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Abstract: Foraminiferal biostratigraphy has been used extensively in the re-survey of the Chalk Group of southern England since the 1990s and a biozonation based on 21 zones and numerous subzones has been developed. The scheme is closely related to, and extensively tested against, the new lithostratigraphy for the Chalk Group based on examination of well described key chalk exposures, from significant borehole cores, many additional short sequences in chalk exposures and a large number of field samples taken throughout southern England, including the Isle of Wight. The BGS zonal scheme is defined in its entirety for the first time herein and correlated with the currently available United Kingdom benthonic foraminiferal scheme.



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Editor
Proceedings of the Geologists Association.

Dear Sir

I have attended to the majority of the corrections identified by the reviewer and I resubmit 'Foraminiferal biozones and their relationship to the lithostratigraphy of the Chalk Group of southern England' for consideration for the themed set on the Isle of Wight.

The reviewer's comment attached to the title of section 3 is strange one as I have said that the biozonation follows, emends and up dates the biostratigraphies of Hart, Swicicki, Bailey, etc. I also find the comment on the absence of index fossils rather strange. This is a problem everywhere, whether you are dealing with ammonites, corals, coccoliths, etc, etc. If the index fossil is not found it is impossible to recognise a zone—it is not just a weakness in foraminifera.

Yours sincerely

Ian Wilkinson



INVESTOR IN PEOPLE



**Foraminiferal Biozones and their relationship to the lithostratigraphy of the
Chalk Group of southern England**

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ABSTRACT. Foraminiferal biostratigraphy has been used extensively in the re-survey of the Chalk Group of southern England since the 1990s and a biozonation based on 21 zones and numerous subzones has been developed. The scheme is closely related to, and extensively tested against, the new lithostratigraphy for the Chalk Group based on examination of well described key chalk exposures, from significant borehole cores, many additional short sequences in chalk exposures and a large number of field samples taken throughout southern England, including the Isle of Wight. The BGS zonal scheme is defined in its entirety for the first time herein and correlated with the existing United Kingdom benthonic foraminiferal scheme.

Key words: Late Cretaceous, Foraminifera, Biostratigraphy, Southern England

1. Introduction

An early foraminiferal biozonation for southern England was erected by Williams-Mitchell (1948), but modern biostratigraphical applications of foraminifera from the Chalk Group was developed, principally, during the 1970's (e.g. Hart, 1970, 1973; Carter and Hart, 1977; Bailey, 1978; Swiecicki, 1980). More recently it has become evident that a high precision biostratigraphy is possible when foraminiferal inceptions and extinctions are related to detailed lithostratigraphy including named marl seams, flint bands and sponge beds. In addition, a major revision of the lithostratigraphical framework of the Chalk Group has taken place (Mortimore, 1986; Bristow et al., 1997; Mortimore et al., 2001; Rawson et al., 2001; Hopson, 2005). For these reasons a reconsideration of the definitions of earlier foraminiferal zonal schemes was carried out by Wilkinson (2000).

The scheme presented here is based on unpublished data collected during mapping carried out by the British Geological Survey (BGS) in the South Downs, North Downs, Marlborough Downs, Berkshire Downs and Chilterns, together with unpublished data sets (e.g. BGS Trunch Borehole and Norfolk chalks). The unpublished PhD theses by Hart (1970), Bailey (1978) and Swiecicki (1980) provide

1 | valuable information and, together with Carter and Hart (1977), Hart (1982), Bailey et
2 | al. (1984), Jarvis et al. (1988), Hart et al. (1989) and Paul et al. (1999) are fundamental
3 | to the zonal scheme adopted here. More recently, Hart (2000), Hampton et al. (2007)
4 | and Hart (2008) have added important data sets incorporated in the zonal scheme
5 | presented here.
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9 | The present paper is confined to the chalk succession of southern England,
10 | although for the sake of completeness, the zones recognised in Norfolk are also
11 | described. Detailed analysis of the Northern Chalk Province of Lincolnshire and
12 | Yorkshire has lagged behind Southern England due to difficulties associated with the
13 | more indurated chinks of that province. Data have been collected by the BGS, but this
14 | does not allow full integration with the data sets from the Southern and Transitional
15 | provinces. Foraminifera from the Chalk Group of offshore areas in the North Sea Basin
16 | were summarised by King et al. (1989) and several additional, unpublished, data sets
17 | based on boreholes on the UK continental shelf are filed with the British Geological
18 | Survey. As most of the data from offshore areas are derived from hydrocarbon
19 | exploration wells that were drilled by open-hole methods, biostratigraphical
20 | interpretation relies heavily on extinction events ('Last Appearance Datum' or 'First
21 | Downhole Occurrence') of key taxa.
22 |

23 | Although the scheme presented here has been used by the BGS for several
24 | years (Wilkinson, 2000; Bristow et al., 2002; Woods et al., 2007; Wilkinson et al.,
25 | 2010; together with numerous unpublished open file reports of the BGS), it has not
26 | been published in its entirety and for this reason definitions are presented here. Hart et
27 | al. (1989) prefixed their zones 'UKB' (benthonic foraminifera) and 'UKP' (planktonic
28 | foraminifera). In order to differentiate the scheme defined here, zones are prefixed
29 | 'BGS' and subzones are numbered 'i', 'ii', 'iii', etc.
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32 | **2. Foraminifera of the Chalk Group: an overview**

33 | The Late Cretaceous was a time of unusual oceanographic conditions over much of the
34 | northern hemisphere which affected the evolution and distribution of foraminifera. It
35 | was a time when the chalk seas extended from the USA, through Europe and into Asia;
36 | when heavily keeled planktonic foraminifera became widespread; and when
37 | latitudinally arranged biotic realms were developed.
38 |

39 | The depth of the Chalk Sea in Europe varied spatially and temporally, but the
40 | general absence of algae suggests depths were in excess of 150m and the morphology
41 |

1 of the planktonic foraminifera (e.g. Hart [and](#) Bailey, 1979; Bailey et al., 2009) suggest
2 that maximum depths were less than about 500m. In that most marine phyla are present
3 in the Chalk Group, normal marine salinities (about 35 ‰) can be inferred. However,
4 at times the oxygen content of the bottom waters was reduced (e.g. Whatley et al,
5 2003), and occasionally these dysaerobic conditions became extreme with the
6 development of Oceanic Anoxic Events (OAEs). That at the end of the Cenomanian
7 (the Bonarelli OAE) and the accumulation of the Plenus Marls in the UK had a
8 profound influence on benthonic taxa (cf. Hart [and](#) Bigg, 1981; Hart, 1985, 1996;
9 Jarvis et al., 1988).

16 2.1. Cenomanian

17 The Cenomanian fauna is dominated by agglutinated taxa such as
18 *Arenobulimina*, *Flourensina* and *Plectina* (e.g. Hart 1973; Carter [and](#) Hart, 1977; Hart
19 et al., 1989), although hyaline gavelinellids began a phase of diversification at this
20 time, [in the form of *Lingulogavelinella* and *Gavelinella* \(*Berthelina*\). *Gavelinella* was](#)
21 [split into several genera by Revets \(1996, 2001\), although he did not consider their](#)
22 [phylogenetic relationships through time as had, for example, Price \(1977\), Swiecicki,](#)
23 [\(1980\), Edwards \(1981\), Hart and Swiecicki \(1987, 1988\). These authors clearly](#)
24 [demonstrated that biostratigraphically useful evolutionary lineages could be recognised](#)
25 [in *Gavelinella*, several of which were thrown into disarray by Revets' concepts. As](#)
26 [pointed out by Bailey et al \(2009\), detailed examination of the phylogeny of](#)
27 [Gavelinella is required, and until that work is completed, the present author continues](#)
28 [to use the "traditional" concept of the genus, although where possible, Revets' names](#)
29 [are included in parenthesis herein.](#) Miliolids are very rare in the late Cretaceous,
30 although *Quinqueloculina antiqua* and *Spiroloculina papyracea* are sometimes found
31 within the Cenomanian. Planktonic foraminifera in southern England comprise
32 predominantly relatively simple, non-keeled genera such as *Hedbergella*,
33 *Globigerinelloides* and [the](#) biserial [genus](#) *Heterohelix*. However, keeled forms began to
34 [appear](#) into the UK during the Cenomanian; the first species was *Rotalipora*
35 *apenninica*, followed later by *Rotalipora reicheli* and, in the late Cenomanian, species
36 of *Praeglobotruncana* (e.g. *P. stephani*). Double keeled taxa (e.g. *Dicarinella*) are rare
37 in the late Cenomanian.

56 2.2. Turonian

57 The decline in the diversity of benthonic foraminifera through the Plenus Marl
58 and into the basal Holywell Nodular Chalk Formation is demonstrated in the data
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1 presented by Paul et al. (1999). Most of the early Turonian benthonic species ranged
2 up from the Cenomanian, although a few taxa appeared for the first time, including
3 *Arenobulimina preslii*, *Tritaxia jongmansii* and *Lingulogavelinella aumalensis*. Higher
4 in the Turonian other long ranging benthonic species appear in abundance and can be
5 used biostratigraphically, including *Globorotalites michelinianus*, *Reussella kelleri*,
6 *Verneuilina muensteri* and *Lingulogavelinella arnagerensis*. The Turonian is
7 dominated by planktonic taxa (e.g. Hart, 1982, 2008), of which *Praeglobotruncana*
8 *stephani*, *Helvetoglobotruncana helvetica*, *Dicarinella hagni* and *D. imbricata*,
9 *Marginotruncana sigali*, *M. marginata*, *M. canaliculata*, *M. pseudolinneana* and *M.*
10 *cornuta* are biostratigraphically important. *Hedbergella* evolved into *Whiteinella* at this
11 time' the earliest species being *W. archaeocretacea* and *W. aprica*.

20 2.3. Coniacian

21 The Coniacian was a period of diversification amongst the benthonic
22 foraminifera and species of *Stensioeina* are particularly important biostratigraphically.
23 Koch (1977) discussed the lineage in Germany, which began at the
24 Cenomanian/Turonian boundary interval. However the earliest species in English chalk
25 is *Stensioeina granulata levis*, a very rare taxon at the base of the Coniacian (Bailey et
26 al., 1984). Higher in the stage, speciation of two lineages commenced with the
27 development of *Stensioeina granulata* and *S. exsculpta*. Other biostratigraphically useful
28 species include *Loxostomun eleyi*, *Osangularia cordieriana* and *Gavelinella*
29 *thalmanni*, and although the majority of planktonic species are long ranging, the
30 appearance of *Globotruncana bulloides*, *Dicarinella primitiva*, *Marginotruncana*
31 *sinuosa* and *Globigerinelloides rowei* are worthy of note.

41 2.4. Santonian

42 The Santonian benthonic assemblage shows a continued increase in diversity,
43 particularly species of *Stensioeina*, *Cibicides*, *Praebulimina* and *Gavelinella*, including
44 *Gavelinella (Pseudogavelinella) Bolivinoidea* [was, biostratigraphically, one of the](#)
45 [most important genera in the Campanian and Maastrichtian; the first species, *B.*](#)
46 [strigillatus](#), appearing at the top of the [Santonian](#). Planktonic taxa are generally long-
47 ranging, although the occurrence of *Globotruncana linneiana* and the appearance of
48 *Rosita fornicata*, *Rugoglobigerina pilula* and *Heterohelix striata* are useful at the top
49 of the stage (despite the fact that all are rare at the start of their range).

58 2.5. Campanian

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Campanian assemblages are the youngest Cretaceous [faunas](#) found [in southern England](#). Foraminiferal faunas are characterised by the continued radiation of *Bolivinooides*, *Gavelinella* and *Stensioeina*. *Bolivinooides* evolved through two lineages (*B. culverensis*- *B. laevigatus* and *B. culverensis*-*B. decoratus*) both of which diversify further in the late Campanian and Maastrichtian in East Anglia and [the](#) North Sea (in chalks younger than those seen in southern England). *Gavelinella* is represented by a number of long ranging species that originated in the Turonian and Coniacian. Species of *Gavelinella* (*Gavelinella*) and *Gavelinella* (*Pseudogavelinella*) are biostratigraphically useful in the Campanian, particularly the *G. (P.) cristata*- *G. (P.) clementiana* lineage. *Stensioeina*, which ranges through into the Paleogene in the North Sea Basin, reached its maximum diversity in the latest Santonian and early Campanian. The genus *Arenobulimina*, although particularly diverse in the Cenomanian, began a new phase of radiation in the early Campanian with the appearance of species such as *A. footei* and *A. elevata*, presumably branching from the long-ranging species *A. courta*. Of the planktonic taxa, many are long ranging but the extinction of *Rugoglobigerina pilula* high in the *quadrata* macrofaunal Zone, the inception of *Hedbergella holmdelensis* and *Globotruncana rugosa* in the *quadrata/mucronata* boundary interval and *Rosita plummerae* and *Globotruncana austinensis* in the highest *mucronata* [Zone](#) of southern England, are biostratigraphically important.

3. Foraminiferal Zonal Scheme for Southern England

B.G.S. Zone 1 (=UKB1 and 2)

Base: The inception of *Plectina mariae* and *Hagenowina anglica*. *Flourensina intermedia* and *Hagenowina advena* become common. The extinction of the Albian taxa such as *Arenobulimina chapmani* and *Arenobulimina sabulosa*.

Top: The [first appearance](#) of the succeeding zonal index.

Subzone: 1i. Facies related taxa such as *Bulbophragmium aequale folkestonensis*, which is found in the Glauconitic Marl of south-eastern Kent, [were](#) used by Hart et al. (1989) to define his UKB 1 Zone, but due to its very restricted geographical distribution, it is given subzonal status herein.

[Supplementary events:](#) *Vialovella praefrankei* becomes extinct in the lower *carcitanense* Subzone.

Lithostratigraphical position: Basal West Melbury Marly Chalk

1 | **Age:** *Mantelliceras*. *mantelli* macrofaunal Zone.

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4 | **B.G.S. Zone 2 (UKB3)**

5 | **Base:** The [first appearance](#) of *Pseudotextulariella cretosa* and the extinction of
6 | *Flourensina intermedia*.

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9 | **Top:** The extinction of *Marssonella ozawai*.

10 | **Supplementary events:** *Quinqueloculina antiqua* disappears from the record at the top
11 | of the zone, although there are records of this species in the Plenus Marl suggesting the
12 | temporary disappearance must be considered a Lazarus effect.

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15 | **Lithostratigraphical position:** Middle of the West Melbury Marly Chalk

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17 | **Age:** Early *Mantelliceras* *dixoni* macrofaunal Zone.

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21 | **B.G.S. Zone 3 (=UKB4)**

22 | **Base:** The extinction of *Marssonella ozawai*.

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24 | **Top:** The [first appearance](#) of *Flourensina mariae* and *Plectina cenomana*.

25 | **Supplementary events:** *Lingulogavelinella jarzevae* becomes extinct in the basal part
26 | of the zone (low to mid *dixoni* macrofaunal Zone). *Rotalipora reicheli* appears for the
27 | first time in the upper part of the zone (late *dixoni* macrofaunal Zone), but it is rare.

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30 | **Lithostratigraphical position:** Middle part of the West Melbury Marly Chalk

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32 | **Age:** *M. dixoni* macrofaunal Zone.

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37 | **B.G.S. Zone 4 (=UKB 5)**

38 | **Base:** The [first appearance](#) of *Flourensina mariae* and *Plectina cenomana*.

39
40 | **Top:** The extinction of *Praeglobotruncana delrioensis*.

41 | **Subzones:** 4i. An **inter-regnum** subzone between the base of the zone and the [first](#)
42 | [appearance](#) of *Praeglobotruncana stepheni*.

43 | 4ii. The base defined by the [first appearance](#) of *Praeglobotruncana stephani* at the base
44 | of the *Acanthoceras rhotomagensis* Zone (and *Turrilites costatus* Subzone). The top is
45 | defined by the incoming of *Rotalipora cushmani*.

46 | 4iii. The base is defined by the appearance of *Rotalipora cushmani* at base of the *T.*
47 | *acutus* Zone. *Rotalipora greenhornensis* accompanies the subzonal index. The upper
48 | boundary is the top of the zone.

1 **Supplementary events:** *Rotalipora reicheli* becomes extinct late in the *T. costatus*
2 Zone. *Hagenowina anglica*, *Spiroloculina papyracea* and *Favusella washitensis*
3 disappear from the record at the *costatus/acutus* boundary.
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5 **Lithostratigraphical position:** Upper part of the West Melbury Marly Chalk
6 Formation to the middle Zig Zag Chalk Formation
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8 **Age:** *Cunningtoniceras inerme* to earliest *A. jukesbrownei* macrofaunal Zone.
9

10 **B.G.S. Zone 5 (=UKB6)**

11 **Base:** The extinction of *Praeglobotruncana delrioensis* and acme of *Flourensina*
12 *mariae*.
13

14 **Top:** [First appearance](#) of *Lingulogavelinella globosa*.
15

16 **Lithostratigraphical position:** Middle part of the Zig Zag Chalk Formation.
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18 **Age:** *A. jukesbrownei* macrofaunal Zone.
19

20 **B.G.S. Zone 6 (=modified UKB7)**

21 **Base:** [First appearance](#) of *Lingulogavelinella globosa*.
22

23 **Top:** Extinction of *Hagenowina advena* in the base of the Plenus Marl.
24

25 **Supplementary events:** *Dicarinella hagni* and *D. algeriana* appear in the upper part
26 of the Zone (late *C. guerangeri* macrofaunal Zone).
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28 **Lithostratigraphical position:** Uppermost Zig Zag Chalk Formation and basal
29 Holywell Nodular Chalk Formation.
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31 **Age:** Very latest *A. jukesbrownei* macrofaunal Zone and *Metoicoceras. geslinianum*
32 Zone.
33

34 **B.G.S. Zone 7 (=lower UKB 8)**

35 **Base:** Extinction of *Hagenowina advena* in the base of the Plenus Marl Member.
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37 **Top:** [First appearance](#) of *Dicarinella imbricata*, *Whiteinella archaeocretacea*,
38 *Heterohelix globosus* and *Marginotruncana marginata*, together with the extinction of
39 *Rotalipora cushmani*.
40

41 **Supplementary events:** Extinction of *Rotalipora greenhornensis*, *Gavelinella*
42 (*Berthelina*) *cenomanica*, *Tritaxia macfadyeni*, *Plectina cenomana* at the top of Bed 1
43 of the Plenus Marl. Extinction of *Gavelinella (Berthelina) baltica* and *Gavelinella*
44 (*Berthelina*) *intermedia* in Bed 2 of the Plenus Marl. *Rotalipora cushmani* extinction at
45 the top of Bed 3 of the Plenus Marl.
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1 **Lithostratigraphical position:** Basal Holywell Nodular Chalk Formation (Lower
2 Plenus Marl Member

3 **Age:** Early to 'mid' *M. geslinianum* macrofaunal Zone.
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7 **B.G.S. Zone 8 (=upper UKB8 and basal UKB9)**

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9 **Base:** [First appearance](#) of *Whiteinella archaeocretacea*, *Dicarinella imbricata*,
10 *Heterohelix globosus*, *Marginotruncana marginata*, together with the extinction of
11 *Rotalipora cushmani*
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14 **Top:** [First appearance](#) of *Valvulineria lenticularis* and *Helvetoglobotruncana*
15 *helvetica*.
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18 **Supplementary events:** *Gavelinella ammonoides* appears near the top of the zone and
19 *Arenobulimina preslii* becomes more consistently present in and above the Melbourn
20 Rock Bed (in the upper part of the *Neocardioceras. juddi* Zone). *Gavelinella*
21 (*Berthelina*) *reussi* becomes extinct at the top of Bed 7 of the Plenus Marl. *Tritaxia*
22 *jongmansii* appears just below the Round Down Marl (and lateral equivalents) and
23 *Lingulogavelinella aumalensis* appears immediately above
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27 **Lithostratigraphical position:** Lower part of the Holywell Nodular Chalk Formation
28 (the base is within the upper part of the Plenus Marl Member). At Beer, the zonal index
29 species appear immediately below the 'Limonitic Hardgrounds (Hart, 2008).
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31
32 **Age:** Late *M. geslinianum* macrofaunal Zone to late *N. juddi* Zone.
33

34 **B.G.S. Zone 9 (=UKB9 excluding the basal part)**

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36 **Base:** [First appearance](#) of *Valvulineria lenticularis* and consistent
37 *Helvetoglobotruncana helvetica*.
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40 **Top:** [First appearance](#) of *Globorotalites michelinianus* and extinction of
41 *Lingulogavelinella globosa*.
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44 **Supplementary events:** *Whiteinella aprica* appears in the early *Mytiloides* spp Zone.
45 The extinction of *Dicarinella hagni* and *D algeriana* together with the [first appearance](#)
46 of *Marginotruncana sigali* takes place in the 'mid' *Mytiloides* spp macrofaunal Zone.
47 *Gavelinella tourainensis* generally temporarily disappears from the record at the top of
48 the zone.
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51 **Lithostratigraphical position:** Upper part of the Holywell Nodular Chalk Formation
52 and basal part of the New Pit Chalk Formation.
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55 **Age:** Latest *N. juddi* macrofaunal Zone to late *Mytiloides* spp. Zone
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B.G.S. Zone 10 (=basal UKB10)

Base: [First appearance](#) of *Globorotalites michelinianus* and extinction of *Lingulogavelinella globosa*.

Top: [First appearance](#) of *Marginotruncana pseudolinneiana*.

Supplementary events: *Gavelinella tourainensis* [tends to disappear](#) at the base of the zone, but reappears in the upper part of the Turonian. Although a long-ranging taxon, the [first appearance](#) of common *Coskinophragma* is characteristic of the New Pit Chalk (at New Pit Marls) in south eastern England (upper part of the foraminiferal zone and lower part of the *T. lata* Zone). [The extinction of *Globigerinoides bentonensis* is at the upper boundary of the zone.](#)

Lithostratigraphical position: Middle part of the New Pit Chalk Formation

Age: Late *Mytiloides* spp. macrofaunal Zone to early *Terebratulina lata* macrofaunal Zone.

B.G.S. Zone 11 (=lower and middle UKB10)

Base: [First appearance](#) of *Marginotruncana pseudolinneiana*.

Top: [First appearance](#) of *Marginotruncana coronata*.

Subzones: 11i. The extinction of *Marginotruncana sigali* takes place in the lower part of the zone (lower *T. lata* Zone). The concurrent range of that species with *Marginotruncana pseudolinneiana* is considered to be of subzonal significance.

11ii. The upper part of the zone, which lacks *M. sigali*, is characterised by agglutinating species such as *Coskinophragma* sp., *G. laevigata* and *S. praelongata*.

Lithostratigraphical position: Uppermost New Pit Formation and basal Lewes Formation.

Age: 'Mid' *T. lata* macrofaunal Zone.

B.G.S. Zone 12 (=upper UKB10)

Base: [First appearance](#) of *Marginotruncana coronata*.

Top: [First appearance](#) of *Verneuilina muensteri*.

Supplementary events: The extinction of *Helvetoglobotruncana helvetica* is in the lower part of the foraminiferal zone (although the exact position of its extinction is difficult to define due to its rarity in the upper part of its range). *Gavelinella tourainensis* reappears in the highest *T. lata* Zone. *Dicarinella imbricata* disappears from the record within the foraminiferal Zone, approximately at the Lewes Marl,

1 within the *Sternotaxis plana* Zone, although it is rare at the top of its range, so that the
2 exact position of its extinction is difficult to determine with accuracy. *Reussella kelleri*
3 appears for the first time in the upper part of the foraminiferal zone (lower *S. plana*
4 macrofaunal Zone), immediately above the Bridgewick Marls of southern England,
5 although it is rare and patchily distributed in the early part of its range.
6
7 *Lingulogavelinella arnagerensis* appears for the first time in the upper part of the Zone
8 (upper part of *P. plana* macrofaunal Zone) immediately above the Kingston Nodular
9 Chalks of southern England. It is rare and patchily distributed in the lower part of its
10 range.

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16 **Lithostratigraphical position:** Lower part of the Lewes Formation

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18 **Age:** Late *T. lata* and *P. plana* macrofaunal zones.

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22 **B.G.S. Zone 13 (=UKB11)**

23 **Base:** [First appearance](#) of *Verneuilina muensteri*.

24 **Top:** [First appearance](#) of *Stensioeina granulata granulata*

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26 **Supplementary events:** *Stensioeina granulata levis* accompanies the first specimens
27 of *V. muensteri*, immediately above the Navigation Hardground through to the Hope
28 Gap Hardground (basal *M. cortestudinarium* macrofaunal Zone) in southern England,
29 but it is very rare. *Gavelinella (Gavelinella) pertusa* appears within the lower part of
30 the zone, although the exact stratigraphical position of its [first appearance](#) is difficult to
31 place due to its rarity in the earliest part of its range. In the very highest part of the
32 foraminiferal zone (highest *M. cortestudinarium* macrofaunal Zone), *Globorotalites*
33 *michelinianus* generally disappears from the record in southern England (Lazarus
34 effect). *Gavelinella tourainensis* becomes extinct at the top of the foraminiferal zone at
35 the East Cliff/Shoreham 2 Marl (*cortestudinarium/coranguinum* zonal boundary).
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45 **Age:** *Micraster cortestudinarium* macrofaunal Zone.

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49 **B.G.S. Zone 14 (=lower and middle UKB12)**

50 **Base:** [First appearance](#) of *Stensioeina granulata granulata* and extinction of
51 *Gavelinella tourainensis*

52 **Top:** [First appearance](#) of *Stensioeina exsculpta exsculpta*

53 **Supplementary events:** The first appearance of *Osangularia cordieriana* is within the
54 Shoreham Marls and lateral equivalents and *Gavelinella (Gavelinella) thalmani* is
55 first recorded at or immediately above the base of the zone. *Reussella kelleri* generally
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disappears temporarily in southern England at the base of the zone and *Globorotalites michelinianus* reappears within the zone (Lazarus effect). *Marginotruncana sinuosa* ranges from the lower boundary of foraminiferal zone (and the *M. coranguinum* macrofaunal Zone) (or perhaps immediately below it) and becomes extinct in the basal part of the foraminiferal zone. *Dicarinella primitiva* has its [first appearance](#) in the basal *M. coranguinum* macrofaunal Zone.

Lithostratigraphical position: Lower part of the Seaford Chalk Formation (zonal base is at upper Shoreham Marl/East Cliff Marl).

Age: Early *M. coranguinum* macrofaunal Zone.

B.G.S. Zone 15 (=upper UKB12)

Base: [First appearance](#) of *Stensioeina exsculpta exsculpta*

Top: [First appearance](#) of *Loxostomum eleyi*.

Lithostratigraphical position: Lower part of the Seaford Chalk Formation (above the Upper Shoreham Marl, but below Hope Point Marl and lateral equivalents).

Age: Early *M. coranguinum* macrofaunal Zone.

B.G.S. Zone 16 (=UKB13)

Base: [First appearance](#) of *Loxostomum eleyi*.

Top: [First appearance](#) of *Stensioeina granulata polonica*

Supplementary events: *Stensioeina granulata granulata* becomes rare at or near the upper boundary of the zone.

Lithostratigraphical position: Lower part of the Seaford Chalk Formation (Hope Point Marl and Belle Tout Marl 2 through to Chartham Flints, Bailey's Hill Flints and lateral equivalents).

Age: Early (but not earliest) to mid *M. coranguinum* Zone.

B.G.S. Zone 17 (=lower and middle UKB14)

Base: [First appearance](#) of *Stensioeina granulata polonica*.

Top: [First appearance](#) of *Gavelinella(Pseudogavelinella) cristata*.

Subzones: 17i is defined by the [interval between the](#) first appearance of *Stensioeina granulata polonica* (Chartham Flint and lateral equivalents) to the [first appearance](#) of *Cibicides beaumontianus*.

17ii extends from the [first appearance](#) of *Cibicides beaumontianus* at Whittaker's 3" Flint and Rough Brow Flint and lateral equivalents, to the [first appearance](#) of [succeeding subzonal index](#).

17iii can be recognised by the appearance of *Reussella szajnochae praecursor* above Barrois Sponge Bed and lateral equivalents, through to the top of the zone.

Lithostratigraphical position: Upper (but not uppermost) Seaford Chalk Formation (Chartham Flint to immediately below Peake's Sponge Bed).

Supplementary events: Reappearance of *Reussella kelleri* immediately above Whittaker's 3" Flint and lateral equivalents. The extinction of *Lingulogavelinella arnagerensis* is a little above Whittaker's 3 Inch Flint and lateral equivalents.

Age: Upper *M. coranguinum* macrofaunal Zone.

B.G.S. Zone 18 (=uppermost UKB14 and lower UKB15)

Base: [First appearance](#) of *Gavelinella (Pseudogavelinella) cristata*.

Top: [First appearance](#) of *Bolivinooides culverensis*.

Subzones: 18i. [First appearance](#) of *Gavelinella (P.) cristata* and *Gavelinella (G.) stelligera* to the [first appearance](#) of *Stensioeina granulata perfecta*.

18ii. [First appearance](#) of *Stensioeina granulata perfecta* [in](#) the *U. socialis* macrofaunal Zone [a little above Buckle Marl 1 \(and lateral equivalents\) and within the basal Newhaven Chalk](#).

18iii. [First appearance](#) of *Bolivinooides strigillatus* in the upper *U. socialis* macrofaunal Zone, a little below Hawks Brow Flint and lateral equivalents.

18iv. [First appearance](#) of *Rosita fornicata*, *Rugoglobigerina pilula*, *Archaeoglobigerina cretacea* and *Heterohelix striata* at the base of the *U. socialis* macrofaunal Zone.

Supplementary events: *Stensioeina granulata polonica* extinction at Peake's Sponge Bed.

Stensioeina exsculpta gracilis [first appearance](#) in the middle part of the foraminiferal zone, at the *Echinocorys elevata* Band and lateral equivalents at the base of the *Marsupites testudinarius* macrofaunal Zone.

Lithostratigraphical position: Highest Seaford Chalk (immediately below Peake's Sponge Bed and lateral equivalents) and into the basal Newhaven Chalk. At Seaford Head the base of the zone is recognised between [the](#) Buckle Marl and Buckle Flint.

1 | **Age:** [Uppermost](#) *M. coranguinum* macrofaunal Zone to the top of the *U. anglicus*
2 | macrofaunal Zone.
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5 | **B.G.S. Zone 19 (=upper UKB15)**
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7 | **Base:** [First appearance](#) of *Bolivinoidea culverensis*.
8 |

9 | **Top:** [First appearance](#) of *Gavelinella (Pseudogavelinella) usakensis*.
10 |

11 | **Supplementary events:** The [first appearance](#) of very rare *Globotruncana arca* is at the
12 | base of the foraminiferal zone. The extinction of *Globigerinelloides rowei* and
13 | *Stensioeina exsculpta exsculpta* takes place in the earliest *Offaster pilula* macrofaunal
14 | Zone. *Stensioeina pommerana* first appears in the 'mid' *O. pilula* Zone (transitional
15 | specimens closely resembling this species occur in the late Santonian and early
16 | Campanian). *Reussella kelleri* disappears from the record immediately below the
17 | Arundel Sponge Bed and lateral equivalents, near the top of BGS Zone 19.
18 |

19 | **Lithostratigraphical position:** Upper Newhaven Chalk, above Friars Bay Marl 3 and
20 | lateral equivalents
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22 | **Age:** *O. pilula* macrofaunal Zone.
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27 | **B.G.S. Zone 20 (=UKB16, except the very basal part)**
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29 | **Base:** [First appearance](#) of *Gavelinella (Pseudogavelinella) usakensis*.
30 |

31 | **Top:** [First appearance](#) of *Gavelinella (Brotzenella) monterelensis*.
32 |

33 | **Subzones:** 20i. The subzone extends from the base of the zone, between Black Rabbit
34 | Marls 1 and 2 (and lateral equivalents), to the [first appearance](#) of *Eouvigerina galeata*.
35 |

36 | 20ii. The base of the subzone is [defined](#) by the appearance of *Eouvigerina galeata*
37 | between Pepper Box Marls and Lancing Flint (and lateral equivalents).
38 |

39 | 20iii. The base is defined by the appearance of *Pullenia quaternaria* at Whitecliff Marl
40 | (upper *Goniot euthis quadrata* macrofaunal Zone). *Gavelinella (Pseudogavelinella)*
41 | *clementiana* and *Spiroplectammina baudouiniana* also appear at the base of the
42 | subzone, but are generally rare.
43 |

44 | 20iv. The extinction of common *Bolivinoidea culverensis* and the [first appearance](#) of
45 | common *B. decoratus* at Scratchell's Marl 1 (in the uppermost *G. quadrata*
46 | macrofaunal Zone) are characteristic of the subzone.
47 |

48 | **Supplementary events:** *Bolivinoidea culverensis* becomes common or abundant at the
49 | base of the zone immediately below the Arundel Sponge Bed. *Gavelinella (P.) cristata*
50 | becomes extinct immediately above the Arundel Sponge Bed. Rare specimens of
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'*Gavelinella*' cf. *voltziana* appear for the first time above the Lancing Flint and *Gavelinella (P.) trochus* is also present, although the exact stratigraphical position of its [first appearance](#) is not fully known due to rarity of the species in the earliest part of its range. *Gavelinella (Gavelinella) lorneiana* temporarily disappears from the record immediately above the Lancing Flints and lateral equivalents and reappears in the middle part of the foraminiferal zone (mid *quadrata* macrofaunal Zone) at the Cotes Bottom Flint (Lazarus effect). *Rugoglobigerina pilula*, *Stensioeina exsculpta gracilis* and common *Gavelinella stelligera* disappear from the record at the top of the zone (at the Farlington Marls and lateral equivalents).

Lithostratigraphical position: Upper Newhaven, Culver and lower Portsdown Chalk formations. The base of the zone is immediately below the Arundel Sponge Bed, although where present this is placed between Black Rabbit Marls 1 and 2.

Age: Very highest *O. pilula* macrofaunal Zone (immediately below Arundel Sponge Bed), but predominantly *G. quadrata* macrofaunal Zone.

B.G.S. Zone 21 (=UKB17 and lower UKB 18)

Base: [First appearance](#) of *Gavelinella (Brotzenella) monterelensis*.

Top: [First appearance](#) of *Reussella szajnochae szajnochae*.

Subzones: 21i. The subzone can be recognised by the concurrent range of *Gavelinella (B.) monterelensis* and *Gavelinella (P.) usakensis* in the lower part of the *B. mucronata* macrofaunal Zone (between Farlington Marls and the top of the Eaton Chalk).

21ii. The base of the subzone is situated at the extinction of *Gavelinella (P.) usakensis* and [first appearance](#) of *Coryphostoma pliata*.

21iii. The lower boundary is defined by the extinction of *Gavelinella (G.) lorneiana* and *Gavelinella (G.) thalmani* and [first appearance](#) of *Globotruncana bulloides austinensis* and *Globotruncana plummerae*. The upper boundary is placed at the extinction of consistent *Globorotalites michelinianus* and *Rosita fornicata* and [first appearance](#) of *Reussella szajnochae szajnochae* (upper Weybourne Chalk to the base of the Catton Sponge Bed).

Supplementary events: *Gavelinella (B.) monterelensis*, '*G.*' *voltzianus* and *Globotruncana rugosa* all have their [first appearance](#) at the Farlington Marls (at the *quadrata/mucronata* zonal boundary). *Gavelinella (P.) trochus* becomes extinct in the early *Belemnitella mucronata* macrofaunal Zone (at the top of the Eaton Chalk).

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Lithostratigraphical position: Middle and upper Portsdown Chalk The foraminiferal zone can also be observed in the “Weybourne Chalk” and “Beeston Chalk” of Norfolk

Age: Early *Belemnitella mucronata* macrofaunal Zone.

4. Biostratigraphy in Norfolk

The stratigraphically highest foraminiferal zones of the English Chalk are seen only in Norfolk. Here the Campanian and possibly the earliest Maastrichtian is in situ, whereas much of the Maastrichtian on the Norfolk coast comprises large ice-rafted blocks. Foraminiferal biozones are included here for completeness.

B.G.S. Zone 22 (=uppermost UKB18)

Base: [First appearance](#) of *Reussella szajnochae szajnochae*.

Top: [First appearance](#) of *Bolivinoides draco miliaris*.

Supplementary Events: *Globorotalites hiltermanni*, *Bolivina incrassata* and *Eponides beisseli* all appear for the first time together with *Reussella szajnochae szajnochae*. *Globotruncana bulloides bulloides* becomes extinct at the top of the zone (at the top of the Beeston Chalk.

Lithostratigraphical position: “Norwich Chalk Formation” or “Beeston Chalk” of Sheringham, Norfolk.

Age: ‘Mid’ *Belemnitella mucronata* macrofaunal Zone.

B.G.S. Zone 23 (=UKB19)

Base: [First appearance](#) of *Bolivinoides draco miliaris* and *B. sidestrandensis*.

Top: [First appearance](#) of *Bolivinoides peterssoni*.

Supplementary events: *Heterohelix complanata* has its [first appearance](#) at the base of the zone. *Reussella szajnochae szajnochae* occurs in abundance in the highest Campanian. A number of [taxa](#) become extinct at the upper boundary of the foraminifera zone, including *Reussella szajnochae szajnochae*, *Neoflabellina rugosa*, *Gavelinella monterelensis*, *Globorotalites hiltermanni* and *Osangularia cordieriana*.

Lithostratigraphical position: “Norwich Chalk Formation” or “Paramudra Chalk” of Sherringham and Overstrand, Norfolk.

Age: Latest Campanian, late *B. mucronata* macrofaunal Zone

B.G.S. Zone 24 (=UKB20)

1 | **Base:** [First appearance](#) of *Bolivinooides peterssoni*.

2 | **Top:** [First appearance](#) of *Bolivinooides paleocenicus*.

3 | **Subzones:** 24i is defined by the concurrent range of *Bolivinooides peterssoni* and *B.*
4 | *decoratus* (in the ‘Pre-Porosphaera Chalk’). *Hedbergella holmdelensis* apparently
5 | becomes extinct at the top of the subzone.
6 |

7 | 24ii. From the extinction of *Bolivinooides decoratus* to the top of the zone (in the
8 | ‘Porosphaera Chalk’).
9 |

10 | **Supplementary events:** *Globotruncanella havanensis* and *Rugoglobigerina*
11 | *milamensis* are consistently present for the first time above the base of the zone
12 | (although very rare specimens may occur immediately below it). A number of species
13 | appear for the first time at or immediately above the base: *Bolivinooides decurrens*, *B.*
14 | *australis*, *Gavelinella* (?*Pseudogavelinella*) *bembix*, *Osangularia navarroana* and
15 | *Neoflabellina reticulata*. *Pyramidina minuta* has its [first appearance](#) in the highest *B.*
16 | *mucronata* macrofaunal Zone (although it is very rare) and becomes more numerous in
17 | the early Maastrichtian. *Eponides beisseli* and *Valvulineria lenticularis* become extinct
18 | at the top of the zone.
19 |

20 | **Lithostratigraphical position:** Uppermost “Norwich Chalk” and “Trimmingham
21 | Chalk” formations of Overstrand and Sidestrand, Norfolk.
22 |

23 | **Age:** Early *Belemnella lanceolata* macrofaunal Zone ([B. lanceolata sensu stricto and B](#)
24 | [pseudobtusa zones of Mortimore et al., 2001](#)).
25 |

26 | **B.G.S. Zone 25 (=UKB21)**

27 | **Base:** [First appearance](#) of *Bolivinooides paleocenicus*.

28 | **Top:** [First appearance](#) of *Bolivinooides draco draco* (only seen offshore in the North
29 | Sea Basin).
30 |

31 | **Supplementary events:** The ‘Sidestrand Sponge Bed’ and the lower part of the Little
32 | Marl Point Chalk (‘White Chalk’ of Peake & Hancock, 1961, 1970) contain
33 | *Angulogavelinella bettenstaedti* together with *Bolivinooides paleocenicus*.
34 | *Pseudovigerina rugosa* and *Tappanina selmensis* appear in the upper part of the Little
35 | Marl Point Chalk (‘Lunata Beds’ of Peake & Hancock, 1961, 1970) and Beacon Hill
36 | Grey Chalk (‘Grey Beds’ of Peake & Hancock, 1961, 1970).
37 |

38 | **Lithostratigraphical position:** “Trimmingham Chalk Formation” of Sidestrand and
39 | Trimmingham, Norfolk (and offshore in the Rowe Formation).
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Age: [Late *Belemnitella lanceolata* macrofaunal Zone \(*B. obtusa* and *B. sumensis* zones sensu Mortimore et al. 2001\).](#)

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Figure captions

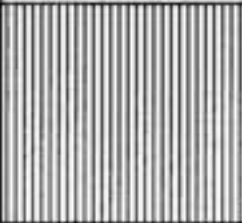
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2 Fig. 1. Lithostratigraphy of the Chalk Group of Southern and eastern England.
3

4 Fig. 2. Foraminiferal biostratigraphical zonation of southern England related to the
5 standard macrofaunal zonal scheme and lithostratigraphy.
6

7 Fig. 3. Foraminiferal zonation in East Anglia related to the standard macrofaunal zonal
8 scheme and lithostratigraphy. Note: The base of BGS26 (defined by the appearance of
9 *Bolivinoides draco draco* and the disappearance of *B. draco miliaris* and *B.*
10 *sidestrandensis*) and the base of BGS27 (defined by the appearance of *Abathomphalus*
11 *mayaroensis*) are not known onshore.
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Figure

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STAGE	GROUP	SUBGROUP	FORMATIONS	
			Southern Province	Northern Province
MAASTRICHTIAN (part)	CHALK	WHITE CHALK		'Trimmingham Chalk'
CAMPANIAN			Portsdown Chalk	Flamborough Chalk
			Culver Chalk	
SANTONIAN			Newhaven Chalk	
CONIACIAN			Seaford Chalk	Burnham Chalk
			Lewes Nodular Chalk	
TURONIAN			New Pit Chalk	Welton Chalk
			Holywell Nodular Chalk	
CENOMANIAN			GREY CHALK	Zig Zag Chalk
		West Melbury Marly Chalk		
				'Norwich Chalk'

Figure

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Stage	Lithostratigraphy		Macrofaunal		Foraminiferal zones/ subzones	First appearance	Last appearance
	Formations	Key marker horizons	zones	subzones			
Campanian (part)	Portsmouth Chalk	Farington Marls Scratchers Marls	<i>B. mucronata</i> (part)		21	<i>Globobuccina bullata</i> , <i>G. plummerae</i> , <i>Corchobolus pilata</i>	<i>Gavelinella kimeana</i> , <i>Gavelinella thamesis</i> , <i>Gavelinella usatensis</i> , <i>Gavelinella trochus</i>
	Culver Chalk	Whitcroft Marls Lewins Flint Cattle Pig Marls Arundel Sponge Bed	<i>G. quadrata</i>	<i>A. cretaceus</i>	20	<i>Bolivina decorata</i> , <i>Pullena guzmani</i> , <i>Gavelinella clementina</i>	<i>Bolivina decorata</i>
		<i>U. pilula</i>			19	<i>Ecovipera pilulata</i> , <i>Gavelinella usatensis</i>	
Bartonian	Newhaven Chalk	Hawks Brow Flint E. elevate Band Peebles's Sponge Bed Buckie Marls	<i>M. testudinarius</i>	<i>U. socialis</i>	18	<i>Bolivina decorata</i> , <i>Bolivina striatula</i> , <i>Stenobuccina granulata perfecta</i> , <i>Gavelinella cristata</i>	<i>Stenobuccina granulata polonica</i>
		Sarnes Sponge Bed			17	<i>Reussella stajnochowi precursor</i>	
	Seaford Chalk	Whitaker's 3' Flint Rough Brow Flint Chartham Flint Baly's Hill Flint Hope Point Marls	<i>M. corangulum</i>	16	<i>Stenobuccina granulata polonica</i>		
Coniacian	Lewes Nodular Chalk	Shoreham Marls		15	<i>Loxostomum aleyi</i>	<i>Gavelinella fourcensis</i>	
		'Top Rock?' 'Navigation Hardground'		14	<i>Stenobuccina exsculpta exsculpta</i> , <i>Stenobuccina granulata granulata</i>		
Turonian	New Pit Chalk	Southern Marls New Pit Marls	<i>M. cortestudinarius</i>	<i>S. plana</i>	13	<i>Vernulina muensteri</i>	<i>Marginaloculina sigel</i>
		Gun Gardens Main Marls Lakerith Marls			12	<i>Marginaloculina constricta</i>	
	Holywell Nodular Chalk	Metbourne Rock Perus Marls	<i>T. late</i>	11	<i>Marginaloculina pseudolinnæna</i>		
Cenomanian	Zig Zag Chalk	Cast Bed	<i>Mytiloides</i> spp.	<i>T. acutus</i>	10	<i>Glaucostaffes nichelinus</i>	<i>Lingulogavelinella globosa</i>
					9	<i>Valvulineria lentoculata</i> , <i>Præglabrochama helvetica</i> , <i>D. imbricata</i> , <i>W. archæocretacea</i> , <i>H. globosus</i> , <i>M. marginata</i>	<i>Rotalione cushmani</i> , <i>Hagenowina advena</i>
	West Melbury Marly Chalk	Cast Bed	<i>M. juxta</i>	8		<i>Lingulogavelinella globosa</i> , <i>Flourensina mariae acra</i>	
			<i>M. gestianum</i>	7		<i>Rotalione cushmani</i>	
			<i>C. guzmani</i>	6		<i>Præglabrochama stephani</i> , <i>Flourensina mariae</i> , <i>Placina zanzbari</i>	
West Melbury Marly Chalk	Cast Bed	<i>A. mottmagense</i>	5		<i>Pseudobuccella ovalis</i>	<i>Marsconella cuneata</i> , <i>Quinqueculina arripus</i> , <i>Flourensina intermedia</i>	
		<i>C. nama</i>	4		<i>Plectina mariae</i> , <i>Hagenowina anglica</i>	<i>Bulicophragmium aequale</i> , <i>Boltonensis</i> , <i>Arenobullina daphni</i> , <i>Arenobullina subulosa</i>	
			<i>M. dixonii</i>	<i>M. saabi</i>	3		
			<i>M. manselli</i>	<i>S. schubertii</i>	2		
			<i>N. carolinense</i>		1		

Figure

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Age	Lithostratigraphy		Macrofaunal Zonation	Foram zonation		Key Foraminifera		
	Peake & Hancock, 1961	Hopson, 2005		UKB	BGS			
Early Maastrichtian	'Iunata Chalk'	'Trimingham Chalk'	<i>B. lanceolata</i>	21 (part)	25 (part)	← <i>Bolivinooides paleocenicus</i>		
	'Sidestrand Sponge Beds'						* <i>B. sumensis</i>	* <i>B. obtusa</i>
	'Porosphaera Chalk'			* <i>B. pseudobtusa</i>	20	24	ii	← <i>Bolivinooides decoratus</i>
	'Pre-Porosphaera Beds'			* <i>B. lanceolata</i> s.s.			i	← <i>Bolivinooides peterssoni</i>
Late Campanian	'Paramoudra Chalk'	'Norwich Chalk'	<i>B. mucronata</i> (part)	19	23	← <i>Gavelinella monterelensis</i> , <i>Neoflabellina rugosa</i> , <i>Loxostomum eleyi</i> , <i>Globorotalites hiltermanni</i>		
	'Beeston Chalk' & CSB							
	'Weybourne Chalk'	Portsdown Chalk (part)		18	21	iii	← <i>Reusella szajnochae szajnochae</i> , <i>Bolivina incrassata</i> , <i>Globorotalites hiltermanni</i>	
					ii	← <i>Gavelinella thalmani</i> , <i>G. forneliana</i>		
						← <i>Coryphostoma piata</i>		
						← <i>Gavelinella usakensis</i> , <i>G. trochus</i>		

CSB: 'Catton Sponge Beds'

* After Mortimore, Wood & Gallois, 2001

← Last appearance
← First appearance