebulimina carseyae*, *P. obtusa*, *G. denticulata*, *G. voltziana* and *G. clementiana*, whilst *C. pliata* appears for the first time as a rare but consistent component of the fauna. *G. thalmanni* has not been found above this level. Sub-biozones B3ii to B3iii are approximately co-extensive with the macrofossil subzone *Belemnitella minor*.

c) Sub-Biozone iii). Assemblage biozone - mid-Upper Campanian.
Type section: Alum Bay, Isle of Wight (F 14-F 1 part)
Thickness: 19m. (min.)

This sub-biozone may be most readily distinguished from those preceding, by the absence of *G. lorneiana* and *G. thalmanni*.

d) Sub-Biozone iv). Assemblage biozone - upper Upper Campanian
Type section: Catton Grove, Norwich (T.C. 229109)
Thickness: Unknown.

The base of this sub-biozone is marked by the major bio-horizon of the Catton sponge bed, which probably represents a major break in sedimentation. The characteristic faunal assemblage of this zone has a distinctly late Campanian aspect. *G. micheliniana* and *E. concinna* are absent, whilst *Pseudouvigerina cristata*, *Reussella szajnochae szajnochae*, *Neoflabellina praereticulata*, *Eponides beisseli*, *Globorotalites hiltermanni*, *Gavelinella complanata*, *G. multipunctata* and *Bolivina incrassata* all appear at the base of the biozone.
4) Biozone B4: Partial Phylozone Bolivinoides draco miliaris -
upper Upper Campanian.
Type section: Whitlingham Pit, Norfolk (T.G. 268 078)
Thickness: Unknown.
The base and top of this biozone are not exposed adequately anywhere in England to the author's knowledge. The designated type section lies wholly within biozone B4. This zone is defined as comprising that part of the range of B. draco miliaris prior to the first appearance of B. peterssoni.

a) Sub-Biozone 1). Assemblage biozone - upper Upper Campanian.
Type section: Whitlingham Pit, Norfolk (T.G. 268 078)
Thickness: Unknown.
This assemblage sub-biozone is co-extensive with biozone B4. The characteristic fauna of this zone includes B. sidestrandensis, N. permutata and S. pseudoscripta, in addition to B. draco miliaris. R. szajnochae szajnochae occurs in flood proportions in the uppermost levels of this zone, whilst C. clementiana s.l. becomes extinct within it. This sub-biozone is approximately co-extensive with the macrofossil subzone of Belemnitella lanceolata.

5) Biozone B5: Partial Phylozone Bolivinoides peterssoni -
lower Lower Maastrichtian.
Type section: Overstrand Upper Mass, Norfolk (T.G. 255 406)
Thickness: Unknown.
This biozone is defined as comprising that part of the range of B. peterssoni prior to the first appearance of B. paleocenicus. The designated type section lies wholly within this biozone. This biozone is approximately co-extensive with the macrofossil zone of Belemnitella lanceolata.
a) Sub-Biozone i). Assemblage biozone - lower Lower Maastrichtian.
Type section: Overstrand Upper Mass, Norfolk (T.G. 255 406)
Thickess: Unknown.
Associated with the first appearance of B. peterssoni is the local (?)
extinction of R. szajnochae szajnochae, N. ruposa, G. hiltermanni
and G. monterelensis. O. cordieriana and N. praereticulata become
markedly less abundant and finally extinct early in the biozone. The
following species make their first appearance near the base of this
zone: B. decorrenas, B. australis, E. sp.B, P. minuta, N. reticulata,
G. limbosa, G. bembix and O. navarroana.

b) Sub-Biozone ii). Assemblage biozone - Lower Maastrichtian.
Type section: Sidestrand Erratic, Norfolk (T.G. 256 404)
(Flint Bands X - Q)
Thickess: 8.5m. (min.)
The type section lies completely within biozone B5ii. The boundary
between biozones B5ii and B6i is located at the level of the sponge beds
on the Sidestrand East Platform. Sub-biozone B5ii may be distinguished
from B5i principally by the absence of B. decoratus. Within this
sub-biozone P. carseyae and P. obtusa become extinct.

6) Biozone B6 : Partial Phylozone Bolivinoides paleocenicus -
Lower Maastrichtian.
Type section: Trimingham (Little Marl Point), Norfolk
(T.G. 298 380) (Flint Bands K - B)
Thickess: 6m. (estimate).
The base of this biozone is exposed at Sidestrand East Platform at the
level of the lowest sponge bed. The designated type section lies
wholly within the biozone. Biozone B6 is defined as comprising that
part of the total range of B. paleocenicus prior to the first
appearance of *B. draco draco*.

a) Sub-Biozone 1). Assemblage biozone - Lower Maastrichtian.

Type section: Trimingham (Little Marl Point), Norfolk.

(T.G. 298 380) (Flint Band K - Marl G)

In addition to *B. paleoecenicus*, *C. bosqueti* is first recorded from this sub-biozone, whilst both *V. lenticula* and *E. beisseli* are absent. The middle layers of this zone are marked by a flood of *A. bettenstaedti*.

b) Sub-Biozone ii). Assemblage biozone - Lower Maastrichtian.

Type section: Trimingham (Little Marl Point), Norfolk.

(Flint Bands F - B).

Thickness: 3m. (min.)

The characteristic fauna of this sub-biozone includes *P. rurosa* and *T. selmensis*, the former occurring in flood proportions. *G. voltziana* becomes noticeably less abundant at this level.

7) Biozone B7 : Total Range Zone Bolivincides draco draco -

upper Lower (?) to Upper Maastrichtian.

Type section: Shell 44/2-1 (3060' - 3210 ft.)

Thickness: 180 ft. (59m.) (min.)

Biozone B7 is not exposed onshore in England, but has been found extensively in the North Sea Basin. There is some debate as to the correlation of the base of this zone with the parallel macrofossil zonation schemes. No sub-biozonal divisions have been formally recognised within this unit. The base of this biozone is marked downhole by the first appearance of *B. draco miliaris*. 
6.4. Comparison of Foraminiferal Zonal Schemes.

There have been numerous descriptions of foraminiferal faunas from the Upper Cretaceous of Europe published over the last 150 years. A detailed analysis and comparison of these is clearly beyond the scope of the present work and the reader is referred to the bibliography for a comprehensive listing.

As noted previously, comparison of the proposed planktonic zonal scheme with other published studies is hampered by problems of provincialism, which permit only a broad correlation with the internationally recognised foraminiferal zones described from the Tethyan region (Papp 1956; Hiltermann 1963; Barr 1962, 1972; Bandy 1967; Pessagno 1967, 1969; van Hinte 1963, 1969, 1972, 1976; Postuma 1971; Rodriguez 1977); for as noted by Bandy (1967) "any standard planktonic foraminiferal zonation in deep-water sections of tropical areas will deteriorate towards and across... the boundary of the tropical region".

The data presented by van Hinte (1976), is amongst the most recent summaries. In that scheme no clear delimitation of the Campanian/Santonian boundary was presented. *Globotruncana concavata* and *G. elevata*, often considered as useful guides for the Santonian and Campanian stages respectively, have not been found in the present study, though it should be noted that Barr (1962) recorded both from Culver Cliff on the Isle of Wight, presumably from 'flint meal' faunas. The dominant faunal elements present in the *Archaeoglobigerina cretacea/Rugoglobigerina (?) pilula* biozone, are all to be found in strata of Santonian age. However, the distinctive *Globigerinelloides multispina* has not been recorded in pre-Campanian strata (Pessagno 1967, 1969). Its presence in the benthonic biozone Biii corroborates the placing of
this unit within the Lower Campanian.

The *G. ruposa* biozone appears to be coincident with the uppermost *elevata, stuartiformis, subspinosa* and *calcarata* zones, sensu van Hinte (1976). The presence of *G. ruposa* in strata of Upper Campanian age has been recognised by Barr (1962), Salaj-Samuel (1966) and Vasilenko (1961). The Upper Campanian age of this biozone is confirmed by the presence of *G. plummerae, G. hilli* and *G. cf. bollii*, which have been recorded by Pessagno (1967,1969) from the uppermost Campanian of the U.S.A., and by *H. complanata* recorded by Stenestad (1968) from the Upper Campanian of Denmark. None of the index *Globotruncana* species, recognised as stratigraphically important in the Upper Campanian of the Tethyan region, have been found in the present study, with the exception of rare specimens of *G. arca* and *G. ventricosa*

The *R. ruposa - G. havanensis* biozone is virtually restricted to the Maastrichtian Stage. The two index species, though found rarely in strata of uppermost Campanian age (Pessagno 1967, 1969), only become dominant faunal elements in the Maastrichtian of the Tethyan region (van Hinte 1976). Two species restricted to this biozone, *Rupoglobigerina milamensis* and *Hedbergella (?) monmouthensis*, have only been recorded from strata of Maastrichtian age (Pessagno 1967,1969; Smith & Pessagno 1973). This biozone is co-extensive with the *scutilla, pensseri, stuarti* and *contusa* zones, sensu van Hinte (1976).

The *A. mayaroensis* zone is the only planktonic foraminiferal biozone found in the present study which appears to allow correlation between the Tethyan and Boreal faunal provinces, being widely recorded from both. The present record of this biozone from the North Sea basin represents one of the most northerly recorded occurrences reported to date. The presence in these northern latitudes of many planktonic foraminifera which are commonly recorded from the Tethyan region, eg. *G. contusa patelliformis* and *P. elegans*, may in part be related to
a warm climatic pulse in the latest Maastrichtian (Chapter 8).

The most recent stratigraphic studies of Campanian and Maastrichtian benthonic foraminifera from Europe have been those of Hofker (1966) and Koch (1977). The former entailed a highly detailed study of the foraminifera from the Limburg area of southern Holland. Problems associated both with facies and taxonomy, between this and the present study, have reduced the extent to which a detailed stratigraphic comparison can be made, however.

The work of Koch (1977) is a comprehensive study of 11 selected species of foraminifera from the Pompeckj Block of N.W. Germany, and represents a synthesis of many years of detailed stratigraphic study by German palaeontologists, notably Ernst (1968), Schmid (1959, 1967), Ernst and Schulz (1974), Wichert (1953a), Hiltermann (1952, 1956), Hiltermann and Koch (1950, 1955, 1962), Koch (1973, 1975). Koch has recognised the following foraminiferal biozones in the Campanian and Maastrichtian:

- *Pseudotextularia elegans*
- *Gavelinella danica*
- *Bolivinoides draco draco*
- *Neoflabellina reticulata*
- *Bolivinoides draco miliaris*
- *Neoflabellina numismalis*
- *Bolivinoides decoratus decoratus*
- *Bolivinoides strigillatus* (pars)

The basal zone is clearly coincident with biozone B1 recognised in the present study. In addition to the zonal index, Koch (1977) also records *N. suturalis*, *S. granulata incondita*, *S. exsulpta gracilis* and *N. rugosa*, all of which have been found in biozone B1. The base of
the supradjacent B. decoratus decoratus biozone ( sensu Koch 1977 ),
is marked by the extinction of B. strigillatus and the first
appearance of B. decoratus decoratus, S. pommerana and B. granulatus
( = B. pustulatus of the present study ). As noted earlier however
( Chapter 5 ), most German micropalaeontologists ( Koch pers. comm. )
do not formally recognise the intermediate morphospecies B. culverensis
within the B. strigillatus - B. decoratus phylogenetic lineage. Thus,
the base of the B. decoratus decoratus biozone sensu Koch ( 1977 )
corresponds not to biozone B3 ( index species B. decoratus ) of the
present study, but to biozone B2 ( index species B. culverensis ).

The Neoflabellina numismalis biozone sensu Koch ( 1977 ) is
marked by the first appearance of B. laevigatus and N. numismalis and
the virtual extinction of S. exsulcata gracilis. N. numismalis, the
index form for this zone, has not been found in the present study. The
base of this biozone probably corresponds with the base of biozone B3.

The B. draco miliaris biozone sensu Koch ( 1977 ) is clearly
coincident with biozone B4 of the present study, B. draco miliaris
being the index species for both. G. clementiana becomes extinct in
the middle of this biozone, both in N.W. Germany and Britain, whilst
B. sidestrandensis ( = B. decoratus regularis sensu Koch 1977 ),
B. incrassata and N. praereticulata appear for the first time. N. rugosa
becomes extinct at the top of this biozone in both areas.

The base of the Maastrichtian stage is taken at the base of the
N. reticulata biozone ( Koch 1977 ). This level is also marked by the
first appearance of O. navarroana, B. peterssoni and the planktonic
G. havenensis, and is clearly correlatable with the base of biozone B5
recognised in the present study. Within the N. reticulata biozone of
Koch ( 1977 ), B. paleocenicus was recorded, indicating a correlation
with biozones B5 and B6 recognised in the present study. The overlying
B. draco draco biozone of Koch ( 1977 ) is clearly coincident with
biozone B7, which also includes the overlying G. danica and P. elegans biozones of Koch (1977), the latter apparently being co-extensive with the A. mayaroensis biozone recognised in the present study.

The marked similarity of the foraminiferal successions between Britain in particular Norfolk, and N.W. Germany, clearly suggests that open marine conditions existed between the two, with both belonging to the same foraminiferal biogeoprovince.

Comparison in detail with other foraminiferal faunas described from other areas, is beset by problems. However, it may be stated that broadly similar faunal successions of both benthonic and planktonic foraminifera have been described from Scandinavia (Brotzen 1945), Holland (Villain 1977), France (van Hinte 1965, 1966a, b; Sérone-Vivien 1972), Poland (Bieda and Witwicka 1958), Moravia (Hanzlikova 1972) and the Mangyshlak Peninsula on the eastern shore of the Caspian Sea (Vasilenko 1961). This strongly suggests the existence of a broad region characterized by stable, relatively constant palaeoenvironmental conditions, extending from the Caspian Sea area across N.W. Europe to Britain and Ireland (Chapter 8). The presence of such a stable region might indicate that over this broad area benthonic foraminifera may possess a stratigraphic potential at least equal to that of the planktonics.
CHAPTER 7

STRATIGRAPHIC CONCLUSIONS

7.1. Introduction

In the present chapter the stratigraphically important foraminiferal species obtained from each section are discussed. Lithological logs of each section are provided to enable accurate delimitation of the proposed zonal boundaries and their ready recognition in the field. Full range charts of the total foraminiferal fauna present in each section are given in the Enclosures. Detailed correlation charts of the sections studied are given in Text figs. 7:26, 7:27.

7.2. Southern England

1). Scratchell's Bay (Text figs. 7:1)

The present study represents the first bed-by-bed logging and foraminiferal analysis of this section ever undertaken. The lowest levels studied are known to range down into the uppermost Santonian (Brydone 1914, C. Wood pers. comm.). This chalk is indurated and only a relatively impoverished foraminiferal fauna was obtained. The fauna is dominated by Reussella kelleri, Gavelinella cristata, Globorotalites micheliniana, Loxostomum elevi and Bouvierina aculeata. In addition, Valvulineria lenticula, Arenobulimina obliqua, Marssonella trochus, Gavelinella lorneiana, C. stellifera occur in some abundance. Stensioina granulata incondita, S. exsculpta gracilis, Bouvierina sp.A and Bolivinoides strigillatus also occur sporadically at this level. These species together comprise the typical faunal assemblage found in sub-biozone Blii. Some 19m. above the base of the section Bolivinoides culverensis, Pyramidina rudita, Pseudouvierina plummerae, Osangularia
Fig. 7: Biozonation – Scratchell's Bay.
(for key to lithological logs see fig. 4:3. Relative abundances on range charts represent abundance levels of 3%, 10%, and 10+%).
cordieriana, Stensioina pommerana and Globigerinelloides multispina all make their first appearance in the section. This level is taken to mark the base of sub-biozone Bliii and appears to coincide with the "Lower Pilula Band" of Brydone (1914).

There is a general increase in faunal diversity and abundance from this level onwards. Some 42m. above the base of the studied section a marked change has been found to occur in the foraminiferal fauna. At this level B. strigillatus, R. kelleri, Eouvigerina sp. A and and G. cristata become extinct, whilst B. culverensis, O. cordieriana and S. pommerana become markedly more abundant. Gavelinella usakensis makes its first appearance at this level, which is taken to mark the base of biozone B2. Lithologically, this biozonation coincides with the Planoconvexa Bed (Hancock 1976) and with the base of the macrofaunal biozone of Conioteuthis quadrata (C. Wood pers. comm.). Some 13m. above the Planoconvexa Bed, Bolivinoides pustulatus, Gavelinella trochus and G. involuta make their first appearance, marking the base of sub-biozone B2i1. Eouvigerina paleata is also found sporadically at this level. 30m. above the Planoconvexa Bed the first record of Pullenia quaternaria marks the base of sub-biozone B2i1i.

Up to biozone B2 the planktonic foraminiferal fauna is dominated by Globotruncanca bulloides, G. fornicata, G. linneiana, Archaeoglobigerina cretacea, Globigerinelloides aspera and Heterohelix striata, together with rare Rugoglobigerina (?) pilula and Globigerinelloides multispina. However, a marked decline in faunal diversity and abundance occurs from the upper levels of sub-biozone B2i1 onwards in Scratchell's Bay. Associated with this decline is the first appearance of the benthonic species Planorbulina cf. oretae, possibly indicative of local shallowing (Chapter 8).

Some 59m. above the Planoconvexa Bed, a major foraminiferal biohorizon is found, characterized by the virtual extinction of many of
the most characteristic foraminifera of the preceding strata, including *B. culverensis*, *G. stelligera*, *S. exsculpta gracilis* and *S. granulata incondita*. Whilst *Gavelinella voltziana*, *Gavelinella monterelensis* and *B. decoratus* all appear for the first time, *Gavelinella clementiana* appears for the first time a short distance above this biohorizon. In addition, *G. trochus* and *Bolivinoides laevigatus praellaevigatus* become markedly more abundant. This biohorizon is taken as the base of biozone B3 and coincides lithologically with the lower of a pair of prominent marl seams. Detailed comparison with the measured section published by Brydone (1914) indicates that this horizon is probably that taken by this later author as the base of the *Belammitella mucronata* zone, though this has been impossible to confirm by more recent studies (Wood pers. comm.) Biozone B3 occupies the remaining 39m. of the Scratchell's Bay section up to and including the Needles Headland. The latter proved impossible to sample and represents a stratigraphic gap of approximately 15.8m. between the Scratchell's Bay section and the supradjacent Alum Bay.

2) *Alum Bay* (Text fig. 7:2)

The lower levels exposed in this rather inaccessible strike section belong to sub-biozone B3i. Some 40m. below the Cretaceous/Tertiary boundary, a major fall covers the foot of the cliff. The chalk exposed directly below the fall is characterized by the absence of *G. usakensis* and the marked increase in abundance of *Praebulimina caseyae*, *P. obtusa*, *G. voltziana*, *Spiropleatammina baudouiniana*, *Heterostomella rugosa* and *G. clementiana*, whilst *Coryphostoma pliata* occurs for the first time above this level. This biohorizon is taken to mark the base of sub-biozone B3ii. Examination of the macrofauna obtained from the fall indicates a close comparison with the "Weybourne Chalk" of Norfolk (Wood pers. comm.). Some 19m. below the top of the chalk, *G. lorneiana* and *G. thalmannii* become extinct at a level which
Fig. 7: 2 Biozonation: Alum Bay.

Fig. 7: 3 Biozonation: Studland Bay.
is taken as the base of sub-biozone B3ii, which occupies the remainder of the section.

3). Studland Bay (Text fig. 7:3)

The fauna from the uppermost levels of chalk exposed at this locality is dominated by *G. micheliniana*, *G. lorneiana*, *G. voltziana*, *G. clementiana* and *Stensioina pommerana*. *B. decoratus*, *B. laevigatus*, *G. monterelensis*, *P. obtusa* and *P. carseyae* also occur in moderate abundance, clearly placing this level within sub-biozone B3ii.

7.3. Norfolk

1). Wells-next-the-Sea (Text fig. 7:4)

The foraminiferal fauna of this section is dominated by *Arenobulimina obliqua*, *M. trochus*, *Cyroidinoides nitida*, *Cibicides beaumontianus*, *Praebulimina reussi*, *G. stelligera*, *G. lorneiana*, *S. granulata incondita*, *S. exsculpta praecilis*, and *G. micheliniana*. *B. strigillatus* has been found sporadically throughout the section. The lowest 4m of this section contains abundant *R. kelleri* and thus correlates closely with sub-biozone Blii. Above this level *R. kelleri* disappears, whilst *S. pommerana* and *O. cordieri ana* become much more abundant and this level is correlatable with sub-biozone B2i. Peake and Hancock (1970) considered that the boundary between *O. pilula* and *C. quadrata* is exposed in this pit, a correlation which is in close agreement with the results of the present study.

2). Stiffkey Hall Farm (Text fig. 7:5)

The dominant faunal elements at this locality are those of the preceding section. In addition, the following stratigraphically important species have been found: *Reussella szajnochae praecursor*. 
<table>
<thead>
<tr>
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<th>MIDDLE CAMPANIAN</th>
<th>SUBSTAGE</th>
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<tr>
<td></td>
<td></td>
<td>SAMPLE POINTS</td>
</tr>
</tbody>
</table>

**Fig. 7.4 Bictonation:** Wells-next-the-Sea.

- **Lower:**
  - B. strigilatum
  - R. helleri
  - C. crista
  - C. tholomiae
  - Euvigerina sp. A
  - L. bonneae
  - C. exocta gracilis
  - S. granulata incondita
  - M. rugosa
  - O. bollii
  - O. stelligera
  - O. m. gr. micheliniana
  - O. c. m. cordieri
  - O. ex. m. str.

- **Middle:**
  - A. cretacea
  - G. bullidites
  - G. libnayana

**Legend:**
- biozones
- sample points

**Note:** The chart illustrates the biozonation of the Lower and Middle Cretaceous strata at Wells-next-the-Sea, with specific species listed for each biozone.
Fig. 7:6 Biozonation: Alderford Common.

Fig. 7:5 Biozonation: Stiffkey Hall Farm.
Bolivinoides culverensis, Bolivinoides pustulatus, G. usakensis, Eouvigerina (?) galeata and Pullenia quaternaria, indicative of a stratigraphic position within the lower levels of sub-biozone B2iii. Peake and Hancock (1961, 1970) concluded that this section was located near the top of the G. quadrata zone. The results of the present study suggest that this locality is not as young as they suggest.

3). Alderford Common (Text fig. 7:6)

The fauna is closely comparable with that of the preceding locality. The planktonic foraminifers Globigerinelloides multispina is slightly more abundant at this locality. This section is situated within sub-biozone B2iii, probably at a slightly higher stratigraphic level than Stiffkey Hall Farm. Such a conclusion is in agreement with the conclusions of Peake and Hancock (1961).

4). Bawburgh Pit (Text fig. 7:7)

This degraded pit possesses a fauna closely comparable to that of the Alderford Common pits. In addition, Gavelinella involuta occurs in moderate abundance indicating a position close to the top of sub-biozone B2iii.

5). Cley (Text fig. 7:8)

The chalk obtained from this section contains a rich fauna including Bolivinoides decoratus, B. pustulatus, B. laevigatus and G. monterelensis, indicative of a stratigraphic position within sub-biozone B3i.

6). Weybourne - Old Hythe Gap (Text fig. 7:9)

The foraminiferal fauna from this section is closely comparable
Fig. 7:8 Biozonation: Cley.

Fig. 7:7 Biozonation: Bawburgh Pit.
Fig. 7: Biozonation - Weybourne. (flint bands after Peake & Hancock 1961)

<table>
<thead>
<tr>
<th>Biozone</th>
<th>Upper Cretaceous</th>
<th>Substage</th>
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<th>Benthonic Foraminiferal Biozone</th>
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**SAMPLING POINTS**

- H
- E
- C
- D
- B
- A

**Fig. 7.19** Biozonation - Weybourne. (flint bands after Peake & Hancock 1961)
with that from the Keswick quarry, suggesting a close correlation between the two. *C. pliata* and the highly inflated varieties of *P. obtusa* first appear at the level of flint U, indicating that this section is very close to the base of sub-biozone B3ii. Peake and Hancock (1961, 1970) consider this section to expose chalk from the *B. minor* subzone.

7). **Keswick Quarry** (Text fig. 7:10)

The foraminiferal fauna of this quarry is quite rich and diverse. It is dominated by *Praebulimina carseyae*, *P. obtusa*, *B. decoratus*, *B. laevigatus*, *C. nitida*, *G. voltziana*, *G. denticula*, *G. monterelensis*, *G. clementiana*, *S. pommerana*, *O. cordieriana* and *G. micheliniana*. In addition, *C. pliata* and *P. quaternaria* occur sporadically. The characteristic Campanian planktonic fauna also contains *Globotruncanarca* and *G. rugosa*. Such a fauna is highly indicative of a stratigraphic position near the base of sub-biozone B3ii. Peake and Hancock (1970) considered the quarry to expose chalk correlatable with the mid "Weybourne Chalk" of the north Norfolk coast, a conclusion which is supported by the present study.

8). **Eaton Golf Course** (Text fig. 7:11)

The chalk from this pit contains a rich and diverse foraminiferal fauna characteristic of sub-biozone B3iii. This fauna is closely comparable to that documented for the previous two localities, which lie in zone B3ii, but lacks the distinctive species *G. lorneiana* and *G. thalmanni*. In addition, the degree of inflation and development of species of the genus *Praebulimina* also strongly suggests that this pit lies within the sub-biozone B3iii. Mr. C. Wood (pers. comm.) has suggested that, on macrofaunal evidence, the chalk of these pits overlaps that exposed between Weybourne Hope and Sheringham.
Fig. 7:10 Biozonation: -- Keswick Quarry.

Fig. 7:11 Biozonation: -- Eaton Golf Course.
9). **Catton Grove (Text fig. 7:12)**

This section exposes the junction between sub-biozones B3ii and B3iv. The junction is taken at the distinctive biohorizon of the Catton Sponge Bed. Below this horizon, the chalk contains the typical foraminiferal fauna of sub-biozone B3ii, lacking the species *G. lorneiana* and *G. thalmanni*, which characterize the earlier biozones of the Campanian. *G. micheliniana* becomes extinct at the Sponge Bed as does *Eponides concinna*, whilst the following species all make their first appearance above the biohorizon: *Globorotalites hiltermanni*, *Gavelinella complanata*, *Gavelinella multipunctata*, *Bolivina incrassata*, *Pseudouigoria cristata*, *Reussella szajnochae szajnochae*, *Neoflabellina praereticulata* and *Eponides beisseli*, all of which are characteristic of biozones B3iv and B4. Planktonic foraminifera are generally abundant and diverse below the Catton Sponge Bed, the fauna being dominated by *A. cretacea*. Above the Sponge Bed however, a drastic decline in number was found with only *H. striata*, *G. aspera* and *G. multispina* remaining constant in numbers across the biohorizon. The length of time represented by the non-sequence is indeterminable, but, in view of the large faunal change involved, may be considerable. Peake and Hancock (1961, 1970) consider this section to expose chalk from the upper B. minor subzone.

10). **Coastal Exposures - Sheringham to East Runton (Text fig. 7:13)**

These poorly exposed, discontinuous, sections yield foraminiferal faunas indicative of both sub-biozones B3iv and B4i. The junction between these two biozones is located at T.G. 182 434, near the sea defence groyne, and is marked faunally by the incoming of *Bolivinoides draco miliaris*, *B. sidestrandensis*, *Neoflabellina permutata* and *Stilostomella pseudoscripta*. The indurated nature of many of these localities resulted in a rather impoverished planktonic fauna however.
Fig. 7:12 Biozonation: - Catten Grove.

(flint bands after Peake & Hancock 1961)

Fig. 7:13 Biozonation: - Sheringham.

(flint bands after Peake & Hancock 1961)
This section lies wholly within sub-biozone B3iv and contains a well preserved and characteristic fauna of this level as documented above. The planktonic species Globotruncana plummerae, G. hilli, G. ventricosa and Heterohelix complanata first appear at this level, in a fauna dominated by A. cretacea, G. bulloides austenensis, G. bulloides bulloides, G. rugosa and G. fornicata. Peake and Hancock (1970) indicated that this quarry may lie only slightly above the level of the Catton Sponge Beds.

This pit is closely comparable faunally with the Caistor St. Edmunds quarry and clearly belongs to sub-biozone B3iv. The well preserved, diverse planktonic assemblage is dominated by A. cretacea and G. bulloides together with G. fornicata, G. plummerae, G. hilli and G. linneiana.

The abundant well preserved foraminiferal fauna obtained from this quarry is highly distinctive of sub-biozone B3iv. Present are R. szajnochae, B. incrassata, G. hiltermanni and E. beisseli, whilst E. draco miliaris, B. sidestrandensis and S. pseudoscripta, the characteristic species of biozone B4 are absent. The planktonic fauna from this locality is also abundant and diverse, being dominated by A. cretacea, G. bulloides austenensis and G. plummerae, together with G. arca, G. fornicata, G. bulloides bulloides, G. rugosa, G. hilli, H. striata, G. aspera and G. multispira. There has been some debate in the past as to the stratigraphic position of this quarry. Peake and Hancock (1961) placed this quarry within their "Beeston Chalk" unit, at a somewhat higher stratigraphic position than the Caistor quarry. Peake and Hancock (1970) have revised this opinion, correlating this pit with the basal
Fig. 7:15 Biozonation: Caistor St. Edmunds. (alphabetical flint designations after Peake & Hancock 1961)

Fig. 7:14 Biozonation: Arminghall Pit. (B= influx of biserial G.multispina)
Fig. 7.16 Biozonation - Frettenham Quarry.

Fig. 7.17 Biozonation - Whitlingham Pit.
"Paramoudra Chalk" exposed in the East Runton erratic. The present findings would tend to support the previous correlation placing this section in the upper "Beeston Chalk".

14). Whitlingham Pit (Text fig. 7:17)

The chalk of this pit contains an abundant, well preserved, foraminiferal fauna containing abundant *B. draco miliaris*, *B. sidestrendensis* and *S. pseudoscripta*, characteristic of biozone B4. Planktonic foraminifera were abundant at this locality. The fauna was dominated by *A. cretacea*, *H. striata*, *G. aspera* and *G. multispina*. Peake and Hancock (1970) concluded that this pit exposed chalk from the mid "Paramoudra Chalk" belonging to the upper *B. lancei* subzone.

15). Postwick Riverbank (Text fig. 7:18)

The chalk obtained from this locality contains a well preserved fauna characteristic of a level high in biozone B4. The index species *B. draco miliaris* is common here and the abundant planktonic fauna is dominated by forms transitional between *A. cretacea* and *Rugoglobigerina rugosa*. Mr. G. Wood (pers. comm.) considered that the chalk formerly exposed in the nearby Postwick Grove Pit was extremely close to the Campanian/Maastrichtian boundary.

16). Overstrand Hotel Lower Mass (Text fig. 7:20)

In view of the internal thrusting present within this glacial erratic, and the continuing debate as to its stratigraphic position (Peake and Hancock 1961, 1970; Wood 1967), the foraminiferal fauna obtained from each thrust slice will be discussed separately. The chalk from all the thrust masses was soft and a rich, well preserved fauna was obtained throughout.
**Fig. 7:18** Biozonation: - Postwick Riverbank.

**Fig. 7:19** Biozonation: - Overstrand Minor Mass.
a) Thrust Slice 1.

The planktonic fauna from this slice is not abundant, but contained the following: *Globotruncanella havanensis*, *R. rugosa*, *G. arca*, *H. striata*, *H. complenata*, *G. aspera*, *G. multispina*; the first of these are of some stratigraphic significance, having been most commonly recorded from strata of Maastrichtian age. It should be noted however, that both have also been recorded from strata of uppermost Campanian age (Pessagno, 1967), and thus their presence is not diagnostic. The benthonic fauna is dominated by *G. voltziana*, *E. beisseli*, *B. decoratus*, *P. obtusa*. *R. szajnochae szajnochae* occurs in flood proportions. Transitional forms between *O. cordieriana* and *O. navarroana* are moderately abundant as are those between *B. laevigatus laevigatus* and *B. peterssoni*. *Pyramidina minuta* and *Bolivina decurrens* also first appear at this level. Such a benthonic fauna is highly characteristic of the uppermost Campanian/lowest Maastrichtian boundary in N.W. Europe (Koch 1977), but its transitional nature makes the exact delimitation of the age of this thrust slice somewhat problematical. In the present study, the flood of *R. szajnochae szajnochae* at this level has been found to be a correlatable datum plane within the North Sea Basin and has been taken for practical reasons to mark the top of the Campanian in this region. In view of the lack of a suitable type section for this boundary (Chapter 2), such an admittedly arbitrary action is felt to be justified. Kaever (1961) has recorded the stratigraphic range of *G. hiltermanni* as restricted to the Campanian; in agreement with the present results. In conclusion therefore, the available foraminiferal evidence suggests that the lowest thrust slice of the Overstrand Lower Mass should be tentatively assigned to biozone B4 of the uppermost Campanian.
b) Thrust Slice 2.

The benthonic foraminiferal fauna from this slice shows marked differences from that of Thrust Slice 1, thus indicating that the two are stratigraphically distinct and not a simple, repetitive series. Once again, planktonic foraminifera are rare and restricted. The benthonic fauna is dominated by *Cibicides beaumontianus*, *G. voltsiана*, *S. pommerana*, *P. obtusa* and *B. incrassata* in flood proportions in the basal layers. *B. peterssoni*, *O. navarroana* and *Praebulimina laevis* also occur in moderate abundance and are indicative of a Lower Maastrichtian age. *Heterostomella foveolata* and *Euvigerina* sp. *B* occur for the first time at this level. Notably absent from the fauna of this mass are *G. hiltermanni* and *R. szajnochae szajnochae*, whilst transitional forms between *B. decoratus* and *Bolivinoides australis* are found in the basal levels of this thrust slice. On the foraminiferal evidence, this thrust slice can be considered to be of lowest Maastrichtian age, assignable to sub-biozone B51.

c). Thrust Slice 3.

The foraminiferal fauna of this slice is closely comparable to that of Thrust Slice 2 and this, together with the lithological similarities, suggests that the two may be repetitive slices of a higher stratigraphic level.

d). Thrust Slice 4.

This is the first thrust slice to contain an abundant planktonic fauna, with *R. rugosa* being the dominant element. The benthonic fauna is generally comparable with that of the two subjacent thrust slices, though in detail there are differences: *Coryphostoma limbosa* first appears at this level, whilst *B. peterssoni* becomes an important faunal constituent. This evidence suggests that this upper thrust slice
Fig. 7:20 Biozonation: Overstrand Lower Mass.

Fig. 7:21 Biozonation: Overstrand Upper Mass.

(TP = thrust plane)
is of Lower Maastrichtian age and is the youngest slice present in the Overstrand Hotel Lower Mass. It is assignable to sub-biozone B51.

From the foregoing, it may be seen that the foraminiferal evidence complements the field evidence, to suggest the presence of a rather complex series of thrust slices within the Overstrand Hotel Lower Mass, which are mostly assignable to the Lower Maastrichtian, though the basal layer probably contains strata of uppermost Campanian age. In the light of the complexities outlined above, and the scarcity of macrofossils at this locality (Peake and Hancock, 1970), it is hardly surprising that the exact stratigraphic position of the Overstrand Hotel Lower Mass should have been the subject of considerable debate. Peake and Hancock (1961) concluded that this mass was assignable to the top of the Campanian, though they later (Peake and Hancock, 1970) hypothesised that this mass might fall within the Maastrichtian. They admitted however, that there was no macrofossil evidence to suggest that it was "anything other than Campanian". Wood (1967) considered that beds of both uppermost Campanian and Lower Maastrichtian age might be present in the mass, a hypothesis which the present study indicates to be the most likely.

17). Overstrand Minor Mass (Text fig. 7:19)

The chalk obtained from this small erratic block was soft and yielded a diverse and well preserved foraminiferal fauna. Planktonic foraminifera are neither abundant nor diverse at this locality, though G. havenensis and R. rugosa are present. The benthonic fauna is well developed, however, and is closely comparable with that obtained from the lowest thrust slice of the Overstrand Lower Mass, with G. hiltermanni, B. decoratus and R. szajnochae occurring in abundance. This erratic block is thus tentatively assigned to the
uppermost Campanian.

18). Overstrand Hotel Upper Mass (Text fig. 7:21)

The chalk obtained from this locality, though slightly indurated and affected by periglacial action, yielded a rich and diverse foraminiferal fauna. The planktonic fauna is dominated by *R. rugosa* with subordinate *R. milamensis*. The benthonic fauna is dominated by *G. voltziana*, *S. pomerana*, *G. nitida*, *P. laevis*, *B. incrassata*, *B. sidestrandensis* and *B. peterssoni*, the latter indicative of a Lower Maastrichtian age. *N. reticulata*, *C. limosa*, *B. miliaria*, *B. australis*, *B. decurrens* and *Equivigerina sp. B* also occur in low abundance, strongly supporting the Lower Maastrichtian age of this mass. Wood (1967) has recorded the diagnostic Lower Maastrichtian belemnite *Belemnella lanceolata* from the chalk of this locality which is assignable to biozone B51.

19). Sidestrand Western Mass (Text fig. 7:22)

The succession exposed in the main Sidestrand Mass has been subdivided faunally and lithologically (Peake & Hancock, 1961) into the Pre-Porosphaera and Porosphaera Beds. There are few microfaunal differences between these divisions however, and both are included in the present comments. The chalk from this locality is only moderately indurated and an abundant and diverse foraminiferal fauna was obtained throughout. The planktonic fauna is dominated by abundant *R. rugosa*, with rare *R. milamensis*, *G. havanensis*, *G. arca*, *G. multiapina*, *H. striata* and *H. complanata*. The benthonic fauna is dominated by *Gavelinella bembix*, *C. beaumontianus*, *G. voltziana*, *S. pomerana*, *E. beisseli*, *B. peterssoni*, *B. sidestrandensis*, *B. incrassata* and *P. laevis*. *Cibicides bosqueti* becomes a persistent member of the fauna only within the Porosphaera Beds. *B. decoratus*, *P. carsevae* and
P. obtusa are noticeably absent from this locality. The fauna from the Sidestrand Western Mass is assignable to sub-biozone B5ii. Wood (1967) and Peake and Hancock (1970) consider this locality to be assignable to the upper B. lanceolata zone of the Lower Maastrichtian.

20). Sidestrand Sponge Beds (Text fig. 7:22)

The complex of sponge beds and hardgrounds exposed on the foreshore platform is indurated and only a somewhat impoverished foraminiferal fauna is obtainable. The planktonic fauna, generally similar to that of the preceding locality though somewhat reduced in numbers, is dominated by R. rugosa. The benthonic fauna is also closely comparable with that of the main Sidestrand Mass. The most marked differences, however, are in the flood of Angulogavelinella bettenstaedti in the middle sponge beds and in the presence of Bolivinoides paleoecicus, which clearly places the Sponge Beds within biozone B6i. O. cordieriana is absent in this zone. Wood (1967) and Rawson et al. (1978) have concluded that the Sidestrand Sponge Beds represent the junction between the macrofossil zones of B. lanceolata and B. occidentalis. However, in many areas of the world (van Hinte 1976; Koch 1977), the first appearance of the characteristic foraminiferal species Bolivinoides draco draco has been found to coincide with the base of this macrofossil zone. In view of the absence of this species from both the Sidestrand Sponge Beds and the supradjacent Trimingham erratic, it must be stated that the assignment of these masses to the B. occidentalis zone is not supported by the available foraminiferal evidence. The remarks by Wood (1967) as to the lack of rigidly defined limits to the belemnite zones used on the Continent and the intergradational nature both of the various index species, and therefore also the zones which they define, may have a bearing on this problem.
Fig. 7:23 Biozonation: Trimingham.
(lithohorizons after Peake & Hancock 1961)

Fig. 7:22 Biozonation: Sidestrand.
(lithohorizons after Peake & Hancock 1961)
21). Trimmingham (Little Marl Point) (Text fig. 7:23)

The 7.5m. of chalk exposed at this locality, though affected by periglacial action, is only moderately indurated and a well preserved and diverse foraminiferal fauna is obtainable throughout. It has been subdivided (Brydone 1908; Peake & Hancock 1961,1970; Wood 1967) into three units: a lower unit included within the Sponge Beds, a middle unit of White Chalk without Ostrea lunata and an upper unit of White Chalk with O. lunata. The first two of these contain a foraminiferal fauna closely comparable with that of the preceding Sponge Beds and assignable to sub-biozone B6i. The White Chalk with O. lunata does, however, show microfaunal changes which readily characterize this unit: Pseudouvigerina rugosa occurs in flood proportions and Teppanina selmensis occurs for the first time. In addition, G. voltziana shows a marked reduction in abundance, whilst early transitional forms between B. draco miliaris and B. draco draco occur rarely. This fauna places the White Chalk with O. lunata in sub-biozone B6ii, whilst the presence of the latter clearly implies that the internationally recognised B. draco draco biozone (van Hinte 1976; Koch 1977) does not occur onshore in England. As noted above, Wood (1967) has assigned this locality to the B. occidentalis macrofossil zone.

22). Marl Point (Trimingham) (Text fig. 7:23)

The indurated grey chalk, with abundant O. lunata obtained from this locality produced a reduced foraminiferal fauna which is tentatively assignable to sub-biozone B6ii.

7.4. North Sea Basin

1). Well 4k/2-1 (Text fig. 7:24)

The cutting samples (3060' - 4500') provided from this well
Fig. 7: Biozonation - Shell/Esso 44/2-1.
represented a virtually complete Campanian and Maastrichtian succession. The nature of the samples however, necessitates a consideration of the foraminiferal fauna obtained, in terms of their 'downhole' occurrence. Lithologically, the succession penetrated belonged to the Hod and Tor Formations of the Chalk Group represented by a moderately hard, white, chalky limestone with occasional less indurated marly layers and red, stained, chalky limestones. This increased degree of induration is directly related to the increased depth of burial of the chalk of the North Sea Basin (Scholle 1974; Hancock & Scholle 1975). In general, the foraminiferal faunas obtained showed a degeneration in preservational state downhole, again presumably related to increasing depth of burial (Schlanger & Douglas 1974).

The youngest sample examined from this well (3060 ft.) contained abundant chalk fragments which yielded an abundant fauna of planktonic foraminifers including Abathomphalus mayaroensis, G. havanensis, R. ruposa, R. rotundata, G. multispina, H. striata and Pseudotextularia elegans, indicative of a position within the internationally recognised A. mayaroensis zone (Bandy 1967; Pessagno 1967; van Hinte 1976).

The associated benthonic fauna is dominated by B. incrassata s.l. B. draco draco, G. cf. bembix, G. cf. denticula and S. pommerana, with rare N. reticulata, Pseudouvirgerina cristata and B. peterssoni, and is assignable to the benthonic foraminiferal biozone B7. A major faunal change occurs at 3240', some 180' (59m.) below the topmost Cretaceous sample, where B. draco miliaris, Pyramidina triscula, P. ruposa, N. permutata and A. bettenstaedtii all make their first downhole appearance. This level is taken to mark the top of the benthonic biozone B6. At 3300', O. cordieriana and P. minuta first appear at a level which may represent the top of biozone B5. At 3390' a major faunal change occurs with the incoming of abundant R. szajnochae szajnochae of a form characteristic of the uppermost Campanian. Associated with this level is the first downhole occurrence of G. hiltermanni, Eponides beisseli.
and G. monterelensis, with a marked increase in abundance of G. cf. arca
and A. cretacea, which clearly mark the Campanian/ Maastrichtian boundary
and the top of biozone B4. Thus, a thickness of 330 ft. ( 100m. )
of Maastrichtian strata has been proven in this well.

At 3480' a red stained band of chalk was penetrated and associated
with this level is the oncoming of B. decoratus, G. micheliniana and
N. buticula, indicating a level close to the top of biozone B3, and
this conclusion is supported by the occurrence of G. lorneiana at
3570', R. szajnochae praeccursor at 3660' and N. rugosa and G. clementiana
at 3700'. An indication that the basal levels of biozone B3 are present
in the 3850' - 3900' interval is the presence of rare S. exsulcpta
gracilis, B. pustulatus and the increase in abundance of G. bulloides
bulloides and G. linneiana. The flood of S. exsulcpta gracilis and
S. granulata incondita at 3970' has been taken to mark the top of
biozone B2, this being confirmed by the rare occurrence of B. culverensis
in 3980', G. uskensis at 3960' and G. stellipera at 4000'. The top of
biozone B1 has been taken at 4140' at the first downhole occurrence of
the index species B. strigillatus. Associated with this level also are
the first occurrence of G. cristata at 4030' and R. kelleri at 4300'.
The location of the Campanian/Santonian boundary is more problematic
due in part to the lack of suitable, well preserved material from this
level from onshore Britain. However, the occurrence of moderately
abundant S. exsulcpta exsulcpta at 4490' has been tentatively taken to
indicate the top of the Santonian stage. Thus, a total stratigraphic
thickness of 1100' ( 335m. ) of Campanian strata has been recorded.

2). Well 29/25-1 ( Text fig. 7:25 )

The cutting samples ( 6080' - 7000' ) provided from this well
represent an almost complete Maastrichtian and Campanian succession,
though the Campanian/Santonian boundary was not represented.
<table>
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<th>CAMPANIAN</th>
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<th>DANIAN STAGE</th>
<th>STAGE</th>
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<td>B3/4</td>
<td>B5</td>
<td>B6</td>
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<td>6.00</td>
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<td>7.12</td>
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**Fig. 7:25 Biozonation - Shell/Esso 29/25-1.**

**SMPLE POINTS**

- G. stelligera
- S. granulata incandita
- S. squamata gracilis
- G. laurina
- G. petulatus
- P. obtusa
- G. lawgiatus
- G. incolita
- G. painhoensis, szajnochus
- G. decoratus
- G. montegienses
- G. unifermtani
- P. minuta
- G. cordieriana
- B. dacro multeri
- B. deltidial
- B. palaiocentum
- B. dacro dacro
- B. incrassata
- G. nemerana
- G. millimana
- G. trotoloides
- A. cratacea
- G. elega
- G. havenensis
- G. rugosa
- G. cotula
- G. rotundata
- G. elega
- G. masunensis
Lithologically, the strata penetrated were hard, grey, chalky limestones which yielded a poorly preserved, partially recrystallised foraminiferal fauna, possibly as a result of depth of burial. The youngest samples provided from this well 6080' and 6120' contained no chalk fragments. The first sample to possess a Cretaceous fauna was obtained from 6160' and contained an abundant planktonic fauna containing *P. elegans*, *R. rotundata*, *R. ruposa*, *G. contusa* and *G. area*, indicative of the *A. mayaroensis* biozone. The poorly preserved fauna obtained from this well allowed only a general degree of correlation. The first recorded faunal change occurred at 6280', where *E. beisseli* appeared for the first time. This level has been taken to indicate the top of biozone B6, thus giving a total thickness for the Upper Maastrichtian of approximately 148' (45m.). At 6440' a band of red stained chalk was encountered and associated with this level is the first downhole occurrence of *B. draco miliaris* and *O. cordieriana*, indicative of the top of biozone B5. At 6640' - 6680' a major faunal change is recorded, by the first downhole occurrence of *R. szajnochae szajnochae*, *G. hiltermanni* and *G. monterelensis*, thus signifying the location of the Campenian/Maastrichtian boundary and giving a total thickness of Maastrichtian strata in this well of approximately 508' (154m.). At 6800' the first downhole occurrence of *S. exsulcata praecilia* and *S. pranulata incondita* is taken to mark the top of biozone B2, close to the level of increase in abundance of *C. bulloides* and *C. linneiana* (6760'), whilst *B. pustulatus* and *G. usakensis* first occur at 6840' and *C. stelligera* occurs at 7000'. A minimum thickness for the Campanian stage in this well of approximately 360' (110m.) is indicated.

7.5. Conclusions

The foregoing stratigraphic conclusions are summarized in Text figs. 7:26, 7:27. It may be concluded that changes in the foraminiferal fauna of the Campanian and Maastrichtian chalk of the United Kingdom are of
fundamental stratigraphic use. These changes may be recognised on an inter-regional scale and have permitted the erection of 4 planktonic foraminiferal biozones and 15 benthonic foraminifera sub-biozones. The latter are of an average duration of 1.14 Ma and have permitted the detailed correlation of 25 onshore localities from southern England and Norfolk, and two wells from the North Sea. The biozonation proposed herein has also allowed correlation to be made with other foraminiferal faunas described on an international basis as well as with the Campanian and Maastrichtian stratotypes.
Fig. 7:26 Correlation of studied sections:— Norfolk.
CHAPTER 8

PALAEOECOLOGY

8.1. Introduction

Palaeoecology, the study of the ecological factors which governed fossil organisms, is beset by numerous problems. These include the incomplete nature of the fossil record and diagenetic alteration, which together effectively prevent any complete reconstruction of past ecosystems, modes of life and community dynamics. Within the limits imposed by these restraints, much information of a general nature may be obtainable.

Prior to any palaeoecological study, however, it is necessary to determine to what extent one is dealing with a biocenosis (living community) or transported thanatocoenosis. In the present study, the general lack of sedimentological indications of current activity, lack of size sorting and presence of numerous fragile, juvenile specimens, has been taken to indicate that the majority of the benthonic foraminifera found during the present study lived close to the locality where they were deposited.

Distribution patterns of living foraminifera are controlled by a complex series of inter-related ecological factors. Temperature, salinity, depth of water column, oceanic current patterns and nutrient supply are the principal factors controlling distribution patterns, numerical abundance and specific diversity in the planktonic foraminifera. Benthonic foraminifera are, in addition, influenced by substrate, turbidity and sedimentation rates. It must be assumed that Cretaceous foraminifera were governed by similar factors. Thus, by a combination of uniformitarian approach and comparative anatomical studies, various aspects of their palaeoecology may be deduced, and information may be
gained as to the depositional environment of the chalk.

8.2. Salinity

The widespread occurrence of planktonic foraminifera in the Campanian and Maastrichtian chalk, suggests that normal marine salinities prevailed within the range 34 – 37 parts per thousand. This conclusion is supported by the presence of stenohaline echinoderms, brachiopods and belemnites.

8.3. Temperature

Palaeomagnetic evidence and palaeocontinental reconstructions (Smith & Briden 1977) place the south coast of Britain at a latitude of 40° N during the Campanian and Maastrichtian. This latitude corresponds to the present day position of central Spain, which lies within the sub-tropical belt. During the Campanian and Maastrichtian, the non-glacial climate (Luyendyk et al 1972), with reduced temperature gradients between polar and equatorial regions (Douglas & Sliter 1966), would tend to support the hypothesis of the existence of a sub-tropical climatic regime over the British Isles.

Quantitative estimates of palaeotemperatures have been obtained (Urey et al 1951; Lowenstam & Epstein 1954; Bowen 1961; Spaeth, Hoefs & Vetter 1971) based on 0\(^{18}\) isotope analysis of belemnites, oysters and other calcitic faunal elements. Though open to criticism on various points (Voigt 1964; Kennedy & Garrison 1975; Boltovskoy & Wright 1976), these results provide the only quantitative estimate of palaeotemperatures available to date. They are reproduced in a modified form in Text fig. 8:1. This data suggests a palaeotemperature of approximately 19/20° C in the lower Campanian falling to approximately 15° C by the middle Maastrichtian. These results are in general agreement with the conclusions reached in the present study, as a result of analysis of
Fig. 8:1

S-S: after Speith, Hoefts and Vetter (1971); H-H: after Hancock (1975)
L-L: after Lowenstam and Epstein (1954); K-K: after Kauffmann (1973)
planktonic foraminiferal faunas.

Bandy (1960, 1964, 1967) has concluded that abundant, diversified keeled planktonic foraminifera are generally restricted to oceanic regions between 20° - 40° N and S, a latitude approximately defined by the 17°C surface-water isotherm. This temperature-controlled distribution pattern may be modified by current activity and other palaeoecological factors. Assuming that these findings may be applied to the taxonomically unrelated, keeled planktonic foraminifera of the Cretaceous, we may conclude that in the Campanian and Maastrichtian, diversified Globotruncana faunas should be characteristic of the Tethyan region, whilst one would expect low diversity, non-keeled species to predominate in the Transitional and Boreal biogeographic provinces (Scheibnerova 1970; Sliter 1977). Such conclusions are in general agreement with world-wide distribution patterns. Douglas (1972) has, however, criticised the applicability of these strict latitudinal limits to the foraminiferal faunas of the Pacific Coast of N. America.

In consideration of the stratigraphic distribution of the planktonic foraminifera, the present author wishes to consider first the results obtained from the Norfolk/North Sea regions; those results obtained from the Isle of Wight appear to have been affected by local depth controls (see below). In the North Sea Basin, the chalk is believed to have been deposited in depths of at least 200 - 300m. (Hancock & Scholle 1975), and thus the main control on distribution patterns of planktonic foraminifera may be assumed to have been temperature.

In general, it may be stated that keeled Globotruncana faunas are most abundant and diverse in the lowest Campanian and uppermost Santonian, though even here diversities are low, compared to those recorded from the Tethyan region. In the Upper Campanian and Maastrichtian the planktonic fauna is dominated by species of Archaeoglobigerina, Eucoglobigerina, Globigerinelloides and Heterohelix, with species of the genus Globotruncana being dominated by the G. bulloides, G. linneiana.
groups which characterise the Transitional biogeoprovinoe (Scheibnerova 1970; Sliter 1977). Such a replacement of moderately diverse *Globotruncana* faunas by less diverse 'globigerine' faunas is in general agreement with decreasing oceanic temperatures.

Sliter (1976) has undertaken a review of the planktonic biogeoprovines of the southern hemisphere. Faunas described from the Transitional Biogeoprovine of the southern hemisphere are closely comparable at a species level with those recorded in the present study. The present evidence strongly suggests the existence of identical/equivalent faunal provinces in the northern and southern hemispheres. The Transitional Biogeoprovine in the Campanian and Maastrichtian in both hemispheres is characterized by the following species:

- *Rugoglobigerina* (?) *pilula*
- *R. rugosa*
- *R. milamensis* (= *R. rotundata* sensu Sliter 1976)
- *Globigerinelloides aspera*
- *G. multispina*
- *Hedbergella holmdelensis*
- *H. monmouthensis*
- *Globotruncanella havanaensis*
- *Abathomphalus intermedius*
- *A. mayaroensis*
- *Globotruncanella bulloides* (= *G. marginata* sensu Sliter 1976)
- *G. fornicata*
- *Heterohelix striata*

This data is summarized in Text fig. 8:2. The absence in the present material of the following species recorded from the southern Transitional Biogeoprovine may be attributable to depth considerations (8.5):
Globotruncanana elevata
G. stuarti
G. stuartiformis

whilst G. ventricosa has been found in the present study only at the level corresponding to the postulated maximum of the Upper Campanian transgression. In the uppermost Maastrichtian (A. mayaroensis zone) a rich, diversified planktonic fauna was encountered in the North Sea Basin, and recorded from Scandinavia (Berggren 1962) and Denmark (Troelsen 1955). This fauna shows a distinct Tethyan aspect and is taken to represent a short-lived warm water pulse in N.W. Europe. Such a conclusion is in agreement with recent oxygen isotope studies on European belemnites (Spaeth, Hoefs & Vetter 1971).

Estimation of palaeotemperatures by means of benthonic foraminifera are more problematic, though it has been suggested (Boltovskoy & Wright 1976) that temperatures lower than the optimum for reproduction may result in larger individuals. Such a control may account for the general size increase shown by specimens of benthonic foraminifera through the Campanian, though it must be noted that there is no general agreement regarding the nature of the effects that various environmental factors have on specimen size (Boltovskoy & Wright 1976).

8.4. Surface Currents

Several authors have considered the palaeocirculation of the Atlantic surface waters (Banner 1972; Luyendyk et al 1972; Irving et al 1974). The experimental approach of Luyendyk et al (1972) is worthy of particular note, though requiring modification with respect to palaeogeography along the lines suggested by Hart and Carter (1975) and Hart (1976). It should be noted however, that the recent
palaeocontinental and palaeogeographical reconstructions of the East Indies region (Smith & Briden 1977; Audley-Charles 1978) would suggest the existence of a Malaysian landmass across the equator in late Cretaceous times. This would severely reduce the strength of the postulated Tethyan currents and increase the strength of the proto-Gulf Stream (Luyendyk et al. 1972). Postulated surface oceanic currents in the north Atlantic region during the Campanian and Maastrichtian are illustrated in Text fig. 8:3. Current influences passing across N.W. Europe from the Tethyan region are interpreted as having occasionally introduced exotic specimens of keeled planktonic foraminifera, such as *G. ventricosa* into the typical Transitional fauna of the British Isles.

### 8.5. Depth.

The quantification of estimates of depth of deposition is an area of palaeoenvironmental analysis beset by problems. Hakansson et al. (1974) and Kennedy and Garrison (1975) have given useful reviews of many of these problems and have emphasised the need for an evaluation of several lines of evidence in determining the depth of deposition of the chalk.

The general geological setting of the Upper Cretaceous chalk of N.W. Europe provides some evidence as to its likely depth of deposition. Its development within thick sequences of sedimentary successions typical of deposition in more or less shallow epicontinental seas, indicates that the chalk of N.W. Europe is not a deep-sea sediment, but owes its dominantly biogenic composition and lack of clastic material to reduced erosion, rather than distance from continental areas (Hakansson et al. 1974). The Cretaceous chalks of Europe may be considered as pelagic sediments deposited on a relatively shallow epicontinental sea, in a tectonically stable region. Water depths in most areas of this shallow shelf sea are unlikely to have exceeded 300m. (Kennedy &
Fig.8:3 Upper Campanian Palaeogeography of the North Atlantic Region.
Garrison 1975), though they may have been deeper in trenches within the major depositional basins (Hancock 1975). Relatively high sea levels in the Upper Cretaceous had resulted in major inundation of many of the island masses of the Lower Cretaceous. Indications of land masses in this area are strictly limited. Marginal facies have been described from the Armorican and Central Massifs in France (Séronie-Vivien 1972), the Bohemian Massif (Diener 1967), the Ardennes, Rhenish Massif, Baltic Shield (Brotzen 1945) and Greenland, whilst from the British Isles they are restricted to scattered deposits in the Western Isles of Scotland and in N. Ireland (Bailey 1924, Lee & Bailey 1925, McCugan 1957). Outcrop and suborop distribution patterns suggest that chalk was being deposited over vast areas of N.W. Europe and over most of the British Isles and Eire (Walsh 1960; Barr 1966b; Christensen 1975).

A general lack of borings attributable to light-dependent benthonic organisms, such as thallophytes and the lack of calcareous algal grains, suggests that the bulk of chalk deposition occurred below the euphotic zone (Hakansson et al 1974; Scholle 1974). The depth of the euphotic zone in the relatively clear seas of Upper Cretaceous Europe may have been in the order of 100 - 120m. (Reid 1973; Boltovskoy & Wright 1976). Other studies, based on comparative anatomical studies of various fossil groups, have been undertaken. Notable are the studies of Gignoux (1928) and Reid (1962a,b, 1968, 1973b) on sponge faunas, which yielded depth estimates of 300m. and 90 - 120m. respectively. Nestler (1965), in a study of faunal elements from the Maastrichtian chalk of Rügen, concluded that the depth of deposition ranged from 100 to 250m. Hakansson et al (1974) suggested a figure of 180 - 250m., whilst Hancock (1975,1976) suggested 200 - 300m.

Studies of foraminiferal faunas from the chalk may give additional
information on this problem. Recent studies have shown that planktonic foraminifera show a stratified distribution within the water column (Boltovskoy 1964; Be & Tolderlund 1971; Be 1977), with the highest concentration above 100m. At a specific level there is also a marked depth stratification, and evidence is now accumulating (Douglas & Savin 1978; Hart & Bailey in press) that distinct morphological types have occupied differing depths in the water column at least since Albian times. It is suggested by studies of comparative anatomy, distribution patterns (Hart & Bailey in press) and oxygen isotope studies (Douglas & Savin 1978) that the 'globigerine' forms together with Heterohelix, occupied the shallowest habitats, whilst those with 'globorotalid' morphology occupied the deepest habitats. Hart and Bailey (in press) have attempted to interpret the highly distinctive planktonic record from the Upper Cretaceous of southern England in terms of depth control. They themselves have noted serious problems and discrepancies in the application of such an interpretation in the Santonian (and younger) strata. The reasons for this may be complex and are discussed below.

It is felt that the lack of single keeled planoconvex Globotruncana species in the Campanian of England, is largely a function of temperature (section 8.3), though depth considerations would also preclude their existence. Phleger (1951), Grimsdale & van Morkhoven (1955), Flexer & Starinsky (1970), Eicher (1969), Schnitker (1972), Barr (1962) and Carter and Hart (1977) amongst others, have attempted to use the observation of a relationship between depth of deposition and abundance of planktonic foraminifera. This approach has been typified by analysis of planktonic/benthonic ratios, to give a quantitative estimate of depth of deposition. Though such a relationship may be shown to be true in a general sense, it is highly likely that P/B ratios may also be strongly influenced by current activity and diagenesis. Barr (1962), in a study of P/B ratios from the Upper Cretaceous of the Isle of Wight, studied samples from marl bands and...
'flint meal', and it may be that his resulting conclusions reflect a strong lithological bias (Chapter 2), rather than a simple depth control.

As noted previously (Chapter 3), diagenetic effects may well have biased the planktonic foraminifera obtainable from the bulk of the chalk (Schlanger and Douglas 1974), and the present writer would hesitate to recommend reliance on P/B ratios for quantifying depth of deposition in any but a general sense. It may well prove possible to utilize this method more accurately if sufficient stratigraphic cover could be obtained from 'flint meal' faunas. In this general sense, P/B ratio studies (Text fig. 8:1) may be interpreted as supporting the concept of increasing water depths within the uppermost Campanian and a reduction in water depth in the Maastrichtian. Such results, suggesting a general transgressive phase in the former and regressive phase during the latter, are in broad agreement with results obtained by many workers from a variety of sedimentological and faunal studies (Kaufmann 1973; Matsumoto 1967; Hancock 1975, 1976; Cooper 1977).

Estimation of the magnitude of these transgressive and regressive events is somewhat problematical, though it should be noted that P/B ratios, even in the soft chalks of the uppermost Campanian, are still lower than those obtained from the hard nodular chalks of the Upper Cenomanian to mid-Turonian (Hart & Carter 1975; Carter & Hart 1977). Whether these results can be directly related to the relative magnitudes of these transgressions, or whether the somewhat lower P/B ratios in the uppermost Campanian may be attributable to more complex factors, is open to debate.

It is possible that the temperature induced change from a fauna dominated by robust, keeled Globotruncan species, to one dominated by fragile 'globigerine' forms, may have lowered the preservation potential of the fauna. This in turn, may be reflected in slightly lower planktonic abundances.

Benthonic foraminifera may also provide information for interpreting depth of deposition. Many workers have described
distributions of Recent benthonic foraminifera which may be related
to depth ( see review Boltovskoy & Wright 1976 ) and these results
have been applied to Cretaceous distributions noticeably along the
Pacific coast of N. America ( Sliter & Baker 1972; Sliter 1972 )
and S. Europe ( Schnitker 1972 ). In the present author's opinion
however, much erroneous information has been introduced into the
literature by the extrapolation of comparative anatomical studies at
a specific level to draw conclusions at a generic level. ( Schnitker
1972 ).

In the Scratchell's Bay/Alum Bay area of the Isle of Wight, a
marked ( though probably local ) trend has been noted towards reduced
P/B ratios across the Middle/Upper Campanian boundary. Such results
have been obtained from both 'flint meal' faunas ( Barr 1962 ) and
'normal' chalk ( present study ). The presence of a well preserved,
abundant benthonic fauna through this interval, strongly suggests that
this reduction in planktonic abundances is a primary feature. Coincident
with this marked reduction in the planktonic fauna, large specimens
of Planorbulina cf. cretae are found in abundance. This species has
been widely recorded from strata of uppermost Cretaceous age in
geological settings indicative of relatively warm, shallow waters
( see review Bignot & Larsonneur 1969 ). Sliter and Baker ( 1972 ),
Sliter ( 1972 ) and Boltovskoy and Wright ( 1976 ) have found the
genus Planorbulina to be characteristic of shelf depths shallower than
200m. This association of P. cf. cretae, with reduced planktonic
abundances in the Isle of Wight, is thus interpreted as indicating a
general shallowing of this region, possibly to depths of 100 - 150m.

Other benthonic species have also been shown to be of use for the
determination of depth of deposition. H. Ernst ( 1978 ) has suggested
that high abundances of Cibicides may be indicative of slightly
shallower depths, and the abundance of these forms in the Lower
Maastrichtian of Norfolk does not contradict such a relationship. H. Ernst (1978) has also indicated that abundant Stensioina may be indicative of somewhat deeper chalk deposition, whilst abundant Cavelinella might indicate somewhat shallower depths. It is possible that the reduced numbers of S. exsculpta gracilis found in the Isle of Wight, as compared to Norfolk or the North Sea, might be related to somewhat shallower depths of deposition in the former. It must also be stated that such a relationship might be controlled by temperature induced faunal provincialism. The reduced abundance of members of the 'G. clementiana plexus' in the chalk of the North Sea Basins and Norfolk, may conversely be indicative of, either somewhat deeper depths of deposition in these areas, or faunal provincialism. Sliter and Baker (1972) have shown that smooth 'buliminids' similar to the Cretaceous Praebulimina carseyae, together with morphotypes similar to Pullenia quaternaria, are found in the present day at depths of deposition above 200m. Abundant Stilostomella, Allomorphina, Praebulimina and Gyroidinoides were taken to be indicative of mid-outer shelf depths (200 - 300m.); whilst the upper depth limit of O. cordieriana was placed at 200m.

In conclusion therefore, it may be stated that the Campanian and Maastrichtian chalks studied were probably deposited between depths of 150 - 250m., though it is likely that chalks from the North Sea Basins were deposited at somewhat greater depths, possibly within the range 200 - 300m. In Norfolk and the North Sea Basin a transgressive phase with increasing water depths appears to have been dominant in the Upper Campanian, though there is little evidence from the foraminiferal faunas of depths of deposition greater than 300m. In the Maastrichtian a general regressive phase occurred with depths of deposition in these regions possibly in the range 120 - 180m. In the Isle of Wight, a marked local shallowing appears to have occurred in the Middle and
Upper Campanian, possibly to depths as shallow as 100 - 150m. The causes of this local shallowing are difficult to determine, especially in view of the palaeogeographical setting of the region within the Wessex Basin. It is possible that a similar cause is responsible for the spectacular developments of hardground complexes in the Lower Campanian of the eastern (Culver Cliff) end of the Island. Peake and Hancock (1970) have suggested that contemporaneous movement of salt-domes during chalk deposition might have controlled local sedimentation in Norfolk. It is possible that either minor tectonic activity or salt movement may have controlled the depths of deposition of the Campanian chalk of the Isle of Wight and thus, might have produced the abnormally low P/B ratios recorded by Hart and Carter (1975) and Hart and Bailey (in press) in the post Coniacian succession of southern England.

8.6. Bottom conditions.

Hancock (1976) and Kennedy and Garrison (1975) have reviewed the evidence concerning probable bottom conditions pertaining during the Upper Cretaceous. Their conclusions, based on lithological and macrofaunal evidence, were that soft, thixotropic mud with a high water content, covered large areas of the sea floor which was not influenced by strong current activity. The periodic occurrence of hardgrounds indicates that some areas possessed a firm substrate and that increased current activity was present. Faunal adaptations to life on a soft muddy bottom are not readily apparent in the majority of the foraminifera studied, and it is not clear whether most of the fauna lived as infauna or as epifauna. Certain species of the genus Cibicides clearly show attachment marks. Surfaces of attachment are generally not present, though the general shape of the attached forms might indicate that flat shell fragments might have provided suitable sites.
The spherical growth forms, shown by P. of. cretse in the Campanian chalk of the Isle of Wight (as opposed to its more hemispherical form) (Bignot & Larsonneur 1969), might suggest that such surfaces were not common. Occasional enrolled specimens of Cibicides beaumontianus (= var. A. sensu Bailey 1978 MS.) have been found coiled around echinoid spines. The general predominance of strongly plano-convex morphotypes might indicate a mode of life resting directly on the sediment surface. Adaptations of foraminiferal species to hardground surfaces are also not obvious. It is possible that the flood of Angulogavelinella bettenstaedti in the Sponge Beds of Sidestrand may suggest such a relationship.

8.7. Sedimentation Rates.

Calculations of sedimentation rates are beset by problems related to stratigraphic breaks and problems of compaction. Kennedy and Garrison (1975) have calculated sedimentation rates of 2.0 - 2.4 cm/1000 years for the basal Cenomanian to top Campanian interval. Hakansson et al (1974) calculated a sedimentation rate of 15 cm/1000 years for the Maastrichtian chalk of N.W. Europe.

Assuming a rate of compaction of 10% (Hakansson et al 1974), and omitting corrections for stratigraphic gaps, the total thickness of chalk ooze deposited during the Lower and Middle Campanian in Scratchell's Bay was 110 m, occupying an estimated time span of 6 Ma from 82 Ma to 76 Ma, thus suggesting a net sedimentation rate of some 1.84 cm/1000 years.

8.8. Faunal Diversity

Index of Diversity values (α) after Williams (1947) have been calculated. These show values averaging 8 in the Lower Campanian, rising to approximately 14 in the Upper Campanian and Lower Maastrichtian.
Such results are indicative of normal, stable marine conditions. The marked trend towards increasing diversity throughout the Campanian, may be a reflection of the gradual establishment of a 'boreal' fauna, in response to decreasing water temperatures.
CHAPTER 9

CONCLUSIONS

The foraminiferal fauna from 25 onshore localities from England and two boreholes from the North Sea Basin has been investigated. This study has recorded the stratigraphic distribution of 160 species and subspecies of benthonic and planktonic foraminifera, belonging to 54 genera, on a bed by bed basis, to determine their stratigraphic potential. In total, some 700 individual samples have been examined and over 180,000 individual specimens of foraminifera isolated, described and classified. The effects of various processing techniques on the foraminiferal fauna has been investigated and discussed. In recognition of the fact that biostratigraphic conclusions are only as valid as the taxonomy on which they are based, a thorough revision of the systematics of the foraminifera encountered has been undertaken, with full synonymies and descriptions given for each taxon.

Some 65 species and subspecies of foraminifera have been recognised as being of prime stratigraphic importance. These have enabled the establishment of a tripartite zonal scheme based on planktonic foraminifera, Bolivinoides lineages, and faunal assemblages respectively. The biozones thus established, have been directly related to local rock units, as well as to currently accepted macrofossil biozones. The proposed biozonal scheme has enabled the detailed stratigraphic relationships of many isolated outcrops of chalk within the Norfolk region to be determined, and a detailed correlation to be made with the more continuous coastal exposures of southern England. The applicability of the proposed zonal scheme to offshore borehole material from the North Sea Basin, has been rigorously tested and proven.

The benthonic foraminiferal fauna of the British Campanian and
Maastrichtian chalks have been shown to possess strong affinities with those of N.W. Germany and the Paris Basin, and to a lesser extent, with those of other areas of Europe, as far apart as southern Scandinavia and the shores of the Caspian Sea. The specific composition of the planktonic foraminiferal fauna clearly places Britain within the Transitional biogeoprovine during the Campanian and Maastrichtian. Such a conclusion is in agreement with results obtained from palaeomagnetic studies.

The stratigraphic and geographic distribution of the foraminifera has been interpreted in the light of postulated palaeoecological controls. These studies indicate that an environment with normal marine salinities persisted throughout the Campanian and Maastrichtian, and that decreasing water temperatures characterized this time span. This cooling trend has been interpreted as the major control on the specific composition of the planktonic foraminiferal fauna. A short-lived warm climatic pulse in the latest Maastrichtian A. mayaroensis zone is suggested. Postulated patterns of palaeocurrents are discussed and are suggested to have occasionally introduced Tethyan faunal elements into the region. The depth of deposition of the chalk has also been considered and a predominant transgressive phase is concluded to have dominated the Upper Campanian, whilst a regressive phase dominated the Maastrichtian. In general terms, depths of deposition between 150 - 250m, are suggested for the chalk of Britain, though deposition at somewhat greater depths is considered likely for the chalk of the North Sea Basins. An atypical, local shallowing of the seas over the Isle of Wight during the Middle -Upper Campanian is postulated.

This study of the Foraminifera from the Campanian and Maastrichtian chalks of the United Kingdom has shown their great stratigraphic potential both in the study of onshore and offshore material. Their importance in the study of palaeoecology has also been explored and several important
inferences drawn. In this latter field especially, however, it is felt that much work is still to be done. It may well be, that only through a more intimate understanding of the palaeoecological factors governing their distribution, can we hope to fully utilize the stratigraphic potential of the Foraminiferida.
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108


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Plate 1.

1. Ammodiscus cretaceus (Reuss), 0103, Scratchell's Bay, sample Sc 139, Biozone B2 iii, x 45.
2. Ammodiscus parianus Hedberg, 3008, Scratchell's Bay, sample Sc 173, Biozone B2 ii, x 60.
3. Arenoturrispirillina sp. A., 3000, apertural view, Scratchell's Bay, sample Sc 171, Biozone B2 ii, x 60.
5. Spiroplectammina baudouiniana (d'Orbigny), 3003, Catton Grove, Norfolk, sample Cat.5, Biozone B3 iv, x 60.
6. Spiroplectammina baudouiniana (d'Orbigny), 2807, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iv, x 60.
7. Spiroplectammina baudouiniana (d'Orbigny), 2808, side view, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iv, x 60.
8. Bolivinopsis flexuosa (Reuss), 2500, fragment, Wells-next-the-Sea, Norfolk, sample WNS 3, Biozone B2 i, x 60.
9. Bolivinopsis flexuosa (Reuss), 3005, specimen showing initial coil, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii, x 60.
10. Verneuilina münsteri (Reuss), 3010, Overstrand, Norfolk, sample OLM-1, Biozone B5 i, x 60.
11. Gaudryina rugosa d'Orbigny, 3014, Frettenham, Norfolk, sample F5, Biozone B3 iv, x 30.
12. Gaudryina faujasi (Reuss), 3020, apertural view, Alderford, Norfolk, sample A5, Biozone B2 iii, x 60.
13. Gaudryina faujasi (Reuss), 3018, Catton Grove, Norfolk, sample Cat. 2, Biozone B3 iv, x 60.
15. *Gaudryina concinna* (Reuss), 3204, side view, Catton Grove, Norfolk, sample Cat. 3, Biozone B3 iv, x 60.

16. *Gaudryina concinna* (Reuss), 3205, Weybourne, Norfolk, sample Wl, Biozone B3 ii, x 60.

17. *Migros schoendorfii* Koch, 3022, apertural view, Arminghall, Norfolk, sample Arm. 5, Biozone B3 iv, x 75.

18. *Migros schoendorfii* Koch, 3021, Stiffkey, Norfolk, sample St. 2, Biozone B2 iii, x 75.

19. *Heterostomella rugosa* (d'Orbigny), 3106, Weybourne, Norfolk, sample Wl, Biozone B3 ii, x 60.

20. *Heterostomella rugosa* (d'Orbigny), 3105, Keswick, Norfolk, sample K2, Biozone B3 ii, x 60.

21. *Heterostomella foveolata* (Marsson), 3110, Sidestrand, Norfolk, sample S3 5, Biozone B6 i, x 60.

22. *Heterostomella foveolata* (Marsson), 3110, Overstrand, Norfolk, sample OUM 6, Biozone B5 i, x 60.

23. *Heterostomella gracilis* Hofker, 3206, Sidestrand, Norfolk, sample S6, Biozone B5 ii, x 60.

24. *Heterostomella gracilis* Hofker, 3207, apertural view, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii, x 60.

25. *Heterostomella gracilis* Hofker, 3208, Sidestrand, Norfolk, sample S3, Biozone B5 ii, x 60.
Plate 2.

1. *Tritaxia tricarinata* (Reuss), 3101, Caistor St. Edmunds, Norfolk, sample CS 1, Biozone B3 iv, x 60.

2. *Tritaxia tricarinata* (Reuss), 3100; elongate form, Caistor St. Edmunds, Norfolk, sample CS 1, Biozone B3 iv, x 60.

3. *Tritaxia tricarinata* (Reuss), 3102, apertural view, Caistor St. Edmunds, Norfolk, sample CS 1a, Biozone B3 iv, x 60.

4. *Arenobulimina courta* (Marie), 3501, Stiffkey, Norfolk, sample St. 4a, Biozone B2 iii, x 60.

5. *Arenobulimina elevata* (d'Orbigny), 2300, Overstrand, Norfolk, sample NP 2, Biozone B4 i, x 30.

6. *Arenobulimina elevata* (d'Orbigny), 2301, side view, Overstrand, Norfolk, sample NP 4, Biozone B4 i, x 30.

7. *Arenobulimina footei* Jennings, 3210, side view, Wells, Norfolk, sample WNS 7a, Biozone B2 i, x 60.

8. *Arenobulimina footei* Jennings, 3209, Caistor St. Edmunds, Norfolk, sample CS 8, Biozone B3 iv, x 60.

9. *Arenobulimina obliqua* (d'Orbigny), 3506, Alum Bay, sample AB 25, Biozone B3 ii, x 60.

10. *Arenobulimina obliqua* (d'Orbigny), 3507, side view, Alum Bay, sample Ab 5, Biozone B3 iii, x 60.

11. *Arenobulimina pseudorbignyi* Marie, 3509, Alum Bay, sample AB 28, Biozone B3 ii, x 60.

12. *Arenobulimina puschi* (Reuss), 2203, Caistor St. Edmunds, Norfolk, sample CS 1b, Biozone B3 iv, x 60.

13. *Dorothia pupa* (Reuss), 2403, apertural view, Alderford, Norfolk, sample Al, Biozone B2 iii, x 60.

14. *Dorothia pupa* (Reuss), 3402, side view, Catton Grove, Norfolk, sample Cat. 8, Biozone B3 iv, x 60.

16. *Marssonella trochus* (d'Orbigny), 1847, rapidly flaring form, Scratchell's Bay, sample Sc 111, Biozone B3 i, x 60.

17. *Marssonella trochus* (d'Orbigny), 1847, side view, gradually flaring "oxycon" form, Scratchell's Bay, sample Sc 151, Biozone B2 iii, x 60.

18. *Marssonella trochus* (d'Orbigny), same specimen apertural view, x 60.

19. *Marssonella trochus* (d'Orbigny), same specimen, x 60.

20. *Marssonella ellisorae* Cushman, 1944, oblique view, Overstrand, Norfolk, sample NP 3, Biozone B4 i, x 60.

21. *Marssonella conoidea* (Marie), 1906, apertural view, Arminghall, Norfolk, sample Arm. 5, Biozone B3 iv, x 60.

22. *Marssonella conoidea* (Marie), 1906, Whitlingham, Norfolk, sample W2, Biozone B4 i, x 60.

23. *Marssonella conoidea* (Marie), 1906, side view, Arminghall, Norfolk, sample Arm. 4, Biozone B3 iv, x 60.

24. *Marssonella ellisorae* Cushman, 1944, Overstrand, Norfolk, sample NP. 4, Biozone B4 i, x 60.
Plate 3.
(all magnifications x 60.)

1. *Eggerellina brevis* (d'Orbigny), 3306, microspheric 'globulosa' form, Alum Bay, sample AB 15, Biozone B3 iii.

2. *Eggerellina brevis* (d'Orbigny), 3307, same specimen, side view.

3. *Eggerellina brevis* (d'Orbigny), 3304, megalospheric 'conica' form, Alum Bay, sample AB 7, Biozone B3 iii.

4. *Eggerellina brevis* (d'Orbigny), 3305, megalospheric 'conica' form, side view, Alum Bay, sample AB 3, Biozone B3 iii.

5. *Ataxophragmium variabile* (d'Orbigny), 3309, Scratchell's Bay, sample Sc 159, Biozone B2 iii.

6. *Ataxophragmium variabile* (d'Orbigny), 3308, specimen broken to reveal internal buttresses, Alum Bay, sample AB 35, Biozone B3 ii.

7. *Ataxophragmium crassum* (d'Orbigny), 3312, Alum Bay, sample AB 17, Biozone B3 iii.

8. *Ataxophragmium crassum* (d'Orbigny), 3311, side view, same specimen.

9. *Ataxophragmium mariae* sp. nov., 3603, Alum Bay, sample AB 31, Biozone B3 ii.

10. *Ataxophragmium mariae* sp. nov., 3604, side view, Alum Bay, sample AB 16, Biozone B3-iii.

11. *Ataxophragmium rimosum* (Marsson), 3607, Overstrand, Norfolk, sample NP 3, Biozone B4 i.

12. *Ataxophragmium rimosum* (Marsson), 3608, side view, Overstrand, Norfolk, sample NP 3, Biozone B4 i.

13. *Orbignyna ovata* von Hagenow, 3405, Overstrand, Norfolk, sample NP 4, Biozone B4 i.

14. *Orbignyna ovata* von Hagenow, 3601, side view, Overstrand, Norfolk, sample NP 4, Biozone B4 i.
15. Voloshinovella aequisgranensis (Beissel), 3408, apertural view, Alum Bay, sample AB 13, Biozone B3 iii.

16. Voloshinovella aequisgranensis (Beissel), 3406, side view, Alum Bay, sample AB 4, Biozone B3 iii.

17. Voloshinovella aequisgranensis (Beissel), 3407, Alum Bay, sample AB 17, Biozone B3 iii.
Plate 4.
(all magnifications x 60.)

1. Neoflabellina rugosa rugosa (d'Orbigny), 0502, Catton Grove, Norfolk, sample Cat. 5, Biozone B3 iii.

2. Neoflabellina rugosa leptodisca (Wedekind), 4001, Prettenham, Norfolk, sample P5, Biozone B3 iv.

3. Neoflabellina rugosa leptodisca (Wedekind), 0406, form transitional to N. praereticulata, Whitlingham, Norfolk, sample W2, Biozone B4 i.

4. Neoflabellina baudouiniana (d'Orbigny), 0506, Wells, Norfolk, sample WNS 7a, Biozone B2 i.

5. Neoflabellina buticula Hiltermann, 0505, Keswick, Norfolk, sample KB, Biozone B3 ii.

6. Neoflabellina permutata Koch, 0503, Overstrand, Norfolk, sample NP 3, Biozone B4 i.


9. Neoflabellina reticulata (Reuss), 0401, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii.


11. Praebulimina carseyae (Plummer), 4030, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iv.

12. Praebulimina carseyae (Plummer), 4031, side view, Caistor St. E Edmunds, Norfolk, sample CS 5, Biozone B3 iv.

13. Praebulimina reussi (Morrow), 4028, Wells, Norfolk, sample WNS 4a, Biozone B2 i.

Plate 5.

1. Praebulimina laevis (Beissel), 3702, Overstrand, Norfolk, sample OUM 7, Biozone B5 i, x 60.

2. Praebulimina laevis (Beissel), 3703, side view, Trimingham, Norfolk, sample Tr. 3, Biozone B6 i, x 60.

3. Praebulimina obtusa (d'Orbigny), 2809, Alum Bay, sample AB 30, Biozone B3 ii, x 60.

4. Praebulimina obtusa (d'Orbigny), 2802, "inflated" variety, Alum Bay, sample AB 2, Biozone B3 iii, x 60.

5. Praebulimina obtusa (d'Orbigny), 2803, "inflated" variety, side view, Alum Bay, sample AB 2, Biozone B3 iii, x 60.

6. Praebulimina parva (Franke), 4028, Scratchell's Bay, sample Sc 180, Biozone B2 ii, x 100.

7. Praebulimina pseudoacuta (Marie), 3706, Alum Bay, sample AB 13, Biozone B3 iii, x 100.

8. Praebulimina pseudoacuta (Marie), 3704, Alum Bay, sample AB 13, Biozone B3 iii, x 100.

9. Pyramidina minuta (Marsson), 4002, oblique view, Trimingham, Norfolk, sample Tr. 4, Biozone B6 i, x 150.

10. Pyramidina minuta (Marsson), 4003, side view, Trimingham, Norfolk, Tr. 4, Biozone B6 i, x 150.

11. Pyramidina rudita (Cushman & Parker), 1215, oblique view, Scratchell's Bay, sample Sc 168, Biozone B2 ii, x 150.

12. Pyramidina rudita (Cushman & Parker), 4003, side view, Scratchell's Bay, sample Sc 168, Biozone B2 ii, x 150.

13. Pyramidina trigona (Chapman), 1204, Scratchell's Bay, sample Sc 208, Biozone Bl iii, x 150.

15. **Bolivina decurrens** (Ehrenberg), 0703, Overstrand, Norfolk, sample OLM 3, B5 i, x 100.

16. **Bolivina decurrens** (Ehrenberg), 0704, oblique side view, Overstrand, Norfolk, sample OLM 3, Biozone B5 i, x 100.

17. **Bolivina incrassata** Reuss, 1412, megalospheric form, Overstrand, Norfolk, sample OUM 7, Biozone B5 i, x 60.

18. **Bolivina incrassata** Reuss, 4513, microspheric form, Trimingham, Norfolk, sample Tr. 2, Biozone B6 i, x 60.

19. **Bolivinoides draco draco** (Marsson), 3805, Shell 44/2-1, cutting sample 3240, x 100.

20. **Bolivinoides draco miliaris** Hiltermann & Koch, 2915, Trimingham, Norfolk, sample Tr. 2, Biozone B6 i, x 100.

21. **Bolivinoides draco miliaria** Hiltermann & Koch, 2917, apertural view, Postwick, Norfolk, sample PR 1, Biozone B4 i, x 100.

22. **Bolivinoides draco miliaris** Hiltermann & Koch, 2916, side view, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii, x 100.
Plate 6.

1. Bolivinoides australis Edgell, 2912, Overstrand, Norfolk, sample NP 4, Biozone B4 i, a transitional specimen from B. decoratus showing typically broader form and lobes but lacking initial nodosities of B. australis, x 100.

2. Bolivinoides decoratus (Jones), 4004, Overstrand, Norfolk, sample NP 4, Biozone B4 i, a transitional specimen to B. australis, x 100.

3. Bolivinoides decoratus (Jones), 4902, Caistor St. Edmunds, Norfolk, sample CS 5a, Biozone B3 iv, x 100.

4. Bolivinoides decoratus (Jones), 2907, side view, Alum Bay, sample AB 7, Biozone B3 iii, x 100.

5. Bolivinoides culverensis Barr, 4010, Scratchell's Bay, sample So 140, Biozone B2 iii, x 100.


7. Bolivinoides stri-filatus (Chapman), 4200, Shell 44/2-1, cutting sample 4140, Biozone Bl, x 100, a large, poorly preserved specimen typical of specimens from the North Sea.

8. Bolivinoides stri-filatus (Chapman), 4200, same specimen, apertural view, x 100.


10. Bolivinoides laevigatus laevigatus Marie, 4903, Eaton, Norfolk, sample El, Biozone B3 iii, x 100.

11. Bolivinoides peterssoni Brotzen, 2927, Overstrand, Norfolk, sample OUM 10, Biozone B5 i, x 100.

12. Bolivinoides paleocenicus (Brotzen), 4015, Sidestrand, Norfolk, sample SS 5, Biozone B6 i, x 100.
13. Bolivinoides paleocenicus (Brotzen), 2931, side view, Sidestrand, Norfolk, sample SS 5, Biozone B6 i, x 100.

14. Bolivinoides sidestrandensis Barr, 4016, Overstrand, Norfolk, sample OUM 7, Biozone B5 i, x 100.

15. Tappanina selmensis (Cushman), 4017, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii, x 200.

16. Tappanina selmensis (Cushman), 4018, side view, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii, x 200.

17. Eouvigerina aculeata (Ehrenberg), 4025, Caistor St. Edmunds, Norfolk, sample CS 2a, Biozone B3 iv, x 150.

18. Eouvigerina aculeata (Ehrenberg), 4024, side view, Caistor St. Edmunds, Norfolk, sample CS 2a, Biozone B3 iv, x 150.

19. Eouvigerina sp. A., 1134, side view, Scratchell's Bay, sample Sc 207, Biozone B1 iii, x 100.

20. Eouvigerina sp. A., 1135, Scratchell's Bay, sample Sc 207, Biozone B1 iii, x 100.

21. Eouvigerina sp. B., 4905, side view, Trimingham, Norfolk, sample Tr. 2, Biozone B6 i, x 100.

22. Eouvigerina sp. B., 4906, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii, x 100.

23. Eouvigerina (?) galeata (Vasilenko), 0802, side view, Scratchell's Bay, sample Sc 170, Biozone B2 ii, x 150.

24. Eouvigerina (?) galeata (Vasilenko), 0803, Scratchell's Bay, sample Sc 170, Biozone B2 ii, x 150.

25. Stilostomella pseudoscripta (Cushman), 3720, Overstrand, Norfolk, sample OUM 10, Biozone B5 i, x 100.
Plate 7.
(all magnifications x 100.)

1. Reussella kelleri Vasilenko, 1406, side view, Wells, Norfolk, sample WNS la, Biozone B1 iii.
2. Reussella kelleri Vasilenko, 1405, same sample.
3. Reussella kelleri, Vasilenko, 1407, same sample, apertural view.
4. Reussella szajnochae szajnochae (Grzybowski), 1402, Overstrand, Norfolk, sample NP 1.
5. Reussella szajnochae szajnochae (Grzybowski), 1404, same sample, oblique view.
6. Reussella szajnochae szajnochae (Grzybowski), 1401, same sample, apertural view.
7. Reussella szajnochae praecursor de Klasz & Knipscheer, 4224, Stiffkey, Norfolk, sample St. 1, Biozone B2 iii.
8. Reussella szajnochae praecursor de Klasz & Knipscheer, 4023, side view, Stiffkey, Norfolk, sample St. 4, Biozone B2 iii.
9. Pseudouvigerina cristata (Marsson), 4519, side view, Trimingham, Norfolk, sample Tr. 2, Biozone B6 i.
10. Pseudouvigerina cristata (Marsson), 4520, Overstrand, Norfolk, sample OUM 7, Biozone B5 i.
11. Pseudouvigerina plummerae Cushman, 4516, oblique view, Alum Bay, sample AB 25, Biozone B3 ii.
12. Pseudouvigerina plummerae Cushman, 4517, side view, Alum Bay, sample AB 12, Biozone B3 iii.
13. Pseudouvigerina plummerae Cushman, 4518, oblique view, Caistor St. Edmunds, Norfolk, sample CS 1b, Biozone B3 iv.
14. Pseudouvigerina rugosa Brotzen, 4514, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii.
15. *Pseudouvigerina ruposa* Brotzen, 4515, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii.


17. *Conorbina cf. marginata* Brotzen, 4914, spiral view, Sheringham, Norfolk, sample Sh. 5, Biozone B3 iv.

18. *Conorbina cf. marginata* Brotzen, 4915, side view, Caistor St. Edmunds, Norfolk, sample CS 2, Biozone B3 iv.

19. *Conorbina sigmoidalis* (Schijfsma), 4911, umbilical view, Overstrand, Norfolk, sample OUM 10, Biozone B5 i.

20. *Conorbina sigmoidalis* (Schijfsma), 4912, side view, Alum Bay, sample AB 23, Biozone B3 ii.

21. *Conorbina sigmoidalis* (Schijfsma), 4913, spiral view, Alum Bay, sample AB 93, Biozone B3 i.

22. *Neoconorbina scanica* (Brotzen), 3826, oblique umbilical view, Scratchell's Bay, sample So 133, Biozone B3 i.

23. *Neoconorbina scanica* (Brotzen), 3825, side view, Scratchell's Bay, sample So 121, Biozone B3 i.


26. *Neoconorbina cf. sulcata* (Roemer), 4917, spiral view, Sheringham, Norfolk, sample Sh. 4, Biozone B3 iv.
1. *Valvulineria lenticula* (Reuss), 3901, umbilical view, Catton Grove, Norfolk, sample Cat. 8, Biozone B3 iv, x 100.

2. *Valvulineria lenticula* (Reuss), 3903, side view, Arminghall, Norfolk, sample A 4, Biozone B3 iv, x 100.

3. *Valvulineria mariei* Vasilenko, 5119, umbilical view, Alum Bay, sample Ab 74, Biozone B3 i, x 100.

4. *Valvulineria mariei* Vasilenko, 5120, side view, same sample, x 100.

5. *Eponides beisseli* Schijfsma, 1006, umbilical view, Sidestrand, Norfolk, sample S1, Biozone B5 ii, x 70.

6. *Eponides beisseli* Schijfsma, 1009, side view, Sidestrand, Norfolk, sample S6, Biozone B5 ii, x 70.

7. *Eponides biconvexa* Marie, 5118, umbilical view, Alum Bay, sample AB 62, Biozone B3 i, x 100.

8. *Eponides biconvexa* Marie, 3908, side view, Alum Bay, sample AB 98, Biozone B3 i, x 100.


10. *Eponides concinna* Brotzen, 5122, side view, Scratchell's Bay, sample Sc 139, Biozone B3 i, x 100.

11. *Cibicides beaumontianus* (d'Orbigny), 4417, Alderford, Norfolk, sample Al, Biozone B2 iii, x 100.

12. *Cibicides beaumontianus* (d'Orbigny), 1211, side view, Scratchell's Bay, Sample Sc 152, Biozone B2 iii, x 100.

13. *Cibicides bosqueti* (Reuss), 4419, umbilical view, Sidestrand, Norfolk, sample S6, Biozone B5 ii, x 100.

14. *Cibicides bosqueti* (Reuss), 4420, side view, Sidestrand, Norfolk, sample S 7, Biozone B5 ii, x 100.
15. *Cibicides bosqueti* (Reuss), 4422, spiral view, same sample, x 100

16. *Cibicides ribbingi* Brotzen, 1131, umbilical view, Scratchell's Bay, sample Sc 152, Biozone B2 iii, x 100.

17. *Cibicides ribbingi* Brotzen, 1213, spiral view, same specimen, x 100.


20. *Planorbulina cf. cretae* (Marsson), 4522, same specimen, oblique view, x 60.
Plate 9.

1. *Heterohelix complanata* (Marie), 1712, side view, Overstrand, Norfolk, sample NP 2, Biozone B4 i, x 200.

2. *Heterohelix complanata* (Marie), 1717, apertural view, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii, x 200.

3. *Heterohelix complanata* (Marie), 1713, edge view, Overstrand, Norfolk, sample NP1, Biozone B4 i, x 200.

4. *Heterohelix striata* (Ehrenberg), 1705, side view, Caistor St. Edmunds, Norfolk, sample CS 5a, Biozone B3 iv, x 200.


6. *Heterohelix striata* (Ehrenberg), 1705, close-up of final chamber, same specimen as fig. 4, x 400.

7. *Pseudotextularia elegans* (Rzehak), 1401, side view, Shell 29/25-1, cutting sample 6160, Uppermost Maastrichtian, Biozone B7 i, x 100.

8. *Pseudotextularia elegans* (Rzehak), 1402, edge view, Shell 29/25-1, cutting sample 6200, Upper Maastrichtian, Biozone B7 i, x 100.


10. *Globigerinelloides aspera* (Ehrenberg), 1801, oblique apertural view showing relict apertures, Caistor St. Edmunds, Norfolk, sample CS 5a, Biozone B3 iv, x 100.

11. *Globigerinelloides aspera* (Ehrenberg), 1404, close-up of apertural lip, same specimen, x 200.

12. *Globigerinelloides* cf. *bollii* Pessagno, 4804, side view, Caistor St. Edmunds, Norfolk, sample CS 3, Biozone B3 iv, x 100.

13. *Globigerinelloides* cf. *bollii* Pessagno, 5103, apertural view same specimen, x 100.
14. **Globigerinelloides multispina** (Lalicker), 1915, side view of specimen with paired final chambers, Caistor St. Edmunds, Norfolk, sample CS 7, Biozone B3 iv, × 100.

15. **Globigerinelloides multispina** (Lalicker), 1901, apertural view of specimen with paired apertures and offset, kummerform final chamber, Caistor St. Edmunds, Norfolk, sample CS 3a, Biozone B3 iv, × 100.

16. **Globigerinelloides multispina** (Lalicker), 1909, apertural view of specimens with paired final chambers, Whitlingham, Norfolk, sample W4, Biozone B4 i, × 100.

17. **Hedbergella holmdelensis** Olsson, 1912, umbilical view, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii, × 100.


19. **Hedbergella holmdelensis** Olsson, 2000, spiral view, specimen showing axial elongation of chambers, Caistor St. Edmunds, Norfolk, sample CS 4, Biozone B3 iv, × 100.
Plate 10.
(all magnifications x 100.)

1. *Hedbergella (?) monmouthensis* (Olsson), 4403, umbilical view, Trimingham, Norfolk, sample Tr. 4, Biozone B6 i.

2. *Hedbergella (?) monmouthensis* (Olsson), 5002, same specimen apertural view.

3. *Globotruncanella havanensis* (Voorwijk), 4208, umbilical view, Shell 44/2-1, cutting sample 3420.

4. *Globotruncanella havanensis* (Voorwijk), 4209, side view, Trimingham, Norfolk, sample Tr. 4, Biozone B6 i.

5. *Abathomphalus intermedius* (Bolli), 4205, umbilical view, Shell 44/2-1, cutting sample 3300.

6. *Abathomphalus intermedius* (Bolli), 4207, Shell 44/2-1, cutting sample 3480.

7. *Abathomphalus intermedius* (Bolli), 4206, spiral view, Shell 44/2-1, cutting sample 3360.

8. *Abathomphalus mayaroensis* (Bolli), 4203, umbilical view, Shell 44/2-1, cutting sample 3600.

9. *Abathomphalus mayaroensis* (Bolli), side view, Shell 44/2-1, cutting sample 3960.

10. *Abathomphalus mayaroensis* (Bolli), 4202, spiral view, Shell 44/2-1, cutting sample 3060.

11. *Globotruncana arca* (Cushman), 1608, umbilical view, Weybourne, Norfolk, sample W7, Biozone B3 ii.

12. *Globotruncana arca* (Cushman), 1604, side view, Keswick, Norfolk, sample K2, Biozone B3 ii.

13. *Globotruncana arca* (Cushman), 1605, spiral view, Arminghall, Norfolk, sample A5, Biozone B3 iv.

14. *Globotruncana bulloides bulloides* (Vogler), 4506, umbilical view, Sheringham, Norfolk, sample Sh. 4, Biozone B3 iv.
15. **Globotruncana bulloides bulloides** (Vogler), 1615, side view, Keswick, Norfolk, sample K6, Biozone B3 ii.

16. **Globotruncana bulloides bulloides** (Vogler), 1613, spiral view, Keswick, Norfolk, sample K5, Biozone B3 ii.
Plate 11.
(all magnifications x 100.)

1. *Globotruncana bulloides austinensis* Gandolfi, 1612, umbilical view, Keswick, Norfolk, sample K3, Biozone B3 ii.

2. *Globotruncana bulloides austinensis* Gandolfi 5004, same specimen, side view.

3. *Globotruncana bulloides austinensis* Gandolfi, 4806, same specimen, spiral view.


5. *Globotruncana fornicata* Plummer, 5002, side view, advanced form, Caistor St. Edmunds, Norfolk, sample CS 4, Biozone B3 iv.

6. *Globotruncana fornicata* Plummer, 4214, spiral view, same specimen.


8. *Globotruncana contusa patelliformis* Gandolfi, 5016, spiral view, same specimen.


11. *Globotruncana hilli* Pessagno, 4304, spiral view, same sample.

12. *Globotruncana linneiana* (d'Orbigny), 4416, umbilical view, Shell 44/2-1, cutting sample 3780.

13. *Globotruncana linneiana* (d'Orbigny), 5001, side view, Scratchell's Bay, sample Sc 100, Biozone B3 i.
Plate 12.
(all magnifications x 100 except fig. 11. x 250.)

1. Globotruncana plummerae Gandolfi, 4505, umbilical view, Eaton, Norfolk, sample E2, Biozone B3 iii.
2. Globotruncana plummerae Gandolfi, 4412, side view, Arminghally, Norfolk, sample A5, Biozone B3 iv.
3. Globotruncana plummerae Gandolfi, 4221, Eaton, Norfolk, sample E2, Biozone B3 iii.
4. Globotruncana ruposa (Marie), 4222, umbilical view, final chamber broken, Caistor St. Edmunds, Norfolk, sample 1a, Biozone B3 iv.
5. Globotruncana ruposa (Marie), 4220, side view, Alum Bay, sample AB 73, Biozone B3 i.
6. Globotruncana ruposa (Marie), 4509, spiral view, Eaton, Norfolk, sample E2, Biozone B3 iii.
8. Globotruncana ventricosa White, 5005, side view, Caistor St. Edmunds, Norfolk, sample CS 2, Biozone B3 iv.
9. Globotruncana ventricosa White, 1602, spiral view, Weybourne, Norfolk, sample W2, Biozone B3 ii.
10. Archaeoglobigerina cretacea (d'Orbigny), 1502, umbilical view, Alderford, Norfolk, sample A1, Biozone B2 iii.
11. Archaeoglobigerina cretacea (d'Orbigny), 1501, close-up of final chamber, side view showing keel development, Alderford, Norfolk, sample A3, Biozone B2 iii.
12. Archaeoglobigerina cretacea (d'Orbigny), 1507, spiral view, Caistor St. Edmunds, Norfolk, sample CS 1a, Biozone B3 iv.
13. Rupoglobigerina ruposa (Plummer), 4310, umbilical view, Overstrand, Norfolk, sample OUM 2, Biozone B5 i.

15. *Rugoglobigerina rufosa* (Plummer), 4312, side view, Overstrand, Norfolk, sample OUM 8, Biozone B5 i.
Plate 13.
(all magnifications x 100.)

1. *Rugoglobigerina milamensis* Smith & Pessagno, 4415, umbilical view, Overstrand, Norfolk, sample OUM 8, Biozone B5 i.

2. *Rugoglobigerina milamensis* Smith & Pessagno, 2105, side view, Overstrand, Norfolk, sample OLM 4, Biozone B5 i.


8. *Pleurostomella subnodosa* (Reuss), 4428, side view, Overstrand, Norfolk, sample NP 2, Biozone B4 i.

9. *Pleurostomella subnodosa* (Reuss), 4427, Caistor St. Edmonds, Norfolk, sample CS 7, Biozone B3 iv.


11. *Ellipsidella gracillima* (Cushman), 4431, front view, Postwick, Norfolk, sample PR 1, Biozone B4 i.

12. *Bandyella of. creatvalleyensis* (Trujillo), 4430, side view, Overstrand, Norfolk, sample OLM -1, Biozone B5 i.


14. *Coryphostoma pliata* (Carsey), 4425, side view, Whitlingham, Norfolk, sample W4, Biozone B4 i.
15. *Coryphostoma piliata* (Carey), 4426, same sample.

16. *Coryphostoma limbosa* (Cushman), 4424, side view, Overstrand, Norfolk, sample OLM 5, Biozone B5 i.

17. *Coryphostoma limbosa* (Cushman), 4424, side view, same specimen.

18. *Coryphostoma aff. selmaensis* (Cushman), 5113, front view, Shell 44/2-1, cutting sample 3240, Biozone B7 i.

19. *Coryphostoma aff. selmaensis* (Cushman), 3708, side view, Shell 44/2-1, cutting sample 3060, Biozone B7 i.
Plate 14.
(all magnifications x 100 except fig. 3 x 400.)

1. Loxostomum ele-vi (Cushman), 0904, side view, Alum Bay, sample AB 20, Biozone B3 iii.
2. Loxostomum ele-vi (Cushman), 0906, side view, Scratchell's Bay, sample So 172, Biozone B2 ii.
3. Loxostomum ele-vi (Cushman), 0905, close-up aperture, same specimen.
4. Coryphostoma volgi (Brotzen), 5012, side view, Stiffkey, Norfolk, sample St. 1, Biozone B3 iii.
5. Coryphostoma volgi (Brotzen), 4421, front view, Scratchell's Bay, sample So 170, Biozone B2 ii.
6. Quadrimorphina allomorphinoides (Reuss), 4524, umbilical view, large specimen, Alderford, Norfolk, sample A3, Biozone B2 iii.
7. Quadrimorphina allomorphinoides (Reuss), 4524, side view, same specimen.
8. Quadrimorphina trochoides (Reuss), 3305, Alum Bay, sample AB 3, Biozone B3 iii.
9. Pullenia quaternaria (Reuss), 4813, Caistor St. Edmunds, Norfolk, sample GS 2, Biozone B3 iv.
10. Pullenia quaternaria (Reuss), 5013, same specimen, umbilical view.
11. Pullenia reussi Cushman & Todd, 4814, Sidestrand, Norfolk, sample SS 5, Biozone B6 i.
12. Pullenia reussi Cushman & Todd, 5014, same specimen, umbilical view.
13. Oaancularia cordieriana (d'Orbigny), 0907, umbilical view, Scratchell's Bay, sample So 125, Biozone B3 i.
14. Oaancularia cordieriana (d'Orbigny), 5112, side view, Scratchell's Bay, sample So 125, Biozone B3 i.
15. Oaancularia polyanamera (Vasilonko), 4812, umbilical view, Scratchell's Bay, sample So 149a, Biozone B2 iii.
16. Osanularia polycamerata (Vasilenko), 4209, side view, Scratchell's Bay, sample So 122, Biozön B3 i.
Plate 15.
(all magnifications x 100.)

1. *Osangularia navarroana* (Cushman), 5109, umbilical view, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii.
2. *Osangularia navarroana* (Cushman), 5110, side view, same sample.
3. *Osangularia whitei* (Brotzen), 4527, umbilical view, Wells, Norfolk, sample WNS 1a, Biozone B1 iii.
4. *Osangularia whitei* (Brotzen), 4528, side view, same sample.
5. *Globorotalites conicus* (Carsey), 5008, umbilical view, Frettenham, Norfolk, sample F2, Biozone B3 iv.
7. *Globorotalites hiltermanni* Kaever, 4604, umbilical view, Caistor St. Edmunds, Norfolk, sample CS 1, Biozone B3 iv.
9. *Globorotalites micheliniana* (d'Orbigny), 2602, umbilical view, Catton Grove, Norfolk, sample Cat. 1, Biozone B3 iii.
10. *Globorotalites micheliniana* (d'Orbigny), 4607, side view, same specimen.
11. *Gyroidinoides nitida* (Reuss), 4609, umbilical view, Wells, Norfolk, sample WNS 5a, Biozone B2 i.
12. *Gyroidinoides nitida* (Reuss), 4610, side view, Caistor St. Edmunds, Norfolk, sample CS 6a, Biozone B3 iv.
13. *Gyroidinoides nitida* (Reuss), 4608, spiral view, Wells, Norfolk, sample WNS 4a, Biozone B2 i.
14. *Angulopavelinella bettenstaedti* Hofker, 4611, umbilical view, large specimen, Shell 44/2-1, cutting sample 3920.
15. *Angulopavelinella bettenstaedti* Hofker, side view, Sidestrand, Norfolk, sample SS 5, Biozone B6 i.
16. *Angulogavelinella bettenstaedti* Hofker, 4613, spiral view, Shell 44/2-1, cutting sample 3900.
Plate 16.
(all magnifications x 100.)

1. Gavelinella complanata (Reuss), 1105, umbilical view, Overstrand, Norfolk, sample NP 1, Biozone B4 i.
2. Gavelinella complanata (Reuss), 1109, apertural view, same sample.
3. Gavelinella complanata (Reuss), 1110, spiral view, same sample.
4. Gavelinella pertusa (Marsson), 2612, umbilical view, Overstrand, Norfolk, sample NP 4, Biozone B4 i.
5. Gavelinella pertusa (Marsson), 2613, apertural view, same sample.
6. Gavelinella pertusa (Marsson), 2614, spiral view, same sample.
7. Gavelinella lorneiana (d'Orbigny), 1156, umbilical view, Alum Bay, sample AB 26, Biozone B3 ii.
8. Gavelinella lorneiana (d'Orbigny), 1157, apertural view, Alum Bay, sample AB 31, Biozone B3 ii.
9. Gavelinella lorneiana (d'Orbigny), 1158, spiral view, Alum Bay, sample AB 26, Biozone B3 ii.
10. Gavelinella monterelensis (Marie), 0702, umbilical view, Alum Bay, sample AB 25, Biozone B3 ii.
11. Gavelinella monterelensis (Marie), 0705, apertural view, same sample.
12. Gavelinella monterelensis (Marie), 0706, spiral view, same sample.
13. Gavelinella multipunctata (Bandy), 4618, umbilical view, Overstrand, Norfolk, sample NP 3, Biozone B4 i.
14. Gavelinella multipunctata (Bandy), 4619, same sample.
15. Gavelinella multipunctata (Bandy), 4620, spiral view, same sample.

151
Plate 17.

(all magnifications x 100.)

1. *Gavelinella stelligera* (Marie), 0603, umbilical view, Scratchell's Bay, sample So 184, Biozone B2 i.

2. *Gavelinella stelligera* (Marie), 0602, apertural view, Scratchell's Bay, sample So 186, Biozone B2 i.


4. *Gavelinella thalmanni* (Brotzen), 4617, umbilical view, Scratchell's Bay, sample So 152, Biozone B2 iii.

5. *Gavelinella thalmanni* (Brotzen), 4615, apertural view, same sample.

6. *Gavelinella thalmanni* (Brotzen), 4616, spiral view, same sample.

7. *Gavelinella cristata Brotzeni* (Goel), 1123, umbilical view, Scratchell's Bay, sample So 192, Biozone B1 iii.

8. *Gavelinella cristata Brotzeni* (Goel), 1126, apertural view, Scratchell's Bay, sample So 193, Biozone B1 iii.

9. *Gavelinella cristata Brotzeni* (Goel), 1124, spiral side, Scratchell's Bay, sample So 200, Biozone B1 iii.

10. *Gavelinella cristata cristata* (Goel), 4625, umbilical view, Scratchell's Bay, sample MH 55, B1 iii.

11. *Gavelinella cristata cristata* (Goel), 4625, apertural view, Scratchell's Bay, sample So 199, Biozone B1 iii.

12. *Gavelinella cristata cristata* (Goel), 4626, spiral view, Scratchell's Bay, sample MH 55, B1 iii.


15. *Gavelinella usakensis* (Vasilenko), 1217, spiral view, same specimen.
Plate 18.
(all magnifications x 100.)

1. *Gavelinella trochus* (Goel), 4801, umbilical view, Scratchell's Bay, sample Sc 134, Biozone B3 i.
2. *Gavelinella trochus* (Goel), 5007, apertural view, same specimen.
3. *Gavelinella trochus* (Goel), 4802, spiral view, Scratchell's Bay, sample Sc 136, Biozone B3 i.
4. *Gavelinella clementiana clementiana* (d'Orbigny), 1163, umbilical view, Alum Bay, sample AB 15, Biozone B3 iii.
5. *Gavelinella clementiana clementiana* (d'Orbigny), 1161, apertural view, Alum Bay, sample AB 11, Biozone B3 iii.
6. *Gavelinella clementiana clementiana* (d'Orbigny), 1162, spiral view, Alum Bay, sample AB 15, Biozone B3 iii.
7. *Gavelinella clementiana laevigata* (Marie), 4701, umbilical view, showing well developed umbilical flaps, Caistor St. Edmonds, Norfolk, sample CS 2, Biozone B3 iv.
8. *Gavelinella clementiana laevigata* (Marie), 4703, apertural view of specimen with broken final chamber, Catton Grove, Norfolk, sample Cat. 4, Biozone B3 iii.
9. *Gavelinella clementiana laevigata* (Marie), 4702, spiral view, Frettenham, Norfolk, sample F4, Biozone B3 iv.
10. *Gavelinella bembix* (Marsson), 1146, spiral side, Trimingham, Norfolk, sample Tr. 5, Biozone B6 ii.
11. *Gavelinella bembix* (Marsson), 1201, apertural view, Trimingham, Norfolk, sample Tr. 6, Biozone B6 ii.
12. *Gavelinella bembix* (Marsson), 1202, oblique umbilical view, same specimen.
Plate 19.
(al magnifications x 100.)

1. *Gavelinella denticulata* (Marie), 5108, spiral view, Catton Grove, Norfolk, sample Cat. 1, Biozone B3 iii.

2. *Gavelinella denticulata* (Marie), 4708, apertural view, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iii.

3. *Gavelinella denticulata* (Marie), 4709, umbilical view, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iv.

4. *Gavelinella eriksdalensis* (Brotzen), 4705, spiral view, Wells, Norfolk, sample WNS 6, Biozone B2 i.

5. *Gavelinella eriksdalensis* (Brotzen), 1310, apertural view, Stiffkey, Norfolk, sample St. 6, Biozone B2 iii.

6. *Gavelinella eriksdalensis* (Brotzen), 1309, umbilical view, Stiffkey, Norfolk, sample St. 1a, Biozone B2 iii.

7. *Gavelinella involuta* Hofker, 4715, spiral view, Scratchell's Bay, sample Sc 136, Biozone B3 i.


9. *Gavelinella involuta* Hofker, 4713, umbilical view, Scratchell's Bay, sample Sc 135, Biozone B3 i.

10. *Gavelinella voltziana* (d'Orbigny), 4712, spiral view, Caistor St. Edmunds, Norfolk, sample CS 5, Biozone B3 iv.

11. *Gavelinella voltziana* (d'Orbigny), 5019, apertural view of specimen with broken final chamber, Alum Bay, sample AB 20, Biozone B3 iii.

12. *Gavelinella voltziana* (d'Orbigny), 4711, umbilical view, Alum Bay, sample AB 20, Biozone B3 iii.
Plate 20.
(all magnifications x 100.)

1. Stensioina exsculpta gracilis Brotzen, 4716, umbilical side,
   Stiffkey, Norfolk, sample St. 4a, Biozone B2 iii.

2. Stensioina exsculpta gracilis Brotzen, 4717, apertural view,
   Stiffkey, Norfolk, sample St. 5, Biozone B2 iii.

3. Stensioina exsculpta gracilis Brotzen, 4718, spiral view, same sample.

4. Stensioina granulata inconcita Koch, 5106, umbilical view, Wells,
   Norfolk, sample WNS 6, Biozone B2 i.

5. Stensioina granulata inconcita Koch, 4807, apertural view,
   Scratchell's Bay, sample So 174, Biozone B2 ii.

6. Stensioina granulata inconcita Koch, 5009, spiral view, Scratchell's
   Bay, sample So 180, Biozone B2 ii.

7. Stensioina granulata inconcita Koch, 4719, spiral view, Scratchell's
   Bay, sample So 192, Biozone B2 i.

8. Stensioina pommerana Brotzen, 5018, umbilical view, Overstrand,
   Norfolk, sample NP 4, Biozone B4 i.

9. Stensioina pommerana Brotzen, 5022, apertural view, Caistor St.
   Edmunds, Norfolk, sample CS 3, Biozone B3 iv.

10. Stensioina pommerana Brotzen, 5016, spiral view, Alum Bay, sample
    AB 22, Biozone B3 ii.
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