2020-08

Foraminifera of the Gault Clay Formation: An update

Hart, MB

10.1016/j.pgeola.2019.10.003
Proceedings of the Geologists' Association
Elsevier BV

28th September 2019

Foraminifera of the Gault Clay Formation: an update

Malcolm B. Hart, Thomas Fogerty and Christopher W. Smart

School of Geography, Earth & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA

Tel: +44 1752 584761;
Fax +44 1752 584776;
E-mail address: mhart@plymouth.ac.uk

ABSTRACT

The foraminifera of the Gault Clay Formation (Middle and Upper Albian) are reviewed and their biostratigraphy compared to that of the standard ammonite-based zonation and the original bed numbers that are used by most workers on the formation. The change from an aragonitic assemblage in the Lower Gault to an assemblage dominated by agglutinated foraminifera in the Upper Gault is discussed in terms of changing palaeogeography and sea-level.

Keywords: Gault Clay Formation, Foraminifera, Taphonomy, Palaeoecology

1. Introduction

The Gault Clay Formation is a distinctive blue-grey mudstone that forms an important component of the mid-Cretaceous succession of the United Kingdom. Towards the South-West of England it passes laterally into the Upper Greensand Formation (Jukes-Browne and Hill, 1900; Drummond, 1970; Simmons et al., 1991; Gallois and Owen, 2019 and references therein) while northwards there is a transition into the Red Chalk of Norfolk, Lincolnshire and Yorkshire (Burrows et al., 1890; Gallois and Morter, 1982; Mitchell, 1995; Owen, 1995).

In East Anglia, Gallois and Morter (1982) identified 19 beds (numbered G1–G19). These beds appeared to record small-scale rhythms (*ca.* 1–2 m thick), often with a phosphate-rich, nodular, basal bed. These rhythms are more weakly developed in the Upper Gault Clay, as compared to the Lower Gault Clay. This scheme was rationalized by Gallois et al. (2016) with beds G1–G19 placed within seven distinctive sedimentary units (GE 1–7). How these two schemes relate to the initial bed numbers of the Gault Clay Formation is shown in Gallois et al. (2016, fig. 5) which shows how the various numbering schemes can be correlated across East Anglia and S.E. England (Weald and Folkestone).

The Gault Clay Formation is best known for its molluscan fauna (Casey *in* Smart et al., 1966; Morter and Wood, 1983) with ammonites providing both a viable and detailed biostratigraphy (Spath, 1923–1943; Casey, 1954a, b, 1957, 1961; Owen, 1958, 1963, 1971a, b, 1972, 1976, 1984). The earliest work on the Gault Clay Formation concentrated on the 'type locality' of Copt Point, Folkestone, where De Rance (1868), Price (1874a, b, 1876, 1879) and Jukes-Browne and Hill (1900) established the lithological succession of beds, numbered I–XIII, although initially it was only sub-divided into Beds I–XI: see Hart and Fox (in press) for a recent account of the history of the Copt Point investigations. It was realised, in the 1970s, that there were problems with the interpretation of the Copt Point succession, especially in the upper levels with landslides and solifluction having 'moved' parts of the overlying Glauconitic Marl and, in places, this had become confused with the glauconite-rich mudstones of Bed XII. This resulted in an error that created a mistaken view of the Bed XI – Bed XII – Bed XIII interval as well as the relationships across the Bed XIII – Glauconitic Marl boundary (Hart, 1973a, b). This confusion was resolved during construction of the Channel Tunnel both in the 1970s and, subsequently, in the main construction phase (1988–1991): see Carter and Hart (1977), Hart (1993, 2000) and Harris *et al*. (1996). This history has been described by Hart and Fox (in press, fig. 2) insofar as it impacted on the interpretation of both the hiatus at the base of the Cambridge Greensand and the overall interpretation of the Copt Point succession.

2. Foraminifera of the Gault Clay Formation

The foraminifera of the Gault Clay Formation are abundant, diverse and generally well-preserved. Chapman's classic work on the '*Foraminifera of the Gault of Folkestone*' (Chapman, 1891–1898) was based, almost exclusively, on samples from Copt Point, using Beds I–XIII and measured distances within each unit. There is some confusion that the nomenclature change, from using Beds I–XI to Beds I–XIII, occurred during his work and the new additions were not sampled to the same degree as the lower parts of the succession. It is not known how much of the earlier, mainly European, literature was available to Chapman although this may account for some of his variable use of taxa and other inconsistencies.

We owe our stratigraphical nomenclature to Alcide d'Orbigny and he is often portrayed as the 'father of micropalaeontology' (Vénec-Peyré, 2002, 2004). His 1840 memoir on the Upper Cretaceous of France and adjacent countries has remained one of the major contributions to the science. Reuss (1846, 1851, 1860, 1862, 1863), working mainly on German material, continued the description of the abundant foraminifera in Cretaceous assemblages. Many of the taxa used today date from the mid-19th Century, although the original illustrations of the individual foraminifera, which were acceptable at the time, continue to provide problems for taxonomic work. During the last 20 years of the 19th Century four major publications appeared, two of which are still considered the most important works in their particular fields. Chapman's (1891–1898) monograph on the foraminifera of the Gault Clay (Formation) of Folkestone, which recorded 265 species and varieties, has remained the only comprehensive work on the British Albian. He was preceded by Berthelin (1880) whose monograph on the Albian foraminifera of France described 39 new species, most of which were later recorded by Chapman from Folkestone. The two other important contributions were the monograph on Albian foraminifera by Egger (1900) and a paper on the Red Chalk of northern England by Burrows et al. (1890).

During the first half of the 20th Century there was a significant hiatus in European research (Franke, 1925, 1928; Eichenberg, 1933a, b, 1935a, b; Brotzen, 1934, 1942; Marie 1938, 1941) with much of the research focusing on the higher levels of the Cretaceous succession rather than the Albian. The Cushman Laboratory for Foraminiferal Research was founded in Sharon, Massachussetts (USA) by Joseph Cushman and his name appears against countless taxa that were described or re-assessed by him and his co-workers. Oil exploration was also behind the work of Williams-Mitchell (1948) and this was the first publication on the application of micropalaeontology to oil exploration on-shore U.K. In post-war Europe there was a sudden demand for micropalaeontological expertise and a wave of new work began in N. W. Europe (ten Dam, 1947, 1948a, b, 1950; Bartenstein and Brand, 1949, 1951; Bartenstein, 1952, 1954, 1965; Bartenstein *et al*., 1957, 1966; Hofker, 1954, 1957; Barnard and Banner, 1953, 1981; Barnard, 1958, 1962, 1963; Moullade, 1960, 1966: Bartenstein and Bettenstaedt, 1962; Malapris, 1965; Malapris-Bizouard, 1967, 1974; Neagu, 1965; Jannin, 1967; Magniez-Jannin, 1975, 1981, 1983; Gawor-Biedowa, 1972, 1982; Carter and Hart, 1977; Price, 1977). In deeper-water facies and in the Tethyan Realm, while there are a number of taxa in common with N. W. European successions, the assemblages are significantly different: see, for example, Holbourn et al. (2001) and references therein. Since the early 1980s there has been a reduction of work relating to Albian (and Cenomanian) foraminifera (but see Burnhill and Ramsay, 1981; Hart et al., 1989; King et al., 1989; Freig and Kemper, 1989; Meyn and Vespermann, 1994; and Hart, 2000).

One exception to this has been the collaborative work on the Kirchrode I and II Boreholes in Germany (Fenner et al., 1996; Fenner, 2001a, b, c; Tyszka and Thies, 2001; Tyszka, 2006). In particular, Tyszka (2006) has presented a revised taxonomy for the Albian Gavelinellidae, prompted by the generic revisions introduced by Revets (1996, 2001). While these suggested revisions are significant, the approach adopted by Revets (a study of only holotypes, paratypes, syntypes, *etc*.) has highlighted the problems of Gavelinellidae phylogeny and the authors have, for simplicity, retained the use of *Berthelina* and *Gavelinella* for many of the Albian and Cenomanian taxa while accepting that these determinations are in need of further revision (as was begun by Tyszka, 2006). The degree of morphological variation (inflation of chambers, size and form of umbilical boss, strength of peri-umbilical ornament, *etc.*) through the succession is significant and almost none of these variations were considered by Revets in his typological approach. Tyszka's (2006) analysis goes some way towards developing a better understanding of this variability though there is still a need to look at this topic in terms of environmental and other changes.

3. Investigated successions of the Gault Clay Formation.

In South-East England there are numerous locations where the Gault Clay Formation can be sampled for micropalaeontological research (Fig. 1). Extending from Copt Point, near Folkestone, the outcrop includes locations in the South Downs (*e.g.*, Eastbourne), the North Downs (*e.g.*, Sevenoaks), the Isle of Wight (both Culver Cliff and Compton Bay), and the Chilterns (*e.g.*, Mundays Hill Quarry). Added to the exposures on the coast and in working (or disused) quarries are the numerous boreholes (*e.g.*, Arlesey, Glyndebourne, Mundford 'C', *etc*.) that have intersected the Gault Clay Formation. This is particularly true of the area close to, and within, the site of the Channel Tunnel (see Hart, 1993, 2000; Harris et al., 1996; Hart and Fox, in press).

3.1. Glyndebourne Borehole

This borehole was drilled in 1973 during the mapping of the Lewes District (East Sussex) by the British Geological Survey (Lake et al., 1987). The micropalaeontology was investigated by Harris (1982) and a brief report on the foraminifera and ostracods published by Hart and Harris (2012). A more complete assessment of the foraminifera is in preparation. The biostratigraphy of the Glyndebourne borehole, which is mainly based on ammonites and bivalves, was included in the British Geological Survey Memoir (Lake et al., 1987) for the Lewes District.

3.2.Mundays Hill Quarry

This quarry, located in Bedfordshire (SP 93427 27985) exposes the contact between the Gault Clay Formation and the underlying Woburn Sands. The quarry has recently been 'refreshed' and a new succession (11.40 m thick) of the Gault Clay Formation became available in 2018. Historical work has divided the succession into 5 beds (numbered upwards from the contact with the underlying Woburn Sands), each of which is capable of further subdivision. The ammonite biostratigraphy was determined by Owen (1972), who placed the base of the Gault Clay Formation within the Spathi Subzone. One of the most important 'breaks' in the succession is above the Intermedius Subzone, where Owen (1972) records the absence of the Daviesi and Nitidus subzones, creating a significant hiatus between the Niobe Subzone and the Cristatum Zone/Subzone. Subsequent work on the Bedfordshire successions has confirmed this hiatus (Gallois et al., 2016).

The Woburn Sands/ Gault Clay Formation boundary in Bedfordshire is highly variable and has been described by Lamplugh and Walker (1903), Lamplugh (1922), Owen (1972) and Smart (1997). Much of the debate concerns the age and nature of the Shenley Limestone, a shallow-water carbonate that is only intermittently present in the Leighton Buzzard area (Lamplugh, 1921; Eyers, 1992; Smart, 1997), though not presently seen in the Munday's Hill Quarry (Fogerty et al., 2019).

3.3. Copt Point (Folkestone).

The classic section at Copt Point remains a key reference, with the foraminiferal succession being described by Hart (1973b) in the Proceedings Volume of the conference on the '*Boreal Lower Cretaceous*' organised in by Raymond Casey and Peter Rawson in 1972. As explained elsewhere the error in the Bed XI/XII/XIII analysis has now been corrected (Carter and Hart, 1977; Hart et al., 1989; Hart and Fox, in press).

3.4. Arlesey Borehole

The BGS Arlesey Borehole was drilled by the British Geological Survey in June 1991. It was located at TL18873463, which is only 40 m to the east of the former Arlesey brickpit. With a total depth of 83.49 m it provided a complete succession of the Gault Clay Formation (thickness 57.35 m) as well as recording ~1.07 m of the overlying Cambridge Greensand (Woods et al., 1995, fig. 2). The hiatus at the base of the Cambridge Greensand is clearly shown in the borehole log, as is the presence of a layer of phosphate pebbles at the base of the Dispar Zone. Parts of the uppermost Gault Clay Formation were recorded as being noticeably un-fossiliferous (Woods et al*.,* 1995, pp. 274–276). Wilkinson, who studied the ostracods and foraminifera, also noted that, in places, the "impoverished microfauna for much of the Upper Gault do not allow detailed biostratigraphical information" (Woods et al*.,* 1995, p. 276). It is noticeable that many of the ranges recorded in the distribution charts (*op. cit.,* figs 3, 4) are based on only a few records, with no data provided from the Cambridge Greensand. The records of *Globigerinelloides bentonensis*, while appearing to coincide with the Zone 6 ‘flood’ of large specimens, are quite limited as this taxon has a much longer total range than is indicated. The same is true of species such as *Citharinella pinnaeformis* and *Arenobulimina* spp. In the samples collected from Arlesey, Barrington and the M11 Cambridge bypass, some of which were described by Hart (1973a), the assemblages appeared to be more ‘normal’ with all the diagnostic taxa present in the expected proportions and overall ranges. These data were directly comparable to, for example, the successions at Folkestone and in the BGS Glyndebourne borehole (Hart and Harris, 2012). In the Glyndebourne succession the assemblages of foraminifera in both the Gault Clay Formation and the transition to the overlying chalk was both diverse and abundant (Hart and Harris, 2012, figs 2, 3). This was also true of the ostracods (Hart and Harris, 2012, fig. 5) where the Dispar Zone contained all the diagnostic taxa. Direct comparisons to the Arlesey Borehole (Woods et al., 1995, fig. 3) are difficult as so few samples are recorded as containing diagnostic, or indeed any, taxa. Samples from the Arlesey Borehole, inspected by MBH, partly agree with the paucity of the assemblage though there are some discrepancies recorded. Zone 6a is probably not present, and that agrees with both Woods et al. (1995) and other work by the authors. This is not really surprising as Zone 6a has a well-known, but rather limited distribution, within the successions of the Channel Tunnel (and parts of Surrey) and the hiatus at the base of the Cambridge Greensand is clearly more significant than the comparable hiatus in the area of the Channel Tunnel.

3.5. Mundford ‘C’ Borehole

This borehole, located in East Anglia north-west of Thetford, was studied by Sandman (1986), though the work was never formally published. The assemblages of foraminifera are comparable to those recorded from Munday’s Hill Quarry (Fogerty et al., 2019) and the Cambridge bypass (Hart and Fox, in press).

4. Foraminiferal Zonation

The first meaningful attempt at a zonation of the Gault Clay Formation in the twentieth century was by Carter *in* Bruckshaw (1961) in which the distribution of key foraminifera in the Albian – Turonian interval was presented (Fig. 2). When this preliminary zonation was published none of the taxa (listed as 1–45) were identified; the figure was published without a full caption! Indeed, even in the more complete Channel Tunnel Investigation by D.J. Carter in 1964–1966, many of the taxa were informally identified by number (*e.g*., *Arenobulimina* C.T.P. sp.45). Some taxa had names applied but these were regarded as 'tentative' as the pressure of time to get the correlation across the English Channel completed meant that taxonomic work was not a priority. Indeed, D.J. Carter had been selected for the task as a result of his industrial micropalaeontological experience (Hart and Bailey, 2013) rather than his research and publication record. MBH is still in possession of the original line drawings done by D.J. Carter, and the range of informal names used. In the caption to Figure 2, some of the valid names have been applied, though many remain either informal or provisional.

The zonation of the uppermost Gault Clay was confused by Hart (1973a, b), as explained in Hart and Fox (in press), but clarified in Carter and Hart (1977) after further work on borehole material recovered from the Dover/Folkestone area. This revised zonation (Fig. 3) was carried forward into the '*Stratigraphical Atlas of Fossil Foraminifera*' (Hart et al., 1989). The numbering scheme (3 – 6 for the Gault Clay), adopted by Hart (1973a, b), Carter and Hart (1977) and Hart et al. (1989), derives from the original 1961 scheme.

Zone 3 (Middle Albian): Concurrent Range Zone, *Conorboides lamplughi* and *Epistomina spinulifera*. The assemblage in this zone is somewhat limited although those species that do occur are quite distinctive. *Conorboides lamplughi* is not found above Zone 3, but many of the other characteristic taxa (*e.g*., *Gavelinella tormarpensis*, *Hoeglundina chapmani*, *H. carpenteri*, *E. spinulifera* and *Arenobulimina macfadyeni*) continue into higher levels of the succession.

Zone 4 (Middle Albian): Concurrent Range Zone, *Hoeglundina carpenteri* and *Dorothia filiformis*. Within this zone *E. spinulifera* occurs in flood abundance and specimens are often very large and highly ornamented. This was demonstrated by Hart (1984, fig. 3) in a simple biometric analysis based on measurements of relatively large numbers of individuals. This is particularly seen in Beds Vll – lX(lower) in the Folkestone succession close to the Middle/Upper Albian boundary. The other taxa associated with this zone, such as *Hoeglundina carpenteri*, *H. chapmani* and *Dorothia filiformis*, continue above.

Zone 4a (Middle to Upper Albian transition): Concurrent Range Zone, *Epitomina spinulifera* and *Citharinella pinnaeformis*. This zone can either be missing or may be very thinly developed. Its recognition depends on the dwindling numbers of *E. spinulifera* (some of which may be reworked) and the early appearances of *Citharinella pinnaeformis*. Even though the latter species is very distinctive and (normally) easy to identify, even in fragments, it is un-common at the beginning of its range. It is unclear as to which species gives rise to *C. pinnaeformis*, and so an evolutionary boundary to Zone 4a cannot be identified. The other taxa associated with this zone include distinctive forms such as *Arenobulimina chapmani*, *Nodobacularia nodulosa* and *Spiroloculina papyracea*. The change-over from an assemblage with *Arenobulimina macfadyeni* to one with *A. chapmani* is also quite distinctive.

Zone 5 (Upper Albian): Assemblage zone of *Citharinella pinnaeformis*. Although this zone is 'named' after *C. pinnaeformis*, this species is usually quite rare and specimens often fragmentary. The remainder of the assemblage is, however, quite distinctive and includes *Arenobulimina chapmani* (which is the dominant species), *Tritaxia pyramidata*, *Quinqueloculina antiqua*, *Dorothia filiformis*, *Nodobacularia nodulosa*, *Spiroloculina papyracea* and the first occurrences of *Eggerellina mariae*. Also making an appearance is *Spiroplectinata annectens*, which often develops a quite distinctive growth style. With an initial triserial component, the greater part of the test is biserial but can, in the later growth stages, develop a uniserial pattern of slightly inflated chambers. This often gives the final specimen a rather bizarre, but distinctive, appearance (Fogerty et al., 2019, pl. 4, figs 7-9).

Zone 5a (Upper Albian): Concurrent Range Zone of *Citharinella pinnaeformis* and *Arenobulimina sabulosa*. The appearance of the quadriserial, strongly rugose, *A. sabulosa*, together with *Marssonella ozawai* alongside *C. pinnaeformis* makes a distinctive assemblage but it is often missing from Gault Clay successions as a result of an hiatus at this level. Near the upper end of its range *C. pinnaeformis* also becomes even less common than previously, and one is often reliant on the identification of small fragments (which are, fortunately, quite characteristic). This may be a problem for the identification of this zone though the associated species are quite distinctive. Other associated species include *T. pyramidata*, *Berthelina intermedia* and *Arenobulimina chapmani*; the latter often being the most abundant species present.

Zone 6 (Upper Albian): Concurrent Range Zone of *Vaginulina mediocarinata* and *Arenobulimina frankei*. *Arenobulimina sabulosa* and *A. chapmani* are normally the dominant species, associated with *M. ozawai*. At this level *D. filiformis* and *N. nodulosa* are becoming quite rare. While planktic foraminifera are not part of this zonation, there is a distinctive 'flood' of *Globigerinelloides bentonensis* in the middle of Zone 6 (see Carter and Hart, 1977; Hart, 2000; Hart and Fox, 2019).

Zone 6a (uppermost Albian): Concurrent Range Zone of *Arenobulimina sabulosa* and *Flourensina intermedia*. This zone is characterized by a distinctive overlap of Albian and Cenomanian taxa. Typically Albian species include *A. chapmani*, *A. sabulosa* and *A. frankei*, in the lower part while gradually appearing up-section are typically Cenomanian taxa such as *F. intermedia*, *A. advena*, *Gaudryina austiniana* and *Berthelina cenomanica*. There are transitional forms present where the differences are quite subtle but highly distinctive. This includes transitional forms between *A. chapmani* and *A. advena*, *A. sabulosa* and *A. anglica*, *Berthelina intermedia* and *B. cenomanica*, most of which are parts of their respective evolutionary lineages (Bailey et al., 2009). There are also early forms of *Plectina mariae* and *Berthelina baltica*. As indicated by Hart and Fox (in press), Zone 6a has a 'patchy' distribution and is normally cut out by the discontinuity (erosion surface) at the Albian/Cenomanian boundary. It is best recorded in Channel Tunnel boreholes off-shore Folkestone and, as a result, its position within the ammonite stratigraphy is not known. In distribution it appears to be uppermost Albian and may, therefore, represent a part of the *Stoliczkaia dispar* Zone.

The overlying Zone 7 is typically associated with a range of taxa with known Cenomanian affinities and, when present, is characterised by the Glauconitic Marl at the base of the chalk succession in South-East England (especially in the

Dover/Folkestone area and in Channel Tunnel boreholes). Towards the west, and the north, the age of the basal glauconitic chalk becomes younger as described by Carter and Hart (1977) and Hart and Fox (in press).

5. Distribution of Aragonitic Foraminifera

One of the important groups of foraminifera recorded in the Gault Clay Formation are the members of the Superfamily Robertinacea (Loeblich and Tappan, 1964). These genera and species are now represented by the Ceratobuliminidea Cushman, 1927 following Loeblich and Tappan (1987). The Lower Cretaceous members of this superfamily were described by Hart (1984), especially those recorded from the Gault Clay Formation. The following species are recorded:

Conorboides lamplughi (SHERLOCK, 1914); *Pulvinulina lamplughi* SHERLOCK, 1914, p. 290, pl.19, fig.16.

Epistomina sp. cf. *E. cretosa* TEN DAM, 1947, p. 29, fig. 6.

Epistomina spinulifera (REUSS, 1862); *Rotalia spinulifera* REUSS, 1862, p. 93, pl.13, figs 3a-5c.

Hoeglundina carpenteri (REUSS, 1862); *Rotalia carpenteri* REUSS, 1862, p. 94, pl.13, fig. 6a-c.

Hoeglundina chapmani (TEN DAM, 1948); *Pulvinulina caracolla* (ROEMER), CHAPMAN, 1898, p. 7, pl.1, fig. 9.

Epistomina cretosa is rarely described and there is a suspicion that it has probably been included within *E. spinulifera* by some authors, as the two species are morphologically very similar. For example, Haig et al. (1996, fig. 7R, S) illustrate highly ornamented forms attributed to *E. cretosa* that appear to be more closely related to *E. spinulifera*. The primary difference between the two species is the presence of a double keel in *E. cretosa* rather than the single, spinose keel in *E. spinulifera*. This double keel can be seen in the specimens figured by Hart (1984, pl. 2, figs 12, 16) but is not present in Haig et al.'s specimens. The Haig et al. (1996) assemblage of Albian foraminifera also includes specimens of *Conorboides* *lamplughi* and *Epistomina chapmani* that are exceptionally close in appearance to the N.W. European taxa. This appears to indicate that some of these aragonitic taxa are cosmopolitan, as is much of the Albian assemblage in Western Australia.

All of these taxa are restricted (mainly) to the Lower Gault Clay and, in this part of the succession are present in large numbers. When plots of superfamilies (*sensu* Loeblich and Tappan, 1964 or 1987) are constructed, there is a very distinctive distribution of these aragonitic foraminifera within Beds I–IX (Lyelli Subzone to Orbignyi Subzone) of the Lower Gault Clay. This was noted by Hart (1973b) and Hart and Carter (1975), as was the similarity to the superfamily distribution in the Atherfield Clay succession (Lower Aptian) of southern England (Hart and Carter, 1975, text-fig. 3). The famous Atherfield Clay succession of the Isle of Wight was investigated by Crittenden (1988), but he only recorded very intermittent occurrences of *H. chapmani* in this succession below the Lower Lobster Bed, with nothing like the pattern of distribution recorded by Hart and Carter (1975). Crittenden also recorded *H. chapmani* in the Southern North Sea Basin, but this was also in low numbers. This Middle Albian distribution of the aragonitc foraminifera appears to occur in Kent (and parts of the Channel Tunnel which drilled into the Gault Clay Formation) as well as the eastern parts of Surrey. The more arenaceous Gault Clay of the Isle of Wight does not record the same distribution, but recent work in Bedfordshire (*e.g.*, Munday's Hill Quarry; Fogerty et al., 2019, fig. 4) has shown that the general pattern, within the mudstone facies, is present north of the Thames.

Aragonitic foraminifera are characterised by a distinctive, lustrous test and, preserved in mudstones, are often in-filled with pyrite. In parts of the Jurassic succession, only the pyritic infillings remain, the aragonitic test having been lost during taphonomy and burial. One must ask, therefore, whether the distribution of the aragonitic foraminifera in the Gault Clay Formation is a primary signal or whether it is one dominated by taphonomy?

Aragonitic foraminifera are normally associated with mudstone successions in the geological record (Makrides, 1979; Haig et al., 1996; McMillan, 2008). They are often found alongside ammonites and other molluscs that also show aragonite preservation while, in a lithology such as the chalk, aragonitic fossils are normally absent. Mudstone successions are often aquacludes, having been compacted by 70–80% as a result of de-watering and burial. Hart et al. (2019, fig. 6) showed that sand (or silt) rich sediments do not compact to the same degree, thereby allowing the flow of groundwater through the sediment, removing the aragonitic (and some calcitic) foraminifera. Selective preservation of aragonitic foraminifera in compacted mudstones is, therefore, to be expected. Counts of benthic foraminifera based on samples of compacted mudstones, which if reduced in thickness by 70–80%, must represent large numbers of annual cycles though the ratio of aragonitic taxa to calcareous and agglutinated taxa will hopefully remain indicative of the original assemblages.

In the Jurassic strata of the Dorset Coast, Oxford et al. (2000, 2004) showed that the fluctuations in the numbers of aragonitic and other foraminifera might represent sequences and parasequence with larger numbers of epsitominids often being associated with zones of maximum flooding. The same patterns also seem to have been preserved within the Speeton Clay Formation (Hart et al., 2009).

The ‘Gault Clay Cycles’ identified by Gallois and Morter (1982) may be parasequences as they appear to be laterally persistent. The higher percentages of aragonitic foraminifera in the Lower Gault Clay (and the Lower Atherfield Clay; Hart and Carter, 1975) certainly indicate that the lower parts of the Gault Clay Formation and the Atherfield Clay Formation were suitable for the preservation of aragonitic foraminifera. This is not the case in the Gault Clay succession of the Isle of Wight where aragonitic foraminifera are missing and, when sieved, the mudstones have a higher sand and silt component. Whether this is a primary exclusion from a more sandy/silty environment or a preservational affect is impossible to say, though it may be significant that not even the pyrite moulds of aragonitic foraminifera are recorded in these locations.

6. Palaeoecology and Palaeogeography

If the distribution of aragonitic foraminifera is a primary, palaeoecological signal, what other changes in the assemblage provides supporting evidence? Agglutinated taxa are very much more abundant after the Cristatum Zone and this is true at

Folkestone (Fig. 3), Munday's Hill Quarry (Fogerty et al., 2019, fig. 4) and in the Glyndebourne borehole (Fig. 4). Species such as *Arenobulimina*, *Marssonella*, *Tritaxia* and *Cribrostomoides* all require clastic material with which to construct their tests and the occurrence of – predominantly – silt-grade sediment is more abundant above the Cristatum Zone. While one must be cautious in using planktic foraminifera, and planktic/benthic ratios, as a guide to water depth it is clear that, especially in the smaller size fractions, planktic taxa increase in abundance up-section (above the Cristatum Zone).

This general increase in planktic foraminifera (*e.g.*, *Muricohedbergella delrioensis*, *M. infracretacea*, *M. planispira*) up-section has been recorded across South-East England, including Munday's Hill Quarry (Bedfordshire); see Fogerty et al. (2019, fig. 7). With the same pattern discernable across much of South-East England, this appears to be a basin-wide feature and must be linked to large scale changes in either water depth or palaeogeography. There has been little in the way of detailed discussion of Albian palaeogeography since the publication of the '*Atlas of Palaeogeography and Lithofacies*' (Hancock and Rawson *in* Cope et al., 1992). The only map for the interval occupied by the Gault Clay Formation is for the Upper Albian (Hancock and Rawson, 1992, map K3, p. 137) which shows the 'Red Chalk' to the north and the greensand facies to the south-west. The Weald Basin and Channel Basin are in open connection to the Paris Basin (to the south) and this is demonstrated by the similarity in foraminiferal assemblages in South-East England, the Paris Basin and, across the Southern North Sea Basin (King et al., 1989), in the Netherlands and North Germany.

The base of the Gault Clay Formation is highly transgressive and this may well be a sequence boundary. The Lower Gault Clay and Upper Gault Clay are quite distinctive, separated by horizons of phosphate pebbles in the Cristatum Zone. In Bedfordshire the boundary is also a significant hiatus with the Nitidus and Daviesi subzones missing. The more silt-rich Upper Gault Clay, with its more abundant and diverse agglutinated foraminiferal assemblage and increasing numbers of planktic foraminifera may represent a major flooding event (Transgressive Systems Tract, TST), which resulted in the development of a Highstand Systems Tract (HST).

7. Summary

The distribution of foraminifera in the Gault Clay Formation is shown to provide a viable tool for regional correlation. Many of the significant changes in the assemblage are shown to coincide with known hiatuses in the ammonite succession and the presence of phosphate concentrations. The Lower Gault Clay, in the mudstone facies, is always characterized by the presence of aragonitic foraminifera, often showing exquisite preservation. Of particular interest is the presence of comparable assemblages in the Indian Ocean (offshore South Africa) and in the Carnarvon Basin of Western Australia which suggests that some of these taxa, in appropriate facies, are quite cosmopolitan.

Acknowledgements

TF acknowledges the help provided by Gary McNeely and Aggregate Industries in providing access to Munday’s Hill Quarry. Dr Steve Stukins and Dr Haydon Bailey facilitated the microscope work undertaken by TF at the Natural History Museum (London). Mr Tim Absalom (University of Plymouth) is thanked for providing the final versions of the figures.

References

Bailey, H.W., Hart, M.B., Swiecicki, A., 2009. Evolutionary lineages of benthic foraminifera in the chalk seas of N. W. Europe and their application to problem solving. In: Demchuk, T.D., Gary, A.C. (eds), Geologic Problem Solving with Microfossils: A Volume in Honor of Garry D. Jones, SEPM Special Publication 93, 233–249.

Barnard, T.,1958. Some Mesozoic adherent foraminifera. Palaeontology 2, 1–27.

Barnard, T.,1962. Polymorphinidae from the Upper Cretaceous of England. Palaeontology 1, 116–124.

Barnard, T.,1963. The morphology and development of species of *Marssonella* and *Pseudotextulariella* from the Chalk of England. Palaeontology 6, 41–54.

Barnard, T., Banner, F.T.,1953. Arenaceous Foraminifera from the Upper Cretaceous of England. Quarterly Journal of the Geological Society, London 109, 173–216.

Barnard, T., Banner, F.T.,1981. The Ataxophragmiidae of England: Part 1, Albian-Cenomanian *Arenobulimina* and *Crenaverneuilina*. Revista Española de Micropaleontologia 12, 383–430.

Bartenstein, H., 1952. Taxonomische Bemerkungen zu den *Ammobaculites*, *Haplohphragmium*, *Lituola* und verwandten Gattungen. Senckenbergiana 33, 313–342.

Bartenstein, H., 1954. Revision von Berthelin's Mémoire 1880 über die Alb-Foraminiferen von Montcley. Senckenbergiana Lethaea 35(1–2), 37–50.

Bartenstein, H., 1959. Feinstratigraphisch wichtige Ostracoden aus dem nordwestdeutschen Valendis. Paläontologische Zeitschrift 33, 224–242.

Bartenstein, H.,1965. Taxinomische Revision und Nomenklatur zu Franz E. Hecht 'Standard-Gliederung der nordwestdeutschen Unterkreide nach Foraminiferen' (1938). Senckenbergiana Lethaea, Frankfurt 46, 327–366.

Bartenstein, H., Brand, E., 1949. New genera of Foraminifera from the Lower Cretaceous of Germany and England. Journal of Paleontology 23(6), 669–672.

Bartenstein, H., Brand, E., 1951. Mikropaläontologische Untersuchungen zur Stratigraphie des nordwest-deutschen Valendis. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft 485, 239–336.

Bartenstein, H., Bettenstaedt, F., 1962. Marine Unterkreide (Boreal und Tethys). In: Simon, W., Bartenstein, H. (eds), Leitfossilien der Mikropaläontologie, Berlin, 225–297.

Bartenstein, H., Bettenstaedt, F., Bolli, H. M.,1957. Die Foraminiferen der Unterkreide von Trinidad, B. W. I. Erster Teil: Cucheund und Toco Formation. Eclogae Geologicae Helvetiae 50, 5–67.

Bartenstein, H., Bettenstaedt, F., Bolli, H. M., 1966. Die Foraminiferen der Unterkreide von Trinidad, B. W. I.: Maridale Formation (Typlokalitat). Eclogae Geologicae Helvetiae 59, 129–178.

Berthelin, G.,1880. Mémoire sur les Foraminifères de l'Étage Albien de Montcley (Doubs). Mémoire de la Société Gélogique de France, Paris (3), 1(5), 1–84.

Brotzen, F.,1934. Foraminiferen aus dem Senon Palastinas. Zeitschrift des Deutschen Palästina-Vereins 57(1), 28–72.

Brotzen, F., 1942. Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik des Rotaliiformes. Sveriges Geologiska Undersökning 36(8) , 1–60.

Bruckshaw, J.M., Goguel, J., Harding, H.J.B., Malcor, R., 1961. The work of the Channel Study Group, 1958–60. Proceedings of the Institution of Civil Engineers 18, 149–178.

Burnhill, T.J., Ramsay, W.V., 1981. Mid-Cretaceous palaeontology and stratigraphy, Central North Sea. In; Petroleum Geology of the north-west European Continental Shelf, Institute of Petroleum, London, 245–254.

Burrows, H.W., Sherborn, C.D., Bailey, G., 1890. The foraminifera of the Red Chalk of Yorkshire, Norfolk and Lincolnshire. Journal of the Royal Microscopical Society, London 8, 549–566.

Carter, D.J., Hart, M.B., 1977. Aspects of mid-Cretaceous stratigraphical micropalaeontology. Bulletin of the British Museum, Natural History (Geology) 29, 1–135.

Casey, R., 1954a. Falciferella, a new genus of Gault Ammonites, with a review of the family Aconeceratidae in the British Cretaceous. Proceedings of the Geologists' Association 65(3), 262–277.

Casey, R., 1954b. New genera and subgenera of Lower Cretaceous ammonites. Journal of the Washington Academy of Sciences 44, 106–115.

Casey, R., 1957. The Cretaceous Ammonite genus *Leymeriella*, with a systematic account of its British occurrences. Palaeontology 1, 28–59.

Casey, R., 1961. The stratigraphical palaeontology of the Lower Greensand. Palaeontology 3, 487–621.

Casey, R., 1965. A monograph of the Ammonoidea of the Lower Greensand. Part VI. Palaeontographical Society, London (Monograph), 399–546.

Casey,R., 1966. Palaeontology of the Gault. In; Smart, J.G.O., Bisson, G., Worssam, B.C. (eds), Geology of the country around Canterbury and Folkestone, British geological Survey, Memoir, HMSO, London, 102–113.

Chapman, F., 1891–1898. The foraminifera of the Gault of Folkestone. Journal of the Royal Microscopical Society, London (Part 1) 1891, 565–575; (Part 2) 1892, 319–330; (Part 3) 1892, 749–758; (Part 4) 1893, 579–595; (Part 5) 1893, 153–163; (Part 6) 1894, 421–427; (Part 7) 1894, 645–654; (Part 8) 1895, 1–14; (Part 9) 1896, 581–591; (Part 10) 1898, 1–49.

Crittenden, S., 1988. The lithostratigraphy and biostratigraphy (Foraminifera) of the Early Cretaceous of the Southern North Sea Basin. Unpublished PhD Thesis, Council for National Academic Awards (CNAA), University of Plymouth.

Dam, A. ten,1947. On foraminifera of the Netherlands No. 9. Sur quelques espèces nouvelles ou peu connues dans le Crétacé Inférieur (Albien) des Pays-Bas. Geologie Mijnbouw, n.s., 8, 25–29.

Dam, A. ten, 1948a. Foraminifera from the Middle Neocomian of the Netherlands. Journal of Paleontology 22, 175–192.

Dam, A. ten, 1948b. Les espèces du genre *Epistomina* Terquem, 1883. Revue de l’Institut Français du Pétrole, Paris, n.s., 3(6), 161–170.

Dam, A. ten,1950. Les Foraminifères de l’Albien des Pays-Bas. Memoires de la Société Géologique de France, Paris, n.s., 29(63), 1–66.

De Rance, 1868. On the Albian or Gault of Folkestone. Geological Magazine 5, 163–171.

Drummond, P.V.O., 1970. The Mid-Dorset Swell. Evidence of Albian–Cenomanian movements in Wessex. Proceedings of the Geologists' Association 81, 679–714.

Egger, J.G.,1900. Foraminiferen und Ostrakoden aus dem Kreidemergeln der oberbayerischen Alpen. Abhandlungen, Bayerische Akademie der Wissenschaften, Munich 21, 1–230.

Eichenberg, W.,1933a. Die Foraminiferen der Unterkreide. 1 Folge. Foraminiferen aus dem Albien von Weden am Mittellandkanal. Jahresbericht der Neidersächsiche Geologische Verein 25, 1–32.

Eichenberg, W., 1933b. Die Foraminiferen der Unterkreide. 2 Folge. Foraminiferen aus dem Barreme von Weden am Mittellandkanal. Jahresbericht der Neidersächsiche Geologische Verein 25, 167–200.

Eichenberg, W.,1935a. Die Foraminiferen der Unterkreide. 3 Folge. Foraminiferen aus dem Hauterive von Weden am Mittellandkanal. Jahresbericht der Neidersächsiche Geologische Verein 26, 150–196.

Eichenberg, W., 1935b. Die Foraminiferen der Unterkreide. 4 Folge. Foraminiferen aus dem Apt von Weden am Mittellandkanal. Jahresbericht der Neidersächsiche Geologische Verein 27, 1–40.

Eyers, J., 1992. Sedimentology and palaeoenvironment of the Shenley Limestone (Albian, Lower Cretaceous); an unusual shallow-water carbonate. Proceedings of the Geologists' Association 103, 293–302.

Fenner, J., 2001a. Middle Albian geography, oceanography and climate and the setting of the Kirchrode I and II borehole sites. Palaeogeography, Palaeoclimatology, Palaeoecology 174, 5–32.

Fenner, J., 2001b. Kirchrode I and II boreholes: technical details and evidence on tectonics, and palaeoceanographic development during the Albian. Palaeogeography, Palaeoclimatology, Palaeoecology 174, 33–65.

Fenner, J., 2001c. Palaeoceanographic and climate changes during the Albian, summary of the results from the Kirchrode boreholes. Palaeogeography, Palaeoclimatology, Palaeoecology 174, 287–304.

Fenner, J., Bruns, A., Cepek, P., Köthes, A., Owen, H.G., Prauss, M., Riegel, W., Thies, A., Tyszka, J., Weiss, W., Wiedmann, J.,1996. Paleontological results from the Boreal Albian (boreholes Kirchrode I and II), biostratigraphy, paleoenvironment and cycle analysis. In: Reitner, J., Neuweiler, F. and Gunkel, F. (Eds.), Global and regional controls on biogenic sedimentation, Part II. Cretaceous sedimentation. Göttinger Arbeiten Geologie Paläontologie, Sb2, Universität Göttingen, 5–12.

Fogerty, T., Hart, M.B., Page, K.N., Smart, C.W., 2019. The foraminiferal biostratigraphy and palaeoenvironmental interpretation of the Gault Clay Formation (Middle and Upper Albian) at Munday's Hill Quarry, Bedfordshire. Micropaleontology, (in press).

Franke, A.,1925. Die Foraminiferen der pommerschen Kreide. Abhandlungen aus dem Geologisch-Paläontologischen Institut der Universität Griefswald 6, 1–96.

Franke, A., 1928. Die Foraminiferen der Oberen Kreide Nord- und Mitteldeutschlands. Abhandlungen der Preussischen Geologischen Landesanstalt, Berlin, Neue Folge 111, 1–207.

Frieg, C., Kemper, E.,1989. Mikropaläontologische Gliederung und Abgrenzung von Ober-Alb und Unter-Cenoman in Nordwestdeutschland. Geologisches Jahrbuch A 113, 73–192.

Gallois, R.W., Morter, A.A., 1982. The stratigraphy of the Gault of East Anglia. Proceedings of the Geologists' Association 93, 351–368.

Gallois, R.W., Morter, A.A., Owen, H.G., 2016. The stratigraphy of the Gault Formation (Early Cretaceous, Albian) in East Anglia and south-east England. Proceedings of the Geologists' Association 127(5), 606–628.

Gawor-Biedowa, E., 1972. The Albian, Cenomanian and Turonian foraminifers of Poland and their stratigraphic importance. Acta Palaeontologica Polonica 17, 3–174.

Gawor-Biedowa, E.,1982. Biostratigraphy of the Albian Cenomanian and Turonian deposits of western and central Poland based on the occurrence of foraminifers. – Biuletyn Instytutu Geologicznego 329(11), 63–138 [in Polish with English and Russian summaries].

Haig, D.W., Watkins, D.K., Ellis, G., 1996. Mid-Cretaceous calcareous and siliceous microfossils from the basal Gearle Siltstone, Giralia Anticline, Southern Carnarvon Basin. Alcheringa 20(1), 41–68.

Hancock, J.M., Rawson, P.F., 1992. Cretaceous. In: Cope, J.C.W., Ingham, J.K., Rawson, P.F. (eds), Atlas of palaeogeography and lithofacies, Geological Society, London, Memoir 13, 131–139.

Harris, C.S., 1982. Unpublished PhD Thesis, Council for National Academic Awards, Plymouth Polytechnic (now University of Plymouth).

Harris, C.S., Hart, M.B., Varley, P.M., Warren, C.D. (eds), 1996. Engineering Geology of the Channel Tunnel. Thomas Telford, London.

Hart, M. B., 1973a. Foraminiferal evidence for the age of the Cambridge Greensand. Proceedings of the Geologists' Association, London 84, 65–82.

Hart, M. B., 1973b. A correlation of the macrofaunal and microfaunal zonations of the Gault Clay in southeast England. In: Casey, R., Rawson, P.F. (eds), The Boreal Lower Cretaceous, Geological Journal, Special Issue, 5, 267–288.

Hart, M.B., 1984. The Superfamily Robertinacea in the Lower Cretaceous of the UK and adjacent areas of NW Europe. In: Oertli, H.J. (Ed.), Benthos '83, 2nd

International Symposium on Benthic Foraminifera (Pau, April 1983), Elf Aquitaine, Esso REP and Total CFP, Pau and Bordeaux, 289–298.

Hart, M. B., 1993. Engineering and economic geology. In: Jenkins, D.G. (Ed.), Applied Micropalaeontology, Kluwer Academic Publishers, Netherlands, 225–262.

Hart, M. B., 2000. Foraminifera, sequence stratigraphy and regional correlation; an example from the uppermost Albian of Southern England. Revue de Micropaléontologie 43, 27–45.

Hart, M.B., Bailey, H.W., 2013. Key figures from the history of research on the Foraminifera of the Chalk Group in the UK. In: Bowden, A.J., Gregory, F.J., Henderson, A.S. (eds), Landmarks in Foraminiferal Micropalaeontology: History and Development, The Micropalaeontological Society, Special Publications, Geological Society, London, 85–102.

Hart, M.B., Carter, D.J., 1975. Some observations on the Cretaceous Foraminiferida of Southeast England. Journal of Foraminiferal Research 5(2), 114–126.

Hart, M.B., Harris, C.S., 2012. Albian–Cenomanian foraminifera and Ostracoda from the Glyndebourne Borehole, Sussex, U.K. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 266, 319–335.

Hart, M.B., Fox, L.F., (*in press*). Micropalaeontology and stratigraphical setting of the Cambridge Greensand. Proceedings of the International Symposium on the Cretaceous System, Wien, 2017.

Hart, M.B., Bailey, H.W., Crittenden, S., Fletcher, B.N., Price, R.J., Swiecicki, A., 1989. Cretaceous. In: Jenkins, D.G., Murray, J.W. (eds), Stratigraphical Atlas of Fossil Foraminifera [2nd Edition], Ellis Horwood Ltd, Chichester, 273–371.

Hart, M.B., Price, D.G., Smart, C.W., 2009. Foraminifera and sequence stratigraphy of the lower part of the Speeton Clay Formation (Lower Cretaceous) in N.E. England. Annalen des Naturhistorischen Museum in Wien, Serie A, 110A, 423–442.

Hart, M.B., Page, K.N., Price, G.D., Smart, C.W., 2019. Reconstructing the Christian Malford ecosystem in the Oxford Clay Formation (Callovian, Jurassic) of Wiltshire: exceptional preservation, taphonomy, burial and compaction. Journal of Micropalaeontology 38, 133–142.

Hofker, J., 1954. Uber die Familie Epistomariidae, (Foram), Palaeontographica, Abt A, 105, 166–206.

Hofker, J., 1957. Foraminiferen der Oberkreide von Nordwestdeutschland und Holland, Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 103(3), 312–340.

Holbourn, A., Kuhnt, W., Soeding, E., 2001. Atlantic paleobathymetry, paleoproductivity and paleocirculation in the late Albian: the benthic foraminiferal record, Palaeogeography, Palaeoclimatology, Palaeoecology 170(3–4), 171–196.

House, M.R., 1993. Geology of the Dorset Coast. Geologists' Association Field Guide 22 [2nd Edition], Geologists' Association, London, 164pp.

Jannin, F., 1967. Les 'Valvulineria' de l'Albien de l'Aube, Revue de Micropaléontologie 10(3), 153–178.

Jukes-Browne, A.J., Hill, W., 1900. The Cretaceous Rocks of Britain. Volume 1, The Gault and Upper Greensand of England. Memoirs of the Geological Survey, Great Britain, 499pp.

King, C., Bailey, H.W., Burton, C.A., King, A.D.,1989. Cretaceous of the North Sea. . In: Jenkins, D.G., Murray, J.W. (eds), Stratigraphical Atlas of Fossil Foraminifera [2nd Edition], Ellis Horwood Ltd, Chichester, 272–417.

Lake, R.D., Young, B., Wood, C.J., Mortimore, R.N.,1987. Geology of the country around Lewes. Memoir for 1:50 000 geological sheet 319 (England & Wales), HMSO, London, 117pp.

Lamplugh, G.W., 1921. The age of the Shenley Limestone (Correspondence). Geological Magazine 58, 140.

Lamplugh, G.W., 1922. On the junction of the Gault and Lower Greensand near Leighton Buzzard (Bedfordshire). Quarterly Journal of the Geological Society, London 78, 1–80.

Lamplugh, G.W., Walker, J.F., 1903. A fossiliferous band at the top of the Lower Greensand near Leighton Buzzard. Quarterly Journal of the Geological Society, London 59, 234–265.

Loeblich, A.R. Jr, Tappan, H., 1964. Protista 2. Sarcodina, chiefly ‘Thecamoebians’ and Foraminiferida. In: Moore, R.C. (Ed.), Treatise on Invertebrate Paleontology, Part C, 1, 1–510; 2, 511–900, Lawrence, Kansas.

Loeblich, A.R. Jr, Tappan, H., 1987. Foraminiferal genera and their classification. Van Nostrand Reinhold, New York, 2 volumes.

McMillan, I.K., 2008. Aragonitic-walled benthic foraminifera (Epistomina) in the Cretaceous ‘mudbelt’ off southern Africa, and post-mortem cross-shelf transport of tests. African Natural History 4, 17–24.

Magniez-Jannin, F., 1975. Les Foraminifères de l’Albien de l’Aube : Paléontologie, Stratigraphie, Écologie. Cahiers de Paléontologie, 351pp.

Magniez-Jannin, F., 1981. Découverte de *Planomalina buxforfi* (GANDOLFI) et d’autres foraminifères planctoniques inattendus dans l’Albien Supérieur d’Abbots Cliff (Kent, Angleterre): consequences paléogeographique et biostratigraphiques. Geobios 14, 91–97.

Magniez-Jannin, F., 1983. Essai de corréllation des zones de foraminifères de l’Albien stratotypique (Aube, France) avec les zones d’ammonites, Geobios, 16(4), 405–418.

Makrides, M., 1979. Foraminifera of the Upper Cretaceous Mzamba Formation, Transkei, southern Africa. Unpublished MSc Thesis, University of Witwatersrand, Johannesburg.

Malapris, M., 1965. Les Gavelinellidae et formes affines du gisement Albien de Courcelles (Aube), Revue de Micropaléontologie 8(3), 131–150.

Malapris-Bizouard, M., 1967. Les Lingulogavelinelles de l'Albien inférieur et moyen de l'Aube, Revue de Micropaléontologie 10(2), 128–150.

Malapris-Bizouard, M., 1974. Les premières Gavelinelles du Crétacé inférieur, Bulletin d'Information des Geologues du Bassin de Paris, No. 40, 9–23.

Marie, P., 1938. Sur quelques Foraminifères nouveaux ou peu connus du Crétacé du bassin de Paris, Bulletin de la Société Géologique de France, Ser. 5, 8, 91–104.

Marie, P., 1941. Les Foraminfères de la Craie à *Belemnitella mucronata* du Bassin de Paris. Mémoires du Muséum National d'Histoire Naturelle, Paris, n.ser. 12(1), 1–296.

Mitchell, S.F., 1995, Lithostratigraphy and biostratigraphy of the Hunstanton Formation (Red Chalk, Cretaceous) succession at Speeton, North Yorkshire, England. Proceedings of the Yorkshire Geological Society 50, 285–303.

Meyn, H., Vespermann, J., 1994. Taxonomische Revision von Foraminiferen der Unterkreide SE-Niedersachsens nach Roemer (1839, 1841, 1842), Koch (1851) und Reuss (1863). Senckenbergiana Lethaea 74, 49–272.

Morter, A.A., Wood, C.J., 1983. The biostratigraphy of Upper Albian–Lower Cenomanian *Aucellina* in Europe. Zitteliana 10, 515–529.

Moullade, M., 1960. Sur quelques Foraminifères du Crétacé inférieur des Baronnies (Drôme), Revue de Micropaléontologie 3, 131–142.

Moullade, M., 1966. Étude stratigraphique et micropaléontologique du Crétacé Inférieur de la 'Fosse Vocontienne', Documents des Laboratoires de Géologie de la Faculté des Sciences de Lyon 15(1–2), 369pp.

Neagu, T., 1965. Albian Foraminifera of the Rumanian Plain, Micropaleontology 11(1), 1–38.

Orbigny, A.D. d', 1840. Mémoire sur les Foraminifères de la craie blanche du basin de Paris. Mémoire de la Société Gélogique de France, Paris 4(1), 1–51.

Owen, H.G. 1958. Lower gault sections in the Northern Weald and the zoning of the Lower Gault. Proceedings of the Geologists' Association 69(3), 148–165.

Owen, H.G., 1963. Some sections in the Lower Gault of the Weald. Proceedings of the Geologists' Association 74, 35–54.

Owen, H.G., 1971a. Middle Albian Stratigraphy in the Anglo-Paris Basin. Bulletin of the British Museum (Natural History), (Geology), Supplement 8, 1–164.

Owen, H.G., 1971b. The stratigraphy of the Gault in the Thames Estuary. Proceedings of the Geologists' Association 82, 187–207.

Owen, H.G., 1972. The Gault at its junction with the Woburn Sands in the Leighton Buzzard area, Bedfordshire. Proceedings of the Geologists' Association 83, 287–312.

Owen, H.G., 1976. The stratigraphy of the Gault and Upper Greensand of the Weald, Proceedings of the Geologists' Association 86, 475–498 [for 1975].

Owen, H.G., 1984. The Albian Stage: European Province chronology and ammonite zonation. Cretaceous Research, **5**, 329–344.

Owen, H.G., 1995. The upper part of the Carstone and the Hunstanton red chalk (Albian) of the Hunstanton Cliff, Norfolk. Proceedings of the Geologists' Association 106, 171–181.

Oxford, M.J., Hart, M.B., Watkinson, M.P., 2000. Micropalaeontological investigations of the Oxford Clay – Corallian succession of the Dorset Coast. Geoscience in South-West England 10, 9–13.

Oxford, M.J., Hart, M.B., Watkinson, M.P., 2004. Foraminiferal characterisation of mid-Upper Jurassic sequences in the Wessex Basin (United Kingdom). Rivista Italiana di Paleontologia e Stratigrafia 110, 209–218.

Price, F.G.H., 1874a. On the Gault of Folkestone. Quarterly Journal of the Geological Society, London 30, 342–366.

Price, F.G.H., 1874b. On the Lower Greensand and Gault of Folkestone. Proceedings of the Geologists' Association 4, 135–150.

Price, F.G.H., 1876. Excursion to Sandgate and Folkestone. Proceedings of the Geologists' Association 4, 554–556.

Price, F.G.H., 1879. *The Gault*. London, Taylor & Francis Ltd.

Price, R.J., 1977. The stratigraphical zonation of the Albian sediments of northwest Europe, as based on foraminifera. Proceedings of the Geologists' Association 88(2), 65–91.

Reuss, A.E.,1846. Die Versteinerungen der böhmischen Kreideformation 2, 1–148.

Reuss, A.E., 1851. Die Foraminiferen und Entomostraceen des Kreidemergels von Lemberg. Naturwissenschaftliche Abhandlungen, Wien 4(1), 17–52.

Reuss, A.E., 1860. Die Foraminiferen der Westphalischen Kreideformation. Sitzungsberichte der K. Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Classe 40, 147–238.

Reuss, A.E.,1862. Entwurf einer systematischen Zusammenstellung der Foraminiferen. Sitzungsberichte der K. Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Classe 44, 355–396 (1861).

Reuss, A.E., 1863. Die Foraminiferen des norddeutschen Hils und Gault. Sitzungsberichte der K. Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Classe 46, 5–100.

Revets, S.A., 1996. The generic revision of five families of rotaliine foraminifera. Part I, the Bolivinitidae, Part II, the Anomalinidae, Alabaminidae, Cancrisidae and Gavelinellidae. Cushman Foundation, Special Publication 34, 113pp. + 31 pls.

Revets, S.A., 2001. The revision of *Gavelinella* Brotzen, 1942, *Berthelina* Malapris, 1965 and *Lingulogavelinella* Malapris, 1965. Cushman Foundation, Special Publication 37, 110pp. + 20 pls.

Sandman, R.I., 1986. Middle and Upper Albian Foraminiferida of the Mundford ‘C’ borehole, East Anglia. Unpublished MSc Thesis, University of Hull, 186pp.

Simmons, M.D., Williams, C.L., Hart, M.B.,1991. Sea-level changes across the Albian-Cenomanian boundary in south-west England. Proceedings of the Ussher Society **7**(4), 408–412.

Smart, P.J., 1997. The basal gault and Gault-Woburn Sands junction beds in Chamberlain’s Barn Quarry, Leighton Buzzard, Bedfordshire, England. Proceedings of the Geologists‘ Association 108, 287–292.

Spath, L.F., 1923–43. A monograph of the Ammonoidea of the Gault, Parts 1–16, Palaeontographical Society (Monograph), 787pp.

Tyszka, J., 2006. Taxonomy of Albian Gavelinellidae (Foraminifera) from the Lower Saxony Basin, Germany. Palaeontology 49(6), 1303–1334.

Tyszka, J., Thies, A., 2001. *Spiroplectinata*, key benthic foraminifer genus for palaeoceanographic reconstruction of the Albian Lower Saxony Basin. Palaeogeography, Palaeoclimatology, Palaeoecology 174, 199–220.

Vénec-Peyré, M.-T., 2002. Les travaux micropaléontologiques d’Alcide d’Orbigny. – Comptes Rendus Palevol 1, 449–459.

Vénec-Peyré, M.-T., 2004. Beyond frontiers and time: the scientific and cultural heritage of Alcide d’Orbigny. Marine Micropaleontology 50, 149–159.

Williams-Mitchell, E., 1948. The zonal value of Foraminifera in the Chalk of England. Proceedings of the Geologists’ Association, London 59, 91–112.

Woods, M.A., Wilkinson, I.P., Hopson, P.M., 1995. The stratigraphy of the Gault Formation (Middle & Upper Albian) in the BGS Arlesey Borehole, Bedfordshire. Proceedings of the Geologists’ Association 106, 271–280.

Taxonomic notes on foraminifera discussed in the text (alphabetical order).

As this is not a taxonomic paper, the following generic determinations largely follow Loeblich and Tappan (1987), even though a number of subsequent revisions (e.g., Revets 1996, 2001) have been proposed. As the author's names for these taxa are part of the formal name of the fossil, they are not included in the reference list.

Benthic taxa :

Arenobulimina advena (CUSHMAN, 1936); *Hagenowella advena* CUSHMAN, 1936, p. 43, pl. 6, fig. 21a-b.

Arenobulimina anglica CUSHMAN, 1936, p. 27, pl. 4, fig. 8a-b.

Arenobulimina chapmani CUSHMAN, 1936; *Bulimina preslii* CHAPMAN, 1892, p. 755, pl. 12, fig. 4 (*non* REUSS).

Arenobulimina frankei CUSHMAN, 1936, p. 27, pl. 4, fig. 5a-b.

Arenobulimina macfadyeni CUSHMAN, 1936; *Bulimina orbignyi* CHAPMAN, 1892, p. 754, pl.12, fig. 2 (*non* REUSS).

Arenobulimina sabulosa (CHAPMAN, 1892); *Bulimina preslii* REUSS var. *sabulosa* CHAPMAN, 1892, p. 755, pl.12, fig. 5.

Ataxophragmium depressa (Perner); Bulimina depressa Perner, 1892, p. 55 (p. 27), pl. 3, fig. 3a-b.

Berthelina baltica (BROTZEN, 1942); *Gavelinella baltica* BROTZEN, 1942, p. 50, pl. 1, fig. 7.

Berthelina cenomanica (BROTZEN, 1942); *Cibicidoides* (*Cibicides*) *cenomanica* BROTZEN, 1942, p. 54, pl. 2, fig. 2a–c.

Berthelina intermedia (BERTHELIN, 1880); *Anomalina intermedia* BERTHELIN, 1880, p. 67, pl. 4, fig.14a-b.

Citharinella pinnaeformis (CHAPMAN, 1894); *Frondicularia pinnaeformis* CHAPMAN, 1894, p.185, pl.3, figs 9-11.

Conorboides lamplughi (SHERLOCK, 1914); *Pulvinulina lamplughi* SHERLOCK, 1914, p. 290, pl.19, fig.16.

Dorothia filiformis (BERTHELIN, 1880); *Gaudryina filiformis* BERTHELIN, 1880, p. 25, pl.1, fig. 8.

Dorothia gradata (BERTHELIN, 1880); *Gaudryina gradata* BERTHELIN, 1880, p. 24, pl. 1, fig. 6a-b.

Eggerellina mariae TEN DAM, 1950, pp.15-16, pl.1, fig.17.

Epistomina spinulifera (REUSS, 1862); *Rotalia spinulifera* REUSS, 1862, p. 93, pl.13, figs 3a-5c.

Flourensina intermedia TEN DAM, 1950, p.15, pl.1, fig.16.

Flourensina mariae CARTER and HART, 1977, pp, 9-10, pl. 2, fig. 6.

Gaudryina austiniana (CUSHMAN, 1936); *Gaudryina* (*Siphogaudryina*) *austinana* CUSHMAN, 1936, p. 10, pl. 2, fig. 6a–b.

Gavelinella tormarpensis BROTZEN, 1942, p. 52, pl. 1, fig. 6.

Hoeglundina carpenteri (REUSS, 1862); *Rotalia carpenteri* REUSS, 1862, p. 94, pl.13, fig. 6a-c.

Hoeglundina chapmani (TEN DAM, 1948); *Pulvinulina caracolla* (ROEMER), CHAPMAN, 1898, p. 7, pl.1, fig. 9.

Lingulogavelinella albiensis MALAPRIS, 1965, p. 140, pl. 4, figs 5-8, pl. 5.

Lingulogavelinella globosa (BROTZEN); *Anomalinoides globosa* BROTZEN, 1945, p. 58, pl. 2, fig. 6a-c.

Lingulogavelinella jarzevae (VASILENKO, 1954); *Cibicides (Cibicides) jarzevae* VASILENKO, 1954, p.121, pl.17, fig. 3a-c.

Marssonella oxycona (REUSS, 1860); *Gaudryina oxycona* REUSS, 1860, p. 229, pl. 12, fig. 3.

Marssonella ozawai CUSHMAN, 1936, p. 43, pl. 4, fig. 10a-b.

Nodobacularia nodulosa (CHAPMAN, 1891); *Nubecularia nodulosa* CHAPMAN, 1891, p. 573, pl. 9, fig. 2.

Plectina cenomana CARTER and HART, 1977, pp. 12-13, pl. 2, fig. 9.

Plectina mariae (FRANKE, 1928); *Gaudryina ruthenica* REUSS var. *mariae* FRANKE, 1928, p. 146, pl. 13, fig. 15a–b.

Pseudotextulariella cretosa (CUSHMAN, 1932); *Textulariella cretosa* CUSHMAN, 1932, p.97, pl.11, figs 17-19.

Quinqueloculina antiqa (FRANKE, 1928); *Miliolina venusta* KARRER; CHAPMAN, 1891, p. 9, pl. 9, figs 5, 6.

Sagrina asperula Chapman, 1896, p. 115, pl. XlI, fig. 1.

Spiroloculina papyracea BURROWS, SHERBORN & BAILEY, 1890, p. 551, pl. 8, fig. 1.

Spiroplectinata annectens (PARKER & JONES, 1863); *Textularia annectens* PARKER & JONES, 1863, p. 92, text.fig. 1.

Tritaxia macfadyeni Cushman, 1936, p. 3, pl. 1, fig. 6a-b.

Tritaxia pyramidata REUSS, 1862, pp. 32, 88, pl.1, fig. 8a-c.

Vaginulina mediocarinata TEN DAM, 1950, pp. 36–37, pl. 3, fig. 3.

Planktic Taxa:

Dicarinella hagni (SCHEIBNEROVA); *Praeglobotruncana hagni* SCHEIBNEROVA, 1962, pp. 219, 225-226, text-fig. 6a-c.

Dicarinella imbricata (Mornod); Globotruncana imbricata Mornod, 1949, p. 589, text-fig. 5, llla-d.

Favusella washitensis (CARSEY, 1926); *Globigerina washitensis* CARSEY, 1926, p. 44, pl. 7, fig.10, pl. 8, fig. 2.

Globigerinelloides bentonensis (MORROW, 1934); *Anomalina bentonensis* MORROW, 1934, p. 201, pl. 30, fig. 4a-b.

Guembilitria harrisi TAPPAN, 1940, p. 115, pl. 19, fig. 2a-b.

Helvetoglobotruncana helvetica (BOLLI); *Globotruncana helvetica* BOLLI, p. 226, pl. 9, figs 6-8, text-fig. 1 (9-12).

Heterohelix globulosa (Ehrenberg); Textularia globulosa Ehrenberg, 1840,

Heterohelix moremani (CUSHMAN, 1938); *Guembelina moremani* CUSHMAN, 1938, p. 10, pl. 2, figs 1-3.

Marginotruncana pseudolinneiana Pessagno, 1967, p. 310, pl. 65, figs 24-27, pl. 76, figs 1-3, 24-27.

Muricohedbergella delrioensis (CARSEY); *Globigerina cretacea* D'ORBIGNY var. *delrioensis* CARSEY, 1926, p. 43.

Muricohedbergella infracretacea (GLAESSNER); *Globigerina infracretacea* GLAESSNER, 1937, p. 28, text-fig. 1.

Muricohedbergella planispira (Tappan); *Globigerina planispira* Tappan, 1940, p. 12, pl. 19, fig. 12.

Praeglobotruncana delrioensis (Plummer); *Globrotalia delrioensis* Plummer, 1931, p. 199, pl. 13, fig. 2a-c.

Rotalipora cushmani (Morrow); *Globorotalia cushmani* Morrow,1934, p. 199, pl. 31, figs 2, 4.

Thalmanninella globotruncanoides (Sigal); Rotalipora globotruncanoides Sigal, 1948, p. 100, pl. 1, fig. 4, pl. 2, figs 3-5.

Thalmanninella greenhornensis (Morrow); *Globorotalia greenhornensis* Morrow, 1934, p. 199, pl. 39, fig. 1.

Thalmanninella reicheli (Mornod); Globotruncana (Rotalipora) reicheli Mornod, 1949, p. 583, text-fig. 5, IVa-c.

Figure Captions:

Figure 1. Outline geological map of South-East England showing the localities mentioned or discussed in the text.

Figure 2. Original zonation of the mid-Cretaceous of Southern England using foraminifera (Carter *in* Bruckshaw et al., 1961) reproduced with the permission of the Institution of Civil Engineers. Zones 3–6 represent the Gault Clay Formation. Some key taxa are identified with both the original names (applied by D.J. Carter), updated where possible, but others remain indeterminate. (1) *Marginotruncana pseudolinneiana*; (2) *Helvetoglobotruncana helvetica*; (3) *Dicarinella imbricata*; (4) *Heterohelix globulosa*; (8) *Dicarinella hagni*; (10) *Lingulogavelinella globosa* (*Biorostella* sp., C.T.P.); (12) *Tritaxia pyramidata* and *T. macfadyeni*; (13) *Spiroplectinata annectens*; (14) *Flourensina mariae* (*Flourensina crenata* C.T.P.); (15) *Rotalipora cushmani*; (16) *Pleurostomella* sp. 26 C.T.P.; (17) *Plectina cenomana*; (18) *Plectina mariae*; (19) *Pernerina* sp. C.T.P., now *Arenobulimina depressa*; (20) *Spiroloculina papyracea*; (21) *Thalmanninella reicheli* and *T. greenhornensis*; (22) *Praeglobotruncana* sp. cf. *P. delrioensis*; (23) *Thalmanninella globotruncanoides*; (24) *Arenobulimina advena*; (25) spicules of hexactinellid sponges; (26) *Flourensina intermedia*; (27)

Marssonella ozawai; (28) *Quinqueloculina antiqua*; (29) *Dorothia filiformis*; (30) *Muricohedbergella* spp.; (31) *Nodobacularia nodulosa*; (32) *Arenobulimina chapmani*; (33) *Dentalina* sp. 38 C.T.P.; (35) *Epistomina spinulifera*; (37) *Sagrina asperula*; (38) *Conorboides lamplughi*; (39) *Citharinella pinnaeformis*; (40) *Ammobaculoides* sp. C.T.P.; (43) *Hoeglundina chapmani*; (44) *Hoeglundina carpenteri*.

Figure 3. Copt Point succession of the Gault Clay Formation showing the lithology, ammonite zonation, foraminiferal zonation and the distribution of the various superfamilies (*sensu* Loeblich and Tappan, 1964).

Figure 4. Distribution of stratigraphically significant foraminifera in the Glyndebourne Borehole (based on Hart and Harris, 2012). It is interesting to note that the range of *Favusella washitensis* appears much longer than in the Copt Point succession and this is reflected in the expanded Zone 4/5 transitional interval picked out by the benthic foraminifera.