

SPECIAL PAPERS IN PALAEOLOGY

Number 14

PALAEOGENE FORAMINIFERIDA
AND PALAEOECOLOGY,
HAMPSHIRE AND PARIS BASINS
AND THE ENGLISH CHANNEL

BY

J. W. MURRAY

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BY
JOHN W. MURRAY
and
CHRISTOPHER A. WRIGHT

With 20 plates and 47 text-figures

THE PALAEOONTOLOGICAL ASSOCIATION
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ABSTRACT. The classic exposures of the Hampshire and Paris Basins have been measured and sampled systematically. For each locality data are provided on the lithological succession, the range of foraminiferid species and their abundance, and general features of the assemblages (diversity index, ratios of the sub-orders Textulariina, Miliolina, Rotaliina, and percentage dominance). Similar assemblages have been grouped into faunules and a palaeoecological interpretation of these has been made by careful comparison of the data with those for recent foraminiferids.

It is concluded that the Palaeogene sediments of the Hampshire Basin were deposited by one or more rivers flowing from the north-west. The environments recognized are marginal marine and, apart from continental and freshwater situations, include nearshore shelf, deltaic marine, lagoonal, fluviomarine, and marsh. By contrast the Paris Basin was a region of enclosed shallow shelf, lagoonal and littoral environments of normal or hypersalinity. During the Lutetian subtropical assemblages of southern origin were established in the Paris Basin and in the Channel and its Western Approaches.

Correlation within the Hampshire Basin and with the Paris Basin and submarine occurrences is discussed in the light of the environmental control of individual species.

No new species have been named. Many of the common species are illustrated in twenty plates of scanning electron photomicrographs.

INTRODUCTION

THE Tertiary deposits of the Paris Basin have been studied by many people during the last hundred years. Various aspects of these beds have formed the subject of numerous theses from the Université de Paris. Exploration for petroleum has led to many boreholes being sunk in the area and this has yielded information both on the Tertiary deposits and on the 'basement' on which they lie.

By contrast the Hampshire Basin has been much less studied. During the last century the stratigraphy was worked out and much use was made of the macrofossils. In this century the principal worker has been D. Curry. Only in the past few years have theses been based on studies of these deposits. Rather surprisingly, there are no boreholes which penetrate the thicker parts of the succession although the depth to basement is known from geophysical work.

The present research was initiated in 1967. In the following year the authors received a grant from the Natural Environment Research Council to study the Tertiary to Recent history of the Western Approaches to the English Channel. The results of this study are presented here in two ways. First, the stratigraphic distribution of foraminiferids is described. Second, an attempt has been made to reconstruct the environments of deposition using foraminiferid assemblages. When similar studies have been made of other groups of fossils in these beds, it should be possible to produce a synthesis of the environmental interpretations. However, at present there are few detailed published interpretations with which to compare our results.

The English succession from the London Clay up to the top of Barton Clay and the French succession from the Cuisian up to the top of Auversian was studied mainly by C. A. Wright. The English succession from the Middle Headon to the Hamstead Beds and the French succession from the Ludian to the Stampian were studied mainly by J. W. Murray. The fieldwork, scanning electron microscopy, interpretation, and conclusions are the results of our joint efforts.

Acknowledgements. This research was supported by a grant from the Natural Environment Research Council during the period 1968-1972. We are grateful to the land and quarry owners who allowed access to sections, to Mr. D. Hamilton who kindly allowed access to the collection of samples from the English Channel and Western Approaches, and to Professor D. Curry for presenting samples from Bracklesham, Bois-Gouët, and the Cotentin Peninsula.

Dr. C. G. Adams (British Museum, Natural History) and Mme Y. Le Calvez (Musée d'Histoire Naturelle, Paris) offered us every assistance in the examination of the collections in their care and in discussing results. Dr. H. Hagn and Dr. C. H. Daniels provided comparative material of named species.

Professor H. Hinton kindly allowed access to the scanning electron microscope. We are grateful to Mr. R. Godwin for photography, Mrs. J. Rowland and Mrs. E. Hill for typing, and Mr. A. Hook for laboratory assistance.

Finally, we wish to thank Professor D. L. Dineley for encouragement and, with other members of the Geology Department, for profitable discussion of results.

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METHODS

Choice of sections. In the Hampshire Basin there are continuous well-exposed sections from the Reading Beds up to the Headon Beds and Bembridge Beds at the west and east ends respectively of the Isle of Wight. There are, in addition, other cliff and inland exposures which give supplementary information.

In the Paris Basin outcrops are generally small, being restricted to natural exposures along escarpments and man-made pit or quarry exposures. Consequently, the stratigraphy has had to be pieced together. The aim of our sampling has been to compile a biostratigraphy for the Paris Basin in general. Therefore, selected exposures were visited, measured, and sampled. There has been no attempt to sample all possible sections in England or France.

Fieldwork. The sections were carefully measured and systematically sampled during the period September 1967–April 1972. Some of the coastal sections are affected by slipping and good exposures are not always available. Details of the sampling are given below:

Locality	Date	No. of samples
Alum Bay	September 1967	64
Headon Hill	" "	27
Clapham, Sussex	September 1968	7
Swanwick	" "	26
Barton	" "	120
Whitecliff Bay	January 1969	205
French localities	July 1969	213
Alum Bay	March 1970	12
Colwell Bay	" "	12
Hamstead	" "	45
Gurnard	" "	5
Sundry		13
Total		749

At each section the surface to be sampled was scraped clean to reduce the risk of contamination. In general, a sample was approximately 5 cm thick and up to 30 cm wide laterally. The average weight was approximately 2 kg.

Laboratory methods. Each sample was emptied into an aluminium container and dried in an oven at 80 °C. It was then immersed in water and allowed to stand overnight. Clays often proved difficult to break down so a few crystals of sodium hexametaphosphate were added to the water to speed up the process. If this was unsuccessful, the sample was boiled with Quaternary O, following the method described by Zingula (1968). When breakdown was complete, the sample was washed on a 200 mesh sieve (aperture 0.076 mm). The residue remaining on the sieve was dried, and when cool a flotation was carried out using carbon tetrachloride or trichlorethylene.

A portion of each flotation was spread evenly over a gridded slide and picked systematically until 250 or more foraminiferids had been mounted. Many English samples failed to yield this number. The residues were examined for foraminiferids which remained after flotation, e.g. *Nummulites* and pyritized forms.

Possible Errors. Great care was taken in sampling, sample processing, and picking to minimize the likelihood of errors. Large samples were taken to make them as representative as possible. The sampling interval was kept as small as was practical with a research topic of this size. Wherever possible at least 250 individuals were identified as this is generally accepted to be a reasonable size for an assemblage count. The minimum count accepted for percentage and diversity determination is 100 individuals.

To assess the reliability of these methods two tests were carried out:

- (a) repetitive assemblage counts from the same sample.
- (b) repetitive sampling of the same stratigraphic bed.

Eleven counts of between 250 and 500 individuals were carried out on a single sample. The same species were consistently the most abundant and the following results were obtained:

Mean %	Standard deviation
28.75	1.76
26.47	1.61
17.18	0.78
10.55	1.49
5.29	1.04
1.72	0.59

Similarity values between all pairs of counts ranged from 85.3 to 94.5%.

Repetitive sampling of the same stratigraphic bed was carried out on the Middle London Clay of Whitecliff Bay. Four samples were taken over a 5 m distance. The same five species were abundant in each sample with mean percentage and standard deviation values of 22.82 ± 4.30 , 19.37 ± 4.72 , 17.30 ± 3.94 , 13.67 ± 2.16 , 11.07 ± 1.38 . A similarity matrix of all sample pairs gave values of 74.6–87.7%. The diversity values varied slightly ($\alpha = 3.87 \pm 0.44$) and the proportion of the suborder Rotaliina was constant ($99.30 \pm 0.26\%$).

Methods of assembling the data. For each stratigraphic section a range chart with quantitative data has been plotted for the common and ecologically important species. The original data are presented in Tables, which have been deposited at the British Library (see p. 122). Several additional methods have been used.

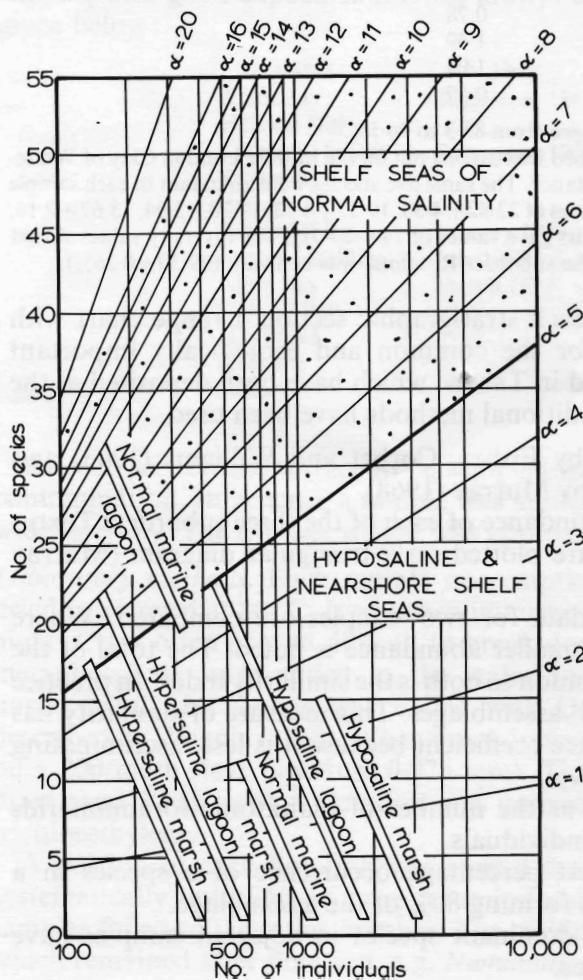
- (a) Diversity: the index α proposed by Fisher, Corbet and Williams (1943) and applied to modern foraminiferids by Murray (1968).
- (b) Triangular plot: the percentage abundance of each of the three suborders Textulariina, Miliolina, and Rotaliina are plotted on a triangular diagram (Murray 1968).
- (c) Similarity index: the percentage data for two samples are compared. Where a species is common to both, the smaller abundance is noted. The total of the minimum values for the species common to both is the similarity index. In practice values of $> 80\%$ indicate 'identical' assemblages. This measure of similarity has been used in preference to a distance coefficient because it is less discriminating and in our opinion more satisfactory.
- (d) Planktonic-benthic ratio: defined as the number of planktonic foraminiferids divided by the number of benthic individuals.
- (e) Percentage dominance: the highest percentage occurrence of a species in a sample; also the number of species forming 80% of the assemblage.
- (f) Faunules: similar associations of dominant species in adjacent samples have been grouped together into faunules.

CRITERIA USED IN THE PALAEOECOLOGICAL INTERPRETATION

Palaeoecological interpretations have been attempted only on samples which appear to show no preferential preservation of individual foraminiferid species. In the rare cases where solution is believed to have altered the composition of the assemblages these are discussed in the text.

The approach to making a palaeoecological assessment of an assemblage has been as follows:

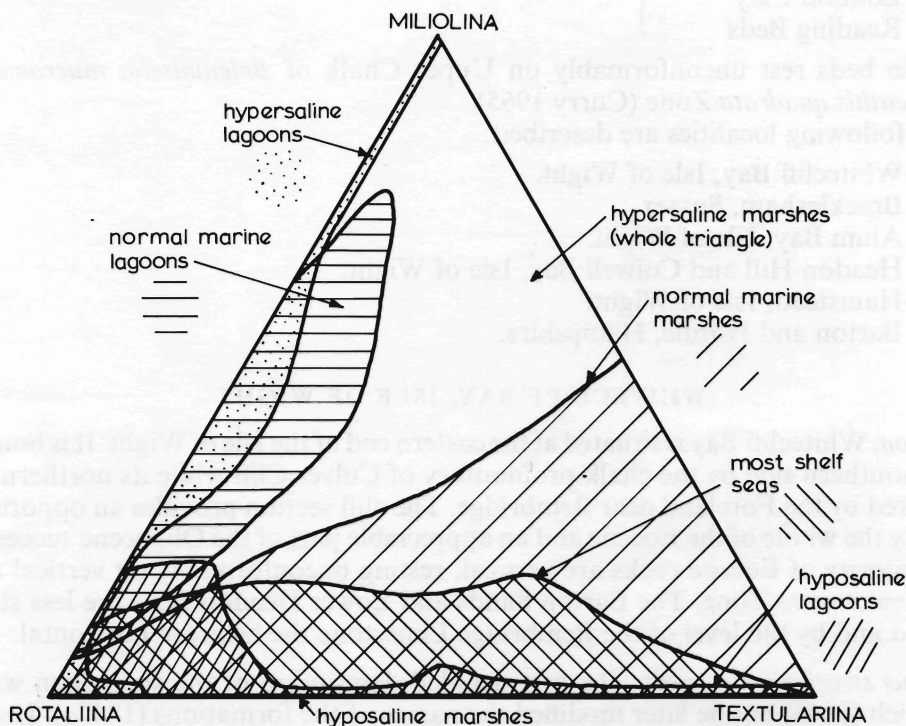
1. Examine the assemblage for signs of abrasion, size-sorting, and mixing. If any of these are well developed the palaeoecological interpretation is likely to be partly in error. If not, then,
2. Examine the α summary diagram (text-fig. 1) compiled from modern ecological studies (Murray, *in* Wright and Murray 1972). In a general sense $\alpha = 5$ is a boundary



TEXT-FIG. 1. Summary of the α indices for living foraminiferids showing the total range for each environment (from Wright and Murray 1972).

separating normal marine environments (salinity 32–37‰) from abnormal environments (hyposaline < 32‰, hypersaline > 37‰). The index should give an indication of the range of environmental possibilities.

3. Examine the triangular plot summary diagram (text-fig. 2) to see which environments are indicated.
4. Using α and triangular plot only a limited number of environments should be indicated as possibilities.
5. For the genera present look for those which have restricted occurrence (data in Murray 1973).
6. Using all this information it is usually possible to reconstruct the environment with some certainty.



TEXT-FIG. 2. Summary triangular plot for living foraminiferids (from Murray 1973).

Additional information comes from planktonic–benthic ratios. In modern seas there is an increase in abundance of planktonic foraminiferids in passing from land towards the ocean. Their occurrence in shelf sediments depends on proximity to open ocean and movement of water from the oceanic area across the shelf. In the North Sea at present planktonic foraminiferids are abundant in the deep water between Shetland and Norway but south of a line joining the Firth of Forth and the Skagerrak they are rare (Jarke 1961).

ENGLAND: HAMPSHIRE BASIN

The extent of the Palaeogene Beds is shown in text-fig. 3. The generalized succession is as follows:

Hamstead Beds	}	Oligocene
Bembridge Beds		
Osborne Beds		
Headon Beds	}	Eocene
Barton Beds		
Bracklesham Beds		
Bagshot Sands		
London Clay		
Reading Beds		

These beds rest unconformably on Upper Chalk of *Belemnitella mucronata* or *Gonioteuthis quadrata* Zone (Curry 1965).

The following localities are described:

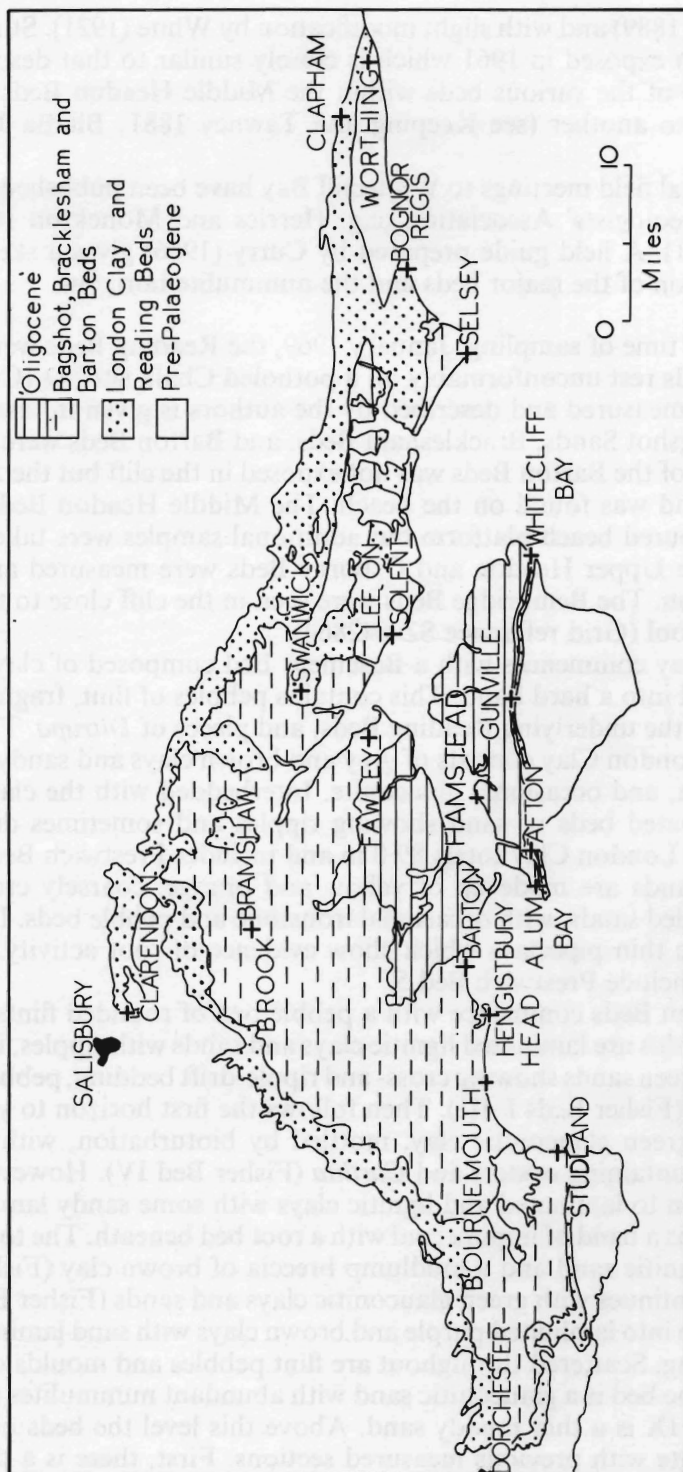
Whitecliff Bay, Isle of Wight.
 Bracklesham, Sussex.
 Alum Bay, Isle of Wight.
 Headon Hill and Colwell Bay, Isle of Wight.
 Hamstead, Isle of Wight.
 Barton and Hordle, Hampshire.

WHITECLIFF BAY, ISLE OF WIGHT

Location. Whitecliff Bay is situated at the eastern end of the Isle of Wight. It is bounded on its southern side by the chalk promontory of Culver Cliff while its northern limit is marked by the Foreland near Bembridge. The cliff section provides an opportunity to study the whole of the Eocene and an appreciable part of the Oligocene succession. The majority of Eocene rocks are vertical, resting unconformably on vertical chalk of the *mucronata* Zone. The Barton Sands and Lower Headon Beds are less steeply inclined and by the level of the Bembridge Limestone the beds are horizontal.

Previous stratigraphic work. The first detailed description of the succession was by Prestwich (1846) but he later modified the names of the formations (1847a). He gave numbers to the major lithological units. The Bracklesham Beds were redescribed by Fisher (1862). He defined the base of the Bracklesham Beds as the pebble bed already distinguished by Prestwich as bed number 6. This defined the extent of the Bagshot Beds, a formation named by Prestwich a few years earlier (1847b) but never distinguished from the Bracklesham Sands. Fisher also described and subdivided the Bracklesham Beds in more detail and applied Roman numerals to the lithological and faunal units. However, he did not define the base of the Barton Beds because of their poor exposure. This boundary was later defined by Keeping (1887) on the appearance of *Nummulites prestwichianus (elegans)*. Gardner *et al.* (1888) described the Barton succession, dividing it into Lower, Middle, and Upper parts.

The Headon Beds were measured by Forbes and described in detail by Bristow,



TEXT-FIG. 3. Geological map of the Hampshire Basin showing the extent of the Palaeogene Beds. ('Oligocene' is used in the sense of the Geological Survey to include the succession from the Lower Headon to Upper Hamstead Beds.)

Reid and Strahan (1889) and with slight modification by White (1921). Stinton (1971) described a section exposed in 1961 which is closely similar to that described here. The nomenclature of the various beds within the Middle Headon Beds has varied from one author to another (see Keeping and Tawney 1881; Bhatia 1955, 1957; Stinton 1971).

Reports of several field meetings to Whitecliff Bay have been published in the Proceedings of the Geologists' Association (e.g. Herries and Monckton 1895; Curry 1954; Stinton 1971). A field guide prepared by Curry (1966) gives a sketch section showing the position of the major beds and the nummulite horizons.

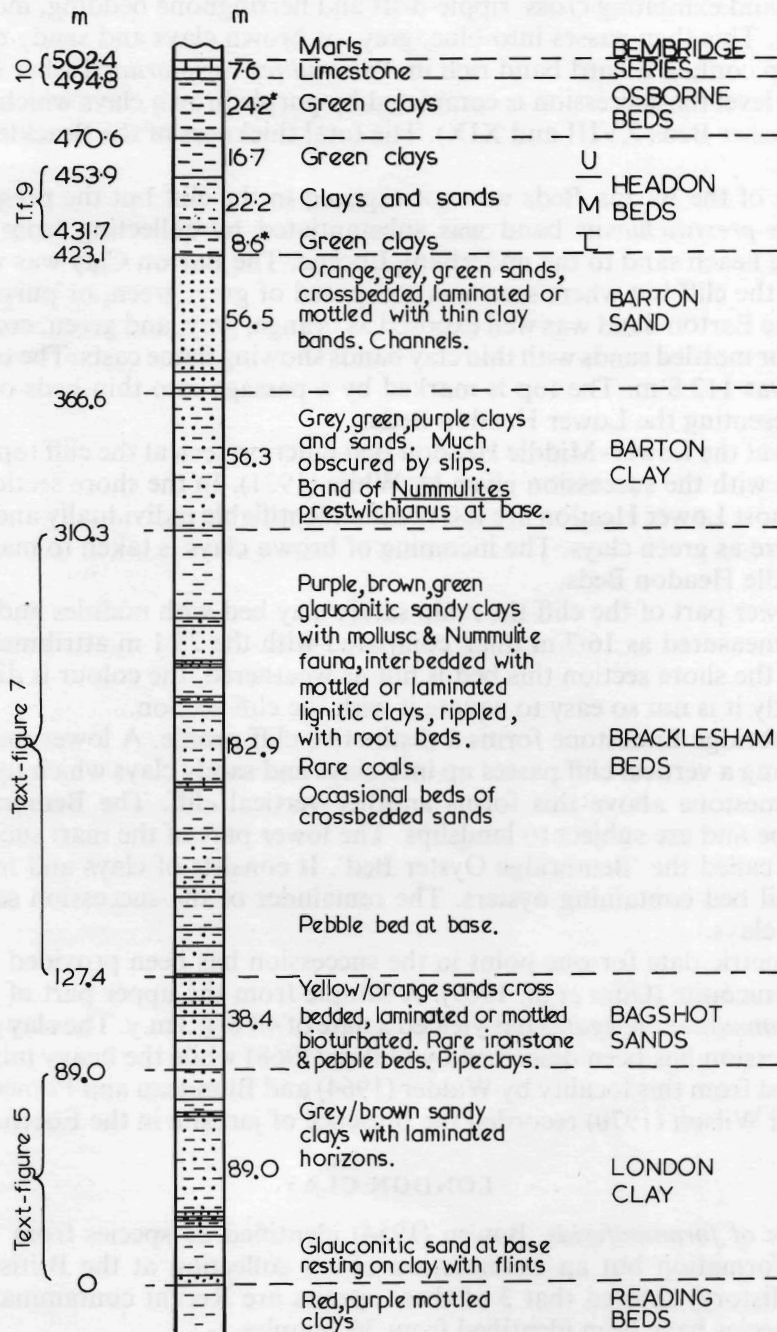
Succession. At the time of sampling, January 1969, the Reading Beds were obscured by slips. These beds rest unconformably on a potholed Chalk surface (Curry 1966).

The succession measured and described by the authors is given in text-fig. 4. The London Clay, Bagshot Sands, Bracklesham Beds, and Barton Beds were sampled in the cliff. The base of the Barton Beds was not exposed in the cliff but the *Nummulites prestwichianus* band was found on the beach. The Middle Headon Beds were well exposed in the scoured beach platform but additional samples were taken from the cliff. Similarly, the Upper Headon and Osborne Beds were measured and sampled in the beach section. The Bembridge Beds were seen in the cliff close to the grounds of Bembridge School (Grid reference SZ 642864).

The London Clay commences with a Basement Bed composed of clays and sand partially cemented into a hard band. This contains pebbles of flint, fragments of red clay derived from the underlying Reading Beds, and pieces of *Ditrupea*. The majority of the overlying London Clay consists of grey and brown clays and sandy clays, with lignite, white mica, and occasional glauconite. Interbedded with the clays are thin, often finely laminated beds of sand showing ripples and sometimes disturbed by bioturbation. The London Clay totals 89.0 m and includes Prestwich Beds 3 and 4.

The Bagshot Sands are made up of yellow and orange, coarsely cross-bedded, laminated or mottled sands, with occasional ironstone and pebble beds. Interbedded with the sands are thin pipeclays which show evidence of root activity. The sands total 38.4 m and include Prestwich Bed 5.

The Bracklesham Beds commence with a pebble bed of rounded flints in a sandy matrix. Overlying this are laminated lignitic clays and sands with ripples, interbedded with orange and green sands showing cross- and ripple-drift bedding, pebble horizons, and rare burrows (Fisher Beds I–III). Then follows the first horizon to yield a good marine fauna, a green glauconitic clay, mottled by bioturbation, with three shell beds at the base containing oysters and *Cardita* (Fisher Bed IV). However, the next bed marks a return to laminated and lignitic clays with some sandy laminae. In the middle of this bed is a band of impure coal with a root bed beneath. The top is marked by thin beds of lignitic sand and a mudlump breccia of brown clay (Fisher Bed V). The succession continues with green glauconitic clays and sands (Fisher Beds VI and VII) which pass up into laminated purple and brown clays with sand laminae showing ripple-drift bedding. Scattered throughout are flint pebbles and moulds of molluscs. In the middle of the bed is a glauconitic sand with abundant nummulites (Fisher Bed VIII). Fisher Bed IX is a thin muddy sand. Above this level the beds observed are difficult to correlate with previous measured sections. First, there is a thick yellow



TEXT-FIG. 4. Palaeogene succession at Whitecliff Bay, Isle of Wight.

* = Measurements from White (1921).

and green sand exhibiting cross, ripple-drift and herringbone bedding, mottling, and some shells. This then passes into blue, grey, or brown clays and sandy clays which near the top contain a hard band rich in *Nummulites variolarius* (Fisher Bed XVII). Above this level the succession is completed by purple brown clays which are poorly exposed (Fisher Beds XVIII and XIX). The total thickness of the Bracklesham Beds is 182.9 m.

The base of the Barton Beds was not exposed in the cliff but the presence of the *Nummulites prestwichianus* band was substantiated by collecting from holes dug through the beach sand to the underlying Eocene. The Barton Clay was very poorly exposed in the cliff but where seen was composed of grey, green, or purple clays. In contrast, the Barton Sand was well exposed as orange, grey, and green, cross-bedded, laminated or mottled sands with thin clay bands showing flame casts. The total Barton thickness was 112.8 m. The top is marked by a passage into thin beds of clays and sands representing the Lower Headon Beds.

The beds at the Lower-Middle Headon Bed junction seen at the cliff top are clearly identifiable with the succession given by White (1921). In the shore section the beds of the topmost Lower Headon are less readily identifiable individually and have been grouped here as green clays. The incoming of brown clays is taken to mark the base of the Middle Headon Beds.

In the lower part of the cliff the main sandy clay bed with nodules and moulds of shells was measured as 16.7 m thick compared with the 23.1 m attributed to it previously. In the shore section this bed is not as weathered, the colour is different and consequently it is not so easy to equate it with the cliff section.

The Bembridge Limestone forms a distinctive cliff profile. A lower massive limestone forming a vertical cliff passes up into clays and sandy clays which form a slope. Massive limestone above this forms another vertical cliff. The Bembridge Marls form a slope and are subject to landslips. The lower part of the marl succession has often been called the 'Bembridge Oyster Bed'. It consists of clays and muddy sand with a fossil bed containing oysters. The remainder of the succession seen in 1969 consists of clays.

A radiometric date for one point in the succession has been provided by a K-Ar study of glauconite (Odin *et al.* 1969). A sample from the upper part of Fisher Bed VI with *Nummulites laevigatus* has yielded a date of 48.6 ± 3 m.y. The clay mineralogy of the succession has been described by Gilkes (1968) while the heavy minerals have been studied from this locality by Walder (1964) and Blondeau and Pomerol (1968a). Wright and Wilson (1970) recorded the presence of jarosite in the Eocene clays.

LONDON CLAY

Distribution of foraminiferids. Bowen (1954) identified 23 species from 10 samples from this formation but an examination of his collection at the British Museum (Natural History) showed that 3 of these species are Recent contaminants. In this study 42 species have been identified from 36 samples.

The distribution of species is shown in text-fig. 5 while the percentage abundance data are set out in Table 1.¹ All the samples from the basal 38.0 m of the London

¹ Tables are deposited at the British Library, see list, p. 122.

Clay proved barren except for three at 1.1, 2.6, and 14.3 m. The large central bed of grey sandy clay with a marine mollusc fauna also yielded abundant foraminiferids but unfortunately 12.8 m could not be sampled as they were obscured by a large land slip. The top 19.5 m also proved barren except for the two isolated samples at 81.4 and 88.7 m.

The assemblages may be divided into six faunules (text-fig. 6). Faunule 1 comprises the isolated samples at the base of the London Clay. Dominant forms include *Cibicides lobatulus* (39.2%), *Cibicidoides proprius* (45.1%), and *Nonion laeve* (14.7%) while the reworking of the chalk is indicated by the presence of *Planomalina* sp. The isolated samples W11 and W20 are grouped together as faunule 2 even though they are separated by sediments which are barren of foraminiferids. This is because they have species in common which die out soon after the top of the faunule and are characteristic of the Lower London Clay. Dominant species include *Bolivinopsis adamsi* (1.4–47.8%), *Cibicides cunobelini* (6.3–42.9%), *Cibicides lobatulus* (0–17.1%), *Elphidium hiltermanni* (0.4–18.6%), and *Epistominella vitrea* (14.3–20.6%). Faunule 3 marks the appearance of three new dominant species: *Uvigerina batjesi* (33.7%), *Pullenia quinqueloba* (11.4%), and *Anomalinoides nobilis* (10.2%) plus *Cibicidoides proprius* (14.5%) and *Bolivinopsis adamsi* (10.2%). This trend continues with the appearance of three new dominant species in faunule 4: *Alabamina obtusa* (5.2–25.0%), *Cibicides simplex* (3.2–16.2%), and *Praeglobobulimina ovata* (4.4–40.2%). They are accompanied by *Pullenia quinqueloba* (18.8–27.3%), *Anomalinoides nobilis* (7.5–14.1%), and *Epistominella vitrea* (0–10.5%). Faunule 5 marks the return of *Elphidium hiltermanni* as the dominant species (30.9–73.0%) but it is accompanied by *Praeglobobulimina ovata* (5.5–9.9%) and abundant planktonics including *Globigerina aquiensis* (8.1–12.8%), and *Turborotalia esnaensis* (3.2–20.9%). *Praeglobobulimina ovata* continues into faunule 6 (13.0%) but the assemblage is characterized by the return of *Cibicides* dominance in the form of *Cibicides* cf. *C. pygmeus* (10.1%), *Cibicides simplex* (43.5%), and *Cibicidoides proprius* (14.4%).

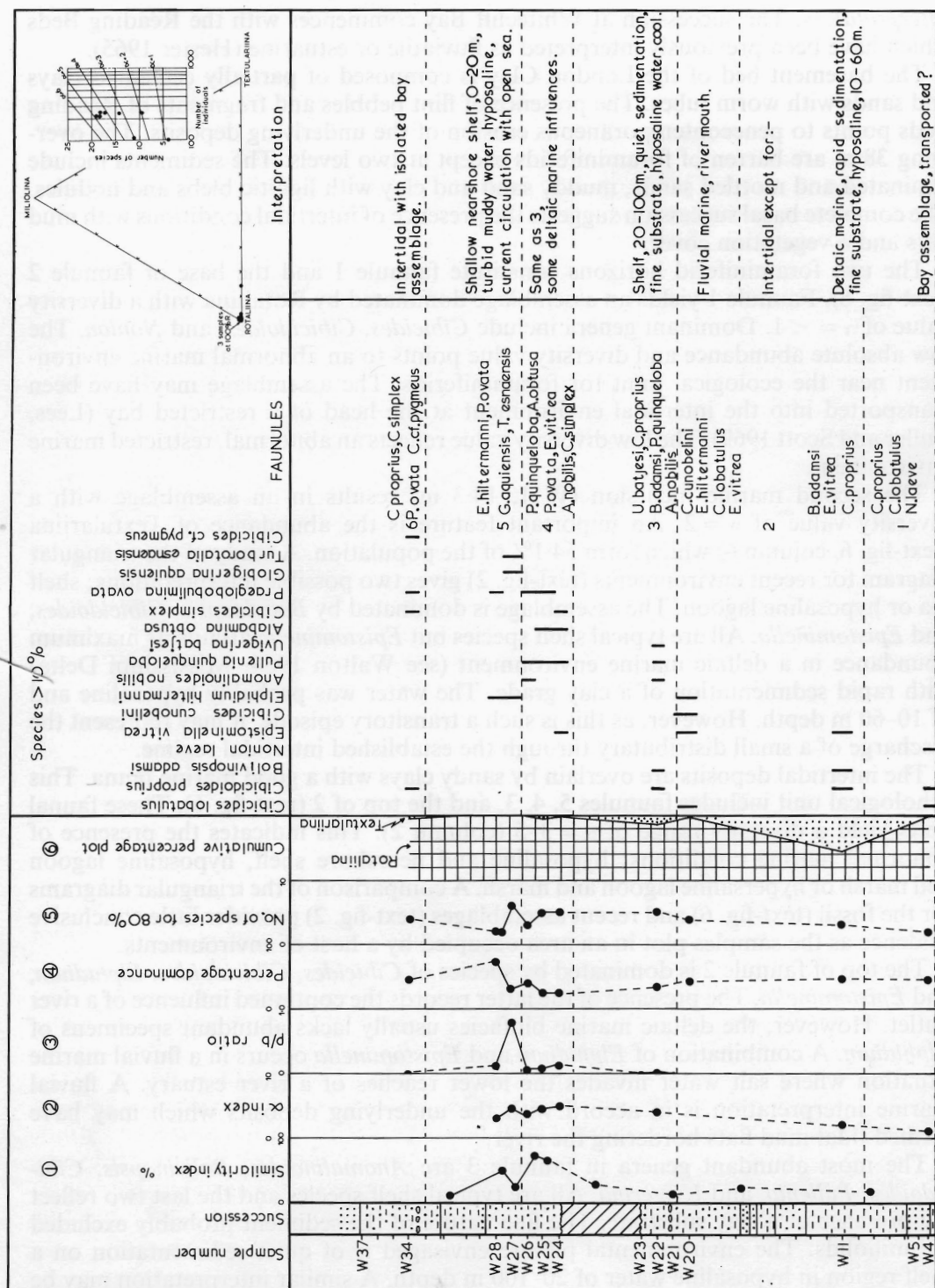
The distribution of species in the succession indicates a vague cyclical influence. Faunules 1 and 6 are both dominated by species of *Cibicides* and they are followed or preceded in faunules 2 and 5 by assemblages rich in *Elphidium hiltermanni*. Several species dominate the assemblages in faunules 3 and 4 but are not important above or below this level. These include *Anomalinoides nobilis*, *Pullenia quinqueloba*, *Alabamina obtusa*, and *Uvigerina batjesi*. The cyclical character of the faunas is reduced by the appearance and disappearance of some of the associated species. Between samples W20 and W23, in the space of 7.3 m, several major changes take place; the disappearance of *Bolivinopsis adamsi* and *Cibicides cunobelini* and the appearance of *Anomalinoides nobilis*, *Alabamina obtusa*, *Cibicides simplex*, *Praeglobobulimina ovata*, and the planktonic species. Consequently, the species associated with *Elphidium hiltermanni* in faunule 2 are not the same as in faunule 5. There are obvious features against the presence of a true cycle, for example the distribution of Textulariina, but there does appear to be the hint of a repetition in the foraminiferid assemblages.

The species with important ranges have been indicated above. Obviously the level at which the fauna changes is of great importance. The appearance of planktonic species may also be used for correlation. The London Clay assemblages, as a whole, are characterized by the species discussed above together with *Epistominella vitrea*, *Gyroidina angustiumbilitica*, *Pulsiphonina prima*, and *Quinqueloculina imperialis* var. *porterensis*.

General features of the assemblages. The data are plotted in text-fig. 6. In the Lower London Clay, the similarity values are small, this being due to the large thickness of barren strata between foraminiferid-bearing samples. However, higher in the succession, more samples yield foraminiferids and the similarity values increase. They clearly pick out the difference between faunules 3, 4, 5, and 6.

The values for the diversity index α fall in the range $\alpha = 1$ –5. When plotted against the succession, the α values show a progressive increase (column 2, text-fig. 6) from $\alpha = 1$ in faunule 1 to $\alpha = 5$ in faunule 4.

The planktonic foraminiferids are well represented in the assemblages and are



TEXT-FIG. 6. General features of the foraminiferid assemblages and their interpretation, London Clay, Whitecliff Bay.

Interpretation. The succession at Whitecliff Bay commences with the Reading Beds which have been previously interpreted as fluviatile or estuarine (Hester 1965).

The basement bed of the London Clay is composed of partially cemented clays and sands with worm tubes. The presence of flint pebbles and fragments of Reading Beds points to penecontemporaneous erosion of the underlying deposits. The overlying 38 m are barren of foraminiferids except at two levels. The sediments include laminated and mottled sands, muddy sand and clay with lignitic blebs and nodules. The complete basal succession suggests the presence of intertidal conditions with mud flats and a vegetation cover.

The two foraminiferid horizons constitute faunule 1 and the base of faunule 2 (text-fig. 6). Faunule 1 yields an assemblage dominated by *Rotaliina* with a diversity value of $\alpha = < 1$. Dominant genera include *Cibicides*, *Cibicoides*, and *Nonion*. The low absolute abundance and diversity value points to an abnormal marine environment near the ecological limit for foraminiferids. The assemblage may have been transported into the intertidal environment at the head of a restricted bay (Lees, Buller and Scott 1969). The low diversity value reflects an abnormal, restricted marine environment.

The second marine incursion (W11, 14.3 m) results in an assemblage with a diversity value of $\alpha = 2$. An important feature is the abundance of *Textulariina* (text-fig. 6, column 6) which form 54.1% of the population. A study of the triangular diagram for recent environments (text-fig. 2) gives two possible interpretations; shelf sea or hyposaline lagoon. The assemblage is dominated by *Bolivinos*, *Cibicoides*, and *Epistominella*. All are typical shelf species but *Epistominella* attains its maximum abundance in a deltaic marine environment (see Walton 1964: Mississippi Delta) with rapid sedimentation of a clay grade. The water was probably hyposaline and of 10–60 m depth. However, as this is such a transitory episode, it may represent the discharge of a small distributary through the established intertidal regime.

The intertidal deposits are overlain by sandy clays with a good marine fauna. This lithological unit includes faunules 5, 4, 3, and the top of 2 (text-fig. 6). These faunal units yield a diversity range of $\alpha = 3-5$ (column 2). This indicates the presence of abnormal marine conditions; hyposaline and nearshore shelf, hyposaline lagoon and marsh or hypersaline lagoon and marsh. A comparison of the triangular diagrams for the fossil (text-fig. 6) and recent assemblages (text-fig. 2) provides little conclusive evidence as the samples plot in an area occupied by a host of environments.

The top of faunule 2 is dominated by species of *Cibicides*, *Cibicoides*, *Elphidium*, and *Epistominella*. The presence of the latter records the continued influence of a river outlet. However, the deltaic marine biofacies usually lacks abundant specimens of *Elphidium*. A combination of *Elphidium* and *Epistominella* occurs in a fluvial marine situation where salt water invades the lower reaches of a river estuary. A fluvial marine interpretation is in accord with the underlying deposits which may have formed tidal mud flats bordering the river.

The most abundant genera in faunule 3 are *Anomalinos*, *Bolivinos*, *Cibicoides*, *Pullenia*, and *Uvigerina*. All are typical shelf species and the last two reflect the presence of a clay substrate. The fine nature of the sediment probably excluded the miliolids. The environmental picture envisaged is of quiet sedimentation on a shelf region in hyposaline water of 20–100 m depth. A similar interpretation may be

suggested for faunule 4 though the increase in *Epistominella* reflects a continued river influence.

Faunule 5 marks the reappearance of abundant specimens of *Elphidium*. These are accompanied by *Praeglobobulimina* and numerous planktonic individuals. The latter make their first appearance in faunule 3 but attain a marked abundance in faunule 5 (text-fig. 6, column 3). Such a feature records an increase in the current circulation with the open sea. The dominance of *Elphidium* points to a shallow, nearshore shelf environment. The planktonics were probably contributed as dead individuals but their presence indicates the activity of currents right up to the coastline.

This trend towards shallow conditions is completed by sediments barren of foraminiferids except in one sample. The sediments include laminated, bioturbated, and rippled clays and sands which suggest a return to intertidal conditions. The foraminiferid assemblage is dominated by species of *Cibicides*, *Cibicidoides*, and *Praeglobobulimina*. The return to *Cibicides* dominance compares with faunule 1 when a similar isolated assemblage occurred within intertidal sediments.

As a summary, the London Clay represents the following progression of environmental situations:

- (a) At the base, intertidal conditions bordering a restricted bay and river outlet.
- (b) Fluvial-marine conditions in the mouth of a river channel.
- (c) Shelf, quiet sedimentation, clay substrate, 20–100 m depth, hyposaline water, removed from the river mouth.
- (d) Shallow nearshore shelf, 0–20 m, good current circulation.
- (e) Intertidal conditions.

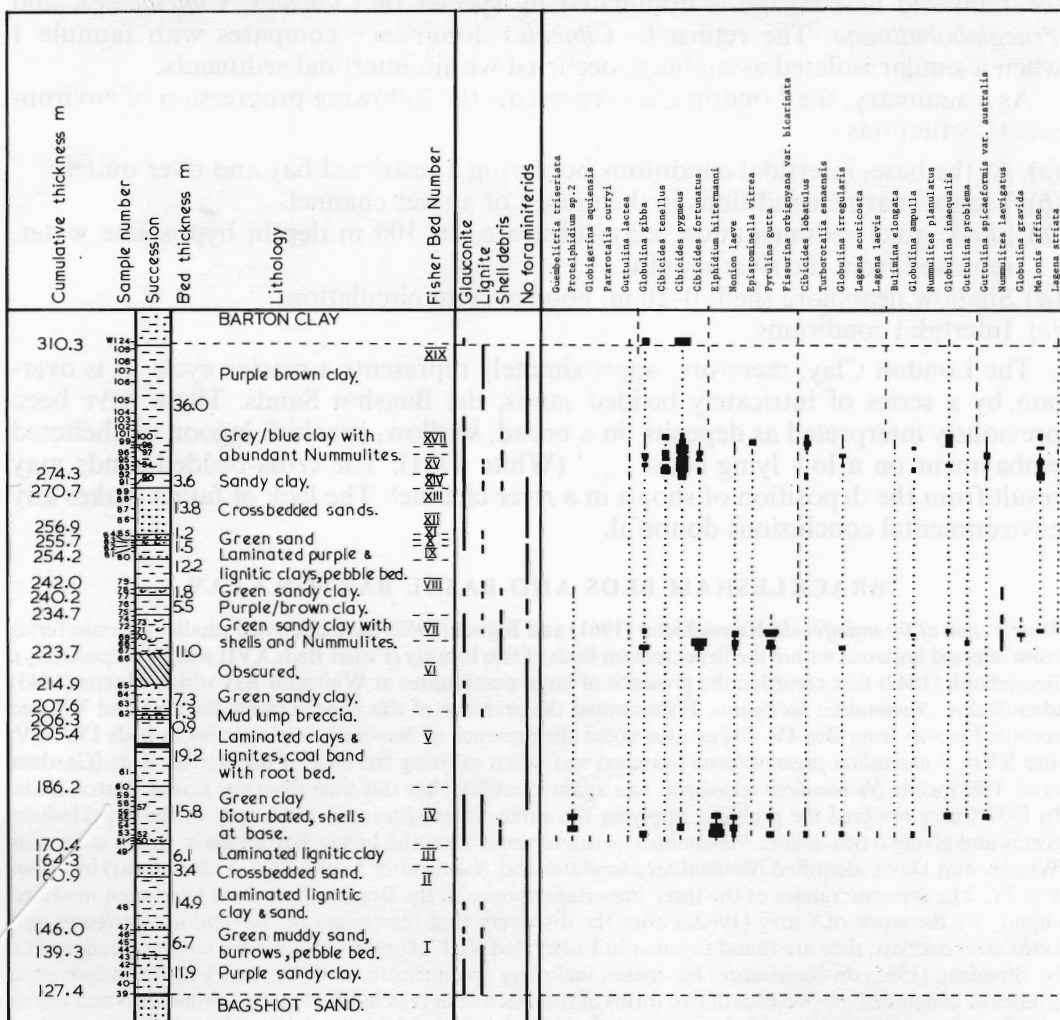
The London Clay, therefore, approximately represents a marine cycle. It is overlain by a series of intricately bedded sands, the Bagshot Sands. These have been previously interpreted as deposits 'in a broad, shallow, brackish lagoon or sheltered embayment on a low lying coast . . .' (White 1921). The cross-bedded sands may result from the deposition of shoals in a river channel. The lack of fauna makes any environmental conclusions doubtful.

BRACKLESHAM BEDS AND BASAL BARTON CLAY

Distribution of foraminiferids. Kaasschieter (1961) and Bignot (1962) have discussed smaller foraminiferids from selected horizons within the Bracklesham Beds of this locality (Fisher Beds XVII and IV respectively). Bowerbank (1842) first recorded the presence of large nummulites at Whitecliff Bay which Morris (1843) identified as *Nummulites laevigatus*. Fisher noted the presence of this species in his Beds VI and VII and recorded it also from Bed IV. Fisher also noted the presence of *Nummulites variolarius* in Beds IX, XIV, and XVII. *Nummulites prestwichiana (elegans)* was taken as fixing the base of the Barton Beds (Gardner *et al.* 1888) while *Nummulites variolarius* was again identified, but this time from the Lower Barton Beds. In 1937 Curry resolved the problem, applying the name *Nummulites variolarius* only to the Bracklesham forms and giving a new name, *Nummulites rectus*, to those from the Lower Barton Beds. In the same year Wrigley and Davis identified *Nummulites planulatus* and *Nummulites lucasana* (= *N. lucasianus*) in Fisher Bed IV. The separate ranges of the three important species in the Bracklesham Beds have been modified slightly by the work of Curry (1962a) after the discovery that the ranges of *Nummulites laevigatus* and *variolarius* overlap; they are found together in Fisher Bed VIII. More extensive work has been undertaken by Blondeau (1965) on *Nummulites laevigatus*, including specimens from Fisher Bed VII. From biometric studies he concluded the presence of two forms of the species but rejected *Nummulites britannicus* and *scaber* as only varieties. Pavlovec (1969), however, disagreed and included Blondeau's identifications in *Nummulites britannicus*, this being part of the phylogenetic group *Nummulites planulatus-puschi* in the Upper Cuisian

and Lower Lutetian. This group, characterized by its high chambers, has been divided from the *Nummulites laevigatus-brongniarti* group which has low chambers. As the intention is to compare French and English assemblages, the *Nummulites* from this succession have been identified as *Nummulites planulatus*, *laevigatus* s.l., and *variolarius* in accordance with French usage.

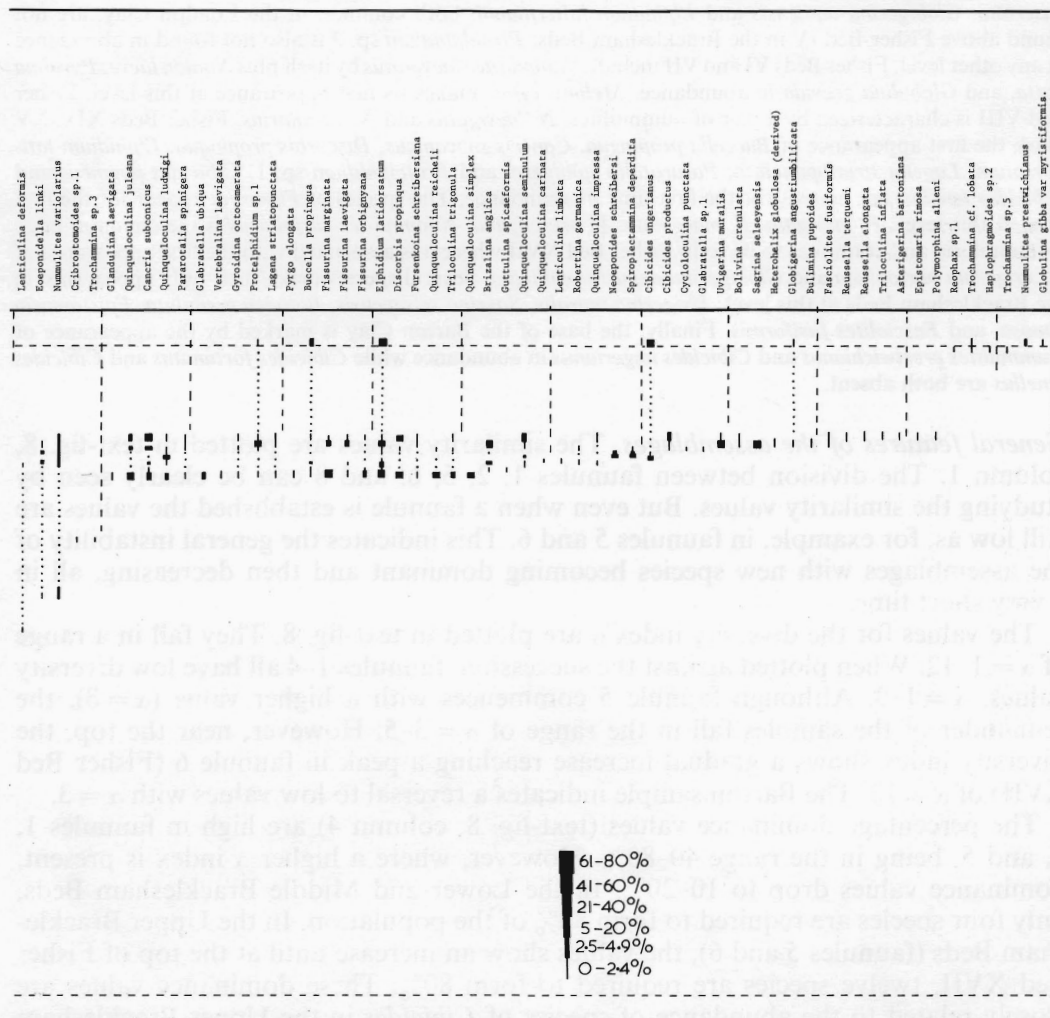
The distribution of foraminiferid species is given in text-fig. 7; the percentage abundance data are set out in Table 2. The assemblages may be divided into a number of faunules (text-fig. 8). To avoid congestion on text-fig. 7 the sample positions are tabulated in Table 3. Faunule 1 equates with Fisher Bed IV and is defined by the presence of *Nummulites planulatus*. Important smaller foraminiferids include *Elphidium hiltermanni* (21.4-64.3%), *Globulina gibba* (0-10.1%), *Protelphidium* sp. 2 (0-40.0%), and *Nonion laeve* (0-10.3%). The faunule is characterized by abundant species of the Elphidiidae-Nonionidae (68.3-93.7%) and Polymorphinidae (0-26.2%) to the virtual exclusion of all other forms (see text-fig. 8, column 5). Faunule 2 equates with Fisher Beds VI and VII and is defined by the presence of *Nummulites laevigatus* alone. Abundant smaller foraminiferids include *Pyrulina gutta* (5.9-61.8%) and *Nonion laeve* (3.1-20.0%). Associated with these at the top of Fisher Bed VI are *Cibicides fortunatus* (26.1-73.2%), *Globulina gibba*



TEXT-FIG. 7. Distribution chart of the foraminiferids from the

(0.26.1%), and *Globulina irregularis* (0.13.8%) while at the base of Fisher Bed VII, *Globulina gravida* is the associated species. The faunule is dominated by species of Polymorphinidae (9.1.79.9%) and Nonionidae (3.1.22.8%) with *Cibicides* important only at the base (i.e. top of Fisher Bed VI). Faunule 3 equates with Fisher Bed VIII and is composed of sparse smaller foraminiferids and nummulites. Species of the latter include *N. laevigatus* and small *N. variolarius* (Curry 1962a). Faunule 4, though poor in individuals, is important because of its fauna of simple agglutinated forms including *Cribrostomoides* and *Trochammina*.

After a few metres barren of foraminiferids, the sandy clays of Fisher Beds XIV–XVII yield an abundant fauna which can be divided into two faunules, 5 (Fisher Beds XIV–XVI) and 6 (Fisher Bed XVII). Both are dominated by *Nummulites variolarius* but among the smaller species, *Cibicides pygmeus* (7.6–55.6%) and *Cibicides tenellus* (0.26.8%) are the most common forms. Faunule 5, however, contains a wide range of accessory species and samples only a metre apart, though dominated by the three species listed above, contain different secondary forms. Among these are: *Globulina gibba* (0.15.3%), *Cibicides fortunatus* (0.15.5%), *Elphidium latidorsatum* (0.12.2%), *Globulina inaequalis* (0.11.4%), *Guttulina spicaeformis* var. *australis* (0.11.6%), *Neoponides schreibersi* (0.15.6%), *Cancris subconicus* (0.14.4%), and *Melonis affine*



Bracklesham Beds and Lower Barton Clay, Whitecliff Bay.

(0–16.3%). Assemblages are characterized by a general dominance of *Cibicides* species with polymorphinids and miliolids contributing the bulk of the remainder of the fauna (text-fig. 8, column 5). Faunule 6 has the same three dominant species but these are associated with *Cibicides lobatulus* (2.8–16.0%), *Sagrina selseyensis* (0–13.7%), *Discorbis propinqua* (0–19.1%), and rare *Fasciolites fusiformis*. The assemblages are composed of a large number of species which have small percentage abundances. They are far less dominated by *Cibicides* and this is associated with an increase in miliolids, polymorphinids, etc.

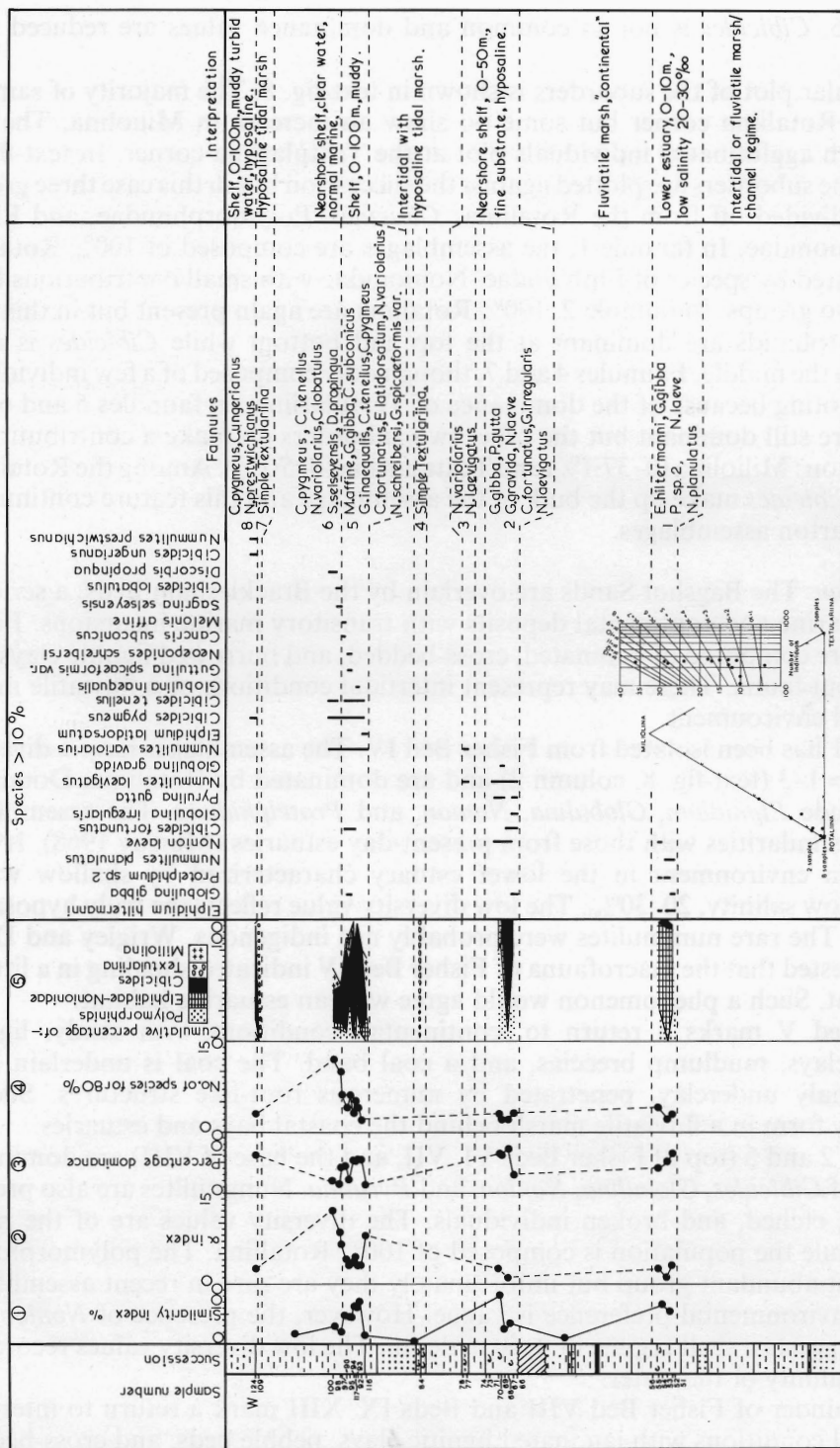
The next 24.7 m of section was difficult to sample (see above), and unfortunately the samples proved barren until faunule 7 recovered from the top of Fisher Bed XIX. The assemblage is composed of simple agglutinated forms poor in individuals but of importance because of the presence of species of *Haplophragmoides*, *Trochammina*, and *Reophax*. Directly overlying this, the next sample yielded *Nummulites prestwicianus* indicating the base of the Barton Clay. The assemblage, faunule 8, is dominated by species of *Cibicides*, including *C. pygmeus* (65.1%) and *C. ungerianus* (17.0%). Much of the remaining Barton Clay was not exposed and samples from the Barton Sand above were barren.

Species with important ranges have already been noted in the faunules. However, Fisher Bed IV is characterized by the presence of *Nummulites planulatus*. Another species seen only at this level is *Guembelitra triseriata*. *Globigerina aquiensis* and *Elphidium hiltermanni*, both common in the London Clay, are not found above Fisher Bed IV in the Bracklesham Beds. *Protelphidium* sp. 2 is also not found in abundance at any other level. Fisher Beds VI and VII include *Nummulites laevigatus* by itself plus *Nonion laeve*, *Pyrulina gutta*, and *Globulina gravida* in abundance. *Melonis affine* makes its first appearance at this level. Fisher Bed VIII is characterized by a pair of nummulites, *N. laevigatus* and *N. variolarius*. Fisher Beds XIV–XV mark the first appearance of *Buccella propinqua*, *Cancris subconicus*, *Discorbis propinqua*, *Elphidium latidorsatum*, *Lagena striatopunctata*, *Pararotalia spinigera*, and *Protelphidium* sp. 1. *Cibicides pygmeus* and *Cibicides tenellus* are present for the first time in abundance. The species of *Fissurina* appear for the first time at this level; *F. laevigata*, *F. marginata*, *F. orbignyana*. *Nummulites variolarius* is the common large foraminiferid and continues to be so in Fisher Bed XVII where it is associated with the first appearance of *Asterigerina bartoniana* and *Globigerina angustumbilicata*. Several species make their only appearance in the Bracklesham Beds at this level: *Uvigerina muralis*, *Sagrina selseyensis*, *Bolivina crenulata*, *Epistomaria rimosa*, and *Fasciolites fusiformis*. Finally, the base of the Barton Clay is marked by the appearance of *Nummulites prestwicianus* and *Cibicides ungerianus* in abundance while *Cibicides fortunatus* and *Cibicides tenellus* are both absent.

General features of the assemblages. The similarity values are plotted in text-fig. 8, column 1. The division between faunules 1, 2, 5, 6, and 8 can be clearly seen by studying the similarity values. But even when a faunule is established the values are still low as, for example, in faunules 5 and 6. This indicates the general instability of the assemblages with new species becoming dominant and then decreasing, all in a very short time.

The values for the diversity index α are plotted in text-fig. 8. They fall in a range of $\alpha = 1$ –12. When plotted against the succession, faunules 1–4 all have low diversity values, $\alpha = 1$ –3. Although faunule 5 commences with a higher value ($\alpha = 8$), the remainder of the samples fall in the range of $\alpha = 3$ –5. However, near the top, the diversity index shows a gradual increase reaching a peak in faunule 6 (Fisher Bed XVII) of $\alpha = 12$. The Barton sample indicates a reversal to low values with $\alpha = 3$.

The percentage dominance values (text-fig. 8, column 4) are high in faunules 1, 2, and 5, being in the range 40–80%. However, where a higher α index is present, dominance values drop to 10–20%. In the Lower and Middle Bracklesham Beds, only four species are required to form 80% of the population. In the Upper Bracklesham Beds (faunules 5 and 6), the values show an increase until at the top of Fisher Bed XVII, twelve species are required to form 80%. These dominance values are closely related to the abundance of species of *Cibicides* in the Upper Bracklesham Beds and of polymorphinids and Nonionidae–Elphidiidae lower down. For example,



TEXT-FIG. 8. General features of the foraminiferid assemblages and their interpretation, Bracklesham Beds and the Lower Barton Clay, Whitecliff Bay.

in faunule 6, *Cibicides* is not so common and dominance values are reduced considerably.

A triangular plot of the suborders is shown in text-fig. 8. The majority of samples plot at the Rotaliina corner but some do show an increase in Miliolina. The two samples with agglutinated individuals plot at the Textulariina corner. In text-fig. 8, column 5, the suborders are plotted against the succession but in this case three groups have been divided off from the Rotaliina: *Cibicides*, Polymorphinidae, and Elphidiidae–Nonionidae. In faunule 1, the assemblages are composed of 100% Rotaliina and dominated by species of Elphidiidae–Nonionidae with small contributions from the other two groups. In faunule 2, 100% Rotaliina are again present but in this case the polymorphinids are dominant at the top and bottom while *Cibicides* is most abundant in the middle. Faunules 4 and 7, though only composed of a few individuals, are worth noting because of the dominance of Textulariina. In faunules 5 and 6, the Rotaliina are still dominant but the other two suborders do make a contribution to the population: Miliolina (0–37.1%) and Textulariina (0–5.1%). Among the Rotaliina, species of *Cibicides* make up the bulk of the assemblage and this feature continues in the basal Barton assemblages.

Interpretation. The Bagshot Sands are overlain by the Bracklesham Beds, a series of marginal marine and continental deposits with transitory marine incursions. Fisher Beds I–III are composed of laminated, cross-bedded, and burrowed lignitic clays and sands without fauna. These may represent intertidal conditions or a fluviatile marsh and channel environment.

Faunule 1 has been isolated from Fisher Bed IV. The assemblages have a diversity range of $\alpha = 1-3$ (text-fig. 8, column 2) and are dominated by Rotaliina. Dominant genera include *Elphidium*, *Globulina*, *Nonion*, and *Protelphidium*. The assemblages have many similarities with those from present-day estuaries (Murray 1968). It may represent an environment in the lower estuary characterized by shallow water, 0–10 m, of low salinity, 20–30‰. The low diversity value reflects the truly hyposaline conditions. The rare nummulites were probably not indigenous. Wrigley and Davis (1937) suggested that the macrofauna of Fisher Bed IV indicated shoaling in a littoral environment. Such a phenomenon would agree with an estuarine habitat.

Fisher Bed V marks a return to 'continental' conditions with sandy, lignitic laminated clays, mudlump breccias, and a coal band. The coal is underlain by a bleached shaly underclay, penetrated by numerous root-like structures. Such a deposit may form in a fluviatile marsh behind the coastal bays and estuaries.

Faunules 2 and 5 (top of Fisher Beds VI, VII, and the base of VIII) are dominated by species of *Cibicides*, *Globulina*, *Nonion*, and *Pyrulina*. Nummulites are also present as abraded, etched, and broken individuals. The diversity values are of the range $\alpha = 1-2\frac{1}{2}$ while the population is composed of 100% Rotaliina. The polymorphinids are the most abundant group but unfortunately they are rare in recent assemblages and their environmental preference is vague. However, the presence of *Nonion* and *Cibicides* suggests a shelf regime of 0–50 m depth. The low diversity values record the abnormal salinity of the water.

The remainder of Fisher Bed VIII and Beds IX–XIII mark a return to intertidal and channel conditions with laminated lignitic clays, pebble beds, and cross-bedded

sands. The nature of these marginal marine deposits is indicated at one level by faunule 4. This is composed of simple Textulariina genera, *Cribrostomoides* and *Trochammina*. Such an assemblage suggests the presence of a hyposaline tidal marsh. The foraminiferids are associated with shell beds of nearshore marine molluscs which have been washed on to the marsh environment (cf. Greensmith and Tucker 1969).

Fisher Beds XIV–XVII yield the most abundant foraminiferid faunas of the Whitecliff Bay succession (faunules 5 and 6, text-fig. 8). Diversity values range from $\alpha = 3$ –12 being highest in faunule 6. Such a range suggests a transition from abnormal to fully marine conditions (text-fig. 1). Miliolids make their first appearance at this level.

Faunule 5 is dominated by species of *Cibicides*, which contribute between 7.6 and 82.4% of the fauna. Other abundant genera include *Globulina*, *Melonis*, *Cancris*, *Elphidium*, *Guttulina*, *Neoeponides*, and *Fissurina*. All are typical shelf forms which indicate muddy conditions in water of 0–100 m depth.

Faunule 6, while still containing abundant *Cibicides*, also includes several distinctive environmental indicators. These include species of *Discorbis* and *Fasciolites*. This suggests a slight warming of the sea. A more complete southern fauna is seen at Selsey at the same horizon. The presence of *Quinqueloculina seminulum* indicates a summer bottom temperature greater than 10 °C while *Discorbis* and *Fasciolites* suggest a maximum of at least 18 °C. However, these few genera represent only a very diluted southern influence. For a brief period, the sea was shallow and clear with perhaps a flora which provided a habitat for some of the microfauna.

However, these conditions were soon destroyed by the return of barren, intertidal clays which complete the Bracklesham formation.

The base of the Barton Clay is marked by the appearance of *Nummulites prestwichianus*. This horizon is underlain by faunule 7, composed of simple Textulariina including *Trochammina*. This may be interpreted as a hyposaline tidal marsh (Murray 1972) and marks the transition to marine conditions in faunule 8 at the base of the Barton Clay. This assemblage has a diversity value of $\alpha = 2\frac{1}{2}$ and is dominated by Rotaliina in the form of *Cibicides* which constitute 78.5% of the population. This indicates a return to muddy turbid shelf conditions of 0–100 m depth range. The low α value points to the presence of hyposaline water while abundant *Cibicides* record the cool-water influence to the fauna.

Unfortunately the remaining Barton Clay was not well enough exposed to be sampled. A study of the published section (Gardner *et al.* 1888; White 1921) reveals a succession of sandy clays, laminated clays, and mottled sandy clays with few recorded fossils. These suggest a return to intertidal, fluvial marsh, and channel environments. The sequence is completed by the Barton Sand which may represent a marine sand bar or shoal across the entrance to the basin.

MIDDLE HEADON BEDS

Distribution of foraminiferids: (a) *Shore section.* In the basal three samples *Quinqueloculina contorta* is the dominant species accompanied by *Quinqueloculina seminulum*, *Triloculina trigonula*, and *Cibicides pseudo-ungarianus* (text-fig. 9, Table 4). Sample 1535 has, in addition, *Pararotalia audouini*. These four samples are grouped together as faunule 1. They correspond to the Brockenhurst and Roydon Zones in the sense of Bhatia (1955) and Beds G–H, Brockenhurst Beds of Stinton (1971).

Following a barren interval, foraminiferids are sparsely present in faunule 2 dominated by *Pararotalia curryi*. Another barren interval separates this from faunule 3 dominated by *P. curryi*, *Quinqueloculina seminulum*, and *Protelphidium* cf. *P. roemeri*.

Further barren sediments pass up into clays with faunule 4. Sample 1508 is dominated by *Protelphidium* cf. *P. roemeri* and the textularians *Ammobaculites* cf. *A. pseudorostratus* and *A. yazooensis* not seen elsewhere in the succession. At the top of faunule 4 these textularians are absent and the dominant forms are *Quinqueloculina seminulum* and *Protelphidium* cf. *P. roemeri*.

Foraminiferids are absent from the remainder of the Middle Headon Beds but they make a brief reappearance in faunule 5, dominated by *Protelphidium* cf. *P. roemeri*, at the base of the Upper Headon Beds. They are then absent throughout the succession as far as the Bembridge Limestone.

Planktonic foraminiferids are present at two levels (samples 1533 and 1538). The second occurrence, in faunule 2, is in the 'Barren' sands of Bhatia (1955) and in the Royden Beds of Stinton (1971).

(b) *Section in the upper part of the cliff.* The upper part of the Lower Headon Beds is devoid of foraminiferids. In the Middle Headon Beds a single sample yielded foraminiferids (1480). This is equivalent to the Brockenhurst Zone at the base of faunule 1 in the shore section. However, the dominant species differ here, being *Cibicides refulgens*, *C. pygmeus*, and *Globulina gibba*. Planktonic foraminiferids are present. All other samples in this section failed to yield foraminiferids.

(c) *Section in the lower part of the cliff.* The majority of the samples were unproductive. The three that yielded foraminiferids are all dominated by *Quinqueloculina seminulum* and have the accessory species *Pararotalia curryi* and *Protelphidium* cf. *P. roemeri*. These assemblages probably equate with faunule 3 in the shore section.

General features of the assemblages

(a) *Shore section.* In faunule 1 the α diversity values rise from 1+ to 4 from samples 1532 to 1535. Agglutinated forms are absent. Miliolina form 53–94% of the total. Faunule 2 is represented by two sparsely fossiliferous samples. Faunule 3 has a diversity of $\alpha = 1\frac{1}{2}$ and plots along the Miliolina-Rotaliina side of the triangle. The two samples of faunule 4 are different from one another as 1509 is 100% Rotaliina and 1508 has 55% Textulariina. The diversities are $\alpha < 1$ and 1 respectively.

(b) *Section in the upper part of the cliff.* Sample 1480 has a diversity of $\alpha = 4$ and is 100% Rotaliina.

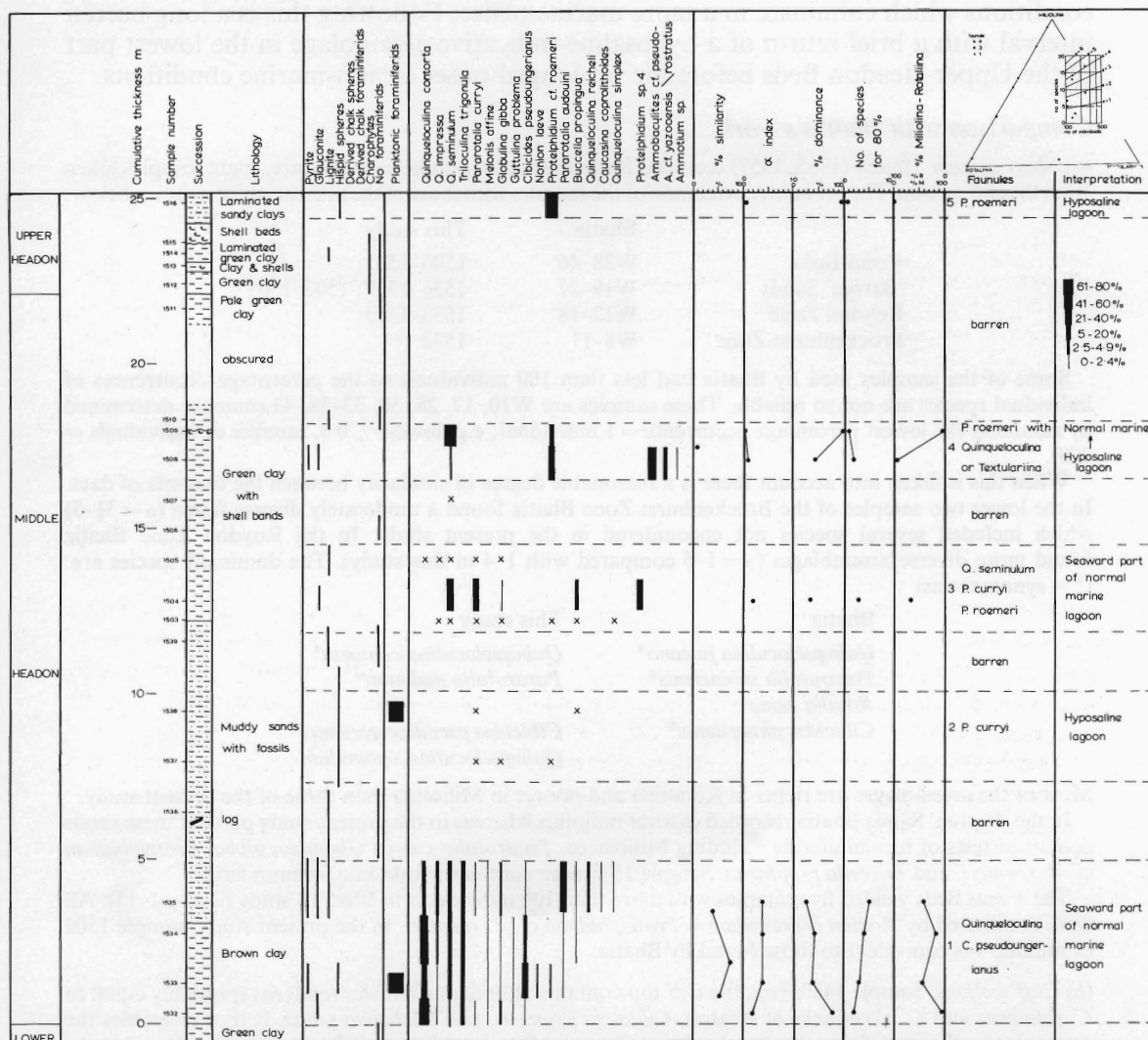
(c) *Section in the lower part of the cliff.* Sample 1501 has a diversity of $\alpha = < 1$ and has 98.2% Miliolina and 1.8% Rotaliina.

Interpretation. On the triangular diagram (text-fig. 9) the faunule 1 samples lie in the fields for hypersaline and normal marine lagoons. The diversity values suggest that the environment was of abnormal salinity. The genera present include *Quinqueloculina*, *Triloculina*, *Pararotalia*, and *Cibicides*. In modern environments the Miliolacea occur in normal marine and hypersaline and *Cibicides* in normal marine waters. There are no data on modern *Pararotalia*. Sample 1480 from the same faunule also includes *Eponides* and *Globulina* both of which are normal marine shelf forms. In addition planktonic foraminiferids are present in this faunule.

The best interpretation of faunule 1 seems to be that it represents the seaward part of an enclosed lagoon or bay with normal or slightly hypersaline salinities. None of the genera is diagnostic of temperature but with the exception of *Pararotalia* they live in the present-day seas along the European seaboard. The summer temperature was perhaps therefore in the range 16–18 °C as in the modern seas. The absence of warm, shallow-water dwelling miliolaceans such as *Spirolina* perhaps supports this argument. The miliolaceans probably lived on weeds growing on the sediment and were contributed to the sediment after death. It is probable that the planktonic foraminiferids, which are all extremely small, were transported into the lagoon from the open sea outside. A comparable modern environment is the lagoon to the south of the Ebro Delta, Spain (Scrutton, unpublished thesis).

Faunule 2 can probably be interpreted as representing hyposaline conditions in a lagoon. Faunule 3 starts and ends with assemblages dominated by *Quinqueloculina seminulum* while in the middle *Protelphidium* cf. *P. roemeri* and *Pararotalia curryi* are dominant. With the exception of the absence of *Cibicides* these assemblages resemble those of faunule 1 and probably represent a similar environment.

Faunule 4 includes the Textulariina-rich sample (1508). The diversity is very low ($\alpha = 1$) and on the triangular plot it falls in the field of hyposaline lagoons. Assemblages dominated by simple agglutinated species characterize the inner parts of modern hyposaline lagoons (Murray 1968). The final assemblage in faunule 4 is dominated by *Q. seminulum* and must represent a return to normal marine conditions.



TEXT-FIG. 9. Distribution chart of the foraminiferids from the Middle Headon Beds, Whitecliff Bay.

The absence of foraminiferids from part of the succession can be shown in the cliff sections to be due to subsequent destruction by weathering. The shore section looked fresh and the absence of foraminiferids from parts of the succession is perhaps original. That being so the succession can be interpreted as representing an initial transgression in the Brockenhurst-Roydon Zones, faunule 1, times with the development of a lagoon in which normal marine conditions prevailed at Whitecliff Bay.

The barren interval between faunules 1 and 2 may represent silting up of the lagoon and a temporary return to unfavourable conditions for foraminiferids. Faunule 2 then represents a re-establishment of lagoon conditions. A similar repetition is represented by the next barren interval and faunule 3, and a further barren interval and faunule 4. However, the latter shows clear indication of hyposaline, inner lagoon, conditions which culminate in a more marine phase. Following this is a long barren interval with a brief return of a hyposaline-indicative assemblage in the lowest part of the Upper Headon Beds before the prolonged onset of non-marine conditions.

Comparison with Bhatia's work

(a) *Shore section.* Bhatia (1955, 1957) recorded foraminiferid assemblages from thirty-eight samples taken from the cliff section. The probable correlation of the samples with those of the present study is shown below:

	Bhatia	This study
Venus Beds	W28-46	1506-1511
'Barren' Sands	W19-27	1536-1539; 1503-1505
Roydon Zone	W12-18	1533-1535
Brockenhurst Zone	W8-11	1532

Some of the samples used by Bhatia had less than 100 individuals so the percentage occurrences of individual species are not so reliable. These samples are W10, 17, 28, 30, 33-38, 43 (number determined by assuming the lowest percentage occurrence = 1 individual; e.g. lowest % 0.5, number of individuals = 200).

When this is taken into account there is a reasonable degree of similarity between the two sets of data. In the lower two samples of the Brockenhurst Zone Bhatia found a moderately diverse fauna ($\alpha = 3\frac{1}{2}$ -5) which included several species not encountered in the present study. In the Roydon Zone Bhatia found more diverse assemblages ($\alpha = 1$ -5 compared with 1-4 in this study). The dominant species are: (* = synonymous)

Bhatia	This study
<i>Quinqueloculina juleana</i> *	<i>Quinqueloculina contorta</i> *
<i>Pararotalia subinermis</i> *	<i>Pararotalia audouini</i> *
<i>Rotalia canui</i>	—
<i>Cibicides aknerianus</i> *	<i>Cibicides pseudoungerianus</i> *
	<i>Quinqueloculina seminulum</i>

Most of the assemblages are richer in Rotaliina and poorer in Miliolina than those of the present study.

In the 'Barren' Sands Bhatia recorded casts of miliolids whereas in the present study parts of these sands contained tests of foraminiferids including Miliolacea, *Pararotalia curryi*, *Globulina gibba*, *Protelphidium* cf. *P. roemeri*, and *Buccella propingua*. Sample 1538 even contains planktonic foraminiferids.

The Venus Beds yielded five samples with more than 100 individuals in Bhatia's study ($\alpha = < 1$ -1 $\frac{1}{2}$). All were dominated by *Nonion depressulum* = *Protelphidium* cf. *P. roemeri*. In the present study, sample 1509 of faunule 4 is equivalent to those found by Bhatia.

(b) *Cliff sections.* Sample 1480 from the cliff top contains abundant *Cibicides refulgens* (probably equal to *C. refulgens* and *C. aknerianus* of Bhatia), *Cibicides pygmeus*, and *Globulina gibba*. It thus resembles the assemblages obtained from the Brockenhurst Zone by Bhatia although it has fewer species and lacks planktonic individuals.

The samples from the *Venus* Beds in the lower part of the cliff resemble the miliolid-rich samples obtained from the same beds by Bhatia.

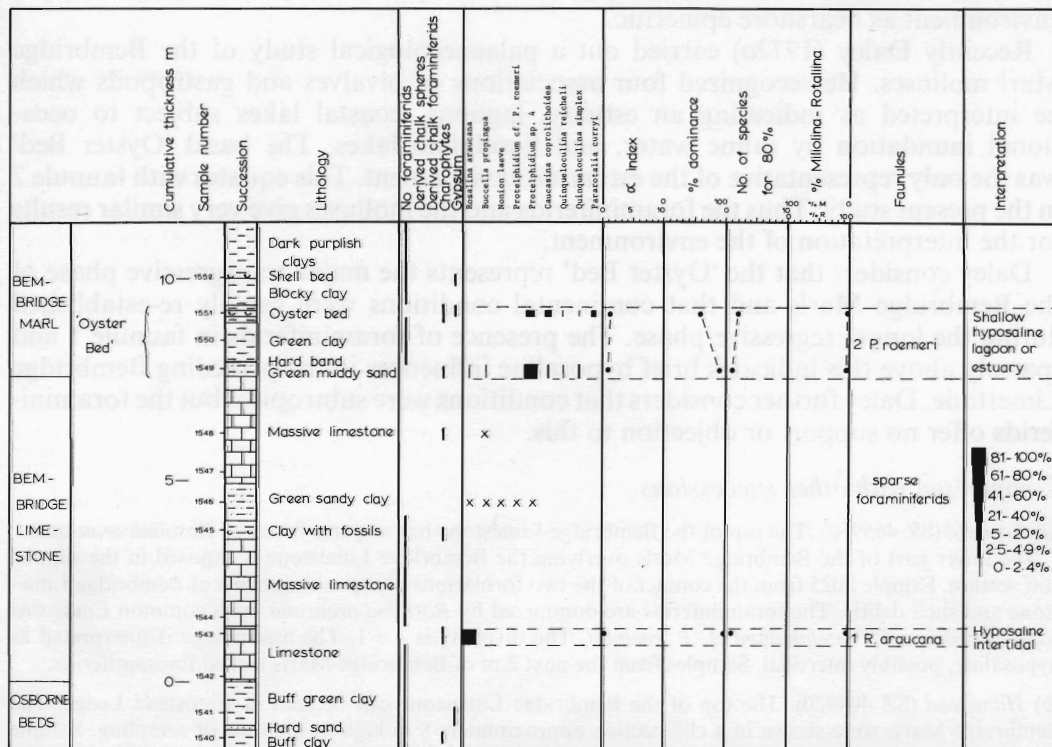
Bhatia (1957) interpreted the Brockenhurst Zone as deeper-water infraneritic and the Roydon Zone as slightly shallower and perhaps slightly warmer. The 'Barren' Sands yielded only internal moulds of *Q. seminulum* so no reliable interpretation was possible. The *Venus* Beds were interpreted as shallow-water epineritic becoming progressively less saline and possibly even oxygen deficient.

There is fair agreement between Bhatia's interpretation and that of the present study. The greater amount of ecological data now available favours the generally shallow depths used in the present interpretation rather than the deeper open-shelf conditions envisaged by Bhatia.

BEMBRIDGE BEDS

Distribution of foraminiferids. Foraminiferids are absent from the topmost clays of the Osborne Beds. They first occur near the top of the lowermost limestone of the Bembridge Limestone. Sample 1543 yielded a monospecific assemblage of *Rosalina araucana*—faunule 1. Foraminiferids are sparsely present in the sandy clays and upper limestone of the Series (text-fig. 10, Table 5).

The main occurrence is in the lower part of the Bembridge Marls. The basal sandy clays have an assemblage dominated by *Protelphidium* cf. *P. roemeri*. Then there is a barren interval followed by a final occurrence in the 'Oyster Bed'. Here, in addition



TEXT-FIG. 10. Distribution chart of the foraminiferids from the Bembridge Beds, Whitecliff Bay.

to *Protelphidium* cf. *P. roemeri*, there are common *Caucasina coprolithoides* and *Pararotalia curryi*. These two occurrences have been grouped into faunule 2. The remainder of the Bembridge Marls sampled (up to about 25 m above the base) proved to be barren of foraminiferids.

General features of the assemblages. The three samples with more than 100 individuals are all of very low diversity ($\alpha = < 1-1\frac{1}{2}$), have a high percentage dominance of the most abundant species and are almost 100% *Rotaliina* (text-fig. 10).

Interpretation. Faunule 1, consisting exclusively of *Rosalina araucana*, is indicative of very unfavourable conditions for foraminiferids. The water was very hyposaline, probably with a salinity of $< 10\text{‰}$. It could have been intertidal or very shallow subtidal. The sparse foraminiferids above faunule 1 indicate unfavourable conditions or transport of foraminiferids into the area of deposition.

Faunule 2 is dominated by *Protelphidium* cf. *P. roemeri*. The low diversity and high percentage dominance likewise point to unfavourable conditions. The high content of *Rotaliina* suggests hyposaline water. The faunule probably represents a shallow hyposaline lagoon or estuary with salinities in the range 10–25 ‰. The foraminiferids give no guide to the temperature.

Bhatia (1955, 1957) did not sample the Bembridge Limestone but he recorded foraminiferids from the Bembridge Marls and noted their similarity with those from the Middle Headon Beds of Headon Hill and Colwell Bay. He interpreted the environment as nearshore epineritic.

Recently Daley (1972a) carried out a palaeoecological study of the Bembridge Marl molluscs. He recognized four associations of bivalves and gastropods which he interpreted as indicating an estuary, lagoons, coastal lakes subject to occasional inundation by saline water, and floodplain lakes. The basal 'Oyster Bed' was the only representative of the estuarine environment. This equates with faunule 2 in the present study. Thus the foraminiferids and the molluscs give very similar results for the interpretation of the environment.

Daley considers that the 'Oyster Bed' represents the major transgressive phase of the Bembridge Marls and that continental conditions were rapidly re-established during the longer regressive phase. The presence of foraminiferids in faunule 1 and sparsely above this indicates brief hyposaline influences in the preceding Bembridge Limestone. Daley further considers that conditions were subtropical but the foraminiferids offer no support or objection to this.

Comparison with other successions

(a) *Gurnard* (SZ 465950). The top of the Bembridge Limestone has a sparse fauna of *Rosalina araucana*.

The lower part of the Bembridge Marls overlying the Bembridge Limestone is exposed in the slipped cliff section. Sample 2025 from the contact of the two formations contains fragments of Bembridge Limestone and shell debris. The foraminiferids are dominated by *Rosalina araucana*, with common *Caucasina coprolithoides* and *Protelphidium* cf. *P. roemeri*. The diversity is $\alpha = 1$. The assemblage is interpreted as hyposaline, possibly intertidal. Samples from the next 2 m of Bembridge Marls lacked foraminiferids.

(b) *Hamstead* (SZ 404920). The top of the Bembridge Limestone can be seen in Hamstead Ledge. The Bembridge Marls were shown in a cliff section approximately 8 m high at the time of sampling. Sample 2043 from 1.3 m above the contact yielded an assemblage dominated by *Caucasina coprolithoides* (80.5%) with subsidiary *Buliminella elegantissima* and a diversity of $\alpha = < 1$. Sample 2030 from 2.5 m above the

base has a similar fauna (Table 5). Foraminiferids are absent from the next 1.85 m of clays and make a brief reappearance in sample 2034, 4.35 m above the base. No further occurrences of foraminiferids were found in the remaining 5 m of Bembridge Marls which were sampled.

In the Whitecliff Bay succession sample 1551 from the top of the 'Oyster Bed' had an assemblage dominated by *Protelphidium* cf. *P. roemeri* with *Caucasina coprolithoides* as a subsidiary species. The samples from Gurnard and Hamstead bear greatest resemblance to this assemblage although they are by no means identical. Daley (1972a) interprets the lower Bembridge Marls at Gurnard and Hamstead as brackish lagoonal. No modern analogues of a *Caucasina* dominant assemblage are known but the very low diversity and high Rotaliina content suggests a hyposaline, lagoonal environment.

ALUM BAY, ISLE OF WIGHT

Location. Alum Bay is situated at the western end of the Isle of Wight. It is bounded on its southern side by the Chalk cliffs of High Down which form a promontory terminated by the Needles. The northern limit of the bay is Hatherwood Point. The cliffs vary in height from 45 to 100 m and display a complete succession of Eocene strata. This succession continues into the Oligocene on Headon Hill. The Eocene beds are vertical, striking east-west. However, to the north, on Headon Hill, the beds are horizontal. The attitude of the succession is governed by its position in the monoclinal fold which forms the backbone of the island.

Previous stratigraphic work. The earliest account was by Webster (1814). In 1846 Prestwich (pp. 255-259) gave each group of beds a number and described their lithology, thickness, and fauna. In 1847a he revised the formation names, applying the terms Barton Beds, etc. Fisher (1862) took as the base of the Barton Beds, the '*Nummulina prestwichiana*' band. He also described what he considered constituted the Bracklesham Beds: 17.4 m of sand and clay between the nummulite band and the marked pebble bed taken as the base of the Barton series by Prestwich. Gardner *et al.* (1888) redescribed the Barton Beds and divided the formation into lower, middle, and upper parts. They noted the lack of a well-developed *Chama* Bed and the increased thickness of the Middle Barton Beds in comparison with the type section. Bristow *et al.* (1889) produced measured sections of the Reading Beds and the London Clay. Also, they revised the thickness of the Bracklesham Beds by moving the base to 110 feet (33.6 m) below the pebble bed. In the third edition of the memoir on the Isle of Wight, White (1921) added 172 feet (52.4 m) of sands and clays to the top of the London Clay as originally defined by Bristow *et al.* The Bagshot Beds were taken to be only 76 feet (23.2 m) thick while the Bracklesham Beds made up the remaining 571 feet (165.2 m) of strata below the Barton Beds. However, none of the divisions between the London Clay, Bagshot and Bracklesham Beds were definite, as the lithology of sand and laminated clays provided no opportunity for fixing a faunally based boundary. In fact White, when discussing the choice of the base of the Bracklesham Beds, states that the horizon chosen 'seems as good as any'.

This whole problem has possibly been resolved by work on the microplankton by Eaton (1971). By studying the faunas in proved Bracklesham strata at Whitecliff Bay and correlating these with similar assemblages at Alum Bay, the following suggestions have been made:

- (i) The top of the London Clay is as originally defined by Prestwich, at the top of Bed 6.
- (ii) The Bagshot Sands are represented only by Bed 7.
- (iii) The Bracklesham Beds include the whole succession from Beds 8-29 (in part).

Curry (1957, 1966) has produced a field report and guide to the section.

Succession. At the time of sampling, the Reading Beds were obscured by slumped material therefore no measurement was attempted. However, the Reading Beds have been described (in White 1921) as a series of red, white, brown, and grey clays, mottled in places. The base is marked by 0.9 m of brown sand which rests on and infills hollows in the unevenly eroded surface of the underlying Chalk. The total thickness of the Reading Beds is 25.6 m.

The succession measured is given in text-figs. 11 and 13, commencing at the base of the London Clay and ending at the base of the Barton Sands, on the northern side of the bay.

The basement bed of the London Clay is followed by 46.6 m of blue, grey, or brown clays with scattered reworked flints and shell material (Prestwich Bed 4). Several conspicuous lines of septaria are present including one with shells of *Pinna affinis* J. Sowerby.

The formation is completed (Prestwich Beds 5 and 6) by 23.8 m of laminated muddy sands and clays interspersed with thin bands of clean sand. These beds display ripple marks, shallow channels, mud flake breccias, and cross-bedding. Bands rich in lignite and plant remains are common. The total thickness of the London Clay was found to be 70.4 m.

The Bagshot Beds are represented only by Prestwich Bed 7. This is composed of 7.0 m of yellow and white sand with some mud laminae.

The overlying Bracklesham Beds are composed of a large thickness of variegated sands. Interbedded with these are beds of laminated clays and mottled muddy sand, often extremely rich in plant debris and lignite. This part of the succession is terminated by a thick pebble bed (0.3 m) composed of well-rounded cobbles of flint, often up to 0.3 m in diameter. The Bracklesham Beds (Prestwich Beds 8–28) measure 231.4 m in thickness.

The succession between the pebble bed and the nummulite band has been considered as definitely (Fisher 1862; White 1921) or possibly (Prestwich 1846; Curry 1966) attributable to Bracklesham Beds. The work of Eaton (1971) postulates that it is equivalent to Beds XVII–XIX (in part) at Whitecliff Bay and therefore is part of the Upper Bracklesham Beds. The sediments are composed of lignitic sandy clays and silts with burrows, passing up into laminated clays with *Panopea*. This is followed by a glauconitic clay, with shell debris, which contains the band of *Nummulites prestwichianus*, taken as the base of the Barton formation. This band was found to be 25.9 m above the pebble bed although previous workers found that it was only 14.6 m above this datum.

The Lower Barton Beds comprise 17 m of glauconitic grey or brown clay with scattered septaria. The Middle Barton Beds are brown, grey, or green mottled sandy clays with shell pockets and scattered septaria, passing up into clays with septaria and reworked flints. The top beds are dark clays with abundant shells and shell debris. The Middle Barton Beds are 54 m thick and pass up into a large mass of Upper Barton/Lower Headon unfossiliferous sand, which has not been measured or sampled.

The clays of the Alum Bay succession have been studied by Gilkes (1968). The London Clay is composed of illite-montmorillonite while the remaining formations are characterized by clays composed of illite-kaolinite. The heavy minerals have been studied by Walder (1964) and Blondeau and Pomerol (1968).

From previous work it has been established that the major part of the Alum Bay succession is composed of unfossiliferous sands of a 'continental origin'. A marine mollusc fauna has been retrieved only from the basal part of the London Clay and from the clays above the Bracklesham pebble bed. Trial samples from the sands proved barren and therefore extensive sampling was not undertaken.

LONDON CLAY

Distribution of foraminiferids. London Clay foraminiferids from this locality have been studied by Bowen (1954). He identified fourteen species which he considered were of little stratigraphic importance. Kaaschieter (1961) has also studied six samples from this level.

The range of foraminiferids is given in text-fig. 11 and the percentage abundance of the species is given in Table 6. Foraminiferids occur in the lower London Clay only between 4.6 and 41.5 m above the base. The assemblages can be divided into two faunules. The first contains *Bolivinosia adamsi* (0.4–52.7%), *Cibicides cunobelini* (11.3–60.8%), *Pullenia quinqueloba* (0–20.0%), *Elphidium hiltermanni* (2.8–19.2%), and *Cibicides lobatulus* (0–14.6%). Faunule 2 is characterized by different species with the exception of *Pullenia quinqueloba* (3.9–12.7%). These are *Cibicoides proprius* (35.7–71.2%), *Anomalinosia nobilis* (0–10.5%), *Cibicides simplex* (0–29.8%), and *Alabamina obtusa* (0–31.6%).

Important ranges include the restricted ones of *Cibicides cunobelini*, *Alabamina obtusa*, *Cibicides simplex*, and *Textularia agglutinans*. The London Clay assemblages are in general characterized by the species in the faunules plus *Pulsiphonina prima*, *Brizalina anglica*, and *Gyroidina angustiumbilicata*. Another useful datum is the level of appearance of planktonic species in the assemblages.

General features of the assemblages. The similarity indices are plotted in text-fig. 12, column 1. The change from faunule 1 to 2 can be clearly seen from the low value of 5.7%. Once faunule 2 is established, the index is consistently high, 53.9–74.1%. The values of the diversity index α plot in the range $\alpha = 2-4\frac{1}{2}$. They show little trend when plotted against the succession though the highest value does coincide with the appearance of planktonic species and the establishment of a new faunule.

The planktonic/benthonic ratio is plotted in text-fig. 12, column 3. Values range from 0.007 to 0.04, all being fairly low. However, in this case, it is the level of appearance that is important.

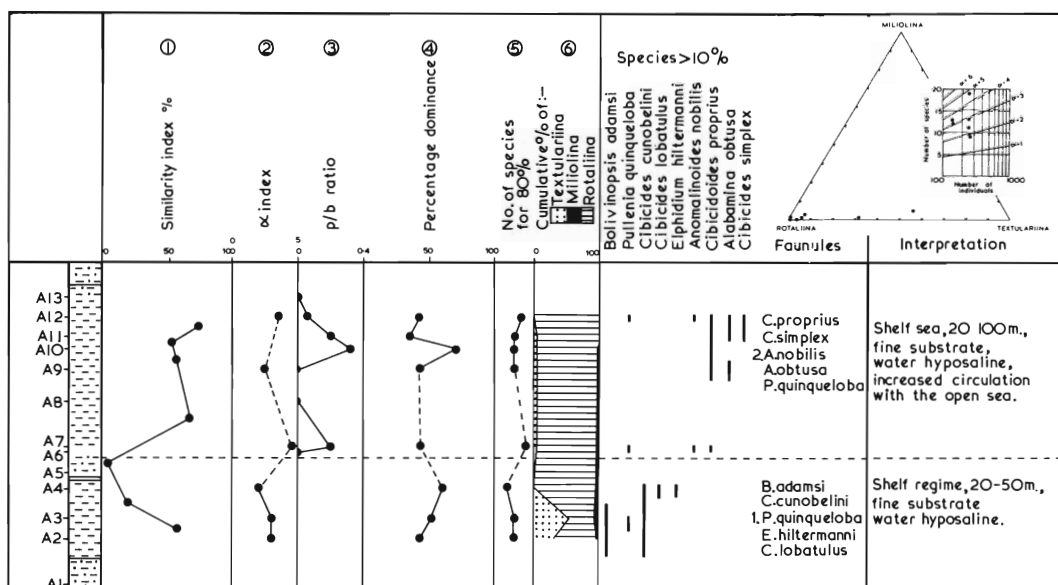
The majority of percentage dominance values fall in the range 35–60% with little obvious trend (column 4). Faunule 1 requires 2–3 species to form 80%, faunule 2 needs 3–5 (column 5).

In a plot of the suborders (text-fig. 12) the samples fall in the lower region of the triangle, indicating a general lack of Miliolina. However, when these values are plotted against the succession it can be seen that the basal assemblages are dominated by Textulariina (31.4–51.0%). The remaining samples from higher in the London Clay abound in Rotaliina, the other suborders forming only minor constituents.

Interpretation. The succession at Alum Bay commences with the Reading Beds which have been interpreted as being of a fluvial and estuarine origin (Hester 1965). The London Clay with its associated foraminiferid faunas marks the first appearance of truly marine conditions. However, this marine episode constitutes only a minor part of the total succession.

Six samples yielded the requisite number of foraminiferids to calculate a diversity index. All the values are low (text-fig. 12), the range being $\alpha = 2-4\frac{1}{2}$. This points to the existence of the abnormal marine situation of a hyposaline and nearshore shelf (text-fig. 1). Other environments indicated include hyposaline lagoon and marsh or hypersaline lagoon and marsh. A comparison of the London Clay triangular plot (text-fig. 12) with that for recent environments (text-fig. 2) results in the possibility of either a hyposaline lagoon or a shelf sea situation. Therefore, shelf seas and hyposaline lagoons are the two possibilities which both population plots have in common.

Faunule 1 is dominated by species of *Cibicides*, *Pullenia*, *Bolivinosia*, and *Elphidium*. All are represented by specimens of a full size range which show little evidence of



TEXT-FIG. 12. General features of the foraminiferid assemblages and their interpretation, London Clay, Alum Bay.

UPPER BRACKLESHAM AND BARTON BEDS

Distribution of foraminiferids. Previous work on the foraminiferids from this part of the succession is confined to the publications of Kaasschieter (1961) and Curry (1937).

The distribution of foraminiferids is given in text-fig. 13 and the percentage data for each species are set out in Table 7. Foraminiferids are present at three levels in the succession: during the transition from the Upper Bracklesham to Lower Barton Beds and twice during the Middle Barton Beds. The assemblages fall into five faunal units. Faunule 1A (text-fig. 14) is dominated by *Cibicides pygmeus* (21.6–61.0%), *Cibicides ungerianus* (1.1–16.7%), *Elphidium latidorsatum* (0.8–27.5%), *Globulina gibba* (0.8–31.8%), and *Cibicides tenellus* (0–14.8%). Faunule 2 is very poor in individuals but those present contrast strongly with the other assemblages as they are species of *Cribrostomoides* and *Trochammina*. Faunule 1B is characterized by the presence of *Nummulites prestwichianus* but among the important smaller foraminiferids are *Cibicides pygmeus* (23.8–56.1%), *Cibicides ungerianus* (14.4–31.1%), *Cibicides tenellus* (0–14.7%), *Melonis affine* (4.0–10.9%), and *Buccella propingua* (2.9–9.6%). Faunule 3 is important because of the appearance of *Nummulites rectus*. Smaller foraminiferids are dominated by *Cibicides ungerianus* (3.1–26.6%), *Cibicides pygmeus* (42.0–52.3%), and *Cibicides fortunatus* (0–38%). Foraminiferids are absent from the next 10.7 m before faunule 4 is established with abundant *Cibicides ungerianus* (46.7–70.5%), *Globulina gibba* (2.4–14.8%), *Glandulina laevigata* (1.6–12.3%), *Guttulina rotundata* (1.6–13.7%), and *Nonion laeve* (0–14.8%). Foraminiferids are again absent for the next 10.6 m before faunule 5 appears, dominated by *Cibicides ungerianus* (17.6–79.9%), *Quinqueloculina ludwigi* (0.4–28.0%), *Glandulina laevigata* (1.3–28.9%), and *Globulina gibba* (0.8–17.8%).

The restricted range of the nummulite species is important for fixing the base of and correlating the Lower Barton succession with neighbouring localities (see also Curry 1937, pl. 19). The agglutinated species, though only represented by eight individuals, mark an important level. The range of *Cibicides tenellus* appears to pick out the base of the Barton Beds. Within the Barton succession, the restricted ranges of *Glandulina aequalis* and *Quinqueloculina bicarinata* to the top of the Middle Barton Beds are of note. Otherwise, the Barton assemblages are characterized by the association of species present in the faunules but this does not mean that they are all restricted to the Barton Beds. Additional forms include *Globigerina angustum-bilicata* and *Protelphidium* sp. 1.

An interesting datum is the change in dominance between *Cibicides pygmeus* and *Cibicides ungerianus* (see text-fig. 14, column 7). From the time of the appearance of foraminiferids in the Upper Bracklesham Beds to the top of faunule 3 (top limit of *Nummulites rectus*), *Cibicides pygmeus* is dominant. Above this level, the situation reverses and *Cibicides ungerianus* becomes the important form.

General features of the assemblages. The similarity indices are plotted in text-fig. 14, column 1. In general they do not vary a great deal. This is because of the continual dominance of *Cibicides* species through all the faunules. The divisions between faunules are chosen on the appearance of other distinctive species, e.g. *Quinqueloculina ludwigi* in faunule 5, and not on the bulk change in the fauna. The two dominant species of *Cibicides* themselves provide a similarity index between 20–60%, before the addition of accessory species. The low similarity index between faunules 3 and 4 is due to a change in the dominance of the two *Cibicides* species. The similarity indices indicate a continual dominance by a few species, with changes occurring in the distribution of the accessory species.

The values of the diversity index α are plotted in text-fig. 14. The majority fall in the range $\alpha = 2-5\frac{1}{2}$. It can be seen that the α values from the top of the Middle Barton Beds are slightly higher than for the rest of the succession.

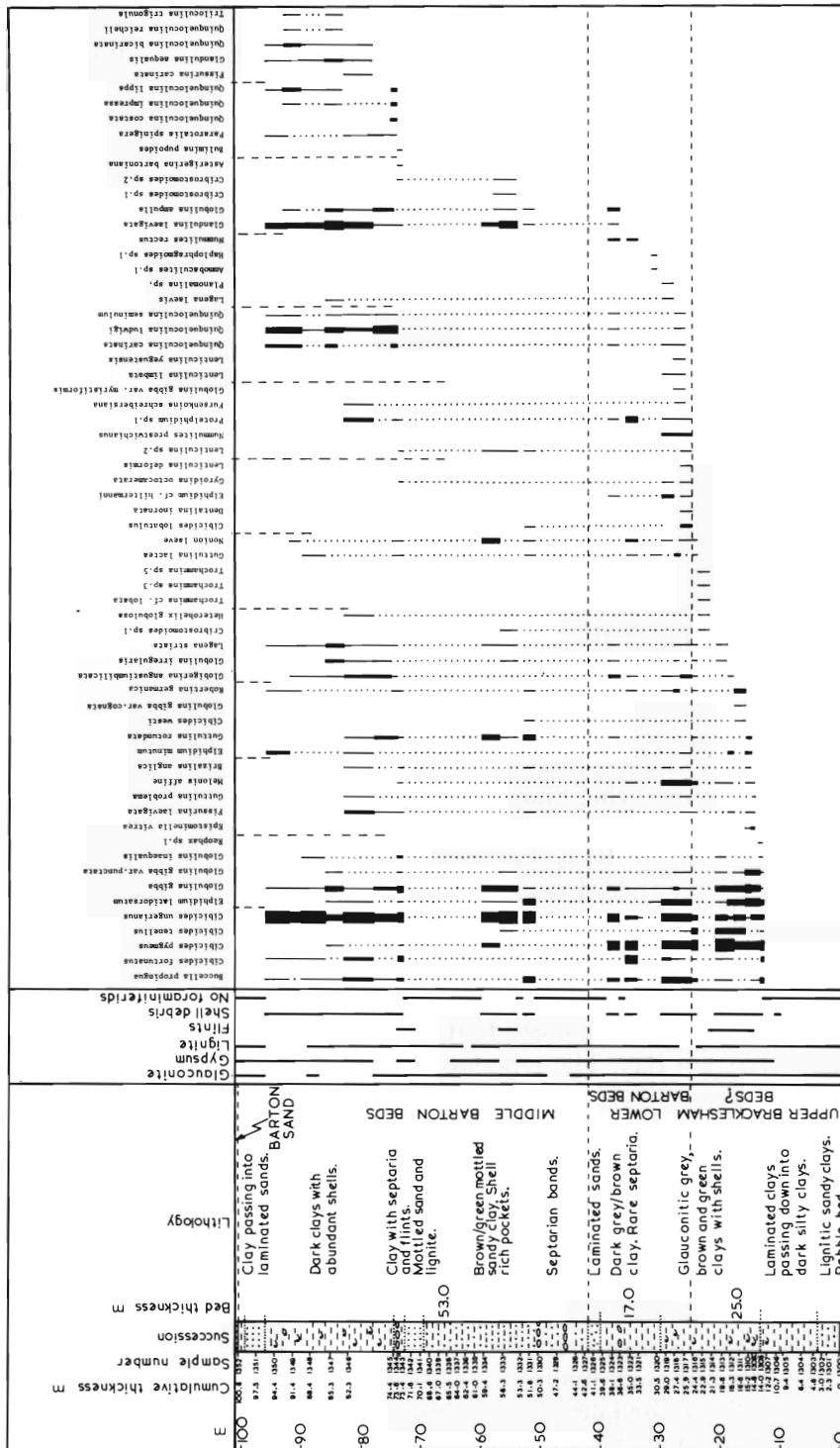
Planktonic foraminiferids are present in many of the samples but never in great numbers. The planktonic-benthic ratio varies from 0 to 0.05. Peaks occur where new benthic species become abundant in the faunules, e.g. species of *Nummulites* in faunules 1B and 3 and *Quinqueloculina ludwigi* in faunule 5. This may be associated with a slight rise in α value.

The percentage dominance data (text-fig. 14, column 5) and the number of species forming 80% (column 6) show generally higher dominance values in the Middle Barton than in the Lower Barton Beds. However, these values are strongly controlled by the abundance of *Cibicides* species. Where the percentage occurrence of *Cibicides* species is greatly reduced, then the dominance values are lowered and an abnormally high number of species is required to form 80%, e.g. sample 1347: total *Cibicides* only 18%, dominance value 28.9% with seven species needed to form 80% of the population. The majority of samples have three or four species which constitute the major bulk of the population.

A triangular plot of the suborders is given in text-fig. 14. The majority of points fall in the Rotaliina corner but six samples show an increase in the content of Miliolina. Plotted against the succession (text-fig. 14, column 6), these six samples all occur at the top of the Middle Barton Beds and it is this increase in Miliolina which characterizes faunule 5. All other samples are dominated by Rotaliina except for faunule 2 with its eight Textulariina individuals.

Interpretation. The foraminiferid assemblages yield a diversity range of $\alpha = 2-5\frac{1}{2}$. Such a range indicates abnormal marine conditions with a hyposaline nearshore shelf environment. Other possibilities (text-fig. 1) include hyposaline marsh and lagoon or hypersaline marsh and lagoon. A comparison of the triangular diagram for the fossil assemblages (text-fig. 14) with that for the recent data (text-fig. 2) provides little conclusive evidence as the samples fall in a field occupied by a host of environments.

Faunules 1A, 1B, 3, and 4 (text-fig. 14) are dominated by species of *Cibicides*, *Buccella*, *Elphidium*, *Glandulina*, *Globulina*, *Guttulina*, *Melonis*, and *Nonion*. How-



TEXT-FIG. 13. Distribution chart of the foraminiferids from the Upper Bracklesham Beds and Barton Clay, Alum Bay.

ever, in each case, *Cibicides* forms the major part of the fauna. All the genera are typical shelf forms living on a fine substrate in turbid water of 0–100 m depth. The low diversity values suggest that the water was slightly hyposaline (32–33‰). Planktonic individuals are represented in most of the samples but as discussed previously, appear to show a slight peak with the appearance of new benthic species and a slightly higher diversity value. This suggests improved communication with the open sea although the environment was restricted for the majority of the time. The continual dominance of *Cibicides* points to a cool-water aspect to the fauna. The absence of miliolids may result from the unsuitable clay substrate and hyposalinity.

The shelf regime is interrupted at three levels:

(i) Just below the *prestwichianus* horizon, faunule 2 is composed of simple agglutinated species of *Cribostrumoides* and *Trochammina*. Such an assemblage is thought to represent a tidal hyposaline marsh environment.

(ii) In the Lower and Middle Barton Beds there are two horizons which are devoid of foraminiferids. The sediments include laminated sands and clays and mottled sands with scattered flints. These appear to result from intertidal conditions developed when the rate of subsidence of the basin was slower than the rate of sediment accumulation.

Finally, faunule 5 is dominated by species of *Cibicides*, *Quinqueloculina*, *Glandulina*, and *Globulina*. Miliolids are abundant for the first time (text-fig. 14, column 6) and may reflect the coarsening of the sediment and an increase in current activity. The latter is expressed as shell-rich drifts and pockets. All the genera are typical shelf species but the abundant miliolids point to a nearshore shelf regime, depth 0–50 m. A sudden burst of planktonic individuals reflects improved water circulation. The water was probably more turbid than in earlier times, muddy and slightly hyposaline (32–33‰).

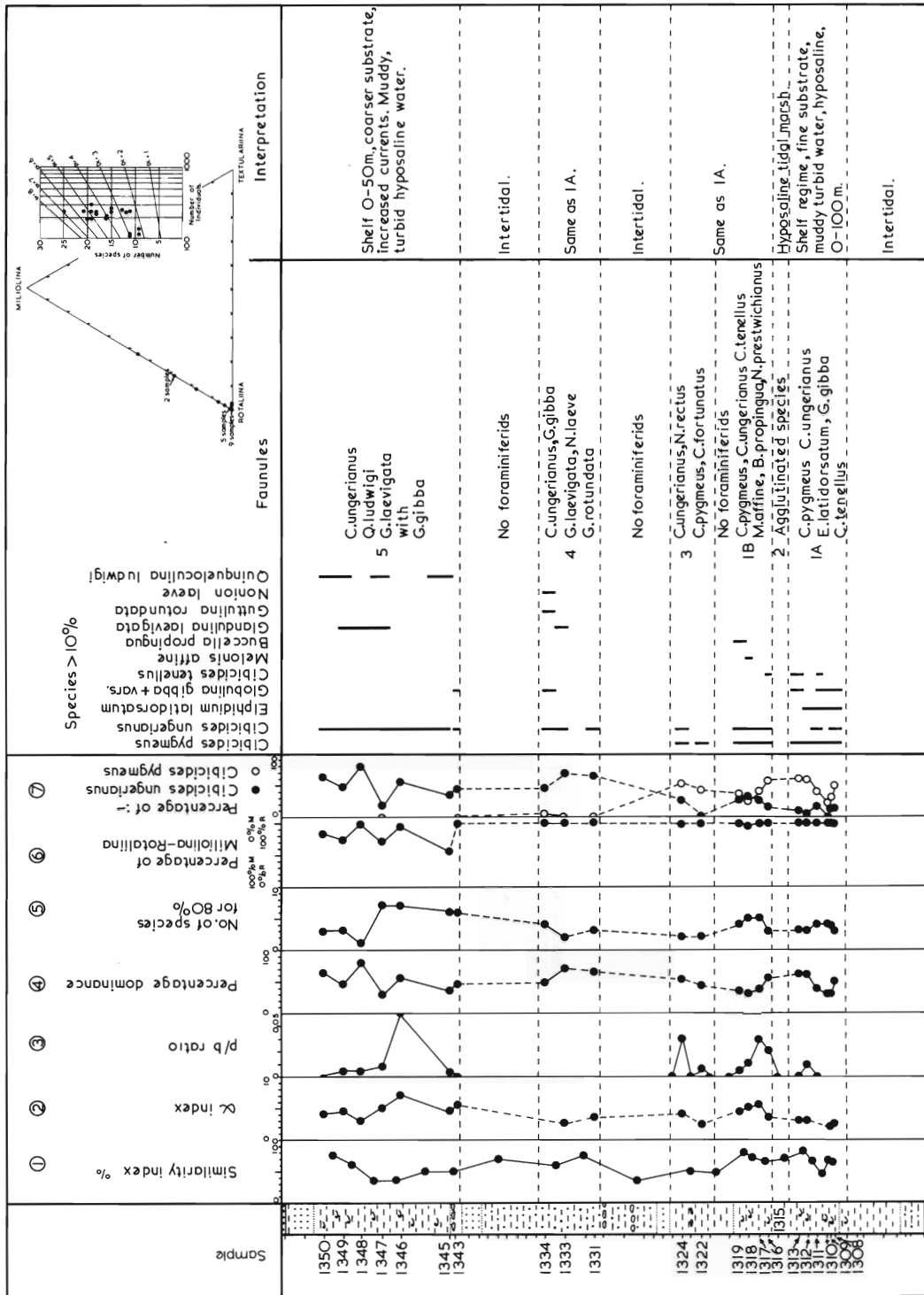
Above the Middle Barton Beds, the foraminiferids die out and the clays pass into the Barton and Headon Sands. These clean sands may result from the tidal accumulation of a bar or spit.

HEADON HILL, ISLE OF WIGHT

Location. The Headon Beds are named after Headon Hill at the west end of the Isle of Wight close to Alum Bay. The type locality is in the cliffs at the west end of the hill (SZ 306859).

Previous stratigraphic work. A comprehensive bibliography on the Headon Beds has recently been published by Edwards (1971). Forbes (1853) first described the Headon Series which he divided into Lower and Upper (brackish and freshwater) and Middle (brackish or marine) representatives. His subdivisions have been followed, with slight modification, by subsequent workers, e.g. Bristow, Reid and Strahan (1889) and White (1921).

Succession. The section measured for this study in 1967 closely resembles that observed by Forbes although many landslips must have altered the exposures since then. Forbes recorded a thickness for the Middle Headon Beds of $33\frac{1}{4}$ feet (10.3 m), and Bhatia (1955) $30\frac{1}{2}$ feet (9.3 m), compared with 10.8 m recorded here.



TEXT-FIG. 14. General features of the foraminiferal assemblages and their interpretation, Upper Bracklesham Beds and Barton Clay, Alum Bay.

in most samples and the number of species required to make 80% of each assemblage is only 1–4. The Textulariina are scarcely represented. Overall, the Rotaliina are dominant.

All the abundant species are extremely small (< 0.03 mm in length or diameter). *Quinqueloculina reicheli* and *Pararotalia curryi* are represented mainly by juveniles. The assemblages are of two main types, (a) *Rosalina araucana*–*Quinqueloculina reicheli*, and (b) *Protelphidium* cf. *P. roemeri*, dominant. Faunules 1, 3, and 5 are of type (a) and 2 and 4 of type (b).

Interpretation. The low diversity indicates an abnormal environment. However, the presence of Miliolina in abundances of up to 60% suggests that salinities were sometimes close to normal. The very small size and the abundance of juveniles indicates unfavourable conditions or transport of small individuals.

The lack of foraminiferids in the *Neritina* Bed suggests that it is non-marine. The *Venus* Bed marks the introduction of salt water into the area. The foraminiferids show a cyclic distribution from the *Rosalina araucana*–*Quinqueloculina reicheli* assemblage (faunule 1) to that of *Protelphidium* cf. *P. roemeri* (faunule 2), and then back to the *R. araucana*–*Q. reicheli* assemblage (faunule 3). The same cycle is repeated in the upper clays and basal Upper Headon Beds with the absence of *Pararotalia curryi*. The cycles may represent the transition from intertidal zone where conditions were normal marine or even slightly hypersaline, perhaps due to evaporation, and the assemblage was rich in Miliolina, to subtidal hyposaline lagoon with the *Protelphidium* cf. *P. roemeri* assemblages.

Reworking of older deposits is seen in the intertidal parts of the cycles; fragments of limestone, possibly from the Lower Headon Beds, are present in samples 1377, 1376, 1371, 1370, and 1369. The limestone must have been sufficiently lithified to be reworked and it must have been exposed at the surface. Derived Upper Cretaceous microfossils are present in faunule 2. Daley and Edwards (1971) have postulated the existence of a Palaeogene fold south-west of the Needles (their 'south-western' anticline). This might already have been active in Middle Headon times and provided a source of these reworked materials.

Bhatia (1957) interpreted the palaeoecology thus: '... initially deposited under shallow marine conditions at depths less than 50 fathoms. During the deposition of the lower part of the middle Headon Beds, however, the rapidly shallowing sea gave place to lagoonal or brackish-water conditions, as shown by the abundance of brackish-water fossils.'

The species names used in this study differ substantially from those used by Bhatia (1955, 1957). The distribution of individual species is very different in the two studies. Bhatia recorded foraminiferids from the lower part of the *Neritina* Bed and found the main arrival of foraminiferids in the top of the *Neritina* Bed rather than in the *Venus* Bed. Most of his assemblages are *Pararotalia curryi*–*Protelphidium* cf. *P. roemeri* dominant (*Rotalia viennensis*–*Nonion depressulum* of Bhatia). He did not record any assemblage corresponding with the *Rosalina araucana*–*Quinqueloculina reicheli* faunule of this study. Thus the cyclic repetition of faunules is not apparent from his data. However, the section he measured was at the north-east corner of Headon Hill where the beds show more affinity with those of Colwell Bay.

COLWELL BAY, ISLE OF WIGHT

Location. The section was measured in the cliffs north of the pier and beach huts (SU 329881).

Previous stratigraphic work. The section was described in detail by Forbes and Bristow

(see Bristow, Reid and Strahan 1889). The present study follows the boundaries proposed by them for the Lower, Middle, and Upper Headon Beds.

Succession. The succession measured in March 1970 is shown in text-fig. 16. The lower part of the Middle Headon Beds equivalent to the *Neritina* Bed on Headon Hill was obscured although the How Ledge Limestone at the top of the Lower Headon Beds was well exposed. Slightly more than 3 m of the *Venus* Bed were exposed. Above, the succession consists of clays and sands.

Distribution of foraminiferids. The How Ledge Limestone at the top of the Lower Headon Beds is barren of foraminiferids as it is at Headon Hill. A *Protelphidium* cf. *P. roemeri*-*Protelphidium* sp. 4 faunule is present throughout the exposed *Venus* Bed and continues into the overlying 1.8 m of dark clays. In the pale-green clayey sands above this *Quinqueloculina impressa* is the dominant species together with *Q. reicheli*. The remainder of the Middle and the lower part of the Upper Headon Beds proved to be barren (see Table 9).

General features of the assemblages. The diversity values range from $\alpha = < 1$ to 3. Faunule 1 is almost 100% *Rotaliina* (text-fig. 16) whereas faunule 2 has 84% *Miliolina*. Derived Cretaceous foraminiferids are commonly associated with faunule 1.

Interpretation. The low diversity values suggest an abnormal environment. In faunule 1 the dominance of *Protelphidium* and the near absence of *Miliolina* suggests a hyposaline environment such as a lagoon or estuary. By analogy with modern examples, e.g. Christchurch Harbour (Murray 1968), the water would have been just subtidal and very shallow.

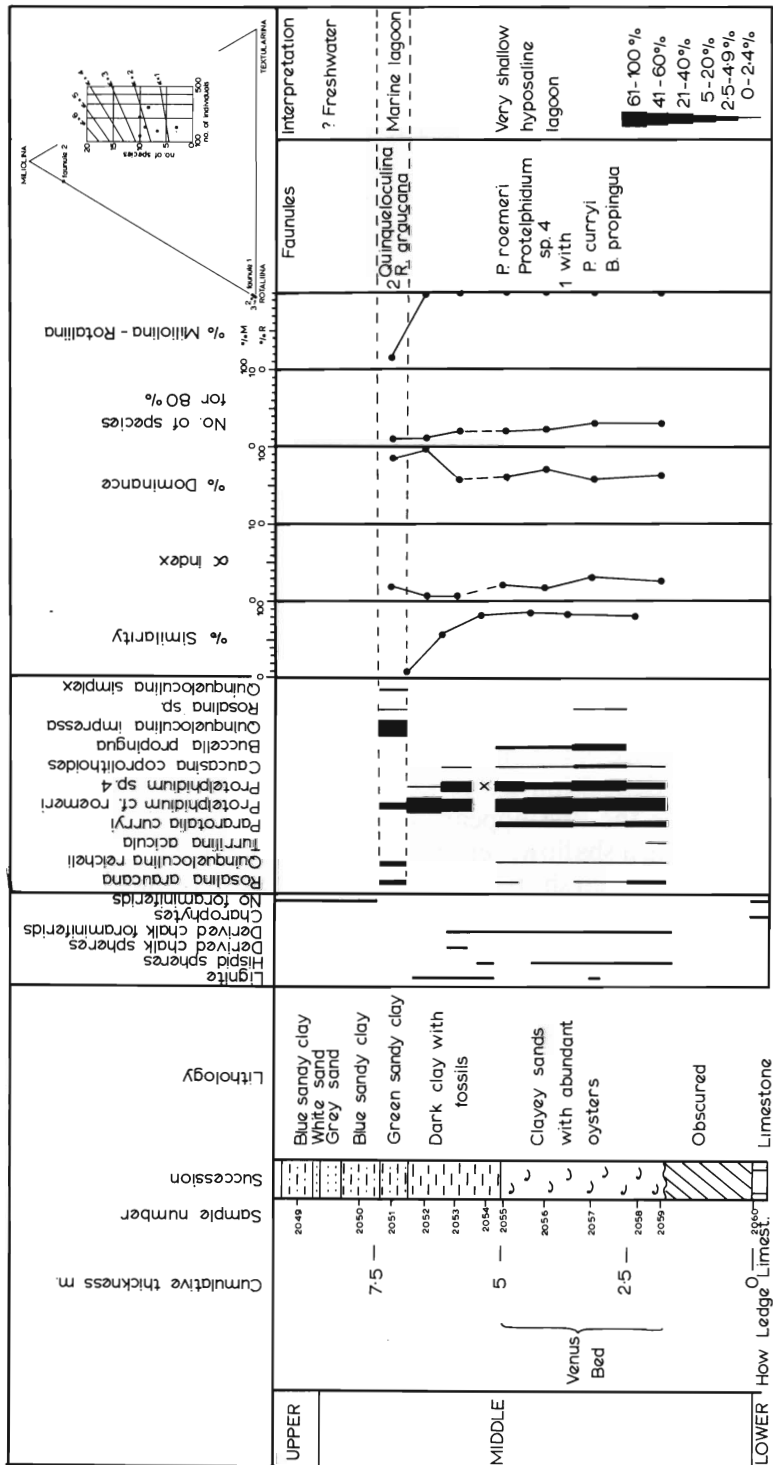
The presence of large *Quinqueloculina impressa* in faunule 2 suggests that salinities were close to normal ($> 32\text{‰}$) and that marine vegetation was available as a substrate on which the foraminiferids lived. It is possible but unlikely that conditions were hypersaline (even though this faunule plots in the field for hypersaline lagoons on the triangular diagram) because following this foraminiferids die out with the return of probably freshwater conditions.

Bhatia (1955, 1957) recorded foraminiferids throughout this section from immediately above the How Ledge Limestone to near the top of the Middle Headon Beds. He found two dominant species, *Pararotalia curryi* and *Protelphidium* cf. *P. roemeri* (= *Rotalia viennensis* and *Nonion depressulum* of Bhatia). In this study *Pararotalia curryi* was found to be present in low abundance. Bhatia also recorded common *Rosalina araucana* (= *Valvulineria araucana*) in the *Venus* Bed. This was also found to be rare in the present study. Apart from these differences, there is some measure of agreement between Bhatia's data and faunule 1. However, he did not find an assemblage equivalent to faunule 2.

HAMSTEAD CLIFF, ISLE OF WIGHT

Location. The Lower Hamstead Beds are exposed on the foreshore at the foot of Hamstead Cliff, Isle of Wight. There are further discontinuous exposures within the landslipped cliff. The Upper Hamstead Beds were visible at the cliff top near the trig. point (SZ 389908) in 1970 at the time of sampling.

Previous stratigraphic work. Forbes (1853, 1856) described these beds as the Hempstead Series and recognized four divisions from top to bottom: *Corbula* Beds, Upper, Middle, and Lower Hempstead Freshwater and Estuary Marls. Bristow, Reid and



TEXT-FIG. 16. Distribution chart of the foraminiferids from the Middle Headon Beds, Colwell Bay.

Strahan (1889) considered the boundaries between these divisions to be gradational. They renamed the deposits the Hamstead Beds and recognized upper 'Marine Beds' and lower 'Freshwater, estuarine and lagoon beds'.

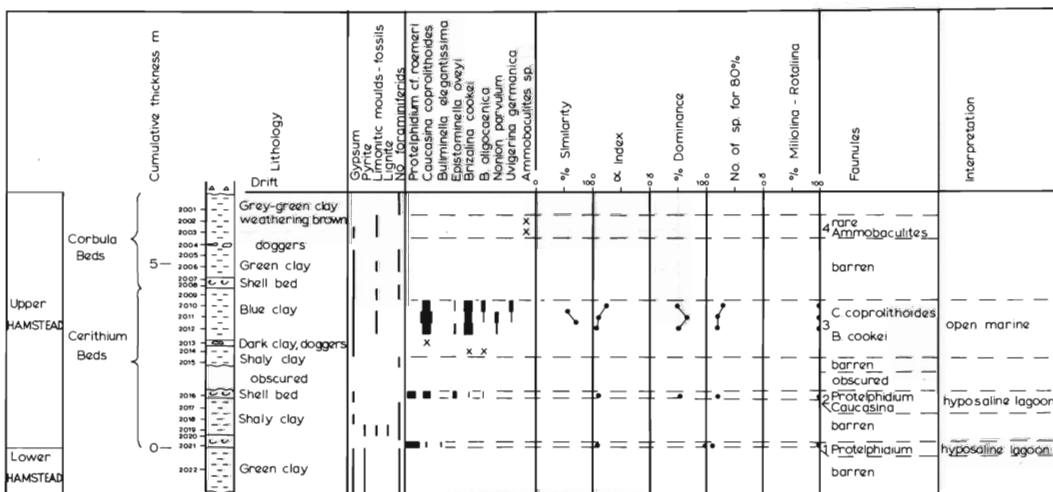
Succession. The main section measured was from the top of the Lower Hamstead Beds through the Upper Hamstead Beds in the cliff top at SZ 389908, text-fig. 17. Additional samples were taken from the Lower Hamstead Beds in the cliff and fore-shore exposures but all were barren of foraminiferids.

Distribution of foraminiferids. Faunule 1, marked by the dominance of *Protelphidium* cf. *P. roemeri*, occurs in a shell bed, with abundant *Polymesoda convexa* (Brongniart) and common *Pirenella monilifera* (Defrance). This is taken to represent the base of the Upper Hamstead Beds (text-fig. 17, Table 10). Following a barren interval of shaly clays, faunule 2, with *Protelphidium* cf. *P. roemeri* and *Caucasina coprolithoides* and with subsidiary *Epistominella oveyi*, is likewise associated with a shell bed with 'Corbula'.

Following an obscured interval there is faunule 3. At the base, foraminiferids are sparse, but above a horizon with doggers *Caucasina coprolithoides* and *Brizalina cookei* are abundant and are accompanied by *Nonion parvulum*, *Uvigerina germanica*, and *Brizalina oligocaenica*. The remainder of the succession is barren except for the rare occurrence of *Ammobaculites* sp. in faunule 4.

General features of the assemblages. The diversity values are very low, ranging from $\alpha = <1$ to 3. Faunules 1-3 are 100% Rotaliina (text-fig. 17).

Interpretation. The absence of foraminiferids from the Lower Hamstead Beds appears to be original, due to deposition under non-marine conditions (Keen 1971). In the Upper Hamstead Beds the first appearance of foraminiferids in faunule 1 can be interpreted as indicating a shallow, very hyposaline lagoonal environment. Colonization of the area may have been short-lived as the overlying shales are barren. Faunule 2



TEXT-FIG. 17. Distribution chart of the foraminiferids from the Hamstead Beds, Hamstead Cliff.

marks a second marine incursion. Again it seems probable that the environment was shallow, hyposaline, and lagoonal. Faunule 3 shows an upward increase in diversity. All the species present are mud-loving forms; the sediment consists almost entirely of mud. Modern *Brizalina* ranges from nearshore to bathyal with salinities of 32–36‰. *Uvigerina* is a normal marine genus characteristic of deeper water but also able to live in shallow muddy environments. It seems probable that faunule 3 is almost open marine and it marks the maximum extent of the Hamstead marine transgression. However, conditions cannot have been very favourable (the diversity is low) and it is likely that the pure muddy sediment excluded some species.

Following this foraminiferids are rare. This may not be an original feature. The upper part of the succession is weathered and gypsum is present in the sediment together with limonitic moulds of macrofossils. It is probable that pyrite has been decomposed to limonite and that the sulphur has combined with calcareous shells to form the gypsum. The occurrence of *Ammobaculites* in faunule 4 may be due to fortuitous preservation.

Bhatia (1955) recorded a similar succession of faunas when allowance is made for differences of nomenclature:

Name used here	Name used by Bhatia
<i>Protelphidium</i> cf. <i>P. roemeri</i>	<i>Nonion depressulum</i>
<i>Caucasina coprolithoides</i>	{ <i>Buliminella carteri</i> <i>Bulimina coprolithoides</i>
<i>Brizalina cookei</i>	{ <i>Bolivina fastigia</i> <i>?Bolivina variabilis</i>
<i>Uvigerina germanica</i>	<i>Angulogerina tenuistriata</i>
<i>Nonion parvulum</i>	<i>Pullenia</i> sp.

However, Bhatia recorded *Ammobaculites agglutinans* from the base of the Upper Hamstead Beds and also recorded some species of *Miliolinella* and *Quinqueloculina*.

BRACKLESHAM BAY, SUSSEX

Location. Bracklesham is situated on the western side of Selsey Bill. A succession of Bracklesham Beds occurs beneath a cover of beach sand and Pleistocene clays but may be studied in isolated exposures on the foreshore between Bracklesham (SZ 808958) and Selsey Bill (SZ 840931). However, the outcrops can only be studied at very low tides when the beach sand is not obscuring them. Other beds may be studied by coring where the cover is not too thick. (Sampled, October 1970.)

Previous stratigraphic work. The section was first described by Dixon (1850) but it was Fisher (1862) who produced the first detailed description of the succession (pp. 74–75). He applied numbers to the major lithological units. He measured the beds in paces along the foreshore and consequently the true thickness is not known. Fisher's description was incorporated into two regional guides on the area; Reid 1897, Bognor) and White (1915, Lymington and Portsmouth). Curry, in Curry and Wisden (1958), produced a guide to the section in which he described the Fisher Beds most likely to be exposed at present, and showed their location on a map (ibid., p. 14).

Blondeau and Pomerol (1968a) noted the small proportion of ubiquitous heavy

minerals in the Bracklesham Clays with a greater abundance of metamorphic constituents, especially garnet. The clays are predominantly montmorillonite. Fisher Bed 2 has yielded a K-Ar age of 49.4 ± 3 m.y. (Odin *et al.* 1969).

Succession. The samples collected are believed to come from the following beds although the discontinuous exposure makes it difficult to establish the stratigraphic succession:

(i) The Barn Bed (Fisher Beds 1-4). Outcrops of Eocene were studied on the fore-shore opposite the old site of the Bracklesham Bay Hotel (SZ 808958). These were composed of dark-green clayey sand with abundant glauconite. (Sample S5.)

(ii) The *Nummulites laevigatus* Bed (Fisher Bed 6). With the help of the map in Curry and Wisden (1958), the position of this bed was located and a sample was recovered using a corer. The sample (S4) is a light-green sand with abundant shells, shell debris, and nummulites.

(iii) Fisher Bed 8? A large outcrop of Eocene was studied at SZ 822950. The strata were composed of dark- to light-green mottled clayey sands with abundant glauconite. Some horizons were rich in shells and shell debris while others contained abundant fossil wood and vertebrate remains. This bed is not indicated on Curry's map but it is thought that it may be Fisher Bed 8. Two samples were taken (S2, S3).

(iv) Brook Bed (Fisher Beds 18-20). A reef of Eocene was studied to the west of the windmill at Selsey Bill (SZ 835935). The outcrops were of a dark-green clay with abundant glauconite, shells, and shell debris. This was considered to be the Brook Bed and two samples were taken (S6, S7).

(v) Fisher Bed 21. Professor D. Curry supplied a large sample of grey-green sandy clay with abundant shells from this level (S1).

Distribution of foraminiferids. Published work on the foraminiferids from this locality is confined to the series of papers by Heron-Allen and Earland (1908-1911) on the recent and reworked fossil foraminiferids recovered from the beach sand at Selsey Bill.

The percentage abundance data are set out in Table 11. The fauna from each sample is described and no attempt has been made to identify faunules because of the small number of samples.

The Barn Bed proved barren but a good fauna was recovered from the *Nummulites laevigatus* Bed. The assemblage is dominated by highly abraded, large specimens of the *Nummulites* after which the bed is named. The smaller foraminiferid fauna is dominated by species of polymorphinids, these making up 64.6% of the population. Dominant species include *Globulina irregularis* (34.6%), *Pyrulina gutta* (9.5%), and *Nonion laeve* (26.7%). Fisher Bed 8 was barren to very poorly fossiliferous with scattered *Nummulites laevigatus* and rare smaller foraminiferids. The Brook Bed in contrast with Fisher Bed 6, has very few polymorphinids, the assemblage being dominated by *Cancris subconicus* (45.5%) and *Melonis affine* (10.1%) in the lower part and *Cibicides lobatulus* (14.6%) and *Fissurina orbignyana* (24.3%) at the top. Other important species include *Discorbis propinqua* (8.9%), *Cibicides productus* (6.7%), *Quinqueloculina juleana* (6.3%), and *Triloculina inflata* (6.3%). Finally, the Fisher Bed 21 assemblage is characterized by an exceptionally large number of species, few of which are important contributors to the total population. Dominant species include *Cibicides lobatulus* (11.8%), *Cibicides productus* (11.1%), *Quinqueloculina juleana* (17.4%), *Discorbis propinqua* (7.4%), and *Triloculina inflata* (7.4%). The species of *Fissurina* form 10.3% of the population. The larger foraminiferids are dominated by *Nummulites variolarius*.

The Fisher Bed 21 assemblage is characterized by many interesting species which are not present at any other level in the English Eocene. They include species of *Articulina*, *Sagrina selseyensis*, *Clavulina parisiensis*, *Dendritina elegans*, *Epistomaria rimosa*, *Epistomaria separans*, *Fasciolites fusiformis*, *Glabratella ubiqua*, *Lamellogorbis margaritifera*, *Linderina brugesii*, *Miliola prisca*, *Nummodiscorbis nucleata*, *Orbitolites complanatus*, *Quinqueloculina hexacostata*, *Quinqueloculina parisiensis*, *Rotalia suessonensis*, *Rotalia*

trochidiformis, *Spirolina cylindracea*, *Spiroloculina carinata*, *Spirophthalmidium alatum*, *Triloculina propinqua*, and *Vertebralina laevigata*. This assemblage is specially significant both from a stratigraphic and ecological point of view.

General features of the assemblages. The similarity indices are low owing to the large sampling interval. However, near the top of the succession, between samples S1 and S7, the value reaches 53.9%. This indicates the similarity in the dominant species even though the accessory ones change a great deal.

The values for diversity index α are fairly high ($5-6\frac{1}{2}$) but in Fisher Bed 21 it increases to $\alpha = 27$. This is nearly three times greater than any other α value recorded from the English Eocene.

The percentage dominance data reflect the trend in α index. In Fisher Beds 18-20 the dominance values are 23.4-45.5% but drop to 17.4% in Bed 21. In Fisher Beds 18-20 seven to eight species form 80% of the population while in Bed 21, this figure has risen to seventeen.

There is a virtual absence of Textulariina and there is a steady increase in Miliolina up the section; in Fisher Bed 6, 0.4% Miliolina are present but in the top sample this figure has risen to 35.45%.

Interpretation. Four assemblages yielded the requisite number of foraminiferids needed to calculate a diversity value. The range is $\alpha = 5-6\frac{1}{2}$ with one sample producing a value of $\alpha = 27$. By comparison with the recent diversity data (text-fig. 1), the majority of assemblages fall just within the field of normal saline shelf seas. However, their marginal position suggests a slightly abnormal marine influence. The value of 27 necessitates fully marine conditions of normal salinity. No value as high as this has yet been found in a living assemblage.

The assemblage from the *Nummulites laevigatus* Bed is dominated by species of *Nonion* and polymorphinids. The latter are rarely abundant in living assemblages but they are typically shelf species. Abundant Nonionidae suggest a shallow shelf regime of 0.50 m depth.

The mottled-green clays of Fisher Bed 8 contain rare foraminiferids mixed with vertebrate remains and wood fragments. This assemblage points to a possible intertidal situation.

The Brook Bed yielded an assemblage dominated by *Melonis* and *Cancris* together with *Fissurina* and *Cibicides*. All are typical shelf genera being common at present in the English Channel and its Western Approaches (Murray 1970, 1971). Abundant examples of *Cancris* and *Melonis* (cf. *Nonion parkeri*) have been recorded from the fine clays off Finistère (Bouysse and Le Calvez 1967). However, it has been noted that these forms are less common in the bioclastic sediments of the western Channel (Le Calvez and Boillot 1967). Therefore, the fossil assemblage may be interpreted as indicating a shelf situation with a fine sediment substrate in water of moderate depth, 20-50 m. The depth cannot be defined with any accuracy because if the sediment was fine enough, this assemblage could survive in quite shallow water.

Fisher Bed 21 assemblage is dominated by species of *Cibicides* and *Discorbis* with *Quinqueloculina* and *Triloculina* showing a marked increase, as does the general diversity.

The fauna contains genera which are ecologically distinctive. These include species

of *Articulina*, *Spirolina*, *Dendritina*, *Fasciolites*, *Vertebralina*, and *Orbitolites*. All make their only appearance in the English Eocene assemblages at this one level. They are indicative of shallow, normal marine to hypersaline water of moderate temperature in which seagrass and seaweed grow (Wright and Murray 1972). The appearance of *Discorbis* and *Glabratella* suggests a similar environmental picture. This assemblage appears to have a much warmer-water aspect than the other Eocene faunas. In fact Curry (1965) suggested that the environmental picture evoked was that of the present-day seagrass meadows of the Mediterranean. It is true that many of the genera listed above thrive in such an environment, but a comparison of the bulk composition of the fossil Eocene and recent Mediterranean assemblages (Blanc-Vernet 1969) shows certain obvious differences:

(a) In the Mediterranean, the miliolids show a high diversity with over forty species present. In the Fisher Bed 21 assemblage, only seventeen species have been recorded and many of these are only single individuals.

(b) The discorbids and peneroplids are far more abundant in the Recent assemblages.

(c) The species of *Cibicides* and *Fissurina* are too abundant in the Eocene assemblage.

(d) The 'Mediterranean indicators' are often small, juvenile forms. The specimens of *Discorbis propinqua* are much smaller than their French counterparts while *Spirolina cylindracea* is represented by very small examples. Such a feature may suggest that these forms are living near their environmental limit.

Therefore it appears that the Fisher Bed 21 assemblage is not a true Mediterranean fauna but an attempt by warmer-water species to colonize an area which is only barely ecologically suitable. Many of the foraminiferids suggest the presence of extensive growths of seagrass. Such a flora necessitates clear shallow water in contrast to the turbid, muddy conditions which appear to be prevalent during the remainder of the Eocene. Such a change in sedimentation indicates that detritus was accumulating at a much slower rate and as a result, the high diversity value of the foraminiferid assemblage reflects the lack of diluting sediment. Therefore, it would appear that the top of the Bracklesham Beds at this locality is represented by a slightly condensed sequence. With the reduction of fluvial influences, the water attained normal salinity for a short period. This permitted the colonization by discorbids, large miliolids, peneroplids, etc., which had been previously barred by the turbid, muddy, somewhat hyposaline water. As the salinity and life habitats were favourable, the question arises as to why these southern species did not flourish. For continued survival, these forms require summer temperatures of around 22 °C (Wright and Murray 1972). The assemblages may have resulted from the addition of southern forms during the summer months and a temperature of around 18 °C can be envisaged. Even so, this represents a warming of the Eocene sea during the Bracklesham period. It also appears that many of these forms need hypersaline conditions, so perhaps the salinity was still not high enough. The assemblages as a whole indicate shallow conditions, the depth range suggested being 0–30 m.

The brief appearance of these southern species may be explained by a recent analogue. The Rhône Delta, bordering the Mediterranean, provides an environmental barrier to the peneroplids because of the hyposaline water and reduced temperature. The Rhône has changed its outlet position on several occasions during its

history. Such a change results in the movement of the faunal boundary. During the Eocene, a change in the outlet of the river may have been sufficient to alter the position of the faunal boundary, allowing the incursion of these southern forms.

According to Curry (1965), 'The Bracklesham Beds have yielded a rich molluscan fauna of about 500 species'. Thirty new genera appear, such as *Chama*, *Arca*, *Spondylus*, and *Plicatula* which are attached forms in shallow clear water. Other genera such as *Conus*, *Mitra*, *Oliva*, and *Marginella* are all subtropical or tropical species in shallow water of 0–55 m. The cold-water forms which were present in the London Clay have now disappeared. Curry (*in* Curry and Wisden 1958) states that the base of Fisher Bed 21 contains abundant *Tellina* spp. Modern examples of *Tellina*, around the coasts of Britain, abound in shallow water and live in a range of 0–55 m. They are particularly abundant near low-water mark between 5.5 and 14.6 m (*Tellina fabula* Gmelin).

The information gained from the molluscs appears to agree with the interpretation based on the foraminiferids. They reflect a general warming of conditions and also the shallow depths envisaged. Curry (1965, p. 165) noted that Fisher Beds 21 and 22 contain a rich fauna of 'attached polyzoa and rock- and seaweed-haunting small molluscs, which are rare or absent at other horizons'.

BARTON AND HORDLE, HANTS

Location. The cliff section from Mudeford to Milford-on-Sea, including Barton, is the type locality for the Barton Beds. Also exposed are Upper Bracklesham Beds beneath and Lower and Middle Headon Beds above. The dip of the strata is less than 5° to the east. The section was visited during September 1968 at which time slumping and cliff protection work had obscured much of the section at Highcliff-on-Sea. As a result, the complete succession was not accessible. The section was compiled from four vertical traverses at different points along the cliff. Highcliff Castle (SZ 190923) and Chewton Bunny (SZ 218931) provide sections in the Upper Bracklesham and Lower Barton Beds. West of Barton-on-Sea (SZ 230930) there is a section in the Middle Barton Beds while beneath the golf course, to the east of the town (SZ 250927), the succession is completed by the Upper Barton and Lower Headon Beds.

Previous stratigraphical work. Prestwich (1847a) chose Barton as the type locality for his new formation, the Barton Beds. Wright (1853) produced the first measured section, assigning bed numbers to the major lithological units. Fisher (1862) and Keeping (1887) suggested that the base should be fixed at the *Nummulites prestwichianus* band. Gardner, Keeping and Monckton (1888) published a profile section in which they subdivided the series into Lower, Middle, and Upper Barton Beds. This section was incorporated into the Geological Survey Memoir for the Bournemouth area (Reid 1898). The most detailed work was undertaken by Burton (1929, 1933) who subdivided the succession into fourteen divisions, using a letter code. The section was redescribed by Curry (*in* Curry and Wisden 1958) who suggested that the base of the Barton Beds should be placed at the pebble bed beneath the *Nummulite* band, this being an easily observable feature and a more obvious natural break. This was the base defined by Prestwich in his original type section.

Succession. The section measured and sampled is given in text-fig. 18 with cross-reference to the Burton nomenclature.

The top Bracklesham Beds are white sands with lenses of lignitic material. Then follows a pebble bed of rounded flints in a clay matrix. Resting on this are deep green glauconitic sands which weather to an olive and brown colour. The Lower Barton Beds (A-B) are green sandy clays (A1) and clays (A2) passing up into grey sandy clays with lenses of sand or shell material (A3). The glauconitic clays show signs of bioturbation and are characterized by their varied and well-preserved mollusc fauna. Glauconite grains from Bed A1 have given K-Ar date of 42 ± 2 m.y. (Odin *et al.* 1969).

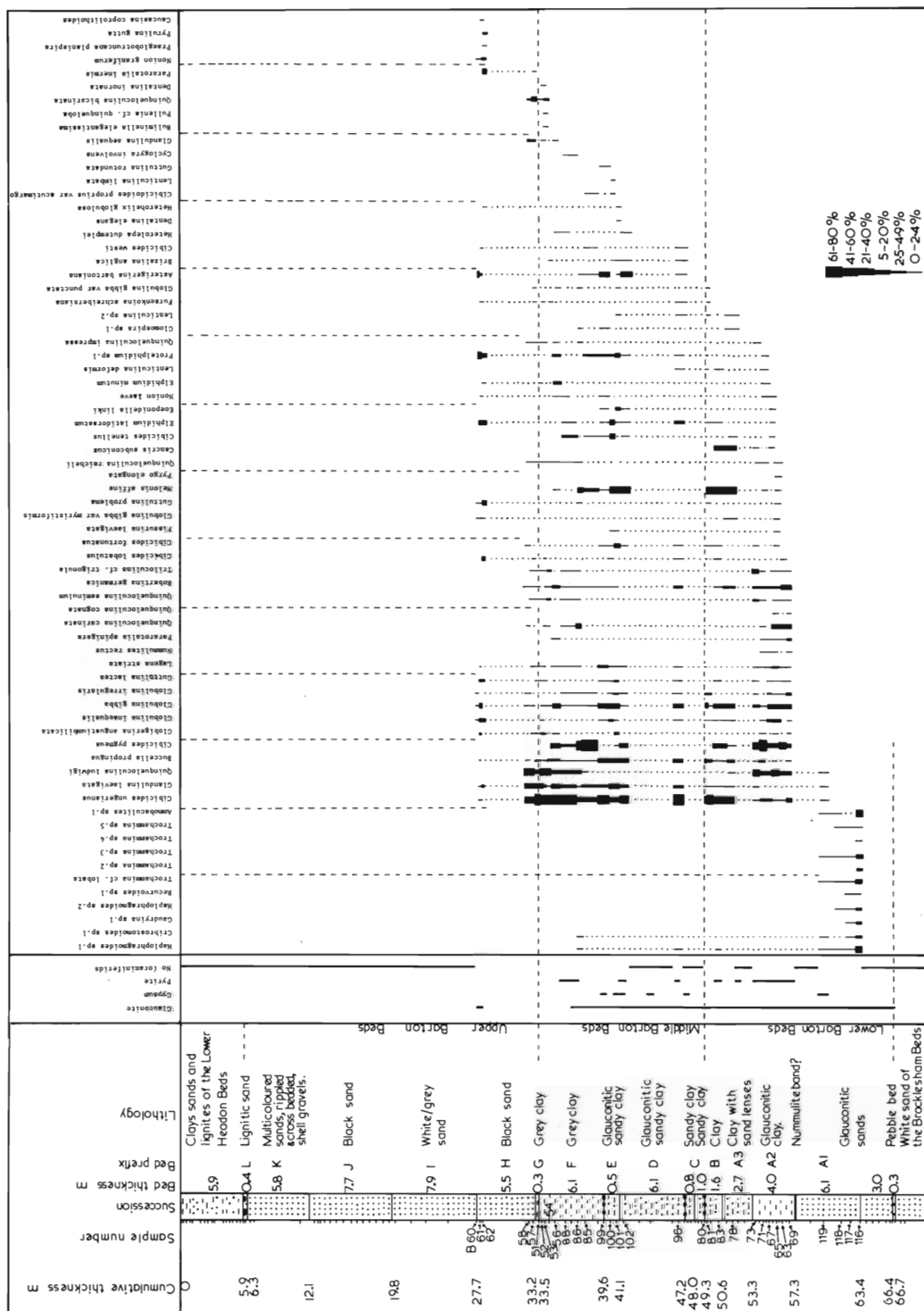
The Middle Barton Beds (C-F) are glauconitic sandy clays (C, D, and E), occasionally weathered to a rusty brown, passing up into a stiff grey clay with abundant shells and shell debris (F). The main occurrence of glauconite finishes above Bed E.

The base of the Upper Barton Beds is marked by a band of hard clay packed with shell debris, called the Hard Band (G). Above is the Chama Bed (H), a blue-grey sandy clay which decreases in clay content towards the top. The bed abounds in examples of *Chama squamosa* from which it takes its name. This is followed by a large thickness of sand; white/grey sands (I), black muddy fine sands (J), and multi-coloured, rippled, and cross-bedded sands with concentrations of gastropods into shell gravels (K). Bed J shows some lateral variation passing into white sands with mottled clays and lignites and then to yellow sands when traced westwards. The Barton succession is completed by a thin band of lignitic clay (L). The section continues into thin beds of clay, sand, or lignite which form the Lower Headon Beds.

The mineralogy of the Barton Clays is montmorillonite, illite, and kaolin with lesser quantities of chlorite. The Barton Sands have a similar montmorillonite mineralogy (Gilkes 1968). The suggestion of a northern source for the sediment has been made by Blondeau and Pomerol (1968a) from a study of the heavy mineral assemblages.

Distribution of foraminiferids. There is little published work on the Barton foraminiferids. Burton (1929, 1933), Gardner *et al.* (1888), and Fisher (1862) recorded the presence of a band rich in *Nummulites prestwichianus (elegans)* near the base of the Barton sequence. Davis (*in* Burton 1929) identified *Lagena*, *Cornuspira*, *Dentalina*, *Cristellaria*, and *Truncatulina* from the Barton Beds; *Nummulites prestwichianus* and *Nummulites rectus* occur at two separate horizons. Bowen (1955) produced a systematic study of the Barton foraminifera, recording only twenty-two species. This paucity in forms was said to be due to the position of the Barton Beds between the lower Eocene faunules and those of the oncoming Oligocene. Finally, Kaasschieter (1961) collected twenty samples and identified thirty-six species (*ibid.*, Table 7, p. 130). In this present study, 120 samples were collected and sixty-nine species have been identified.

Text-fig. 18 is the range chart for the Barton foraminiferids and text-fig. 19 shows the distribution of faunules. Table 12 gives the percentage distribution of the species. All the sample positions have been marked on the section but only those that yielded foraminiferids are numbered. Where the sampling interval is very close, as in Bed A2, not all the samples have been studied once foraminiferids were proved to be present.



TEXT-FIG. 18. Distribution chart of the foraminiferids from the Barton Clay, Barton-on-Sea.

The beds below A1 are barren. The base of A1 is marked by a band of *Nummulites prestwichianus* which has been observed by other workers. Although the iron-rich clay band was located in the field, no nummulites were recovered. Faunule 1 includes agglutinated foraminiferids recovered from the lower half of A1: *Trochammina* cf. *T. lobata* with species of *Ammobaculites*, *Cribrostomoides*, *Haplophragmoides*, and *Trochammina*.

Faunule 2 equates with Bed A2. It is characterized by an abundance of miliolids as shown in text-fig. 19, column 6. Dominant species include *Globulina gibba* (2.0–17.1%), *Cibicides pygmeus* (7.5–60.1%), *Quinqueloculina ludwigi* (10.4–38.8%), *Quinqueloculina seminulum* (0.4–38.9%), and *Quinqueloculina carinata* (0–17.1%).

Beds A3, B, and the base of C fall into faunule 3A because their assemblages are dominated by species of *Rotaliina* (text-fig. 19, column 6). These include *Globulina gibba* (1.6–13.2%), *Cibicides pygmeus* (0–13.2%), *Cibicides ungerianus* (31.6–55.3%), and *Melonis affine* (26.4–38.4%).

The top of Bed C and the majority of Bed D proved barren but one sample near the base of D yielded faunule 3B which contains 64.2% *Cibicides ungerianus*.

Faunule 3C, which includes Beds E and the base of F, is also dominated by *Rotaliina*. Major species include *Cibicides ungerianus* (17.1–46.4%), *Melonis affine* (0.4–27.9%), *Asterigerina bartoniana* (0–10.8%), *Glandulina laevigata* (2.8–12.7%), and *Buccella propingua* (6.0–13.6%).

Faunule 4, which includes the top of Beds F, G, and the base of H, marks the reappearance of the *Miliolina* (text-fig. 19, column 6). Dominant species are *Quinqueloculina ludwigi* (1.2–27.9%), *Cibicides pygmeus* (0–68.9%), *Cibicides ungerianus* (14.8–61.5%), and *Glandulina laevigata* (0.8–19.9%).

Faunule 5 represents only the top 0.6 m of the *Chama* Bed, the remainder being inaccessible. The assemblages include *Globulina gibba* (6.3–28.6%), *Asterigerina bartoniana* (3.9–21.2%), *Cibicides lobatulus* (0–14.3%), *Globulina inaequalis* (9.1–15.6%), and *Protelphidium* sp. 1 (0–25.8%). The number of foraminiferids recovered was very small. The beds above the *Chama* Bed were found to be devoid of foraminiferids during the main sampling but subsequent sampling yielded a sparse assemblage of pyritized *Ammobaculites* cf. *A. pseudorostratus* and *Trochammina* sp. from 1.6 m below the top of Bed J.

The Middle Headon sand at Milford did not yield foraminiferids.

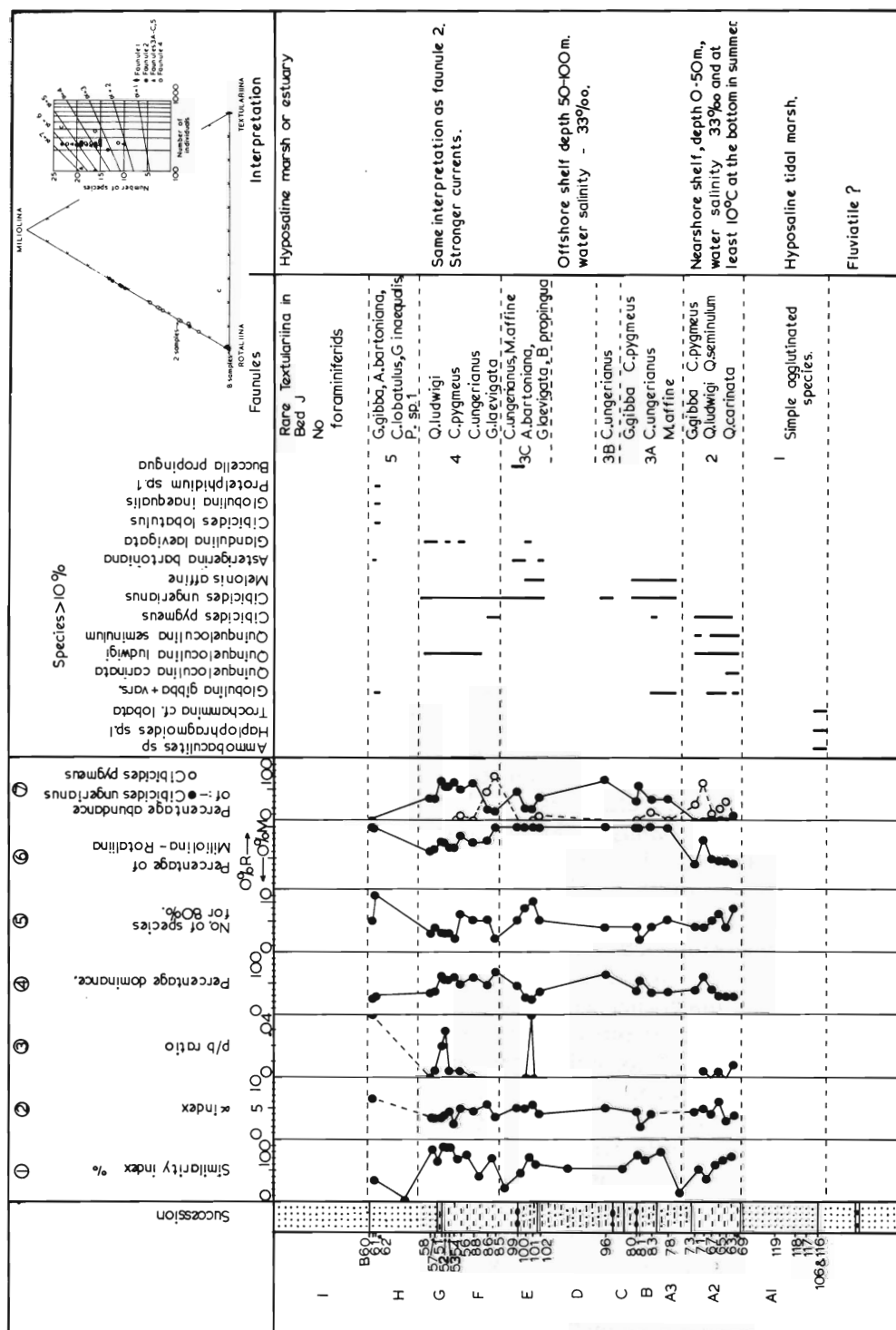
The species which define the faunules also have important ranges. However, the presence of agglutinated species in A1 is of importance for correlation, especially because of their association with the *Nummulites prestwichianus* band. *Nummulites rectus* is found only in Bed A2. *Cancris subconicus* also has a restricted range in the Barton Beds being confined to the lower subdivision. The restricted ranges of *Pararotalia inermis*, *Glandulina aequalis*, and *Quinqueloculina bicarinata* to the top of the Middle Barton Beds may also be important. Certain species characterize, though are not restricted to, the Barton succession: *Cibicides ungerianus*, *Globigerina angustumbilicata*, *Melonis affine*, *Buccella propingua*, *Glandulina laevigata*, *Asterigerina bartoniana*, and *Protelphidium* sp. 1.

Another feature of possible value for correlation is the change in dominance between two species of *Cibicides*. In text-fig. 19, column 7, the percentage abundance of *Cibicides ungerianus* and *Cibicides pygmeus* has been plotted. *Cibicides pygmeus* is dominant in A2 but above this *Cibicides ungerianus* becomes the common form, except for a brief reversal in faunule 6. The change in dominance associated with the upper limit of *Nummulites rectus* distribution may prove an important datum within the Lower Barton Beds.

D. Curry has kindly provided a sample of special interest from Bed E. This has been prepared from the interior of a large gastropod (*Clavilithes*). It has similar dominant species to the surrounding clays of faunule 5: *Melonis affine* (14.5%), *Cibicides ungerianus* (27.8%), *Asterigerina bartoniana* (10.2%), and *Buccella propingua* (7.0%). These values are slightly reduced as the assemblage also contains 22.3% *Textulariina*, the dominant forms being *Trochammina* cf. *T. lobata* (9.9%) and *Karreriella* sp. 1 (7.1%). It is suggested that agglutinated foraminiferids probably made a greater contribution to the Barton assemblages than would be realized from studying a sample at this level. The majority of fragile tests must have disintegrated on burial but because of its specially protected situation, this assemblage has survived (pers. comm. D. Curry).

General features of the assemblages. The boundaries between faunules are clearly picked out by the similarity indices (text-fig. 19, column 1). The diversity index α is in the range 2–6½ for all faunules. There is no marked trend throughout the succession.

Planktonic foraminiferids are extremely rare and are represented by only one species, *Globigerina*



TEXT-FIG. 19. General features of the foraminiferal assemblages and their interpretation, Barton Clay, Barton-on-Sea.

angustumbilicata Bolli (Brönnimann *et al.* 1968). This species occurs in faunules 2, 5, and 6 but the p/b ratio never exceeds 0.04 (4.0% planktonics).

The percentage dominance data and number of species for 80% (text-fig. 19, columns 5 and 6), show a vague trend. Percentage dominance values are low in faunules 2 and 3A but show an increase in faunule 3B. Faunule 3C has low values, the percentage dominance being as low as 27.9% with eight species forming 80% of the population. In contrast, faunule 4 has high dominance values, up to 70%, with only two species needed to form 80% of the total. Finally, faunule 5 has low dominance values.

A triangular plot of the suborders shows that the faunules are clearly separated. Faunule 1 plots in the Textulariina corner but all the remaining faunules are virtually devoid of agglutinated forms. Faunule 2 has a definite field, with one exception, plotting in the range 51.2–59.0% Miliolina. Faunules 3A–C and 5 all plot very near the Rotaliina corner while faunule 4 is characterized by the incursion of Miliolina, the field being 15.2–34.8% Miliolina. The special sample from Bed E occupies a more central position near the base line. The appearance of two miliolid rich faunules is clearly seen in text-fig. 19, column 6. One occurs in the Lower Barton Beds, the other at the top of the Middle Barton Beds.

Interpretation. Below faunule 1 there is a mass of white sand capped by a pebble bed. When traced to the west these deposits pass into current-bedded sands with lenticular masses of shingle, the Boscombe Sands (Curry 1965). These beds have been interpreted as littoral bars and shoals (Gardner *et al.* 1888; White 1917). The lack of internal structure in the sands and the absence of foraminiferids perhaps indicate a fluvial origin.

Faunule 1 is composed entirely of simple agglutinated species, the assemblages plotting at the Textulariina corner (text-fig. 19). Comparison with recent faunas (text-fig. 2) indicates a hyposaline tidal marsh. The assemblage of *Ammobaculites*, *Haplophragmoides*, and *Trochammina* supports this interpretation. The absence of calcareous species may result from solution, a process common in such environments (Murray 1972). The presence of a pyritized band of *Nummulites prestwichianus* at the base of the faunule suggests a current-concentrated assemblage. It has suffered diagenetic modification; calcite solution and pyrite formation. A similar assemblage of agglutinated foraminiferids has been recorded from Hengistbury Head by Chapman (1913). These he interpreted to be of tidal origin in an estuary. With the discovery of *Nummulites prestwichianus* at Hengistbury (Curry 1942), a correlation of the agglutinated faunas is possible suggesting a similar origin for Chapman's assemblage.

Faunules 2–5 have a diversity of $\alpha = 2-6\frac{1}{2}$, with little obvious trend. Environments indicated on text-fig. 1 include hyposaline and nearshore shelf, hyposaline lagoon and marsh, or hypersaline lagoon and marsh.

The triangular plot of faunules 2–5 shows three distinct fields (text-fig. 19); one is located at the Rotaliina corner while the other two are at different regions along the Rotaliina–Miliolina line. From the plot of modern environments (text-fig. 2), the latter assemblages suggest normal marine or hypersaline lagoons while the samples falling at the Rotaliina corner include a full range of environments.

Faunule 2 is dominated by species of *Quinqueloculina*, *Cibicides*, and *Globulina*. The assemblages show little evidence of current reworking, they exhibit a full size range and few specimens are broken. Such an assemblage suggests a shallow shelf regime, the abundance of Miliolina indicating a depth range of 0–50 m. The α values suggest slightly abnormal marine conditions with a salinity of around 33‰. The absence of attached genera suggests a lack of weed growth. The presence of abundant specimens of *Quinqueloculina seminulum* suggests summer bottom temperatures of at least 10 °C (Murray 1971; Jarke 1961), this being necessary for successful repro-

duction. Their abundance also indicates that the water is not below 30‰ salinity (Murray 1968).

Faunule 3 has been subdivided into three parts on the variation of subsidiary species, the similarity values being too high to allow for three separate faunules. The assemblages are dominated by *Rotaliina* (text-fig. 19, column 6). The most abundant groups are species of *Cibicides*, their continual presence producing the high similarity values and suggesting a cool-water aspect to the fauna. Other dominant forms are *Melonis* and *Globulina* at the base and *Melonis*, *Asterigerina*, *Glandulina*, and *Buccella* near the top. All are typical shelf species indicating a depth range of 50–100 m. The α values indicate continuing slightly hyposaline conditions. Percentage dominance values are lowest in 3C, this feature being accompanied by the rare appearance of planktonic species in the Barton assemblages. The sample collected by Professor Curry from this level yielded 22.3% *Textulariina*. As the assemblage was recovered from an extremely protected situation, it suggests that destruction of these fragile forms has taken place in the ordinary assemblages. However, the position of this sample on the triangular plot reinforces the interpretation as it falls more definitely into the shelf field. The presence of species of *Karreriella* and *Cribrostomoides* confirms this interpretation.

Faunule 4 marks a return to miliolid-rich assemblages (text-fig. 19, column 6), dominated by species of *Quinqueloculina*, *Cibicides*, and *Glandulina*. The sediments are well known for their drifts and pockets of shell-rich material, indicating current reworking. The foraminiferids exhibit a full size range, few are broken and the miliolids are distinctive because of their large size. These factors suggest the reworking of a shallow-water assemblage within its environment rather than transport into deeper regions. From the previous discussion, this assemblage suggests shallow shelf, inshore conditions, 0–50 m with slightly hyposaline water. The reappearance of miliolids relates not only to the depth change but also to the increase in currents and the sandier nature of the substrate.

Faunule 5 is dominated by species of *Globulina*, *Asterigerina*, *Protelphidium*, and *Cibicides*. The α values are of little consequence because of the small populations. The contradictory abundance of *Protelphidium* together with *Asterigerina* precludes a definite palaeoecological interpretation. Above this, the sands are barren of foraminiferids except for the agglutinated assemblage in Bed J which indicates a very hyposaline estuarine or marsh environment.

From the previous discussion it can be seen that the Barton Beds at their type locality represent a full marine cycle from continental deposits through marsh, inshore and offshore shelf, and back to shallow-water conditions. The general absence of planktonic species points to little circulation with the open sea and the presence of a barrier to halt free movement of water. The water was at all times slightly hyposaline with a salinity of 33‰ as an estimated figure. The continual abundance of *Cibicides* indicates a general cool-water aspect to the fauna. Although a minimum summer bottom temperature of 10 °C has already been suggested, it is thought that the water temperatures may have been similar to present-day English Channel conditions, that is up to 16–18 °C (Murray 1970).

In a previous interpretation of the Barton succession, Gardner *et al.* (1888) suggested that the deposits were mainly of estuarine character. They concluded that the

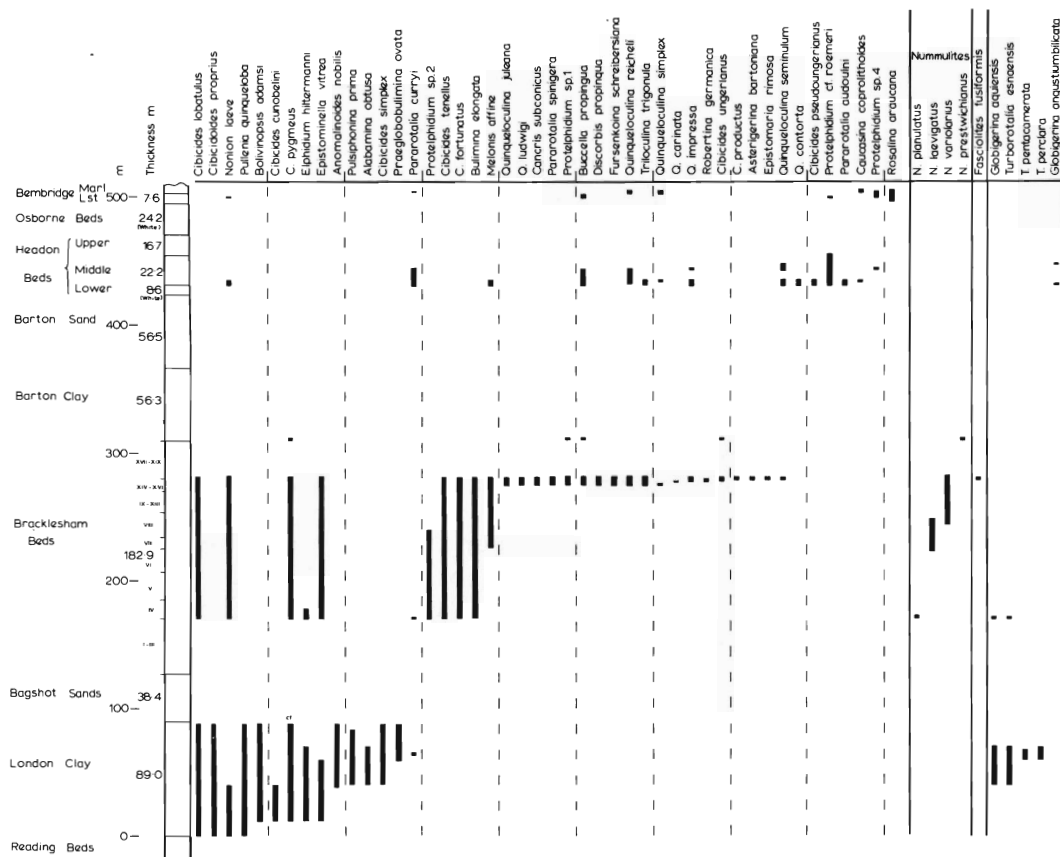
basal sands were in the breakers out to sea while the overlying deposits marked the gradual transition to freshwater conditions. However, the foraminiferid evidence does not agree with this interpretation. The suggestion of a river outlet being present near by may be correct and may account for the slightly hyposaline water conditions.

BIOSTRATIGRAPHY AND CORRELATION WITHIN THE HAMPSHIRE BASIN

The distribution of the majority of smaller benthic foraminiferids, *Nummulites*, and planktonic forms throughout the Whitecliff Bay succession is summarized in text-fig. 20. The smaller benthic foraminiferids show a series of changes each time they enter the succession.

The following forms are found only in the London Clay: *Cibicidoides proprius*, *Pullenia quinqueloba*, *Bolivinopsis adamsi*, *Cibicides cunobelini*, *Anomalinoides nobilis*, *Pulsiphonina prima*, *Alabamina obtusa*, *Praeglobobulimina ovata*, and *Cibicides simplex*.

Species restricted to the Bracklesham Beds (excluding Fisher Beds XI–XVII) are: *Protelphidium* sp. 2, *Cibicides tenellus*, *C. fortunatus*, and *Bulimina elongata*. In Fisher



TEXT-FIG. 20. Summary range chart, Whitecliff Bay.

Beds XV–XVII many new species appear, some of which occur again in the Middle Headon and Bembridge Beds.

Species confined to the Middle Headon Beds are: *Quinqueloculina contorta*, *Cibicides pseudoungerianus*, and *Pararotalia audouini*.

The nummulites and planktonic foraminiferids appear only briefly.

The whole succession reflects the discontinuous existence of marine or near-marine conditions interspersed with non-marine episodes. There must be many small breaks in the succession due to local non-deposition of sediment.

In view of the many small environmental changes recognized by the changes in faunules it would be unwise to attempt to define biozones based on the smaller benthic foraminiferids. The occurrence of nummulites and planktonic foraminiferids may be more reliable. Both groups appear to have more rigid environmental requirements than many of the benthic foraminiferids. The changes necessary to introduce these forms into one part of the basin are likely to permit their occurrence throughout the area synchronously. For example, the removal of a submarine barrier might allow better circulation and communication with the open sea and cause the introduction of planktonic foraminiferids. Such a change would be regional, not local. Thus, the presence of planktonic foraminiferids during a brief interval would provide a stratigraphic datum which could be used for correlation.

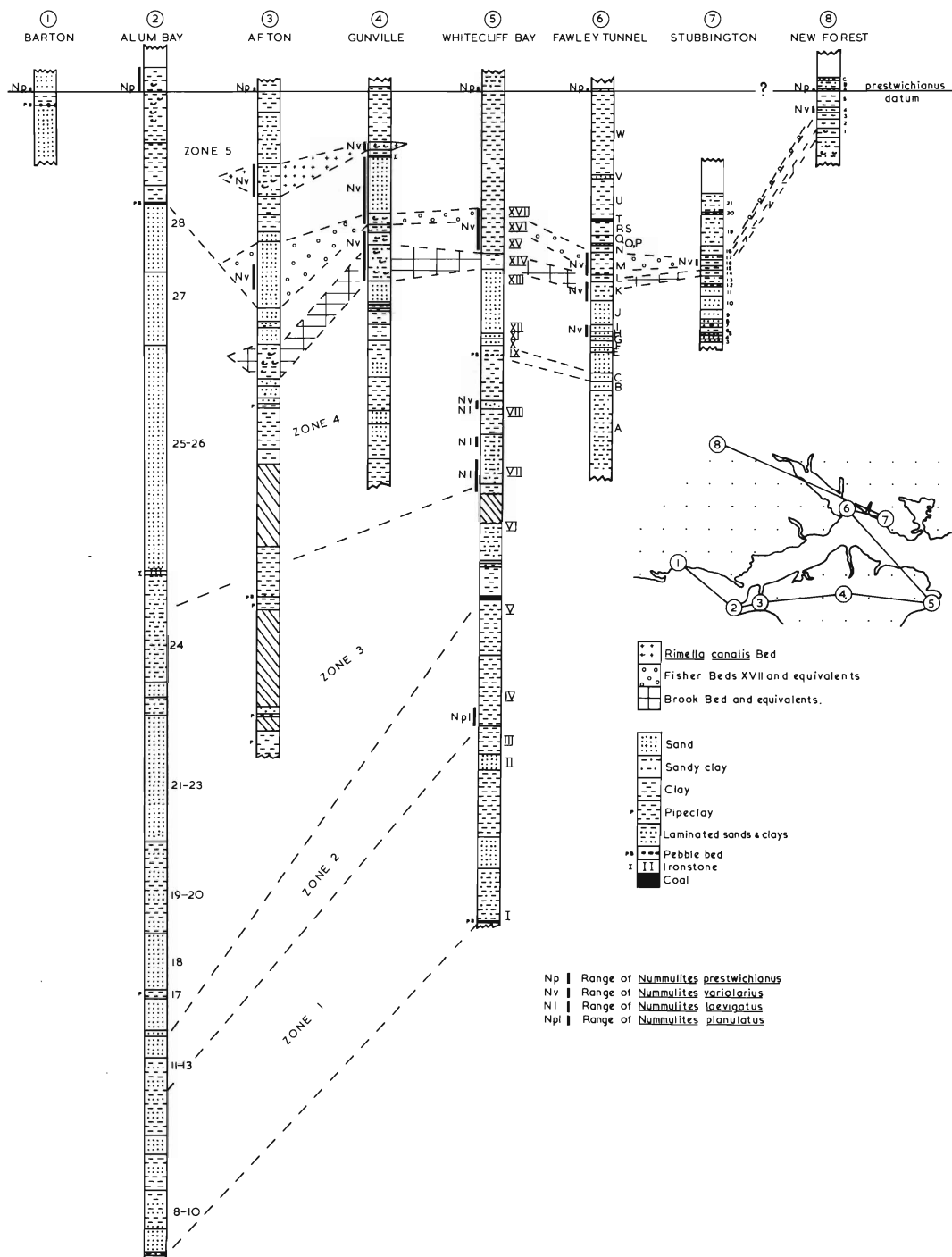
London Clay. Wright (1972) has used the incoming of planktonic foraminiferids in the London Clay as a datum for correlation. At Whitecliff Bay the datum is 41 m above the base. At this level *Cibicides cunobelini* dies out and newly introduced forms include *C. simplex*, *Anomalinoides nobilis*, *Pulsiphonina prima*, *Alabamina obtusa*, *Praeglobulimina ovata*, and *Karreriella danica*. At Alum Bay the datum occurs 21 m above the base. *Cibicides cunobelini* dies out just above the datum while *C. simplex* and *Alabamina obtusa* enter at this level.

Bracklesham Beds. The Bracklesham Beds were subdivided in great detail by Fisher (1862) and short-distance correlation between these different units is possible. However, in this discussion, no attempt is made to correlate every unit. Only important horizons that can be followed across the basin will be dealt with.

The sections have been drawn up in text-fig. 21 using the first appearance of *Nummulites prestwichianus* as an upper datum. The sections utilized are Barton, Alum Bay, and Whitecliff Bay based on work by the author, Afton and Gunville (Curry 1942), the Fawley Tunnel (Curry, Hodson and West 1968), Stubbington (Fisher 1862), and the New Forest localities (Stinton 1970) although the use of the datum at the latter is slightly doubtful (*N. cf. prestwichianus*).

A major advance in correlation has resulted from the work of Eaton (1971). With the aid of microplankton, the sections at Alum Bay and Whitecliff Bay may be directly compared on the basis of five zones:

	Whitecliff Bay	Alum Bay
Zone 5	Beds XVII–XIX (in part)	Beds 28 (in part)–29 (in part)
Zone 4	Beds VII–XVI	Beds 24 (in part)–28 (in part)
Zone 3	Beds V (in part)–VI	Beds 15 (in part)–24 (in part)
Zone 2	Beds IV–V (in part)	Beds 13 (in part)–15 (in part)
Zone 1	Beds I–III	Beds 8–13 (in part)



TEXT-FIG. 21. Correlation of the Bracklesham Bed sections in the Hampshire Basin. (Zones 1-5 are based on Eaton 1971.)

This zonation facilitates the correlation of marine deposits to the east with marginal marine or continental horizons to the west.

The second form of correlation involves the recognition of similar Fisher Bed horizons in the different sections. Although it is referred to here, the Selsey section is not included as no thickness information is available other than an estimate (Curry, Hodson and West 1968).

(i) The first marine horizon at Whitecliff Bay, Bed IV, yields *Nummulites planulatus* and may be correlated with the Cakeham Bed at Selsey.

(ii) Bed VII at Whitecliff Bay yields *Nummulites laevigatus* and may be correlated with a similar fauna from Bed 6 at Selsey.

(iii) The *Campanile* Bed, number 12 at Selsey, may be correlated with Bed C at Fawley and Bed IX at Whitecliff Bay using the mollusc fauna.

(iv) The first horizon which can be traced over a long distance is the Brook Bed. This has been proved at all localities except Alum Bay; Bed XIV at Whitecliff Bay, Bed L at Fawley, Bed 14 at Stubbington, and Beds 18–20 at Selsey.

(v) Another distinctive horizon is Fisher Bed XVII at Whitecliff Bay and Bed 21 at Selsey both of which yield abundant *Nummulites variolarius* accompanied by a distinctive mollusc and foraminiferid fauna. This horizon has been recognized at all localities except Alum Bay.

(vi) At Afton and Gunville, Curry (1942) has distinguished a *Rimella canalis* Bed. This may be correlated with the New Forest section but is not represented at the other localities.

A criticism of these correlations is that they are probably facies controlled. Within a partially closed basin such as the Hampshire Basin, it appears that these facies result from transgressive phases that may be regarded as more or less synchronous. The distribution of *Nummulites* adds weight to this suggestion. A facies correlation over a short distance is the only method available in such a situation.

An important feature is the small thickness of sediment present at the New Forest localities. The succession from the base of the Brook Bed to the first appearance of *Nummulites prestwichianus* is only 10.1 m thick. In the Fawley Tunnel the same sequence is 41.85 m thick, and at Whitecliff Bay it is 39.6 m thick. The section at Stubbington is also reduced.

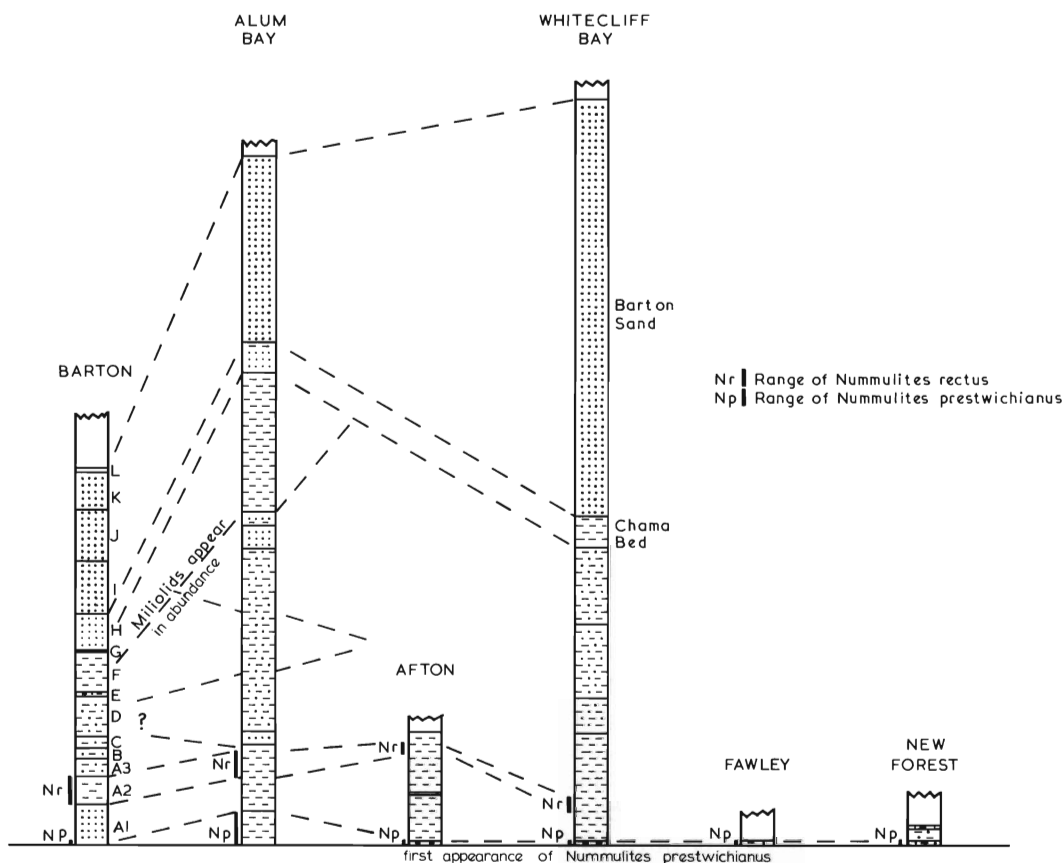
Barton Beds. The Barton Beds of Alum Bay and Barton-on-Sea can be correlated using the lithological and faunal data already presented. However, other sections have been documented in the literature and these are also included: Afton (Curry 1942), Whitecliff Bay (this paper, and White 1921), Fawley Tunnel (Curry, Hodson and West 1968), and the New Forest localities (Stinton 1970) (see text-fig. 22).

The first appearance of *Nummulites prestwichianus* marks the base of the Barton Beds and provides a useful datum. The remainder of the succession has several horizons which may be used for correlation:

(i) In the Lower Barton Beds the appearance of *Nummulites rectus*.

(ii) The Barton Sand is easily distinguishable, occurring between the clays of the Upper Barton and Lower Headon Beds. Although not representing a time unit, the Barton Sand is an easily correlatable facies development.

This leaves the correlation of the Middle Barton Beds. Their relationship is complicated by the lateral transition from truly marine to marginal marine deposits. At Alum Bay two parts of the succession lack foraminiferids and are composed of laminated clays which have already been interpreted as intertidal.



TEXT-FIG. 22. Correlation of the Barton Bed sections in the Hampshire Basin.

The remaining foraminiferid-bearing clays at Alum Bay and Barton may only be tentatively correlated:

(i) An interesting feature is the appearance in abundance of miliolids in the Barton-on-Sea assemblages at the top of Bed F. A similar feature can be seen at Alum Bay and if this level of reappearance is correlated, then the top of F, G, and the bottom of H (6 m) at Barton equate with the top 27 m of the Middle Barton Beds at Alum Bay.

(ii) The open marine fauna of Bed E at Barton may correlate with the short-lived incursion of foraminiferids into the central part of the Middle Barton Beds at Alum Bay.

(iii) The lower of the two marginal marine sectors at Alum Bay may equate with Beds D and C at Barton.

The major features emphasized by this correlation include the marked increase in the Barton Sand to the east of the basin, the large thickness of the Middle Barton Beds at Alum Bay—over three times the thickness at Barton, and the increased thickness of the *Nummulites prestwichianus* Bed at Alum Bay.

Middle Headon Beds. The initial attempts to correlate the very variable deposits of the Headon Beds led to arguments between the Marchioness of Hastings, Judd, and

Tawney and Keeping. A comprehensive list of references on this matter has been given by Edwards (1971). Modern authors have assumed that the marine and hypersaline beds within the Headon Series result from a single marine transgression that commenced with the Brockenhurst Beds (where present) and terminated at the top of the *Venus* Bed or *Meretrix incrassata* Zone of Keeping and Tawney (1881) and White (1915).

From their studies of the Headon Beds throughout the Hampshire Basin Keeping and Tawney (1881) proposed the following subdivisions from top to bottom:

Venus Bed or Headon Hill Zone	
Roydon Zone	} Brockenhurst Beds
Brockenhurst Zone	

The Brockenhurst Zone takes its name from Whitley Ridge railway cutting near Brockenhurst, Hants (SU 318032) where a few inches of shell-sands rest on an irregular surface of Lower Headon Beds. These beds are no longer exposed. The Roydon Zone, named after Roydon brickyard (SU 319004) to the south-east of Brockenhurst, consists of greenish-grey clayey sands, clays with septaria, and further clays with shell beds. About 5.5 m were exposed when Keeping and Tawney described the section. The Roydon Zone was recorded overlying the Brockenhurst Zone at Cutwalk Hill, Lyndhurst. Both zones have been recognized at Whitecliff Bay (Keeping and Tawney 1881; Bhatia 1955, 1957; Stinton 1971).

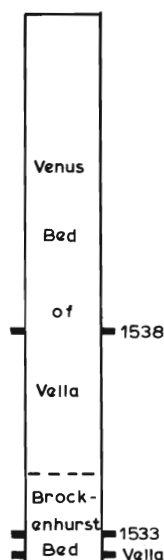
The *Venus* Bed is more widespread in its distribution occurring in the Brockenhurst, Lyndhurst, and Beaulieu regions, and at Headon Hill, Colwell Bay, and Whitecliff Bay on the Isle of Wight.

The only attempt to correlate these beds using foraminiferids is that of Vella (1969). He recorded the occurrence of planktonic foraminiferids, which he called *Globigerina* cf. *augustumbilicata* Bolli, from Whitecliff Bay: near the base of the Brockenhurst Zone and near the base of the Roydon Zone; and from Colwell Bay: near the base of the *Neritina* Bed and near the base of the *Venus* Bed. He therefore correlated the Brockenhurst Zone of Whitecliff Bay with the *Neritina* Bed of Colwell Bay and similarly the Roydon Zone with the *Venus* Bed.

In the present study planktonic foraminiferids have been found in the Brockenhurst Bed at Whitecliff Bay and also in the overlying 'Barren Sands' (sample 1538). They have not been found at Colwell Bay but rare specimens occur at Headon Hill. Text-fig. 23 summarizes these occurrences. The correlations proposed by Vella are less certain in view of the new discoveries of planktonic foraminiferids.

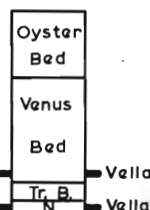
Using the palaeoecological interpretations based on the benthic foraminiferids it is possible to recognize five periods favourable to foraminiferids at Whitecliff Bay. These are separated from one another by barren sediment which may be of non-marine origin (i.e. freshwater or continental). At Colwell Bay there is a single period of continuous foraminiferal record in that part of the succession sampled. At Headon Hill foraminiferids are present in two 'cycles'. Although Bhatia (1955, 1957) also recorded them from the lowest part of the Middle Headon Beds his section was at the north-east corner of Headon Hill and his results resemble those of Colwell Bay. If the first and last appearances of foraminiferids are taken to mark the beginning and end of the transgression it is apparent that there is no obvious correlation based on

WHITECLIFF BAY

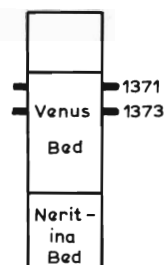


TEXT-FIG. 23. The occurrence of planktonic foraminiferids in the Middle Headon Beds of the Hampshire Basin (some data from Vella 1969; * Vella may have used NE. Headon Hill).

COLWELL BAY *



HEADON HILL

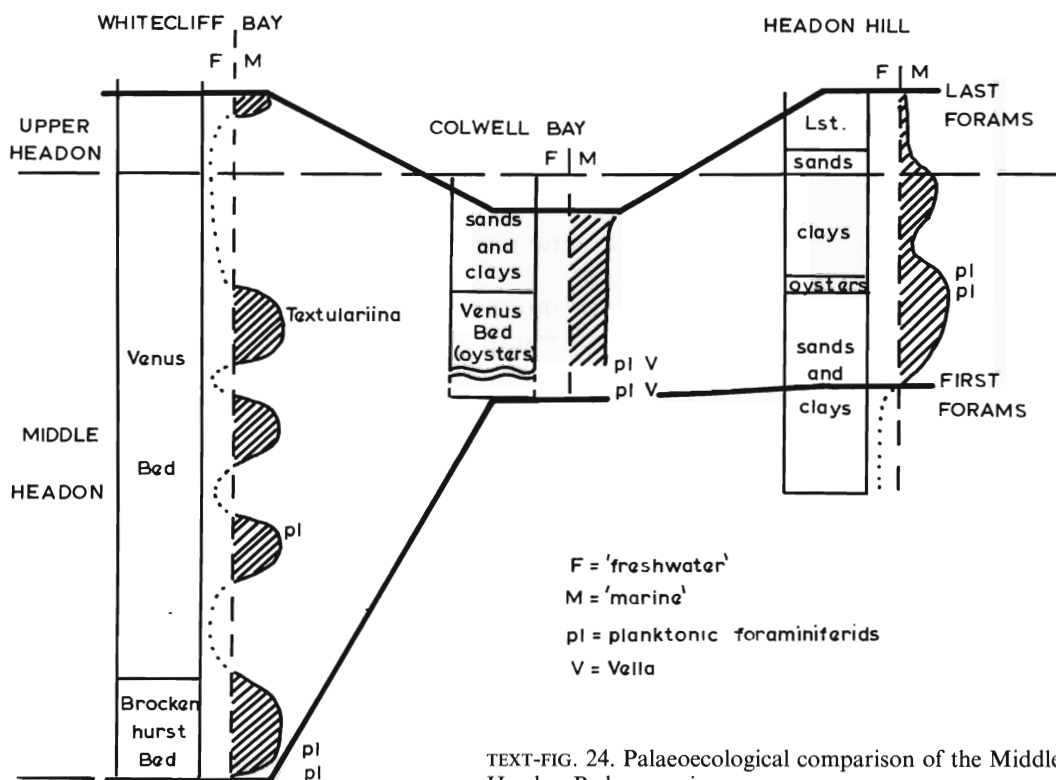


palaeoecology (text-fig. 24). It is interesting to note that foraminiferids occur in the lowest part of the Upper Headon Beds at Whitecliff Bay and at Headon Hill.

Bembridge Beds. At Whitecliff Bay foraminiferids first appear in the Bembridge Limestone and they have a discontinuous occurrence up to the Oyster Bed in the lower part of the Bembridge Marls. At Gurnard, the top of the Bembridge Limestone and the basal part of the Bembridge Marls likewise contain foraminiferids. At Hamstead only the Marls were sampled and these yielded foraminiferids in their lower part. Thus, the Bembridge marine episode started during the deposition of the Bembridge Limestone, reached its maximum in the lower part of the Bembridge Marls, and was followed by non-marine conditions (see Daley 1972a).

PALAEOGEOGRAPHY

At the end of the Cretaceous the sea withdrew from most of Britain. The Chalk became gently deformed and tilted towards the south-east. This was probably associated with the doming and uplift which must have occurred during the separation of Europe and Greenland. It seems likely that the London Basin initially subsided more than the Hampshire Basin as the Thanet transgression came from the east and entered only the London Basin (Hester 1965). Hester also used isopach maps to show that during the time of the Woolwich and Reading Beds, there were two main areas of deposition, the London and Hampshire Basins, at least partially separated by a 'Wealden elevation'. Elsewhere in southern England there is clear evidence of NW.-SE. trending structures which were penecontemporaneous with Mesozoic and Tertiary sedimentation (Donovan 1972). One of the best-known examples is the



TEXT-FIG. 24. Palaeoecological comparison of the Middle Headon Bed succession.

'Mid-Dorset Swell' (Drummond 1970; Kennedy 1970). Drummond (1970, p. 709) wrote: 'The Mid-Dorset Swell clearly had a profound influence upon Vraconian-Cenomanian sedimentation in Wessex, has been intermittently active ever since, and was probably also active during pre-Cretaceous times.'

In south-western England Dearman (1963) has shown the presence of dextral wrench faults having a NW.-SE. or NNW.-SSE. orientation. These are considered to be of Tertiary age. Shearman (1967) has presented additional evidence derived from geomorphological features in support of this contention. He has shown that there is a downthrow to the south-west along the Combe Martin fault. He also makes the important observation that 'The fact that the Combe Martin Valley fault displaced a landform which was not greatly dissimilar from that which exists at the present day, suggests that the general physiography of North Devon had already been rough-hewn by mid-Tertiary times' (ibid., p. 564). The record of movement on the Sticklepath Fault Zone during early Tertiary times is considered by Freshney (1970) to be preserved in the cyclic sediments of the Petrockstow Basin ?Oligocene sediments.

All this evidence suggests that the Palaeogene drainage system arose in the north-west and flowed south-east. It is unlikely that any rivers flowed from Cornwall towards the Hampshire Basin. The rivers eroded and transported sands and clays which must clearly have been derived from rocks older than the Chalk, e.g. Lower

Cretaceous, Jurassic, etc. Reworked Carboniferous megaspores have been recorded from the Upper Headon Beds of Colwell Bay (Dijkstra 1950).

The Eocene palaeolatitude was close to 40° N (Smith, Briden and Drewry 1973). The climate has generally been considered to be warmer than that of the present. In a recent review Daley (1972*b*) has discussed some of the problems of the interpretation of the climatic conditions. He concludes that dry and pluvial periods existed at different times.

Previous palaeogeographic reconstructions include those of Wills (1951), Krutzsch and Lotsch (1958), Davis and Elliott (1957), Curry (1967), Boillot (1964), and Larssonneur (1972). The palaeoecological interpretations of the foraminiferal faunules, which incidentally agree with the general interpretations based on ostracods (Haskins 1971), can be used to add to these palaeogeographic reconstructions.

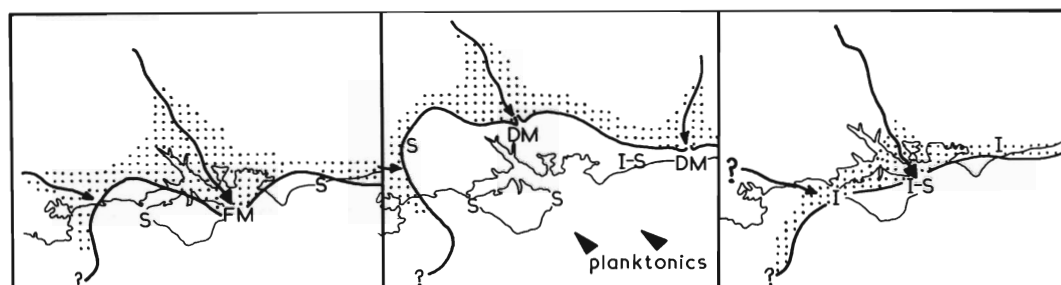
The London Clay resulted from the first major marine incursion into the Hampshire Basin. Palaeogeographic maps have been prepared for three levels: below the planktonic datum, above the datum, and the top of the London Clay (text-fig. 25 top).

Below the datum the succession at Alum Bay is composed of a thin series of near-shore shelf sediments. Whitecliff Bay, however, has a more marginal marine situation, the succession being expanded by a series of intertidal deposits with intercalations of deltaic marine and bay material. These are followed by a fluvial-marine fauna indicating the presence of a river mouth. At Bognor the foraminiferids and sediments suggest shelf and intertidal conditions (based on data in Venables 1962). Thus, a river flowing from the north-west had its mouth near Whitecliff Bay. This produced a small deltaic promontory from which the coastline curved back to accommodate the near-by shelf regions.

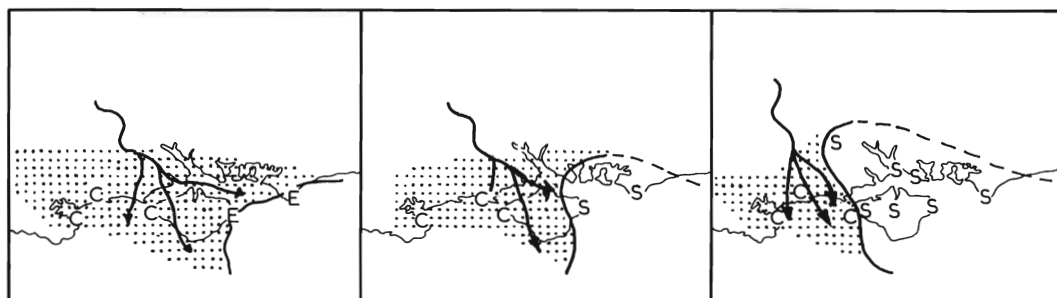
Just below the datum, a major transgressive episode caused a retreat of the coastline. Post datum assemblages indicate shelf biofaces at Alum Bay, Whitecliff Bay, Verwood, and Clarendon?, intertidal to shelf at Bognor, and a deltaic marine biofacies at Swanwick. Because of the coastal retreat, the fluviomarine situation at Whitecliff Bay below the datum was now represented by the deltaic marine assemblage at Swanwick. The mouth of the river occurred to the north. The coastline adopted an arcuate form, including a large embayment in the west of the region. The overstepping of the Reading Beds and Chalk by London Clay at Cranborne (Reid 1902) probably occurred at this time. A deltaic marine assemblage at Worthing reflects the presence of another river whose outlet is near by (text-fig. 25 top, centre).

Finally, at the top of the London Clay, intertidal conditions at Alum Bay and Bognor, and intertidal to shallow shelf at Whitecliff Bay, suggest a NE.-SW. coastline with the majority of the Hampshire Basin lying on the landward side. Thus, the Wealden area seems to have separated the Hampshire and London Basins at this time.

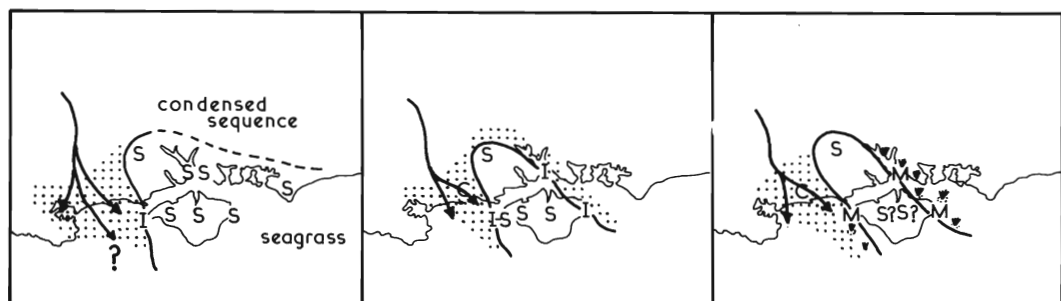
The composition of the London Clay assemblages was controlled by the fine nature of the substrate. The foraminiferids lived on the sediment in quiet shelf conditions. Rapid sedimentation was prevalent only in deltaic marine and, possibly, intertidal environments. The low diversity of the fauna reflects the hyposaline water conditions produced by the continual influx of river water. The depth of the shelf sea never exceeded 100 m and was probably about 50 m for the majority of the time. The



PRE - DATUM POST - DATUM TOP OF LONDON CLAY
 S=Shelf FM=Fluvial marine DM=Deltaic marine I=Intertidal ····Continental



A. *N. planulatus* Bed B. *N. laevigatus* Bed C. Brook Bed



D. Fisher Beds XVII, 21 etc. E. *Rimella canalis* Bed F. 1 metre below *prestwichianus*.

C="Continental", E=Estuary, S=Shelf, I=Intertidal, M=Marsh, ····"Continental" deposits

TEXT-FIG. 25. Palaeogeography of the London Clay sea (*top*) and the Bracklesham Beds (*middle and lower*).

temperature of the water was probably similar to that of the Western Approaches to the English Channel at the present time: up to 16 °C in the summer. Estimates of the air temperature based on the flora range from 21 °C (Chandler 1961) to 25–26 °C (Montford 1970). However, in temperate regions the sea is cooler than the air for much of the year so different values would be expected.

The Bagshot Sands have not yielded foraminiferids; they may be of fluvatile origin.

The overlying Bracklesham Beds exhibit to the full the marginal marine character of the Eocene succession. The earlier workers noted the difference in lithofacies between the western and eastern halves of the basin (Prestwich 1846; Fisher 1862; Bristow, Reid and Strahan 1889). The interdigitation of the marine and continental influences was accounted for by cyclic sedimentation (Stamp 1921) while the extent of the marine incursions has been dealt with by Curry (1965, fig. 3). The presence of an Eocene coastline in the Isle of Wight has been detected using heavy minerals (Blondeau and Pomerol 1968a) and the distribution of clay facies (Gilkes 1968). However, the interpretation of the foraminiferid assemblages aids the reconstruction of the palaeogeography and provides a better understanding of the Bracklesham sea.

The Bracklesham Beds may be divided into two lithofacies:

(a) Laminated lignitic clays and sands, variegated sands, channel deposits, coals, and lignite beds.

(b) Glauconitic sandy clays with a marine fauna.

The first group has been previously discussed in the Alum Bay section. It appears to result from the deposition of a braided river flowing over a wide flood plain, e.g. the Rhône (Kruit 1955). This establishes a wide variety of environments: fluvial marsh, interdistributary channels, sand bars and shoals, ponds and lagoons. At its seaward margin, the distributaries of the river empty through several mouths and not one deltaic promontory. The glauconitic sandy clays represent the deposits of the sea when it encroached on to this flood plain and it is these episodes that are now discussed.

The inferred palaeogeography at different times during the Bracklesham formation is given in text-fig. 25A–F, with reference to the correlation chart, text-fig. 21. The Lower Bracklesham Beds comprise fauna-less, laminated, lignitic clays and sands indicating a 'continental' dominance in the basin. The first identifiable marine-influenced horizon is the *Nummulites planulatus* Bed (IV, the Cakeham Bed and the base of Zone 2) which has been interpreted as estuarine. The equivalent beds to the west are sands. Therefore, a river system dominated the basin, its seaward margin being defined by an arcuate coastline to the east of the Isle of Wight (text-fig. 25A).

An eastward advance of the river system caused a return to sands, laminated lignitic clays, and coals. However, the sea made another short-lived advance during the *Nummulites laevigatus* Bed (VII, 6 at Selsey and the base of 4). A shallow shelf fauna was present at Whitecliff Bay and Selsey while variegated sands were deposited to the west at Alum Bay. Therefore, a small arcuate embayment occurred in the east, establishing a NW.–SE. coastline across the Isle of Wight (text-fig. 25B).

Beds VIII to XIII (Zone 4 in part) and their equivalents at Fawley, Stubbington, and Selsey (text-fig. 21) mark the continued presence of a coastline in approximately the same position. The sediments at Whitecliff Bay were intertidal with occasional tidal marshes. The documented sections of the other three localities suggest shallow shelf conditions with intercalated intertidal episodes. To the west, the 'continental' regime was maintained: sands, clays, and pipeclay.

The Brook Bed marks the first major marine incursion into the basin (text-fig. 21). The coastline retreated to the west, and shelf conditions were established at all

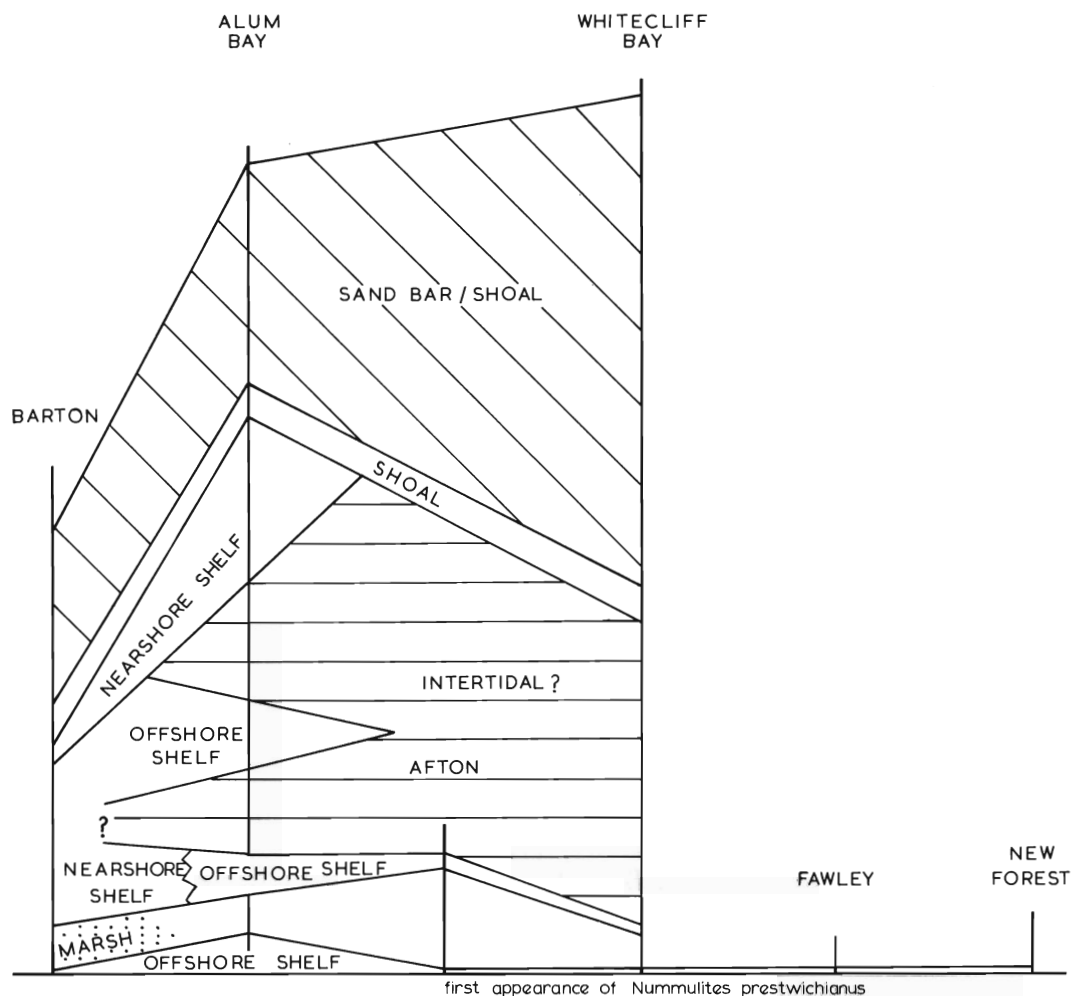
localities except Alum Bay (text-fig. 25c). These marine conditions were maintained in the east but there was a small regression at Afton and Gunville. However, the transgressive episode was soon resumed during Fisher Bed XVII at Whitecliff Bay (base of Zone 5) and its equivalents (text-fig. 21). Shallow shelf conditions were established at all localities and even at Alum Bay there was a trend to intertidal deposits (text-fig. 25d). However, the fauna reveals a change in the conditions. The water was warmer, of normal salinity, and clear with no mud in suspension. The presence of seagrass and seaweed on which some foraminiferids lived suggests that little sediment was being deposited. All these features indicate a reduction in the amount of sediment being transported into the embayment. This may have been caused either by a drying up of the river or, more probably, by a change in the position of its major outlet. The Bournemouth area exhibits fluvial marine and littoral deposits suggesting a river outlet in that region. As a result, the marine embayment in the Hampshire Basin was isolated with little sediment being deposited.

The remainder of the Bracklesham Beds appears to represent a gradual silting up of this embayment. At Afton, Gunville, and in the New Forest, marine bio- and lithofacies occur with good faunas (*Rimella canalis* Bed, text-fig. 21). At Fawley and Whitecliff Bay, laminated, lignitic, and pyritic muds occur. Curry, Hodson and West (1968) interpret these as resulting from deeper-water conditions with low Eh and little current activity. The authors suggest the complete opposite. The documented fauna of pyritized diatoms, fish remains, and arenaceous foraminiferids appears to be a typical marsh assemblage. Therefore, the north-eastern margin shows signs of silting up (text-fig. 25e), and this trend is continued to the *prestwichianus* band. Just below the datum there is a proved marsh at Alum and Whitecliff Bays, and probably also at Fawley. This silting process was finally halted by the Barton transgression.

To summarize, below the Brook Bed (Zones 1 to 3 and 4 in part), continental conditions dominated with the sea only making short-lived encroachments on the eastern margin. Above the Brook Bed (top of 4 and Zone 5), two major transgressive episodes produced a small marine embayment which was then silted up after the river changed its outlet position. Isopach information shows that the major thicknesses occur in the region of coastline movement.

The Bracklesham sea, up to Bed XVI, was slightly hyposaline with turbulent muddy water never more than 100 m deep. The fine substrate was one of the controlling factors on the fauna. Above Bed XVI, the sea was warmer, clear, and of normal marine salinity. A temperature of 18 °C in the summer has been suggested. It is the development of normal marine salinities and not necessarily a rise in temperature alone which caused the distinctive fauna.

The silting-up process at the top of the Bracklesham Beds was halted by the marine transgression which initiated the Barton Clay. This advance of the sea invaded the marsh areas in the north-east, the *prestwichianus* band being recorded at Fawley and Whitecliff Bay. The westward retreat of the NE.-SW. coastline produced a marsh regime at Barton and Hengistbury. This trend continued with the development of a nearshore shelf at Barton and an offshore shelf regime at Alum Bay (text-fig. 26). However, during the Lower and Middle Barton Beds, intertidal conditions dominated at Whitecliff Bay and greatly expanded the sequence at Alum Bay. Both occurrences suggest a barrier to the south with intertidal mud flats developing along its northern



TEXT-FIG. 26. Environmental interpretations applied to the correlation chart for the Barton Beds.

margin. Barton maintains its shelf regime until the *Chama* Bed when marked shoaling occurs. This may result from the development of the Barton Sand which exhibits large thickness in the east with thinning towards the west. This distribution suggests a marine development of sand, as either a shoal or bar, which effectively blocked off the mouth of the embayment. Curry (1965) states 'there is no suggestion of a receding shoreline and it seems that the Barton sea gradually silted up . . .'. This appears to be the situation, the silting-up process heralding the shallow lagoonal and freshwater conditions of the overlying Headon to Hamstead Beds.

The Barton sea marks a return to slightly hyposaline conditions with turbulent muddy water. The depth was never greater than 100 m and probably about 50 m for the majority of the time. The few planktonic specimens suggest a restricted circulation.

In text-fig. 27 the generalized outcrop of the Headon Beds is shown together with records of the three zones and the axes of folds which had developed in pre-Bembridge Marls times.

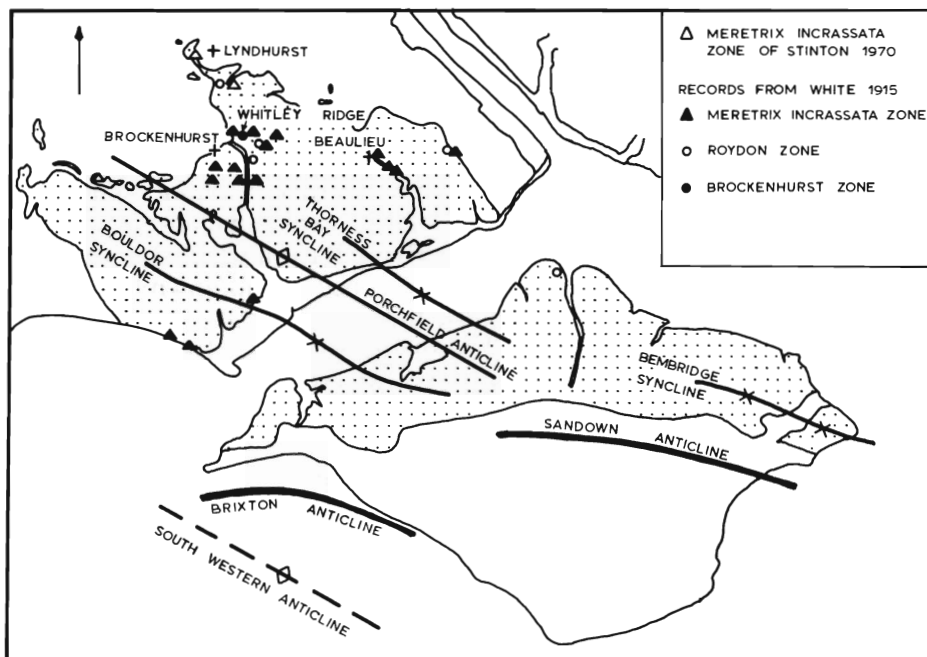
The restricted occurrence of the Brockenhurst Beds led Curry (1965) to postulate that the sea invaded the area from the north or north-east. Nothing is known of their microfauna at the type locality but the macrofauna, which includes a wide range of molluscs (although less diverse than the underlying Barton Clay) and several corals, is marine. The length of time represented by these beds is unknown but either it was short or else sedimentation was slow because the beds are thin everywhere (although Keeping and Tawney 1881, included 17 m of the Whitecliff Bay succession in the Brockenhurst Beds). On the mainland they lie on an eroded surface of the underlying Lower Headon Beds.

The difficulties of correlation have already been stressed but it seems probable that following the Brockenhurst phase the transgression spread laterally to Headon Hill, Colwell Bay, and Hordle Cliff to give rise to the Middle Headon deposits there. At Hordle Cliff the marine succession is thin and presumably this point was close to the westward limit of the transgression. At Headon Hill the environment was subtidal to intertidal and the presence of material reworked from the Lower Headon fresh-water limestones and even from the Chalk may lend support to the concept of a Palaeogene fold to the south-west of the Needles (text-fig. 28). Subsidence and sediment deposition were more or less in equilibrium but the small-scale discrepancies were sufficient to produce 'cyclic' repetition of faunas at Whitecliff Bay and Headon Hill. Colwell Bay probably represents a channel which was permanently subtidal and therefore not affected by these small-scale oscillations.

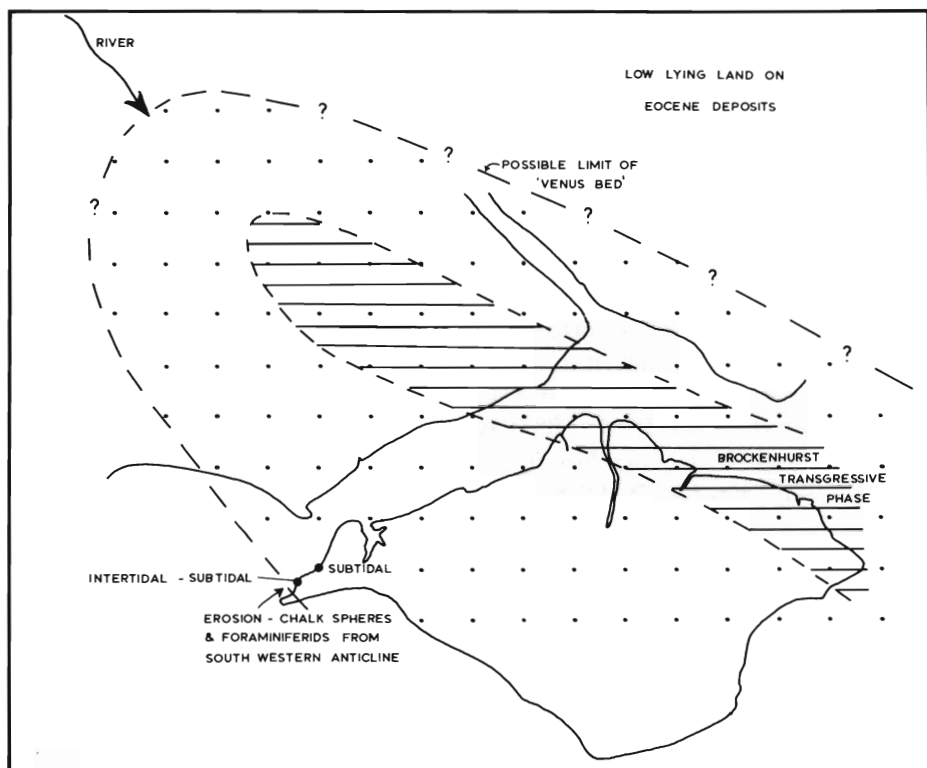
It is likely that the *Venus* Beds *sensu lato* were also deposited to the north and north-east of the axial Brockenhurst deposits and that they have subsequently been removed by erosion. The suggested shape of the Middle Headon 'sea' is in the form of an embayment, closed to the west where it probably received river drainage, and connecting with a sea to the east or south-east. It is probable that during *Venus* Bed times there was a restriction in this connection so that lagoonal conditions prevailed. The water temperature was probably in the range 16–18 °C in the summer. Salinities varied from normal to very hyposaline.

The occurrence of foraminiferids in the Bembridge and Hamstead Beds is so restricted geographically that it is not possible to attempt a palaeogeographical reconstruction. However, it can be said that the basin appears to be very close to being completely silted up at this time. The original area of the transgressions which introduced the foraminiferids may not have been very much greater than the present extent of the deposits, i.e. in the same axial-basin area as the Brockenhurst transgression.

Thus, we have the picture of the Hampshire Basin forming an embayment fed by sediment from the rivers flowing from the north-west and periodically invaded by the sea from the south or south-east.



TEXT-FIG. 27. Generalized outcrop of the Headon Beds (dotted) with the occurrence of the three zones (mainly after White 1915) and Palaeogene 'folds' (after Daley and Edwards 1971).



TEXT-FIG. 28. Palaeogeography of the Middle Headon Beds in the Hampshire Basin.

FRANCE: PARIS BASIN

The extent of the Tertiary deposits is shown in text-fig. 29 together with the sampling localities. The Paris Basin was a region of variable facies throughout the Palaeogene. This has caused stratigraphic confusion. For example, the Bartonian has fifteen different definitions and a dozen subdivisions due to failure to recognize lateral facies equivalents (Feuillée 1964). The historical development of the stratigraphic nomenclature has been summarized in the following works: Ypresian—Feugueur (1963); Lutetian—Blondeau (1964), Blondeau *et al.* (1965); Bartonian—Feuillée (1964), Pomerol (1964, 1965), Denizot (1968), Blondeau and Pomerol (1968a); Stampian—Cavelier (1964a). The generalized succession is shown in text-fig. 30 (after Blondeau *et al.* 1965, 1968).

Systematic accounts of the foraminiferids have been given by Lamarck (1804), d'Orbigny (1826), Terquem (1882), and Le Calvez (1947–1952, 1970). There are few published data on the percentage composition of the assemblages and only a small amount of palaeoecological interpretation has been attempted (Le Calvez 1970).

Sufficient sections were measured and sampled in this study to build up an almost complete succession of the Eocene and Oligocene of the Paris Basin. Most of these localities are described in one or more of the field guides: Fritel (1910), Lapparent (1942, 1946, 1964), Pomerol and Feugueur (1968).

The Eocene assemblages show a limited range of palaeoecological possibilities. Because of this, and to avoid needless repetition, the interpretation of their palaeoecology is not included in each locality description. Instead they are considered together at the end of this section. However, because of the great variation in environmental conditions in the Cormeilles-en-Parisis section its palaeoecology has been discussed separately.

The localities are listed in stratigraphical order.

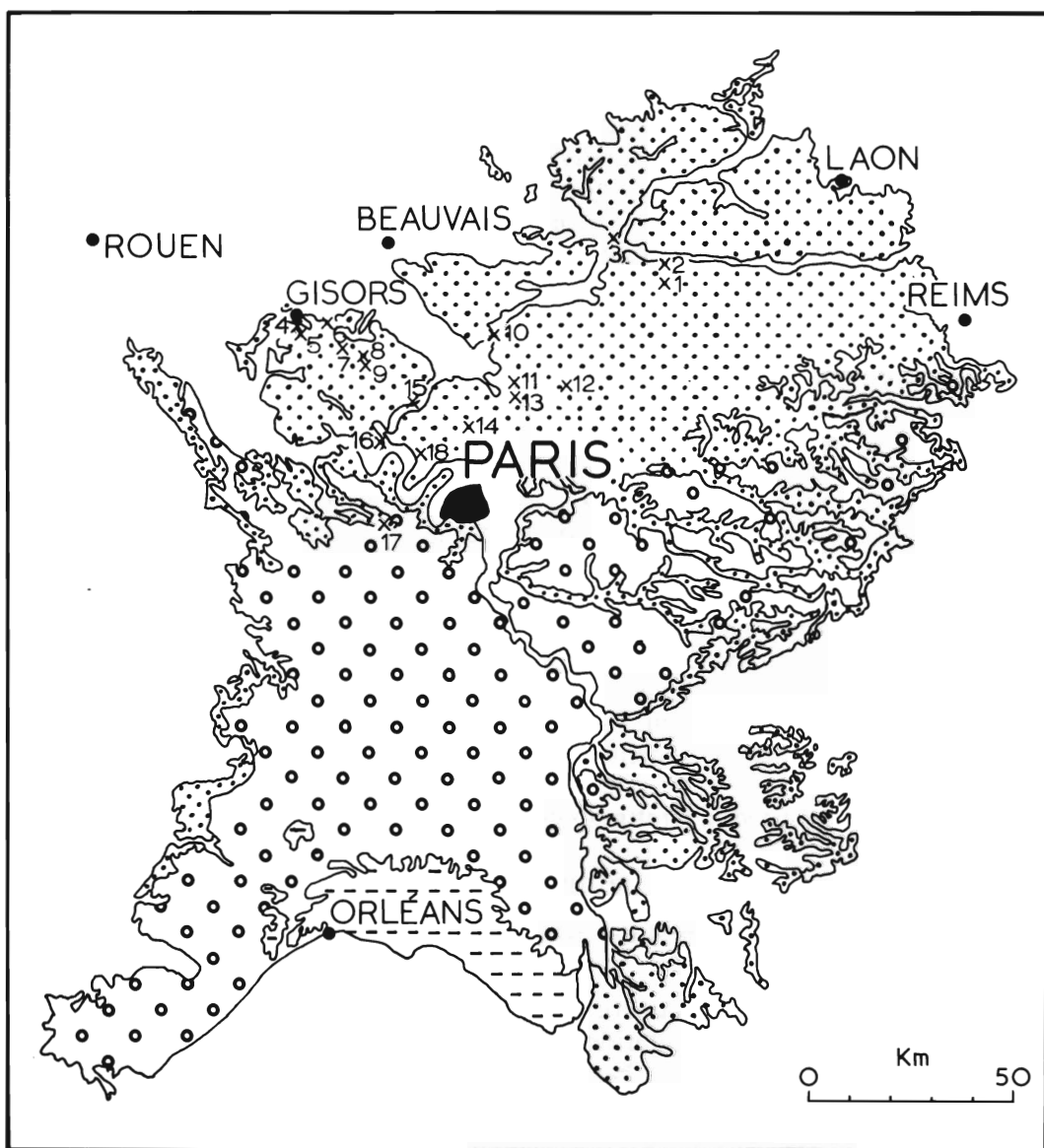
PIERREFONDS

Location. The pit is just north of the town on the east side of the Rue de Mont Berny (N 335).

Previous work. This classic locality is mentioned in the study of the Ypresian by Feugueur (1963). The foraminiferids have been described by Le Calvez (1970). The planktonic species, in particular, have been the topic of several papers; Brönnimann *et al.* (1968), Bignot and Le Calvez (1969). Bignot and Lezaud (1969) have studied the coccolith floras and record several species including *Marthasterites tribrachiatus* and *Discoaster binodosus*. This assemblage places the horizon in Zone NP 11 of the standard Palaeogene nannoplankton zonation (Martini 1970a).

Succession. The major part of the section is composed of yellow and brown sand with abundant *Nummulites* and shell debris. This is capped by white and then glauconitic sand at the top of the pit. The complete succession is attributed to the Niveau de Pierrefonds, Upper Cuisian (see text-fig. 31).

Distribution of foraminiferids. Forty-nine foraminiferid species and varieties have been identified (text-fig. 31, Table 13). The fauna is dominated by *Cibicides lobatulus*



Eocene





Oligocene



Miocene

TEXT-FIG. 29. Geological map of the Paris Basin. Sampling localities: 1, Pierrefonds; 2, Cuise-la-Motte; 3, Mont Ganelon; 4, Mont de Magny; 5, Hérouval; 6, Chaumont-en-Vexin; 7, Liancourt; 8, Chavençon; 9, Le Ruel; 10, St. Leu d'Esserent; 11, La Chapelle-en-Serval; 12, Ermonenville; 13, Le Guépelle; 14, Ezanville; 15, Auvers-sur-Oise; 16, Maurecourt-l'Hautil; 17, Grignon; 18, Cormeilles-en-Parisis.

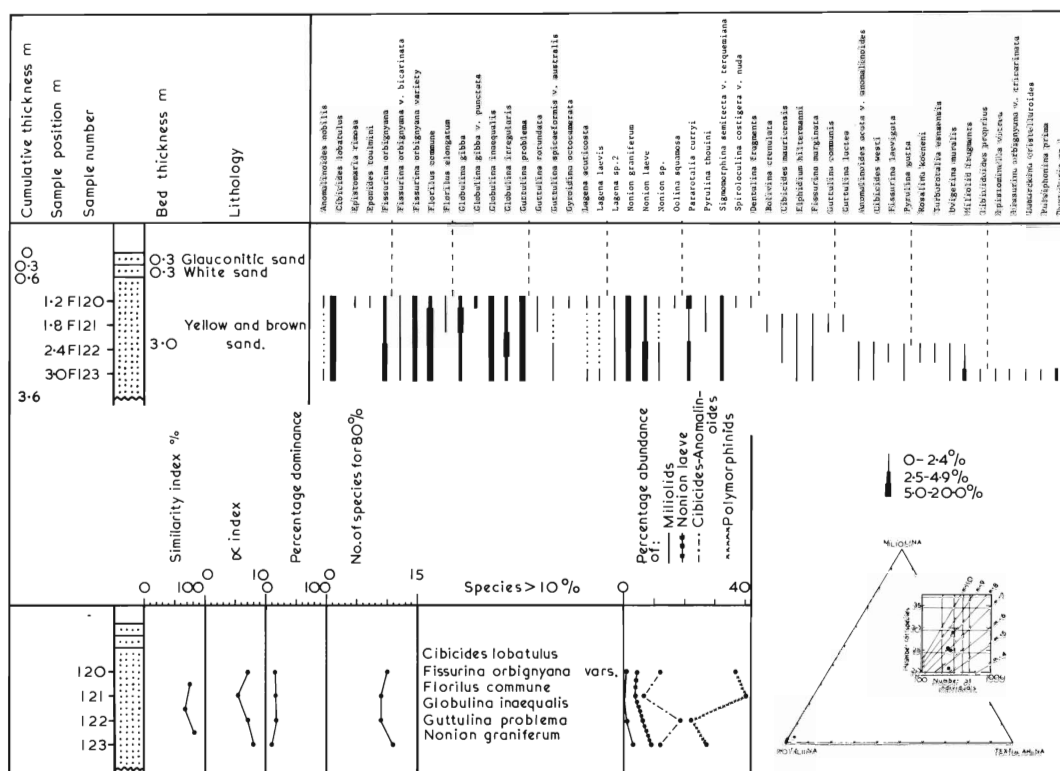
OLIGOCENE	STAMPIAN s.l.	Upper Stampian or Stampian s. str.	Molasse du Gâtinais Calcaire d'Étampes Faluns d'Ormoiy Faluns de Pierrefitte	 Calcaire de Beauce (in part)
		Lower Stampian or Sannoisian	Faluns de Jeurre-Morigny Marnes à <u>O. longirostris</u> Calcaire de Sannois Argile verte de Romainville	
EOCENE	BARTONIAN	Ludian	Marnes blanches de Pantin Marnes bleues d'Argenteuil Marnes et gypse Marnes à <u>Pholadomya ludensis</u>	 Calcaire de St. Ouen
		Marinesian	Sables de Marines Sables de Cresnes Sables de Mortefontaine Calcaire de Ducy Sables d'Ézanville	
		Auverasian	Sables et grès de Beauchamp Sables d'Auvers (Zone du Guépelle & d'Ermenonville) Formation de Mont-Saint-Martin	
	LUTETIAN	Upper	B. Biarritzien - <u>Discorinopsis kerfornei</u>	
		Middle	A. Facies lagunaire à Cérithes (zone IVb of Abrard) Calcaire à <u>Orbitolites complanatus</u> and <u>Nummulites variolarius</u> (zones III and IV of Abrard)	
		Lower	Calcaire à <u>Nummulites laevigatus</u> (zones I and II of Abrard)	
	YPRESIAN	Upper Cuisian Lower	B. Niveau d'Hérouval A. Niveau de Pierrefonds Niveau d'Aizy	
		Sparnacian	Argiles à bancs d'Huîtres et Cyrènes Sables de Sinceny Argiles plastique	

TEXT-FIG. 30. Generalized succession of the Eocene-Oligocene of the Paris Basin (based on Blondeau *et al.* 1965; Blondeau *et al.* 1968; Pomerol and Feugueur 1968).

(5.9–17.0%), *Fissurina orbignyana* plus varieties (13.7–21.2%), *Florilus commune* (3.2–10.0%), *Globulina inaequalis* (5.2–14.5%), *Guttulina problema* (6.7–11.5%), and *Nonion graniferum* (8.5–16.2%). The larger foraminiferids are dominated by abundant *Nummulites planulatus*.

The microfauna also includes nineteen species of ostracods. The macrofauna is dominated by species of *Turritella*, *Eopecten*, *Nucula*, and *Cardium*.

General features of the assemblages. The fauna from the Niveau de Pierrefonds is extremely constant as can be seen from the similarity indices which fall in the range 68.4–78.4%. The values for the diversity index fall in the range $\alpha = 5\frac{1}{2}$ –8. A triangular



TEXT-FIG. 31. Succession, foraminiferid distribution, and general features of the assemblages from the Niveau de Pierrefonds, Pierrefonds.

plot of suborders is given in the same diagram. All the samples plot at or near the *Rotaliina* corner.

As might be expected from the moderately high α indices, the percentage dominance values are low, 10.5–17.0%. The number of species required to form 80% of the population varies from nine to eleven. Also shown in text-fig. 31 is a plot of four groups which constitute the major part of the population; the *Miliolina*, *Nonion laeve*, the *Cibicides*–*Anomalinoidea* group, and the polymorphinids. The fauna is dominated by the polymorphinids and the *Cibicides*–*Anomalinoidea* group but these two appear to be in opposition. If one is abundant, then there is a decline in the other but not in the associated fauna.

MONT DE MAGNY

Location. Mont de Magny is situated 2.5 km to the south of Gisors, on the west side of the road to Chars (N 15).

Previous work. The succession has been described in detail by Feugueur (1947a, 1963) while its relationship with the other Cuisian localities has been discussed also by Feugueur (1947b). The foraminiferids have been noted by Le Calvez (1970, p. 216).

Succession. As the base of the pit is uneven, the top provides a more reliable datum for measurement. Below a disturbed horizon, mottled green and brown sands pass down into similar sands with beds of calcite nodules. A marked shell bed is followed by a series of white calcareous sands with irregularly cemented limestone nodules. A second shell bed occurs at the base of this horizon. This is underlain by a large thickness of cross-bedded and rippled green and brown sands with occasional bands of calcite nodules. In the lowest part of the succession, the cross-bedding of the sands is not so well developed (text-fig. 32).

Distribution of foraminiferids. This is given in text-fig. 32 and percentage abundances in Table 14. No faunal boundaries are obvious from the similarity values or the range of species contributing more than 10% to the fauna. The succession as a whole is dominated by the following species: *Cibicides lobatulus* (7·8–46·2%), *Globulina inaequalis* (2·1–18·0%), *Guttulina problema* (0–13·7%), *Nonion graniferum* (0–17·1%), *Cibicides mauricensis* (0–17·3%), *Cibicides westi* (0·8–57·3%), *Florilus commune* (0–10·4%), and *Nonion laeve* (1·2–21·3%). One feature is the change in dominance between *Cibicides lobatulus* and *Cibicides westi*. From F1 to F11, *Cibicides lobatulus* is dominant but in the cross-bedded sands near the base (F12–19), it is *Cibicides westi* that attains a peak in its abundance. About one-quarter of the specimens of *Cibicides lobatulus* are deformed. This suggests the presence of irregular-shaped objects to which the foraminiferids attached themselves during life.

Several species are stratigraphically important and appear to characterize the Cuisian. These include *Fasciolites oblonga*, *Nummulites planulatus*, *Nonion* sp. 1, *Nonionella* sp. 1, *Cibicides mauricensis*, *Cibicides tallahattensis*, *Anomalinoidea acuta* and varieties, *Anomalinoidea nobilis*, *Asterigerina glabra*, *Asterigerina guerrai*, and the planktonic species. The presence of abundant *Fasciolites oblonga* and *Nummulites planulatus* suggests a correlation of the calcareous sands with the Niveau d'Hérouval. However, the distinctive smaller foraminiferids are completely absent (cf. Hérouval). The mottled sands above the calcareous sands yield a typically Cuisian fauna and therefore it is suggested that the complete section is attributable to the Niveau d'Hérouval and the Sables de Pierrefonds, both being Upper Cuisian in age.

General features of the assemblages. As previously noted, the similarity values are consistently high, in the range 49·4–87·6%. The values of the Fisher diversity index α are 5–8 (text-fig. 32). When plotted against the succession, the only trend is that the highest values occur in assemblages from the calcareous sands. Percentage dominance values range from 14·0 to 46·2% while the number of species required to form 80% of the population varies from only 4 to 10. A triangular plot of the suborders shows the general absence of all but Rotaliina species. There is fluctuating abundance but consistent dominance of species of *Cibicides* and *Anomalinoidea* and there appears to be little trend in the distribution of *Nonion laeve*; but the polymorphinids exhibit a marked increase near the top of the succession. This equates with a decline in the abundance of *Cibicides* species.

HÉROUVAL

Location. The village of Hérouval is reached by turning right off the road from Gisors to Chars (N 15), just south of Mont de Magny. From the farm in the centre of the village, a track leads off to a small pit situated to the north-west.

Previous work. Hérouval has long been a classic locality and the literature on the pit is extensive. The term Niveau d'Hérouval was first coined by de Raincourt (1881). The succession and macrofauna have been described by L. and J. Morellet (1934, 1935), Feugueur (1947*a, b*, 1963), and Pomerol and Feugueur (1968). The macrofauna has been listed in detail; see Cossmann and Pissarro (1904–1913), Furon and Soyer (1947). The microfauna has been described in detail by Le Calvez and Feugueur (1953, 1956) and Le Calvez (1970, p. 220) while the planktonic species have been reported on by Brönnimann *et al.* (1968). The locality has been described in the guide by Fritel (1910).

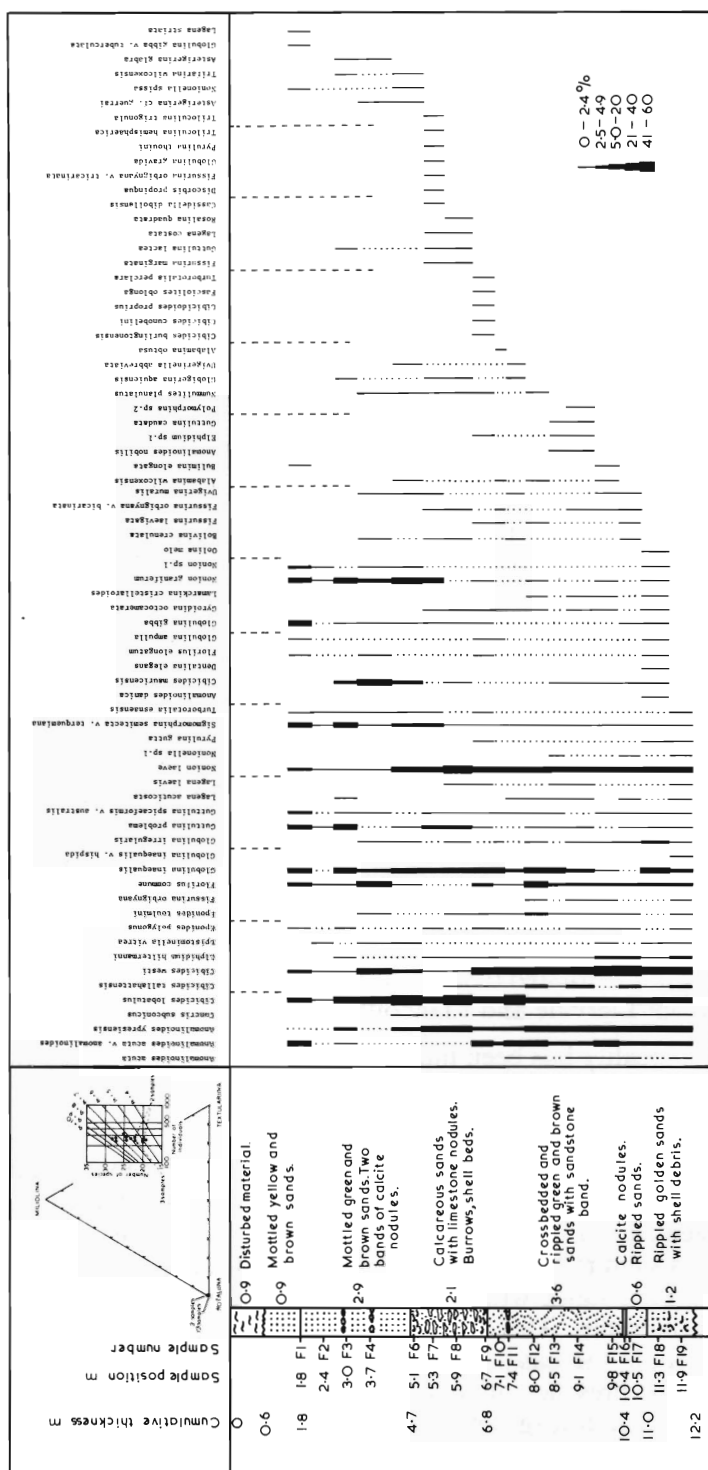
Succession. The lower half of the succession comprises the Niveau d'Hérouval. The term defines a local development of calcareous sands and limestones at the top of the Cuisian in the Vexin region. Its affinities with the Cuisian were proved on macrofaunal evidence (L. and J. Morellet 1935). The horizon is made up of yellow and brown mottled sands which pass up into laminated calcareous sands rich in shells and shell debris. The succession is completed by yellow sands with shell debris (text-fig. 33).

The contact with the overlying Lower Lutetian is marked by the appearance of white calcareous sands rich in glauconite, quartz grit, and shell debris. Above a well-marked shell bed, the sands exhibit irregularly cemented limestone nodules produced by the localized cementation of shell fragments. The section is completed by a series of laminated calcareous sands without limestone nodules.

Distribution of foraminiferids. Previous workers have recorded forty-seven species and varieties of foraminiferids from this locality. In the present study, seventy-five species have been identified; their distribution is given in text-fig. 33 and their percentage abundance in Table 15. A plot of the range of species contributing more than 10% to the fauna shows no definite faunal boundaries. Both horizons are dominated by *Anomalinoides ypresiensis* (6.4–15.3%), *Cibicides lobatulus* (17.1–65.5%), *Cibicides westi* (0–27.1%), and *Nonion laeve* (4.3–16.9%). The Lower Lutetian also has *Textularia minuta* (0–11.3%) and *Cibicides productus* (2.0–10.2%) as dominant species.

Several species present characterize the Cuisian. These include all the planktonic forms, *Cibicides mauricensis*, *Cibicides tallahattensis*, *Fasciolites oblonga*, *Anomalinoides acuta* var. *anomalinoides*, *Nonionella* sp. 1, *Rosalina herouvalensis*, *Spiroloculina morelleti*, and *Nummulites planulatus*. The boundary with the Lower Lutetian is characterized by the disappearance of many of the forms listed above. *Gyroidinella magna* is among those making their first appearance at this level.

The microfauna also includes twenty-seven species of ostracods. The associated macrofauna includes bivalves, gastropods, corals, echinoids, calcareous algae, bryozoa, and sharks teeth. The bryozoa are especially abundant in the Lower Lutetian where the calcareous fraction in the sand is virtually all from this source. The molluscs and bryozoa are listed in Feugueur (1963).



TEXT-FIG. 32. Succession and distribution of foraminiferids from the Cuisian at Mont de Magny near Gisors.

General features of the assemblages. The similarity values range from 35.9 to 82.2%. They are high at the top and bottom of the succession but exhibit a steady decline through the Cuisian to Lutetian boundary. From this, one would expect a marked faunal break at this level. However, the number of species contributing more than 10% to the fauna shows no evident boundary. A comparison of the top and bottom samples (F20/26) produces a similarity value of 61.2%. This suggests that the established Cuisian and Lower Lutetian assemblages are essentially the same. This similarity may arise in part through reworking of the Cuisian faunas into the basal Lutetian.

The Fisher α values fall in the range 4–9. When plotted against the succession, they reach a peak in the Niveau d'Hérouval, coincident with the trough in similarity values.

Percentage dominance values are of the range 17.1–65.6% while the number of species required to form 80% of the population varies from three to eleven. The highest and lowest values of both relate to the trend in α indices. When $\alpha = 9$, the percentage dominance is only 17.1%.

Text-fig. 33 also shows a triangular plot of the three suborders. The majority of assemblages fall at or very near the Rotaliina corner. There are two exceptions; the top sample in the Lower Lutetian has 11.3% Textulariina while one sample from the Niveau d'Hérouval has 14.8% Miliolina.

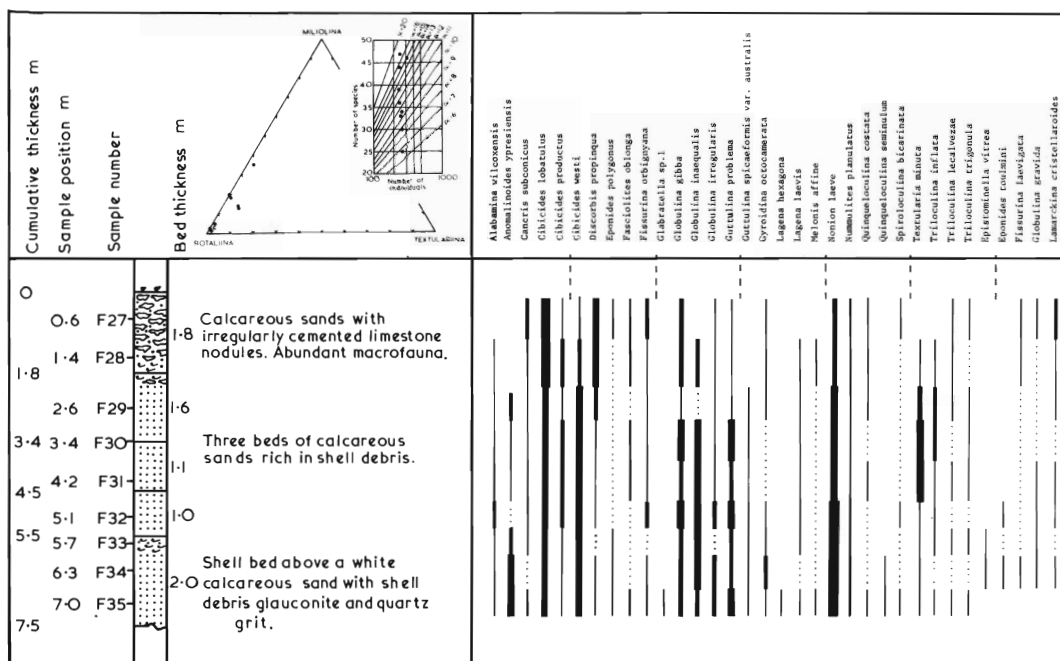
The *Cibicides*/*Anomalinoidea* group is dominant at all levels except one, where α values reach a peak and the similarity values are at their lowest. This also coincides with a peak in Miliolina. This level is probably the classic Hérouval horizon with a highly distinctive fauna composed of species with only restricted ranges; *Fascioliolites oblonga*, *Spiroloculina morelleti*, and *Rosalina herouvalensis*. This assemblage is only briefly established at the top of the Cuisian and *Cibicides* again becomes dominant in the Lower Lutetian. The trend in *Cibicides* is directly opposed to that exhibited by the polymorphinids and *Nonion laeve*.

CHAUMONT-EN-VEXIN

Location. A small quarry situated to the south of Chaumont-en-Vexin, at the junction of the two roads from Lierville and Liancourt, the D153 and the D566 respectively.

Previous work. The locality has been mentioned in the field guides and the foraminiferids have been described by Le Calvez (1970).

Succession. The succession measured is shown in text-fig. 34. It commences with a basal series of white calcareous sands with abundant shell debris, glauconite, and quartz grit. The glauconite and quartz are often rounded and show evidence of reworking and concentration. Above a marked shell bed are three horizons of white to yellow calcareous sand rich in shells and shell debris. The succession is completed by a series of calcareous sands which have undergone local cementation to produce irregular limestone nodules. The complete succession measures 7.5 m. The top of the section may include the basal Middle Lutetian but the remainder is defined as Lower Lutetian by the presence of *Nummulites laevigatus*. The lower portion represents the basal Lutetian transgressive episode resting on the Niveau d'Hérouval which is unfortunately not exposed.

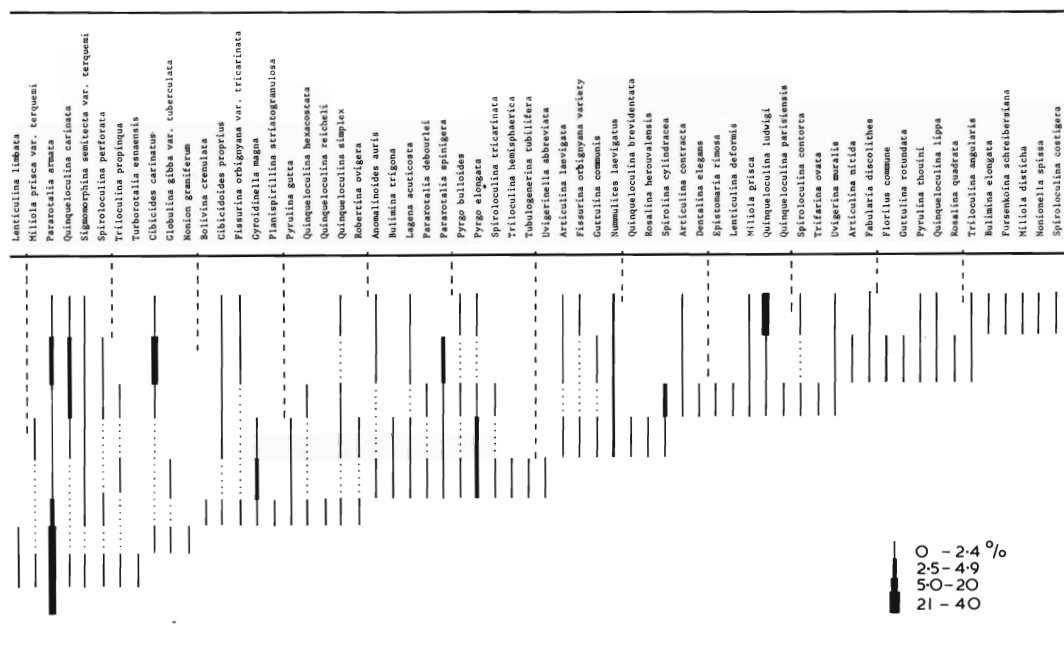


TEXT-FIG. 34. Succession and distribution of foraminiferids from

Distribution of foraminiferids. The distribution of the foraminiferids is given in text-fig. 34 and their percentage abundance in Table 16. The range of species which contribute more than 10% to the population and the values for the similarity indices show no marked faunal boundaries. Any faunal changes occur gradually through the succession, as will be discussed later. The succession as a whole is dominated by *Cibicides lobatulus* (8.1–24.1%), *Discorbis propinqua* (0.4–15.3%), *Nonion laevis* (2.3–36.2%), *Guttulina problema* (0.3–10.8%), and *Cibicides westi* (1.3–10.8%). Several other species are moderately abundant: *Anomalinoides ypresiensis*, *Cibicides carinatus*, *Cibicides productus*, *Globulina gibba*, *Globulina inaequalis*, *Pararotalia armata*, and *Textularia minuta*.

Several species have important ranges. The Lower Lutetian is indicated by *Nummulites laevigatus*. Also present are *Gyroidinella magna* and *Fabularia discolithes* in the transition to the Middle Lutetian. The range of *Fasciolarites oblonga* and *Nummulites planulatus* is also of interest. Both are typical Cuisian forms but are present in all the Lower Lutetian assemblages. They are part of the reworked Cuisian fauna which occurs at this level. It is composed not only of these foraminiferids but also of Cuisian molluscs, shark's teeth, and corals. Although the presence of *Rosalina herouvalensis* and *Pararotalia debourlei* points to a continued Cuisian influence on the fauna, the majority of typical Cuisian forms are absent.

The microfauna includes twenty-four species of ostracods. The associated macrofauna is extremely rich and contains abundant corals including *Turbinolia* and *Sphenotrochus*. The bivalves comprise *Glycymeris*, *Cardita*, *Meretrix*, *Corbula*, *Crassatella*, and *Chama* while the gastropods are represented by *Ampullina* and *Turritella*. Also present are echinoids (*Scutellina*), bryozoa, and calcareous algae.



the Lower and Middle? Lutetian at Chaumont-en-Vexin.

General features of the assemblages. The similarity values range from 50.2 to 80.9% and when plotted against the succession show no marked trough relating to a faunal break. The Fisher α indices fall in the range $\alpha = 6\frac{1}{2}$ –17. When plotted against the succession, they exhibit a gradual increase towards the top, being consistently below $\alpha = 10$ near the base and above 10 higher up. Percentage dominance values are low, 15.4–36.2%. However, the trend in the number of species required to form 80% of the population relates strongly to the trend in α values. Near the bottom of the section, up to eight species are required but as α increases up the succession, then the number of species reaches as high as twenty-one.

A triangular plot of the three suborders (text-fig. 34) shows that one group of assemblages plots near the Rotaliina corner while the other has an increase in Miliolina. The Miliolina and the discorbids exhibit a gradual increase up the succession. The assemblages which plot near the Rotaliina corner come from near the base of the section. Opposing this trend, the abundance of *Nonion laeve* and the polymorphinids shows a gradual decrease towards the top. The *Cibicides* species show no trend but remain abundant throughout the succession. The trend in the distribution of the four groups may reflect a gradual change in the environmental conditions as the Lutetian faunas become established.

LIANCOURT-SAINT-PIERRE

Location. Liancourt is situated on the road from Chaumont-en-Vexin (D566), the previous locality. Two pits were visited. The first is down a track forking from the road just before the railway bridge and to the west of Liancourt. The second is

situated just over the railway bridge, between the road and the railway, in the grounds of the Garde de Chasse.

Previous work. The succession and macrofauna of the first pit was described by Feugueur (1947b, 1963). An analysis of the heavy minerals has been made by Pomerol (1965) and the foraminiferids have been described by Le Calvez (1970). No reference has been found dealing with the second locality in any detail.

Succession. The succession (text-fig. 35) commences with the Lower Lutetian which is exposed at the first site (A). From the previous detailed description, it is obvious that much of the section is now obscured. However, 2.3 m of cross-bedded calcareous sand rich in shell debris, glauconite, and quartz grit were sampled. The second locality (B) provides two discontinuous sections in the Middle Lutetian. The succession is composed of white and yellow sandstones with calcareous cement. They exhibit large-scale bedding features with foreset units up to 3 m across. After a short break the section continues with calcareous sands which pass up into uncompacted white calcareous sands with a rich macrofauna.

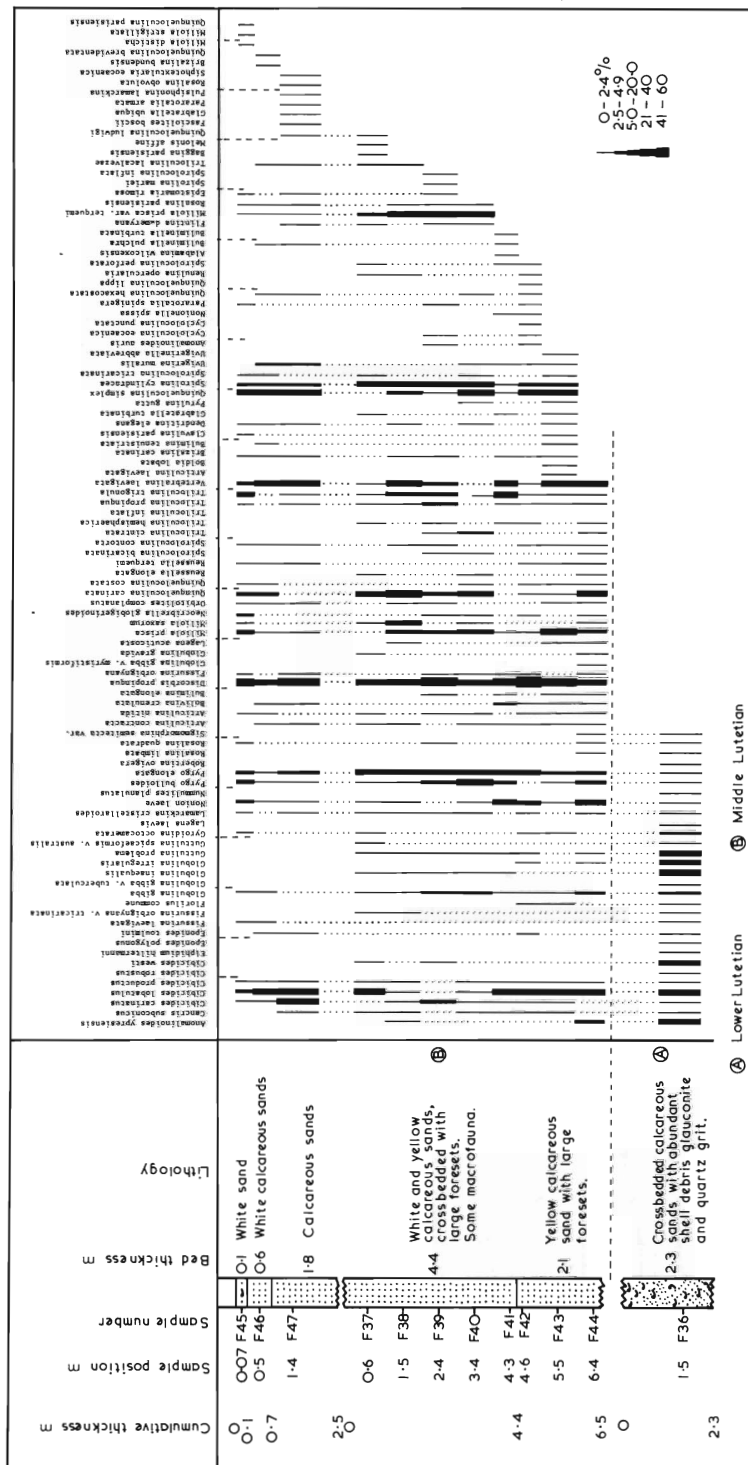
Distribution of foraminiferids. The distribution of foraminiferids is given in text-fig. 35 and their percentage abundance in Table 17.

The range of species forming more than 10% of the population and the trend in similarity values (text-fig. 36) show that it is possible to recognize three faunules. The first is equivalent to the Lower Lutetian and is dominated by *Cibicides lobatulus* (17.8%) and *Cibicides westi* (19.8%). Also present are *Anomalinoidea ypresiensis* (8.5%), *Globulina inaequalis* (7.3%), *Globulina irregularis* (7.3%), and *Guttulina problema* (6.1%), all as minor constituents. The fauna includes abundant *Nummulites planulatus* which have been reworked from the underlying Cuisian.

Faunule 2 equates with the lowest part of the Middle Lutetian. It is dominated by *Cibicides lobatulus* (5.8–12.3%), *Discorbis propinqua* (19.8–43.3%), *Pyrgo elongata* (2.7–9.7%), and *Vertebralina laevigata* (0.5–11.5%). Finally, faunule 3 is dominated by the following species: *Cibicides lobatulus* (0–13.0%), *Discorbis propinqua* (5.4–25.7%), *Miliola prisca* group (2.2–16.5%), *Vertebralina laevigata* (0–12.9%), *Pyrgo elongata* (2.2–14.5%), *Triloculina inflata* (2.3–13.5%), and *Quinqueloculina carinata* (0–21.1%).

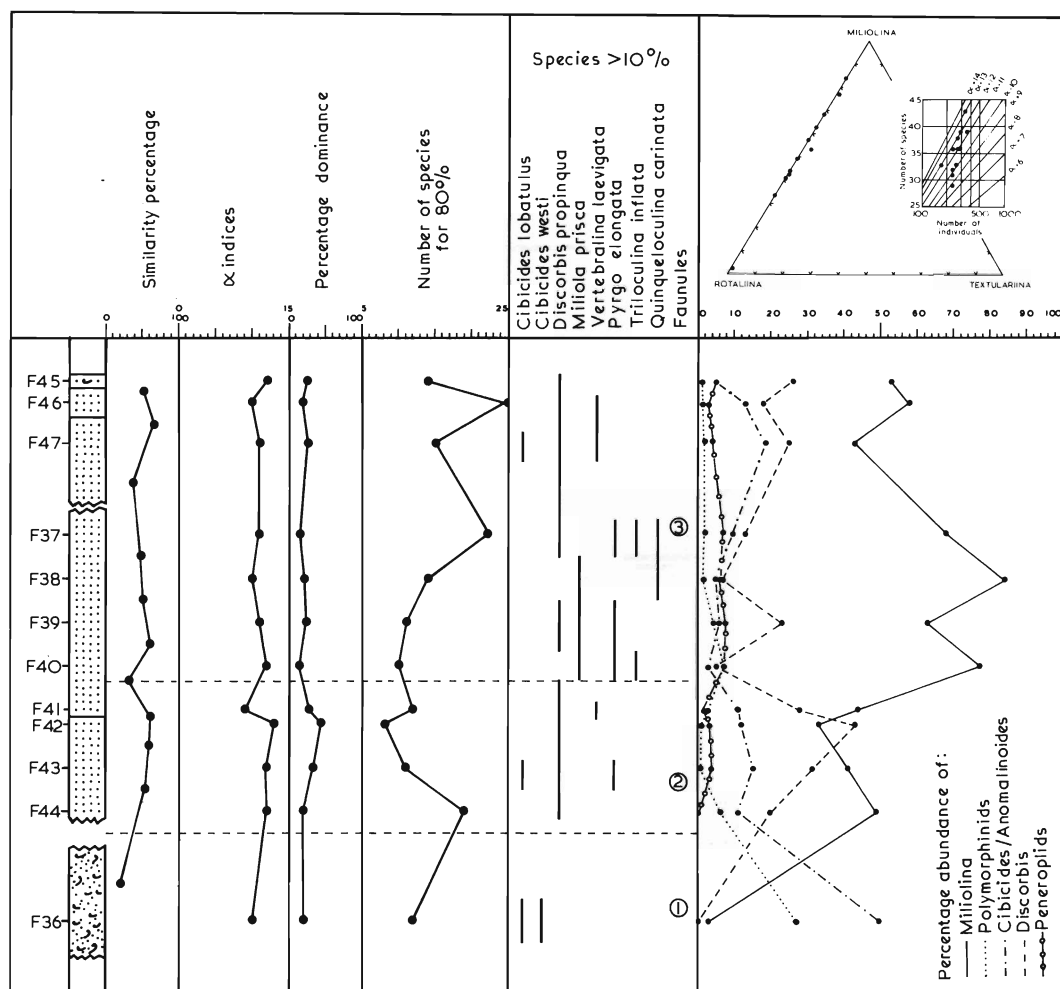
Several species have restricted ranges. The Middle Lutetian is defined by the presence of *Orbitolites complanatus* but this is accompanied by *Fasciolites boscii*, *Flintina dameryana*, *Glabratella turbinata*, *Neocribrella globigerinoides*, *Renulina opercularia*, *Quinqueloculina hexacostata*, and *Vertebralina laevigata* which are all typical Lutetian forms.

The microfauna includes twenty-six species of ostracods. The macrofauna in general is rather sparse. The Lower Lutetian has yielded abundant forms including corals, echinoids, bryozoa, and molluscs. The latter have been listed by Feugueur (1963, p. 190). They include bivalves (*Corbula*, *Meretrix*, *Venericardia*) and gastropods (*Solarium*, *Turritella*, *Collonia*). The Middle Lutetian samples have yielded a macrofauna only from the less consolidated horizons at the top (F45/47). This includes corals (*Turbinolia*), bivalves (*Arca*, *Cardita*, *Meretrix*, and *Cardium*), and gastropods (*Lacuna*, *Cerithium*).



TEXT-FIG. 35. Succession and distribution of foraminiferids in the Lower and Middle Lutetian at Liancourt.

General features of the assemblages. Many of the features described in this section are plotted in text-fig. 36. The similarity values fall in the range 21.9–66.8%. Their distribution clearly distinguishes the faunal boundaries, but even when a faunule is established the percentage similarity values are never very high. The Fisher α values fall in the range $\alpha = 9$ –13, but when plotted against the succession there is little obvious trend as they are consistently high. The percentage dominance values are 13.3–43.4%, the highest values equating with the slight drop in α . The number of species required to form 80% of the population varies from eight to twenty-five. It is highest near the top and bottom of the Middle Lutetian where several species are fairly abundant but none is present in any great number. Text-fig. 36 also shows a triangular plot of the three suborders. The Lower Lutetian sample (F36) falls near the Rotaliina corner but the Middle Lutetian assemblages exhibit an increase in



TEXT-FIG. 36. General features of the assemblages from the Lutetian of Liancourt.

Miliolina. There is a general lack of Textulariina. The increase in Miliolina is even more clearly seen in the percentage abundances of the five most important groups plotted against the succession. The Miliolina are rare in the Lower Lutetian but exhibit a marked increase during the Middle Lutetian. The discorbids and the peneroplids show a similar distribution but differ in being absent from the Lower Lutetian assemblages. Opposing this trend, the polymorphinids and *Cibicides* species are most abundant in the Lower Lutetian and suffer a marked decline above this level.

GRIGNON

Location. Grignon is situated to the west of Paris on the road to Crespières (D198). The classic sand pit is in the grounds of the agricultural college, to the south-east of the village. Permission must be obtained from the Director to visit the site.

Previous work. This locality has long been a classic site for collecting fossils which are characterized not only by their abundance and variety of species but also by their remarkably good state of preservation. More than 1000 species of molluscs, 150 species of foraminiferids, 30 species of ostracods, and 10 of calcareous algae are known. The heavy minerals have been studied by Pomerol (1965) and the foraminiferids have been briefly described by Le Calvez (1970). Much of d'Orbigny's original collection came from this site. The molluscs have been included in several studies by Cossmann and Pissarro (1904–1913) and Furon and Soyer (1947).

Succession. The succession measured is shown in text-fig. 37. The upper part comprises two beds of yellow marly sand, with mollusc impressions and moulds and occasional limestone nodules. These are underlain by a series of white calcareous sands, rich in shell debris and large foraminiferids. The lower part of the section consists of yellow sands. There is then a break estimated to be 1.8 m in thickness. In a hole in the bottom of the pit, yellow sands with shell debris overly yellow sands rich in glauconite and shell material.

Although the glauconite-rich sands at the base are lithologically very similar to the basal Lutetian deposits, the complete succession has been assigned to the Middle Lutetian. From the reconstruction of the Lutetian sea (Blondeau, *in* Pomerol 1967, 1969; Pomerol and Feugueur 1968), it can be seen that the Lower Lutetian does not transgress as far as Grignon. The first deposits in this area are of Middle Lutetian age. It is interesting to note the similarity of the sediments resulting from the initial transgressive episode, regardless of their age. Even when the sea covered the Grignon area it was only 20 m north-east of the Rémarde anticline which was not submerged during the Middle Lutetian. Therefore, the sediments and fauna at Grignon reflect an extremely marginal marine situation.

Distribution of the foraminiferids. The distribution of foraminiferids is shown in text-fig. 37 and their percentage abundance in Table 18. The range of species forming more than 5% to the population and the distribution of similarity values makes it possible to distinguish three faunules (text-fig. 38). Because of the abundance of species, 5% was taken as the critical percentage. Faunule 1 is dominated by *Nonion laeve* (10.0%), *Guttulina problema* (6.0%), *Discorbis propinqua* (9.0%), *Cibicides*

lobatulus (9.3%), and *Cancris subconicus* (9.0%). Faunules 2 and 3 are both dominated by *Miliola prisca* (5.7–10.4%), *Nonion laeve* (1.3–8.8%), *Triloculina inflata* (1.6–6.8%), and *Quinqueloculina crassa* (0.3–6.0%). *Guttulina problema* is another dominant form in faunule 3. Also present are two species which have only been recovered from the residues and are therefore not included in the species count. These are *Orbitolites complanatus* and *Fasciolites boscii*, which are both confined to faunule 2.

The presence of *Orbitolites complanatus* also defines the succession as Middle Lutetian. Other species with restricted ranges include *Quinqueloculina hexacostata*, *Miliola birostris*, *Flintina dameryana*, *Fabularia discolithes*, *Dendritina laevigata*, *Discorbis turbo*, *Planispirillina striatogranulosa*, *Dendritina juleana*, *Glabratella turbinata*, and *Vertebralina laevigata*. Altogether, 121 species have been identified from only 2513 individuals.

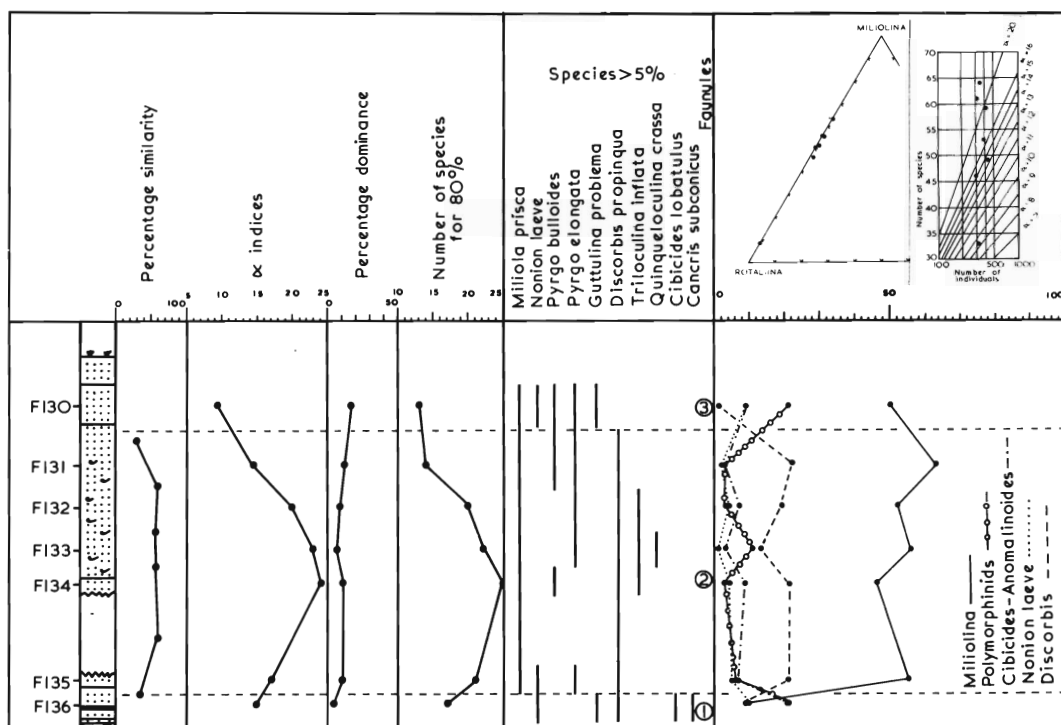
The microfauna includes thirty-two species of ostracods. The macrofauna from the samples includes abundant corals with *Sphenotrochus* and *Turbinolia* especially common. Gastropods include *Cerithium*, *Murex*, *Natica*, *Hipponyx*, *Mitra*, *Turritella*, *Pleurotoma*, *Olivella*, *Conus*, and *Rimella*. Bivalves are represented by *Cardita*, *Arca*, *Glycymeris*, *Corbula*, *Crassatella*, *Cardium*, and *Ostrea*. Also present are abundant serpulids, echinoids, calcareous algae, and bryozoa.

General features of the assemblages. The features discussed in this section are plotted in text-fig. 38. The similarity values pick out the changes in the composition of the assemblages at the top and bottom of the section. The Fisher α values fall in the range 9–24. When plotted against the succession there is a marked trend. In faunule 1 the α value is relatively low ($\alpha = 14$) but increases to a peak of $\alpha = 24$ in the middle of faunule 2. Then there is a gradual decline until $\alpha = 9$ in faunule 3. Percentage dominance values are consistently low (10.0–33.6%). The range of species contributing more than 5% to the population distinguishes three faunules, as previously discussed. However, these are accentuated when a plot of the distribution of the five most important groups is studied. The Miliolina and the discorbid species are both present in faunule 2, especially the Miliolina which increase from 8.6 to 55.5%. Both are consistently abundant in faunule 2 but show a slight drop in faunule 3. Opposing this trend, the polymorphinids, *Nonion laeve*, and the *Cibicides* species are all more abundant in faunules 1 and 3 and show a marked reduction during faunule 2. The general abundance of Miliolina can be seen in the triangular plot of the suborders (text-fig. 38).

Although not plotted, another interesting trend occurs in the distribution of the different genera which constitute the Miliolina. In faunule 3 and the base of faunule 2 (F130/135), the *Pyrgo* species make up 78.3 and 30.3% of the Miliolina. However, in the middle of faunule 2, their abundance drops to 11.4%. Opposing this trend, the *Quinqueloculina*, *Spiroloculina*, *Triloculina*, and *Miliola* species all have their greatest abundance in faunule 2 and decrease as the *Pyrgo* species increase.

LE GUÉPELLE

Location. The small sand pit is situated on the east side of the road from Paris to Senlis (N17), just to the north of the junction with the road to St Witz (D10). This



TEXT-FIG. 38. General features of the assemblages from Grignon.

junction is about 2 km south of Survilliers. The locality is situated virtually on the axis of the Bray anticline.

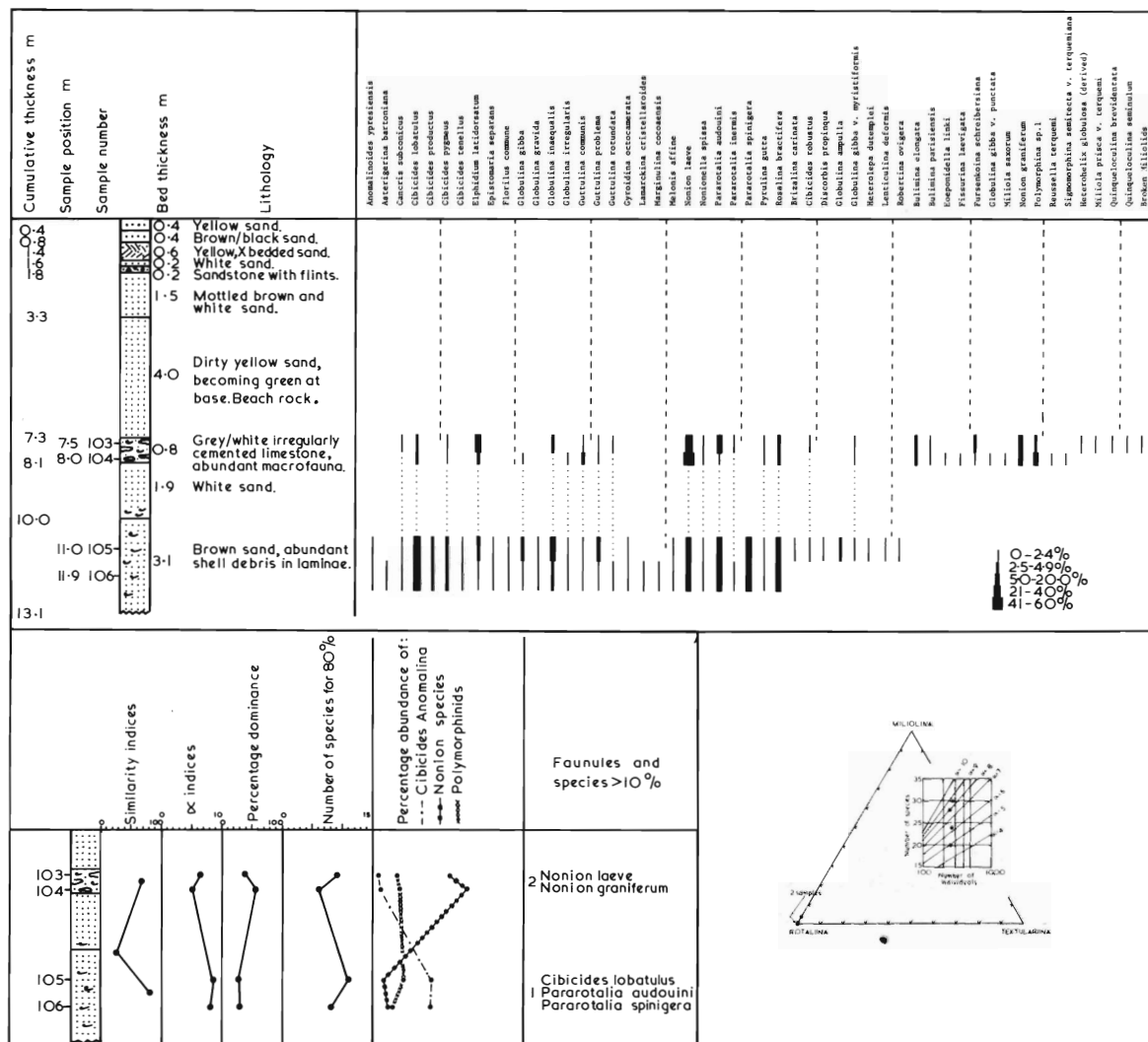
Previous work. L. and J. Morellet (1930) produced a generalized succession and a list of the abundant macrofauna. The molluscs were also included in the study by Furon and Soyer (1947). The most detailed work has been undertaken by Pomerol (1965) and Pomerol *et al.* (1965). These include studies of the heavy minerals, macro- and microfauna. The fossil mammals recovered have been the topic of a special study by Ginsburg, Montenat and Pomerol (1965). The foraminiferids have been described by Le Calvez (1970).

Succession. The succession is shown in text-fig. 39. A soil horizon passes down into a yellow sand which has a gradational lower contact with a black to brown mottled sand. This horizon is thought to be the fossil soil which marks the post-Auversian emersion (Pomerol *et al.* 1965). It is followed by yellow and white cross-bedded sands of possible wind-blown origin. Below an irregularly cemented sandstone band with flint pebbles, the underlying two beds are composed of mottled and dirty sands which have been interpreted as a beach deposit (Pomerol *et al.* 1965). Beneath is a highly distinctive horizon; a grey to white, irregularly cemented, nodular limestone and calcareous sand with an abundant macrofauna. This is the 'agrégat coquillier', the type level for the Guépelle Zone. Below this is a white sand and brown laminated sands with abundant shell debris and glauconite-rich laminae. It is thought that the

lowest 7.5 m of the section, recorded by previous authors, was not visible at the time of sampling.

Distribution of foraminiferids. In previous studies fifty-six species of foraminiferid have been identified. These assemblages have been characterized by an abundance of *Miliolina*. However, in the present study it has been found that miliolids are either rare or absent.

The range of the species and their percentage abundance is given in text-fig. 39 and Table 19 respectively. The range of species forming more than 10% to the population differentiates two faunules. Faunule 1, from the brown sands near the base, is dominated by *Cibicides lobatulus* (26.3–28.6%), *Pararotalia audouini* (12.2–15.7%),



TEXT-FIG. 39. Succession and distribution of foraminiferids from the Auversian of Le Guépelle.

and *Pararotalia spinigera* (5.4–9.8%). The associated macrofauna includes the bivalve *Meretrix* and the solitary coral *Turbinolia*. Faunule 2, from the type horizon, is dominated by *Nonion laeve* (37.4–56.2%), *Nonion graniferum* (6.4–13.7%), and to a lesser extent, *Elphidium latidorsatum*. The abundant macrofauna is dominated by gastropods (*Cerithium*, *Bayania*, *Ampullina*, *Batillaria*, *Turritella*, and *Hydrobia*) and bivalves (*Cardita*). Stratigraphically important species include *Cibicides pygmeus*, *Asterigerina bartoniana*, *Elphidium latidorsatum*, *Cibicides tenellus*, and *Polymorphina* sp. 1. Reworking of the Chalk is suggested by the presence of *Heterohelix globulosa*.

General features of the assemblages. The similarity values reveal a marked change in the fauna between the two faunules. The values of the diversity index α fall in the range $\alpha = 5-8\frac{1}{2}$. When plotted against the succession it is found that faunule 1 has the higher values. On the triangular plot of the suborders all the assemblages plot at or near the Rotaliina corner.

The percentage dominance values range from 26.3 to 56.2%, being highest in faunule 2. The number of species required to form 80% of the population varies from six to eleven, being highest in faunule 1. Both features relate to the trend in α values.

Finally, a plot of the dominant groups shows how the species change in abundance between the two faunules. Faunule 1 is dominated by species of *Cibicides* (36.4–37.8%) while *Nonion* species contribute only a small part of the fauna (6.5–9.0%). However, in faunule 2 the dominant species are reversed with *Nonion* species being most abundant (31.1–67.6%) and the species of *Cibicides* only meagrely represented (3.6–5.0%). The polymorphinids show no trend.

ERMENONVILLE

Location. The small pit is situated in the 'Bois de Perthes', to the north-east of Ermenonville. It is reached by turning right off the road from Meaux to Senlis (N330), in the centre of the town.

Previous work. Lemoine (1911) divided off the Lower Bartonian as the Ermenonvillian. However, later workers realized that this succession is only a lateral variant of the marine sands at Auvers. It is now called the Ermenonville Zone and placed at the same level as the Auvers formation.

The succession and fauna have been described by L. and J. Morellet (1925). Pomerol (1965) has produced an account of the grain size of the sediment, the heavy minerals, and the foraminiferids. The microfauna has also been described by Le Calvez (1970).

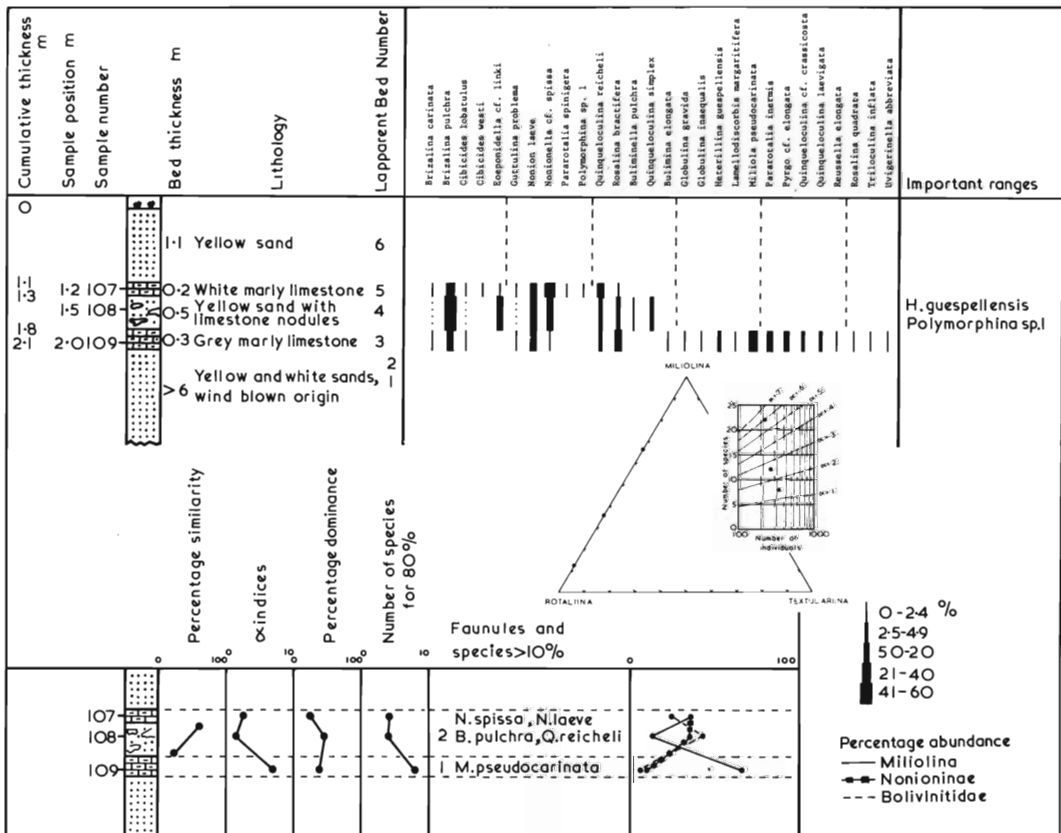
Succession. The lower part of the section was obscured but it was estimated that the yellow sands, at the base, extended beneath the cover for about 6 m, text-fig. 40. These sands have been assigned to the Guépelle Zone and are thought to be of wind-blown origin (Pomerol 1965). Overlying these are the deposits of the Ermenonville Zone, a series of thinly bedded, white or grey, marly limestones, interbedded with a yellow calcareous sand with irregular limestone nodules. These nodules are often loosely cemented shell concentrates. The section is completed by a series of yellow sands, attributed to the Beauchamp formation. The whole succession is equivalent to the Sables d'Auvers.

Distribution of Foraminiferids. The distribution of the foraminiferids and the general features of the assemblages are both plotted in text-fig. 40. The percentage abundance of the foraminiferids is given in Table 20.

The range of species contributing more than 10% of the population picks out two faunules. Faunule 1 is dominated by *Miliola pseudocarinata* (37.2%) and is associated with a rich macrofauna (*Cerithium*, *Batillaria*, *Turritella*, and *Potamides*). The presence of *Batillaria bouei* (Deshayes) confirms that faunule 1 corresponds to Bed 3 of Lapparent (1964). Faunule 2 is dominated by *Nonionella* cf. *spissa* (19.1–21.0%), *Nonion laeve* (14.5–15.8%), *Brizalina pulchra* (22.5–42.8%), and *Quinqueloculina reicheli* (3.2–12.3%). The associated macrofauna includes *Cerithium tiarella* Deshayes and large *Potamides mixtus* (Defrance). These species characterize Beds 4 and 5 of Lapparent. Also present are *Ancilla* and *Meretrix*.

Several of the species are important stratigraphically: *Heterillina guespellensis* and *Polymorphina* sp. 1.

General features of the assemblages. The similarity values suggest the presence of two faunules. The values for the diversity index α fall in the range $\alpha = 1\frac{1}{2}$ –6, being highest



TEXT-FIG. 40. Succession, foraminiferid distribution and general features of the assemblages from the Auversian of Ermenonville.

in faunule 1. The percentage dominance values are of the range 22.5–42.8% while the number of species required to form 80% of the population varies from four to eight. The greatest number of species occurs in faunule 1, equating with the increase in α values. A triangular plot of the suborders shows the three assemblages fall on the Miliolina–Rotaliina line. However, a plot of the three dominant groups provides an opportunity to study how the miliolid content varies. The Miliolina are most abundant in faunule 1 but exhibit a marked decline in the lower part of faunule 2 before increasing again. The Nonioninae and Bolivinitidae show exactly the opposite trend, being most abundant when the Miliolina are at their lowest.

LA CHAPELLE-EN-SERVAL

Location. The disused sand pit is situated on the north side of the road from La Chapelle-en-Serval to Plailly (D118), about 100 m from the bridge over the motorway (A1).

Previous work. Pomerol (1962, 1965) has described the section. Le Calvez and Pomerol (1962) and Le Calvez (1970) have discussed the foraminiferids. Lorenz and Pomerol (1965) also mentioned the locality in their discussion of the marginal marine Marinésian deposits.

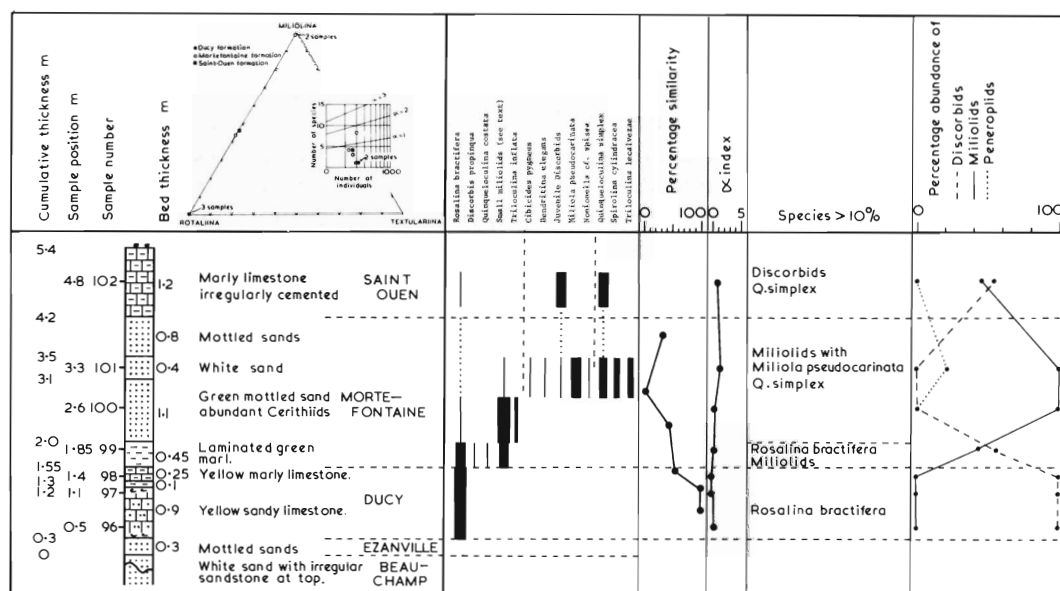
Succession. The pit is divided into two levels by the hard, resistant 'grès de Beauchamp'. This is an irregularly cemented sandstone of variable thickness with grooved top and bottom structures. It rests on the white sands of the Beauchamp formation. The sandstone was taken as a datum and the succession above it is given in text-fig. 41. The Ézanville and Mortefontaine formations are mainly mottled sands and laminated marls while the Ducy and Saint Ouen formations are made up of irregularly cemented marly limestones.

Distribution of foraminiferids. The percentage abundance of the foraminiferids is given in Table 21.

(a) Ducy formation. The foraminiferid assemblages are monospecific accumulations of *Rosalina bractifera*. These occur with ostracods (including *Cypris tenuistriata* Dollfus) and rare charophytes, *Raskyella pecki* L. and N. Grambast being the most common form. The macrofauna is dominated by myriads of small gastropods, including *Hydrobia*.

(b) Mortefontaine formation. In the lower part the assemblages are dominated by *Rosalina bractifera* and miliolids. The latter are difficult to identify because of their small size but include forms similar to *Quinqueloculina simplex* and *Triloculina lecalvezae*. These are accompanied by abundant smooth-shelled ostracods, and gastropods including *Bithinella*.

In the upper part of the formation *Rosalina bractifera* dies out and the assemblages are dominated by miliolids: *Quinqueloculina simplex*, *Triloculina lecalvezae*, and *Miliola pseudocarinata*. Peneroplids are also abundant (11.3%). The macrofauna exhibits a marked change with species of *Cerithium* and *Avicula* occurring in large numbers.



TEXT-FIG. 41. Succession, foraminiferid distributions, and general features, La Chapelle-en-Serval.

(c) Saint-Ouen formation. The foraminiferids are dominated by *Quinqueloculina simplex* and abundant juvenile discorbids which were previously misidentified as planktonic individuals (Milon 1930).

General features of the assemblages. The values for the diversity index α are less than 2. The highest values occur in the Mortefontaine formation. Percentage dominance values are extremely high as would be expected from the low diversity values. The percentage similarity values are low in the Mortefontaine formation, although the high dominance of *Miliolina* gives a general consistency to the fauna.

On the triangular plot of the suborders samples from the Ducy formation plot at the *Rotaliina* corner while assemblages from the Mortefontaine formation plot at the *Miliolina* corner. There is a complete absence of *Textulariina*. A plot of *Miliolina*, discorbid, and peneroplid percentage abundances against the succession brings out the major faunal features of each formation: Ducy—high discorbids, Mortefontaine—high *Miliolina* including peneroplids, Saint Ouen—high discorbids and *Miliolina*.

ÉZANVILLE

Location. The small pit is situated to the east of Ézanville, on the left side of the road to Écouen (N370).

Previous work. The succession and foraminiferid faunas have been described briefly by Pomerol (1965) and Le Calvez (1970).

Succession. Previous authors have recorded 21 m but due to its present overgrown state the authors could measure only 2 m of the succession.

The section commences with the Beauchamp formation, a series of grey and white sands capped by an irregular sandstone band. Balland and Cailleux (1951) have studied the top of this bed and conclude that the material, previously recorded as lignitic, is 'humus'. They interpreted the horizon as a fossil soil. The overlying Ézanville formation is composed of white and brown sands of possible aeolian origin (Pomerol 1965) and green sands with abundant macrofauna. At the top of the section only the basal part of the Ducy formation is exposed—a series of irregularly cemented marly limestones. The overlying Mortefontaine and Saint-Ouen formations are no longer visible.

Distribution of foraminiferids. Le Calvez (1970, p. 240) has recorded foraminiferids from the Beauchamp formation only. However, in the present study samples from the overlying beds have also yielded a microfauna (Table 22).

(a) Ézanville formation. A sample from the green sand yielded an assemblage dominated by *Rosalina bractifera* and small specimens of *Protelphidium* tentatively assigned to *Protelphidium* sp. 3. These occur with abundant gastropods including species of *Cerithium* and *Bayania*.

(b) Ducy formation. The marly limestones yield a monospecific assemblage of *Rosalina bractifera*.

General features of the assemblages. The Ézanville assemblage has a diversity of $\alpha = 1\frac{1}{2}$ and a percentage dominance of 80%. The sample is composed almost entirely of *Rotaliina* (98.5%).

The Ducy assemblage, with only one species present, is characterized by a diversity value of less than 1 and 100% *Rotaliina*. The percentage similarity between the two samples is only 15%.

LE RUEL

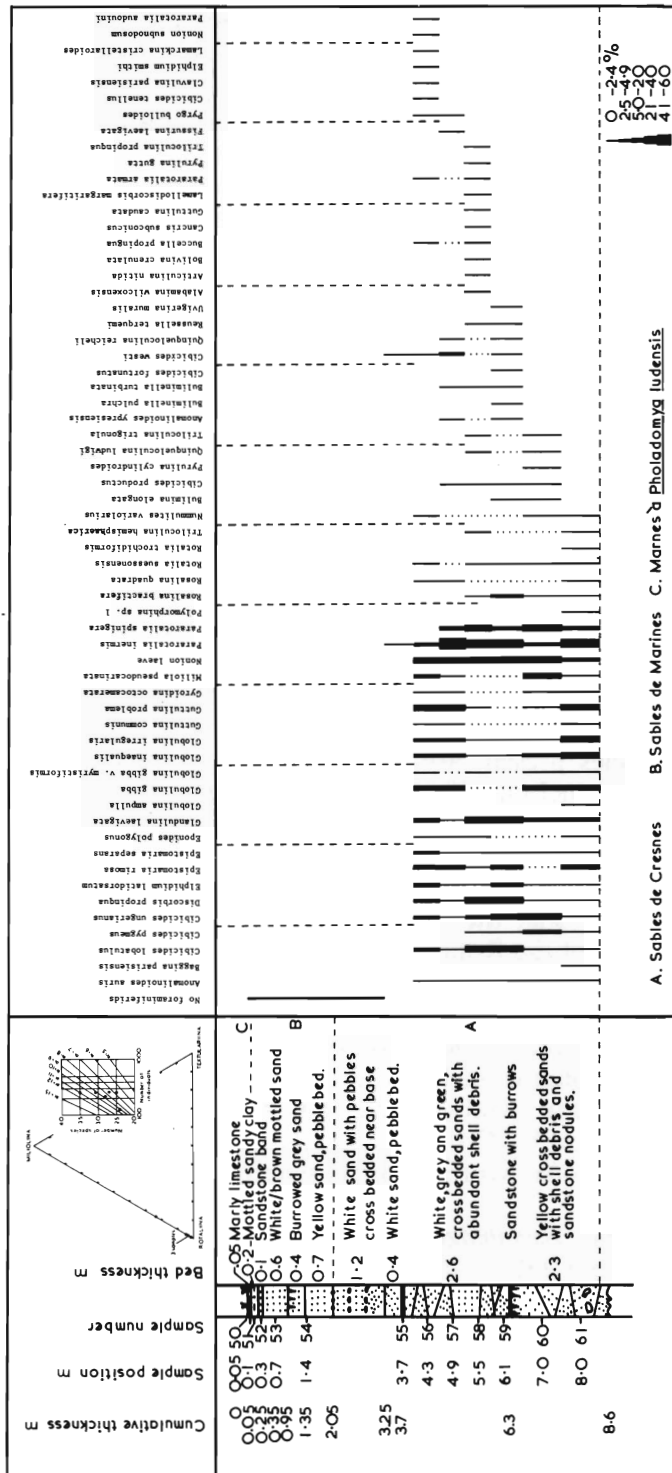
Location. The small sand pit is situated on the right-hand side of the road from Neuilly-en-Vexin to Le Quoniam, 100 m north of the village.

Previous work. The fauna has been described by Furon and Soyer (1947), L. and J. Morellet (1948), and Soyer (1960). The grain size of the sediment, heavy mineral content, and the microfauna have been described by Pomerol (1965). The foraminiferids have been listed by Le Calvez (1970). The complete fauna from Le Quoniam, a neighbouring pit at the same stratigraphic level, has been noted by Perreau (1968) and is useful for comparison.

Succession. The section comprises three formations: the Sables de Cresnes at the base, the Sables de Marines, and the Marnes à *Pholadomya ludensis* at the top.

The succession is given in text-fig. 42. As the base of the pit was obscured by slipped material, it was measured from the top.

The Marnes à *Pholadomya ludensis* are represented by a thin band of white marly limestone. The underlying Sables de Marines are composed of thin beds of unfossiliferous, mottled sand of white, brown, grey, or yellow colour. One band is a thin sandstone with a calcareous cement. This has a planar upper surface but an irregular lower margin and is very similar to the penecontemporaneously cemented



TEXT-FIG. 42. Succession and distribution of foraminiferids from the Sables de Cresnes, Marinesian, Le Ruel.

beach rocks described by Pomerol and Trichet (1969) from similar horizons in the Paris Basin. Also present are marked burrowed horizons where pipes of white sand pass down into the grey sands beneath.

Pomerol (1965) divided the underlying Sables de Cresnes into an upper, horizontally bedded and a lower, cross-bedded member. Below a small pebble bed, the sands are horizontally laminated with occasional thin cross-bedded units. Scattered throughout are well-rounded flint pebbles. Below a more distinctive pebble bed, the sands become strongly cross-bedded with only one thin laminated horizon. The sands are white, green, grey, or yellow in colour and packed with shells and shell debris which are aligned parallel with the cross-bedded units. Flint pebbles are absent. The sands have also suffered cementation which has resulted in irregular sandstone nodules and a sandstone band with burrows.

Distribution of foraminiferids. Pomerol (1965) and Le Calvez (1970) state that the foraminiferid faunas from this locality are poor, both in species and individuals. However, in the present study sixty-one species have been identified from counts of over 250 individuals per sample. The distribution of these forms is given in text-fig. 42 and their percentage abundance in Table 23.

The ranges of species forming more than 10% of the population show no definite faunules. The succession as a whole is characterized by the following dominant species: *Globulina gibba* (0–20·4%), *Pararotalia inermis* (3·0–40·7%), *Miliola pseudocarinata* (0–16·3%), *Cibicides lobatulus* (0·9–9·5%), *Discorbis propinqua* (0·45–12·9%), *Glandulina laevigata* (1·9–11·0%), and *Nonion laeve* (4·5–21·8%).

Several of the species present are important stratigraphically because of their restricted ranges. These include *Cibicides pygmeus*, *Cibicides ungerianus*, *Elphidium latidorsatum*, *Glandulina laevigata*, *Nonion subnodosum*, *Nummulites variolarius*, and *Cibicides tenellus*.

Although the cross-bedded nature of the sands points to active bed-load transport of both sediment and fauna, the foraminiferids are in a very good state of preservation. The majority of the Rotaliina are complete and have a shiny appearance. However, the Miliolina are in a poor state of preservation being either broken or represented by limonitic moulds.

The associated microfauna includes twenty-six species of ostracods and several of charophytes. The macrofauna includes abundant bryozoa, molluscs, corals, and calcareous algae. Common bivalves include *Corbula*, *Cardita*, and *Meretrix*, the gastropods are represented by *Cerithium*, *Ancilla*, *Ampullina*, and *Strepsidura* while the corals include *Turbinolia*. More extensive macrofaunal lists are in the literature.

General features of the assemblages. The similarity values are moderately high throughout the succession (48·4–66·3%) and give no definite clue to the position of any faunal boundaries.

The values for the diversity index α (text-fig. 42) fall in the range 7–11. When plotted against the succession, they show little obvious trend. On the triangular plot all the assemblages plot near the Rotaliina corner with the exception of one which contains 23·3% Miliolina. The percentage dominance values vary from 16·5 to 40·7% and eight to thirteen species are required to form 80% of the population.

Finally, a plot of the major groups shows that each becomes dominant at a different level. The polymorphinids reach their peak of abundance at the top and bottom of the section. Passing up the succession, first the *Miliolina* and then the *Cibicides*, *Nonion laeve*, and *Discorbis* group reach their peak. The only definite trend is that the polymorphinid distribution opposes that of *Cibicides*, *Discorbis*, and *Nonion laeve*.

CHAVENÇON

Location. Chavençon is situated about 7 km north of Marines and is reached by turning right off the road from Marines to Monneville (D28). From the centre of the village a cart track leads south across a valley towards a small wood. By turning right off this track and crossing a field on the border of the wood, one reaches a sunken lane banked by scree composed entirely of fossil gastropods and bivalves.

Previous work. The locality has been mentioned in several field guides and the foraminiferids have been briefly described by Le Calvez (1970, p. 243).

Succession. By excavating the bank, one may study a thin succession in the Eocene:

Marly limestone, white with brown mottling, yielding an abundant gastropod fauna	1.2 m
Brown sand with abundant small gastropods	0.3 m

These two beds have been previously attributed to the Marnes à *Pholadomya ludensis*, at the base of the Ludian.

Distribution of foraminiferids. Three samples have been studied for foraminiferids, one each from the marl and brown sand and one from the gastropod-rich scree which originates from the marly horizon. The percentage abundance of foraminiferids is given in Table 24.

The assemblage from the brown sand (F66) is dominated by *Elphidium latidorsatum* (55.8%) and *Protelphidium* sp. 3 (41.1%) and is similar to the fauna described by Le Calvez from this locality. The macrofauna is composed of small gastropods including *Hydrobia* and *Cerithium*.

The samples from the marly horizon (F64, 65) yield a completely different fauna, dominated by *Miliola* cf. *prisca* (21.0–21.6%), *Protelphidium* sp. 3 (1.3–13.6%), and *Quinqueloculina simplex* (14.6–29.8%). These are accompanied by abundant molluscs which include large gastropods, *Cerithium* and *Natica*. The bivalves include *Crassatella*, *Corbula*, *Cardita*, and *Chama*.

General features of the assemblages. A comparison of the two assemblages from the marly horizon produces a similarity value of 73.9%. However, a comparison of the assemblage from the marl with that from the brown sand results in a similarity of only 4.6%. In all three cases the diversity is low, $\alpha = 1-3$. The composition of the three assemblages by suborders reveals a dominance of *Miliolina* in the marly samples (77.7–97.3%) and a *Rotaliina* dominance in the assemblage from the brown sand (97.0%).

CORMEILLES-EN-PARISIS

Location. Carrière Lambert is cut into the south side of the hill at Cormeilles-en-Parisis in the north-westerly suburbs of Paris.

Previous stratigraphic work and succession. The most recent studies have been carried out by Cavelier (1964*b*) who described the section in detail. He recognized the following divisions:

<i>Lower Stampian:</i>	Thickness m
Sables de Fontainebleau	14.5
Sables et grès de Cormeilles	11.0
Argile à Corbules de Frépillon	1.3
Marnes à Huîtres supérieures	2.0
Plaquette à Hydrobies	0.1
Marnes à Huîtres inférieures	1.2
<i>Lower Stampian (Sannoisian Facies):</i>	
Calcaire de Sannois	3.2
Caillasses d'Orgemont	1.9
Argile verte de Romainville s.l.	7.2
<i>Ludian:</i>	
Marnes blanches de Pantin	(not given)

The correlation with the stages is based on Cavelier (1964*a*).

Most of the succession up to the Argile à Corbules is muddy with very little sand. Gypsum is present either as microscopic nodules or as conspicuous crystals or bands. Even the Calcaire de Sannois is muddy with hard cementstone bands. The muddiness of this succession contrasts strongly with the mainly sandy and calcareous deposits of the Eocene.

Distribution of foraminiferids. Samples 1700, 1699, and 1698 from the Ludian marls at the base of the succession were barren (one specimen of *Eoeponidella* in sample 1700). Sample 1697 from the Glaïses à Cyrènes at the base of the Argile verte de Romainville s.l. yielded a few *Quinqueloculina reicheli* and *Rosalina* sp. Sample 1696 from 1.25 m above the base of the Argile verte s.s. yielded an assemblage dominated by the same species. Two further samples from the middle and upper part of this formation had only a sparse fauna (1695, 1694). Similarly, the Caillasses d'Orgemont yielded few foraminiferids (1693) or were barren (1692).

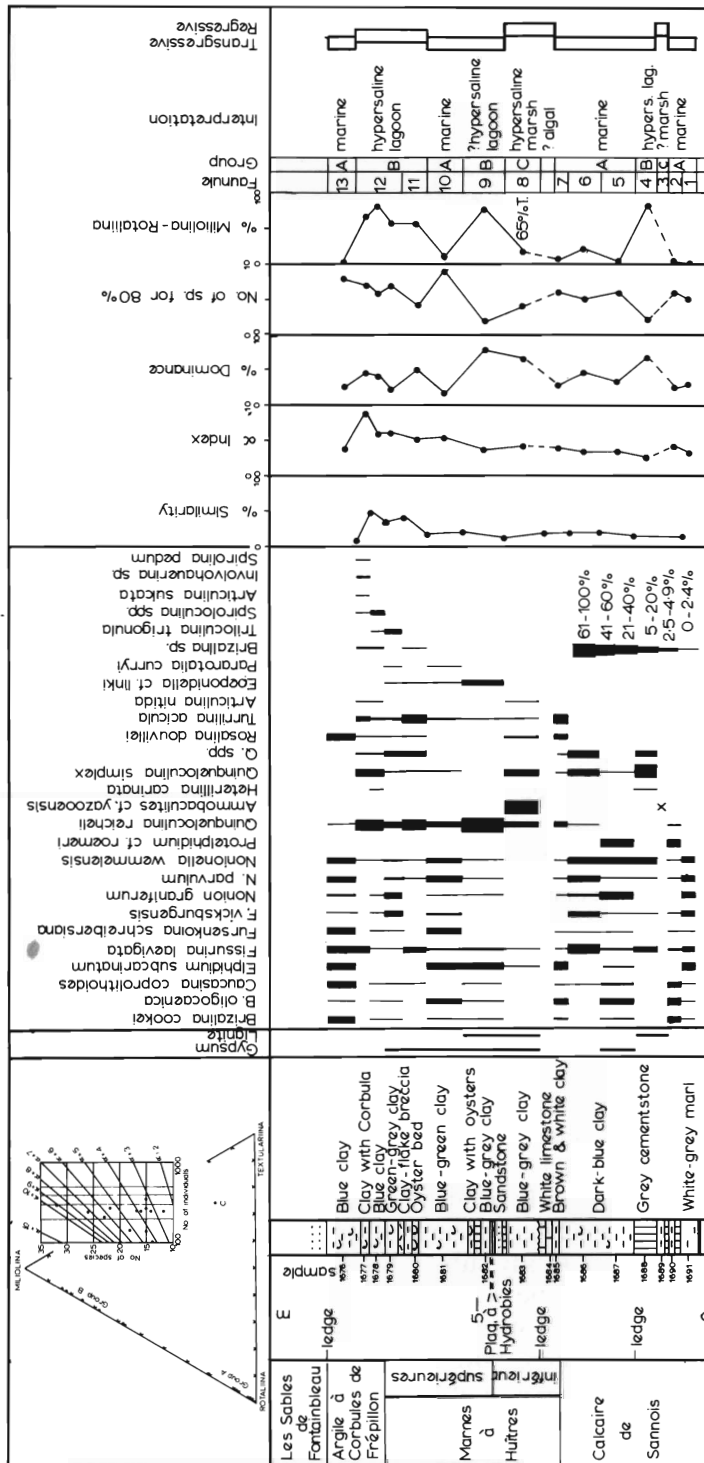
Foraminiferids make their first appearance in abundance at the base of the Calcaire de Sannois (text-fig. 43, Table 25). They continue throughout the succession to the top of the Argile à Corbules de Frépillon with the exception of the limestone represented by sample 1684 in the Marnes à Huîtres inférieures. The following faunules are recognized:

Faunule 1. *Elphidium subcarinatum*, *Fissurina laevigata*, *Nonion graniferum*, and *Nonionella wemmelensis*, 100% Rotaliina, diversity $\alpha = 3\frac{1}{2}$.

Faunule 2. *Brizalina cookei*, *B. oligocaenica*, *Elphidium* sp., and *Protelphidium* cf. *P. roemeri*, 97.2% Rotaliina, diversity $\alpha = 4$.

Faunule 3. *Ammobaculites* cf. *A. yazooensis*, rare.

Faunule 4. *Nonionella wemmelensis*, *Quinqueloculina simplex*, and *Quinqueloculina* spp., 82.6% Miliolina, diversity $\alpha = 2\frac{1}{2}$.



TEXT-FIG. 43. Succession and distribution of foraminiferids at Corneilles-en-Parisis.

Faunule 5. *Nonion graniferum* and *Protelphidium* cf. *P. roemeri*, 96.7% Rotaliina, diversity $\alpha = 3\frac{1}{2}$.

Faunule 6. *Fissurina laevigata*, *Nonionella wemmelsensis*, and *Quinqueloculina* spp., 79% Rotaliina, diversity $\alpha = 3$.

Faunule 7. *Brizalina oligocaenica*, *Elphidium subcarinatum*, and *Turrilina acicula*, 92.6% Rotaliina, diversity $\alpha = 4$.

Then follows a barren interval represented by a laminated, slightly bioturbated white limestone with laminae of quartz sand and calcified tubes which may represent filamentous algae.

Faunule 8. *Ammobaculites* cf. *A. yazooensis*, with subsidiary *Quinqueloculina reicheli*, 65.2% Textulariina, diversity $\alpha = 4\frac{1}{2}$.

Faunule 9. *Quinqueloculina reicheli*, 76% Miliolina, diversity $\alpha = 3\frac{3}{4}$.

Faunule 10. *Brizalina oligocaenica*, *Elphidium subcarinatum*, *Nonion parvulum*, and *Nonionella wemmelsensis*, 91.3% Rotaliina, diversity $\alpha = 5\frac{1}{2}$.

Faunule 11. *Quinqueloculina reicheli* and *Turrilina acicula*, 57.9% Miliolina, diversity $\alpha = 5\frac{1}{2}$.

Faunule 12. *Quinqueloculina reicheli*, *Q. simplex*, and *Quinqueloculina* spp., 56–84% Miliolina, diversity $\alpha = 6\frac{1}{2}$ –9.

Faunule 13. *Nonionella wemmelsensis*, *Elphidium subcarinatum*, and *Rosalina douvillei*, 98.1% Rotaliina, diversity $\alpha = 4$.

General features of the assemblages. The similarity values between adjacent samples (text-fig. 43) are remarkably low. This reveals the big differences between adjacent samples and accounts for the thirteen faunules. The diversity ranges from low to moderately high, $\alpha = 2\frac{1}{2}$ –9. Throughout the Calcaire de Sannois and most of the Marnes à Huîtres inférieures, the values are $\alpha = 2\frac{1}{2}$ – $4\frac{1}{2}$ but above this they rise to a peak in the Argile à Corbules. The percentage dominance is variable in the lower formations but less so in the Argile à Corbules. The number of species required to form 80% of the assemblage shows an inverse relationship to the percentage dominance.

On the triangular plot three groupings can be recognized:

- A. Rotaliina dominant: faunules 1, 2, 5, 6, 7, 10, and 13.
- B. Miliolina dominant: faunules 4, 9, 11, and 12.
- C. Textulariina dominant: faunules 3 and 8.

Interpretation. The low similarity values between adjacent samples and the recognition of so many faunules is a clear indication of varying environmental conditions.

The group A faunules on the triangular plot fall in the field of overlap of hypersaline and normal marine lagoons, seaward parts of hyposaline lagoons, and shelf seas. The diversity values suggest the same range of possibilities. The dominant genera in these faunules are: *Fissurina*, *Nonionella*, *Brizalina*, and *Turrilina*, all basically marine forms which commonly occur in muddy environments; *Quinqueloculina* spp. indicative of salinity $> 32\text{‰}$, shallow water (0–40 m generally) and commonly submarine vegetation or a sandy substrate; *Elphidium*, *Nonion*, *Protelphidium* which occur in marine to hyposaline waters in nearshore and marginal marine environments. Summarizing this information the faunules in group A are indicative of a shallow marine environment with normal salinity, muddy bottom, and possibly slightly turbid waters. The genera give no indication of temperature.

The group B faunules, dominated by Miliolina, fall in the field for hypersaline lagoons and partly in the field for normal marine lagoons on the triangular diagram

(text-fig. 2). The diversity values are consistent with these two possibilities. Each faunule is dominated by one or more species of *Quinqueloculina*. In modern environments this genus occurs at salinities $> 32\text{‰}$ mainly in temperate and tropical seas, at depths of 0–40 m on the inner shelf and in marine and hypersaline lagoons. In faunule 12 there are small numbers of *Articulina nitida*, *A. sulcata*, *Involvohauerina* sp., *Spirolina pedum*, and *Heterillina carinata*. The modern analogues of these forms are tropical or subtropical, shallow-water inhabitants which live in association with a weed cover in either slightly hypersaline or normal marine waters. Taking all these facts into consideration faunule 12 can be interpreted as slightly hypersaline (36–38‰?), subtropical (summer water temperature at least 22 °C), shallow (?5 m) lagoonal, with a muddy bottom and submarine vegetation on which the majority of the miliolids lived.

The other faunules in this group do not include clear indicator species for warm water except for faunule 4 (*Heterillina carinata*). Therefore, faunules 9 and 11 may represent otherwise similar environments in which the summer temperatures were not quite high enough to allow the warm-water species to reproduce. The generally low abundance of these marker species is consistent with their having lived close to the limit of their distribution.

Between samples 1680 and 1679 (within faunule 11) is a clay-flake-breccia which must have formed in the intertidal zone during a dry period. This adds support to the shallow-water interpretation of the foraminiferid assemblages.

Group C comprises faunules 3 and 8. The former is represented by a single specimen of *Ammobaculites* cf. *A. yazooensis*. The latter includes 65% of this species with subsidiary *Quinqueloculina reicheli*. On the triangular plot it falls in the fields for normal marine and hypersaline marshes. The diversity ($\alpha = 4$) is consistent with a hypersaline marsh. Additional evidence of hypersaline conditions is given by the occurrence of *Articulina sulcata*.

Thus, the environmental changes from the base of the Calcaire de Sannois up to the top of the Argile à Corbules de Frépillon are associated with small-scale transgressions and regressions of the sea (text-fig. 43).

Cavelier (1964a) considered the Marnes bleues d'Argenteuil to correspond '... des dépôts de lagune sursalé'. The Marnes blanches de Pantin have yielded freshwater and terrestrial fossils.

The Argile verte commences with the Glaïses à Cyrènes which Cavelier (1964a) regards as a lagoonal phase at the beginning of the Sannoisian transgression. Le Calvez (1970) records a few *Buccella propingua* from the base of the bed. She found the Argile verte s.s. to be no more fossiliferous than the Glaïses à Cyrènes. However, sample 1696 in this study yielded an assemblage dominated by *Quinqueloculina reicheli* and *Rosalina* sp. This indicates marine or even slightly hypersaline conditions. Cavelier (1968) considers the macrofauna to be brackish.

The Caillasses d'Orgemont at the base of the Sannoisian are unfossiliferous gypsiferous beds which Cavelier (1964a) considers to have been deposited in '... les lagunes sursaturées'. Le Calvez (1970) suggests that it was sufficiently hypersaline to be inimical to foraminiferids.

The Calcaire de Sannois was deposited by a slightly transgressive, shallow sea in which molluscs were abundant in individuals and poor in species indicating lower or

higher salinities than normal (Cavelier 1964a). This is basically in agreement with the present interpretation of a transgressive marine and hypersaline lagoon environment. Le Calvez (1966) considered the environment to be lagoonal and low in calcium carbonate because the foraminiferids are small.

Cavelier (1964a, b) interprets the Marnes à Huîtres as the product of a brackish water lagoonal epicontinental sea that showed small transgressions, marked by the oyster-rich layers, and small regressions, such as the Plaquette à Hydrobies. Oertli (1967) considered the salinity to be 25–30‰. Le Calvez (1970) thought that the salinity was more normal in the Calcaire de Sannois and Marnes à Huîtres inférieures than in the Marnes à Huîtres supérieures. This is not in agreement with the results presented here.

Finally, the Argile à Corbules de Frépillon was said by Le Calvez (1970) to have yielded few foraminiferids and she interpreted it to represent a higher salinity environment than that of the Marnes à Huîtres. This contrasts with the present interpretation of a normal marine environment which agrees with the view of Cavelier (1964b).

The interpretations offered here differ from others in emphasizing the marine to hypersaline nature of the environment. This is based largely on the abundance of the miliolaceans which are good environmental indicators in modern seas. Also the number of samples studied in the present investigation seems substantially greater than previously. Consequently, different parts of the same formation have different environmental interpretations.

PALAEOECOLOGY AND PALAEOGEOGRAPHY

The palaeoecological interpretation of the Oligocene succession at Corneilles-en-Parisis has already been discussed. In the Eocene it is possible to divide all the assemblages into four groups each of which is interpreted to represent a different environment.

(i) Assemblages dominated by *Cibicides*, *Nonion*, *Anomalinoides*, *Eponides*, *Textularia*, *Elphidium*, *Pararotalia*, and polymorphinids. These occur in cross-bedded and laminated sands with occasional flint pebbles, sandstone nodules, and burrowed horizons. In all cases, the diversity values are greater than 5, the range being $\alpha = 5-17$. All the assemblages plot at or near the Rotaliina corner in the triangular diagrams. Comparison with the plots for the recent data (text-figs. 1 and 2) shows that all the assemblages indicate fully marine conditions of normal salinity, either in a shelf sea or in a normal marine lagoon. However, all the species are typical shelf forms and the presence of *Elphidium* and *Nonion* suggests a depth range of 0–50 m. Few of the genera are good temperature indicators but the presence of abundant *Cibicides* suggests a cool-water aspect to the fauna. Temperatures may have been similar to those of the Western Approaches to the English Channel at the present time, i.e. a summer mean of 16 °C.

(ii) Assemblages dominated by Miliolina (including *Orbitolites*, *Fasciolites*, and peneroplids), *Discorbis*, *Cibicides*, *Nonion*, *Cancris*, *Valvulina*, and polymorphinids. These occur in calcareous sands rich in organic remains. All the assemblages have diversity values greater than 5, the range being $\alpha = 5-13$. Excessively high values

(e.g. Grignon, $\alpha = 14\text{--}24$) indicate a condensed sequence with little sediment being deposited during a prolonged period of biogenic production. On the triangular diagram these assemblages plot on or near the Miliolina–Rotaliina line, with up to 70% Miliolina. A comparison with the recent diversity data (text-fig. 1) suggests a normal marine shelf or lagoon. However, the triangular plot (text-fig. 2) indicates a trend towards a hypersaline environment. Some of the dominant forms are good environmental indicators:

(a) Modern examples of *Orbitolites* (i.e. *Marginopora*), *Vertebralina*, *Articulina*, and peneroplids live in shallow water (0–35 m) in close association with seagrass and seaweeds. They thrive in normal marine to hypersaline conditions (36–50‰) with water temperatures of 15–30 °C. Summer temperatures greater than 22 °C are necessary to facilitate successful reproduction (Wright and Murray 1972).

(b) Modern examples of *Discorbis* (e.g. *D. dimidiatus*) live in shallow water, 0–18 m, with temperatures of 18–26 °C and salinities of 39–56‰ or greater, in association with seaweed, seagrass, and calcareous algae.

(c) The general abundance of Miliolina indicates shallow-water conditions. Several species present in the French Eocene are known from the Mediterranean at the present time (J. and Y. Le Calvez 1958; Blanc-Vernet 1969). They occur in shallow, warm, slightly hypersaline water in close association with seagrass and algae. They are accompanied by arenaceous, rugose, and alveoline Miliolina, all of which are common in the miliolid dominated assemblages.

Therefore, these assemblages indicate shallow (0–35 m), slightly hypersaline water, 36–40‰ ($\alpha > 5$ makes it doubtful that conditions were fully hypersaline), temperature greater than 22 °C in summer, and a seaweed/seagrass flora. The fossil faunas result from the mixing of forms living on the seagrass with those from the sediment. The associated gastropod fauna, *Cerithium*, *Natica*, *Murex*, and *Conus*, is in accord with such conditions (Parker 1959).

(iii) Assemblages dominated by Miliolina including peneroplids. These have been recovered from sands rich in *Cerithium* and *Natica*. These faunas have diversity values of $\alpha = 1\text{--}3$. Comparison with the recent data (text-figs. 1 and 2) suggests abnormal marine conditions: hypersaline lagoon or marsh, or a nearshore shelf sea. Such assemblages are known from hypersaline lagoons (e.g. Murray 1973, Persian Gulf). They can tolerate salinities of 50‰ and temperatures of 25–27 °C. The macrofauna indicates a similar environment.

(iv) Assemblages dominated by a combination of *Rosalina* and/or *Protelphidium* and *Elphidium*. These have been recorded with abundant charophytes, smooth-valved ostracods, and *Hydrobia*. The diversity values are less than $\alpha = 2$ and the assemblages plot at the Rotaliina corner. Low diversity values indicate abnormal salinities (text-fig. 1). The presence of abundant *Protelphidium* indicates hyposaline conditions (see Murray 1968). The fauna indicates the development of a hyposaline lagoon with freshwater input.

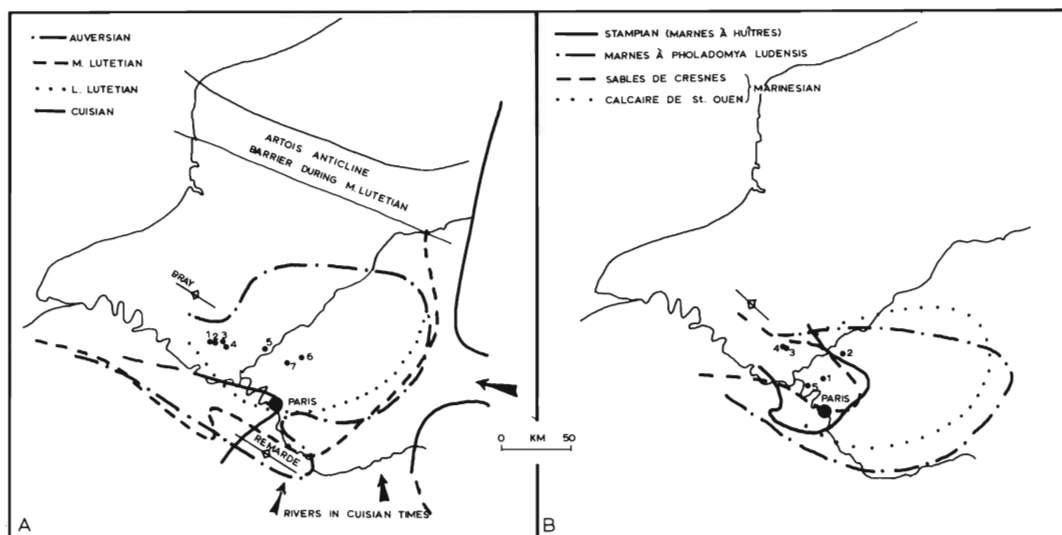
The palaeogeography of the Paris Basin has recently been discussed in detail by Pomerol (1967). In this study sufficient exposures were studied to build up a general biostratigraphic picture of the Eocene–Oligocene. However, it has not been possible to study geographic variation in faunas at any one time. The following discussion

of the palaeogeography is a résumé of that proposed by Pomerol with additional interpretation based on the foraminiferids.

The Paris Basin formed a shallow embayment of the sea in which a series of transgressions and regressions gave rise to five main sedimentary cycles: Thanetian, Ypresian, Lutetian, Bartonian, and Stampian. The limits of the transgressions were controlled partly by the penecontemporaneous development of gentle folds, especially the Artois, Bray, and Remarde anticlines.

Neither the Thanetian nor the basal Ypresian (Sparnacian) have been studied by the authors. The upper Ypresian (Cuisian) is represented by marine sands laid down in a transgressive sea. At Pierrefonds the assemblages are of type 1, dominated by *Cibicides*, *Anomalinoidea*, and polymorphinids, indicating a shelf sea not more than 50 m deep, and of normal salinity. Also present in abundance is *Nummulites planulatus*. Planktonic foraminiferids are rare. Similar assemblages are present at Mont de Magny, near Gisors, and at Hérouval. Here they contain, in addition, *Fasciolites oblonga* which by analogy with modern representatives indicates warm water (temperature $> 22^{\circ}\text{C}$). The Artois anticline which formed an emergent barrier between the Paris and Belgian Basins in the Sparnacian, was not in evidence during the Cuisian as it was presumably flooded by the transgressive sea. 'Belgian' species such as *Rosalina koeneni* and *Pulsiphonina prima* are present in the French assemblages. However, at the end of the Cuisian the sea regressed and only the Hérouval region remained submerged. In the Niveau d'Hérouval the assemblages are of types 1 and 2 with *Fasciolites oblonga*.

Pomerol (1967) considers the Lutetian to be a very good example of a sedimentary cycle. The Lower Lutetian was deposited by a transgressive sea. It consists of calcareous sands with glauconite and quartz grit (Calcaire Grossier: Chaumont-en-Vexin; Liancourt; Hérouval; Ronquerolles, Wright 1973). At each locality the foraminiferid assemblages are of type 1, dominated by *Cibicides*, *Nonion laeve*, polymorphinids, etc., and interpreted as shallow shelf, 0–50 m depth, of normal salinity. The full extent of the transgression was reached during the Middle Eocene (text-fig. 44). At Grignon, which is close to the Remarde Anticline, the lower part of the Middle Lutetian is lithologically similar to the transgressive Lower Lutetian elsewhere. However, the typical deposits of this time are the shell-sand limestones of the Calcaire Grossier. The foraminiferid assemblages are dominated by the Miliolina, including *Orbitolites*, *Fasciolites*, and peneroplids, together with various Rotaliina, such as *Discorbis*, *Nonion*, and *Cancris*. These assemblages are of type 2, interpreted as the product of a hypersaline sea (salinity 36–40‰), with a summer temperature greater than 22°C in the summer, a depth of not more than 35 m, a substrate of sediment banks, partially or wholly colonized by a seagrass flora, very clear water receiving little land run-off and free from sediment in suspension. The Calcaire Grossier consists mainly of biogenic debris showing that terrigenous detritus was being contributed in smaller amounts at this time. Pomerol (1967) notes that material ceased to be supplied from the Massif Central. Around the edge of the sea evaporites formed locally (Fontes and Lucas 1968; Tivollier and Létolle 1968). Pomerol (1967, p. 65) quotes evidence from $\text{O}^{18}/\text{O}^{16}$ analyses of bivalves showing the temperature to be 25°C in the Upper Lutetian. During this time the sea regressed to the west of the Basin probably leaving the Calcaire Grossier as a karstic limestone platform.



TEXT-FIG. 44. Limits of the transgressions in the Paris Basin (based on Pomerol 1967). A, Cuisian to Auversian (1, Mont de Magny; 2, Hérouval; 3, Chaumont-en-Vexin; 4, Liancourt; 5, Ronquerolles; 6, Ermenonville; 7, Le Guépelle). B, Marinesian to Stampian (1, Ézanville; 2, La Chapelle-en-Serval; 3, Le Ruel; 4, Chavençon; 5, Cormeilles-en-Parisis).

A further transgression of limited extent took place in the Bartonian. The continued existence of the Artois Anticline, and the development of the Bray Anticline, limited the embayment to the north (Blondeau *et al.* 1964). Pomerol (1967) interprets the variable sand facies of the Auversian (Lower Bartonian) as a beach and the deposits at Ermenonville as lagoonal. At Le Guépelle the lower faunule, dominated by *Cibicides* and *Pararotalia*, is of shallow shelf type. Faunule 2 above is composed of *Nonion* and *Elphidium*. This may represent an even shallower nearshore situation than faunule 1. Above this is beach rock (text-fig. 39) and a possible post-Auversian soil horizon (Pomerol *et al.* 1965). At Ermenonville the lower faunule is dominated by *Miliola pseudocarinata*. The high content of *Miliolina* suggests hypersaline conditions. Faunule 2, with *Nonion*, *Nonionella*, and *Brizalina*, indicates very shallow shelf conditions.

In the middle Bartonian, Marinesian, the sea readvanced over the tropical podsol soil to deposit the formation d'Ézanville (lagoonal-marine) followed in the centre of the Basin by the Calcaire de Ducy (lagoonal-lacustrine), Mortefontaine formation (lagoonal-marine), and the Calcaire de Saint-Ouen (lagoonal-lacustrine, Pomerol 1967).

At Ézanville the Ézanville formation yielded an assemblage of *Rosalina bractifera* and *Protelphidium*. This indicates a hyposaline lagoon. The Ducy formation above yielded a monospecific assemblage of *Rosalina bractifera*. This probably indicates a hyposaline tidal flat. At La Chapelle-en-Serval the Ducy formation yields the same fauna. The Mortefontaine formation shows a transition from a *Rosalina bractifera*—small miliolid fauna at the base to a *Miliolina*-rich faunule near the top. This indicates a change to hypersaline conditions in a lagoon (see text-fig. 41); the presence of

Spirolina cylindracea strongly supports this interpretation. The top 0.8 m are barren sands. Above this the Saint-Ouen formation has an assemblage of juvenile discorbids and *Quinqueloculina simplex*. This suggests a hypersaline tidal flat environment. Thus, these highly variable environments represent small shallow lagoons which were subject to periodic flooding with freshwater and periods of evaporation leading to hypersalinity.

While the Calcaire de Saint-Ouen was being deposited the Sables de Cresnes accumulated to the west. These sands are cross-bedded and are similar to the Auversian sands. The assemblages are dominated by polymorphinids, *Pararotalia*, *Cibicides*, *Nonion*, and *Miliola*. They represent a shallow nearshore shelf (Le Ruel). The Sables de Marines above were barren.

The Ludian (upper Bartonian) was initiated by the Marnes à *Pholadomya ludensis* transgression, interpreted by Pomerol as a hyposaline lagoon. At Chavençon a lower brown sand yielded an *Elphidium-Protelphidium* assemblage which would agree with this environmental interpretation. However, the marls above have a *Miliola*, *Quinqueloculina*, *Protelphidium* assemblage indicative of hypersaline conditions. Thus, the environment was probably similar to that of the Marinesian. The rest of the Ludian consists of the gypsum beds, the Marnes bleues d'Argenteuil, and the Marnes blanches de Pantin, which have not yielded foraminiferids.

The last marine episode was the Stampian transgression. The lower part of the Stampian (Sannoisian) lacks foraminiferids, but they are present from the Calcaire de Sannois to the Argile à Corbules (text-fig. 43). The palaeoecological interpretation has already been discussed in detail for the section at Cormeilles-en-Parisis. The environment fluctuated from marine to hypersaline lagoon and marsh.

To summarize, the Paris Basin formed a shallow embayment of the sea. Slow subsidence more or less kept pace with sedimentation but periodically it was greater, giving rise to transgression and at other times it was slower, giving rise to regression. The Cuisian sea was normal marine. Slightly hypersaline conditions developed in the Lutetian and locally they were sufficient to give rise to evaporites. The frequency of hypersaline conditions was greatest in the Stampian when land-run off must have been lower and the rivers were bringing down mainly muddy sediment. Text-fig. 44 shows the gradual restriction of the extent of the transgressions especially after the isolation of the Paris Basin by the Artois barrier.

BIOSTRATIGRAPHY

It is clear that the foraminiferids are facies controlled and their use in biostratigraphy must take this into account.

Many of the species are long-ranging as emphasized by Pomerol (1964, 1965), Blondeau *et al.* (1965), and Blondeau and Pomerol (1968a). However, text-fig. 45 shows that there are distinct associations at different times.

Many of the Cuisian species continue into the Lutetian but the Cuisian assemblages are much less diverse.

A large number of new species enter at the base of the Lutetian and many of these continue into the Bartonian. There are further new arrivals in the Middle Lutetian, Auversian, and Marinesian. Due to lack of exposure the Upper Lutetian was not

sampled. Le Calvez (1970) states that it is characterized by a Middle Lutetian fauna augmented by several new species: *Arenagula* (*Discorinopsis*) *kerfornei*, *Alveolina elongata*, and *Linderina brugesi*.

In the Ludian foraminiferids were sparsely present and of Bartonian type. The faunas of the Sannoisian and Stampian s.s. are quite distinct from those of the Bartonian.

The larger foraminiferids are mainly species of *Nummulites*. In the Cuisian *N. planulatus* occurs with *Fasciolites oblonga*. Both species are also present in the basal Lutetian deposits but they are thought to have been reworked from the Cuisian. The typical Lower Lutetian form is *N. laevigatus*. In the Middle Lutetian *Orbitolites complanatus* and *Fasciolites boscii* are present.

Planktonic foraminiferids are very rare. Brönniman *et al* (1968) and Bignot and Le Calvez (1969) have studied material from the same localities but do not agree on the nomenclature. The main feature is that Cuisian forms differ from those of the rest of the Eocene.

There is some disagreement with Le Calvez (1970) regarding the ranges of certain species. *Cibicides mauricensis* and *C. tallahattensis* occur throughout the Eocene according to Le Calvez but are here thought to be restricted to the Cuisian. *Asterigerina bartoniana* is likewise said to range through the Eocene although here it is thought to be restricted to the Bartonian. *Buccella propingua* is said to appear for the first time in the Oligocene but here it is thought to start in the Bartonian (Marinesian). These differences may be partly due to different understanding of the species and partly due to our more intensive sampling.

FRANCE: COTENTIN PENINSULA

On the Contentin peninsula there are several isolated areas of Eocene limestone. The best-known localities are Hauteville and Fresville described in great detail by Vieillard and Dollfus (1875). They divided the Eocene succession into three units:

- C. Coarse limestone with miliolids
- B. Calcareous sand with *Orbitolites*
- A. Nodular limestone with echinoids.

This succession rests unconformably on Chalk of Cenomanian and Maestrichtian age. Vieillard and Dollfus dated the Palaeogene deposits as Lutetian and correlated them with neighbouring French, English, and Belgian sections (*ibid.*, p. 178).

The succession at Fresville is 3.8 m thick and composed of Beds A and B. At Hauteville, 12.5 m of Bed C have been recorded, resting on *Orbitolites* limestone (B).

The lithology of the Lutetian deposits is very similar to that of core samples retrieved from the Western Channel. The beds are an accumulation of organic remains, varying from soft calcareous sands to hard compact limestones. They contain virtually no detrital material. The organic remains are fragments of bivalves, gastropods, echinoids, corals, bryozoa, and calcareous algae together with abundant large foraminiferids.

Several studies have been made of the rich and diverse fauna. The molluscs have been documented by Cossmann and Pissarro (1900–1903), and Canu (1907–1910) has

studied the bryozoa. Lists of foraminiferids have been published by Vieillard and Dollfus (1875), Curry (1960, Table 2), and Boillot and Le Calvez (1961, Table II). Adams (1962a) has made a special study of species of *Nubecularia* from these localities. Poignant (1964) has described *Lituonella* from Fresville.

Two samples of Lutetian material from Fresville and Hauteville (courtesy of D. Curry) have been studied for their general faunal constituents. The Fresville sample is from the calcareous sand with *Orbitolites* while the one from Hauteville is from Bed b5° (Vieillard and Dollfus 1875, p. 108), at the top of the lower half of the coarse miliolid limestone (C).

Both samples are characterized by their diversity (52 species have been recovered from the Hauteville material) and by the large size of the foraminiferids. *Orbitolites complanatus* attains a diameter of 7 mm, *Discorbis vesicularis* is up to 2 mm across, and *Gyroidinella magna* up to 4 mm across. All the suborders are represented: Textulariina—6 species, Miliolina—28 species, and Rotaliina—18 species.

In addition to the species previously recorded, new records include: *Quinqueloculina aspera*, *Quinqueloculina lippa*, *Triloculina inflata*, *Triloculina propinqua*, *Triloculina trigonula*, *Articulina contracta*, *Articulina nitida*, *Spirolina cylindracea*, *Discorbis perplexa*, *Rosalina excavata*, *Elphidium costiferum*, *Cancris subconicus*, *Rotalia discoides*, *Lockhartia* sp., and *Boldia claustrata*.

The Textulariina are represented by large specimens of *Valvulina*, *Valvulammina*, and *Clavulina*. Abundant Miliolina are characterized by large specimens of *Miliola*, *Fabularia*, and peneroplids with *Fasciolites* and *Orbitolites*. The Rotaliina include *Discorbis*, *Glabratella*, *Epistomaria*, *Cancris*, *Elphidium*, *Nonion*, and polymorphinids. Also present are large *Rotalia* and *Lockhartia*. The larger foraminiferids are represented by *Linderina* and *Fabiania* but *Asterocyclina* and *Gypsina* are rare or absent.

The abundance of large miliolids and the presence of *Fasciolites* and *Orbitolites* point to shallow, clear, slightly hypersaline water, subtropical temperatures, and a flourishing seagrass and seaweed flora. Several of the species present, *Quinqueloculina aspera*, *Quinqueloculina costata*, and *Triloculina trigonula*, have been recorded together from the Mediterranean. All are typical shelf forms, abundant in water up to 30 m deep and slightly hypersaline (38‰). The presence of *Discorbis* and *Glabratella* points to a seaweed cover. Adams (1962a) states that some *Nubecularia* specimens coiled around echinoid and polyzoan fragments but the remainder lived attached to seaweeds. Present-day species of *Nubecularia* are common in the Mediterranean, in shallow water associated with seagrass colonies (Blanc-Vernet 1969). Large specimens of *Rotalia* are common in subtropical and tropical seas at present. The restricted development of large benthic roataliids suggests that the salinity may have been too high for them. Therefore, the foraminiferids indicate a shallow sea less than 30 m deep with hypersaline water of 37–40 + ‰ salinity, subtropical with temperatures of at least 22 °C during the summer months and widespread seaweed and seagrass growths.

The macrofauna listed by Cossmann and Pissarro (1900–1903) is abundant both in the number of species and individuals. *Cerithium*, *Potamides*, *Murex*, *Conus*, and *Natica* are among some of the commoner genera. In a study of the macrofauna from the Laguna Madre, Texas, Parker (1959) noted that *Cerithium* distribution was closely tied to areas of hypersaline water (40‰). *Cerithium*-dominant assemblages occur in shallow-water areas with rooted seagrass and benthic algae. These conditions produce a large population of molluscs which live and feed on the flora.

Parker suggested that the high productivity was caused by the abundance of marine vegetation and the increased photosynthesis of the algae, upon which some of the molluscs feed. Curry (1960) observed that many of the species from the Cotentin were rock- and seaweed-haunting types. Therefore, it appears that the macrofauna supports the foraminiferid interpretation.

The palaeogeography of the Lutetian sea in this area was first reconstructed by Boillot (1964) who suggested a strait through the centre of the peninsula with a Cotentin to Jersey island to the north. However, more extensive offshore coring by Bignot, Hommeril and Larssonneur (1968) has not proved any Eocene to the east of the peninsula. These workers concluded that the Lutetian sea did not extend across the peninsula. Their palaeogeography has an embayment which extends into the Carentan Basin, includes Hauteville and Fresville, but closes to the east.

With the shallow depths envisaged, this area was little more than a lagoon with a narrow exit near Jersey. This extension of the shallow, clear, subtropical water produced an environment in which both flora and fauna flourished.

SUBMARINE OCCURRENCES

Submarine outcrops of Palaeogene rocks are now known from many places around southern Britain (text-fig. 46). A comprehensive bibliography of the geology of the English Channel has been given by Smith, Hamilton, Williams and Hommeril 1972.

Continental slope. Curry, Martini, Smith and Whittard (1962) reported Palaeogene chalks from the continental slope west of the English Channel. One station was dated as Upper Eocene (15/8, depth 460–770 m) and another as Middle–Upper Eocene (15/12, depth 930–1060 m). Planktonic foraminiferids *Hantkenina*, *Globanomalina* form 10–25% of the total. Also present is the benthic form *Gyroidinella magna*.

Stride, Curray, Moore and Belderson (1969) recognized undifferentiated Tertiary along the shelf edge and slope on the basis of geophysical work. They suggested Eocene to Miocene ages for these rocks based on projection of the above dated samples to the line of their geophysical traverses. They also showed that there is a trough of Tertiary deposits in the Western Approaches with a maximum thickness of about 4 km. Individual beds can be traced for at least 170 km laterally.

A sample from 48° 15' N. 9° 55' W. at 2500 m depth collected by the 'Alsace' was dated as Oligocene by Bourcart and Marie (1951). However, from the reported identifications of foraminiferids this cannot be considered reliable. It has therefore been omitted from text-fig. 46.

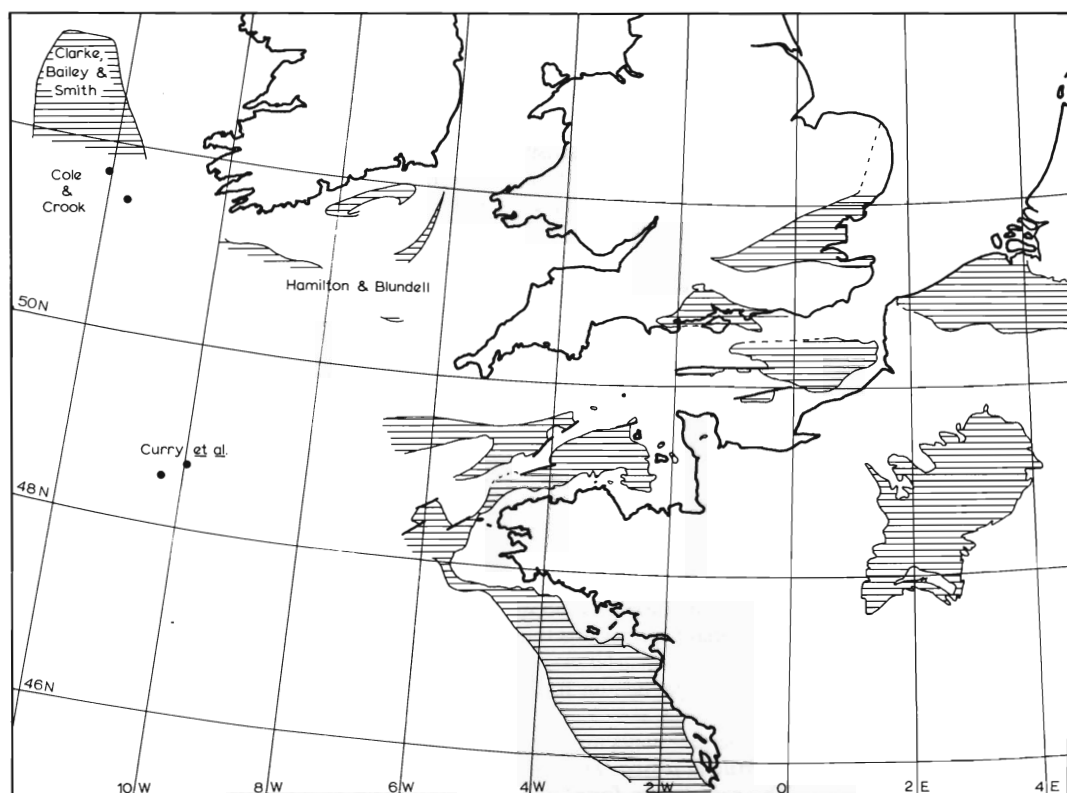
Celtic Sea. Preliminary results suggest the presence of Palaeogene deposits (Hamilton and Blundell 1971).

South-west of Ireland. Cole and Crook (1910) recorded miliolid limestones from a depth of 856 m and 1097–1207 m which they considered to be of Eocene age. This record is of interest in that it lies within the area of the Cainozoic trough postulated by Clarke, Bailey and Smith (1971).

Shelf south of Brittany. Bouysse and Le Calvez (1967), Andreieff, Boillot and Genesseeux (1968), Andreieff, Bouysse, Horn and Homer (1968), Andreieff, Boillot, Buge and Genesseeux (1969), Boillot, Bouysse and Lamboy (1971), and Vanney, Scolari, Lapiere, Martin and Dieuchon (1971) have described the Palaeogene deposits and their distribution.

The Upper Lutetian was divided into seven facies by Andreieff *et al.* (1969). Six of these were bioclastic limestones or sands with larger benthic foraminiferids and one was unfossiliferous dolomite. The assemblages closely resemble those described from the English Channel. The Bartonian is represented by a marly limestone with *Asterigerina bartoniana* and *Nummulites rectus*.

Western English Channel. The presence of Eocene deposits has been recorded by many workers: Worth (1908), King (1954), Curry (1960), Curry, Murray and Whittard (1965), Curry, Hamilton and Smith (1970, 1971), Eden, Wright and Bullerwell (1971), Boillot (1964), Bignot and Hommeril (1964), Bignot,



TEXT-FIG. 46. Submarine Palaeogene outcrops (horizontal shading; based on various authors).

Hommeril and Larssonneur (1968), Boillot and Le Calvez (1961), Lefort (1970a, b), Wright and Murray (1972), and Andreieff, Bouysse, Horn and Monciardini (1970, 1972).

Continental deposits of 'siderolithique' type have been reported from off Cherbourg (King 1954) and north of Roscoff (Boillot 1964).

The only record of 'Palaeocene' deposits is that of Andreieff and Lefort (1972) at two stations north of Brittany. These occur on the south edge of the mid-channel syncline. Grey sandy clays have yielded *Nonion acutidorsatum*, *Gyroidina* cf. *G. danvillensis*, *Siphonina prima*, and *Cibicides cunobelini* together with ostracods and nannoplankton.

However, if differences of nomenclature are taken into account (*N. acutidorsatum* = *Anomalinoides nobilis* of this paper; *G. danvillensis* = *G. angustumbilicata*; *Siphonina prima* = *Pulsiphonina prima*) then this assemblage is very similar to that of the London Clay (see text-figs. 5 and 11). A similar assemblage has been described by Curry (1962b) from the mid-Channel outlier.

The Lower Eocene is known from a single sample containing *Nummulites planulatus* (Curry *et al.* 1970). However, off the coast of Brittany the Lower Lutetian contains *N. planulatus* together with *N. laevigatus*, and Lefort (1970b) considers the former to be remanié from the Lower Eocene. In this area the Lower Lutetian rests unconformably on the armorican basement. In the Western Channel it is a calcareous glauconitic sandstone with *Nummulites* cf. *N. aturicus* (Curry *et al.* 1970).

The Upper Lutetian of the Roscoff region was divided into three facies by Boillot and Le Calvez (1961):

- (a) Littoral facies—breccias and sands with a calcareous cement. They contain glauconite, *Lithothamnium*, *Alveolina*, and smaller foraminiferids, shell debris, etc. These deposits are found at the contact with the armorican basement.

- (b) The 'facies coralligène'—organogenic and algal limestones. This is the common facies. *Lithothamnium*, foraminiferids, and shell debris are the principal components.
- (c) Dolomitic limestones and dolomites. The organic structures are largely destroyed. Boillot considers that this may represent the highest Lutetian deposits, formed in lagoons in the regressive sea.

Curry *et al.* (1970) summarized the Western English Channel occurrences of Upper Lutetian and noted that miliolids are abundantly present together with large rotaliids, but nummulites are generally absent: 'Characteristic fossils include *Orbitolites complanatus*, *Alveolina elongata*, *Gyroidinella magna*, *Fabiania cassis* and *Linderina brugesi*.' Andreieff and Lefort (1972) consider that the water was too shallow (< 20 m) for nummulites.

Wright and Murray (1972) carried out assemblage studies on the same samples. Four well-defined groups of assemblages were recognized:

- (a) *Cibicides*-dominant: *Cibicides* forms 28–83% of the total assemblage. Locally dominant species are *Quinqueloculina lippa* and *Pararotalia inermis*. The rare larger benthic foraminiferids are *Halkyardia minima* and *Linderina brugesi*. The sediment is muddy quartz sand.
- (b) Rotaliina-dominant: these assemblages are composed of 100–47% Rotaliina. *Rotalia lithothamnica* or *R. discoides* are dominant in all assemblages, together with *Miliola prisca* in some. Locally dominant forms include *Rotalia suessonensis*, *R. trochidiformis*, *Pararotalia armata*, *Epistomaria rimosa*, *Discorbis perplexa*, *Asterigerina carinata*, *Pyrgo bulloides*, and *Triloculina trigonula*. Larger benthic foraminiferids are present in low abundance: *Halkyardia minima*, *Linderina brugesi*, *Gypsina* sp., *Fasciolites boscii*, *Sphaerogypsina globulus*, *Orbitolites complanatus*, *Fabiania cassis*, *Asterocyclina stella*, and *Nummulites* spp. The sediments are shell sands.
- (c) Miliolina > Rotaliina: these assemblages also occur in shell sands. Miliolina form 51–70% of the total. *Miliola prisca* is the main dominant species together with *Rotalia lithothamnica* or *R. discoides*. Locally dominant species are *Nonion laeve*, *Discorbis perplexa*, *Pyrgo bulloides*, *Rotalia suessonensis*, *Triloculina trigonula*, and peneroplids. The larger benthic foraminiferids are the same as in the Rotaliina-dominant group.
- (d) Miliolina-dominant: again the sediments are shell sands. Miliolina form 80–98% of the assemblage. The dominant species are *Miliola prisca*, *Triloculina trigonula*, *Pyrgo bulloides*, *Fabularia discolithes*, and *Rotalia discoides*. The rare larger forms include *Halkyardia minima*, *Orbitolites complanatus*, *Fasciolites boscii*, and peneroplids.

Also present in the area are assemblages dated as Priabonian (i.e. Bartonian) by Curry *et al.* (1970) on the presence of *Nummulites fabianii*, *N. rectus*, *N. prestwichianus*, and *Halkyardia ovata*. The sediments are calcareous sandstones and fine-grained bioclastic limestones.

In the region around the Cotentin, Larssonneur (1971) has recorded lacustrine limestones from three stations. These contain charophyte oögonia, freshwater gastropods, and small foraminiferids identified as *Discorbis bractifera* (found in similar environments in the Paris Basin).

Andreieff *et al.* (1970) recorded a supposed Oligocene occurrence off Brittany. The dating was based on the presence of *Quinqueloculina reicheli* and *Halkyardia minima*. As both these forms occur in the Upper Lutetian–Auversian, the Oligocene date is not firmly established. In their 1972 paper this sample (C73) was recorded as Upper Eocene. However, another sample (C10) was considered to be Upper Oligocene to Lower Miocene in age although the microfauna was very mixed and included Cretaceous forms.

Andreieff and Lefort (1972) found two facies of the Oligocene north of Brittany. One sample from west of Brittany is a green clay with a sparse microfauna of *Rosalina douvillei*, *Elphidium subnodosum*, *E. rugosum*, and *E. cf. laeve*. This is correlated with the Lower Oligocene (Sannoissian facies) of the Paris Basin and the Lower Hamstead Beds.

The second facies, represented by two samples, is richly fossiliferous bioclastic limestone with *Falsocibicides aquitanicus*, *Pararotalia canui* (?*P. curryi*), *Rosalina bradyi*, *Stomatorbina concentrica*, *Elphidium repandus oligocaenicus*, *Elphidium minutum*, *Halkyardia minima*, and *Cymbalopora dalmatiana*. Boillot considers this to be similar to the Stampian of Aquitaine. A further two samples were also thought to be Stampian of Aquitaine type but from a near-reef environment.

Central and Eastern English Channel. The deposits have been described by King (1949, 1954), Curry (1962b), Dingwall (1969, 1971), Lapierre, Robert and Ville (1970a, b), Robert (1971), and Bignot (1972).

In mid-Channel, between the Isle of Wight and the Cotentin peninsula, is an outlier of Palaeogene

deposits (King 1954; Curry 1962b). The London Clay yielded *Cibicides cunobelini*, *Anomalinoides nobilis*, *Pullenia quinqueloba*, *Pulsiphonina prima* (= *P. chapmani* of Curry), and *Karreriella*, similar to that of the Hampshire Basin London Clay.

The Cuisian samples were more fossiliferous and yielded *Globigerina aquiensis*. The benthic foraminiferids are a mixture of English London Clay and French Cuisian species. The majority are 'French' but *Quinqueloculina imperialis* var. *porterensis*, *Pullenia quinqueloba*, *Alabamina obtusa*, and *Pulsiphonina prima* are common in the London Clay. All the samples contain derived benthic and planktonic Upper Cretaceous and Lower Palaeogene foraminiferids indicating erosion of these deposits.

Curry also reported the presence of clays with *Lingula*, carbonized plant remains, agglutinated foraminiferids, and pyrite, which he interpreted as possibly of London Clay age. An association of this type is suggestive of intertidal conditions and therefore of considerable palaeoecological significance.

Other, unfossiliferous, samples were thought to represent Reading Beds.

Larsonneur (1971) took a dredge sample from the centre of the syncline of this outlier. The pebbly sediment included blocks of ferruginous sandstone (believed to be *in situ*) and fine-grained quartz sands with a little mud, glauconite, and mica. The foraminiferids, identified by Blondeau, Le Calvez, Margerel, Rioult, and Weyant, included: *Nummulites laevigatus*, *N. variolarius*, *N. orbignyi*, *Pararotalia spinigera*, *Asterigerina bartoniana*, and *Quinqueloculina laevigata*. As many of these are Lutetian species, Larsonneur concluded that the succession here does not stop at the Cuisian. Also *Nummulites orbignyi* is a Belgian Basin species and its occurrence here is of special interest. (It has also been recorded from the Western Channel by Andreieff *et al.* 1972.)

The Mixen rocks off Selsey are composed of miliolid-alveolinid limestones which have been equated with Fisher Beds 21 and 22 at Selsey and Fisher Bed XVII at Whitecliff Bay (Adams 1962b). The extension of the Hampshire Basin east of the Isle of Wight has been shown by Dingwall (1969).

In the Eastern Channel there is an extensive area of Palaeogene deposits in the Dieppe Basin (Dangeard 1928; King 1949, 1954; Lapierre, Robert and Ville 1970b; Robert 1971; Bignot 1972).

Dangeard recorded rolled nummulites in eight dredgings in this area. South of Brighton he found a block of glauconitic limestone with miliolids, alveolinids, and *Orbitolites complanatus*. This can probably be dated as Upper Lutetian. Robert (1971) has interpolated information from the adjacent land to suggest that the Palaeogene in the Dieppe Basin commences with the Landenian and then passes up into the Ypresian and Lutetian. He further considers that Bartonian and even Stampian deposits may be present.

Bignot (1972) has established, on foraminiferal evidence, that the succession extends from the Ypresian to the Bartonian. The Ypresian is represented by sandy, glauconitic marls with a fauna comparable with that of the formation de Varangeville. This includes *Karreriella* cf. *mauricensis*, *Textularia adamsi*, *Angulogerina muralis*, and *Globigerina* cf. *aquiensis*. The Lutetian is the best represented stage. It occurs as sandy glauconitic limestones and marls with abundant miliolids, *Orbitolites* cf. *complanatus*, *Alveolina* cf. *boscii*, and *Nummulites laevigatus*. One sample is considered to be uppermost Lutetian because it contains *Discorinopsis kerfornei* in association with *Nummulites* cf. *variolarius*. Two others with *Orbitolites complanatus* and *Alveolina* cf. *elongata* are also dated as Upper Lutetian. Other samples of pyritic, glauconitic marls with *N. variolarius* are considered by Bignot to be of Bartonian (Auversian) age.

CORRELATION

Much has been written on the correlation of the English and French successions with one another and with those from other parts of Europe. Some of the general problems have been discussed by Curry (1967) and Berggren (1971). It can be seen from the palaeoecological interpretations offered here that, throughout the Palaeogene, conditions were variable both in space and in time. The occurrence of individual benthic species is dependent on the suitability of the environment. Each species has a partial range or even a discontinuous succession of partial ranges. This must be true also of the planktonic forms for these entered the area only when circulation was good and conditions temporarily favoured their existence.

Although the nummulites show the same order of arrival in the two basins this is

not so for many of the smaller benthic foraminiferids (compare text-figs. 20 and 45). This shows that migration was slow and also that mixing of 'English' and 'French' species was sometimes restricted.

Even within a single basin correlation is uncertain (see pp. 52–58 for the Hampshire Basin). It is, therefore, not surprising that many difficulties arise in correlating two separate basins. There is the additional problem of the numerous 'stages' and their different usage by different authors. For instance, Berggren (1971, Table 52.14) has pointed out that the 'Lutetian–Bartonian boundary does not necessarily correspond to an isochronous surface in the different basins'. This is probably true of all the Palaeogene stages as they are all associated with environmental changes.

A summary of the correlation of the Paris, Belgian, and Hampshire Basin successions has been presented by Curry, Gulinck and Pomerol (1969). The following notes offer some comments and speculations on slight modifications to the scheme.

It has already been suggested that the datum marked by the appearance of planktonic foraminiferids is useful for correlating the London Clay of the Hampshire Basin (Wright 1972a). At this level *Cibicides cunobelini* dies out. In the Paris Basin, at the top of the Sparnacian, *Cibicides cunobelini* and *C. succedens* die out. At the base of the Cuisian, in the Niveau d'Aizy, planktonic foraminiferids make their appearance (Le Calvez 1970, pp. 214–217). It is possible that the improved circulation which introduced the planktonic individuals might have affected both basins at the same time. If this is so the Lower and basal Middle London Clay (pre-datum) would correlate with the Sparnacian and the remainder would correlate with the lower part of the Cuisian (text-fig. 47).

The correlation of the Bracklesham Beds with the upper part of the Cuisian, the whole of the Lutetian, and the basal Bartonian is well established on the ranges of *Nummulites planulatus*, *N. laevigatus*, and *N. variolarius*. However, lithologically and environmentally, the Lutetian in the two basins is quite dissimilar and so too are the microfaunas apart from the nummulites.

Asterigerina bartoniana makes its first appearance in the Bartonian (Auversian) in the Paris Basin. In the Hampshire Basin it enters in the Upper Bracklesham Beds of Whitecliff Bay and is present also in the Middle and Upper Barton Beds at Barton. *Pararotalia inermis* appears in the French Auversian–Marinesian. In Hampshire it first appears in the Upper Barton Beds. *Elphidium latidorsatum* ranges from Auversian to Ludian in the Paris Basin and is present from Lower to Upper Barton Beds in Hampshire. It is possible, therefore, that the Auversian approximately equates with the uppermost Bracklesham Beds plus the Lower Barton Beds and the Marinesian with the Middle Barton Beds. This is in agreement with the proposal made by Curry *et al.* (1969).

The next level to yield foraminiferids is the Middle Headon Beds. New arrivals include *Pararotalia audouini* (Auversian–Marinesian in France), *Caucasina coprolithoides*, *Protelphidium* cf. *P. roemeri*, *Nonion parvulum* (Stampian s.l. in France), and *Turrilina acicula* (Stampian s.s. in France). The second and third species are present also in the Bembridge Beds. The Headon to Bembridge Beds have been correlated with the Ludian (Blondeau *et al.* 1965; Cavelier 1969; Curry *et al.* 1969). However, their foraminiferid faunas resemble those of the Sannoisian rather than the Ludian, although it has to be borne in mind that foraminiferids are rare in the upper

Ludian and basal Sannoisian in the Paris Basin. Nevertheless, for the first time in the Palaeogene there is great similarity in the foraminiferid faunas of the Hampshire and Paris Basins. If correlation was made on this evidence alone, the Middle Headon to Bembridge Beds would be equated with the 'Sannoisian' at Cormeilles-en-Parisis. Unfortunately, this conflicts with evidence from other fossil groups. Martini (1970b) has recorded a nannoplankton assemblage from the Brockenhurst Bed of Whitecliff Bay which he correlates with Zone NP20 of the Upper Eocene (= Sables de Grimmeringen of Belgium). He concluded that the 'Lower Oligocene' transgression started in Zone NP20 in England compared with Zone NP21 in northern Germany.

The ostracod *Hemicyprideis montosa* is the typical form of the Sannoisian facies of the Paris Basin. Keen (1971) recorded it from the Argile verte de Romainville and also from the overlying 'Couches de Sannois'. In the Hampshire Basin it occurs in the Bembridge Marls but principally in the Hamstead Beds. However, although this species is euryhaline its distribution is still controlled by the environment and its occurrences may not be isochronous. Considering the ostracod fauna as a whole, Keen (1972) found that the biggest break is at the base of the Sannoisian (between the Bembridge Oyster Marls and the Lower Hamstead Beds in the Hampshire Basin). In view of the opposing evidence from other faunal groups, the correlation proposed by Curry *et al.* (1969) has been retained in text-fig. 47.

The Upper Hamstead Beds yield *Brizalina cookei* and *B. oligocaenica* (Stampian

STAGE	SUBSTAGE	PARIS BASIN	HAMPSHIRE BASIN
STAMPIAN s.l.	SANNOISIAN	Marnes à Huîtres Calcaire de Sannois Argile Verte	Upper Hamstead Beds Lower Hamstead Beds
BARTONIAN	LUDIAN	Marnes blanches Marnes bleues Gypse Marnes à <i>Pholadomya ludensis</i>	Bembridge Beds Osborne Beds M. & U. Headon Beds Lower Headon Beds Upper Barton Beds
	MARINESIAN	Sables de Cresnes	Middle Barton Beds
	AUVERSIAN	Sables d'Auvers + facies	Lower Barton Beds Bracklesham Beds XVII - top
LUTETIAN	LUTETIAN	Calcaire Grossier (zones 1-4a, b)	Bracklesham Beds Fisher Beds VI-XVI of Whitecliff Bay
YPRESIAN	CUISIAN	Niveau d'Hérouval Niveau de Pierrefonds Niveau d'Aizy	Bracklesham Beds I-V Bagshot Sands Part of the Middle and Upper London Clay
	SPARNACIAN	Clays and lignites/Sinceny	Lower and part of the Middle London Clay Woolwich and Reading Beds
THANETIAN		Sables de Bracheux Tuffeau de la Fère	Reading Beds ?

TEXT-FIG. 47. Correlation of the Palaeogene successions in the Hampshire and Paris Basins. (Modified slightly from Curry, Gulinck and Pomerol 1969; Roman numerals = Whitecliff Bay succession.)

s.l. in France) in addition to *Caucasina coprolithoides*, *Nonion parvulum*, and *Protelphidium* cf. *P. roemeri*. Cavelier (1964c) used the short stratigraphic range of *Crassostrea longirostris* to suggest a correlation between the Upper Hamstead Beds and the Caillasses d'Orgemont to Marnes à Huîtres inférieures (i.e. Sannoisian) of the Paris Basin. The foraminiferids lend support to this correlation.

CONCLUDING REMARKS

The distribution of foraminiferid assemblages in the Eocene of the Hampshire Basin, Paris Basin, and Western Approaches/Cotentin area has been described. These assemblages have been used to determine the environmental conditions operating in each area. In these concluding remarks an attempt is made to place these various descriptive and interpretative sections into a regional setting.

A study of the distribution of species in the three areas reveals a marked faunal difference between the foraminiferids of the Hampshire Basin and those of the other two areas. This difference is obvious in an analysis of the three suborders:

Textulariina. Few species are common to both the Hampshire and Paris Basins. The agglutinated fauna in the Hampshire Basin is composed mainly of *Karrieriella*, *Textularia*, *Trochammina*, *Bolivinopsis*, *Spiroplectammina*, *Cribrostomoides*, and *Haplophragmoides* species. The assemblages from the Paris Basin and Western Approaches include *Arenagula*, *Valvulina*, *Valvulammina*, *Clavulina*, and *Textularia*.

Miliolina. Individuals and species of Miliolina are far more abundant in the Paris Basin and Western Approaches than in the Hampshire Basin. Costate, alveoline, and arenaceous miliolids are common in the southern region but rarely appear in the Hampshire Basin. The larger species such as *Orbitolites* and *Fasciolites* have a similar distribution. The majority of typically French species are recorded in the Hampshire Basin only during the Upper Bracklesham Beds (Fisher Beds XVII/21). When miliolids are present in some abundance in the Hampshire Basin assemblages, they are represented by only one or two species and not by the diverse faunas which characterize the French and Western Approaches Lutetian.

Rotaliina. The Rotaliina exhibit a number of distributional features:

(a) The London Clay in the Hampshire Basin has yielded a highly distinctive and restricted benthic fauna composed of *Praeglobobulimina*, *Pullenia*, *Uvigerina*, *Alabamina*, *Gyroidina*, *Anomalinoides*, *Cibicides*, and *Epistominella*.

(b) The assemblages from the Western Approaches are characterized by the presence of large Rotaliina such as *Gypsina*, *Asterocyclina*, *Halkyardia*, *Asanoina*, and species of *Rotalia* and *Pararotalia*. These forms are rare in the Lutetian and Bartonian of the Paris Basin and only present in the Upper Bracklesham Beds in the Hampshire Basin.

(c) Although the Paris Basin and Western Approaches Eocene have many species in common, the composition of the assemblages from the two areas is markedly different. The Paris Basin faunas are characterized by *Nonion*, *Elphidium*, *Cibicides*, and polymorphinids which are present even in the miliolid-dominated assemblages

of the Middle Lutetian. The Western Approaches faunas have *Rotalia* and *Pararotalia* as the additional forms in the miliolid assemblages.

(d) Some of the typically French species make a brief appearance in the Hampshire Basin during the Upper Bracklesham Beds (Fisher Beds XVII/21).

These faunal differences may be explained by the effect that the environmental parameters had on foraminiferid distribution during the Eocene.

Substrate. There are major differences in lithology between the three areas. In the Hampshire Basin the sediments are clays, sandy clays, and sands, often with abundant glauconite and plant debris. The Paris Basin was the site of accumulation of cross-bedded sands, biogenic calcareous sands, and rare marly limestones. The Western Approaches received a little detrital material and deposition resulted mainly from biogenic production in the area. A similar situation exists at present. The sediment in the western English Channel is mainly of biogenic origin (Boillot 1964).

The nature of the sediment had a great influence on the foraminiferid assemblages. The distinctive London Clay faunas are composed entirely of mud-loving species. *Epistominella vitrea* is a good indicator of rapid sedimentation of clay grade material. This species is abundant in the London Clay and is present throughout the English Eocene. However, it is either rare or absent in the other two areas. All of the London Clay species have been identified in the Belgian Basin (Kaasschieter 1961) where the sediment is also clay.

The differences in substrate are the direct result of the rivers which drained into the basins. The marine deposits in the Hampshire Basin are backed by an extensive region of sand and gravel which resulted from fluvial deposition on a fairly large scale. The presence of such a river system requires a suitable climate and drainage direction. The Hampshire Basin is surrounded by Cretaceous and Jurassic strata which would have provided an ample sediment source. All these features combined to make the Hampshire Basin the site of an influx of clay-laden, fresh water. The presence of sediment-laden rivers had another influence on the distribution of foraminiferids. The turbid muddy water restricted the development of a seagrass flora on which a large number of foraminiferids depended for a habitat. In France, rivers draining the surrounding massifs supplied sand but very little clay to the Paris Basin. Consequently, the clear water facilitated the occasional development of a seagrass flora. In the Western Approaches/Cotentin area, the complete lack of sediment input resulted in clear, shallow water in which seagrass, polyzoa, and calcareous algae flourished. Therefore the availability of a seagrass flora also controlled foraminiferid distribution.

Salinity. Salinity is considered to have had an important control on the development of the Eocene foraminiferid faunas. In the Hampshire Basin the influx of fresh water resulted in slightly hyposaline conditions (32–33‰) which are reflected by the foraminiferid faunas (α usually < 5). In the Paris Basin the Cuisian and Bartonian seas were of normal salinity with diverse *Cibicides*-dominated assemblages ($\alpha = > 5$). This difference in salinity again indicates the greater importance of freshwater input in the Hampshire Basin than in the Paris Basin. During the Lutetian in France and the Western Approaches/Cotentin area, salinities reached 38‰ and over. This

resulted from the combined effect of little freshwater input and increased temperatures. The hypersaline conditions allowed the development of miliolid-dominated assemblages with peneroplids and *Orbitolites*.

Temperature. The interpretation of water temperatures gives contrasting results. The presence of *Cibicides*-dominated assemblages in the English Eocene and French Cuisian and Bartonian is thought to reflect a cool-water influence on the fauna. A summer mean of 16 °C has been suggested. However, the peneroplid—larger foraminiferid faunas of the French Lutetian and Western Approaches/Cotentin region—indicate temperatures greater than 22 °C in the summer.

Sources of the faunas. The cool-water fauna is of northern and the warm-water fauna of southern origin. During the Palaeogene the changing environments associated with the subsidence, infilling, and progressive isolation of the Hampshire and Paris Basins by the development of penecontemporaneous 'folds', allowed the interplay of these two faunas. The Channel clearly was a path of migration although the Palaeogene rocks there give a very incomplete record of this. The northern fauna was dominant throughout most of the Palaeogene in the Hampshire Basin. Communication with the London Basin and North Sea area may have been across a shoal in the Wealden area. Periodically, southern forms derived from the Channel made successful but brief appearances. By contrast, in the Paris Basin the southern forms were much more successful in colonizing the area for long periods. The environmental contrasts of the three depositional areas makes precise stratigraphic correlation difficult.

FAUNAL REFERENCE LIST

The Palaeogene foraminiferids of the Paris Basin have recently been described by Le Calvez (1970) while those of the Belgian Basin have been discussed by Kaasschieter (1961) and Batjes (1958).

The authors examined the foraminiferid collections housed in the British Museum (Natural History) and the Musée d'Histoire Naturelle, Paris. These included the Bhatia, Heron-Allen and Earland, Venables, Williamson, d'Orbigny, Le Calvez, and Terquem collections. Many of the holotypes of species mentioned in this paper were examined and compared with our material. For brevity each named species is listed with the original name, author, and date. This provides all the information necessary to find the species in the Catalogue of Foraminifera (Ellis and Messina 1940 et seq.). All generic designations follow those of Loeblich and Tappan (1964). Notes have been added for a few species including the *Protelphidium*–*Nonion* groups. The species marked with an asterisk are illustrated in the plates. Most of the other species are illustrated in Le Calvez (1970), Batjes (1958), and Kaasschieter (1961). A set of hypotypes has been presented to the British Museum (Natural History).

Unfortunately, in this brief list it is not possible to discuss the variability displayed by individual species. It is perhaps worth noting, however, that there is variability both on a geographic scale and also from one time to another.

The Protelphidium-Nonion problem. Throughout the Eocene and Oligocene there are 'nonionid' forms which have the following characteristics in common: planispiral, compressed tests, with 8-9 chambers (rarely 7-10) in the outer whorl, gently curved sutures, umbilici infilled with tubercular ornament, interiomarginal aperture consisting of a row of pores, or a slit with tubercular ornament that resembles a row of pores. Each species shows a wide range of morphological variation.

By using wall structure these species can be divided into two groups. Those with radial calcitic walls are referred to *Protelphidium* and those with granular calcitic walls to *Nonion*. However, in the past wall structure was ignored and often little allowance was made for variability. Many species were erected and the type illustrations and type descriptions are inadequate. This makes identification, without the examination of types, almost impossible. We have therefore been cautious in naming representatives of these genera.

**Protelphidium* sp. 1, Plate 12, figs. 12, 13.

Characterized by a relatively small amount of umbilical tubercular material. The periphery is subacute. The sutures are narrow and deeper toward the umbilicus. Diameter 0.30 mm. Thickness 0.12 mm. (Bed E, Barton Clay.)

**Protelphidium* sp. 2, Plate 12, figs. 14, 15.

The umbilici are only slightly depressed and are strongly ornamented with tubercles. The latter also extend along the sutures. The periphery is rounded. The chambers are slightly more inflated than in *Protelphidium* sp. 1. Diameter 0.28 mm. Thickness 0.10 mm. This shows some similarities with the species described by d'Orbigny as *Nonionina granosa*. (*Nummulites planulatus* bed of Whitecliff Bay.)

**Protelphidium* sp. 3, Plate 13, figs. 1, 2.

This species resembles *Nonion graniferum* but it has a radial calcitic wall. The chambers are inflated. The periphery is rounded and lobulate. The umbilici are slightly depressed and are filled with tubercular ornament that also extends into the umbilical ends of the sutures. Diameter 0.20 mm. Thickness 0.10 mm. (Chavençon, Ézanville.)

**Protelphidium* cf. *P. roemeri* (Cushman), Plate 13, figs. 5, 6. = *Nonion roemeri* Cushman, 1936.

Cushman's specimens were from the Upper Oligocene of Germany. The British specimens have 8-10 chambers in the outer whorl. The periphery is rounded and lobulate. The chambers are moderately inflated. Tubercular ornament extends from the umbilici into the umbilical ends of the sutures. Commonly there is an umbilical knob in each umbilicus but this feature is not always present. Diameter 0.26 mm. Thickness 0.13 mm. The internal structure has recently been discussed by Langer (1967). (Middle Headon Beds.)

**Protelphidium* sp. 4, Plate 13, figs. 3, 4.

The chambers are inflated, the periphery rounded and lobulate. The sutures are deep, especially near the umbilici. The latter are ornamented with tubercles. The wall is fairly coarsely perforate. Diameter 0.16 mm. Thickness 0.07 mm. (Middle Headon Beds and Lower Hamstead Beds.)

**Nonion graniferum* (Terquem), Plate 13, figs. 7, 8. = *Nonionina granifera* Terquem, 1882.

The characteristic feature is the wide umbilicus with large tubercular ornament. The wall structure is granular calcitic. Diameter 0.26 mm. Thickness 0.10 mm. (Common throughout.)

**Nonion laeve* (d'Orbigny), Plate 13, figs. 9–13. = *Nonionina laevis* d'Orbigny, 1826.

This species shows variation with time. Two forms are present in the Cuisian and Lutetian of France. One has a large umbilical boss with a marginal, tuberculate, furrow; the sutures are depressed and narrow rapidly to the margin; the chambers are broad and the periphery rounded in section (Pl. 13, figs. 9, 10). The second form has either a very small boss or a tuberculate umbilical infilling; the sutures are deeply depressed and maintain their width to the periphery; the chambers are much narrower and the periphery is broadly rounded (Pl. 13, fig. 11). Specimens from higher in the Eocene possess a small umbilical boss which is joined to the inner margins of the chambers so there is no marginal furrow; the chambers are more numerous (10–12). The specimens from England are larger than the typical French forms, have more chambers (10–14), and possess a large umbilical boss which is joined to the inner margin of each one; the sutures are only slightly depressed and have few tubercles. Similar forms from the Middle Headon Beds were named by Bhatia *Nonion laeve* (d'Orbigny) var. *subexcavatum* Bhatia (1955). Specimens from the French Oligocene have a small umbilical knob with marginal furrow and deeply incised sutures (Pl. 13, figs. 12, 13). Specimens with more numerous chambers (20) are commonly assigned to *N. subnodosum* (Munster). Transitional forms are common in the Oligocene. Although some authors assign these species to *Elphidium*, the wall structure is granular in all the examples examined by us.

**Nonion parvulum* (Grzybowski), Plate 13, figs. 14, 15. = *Anomalina parvula* Grzybowski, 1896.

This distinctive species has five chambers in the outer whorl and small, deep umbilici. The aperture is an interior marginal slit. As the species appears to be planispiral rather than trochospiral it is here placed in *Nonion* rather than *Anomalina*. Diameter 0.26 mm. Thickness 0.14 mm. (Oligocene, France.)

MAIN LIST OF SPECIES

- **Alabamina obtusa* (Burrows and Holland) = *Pulvinulina exigua* (Brady) var. *obtusa* Burrows and Holland, 1897. Plate 19, figs. 1, 2.
- **Alabamina wilcoxensis* Toulmin, 1941. Plate 18, figs. 12, 15, 16.
- Ammobaculites* cf. *A. pseudostrostratus* Bandy, 1949.
- **Ammobaculites* cf. *A. yazoensis* Bandy, 1949. Plate 1, fig. 1.
- **Anomalinoides acuta* (Plummer) = *Anomalina ammonoides* (Reuss) var. *acuta* Plummer, 1926. Plate 19, figs. 3, 4, 7.
- **Anomalinoides acuta* (Plummer) var. *anomalinoides* (Ten Dam) = *Cibicides anomalinoides* Ten Dam, 1944. Plate 19, figs. 5, 6, 8.
- **Anomalinoides auris* (Le Calvez) = *Anomalina auris* Le Calvez, 1949. Plate 19, figs. 9–11.
- Anomalinoides danica* (Brotzen) = *Cibicides danica* Brotzen, 1940.
- **Anomalinoides nobilis* Brotzen, 1948. Plate 19, figs. 12–14.
- **Anomalinoides ypresiensis* (Ten Dam) = *Cibicides ypresiensis* Ten Dam, 1944. Plate 19, fig. 15; Plate 20, figs. 1, 2.
- Arenagula kerfornei* (Allix) = *Lituonella kerfornei* Allix, 1922.
- **Articulina contracta* (Terquem) = *Vertebralina contracta* Terquem, 1882. Plate 5, figs. 9, 14.
- **Articulina foveolata* Heron-Allen and Earland, 1909. Plate 5, fig. 15.
- **Articulina gibbosula* d'Orbigny, 1846. Plate 5, figs. 7, 8.
- **Articulina laevigata* Terquem, 1882. Plate 5, figs. 16, 22.
- **Articulina nitida* d'Orbigny, 1826. Plate 5, fig. 12.
- Articulina* cf. *A. sulcata* Reuss, 1850.
- **Asterigerina bartoniana* (Ten Dam) = *Rotalia granulosa* Ten Dam, 1944, renamed *Rotalia bartoniana* Ten Dam, 1947. Plate 10, figs. 4–6.
- Asterigerina carinata* d'Orbigny, 1839.
- Asterigerina glabra* (Bermudez) = *Asterigerinata globulospinosa* (Cushman) var. *glabra* Bermudez, 1952.
- Asterigerina* cf. *A. guerrai* (Bermudez) = *Asterigerinata guerrai* Bermudez, 1952.
- Asterocyclina stella* (Gümbel) = *Hymenocyclus stella* Gümbel, 1861.
- **Baggina parisiensis* (d'Orbigny) = *Globigerina parisiensis* d'Orbigny, 1826. Plate 10, fig. 1.

- Boldia claustrata* (Terquem) = *Rotalina claustrata* Terquem, 1882.
Boldia lobata (Terquem) = *Rotalina lobata* Terquem, 1882.
- **Bolivina crenulata* Cushman, 1936. Plate 6, fig. 12.
- **Bolivinopsis adamsi* (Lalicker) = *Spiroplectammina adamsi* Lalicker, 1935. Plate 1, figs. 2, 3.
- Brizalina anglica* (Cushman) = *Bolivina anglica* Cushman, 1936.
- Brizalina bundensis* (Hantken) = *Textularia bundensis* Hantken, 1875.
- Brizalina carinata* (Terquem) = *Bolivina carinata* Terquem, 1882.
- **Brizalina cookei* (Cushman) = *Bolivina cookei* Cushman, 1922. Plate 6, fig. 13.
- Brizalina gracilis* (Cushman and Applin) = *Bolivina gracilis* Cushman and Applin, 1926.
- **Brizalina oligocaenica* (Spandel) = *Bolivina oligocænica* Spandel, 1909. Plate 6, fig. 14.
- Brizalina pulchra* (Terquem) = *Bulimina pulchra* Terquem, 1882.
- **Buccella propingua* (Reuss) = *Rotalia propingua* Reuss, 1856. Plate 8, figs. 2, 3, 7.
- Bulimina elongata* d'Orbigny, 1846.
- Bulimina parisiensis* Kaasschieter, 1961.
- Bulimina pupoides* d'Orbigny, 1846.
- Bulimina simplex* Cushman and Parker var. *colwellensis* Bhatia, 1955.
- Bulimina tenuistriata* Terquem, 1882.
- Buliminella bullina* Le Calvez, 1950.
- Buliminella elegantissima* (d'Orbigny) = *Bulimina elegantissima* d'Orbigny, 1839.
- **Buliminella pulchra* (Terquem) = *Bulimina pulchra* Terquem, 1882. Plate 6, fig. 10.
- **Buliminella turbinata* (Terquem) = *Bulimina turbinata* Terquem, 1882. Plate 6, fig. 11.
- **Cancris subconicus* (Terquem) = *Rotalina subconica* Terquem, 1882. Plate 9, figs. 12–14.
- Cassidella dibollensis* (Cushman and Applin) = *Virgulina dibollensis* Cushman and Applin, 1926.
- Catapsydrax dissimilis* (Cushman and Bermudez) = *Globigerina dissimilis* Cushman and Bermudez, 1937.
- **Caucasina coprolithoides* (Andreae) = *Bulimina coprolithoides* Andreae, 1884. This includes *Buliminella carteri* Bhatia, 1955. Plate 17, fig. 7.
- Ceratobulimina tuberculata* Brotzen, 1948.
- Cibicides burlingtonensis* Jennings, 1936.
- **Cibicides carinatus* (Terquem) = *Truncatulina carinata* Terquem, 1882. Plate 15, figs. 4–6.
- **Cibicides cunobelini* Haynes, 1957. Plate 15, figs. 7–9.
- **Cibicides fortunatus* Martin, 1943. Plate 15, figs. 10–12.
- **Cibicides lobatulus* (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1798. Plate 15, figs. 13–15.
- **Cibicides mauricensis* Howe and Roberts, 1939. Plate 16, figs. 1, 2.
- **Cibicides productus* (Terquem) = *Truncatulina producta* Terquem, 1882. Plate 16, figs. 3–5.
- Cibicides pseudoungerianus* (Cushman) = *Truncatulina pseudoungeriana* Cushman, 1922.
- **Cibicides pygmeus* (Hantken) = *Pulvinulina pygmea* Hantken, 1875, Plate 16, figs. 6–8.
- Cibicides refulgens* de Montfort, 1808.
- Cibicides robustus* Le Calvez, 1949.
- **Cibicides simplex* Brotzen, 1948. Plate 16, figs. 9–11.
- Cibicides tallahattensis* Bandy, 1949.
- **Cibicides tenellus* (Reuss) = *Truncatulina tenella* Reuss, 1865. Plate 16, figs. 12–14.
- **Cibicides ungerianus* (d'Orbigny) = *Rotalina ungeriana* d'Orbigny, 1846. Plate 16, fig. 15; Plate 17, figs. 1, 2.
- **Cibicides westi* Howe, 1939. Plate 17, figs. 3, 5.
- **Cibicoides proprius* Brotzen, 1948. Plate 20, figs. 3, 5, 6.
- Cibicoides proprius* Brotzen var. *acutimargo* (Ten Dam) = *Cibicides proprius* (Brotzen) var. *acutimargo* Ten Dam of Kaasschieter, 1961.
- Clavulina columnatortilis* (d'Orbigny) = *Valvulina columnatortilis* d'Orbigny, 1826.
- **Clavulina parisiensis* d'Orbigny, 1826. Plate 1, figs. 12, 13.
- Cribrostomoides jeffreysii* (Williamson) = *Nonionina jeffreysii* Williamson, 1858.
- Cyclogyra involvens* (Reuss) = *Operculina involvens* Reuss, 1850.
- **Cycloloculina eocaenica* (Terquem) = *Planorbulina eocaenica* Terquem, 1882. Plate 17, fig. 6.
- Cycloloculina punctata* (Terquem) = *Planorbulina punctata* Terquem, 1882.
- Dendritina elegans* d'Orbigny, 1846.
- Dendritina juleana* d'Orbigny, 1846.
- Dendritina laevigata* Terquem, 1882.

- Dentalina elegans* d'Orbigny, 1846.
Dentalina inornata d'Orbigny, 1846.
Dentalina semiplicata d'Orbigny, 1846.
Discorbis perovalis (Terquem) = *Rotalina perovalis* Terquem, 1882.
**Discorbis perplexa* Le Calvez, 1949. Plate 7, figs. 7–9.
**Discorbis propinqua* (Terquem) = *Rosalina propinqua* Terquem, 1882. Plate 7, figs. 10–12.
**Discorbis turbo* (d'Orbigny) = *Rotalia turbo* d'Orbigny, 1826. Plate 7, figs. 13–15.
**Discorbis vesicularis* (Lamarck) = *Discorbites vesicularis* Lamarck, 1804. Plate 7, fig. 16; Plate 8, fig. 1.
**Elphidium costiferum* (Terquem) = *Polystomella costifera* Terquem, 1882. Plate 12, figs. 6, 7.
**Elphidium hiltermanni* Hagn, 1952. Plate 12, figs. 5, 9.
**Elphidium latidorsatum* (Reuss) = *Polystomella latidorsata* Reuss, 1864. Plate 12, fig. 10.
Elphidium minutum (Reuss) = *Polystomella minuta* Reuss, 1865.
Elphidium smithi Cushman and Dusenbury, 1934.
**Elphidium subcarinatum* (Egger) = *Polystomella subcarinata* Egger, 1857. Plate 12, fig. 11.
Elphidium vasseuri Margerel, 1966.
**Eoeponidella linki* Wickenden, 1948. Plate 8, figs. 4, 8.
**Epistomaria rimosa* (Parker and Jones) = *Discorbina rimosa* Parker and Jones, 1865. Plate 10, figs. 7–9.
**Epistomaria separans* Le Calvez, 1949. Plate 10, figs. 10, 11.
Epistominella oveyi (Bhatia) = *Pseudoparrella oveyi* Bhatia, 1955.
**Epistominella vitrea* Parker, 1953. Plate 8, figs. 5, 6.
Eponides advena Cushman, 1923.
**Eponides polygonus* Le Calvez, 1949. Plate 14, figs. 9, 11, 12.
**Eponides toulmini* Brotzen, 1948. Plate 14, figs. 10, 13; Plate 15, fig. 1.
**Fabularia discolithes* Defrance, 1824. Plate 5, fig. 13.
Fasciolites boscii (Defrance) = *Oryzaire boscii* Defrance, 1820.
Fasciolites fusiformis (Sowerby) emend. (Adams) = *Alveolina fusiformis* Sowerby emend Adams, 1962.
Fasciolites oblonga (d'Orbigny) = *Alveolina oblonga* d'Orbigny, 1826.
Fissurina carinata Reuss, 1862.
**Fissurina laevigata* Reuss, 1849. Plate 6, fig. 4.
**Fissurina marginata* (Walker and Boys) = *Serpula marginata* Walker and Boys, 1784. Plate 6, fig. 5.
**Fissurina orbignyana* Seguenza, 1862. Plate 6, fig. 6.
**Fissurina orbignyana* Seguenza var. *bicarinata* Terquem, 1882. Plate 6, fig. 7.
**Fissurina orbignyana* Seguenza var. *tricarinata* (Terquem) = *Fissurina tricarinata* Terquem, 1882. Plate 6, fig. 8.
**Flintina dameryana* (Le Calvez) = *Flintia dameryana* Le Calvez, 1947. Plate 2, fig. 12.
**Florilus commune* (d'Orbigny) = *Nonionina communis* d'Orbigny, 1846. Plate 18, figs. 3, 8.
**Florilus elongatum* (d'Orbigny) = *Nonionina elongata* d'Orbigny, 1826. Plate 18, figs. 4, 5.
**Fursenkoina schreibersiana* (Czjzek) = *Virgulina schreibersiana* Czjzek, 1848. Plate 17, figs. 13, 14.
**Fursenkoina vicksburgensis* (Cushman) = *Virgulina vicksburgensis* Cushman, 1936. Plate 17, fig. 15.
Glabratella turbinata (Terquem) = *Rotalina turbinata* Terquem, 1882.
**Glabratella ubiqua* (Le Calvez) = *Discorbis ubiqua* Le Calvez, 1949. Plate 10, figs. 2, 3.
Glandulina aequalis Reuss, 1863.
**Glandulina laevigata* (d'Orbigny) = *Nodosaria laevigata* d'Orbigny, 1826.
**Globigerina angustiumbilitata* Bolli = *Globigerina ciperoensis angustiumbilitata* Bolli, 1957. Plate 14, figs. 7, 8.
**Globigerina aquiensis* Loeblich and Tappan, 1957. Plate 14, figs. 4, 5.
Globigerina mckannai White, 1928.
Globigerina triplex (Subbotina) = *Acarinina triplex* Subbotina, 1953.
Globigerina yeguaensis Weinzerl and Applin, 1929.
Globulina ampulla (Jones) = *Polymorphina ampulla* Jones, 1852.
Globulina gibba (d'Orbigny) = *Polymorphina gibba* d'Orbigny, 1826.
Globulina gibba (d'Orbigny) var. *cognata* (Franzenau) = *Polymorphina cognata* Franzenau, 1894.
Globulina gibba (d'Orbigny) var. *myristiformis* (Williamson) = *Polymorphina myristiformis* Williamson, 1858.
Globulina gibba (d'Orbigny) var. *punctata* (d'Orbigny) = *Globulina punctata* d'Orbigny, 1846.

- Globulina gibba* (d'Orbigny) var. *tuberculata* (d'Orbigny) = *Globulina tuberculata* d'Orbigny, 1846.
Globulina gravida (Terquem) = *Guttulina gravida* Terquem, 1878.
Globulina inaequalis Reuss, 1850.
Globulina inaequalis (Reuss) var. *hispida* Terquem = *Globulina hispida* Terquem, 1882.
Globulina irregularis d'Orbigny, 1846.
Guembelitra triseriata (Terquem) = *Textilaria triseriata* Terquem, 1882.
Guttulina caudata d'Orbigny, 1826.
Guttulina communis d'Orbigny, 1826.
Guttulina lactea (Walker and Jacob) = *Serpula lactea* Walker and Jacob, 1798.
Guttulina problema d'Orbigny, 1826.
Guttulina rotundata Bornemann, 1855.
Guttulina spicaeformis (Roemer) = *Polymorphina spicaeformis* Roemer, 1838.
Guttulina spicaeformis (Roemer) var. *australis* (d'Orbigny) = *Globulina australis* d'Orbigny, 1839.
**Gyroidina angustumbilicata* Ten Dam, 1944. Plate 20, figs. 8–10.
Gyroidina octocamerata Cushman and Hanna = *Gyroidina soldanii* d'Orbigny var. *octocamerata* Cushman and Hanna, 1927.
**Gyroidinella magna* Le Calvez, 1949. Plate 17, figs. 8–10.
**Halkyardia minima* (Liebus) = *Cymbalopora radiata* Hagenow var. *minima* Liebus, 1911. Plate 18, fig. 2.
**Heterillina carinata* Schlumberger, 1905. Plate 5, figs. 10, 11.
Heterillina guespellensis Schlumberger, 1905.
Heterolepa dutemplei (d'Orbigny) = *Rotalina dutemplei* d'Orbigny, 1846.
Karrerella danica (Franke) = *Gaudryina danica* Franke, 1927. The type has a short neck not observed in the present material.
**Lagenacuticosta* Reuss, 1862. Plate 6, fig. 2.
Lagena costata (Williamson) = *Entosolenia costata* Williamson, 1858.
Lagena hexagona (Williamson) = *Lagena squamosa* (Montagu) var. *hexagona* Williamson, 1848.
Lagena hispida Reuss, 1858.
**Lagena laevis* (Montagu) = *Vermiculum laeve* Montagu, 1803. Plate 6, fig. 1.
**Lagena striata* (d'Orbigny) = *Oolina striata* d'Orbigny, 1839. Plate 6, fig. 3.
Lagena striatopunctata Parker and Jones = *Lagena sulcata* (Walker and Jacob) var. *striatopunctata* Parker and Jones, 1865.
Lamarckina cristellaroides (Terquem) = *Rotalina cristellaroides* Terquem, 1882.
Lamarckina ovula Le Calvez, 1949.
**Lamellodiscorbis margaritifera* (Le Calvez) = *Anomalina margaritifera* Le Calvez, 1947. Plate 8, figs. 9–11.
Lenticulina cf. *L. alatolimbata* (Gümbel) = *Robulina alatolimbata* Gümbel, 1868.
Lenticulina deformis (Reuss) = *Robulus deformis* Reuss, 1851.
Lenticulina inornata (d'Orbigny) = *Robulina inornata* d'Orbigny, 1846.
Lenticulina limbata (Bornemann) = *Robulina limbata* Bornemann, 1855.
Lenticulina cf. *L. limbosa* (Reuss) = *Cristellaria limbosa* Reuss, 1863.
Lenticulina cf. *L. trigonostoma* (Reuss) = *Robulina trigonostoma* Reuss, 1851.
Lenticulina umbonata (Reuss) = *Robulina umbonata* Reuss, 1851.
Lenticulina cf. *L. wilcoxensis* (Cushman and Garrett) = *Darbyella wilcoxensis* Cushman and Garrett, 1939.
Lenticulina yeguatensis (Bermudez) = *Robulus yeguatensis* Bermudez, 1949.
**Linderina brugesi* Schlumberger, 1893. Plate 17, figs. 11, 12.
Marginulina cocoaensis Cushman, 1925.
Marginulina cf. *M. tenuis* Bornemann, 1855.
Marginulina tumida Reuss, 1851.
**Melonis affine* (Reuss) = *Nonionina affinis* Reuss, 1851. Plate 20, figs. 4, 7.
**Miliola birostris* (Lamarck) = *Miliolites birostris* Lamarck, 1804. Plate 4, fig. 17.
Miliola disticha (Terquem) = *Quinqueloculina disticha* Terquem, 1882.
**Miliola prisca* (d'Orbigny) = *Quinqueloculina prisca* d'Orbigny, 1826. Plate 4, figs. 18, 19.
**Miliola prisca* (d'Orbigny) var. *terquemi* Kaasschieter, 1961. Plate 4, figs. 20, 21.
**Miliola pseudocarinata* Le Calvez, 1970. Plate 5, figs. 1, 2.
**Miliola saxorum* (Lamarck) = *Miliolites saxorum* Lamarck, 1804. Plate 5, figs. 3–5.
**Miliola strigillata* (d'Orbigny) = *Triloculina strigillata* d'Orbigny, 1826. Plate 5, figs. 7, 8.

- **Neocribrella globigerinoides* (Parker and Jones) = *Discorbina globigerinoides* Parker and Jones, 1864.
Plate 15, figs. 2, 3.
- Neoeponides schreibersii* (d'Orbigny) = *Rotalina schreibersii* d'Orbigny, 1846.
- Nodosaria parexilis* Cushman and Parker, 1931.
- Nonionella jacksonensis* Cushman, 1933.
- **Nonionella spissa* Cushman = *Nonionella hantkeni* (Cushman and Applin) var. *spissa* Cushman, 1931.
Plate 18, figs. 6, 7, 9.
- **Nonionella* cf. *N. wemmelensis* Kaasschieter, 1961. Plate 18, figs. 10, 11.
- Nummodiscorbis nucleata* (Terquem) = *Amphistegina nucleata* Terquem, 1882.
- Nummulites laevigatus* (Bruguière) = *Camerina laevigata* Bruguière, 1792.
- Nummulites planulatus* (Lamarck) = *Lenticulites planulata* Lamarck, 1804.
- Nummulites prestwichianus* (Jones) = *Nummulina planulata* (Lamarck) var. *prestwichiana* Jones, 1862.
- Nummulites rectus* Curry, 1937.
- Nummulites variolarius* (Lamarck) = *Lenticulites variolaria* Lamarck, 1804.
- Oolina melo* d'Orbigny, 1839.
- Oolina squamosa* (Montagu) = *Vermiculum squamosum* Montagu, 1803.
- **Orbitolites complanatus* Lamarck, 1801. Plate 5, fig. 21.
- Osangularia gyrata* (Terquem) = *Rotalina gyrata* Terquem, 1882.
- **Pararotalia armata* (d'Orbigny) = *Rotalia armata* d'Orbigny, 1826. Plate 11, figs. 6, 7.
- **Pararotalia audouini* (d'Orbigny) = *Rotalia audouini* d'Orbigny, 1826. (*Pararotalia subinermis* Bhatia, 1955, is a synonym.) Plate 11, figs. 8–10.
- **Pararotalia curryi* Loeblich and Tappan, 1957. Plate 11, figs. 11–13.
- Pararotalia debourlei* Le Calvez, 1970.
- **Pararotalia inermis* (Terquem) = *Rotalina inermis* Terquem, 1882. Plate 11, fig. 15; Plate 12, figs. 1, 2.
- **Pararotalia spinigera* (Le Calvez) = *Globorotalia spinigera* (Terquem) Le Calvez, 1949. Plate 12, figs. 3, 4, 8.
- Planispirillina striatogranulosa* (Terquem) = *Spirillina striatogranulosa* Terquem, 1882.
- Polymorphina allenii* Cushman and Ozawa, 1930.
- **Praeglobobulimina ovata* (d'Orbigny) = *Bulimina ovata* d'Orbigny, 1846. Plate 6, figs. 16, 17.
- Pullenia quaternaria* (Reuss) = *Nonionina quaternaria* Reuss, 1851.
- **Pullenia quinqueloba* (Reuss) = *Nonionina quinqueloba* Reuss, 1851. Plate 18, figs. 13, 14.
- Pulsiphonina lamarckana* (Cushman) = *Siphonina lamarckana* Cushman, 1927.
- **Pulsiphonina prima* (Plummer) = *Siphonina prima* Plummer, 1927. Plate 20, figs. 12–14.
- **Pyrgo bulloides* (d'Orbigny) = *Biloculina bulloides* d'Orbigny, 1826. Plate 4, figs. 7, 8.
- **Pyrgo elongata* (d'Orbigny) = *Biloculina elongata* d'Orbigny, 1826. Plate 4, fig. 6.
- Pyrgo eocaenica* Le Calvez, 1947.
- Pyrgo simplex* (d'Orbigny) = *Biloculina simplex* d'Orbigny, 1846.
- Pyrulina cylindroides* (Roemer) = *Polymorphina cylindroides* Roemer, 1838.
- Pyrulina gutta* d'Orbigny, 1826.
- Pyrulina thouini* (d'Orbigny) = *Polymorphina thouini* d'Orbigny, 1826.
- Quinqueloculina aspera* d'Orbigny, 1826.
- Quinqueloculina bicarinata* d'Orbigny, 1878.
- Quinqueloculina brevidentata* Le Calvez, 1947.
- **Quinqueloculina carinata* d'Orbigny, 1826. Plate 2, figs. 13–15.
- Quinqueloculina cognata* Bornemann, 1855.
- **Quinqueloculina contorta* d'Orbigny, 1846. Plate 2, figs. 16–18.
- **Quinqueloculina costata* Karrer, 1867. Plate 3, figs. 1–3.
- **Quinqueloculina crassa* d'Orbigny, 1826. Plate 3, figs. 4–6.
- Quinqueloculina crassicostata* Terquem, 1882.
- Quinqueloculina hexacostata* Le Calvez, 1947.
- Quinqueloculina imperialis* Hanna and Hanna var. *porterensis* Rau, 1948.
- **Quinqueloculina impressa* Reuss, 1851. Plate 3, figs. 7–9.
- **Quinqueloculina juleana* d'Orbigny, 1846. Plate 3, figs. 10–12.
- Quinqueloculina lippa* Le Calvez, 1947.
- **Quinqueloculina ludwigi* Reuss, 1866. Plate 3, figs. 13–15.

- **Quinqueloculina parisiensis* d'Orbigny, 1826. Plate 3, figs. 22–24.
- **Quinqueloculina reicheli* Le Calvez, 1966. Plate 3, figs. 16–18.
- **Quinqueloculina seminulum* (Linné) = *Serpula seminulum* Linné, 1758. Plate 3, figs. 19–21.
- **Quinqueloculina simplex* Terquem, 1882. Plate 4, figs. 1–3.
- Quinqueloculina striata* d'Orbigny, 1826.
- **Renulina opercularia* Lamarck, 1804. Plate 2, fig. 9.
- Reussella elongata* (Terquem) = *Verneuilina elongata* Terquem, 1882.
- Reussella spinulosa* (Reuss) = *Verneuilina spinulosa* Reuss, 1850.
- Reussella terquemi* Cushman, 1945.
- **Robertina germanica* Cushman and Parker, 1938. Plate 20, fig. 15.
- **Robertina ovigera* Cushman and Parker, 1936. Plate 20, fig. 11.
- Robertina* cf. *R. wilcoxensis* Cushman and Ponton, 1932.
- **Rosalina araucana* d'Orbigny, 1839. Plate 8, figs. 12–14.
- **Rosalina bractifera* (Le Calvez) = *Discorbis bractifera* Le Calvez, 1949. Plate 9, figs. 1, 2, 4.
- **Rosalina douvillei* (Cushman) = *Discorbis douvillei* Cushman, 1928. Plate 9, figs. 3, 5, 6.
- Rosalina excavata* Terquem, 1882.
- **Rosalina herouvalensis* (Le Calvez) = *Discorbis herouvalensis* Le Calvez, 1953. Plate 9, figs. 7–9.
- Rosalina humilis* (Le Calvez) = *Discorbis humilis* Le Calvez, 1949.
- Rosalina koeneni* Brotzen, 1948.
- Rosalina limbata* (Terquem) = *Rotalina limbata* Terquem, 1882.
- Rosalina obvoluta* (Terquem) = *Rotalina obvoluta* Terquem, 1882.
- **Rosalina parisiensis* d'Orbigny, 1826. Plate 9, figs. 10, 11.
- Rosalina quadrata* Terquem, 1882.
- **Rotalia discoides* d'Orbigny, 1826. Plate 10, figs. 12–14.
- Rotalia guerini* d'Orbigny, 1826.
- Rotalia lithothamnica* Uhlig, 1886. Plate 11, figs. 1–3.
- Rotalia papillosa* d'Orbigny, 1826.
- Rotalia suessonensis* d'Orbigny, 1826.
- **Rotalia trochidiformis* (Lamarck) = *Rotalites trochidiformis* Lamarck, 1804. Plate 11, figs. 4, 5.
- **Sagrina selseyensis* (Heron-Allen and Earland) = *Bigenerina selseyensis* Heron-Allen and Earland, 1909. Plate 7, fig. 4.
- Sigmoilina tenuis* (Czjzek) = *Quinqueloculina tenuis* Czjzek, 1848.
- Sigmomorphina semitecta* (Reuss) var. *terquemiana* (Fornasini).
- **Siphotextularia canaliculata* (Terquem) = *Textularia canaliculata* Terquem, 1882. Previously assigned to *Bolivina* and *Sagrina* but the wall is agglutinated. Plate 1, figs. 6, 11.
- **Sphaerogypsina globulus* (Reuss) = *Ceriodora globulus* Reuss, 1848. Plate 18, fig. 1.
- Spirillina perforata* (Schultze) = *Cornuspira perforata* Schultze, 1854.
- **Spirolina cylindracea* Lamarck, 1804. Plate 5, figs. 17, 18.
- Spirolina mariei* Le Calvez, 1952.
- **Spirolina pedum* d'Orbigny, 1826. Plate 5, figs. 19, 20.
- Spirolina striata* d'Orbigny, 1826.
- Spiroloculina angulifera* Terquem, 1882.
- **Spiroloculina bicarinata* d'Orbigny, 1826. Plate 1, figs. 14, 15.
- **Spiroloculina carinata* Le Calvez, 1947. Plate 1, figs. 16, 17.
- **Spiroloculina contorta* Le Calvez, 1947. Plate 1, figs. 18, 19.
- Spiroloculina costigera* Terquem, 1882.
- **Spiroloculina costigera* Terquem var. *nuda* Kaasschieter, 1961. Plate 2, figs. 1, 2.
- Spiroloculina inflata* Terquem, 1882.
- **Spiroloculina morelleti* Le Calvez, 1953. Plate 2, figs. 3, 4.
- **Spiroloculina perforata* d'Orbigny, 1826. Plate 2, figs. 5, 6.
- **Spiroloculina tricarinata* Terquem, 1882. Plate 2, figs. 7, 8.
- Spirophthalmidium alatum* (Terquem) = *Spiroloculina alata* Terquem, 1882.
- Spiroplectammina* cf. *S. carinata* (d'Orbigny) = *Textularia carinata* d'Orbigny, 1826.
- **Spiroplectammina deperdita* (d'Orbigny) = *Textularia deperdita* d'Orbigny, 1846. Plate 1, figs. 4, 5.
- **Textularia agglutinans* d'Orbigny, 1839. Plate 1, figs. 7, 8.

- **Textularia minuta* Terquem, 1882. Plate 1, figs. 9, 10.
Trifarina ovata (Terquem) = *Tritaxia ovata* Terquem, 1882.
- **Trifarina wilcoxensis* (Cushman and Ponton) = *Pseudouvigerina wilcoxensis* Cushman and Ponton, 1932. Plate 7, fig. 5.
- **Triloculina angularis* d'Orbigny, 1826. Plate 4, figs. 4, 5.
Triloculina cintrata (Terquem) = *Quinqueloculina cintrata* Terquem, 1882.
Triloculina hemisphaerica Terquem, 1882.
- **Triloculina inflata* d'Orbigny, 1846. Plate 4, figs. 9-11.
Triloculina lecalvezae Kaasschieter, 1961.
- **Triloculina propinqua* Terquem, 1882. Plate 4, figs. 12-14.
- **Triloculina trigonula* (Lamarck) = *Miliolites trigonula* Lamarck, 1804. Plate 4, figs. 15, 16.
Trochammina cf. *T. lobata* Cushman, 1944.
- **Tubulogenerina tubulifera* (Parker and Jones) = *Textularia tubulifera* Parker and Jones, 1863.
- **Turborotalia esnaensis* (Le Roy) = *Globigerina esnaensis* Le Roy, 1953. Plate 14, figs. 1, 2.
Turborotalia pentacamerata (Subbotina) = *Globorotalia pentacamerata* Subbotina, 1947.
- **Turborotalia perclara* (Loeblich and Tappan) = *Globorotalia perclara* Loeblich and Tappan, 1957. Plate 14, figs. 3, 6.
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¹ These Tables have been deposited with the British Library, Boston Spa, Yorkshire, U.K., as Supplementary Publication No. SUP 14003 (26 pages). They may be purchased from the British Library, Lending Division, Boston Spa, Wetherby, Yorks. LS23 7BQ. Prepaid coupons for such purposes are held by many technical and university libraries throughout the world.

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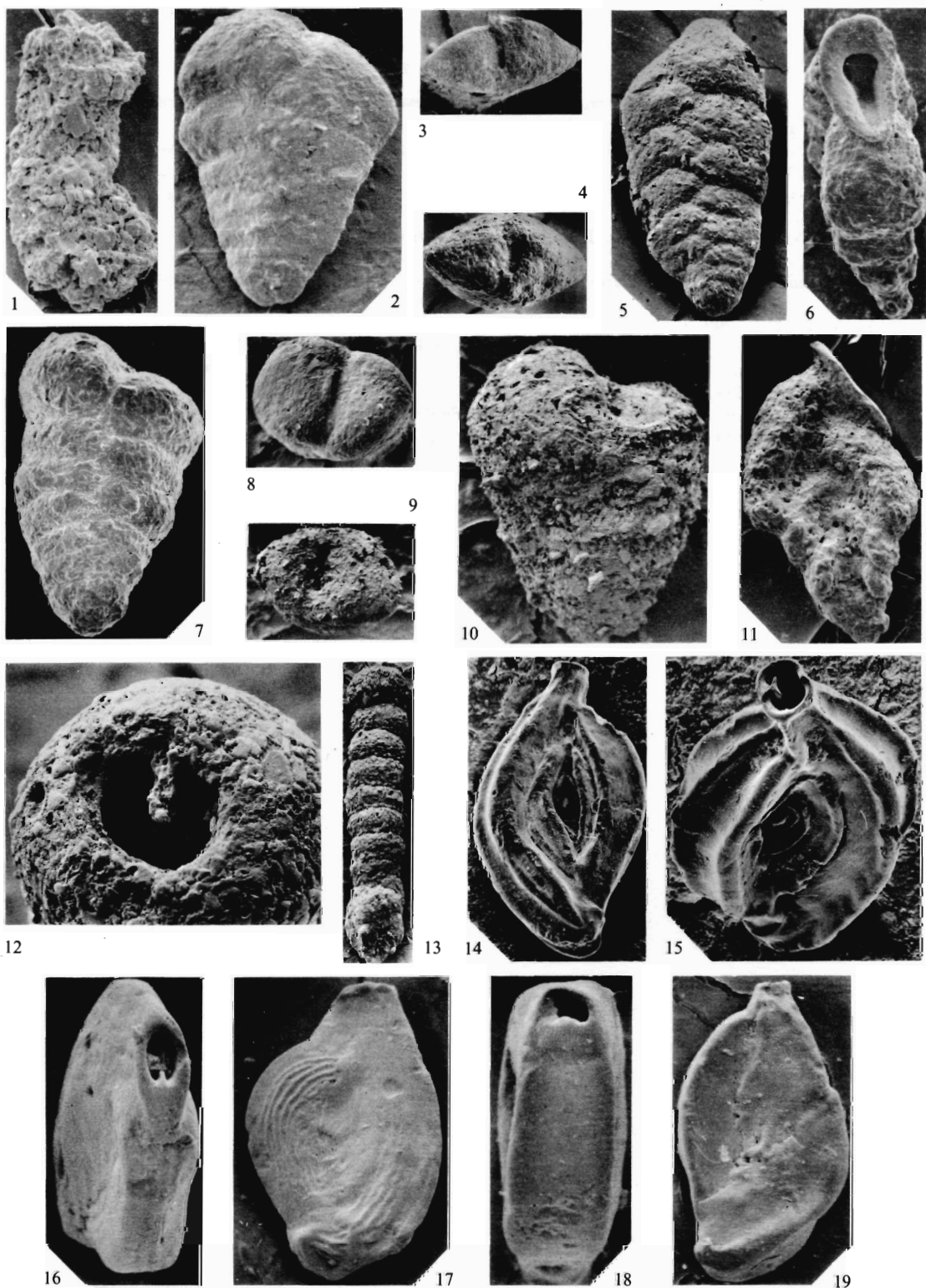
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PLATES

All the illustrated specimens have been deposited in the British Museum (Natural History), London, and bear registered numbers P49113-P49413. The photographs were taken on a Cambridge Instruments Stereoscan scanning electron microscope. The specimens were coated with 40/60 gold/palladium.

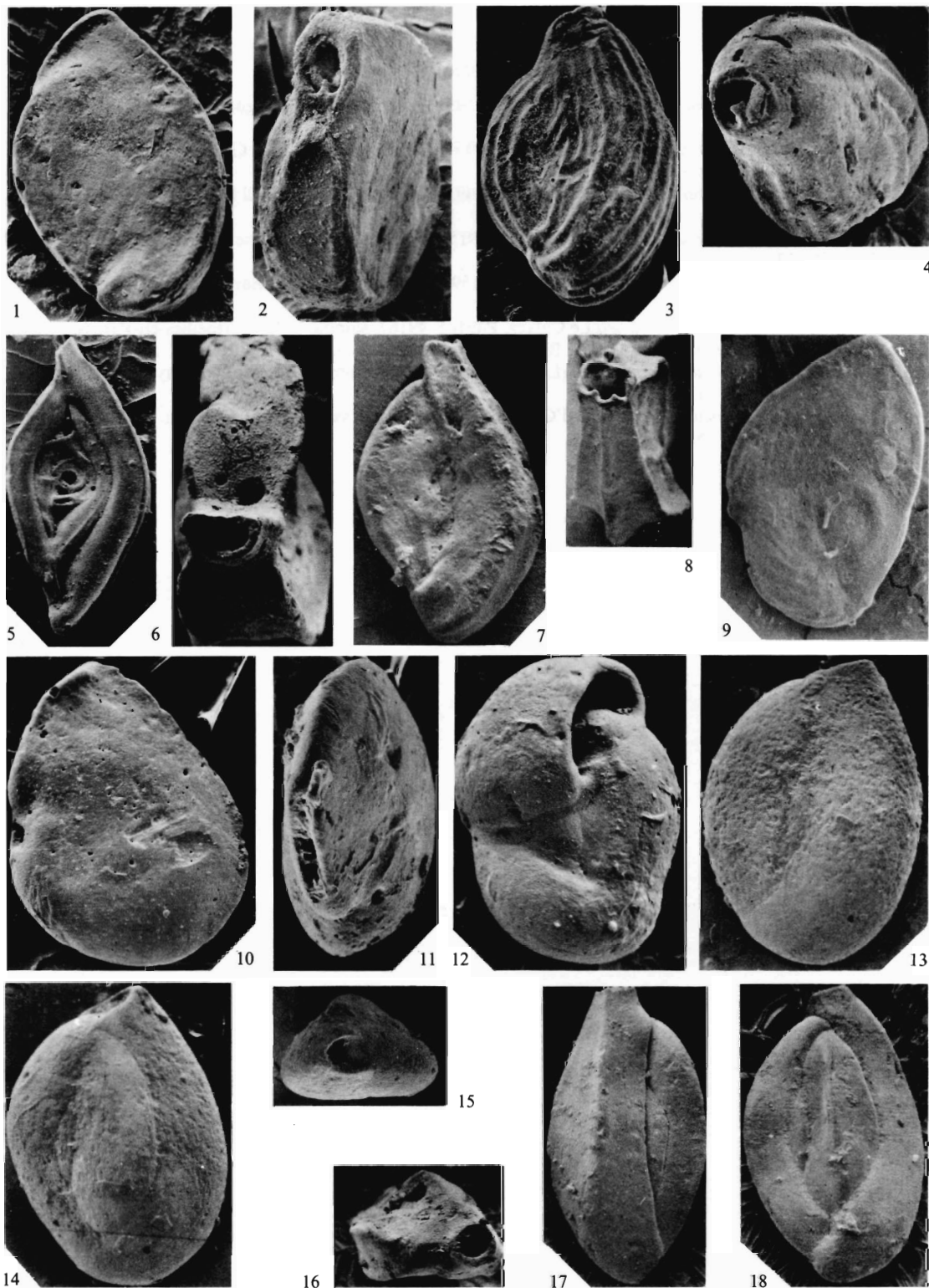
EXPLANATION OF PLATE I

- Fig. 1. *Ammobaculites* cf. *A. yazoensis* Bandy, P49113, sample 1683, Cormeilles-en-Parisis, Marnes à Huîtres inférieures, $\times 270$.
- Figs. 2, 3. *Bolivinopsis adamsi* (Lalicker), P49114-49115, sample W22, Whitecliff Bay, London Clay. 2, $\times 84$; 3, $\times 70$.
- Figs. 4, 5. *Spiroplectamina deperdita* (d'Orbigny), P49116-49117, sample W97, Whitecliff Bay, Bracklesham Beds, Fisher Beds XVI-XVII. 4, $\times 72$; 5, $\times 75$.
- Figs. 6, 11. *Siphotextularia canaliculata* (Terquem), P49118, sample F133, Grignon, Middle Lutetian. 6, $\times 130$; 11, $\times 124$.
- Figs. 7, 8. *Textularia agglutinans* d'Orbigny, P49119-49120, sample W11, Whitecliff Bay, London Clay. 7, $\times 104$; 8, $\times 80$.
- Figs. 9, 10. *Textularia minuta* Terquem, P49121, sample F20, Hérouval, Lower Lutetian. 9, $\times 54$; 10, $\times 84$.
- Figs. 12, 13. *Clavulina parisiensis* d'Orbigny, P49122-49123, sample F134, Grignon, France, Middle Lutetian. 12, $\times 85$; 13, $\times 30$.
- Figs. 14, 15. *Spiroloculina bicarinata* d'Orbigny, P49124-49125, sample F134, Grignon, Middle Lutetian. 14, $\times 44$; 15, $\times 98$.
- Figs. 16, 17. *Spiroloculina carinata* Le Calvez, P49126-49127, sample F132, Grignon, Middle Lutetian. 16, $\times 60$; 17, $\times 146$.
- Figs. 18, 19. *Spiroloculina contorta* Le Calvez, P49128-49129, sample F132, Grignon, Middle Lutetian. 18, $\times 117$; 19, $\times 150$.



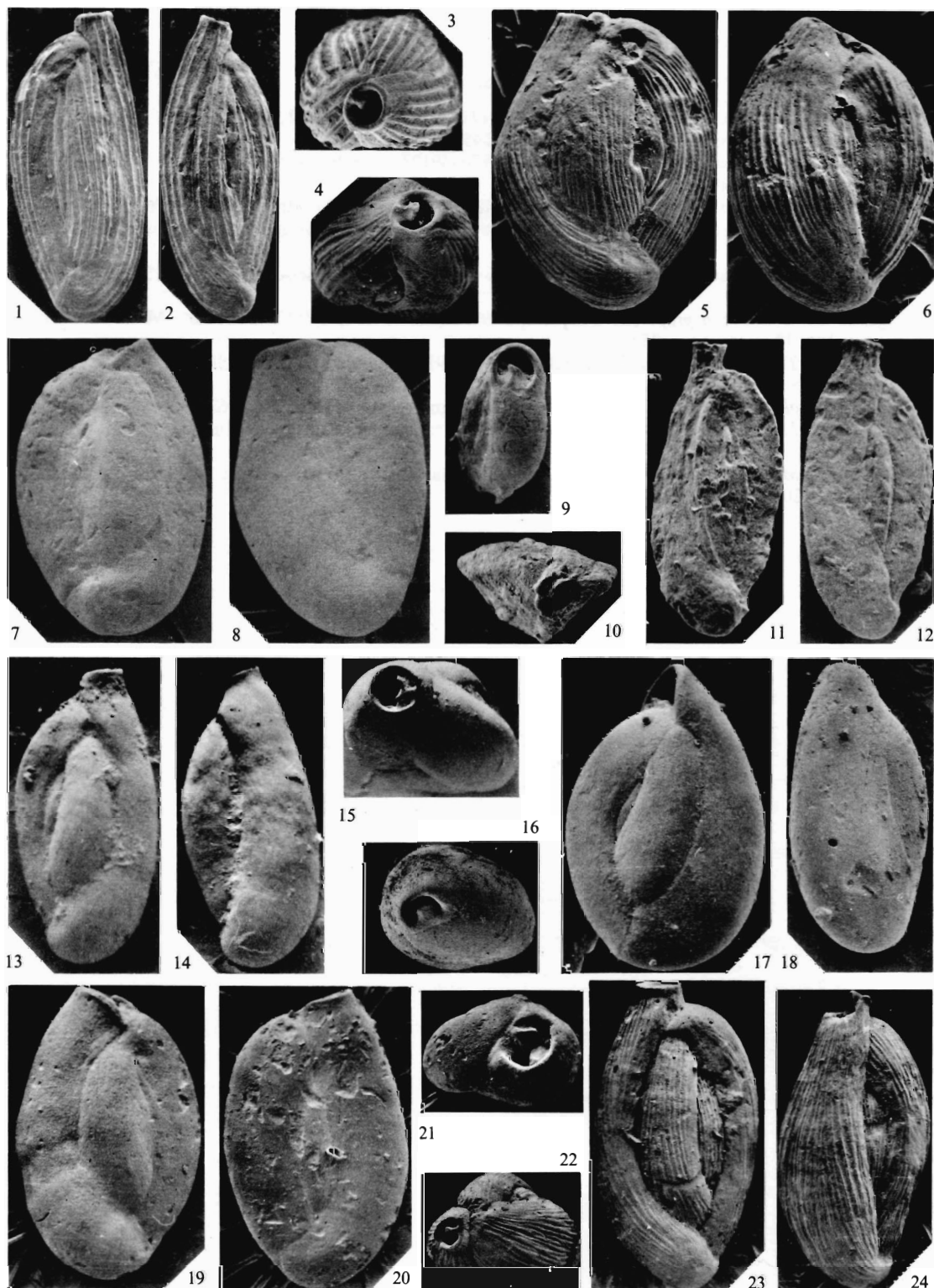
EXPLANATION OF PLATE 2

- Figs. 1, 2. *Spiroloculina costigera* Terquem var. *nuda* Kaasschieter, P49130-49131, sample F24, Hérrouval, Niveau d'Hérrouval. 1, $\times 95$; 2, $\times 143$.
- Figs. 3, 4. *Spiroloculina morelleti* Le Calvez, P49132-49133, sample F24, Hérrouval, Niveau d'Hérrouval. 3, $\times 102$; 4, $\times 135$.
- Figs. 5, 6. *Spiroloculina perforata* d'Orbigny, P49134-49135, sample F42, Liancourt, Middle Lutetian. 5, $\times 68$; 6, $\times 200$.
- Figs. 7, 8. *Spiroloculina tricarinata* Terquem, P49136-49137, sample F132. 7, $\times 113$; 8, $\times 140$. Grignon, Middle Lutetian.
- Fig. 9. *Renulina opercularia* Lamarck, Liancourt, Middle Lutetian, $\times 105$. (Specimen lost.)
- Figs. 10, 11. *Vertebralina laevigata* Terquem, P49139-49140, sample F133, Grignon, Middle Lutetian. 10, $\times 140$; 11, $\times 290$.
- Fig. 12. *Flintina dameryana* (Le Calvez), P49138, sample F133, Grignon, Middle Lutetian, $\times 98$.
- Figs. 13-15. *Quinqueloculina carinata* d'Orbigny, P49141-49143, sample B65, Barton-on-Sea, Barton Clay. 13, $\times 99$; 14, $\times 118$; 15, $\times 75$.
- Figs. 16-18. *Quinqueloculina contorta* d'Orbigny, P49144-49146, sample 1532, Whitecliff Bay, Isle of Wight, Brockenhurst Bed, Middle Headon. 16, $\times 160$; 17, $\times 73$; 18, $\times 60$.



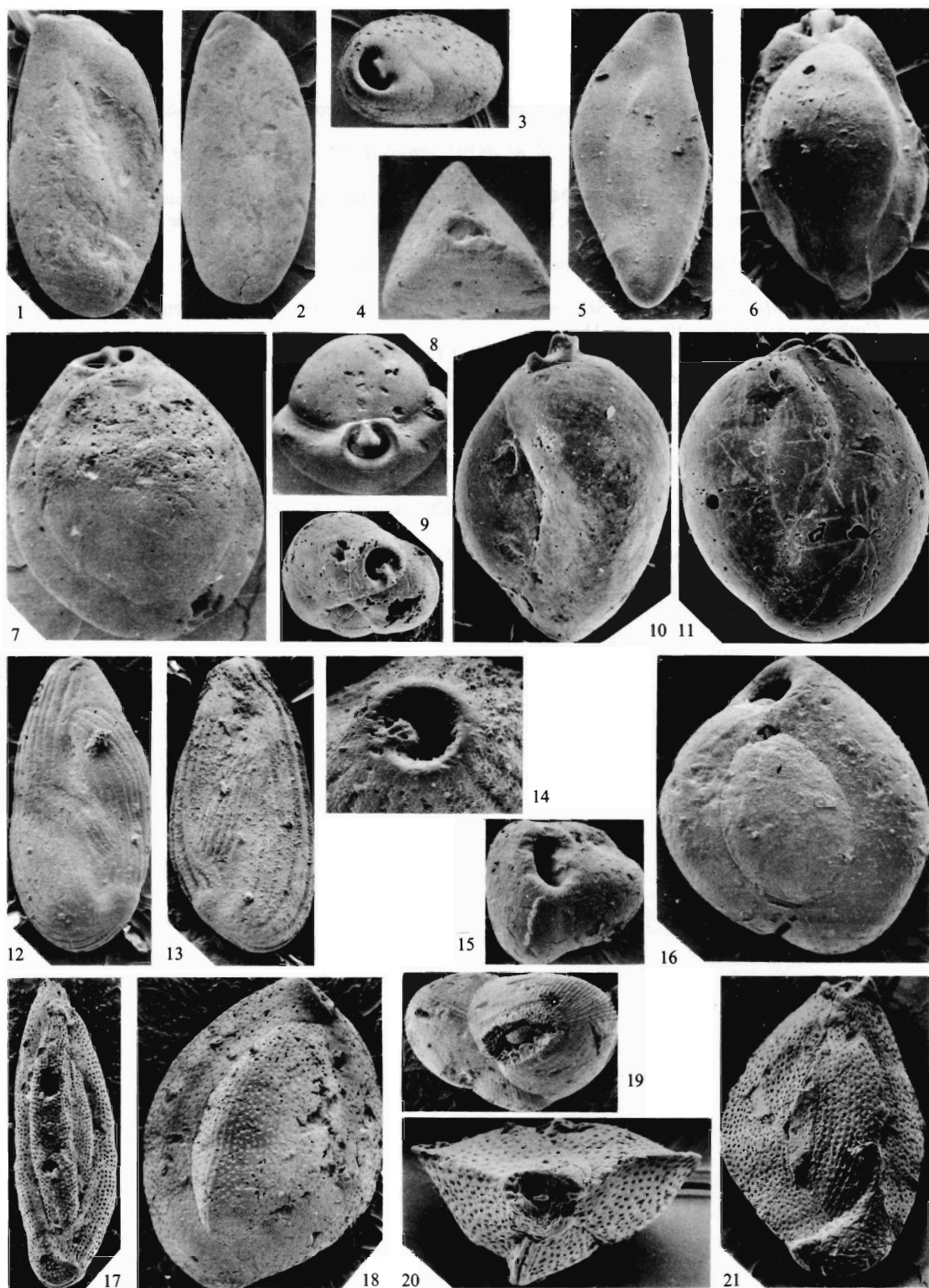
EXPLANATION OF PLATE 3

- Figs. 1–3. *Quinqueloculina costata* Karrer, P49147–49149, sample F132, Grignon, Middle Lutetian. 1, 2, $\times 43$; 3, $\times 55$.
- Figs. 4–6. *Quinqueloculina crassa* d'Orbigny, P49150–49152, sample F131, Grignon, Middle Lutetian. 4, $\times 46$; 5, $\times 58$; 6, $\times 37$.
- Figs. 7–9. *Quinqueloculina impressa* Reuss, P49153–49155, sample 2051, Colwell Bay, Middle Headon Beds. 7, $\times 75$; 8, $\times 73$; 9, $\times 94$.
- Figs. 10–12. *Quinqueloculina juleana* d'Orbigny, P49156–49158, sample S1, Selsey, Fisher Bed 21. 10, $\times 63$; 11, $\times 59$; 12, $\times 73$.
- Figs. 13–15. *Quinqueloculina ludwigi* Reuss, P49159–49161, sample B57, Barton-on-Sea, Barton Clay. 13, 14, $\times 65$; 15, $\times 67$.
- Figs. 16–18. *Quinqueloculina reicheli* Le Calvez, P49165–49167, sample 1677, Corneilles-en-Parisis, Argile à Corbules de Frépillon, sample B54, Barton Clay, Barton. 16, $\times 190$; 17, $\times 109$; 18, $\times 140$.
- Figs. 19–21. *Quinqueloculina seminulum* (Linné), P49168–49170, sample 2051, Colwell Bay, Middle Headon Beds. 19, $\times 77$; 20, $\times 39$; 21, $\times 44$.
- Figs. 22–24. *Quinqueloculina parisiensis* d'Orbigny, P49162–49164, sample F133, Grignon, Middle Lutetian. 22, $\times 31$; 23, 24, $\times 45$.



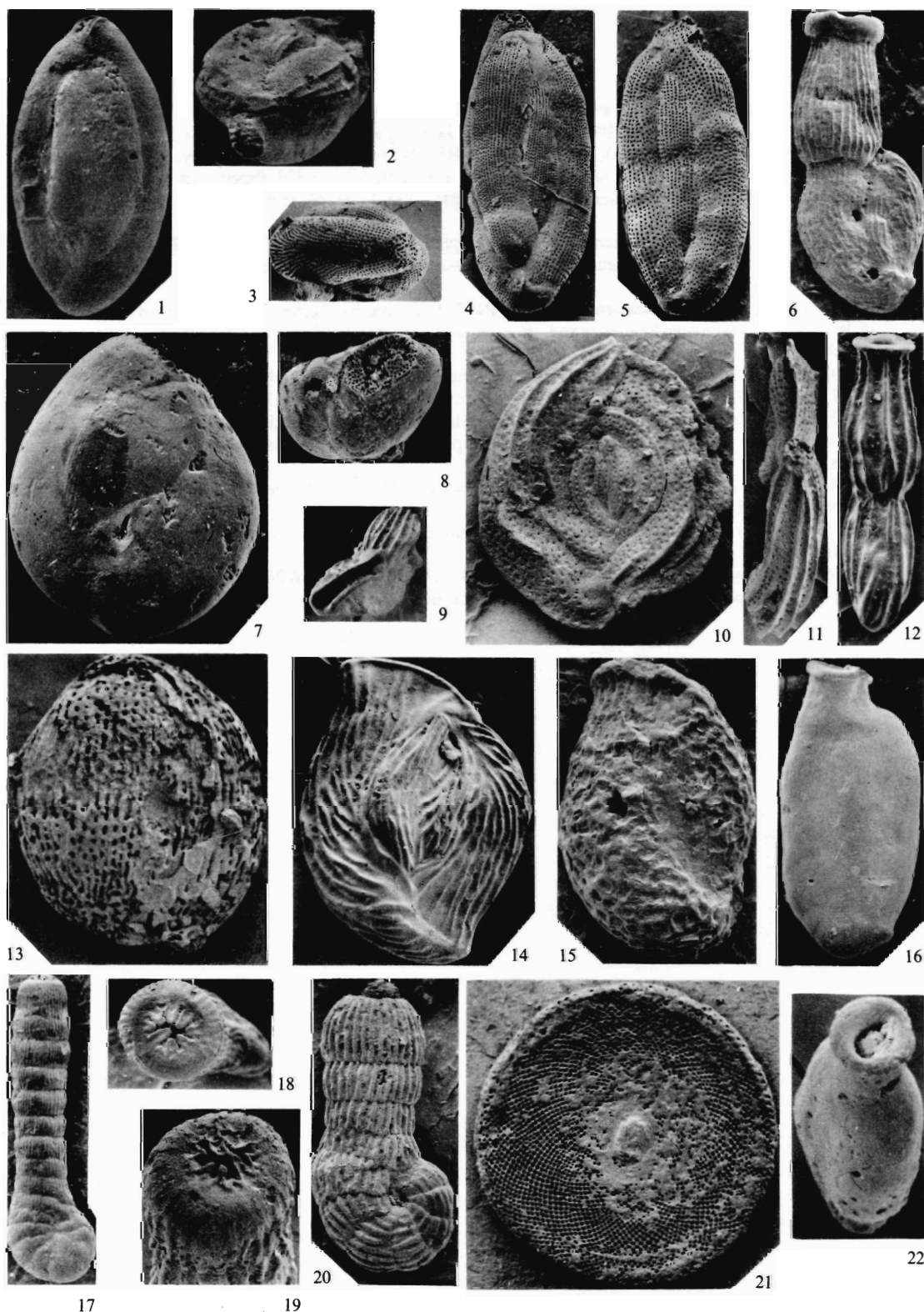
EXPLANATION OF PLATE 4

- Figs. 1-3. *Quinqueloculina simplex* Terquem, P49171-49172, sample 1681, Cormeilles-en-Parisis, Marnes à Huîtres supérieures. 1, $\times 144$; 2, $\times 110$; 3, $\times 145$.
- Figs. 4, 5. *Triloculina angularis* d'Orbigny, P49176-49177, sample 1677, Cormeilles-en-Parisis, Argile à Corbules de Frépillon. 4, $\times 75$; 5, $\times 100$.
- Fig. 6. *Pyrgo elongata* (d'Orbigny), P49175, sample F131, Grignon, Middle Lutetian, $\times 76$.
- Figs. 7, 8. *Pyrgo bulloides* (d'Orbigny), P49173-49174, sample F131, Grignon, Middle Lutetian. 7, $\times 53$; 8, $\times 30$.
- Figs. 9-11. *Triloculina inflata* d'Orbigny, P49178-49180, sample S1, Selsey, Fisher Bed 21. 9, $\times 70$; 10, $\times 123$; 11, $\times 100$.
- Figs. 12-14. *Triloculina propinqua* Terquem, P49181-49183, sample F42, Liancourt, Middle Lutetian. 12, $\times 105$; 13, $\times 98$; 14, $\times 250$.
- Figs. 15, 16. *Triloculina trigonula* (Lamarck), P49184-49185, sample 1535, Whitecliff Bay, Middle Headon Beds. 15, $\times 84$; 16, $\times 104$.
- Fig. 17. *Miliola birostris* (Lamarck), sample F132, Grignon, Middle Lutetian, $\times 62$. (Specimen lost.)
- Figs. 18, 19. *Miliola prisca* (d'Orbigny), P49186-49187, sample F132, Grignon, Middle Lutetian. 18, $\times 52$; 19, $\times 36$.
- Figs. 20, 21. *Miliola prisca* (d'Orbigny) var. *terquemi* Kaasschieter, P49188, sample F43, Liancourt, Middle Lutetian. 20, $\times 80$; 21, $\times 71$.



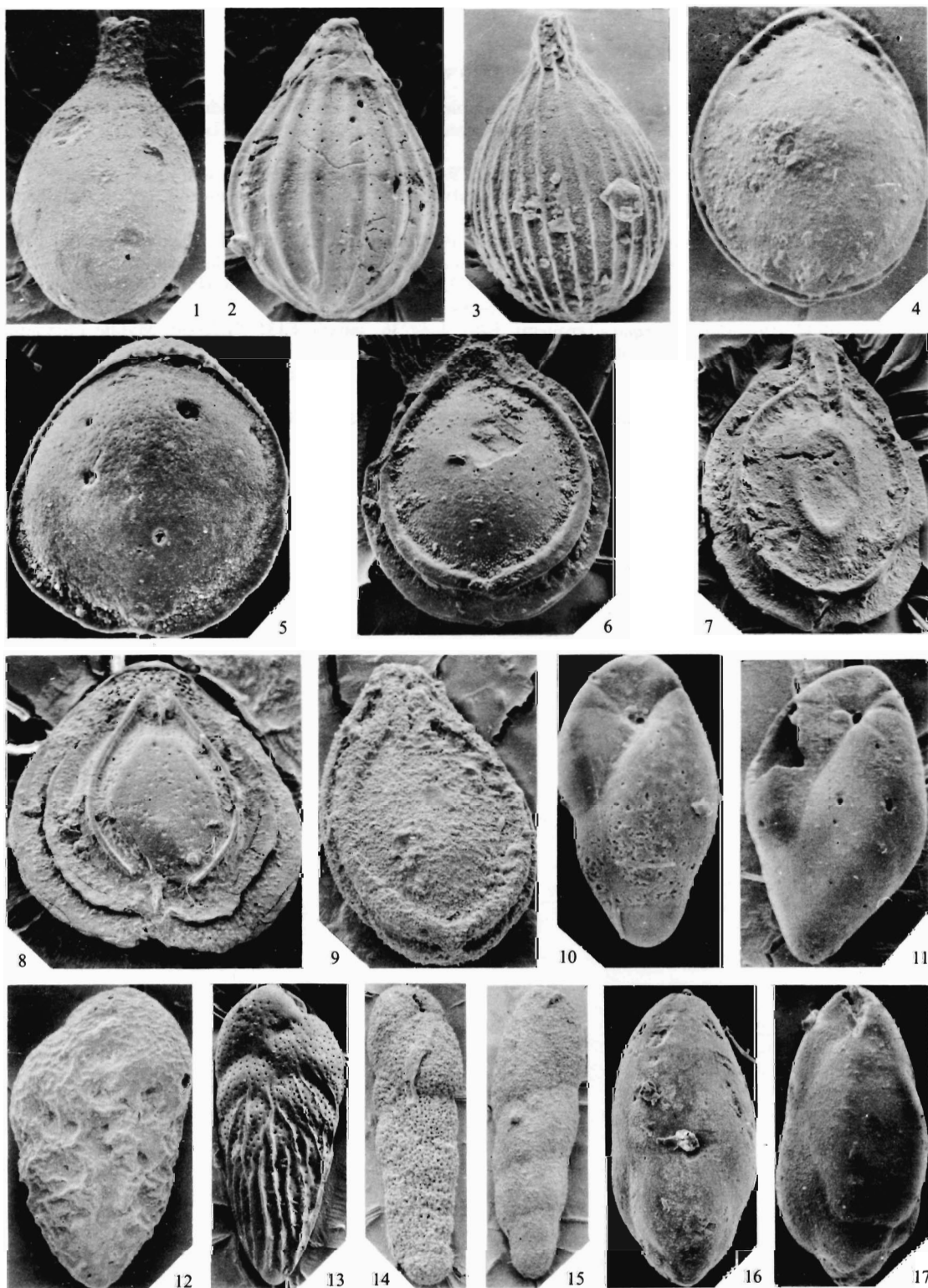
EXPLANATION OF PLATE 5

- Figs. 1, 2. *Miliola pseudocarinata* Le Calvez, P49189-49190, sample F109, Ermenonville, Auversian. 1, $\times 75$; 2, $\times 48$.
- Figs. 3-5. *Miliola saxorum* (Lamarck), P49191-49193, sample F134, Grignon, Middle Lutetian. 3, $\times 32$; 4, $\times 28$; 5, $\times 35$.
- Fig. 6. *Articulina gibbosula* d'Orbigny, P49199, sample F133, Grignon, Middle Lutetian, $\times 145$.
- Figs. 7, 8. *Miliola strigillata* (d'Orbigny), P49194-49195, sample F132, Grignon, Middle Lutetian. 7, $\times 34$; 8, $\times 23$.
- Figs. 9, 14. *Articulina contracta* (Terquem), P49196-49197, sample F134, Grignon, Middle Lutetian. 9, $\times 110$; 14, $\times 122$.
- Figs. 10, 11. *Heterillina carinata* Schlumberger, P49203, sample 1677, Cormeilles-en-Parisis, Argile à Corbules de Frépillon. 10, $\times 58$; 11, $\times 52$.
- Fig. 12. *Articulina nitida* d'Orbigny, P49202, sample F133, Grignon, Middle Lutetian, $\times 81$.
- Fig. 13. *Fabularia discolithes* Defrance, P49223, sample SB1043, Western Approaches, $\times 21$.
- Fig. 15. *Articulina foveolata* Heron-Allen and Earland, P49198, sample S1, Selsey, Fisher Bed 21, $\times 92$.
- Figs. 16, 22. *Articulina laevigata* Terquem, P49200-49201, sample F134, Grignon, Middle Lutetian. 16, $\times 84$; 22, $\times 134$.
- Figs. 17, 18. *Spirolina cylindracea* Lamarck, P49204-49205, sample F133, Grignon, Middle Lutetian. 17, $\times 26$; 18, $\times 52$.
- Figs. 19, 20. *Spirolina pedum* d'Orbigny, P49206-49207, sample 1677, Cormeilles-en-Parisis, Argile à Corbules de Frépillon. 19, $\times 190$; 20, $\times 100$.
- Fig. 21. *Orbitolites complanatus* Lamarck, P49208, sample F132, Grignon, Middle Lutetian, $\times 12$.



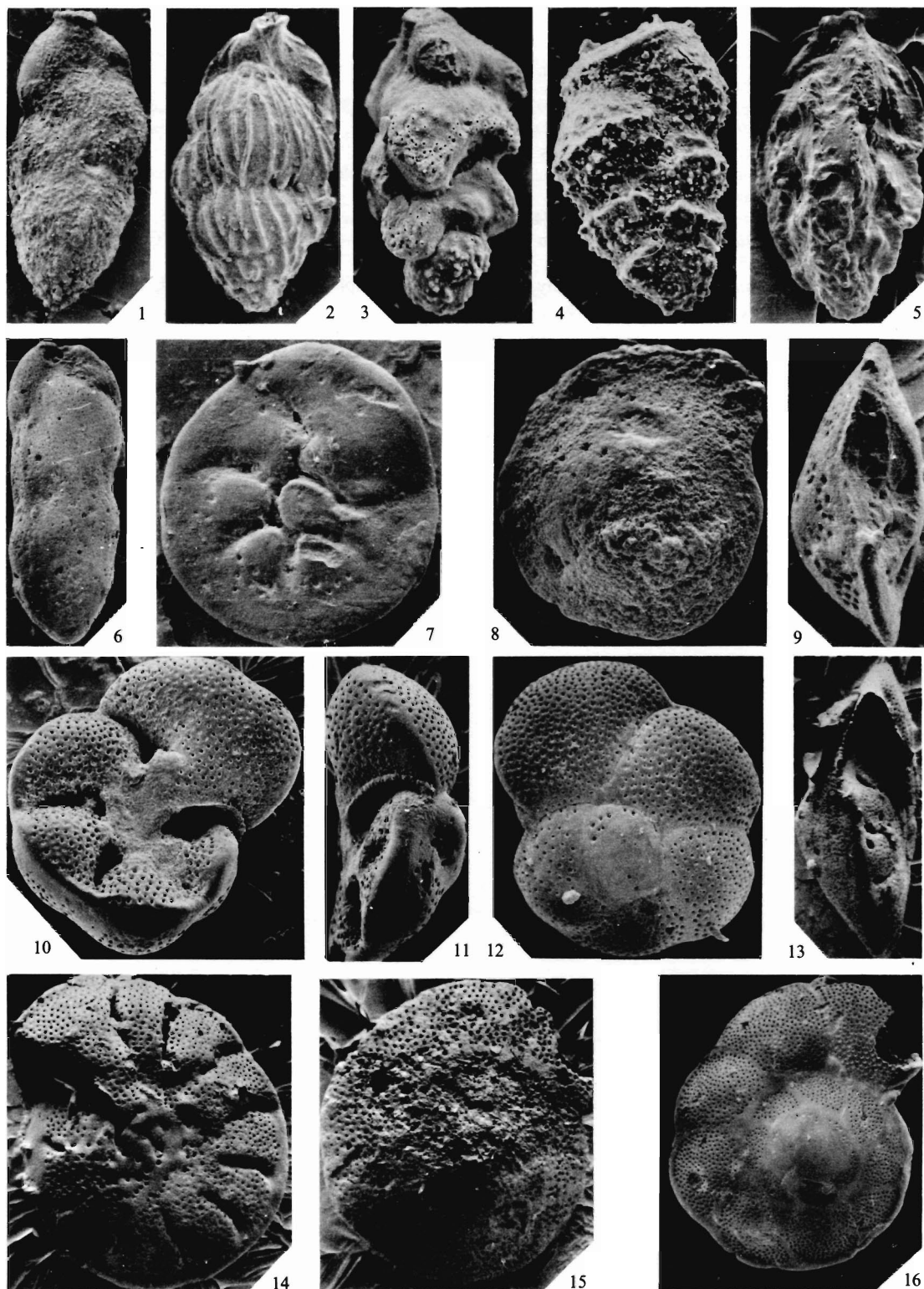
EXPLANATION OF PLATE 6

- Fig. 1. *Lagena laevis* (Montagu), P49210, sample F132, Grignon, Middle Lutetian, $\times 109$.
- Fig. 2. *Lagena acuticosta* Reuss, P49209, sample F133, Grignon, Middle Lutetian, $\times 174$.
- Fig. 3. *Lagena striata* (d'Orbigny), P49211, sample B57, Barton-on-Sea, Barton Clay, $\times 280$.
- Fig. 4. *Fissurina laevigata* Reuss, sample S1, Selsey, Fisher Bed 21, $\times 550$. (Specimen lost.)
- Fig. 5. *Fissurina marginata* (Walker and Boys), P49212, sample W116, Whitecliff Bay, Bracklesham Beds, $\times 260$.
- Fig. 6. *Fissurina orbignyana* Seguenza, P49213, sample F123, Pierrefonds, Niveau de Pierrefonds, $\times 240$.
- Fig. 7. *Fissurina orbignyana* Seguenza var. *bicarinata* (Terquem), P49215, sample F123, Pierrefonds, Cuisian, $\times 100$.
- Fig. 8. *Fissurina orbignyana* Seguenza, variety, P49214, sample F123, Pierrefonds, Cuisian, $\times 60$.
- Fig. 9. *Fissurina orbignyana* Seguenza var. *tricarinata* (Terquem), P49216, sample F36, Liancourt, Lutetian, $\times 190$.
- Fig. 10. *Buliminella pulchra* (Terquem), P49217, sample F132, Grignon, Middle Lutetian, $\times 350$.
- Fig. 11. *Buliminella turbinata* (Terquem), P49218, sample F123, Grignon, Middle Lutetian, $\times 200$.
- Fig. 12. *Bolivina crenulata* Cushman, P49219, sample F41, Liancourt, Middle Lutetian, $\times 250$.
- Fig. 13. *Brizalina cookei* (Cushman), P49220, sample 2011, Hamstead, Isle of Wight, Upper Hamstead Beds, $\times 250$.
- Fig. 14. *Brizalina oligocaenica* (Spandel), P49221, sample 1681, Cormeilles-en-Parisis, Marnes à Huitres supérieures, $\times 150$.
- Fig. 15. *Turritina acicula* (Andreae), P49222, sample 1681, Cormeilles-en-Parisis, Marnes à Huitres supérieures, $\times 140$.
- Figs. 16, 17. *Praeglobobulimina ovata* (d'Orbigny), 16, P49224, sample W26, Whitecliff Bay, London Clay, $\times 110$; 17, sample SW14, London Clay, Swanwick Brickyard, $\times 126$.



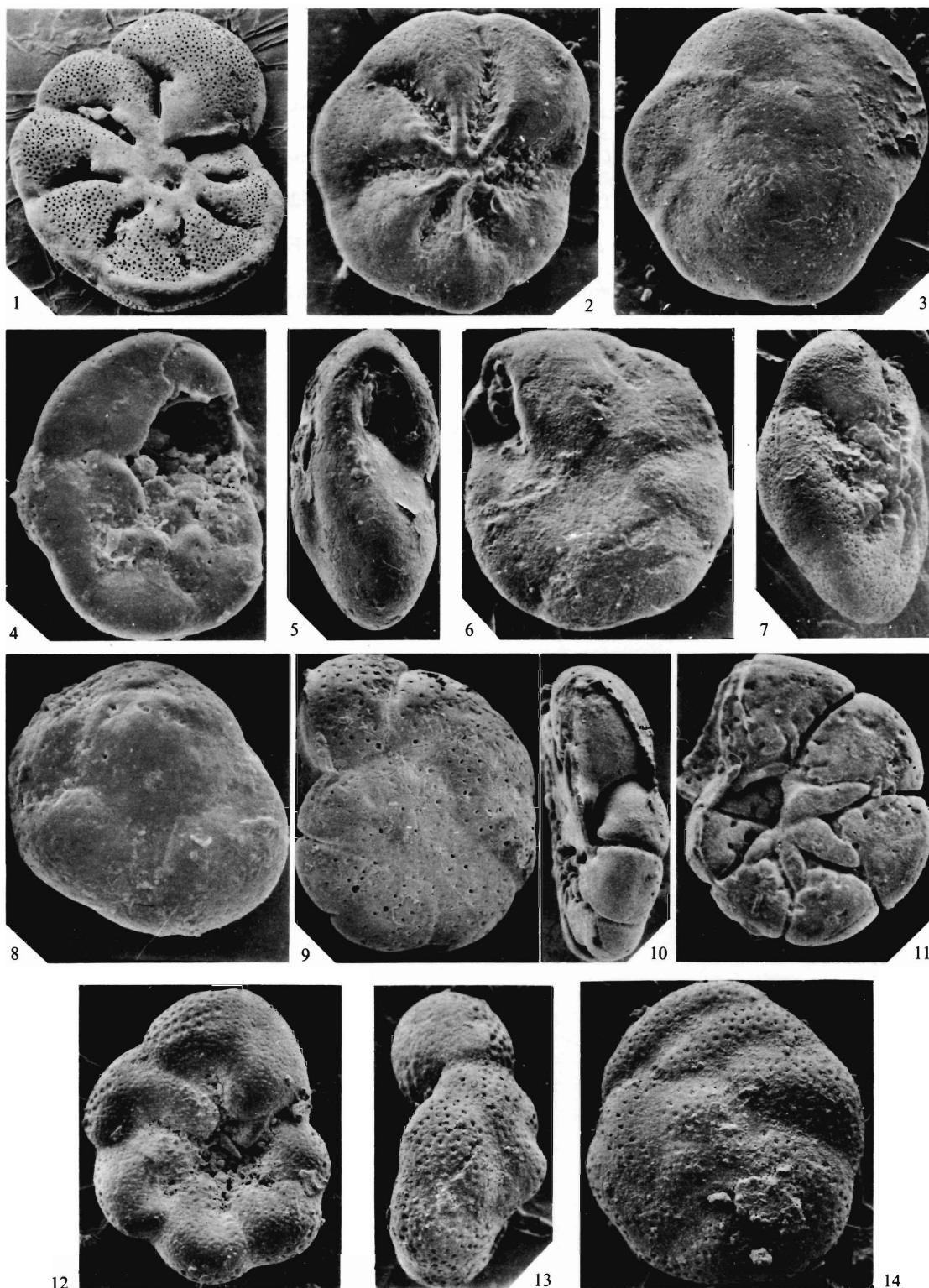
EXPLANATION OF PLATE 7

- Fig. 1. *Uvigerina batjesi* Kaasschieter, P49225, sample W22, Whitecliff Bay, London Clay, $\times 126$.
Fig. 2. *Uvigerina germanica* (Cushman and Edwards), P49226, sample 2010, Hamstead, Isle of Wight, Upper Hamstead Beds, $\times 185$.
Fig. 3. *Uvigerina muralis* Terquem, P49227, sample W98, Whitecliff Bay, Bracklesham Beds, $\times 290$.
Fig. 4. *Sagrina selseyensis* (Heron-Allen and Earland), P49228, sample W98, Whitecliff Bay, Bracklesham Beds, $\times 175$.
Fig. 5. *Trifarina wilcoxensis* (Cushman and Ponton), P49229, sample F22, Mont de Magny, Cuisian, $\times 230$.
Fig. 6. *Uvigerinella abbreviata* (Terquem), P49230, sample F134, Grignon, Middle Lutetian, $\times 115$.
Figs. 7-9. *Discorbis perplexa* Le Calvez, P49231-49233. 7, 9, sample F141, Hauteville, Lutetian. 7, $\times 150$; 9, $\times 175$; 8, sample SB469/2, Western Approaches, $\times 120$.
Figs. 10-12. *Discorbis propinqua* (Terquem), P49234-49236, sample F131, Grignon, Middle Lutetian. 10, $\times 115$; 11, $\times 120$; 12, $\times 140$.
Figs. 13-15. *Discorbis turbo* (d'Orbigny), P49237-49238, sample F131, Grignon, Middle Lutetian. 13, $\times 45$; 14, $\times 44$; 15, $\times 49$.
Fig. 16. *Discorbis vesicularis* (Lamarck), P49239-49240, sample F132, Grignon, Middle Lutetian, $\times 55$.



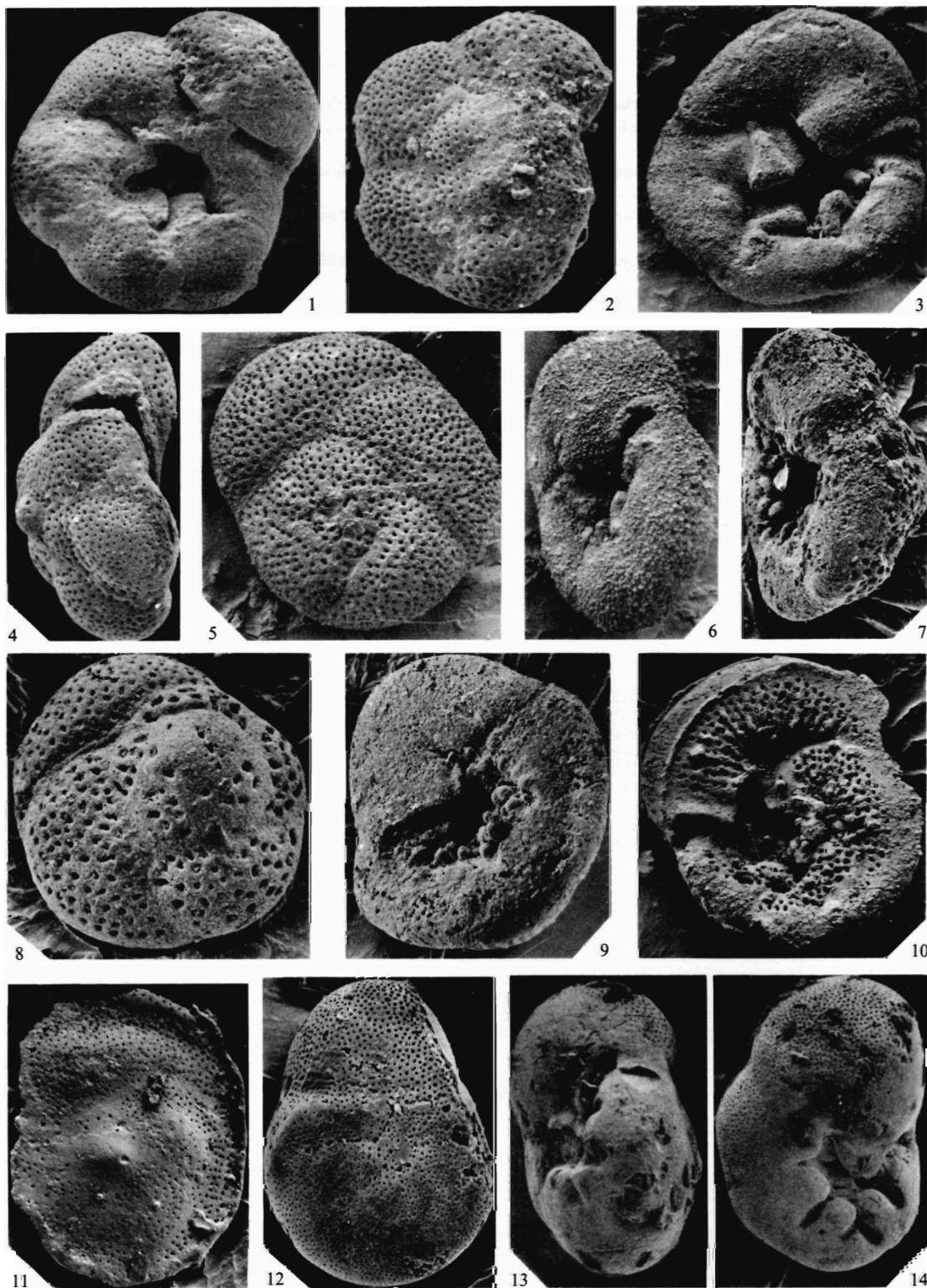
EXPLANATION OF PLATE 8

- Fig. 1. *Discorbis vesicularis* (Lamarck), P49239-49240, sample F132, Grignon, Middle Lutetian, $\times 43$.
 Figs. 2, 3, 7. *Buccella propingua* (Reuss), P49241-49243. 2, 3, Bed E, Barton-on-Sea, Barton Clay; 7, sample 2056, Colwell Bay, Middle Headon Beds. 2, 3, $\times 285$; 7, $\times 310$.
 Figs. 4, 8. *Eoeponidella linki* Wickenden, P49244-49245, sample B101, Barton-on-Sea, Barton Clay. 4, $\times 335$; 8, $\times 360$.
 Figs. 5, 6. *Epistominella vitrea* Parker, P49246, sample W101C, Worthing, London Clay. 5, $\times 480$; 6, $\times 210$.
 Figs. 9-11. *Lamellodiscorbis margaritigera* (Le Calvez), P49247-49249, sample F134, Grignon, Middle Lutetian. 9, $\times 85$; 10, $\times 120$; 11, $\times 85$.
 Figs. 12-14. *Rosalina araucana* d'Orbigny, P49250-49251, sample 1360, Headon Hill, Upper Headon Beds. 12, $\times 270$; 13, $\times 305$; 14, $\times 315$.



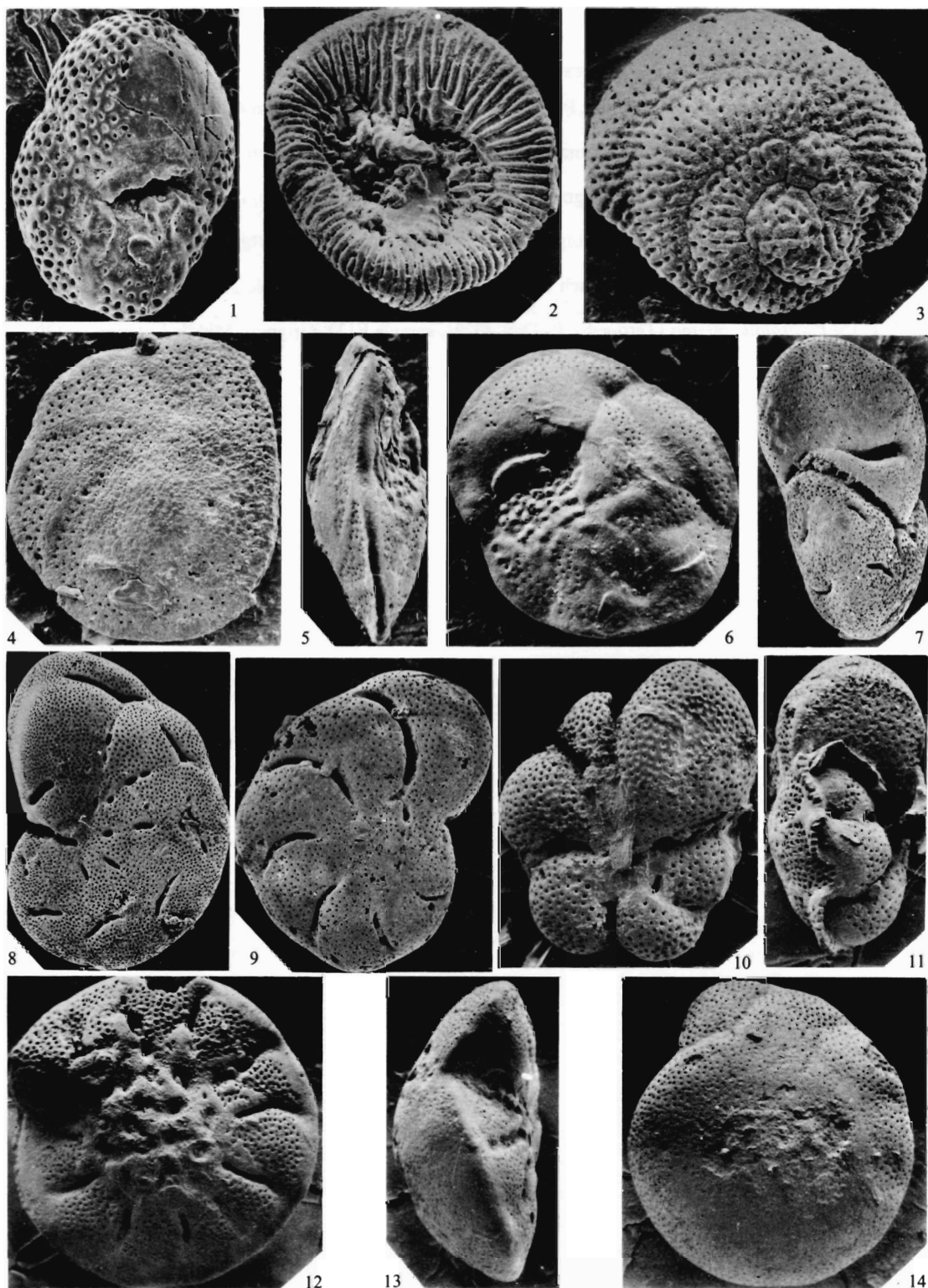
EXPLANATION OF PLATE 9

- Figs. 1, 2, 4. *Rosalina bractifera* (Le Calvez), P49252-49253, sample F98, La Chapelle-en-Serval, Calcaire de Ducy. 1, $\times 110$; 2, $\times 120$; 4, $\times 94$.
- Figs. 3, 5, 6. *Rosalina douvillei* (Cushman), P49254-49256, sample 1676, Corneilles-en-Parisis, Argile à Corbules de Frépillon. 3, $\times 160$; 5, $\times 130$; 6, $\times 156$.
- Figs. 7-9. *Rosalina herouvalensis* (Le Calvez), P49257-49259, sample F24, Hérouval, Niveau d'Hérouval. 7, $\times 155$; 8, $\times 185$; 9, $\times 145$.
- Figs. 10, 11. *Rosalina parisiensis* d'Orbigny, P49260-49261, sample F42, Liancourt, Middle Lutetian. 10, $\times 165$; 11, $\times 103$.
- Figs. 12-14. *Canceris subconicus* (Terquem), P49262-49264, sample F10, Mont de Magny, Cuisian. 12, 13, 14, $\times 135$.



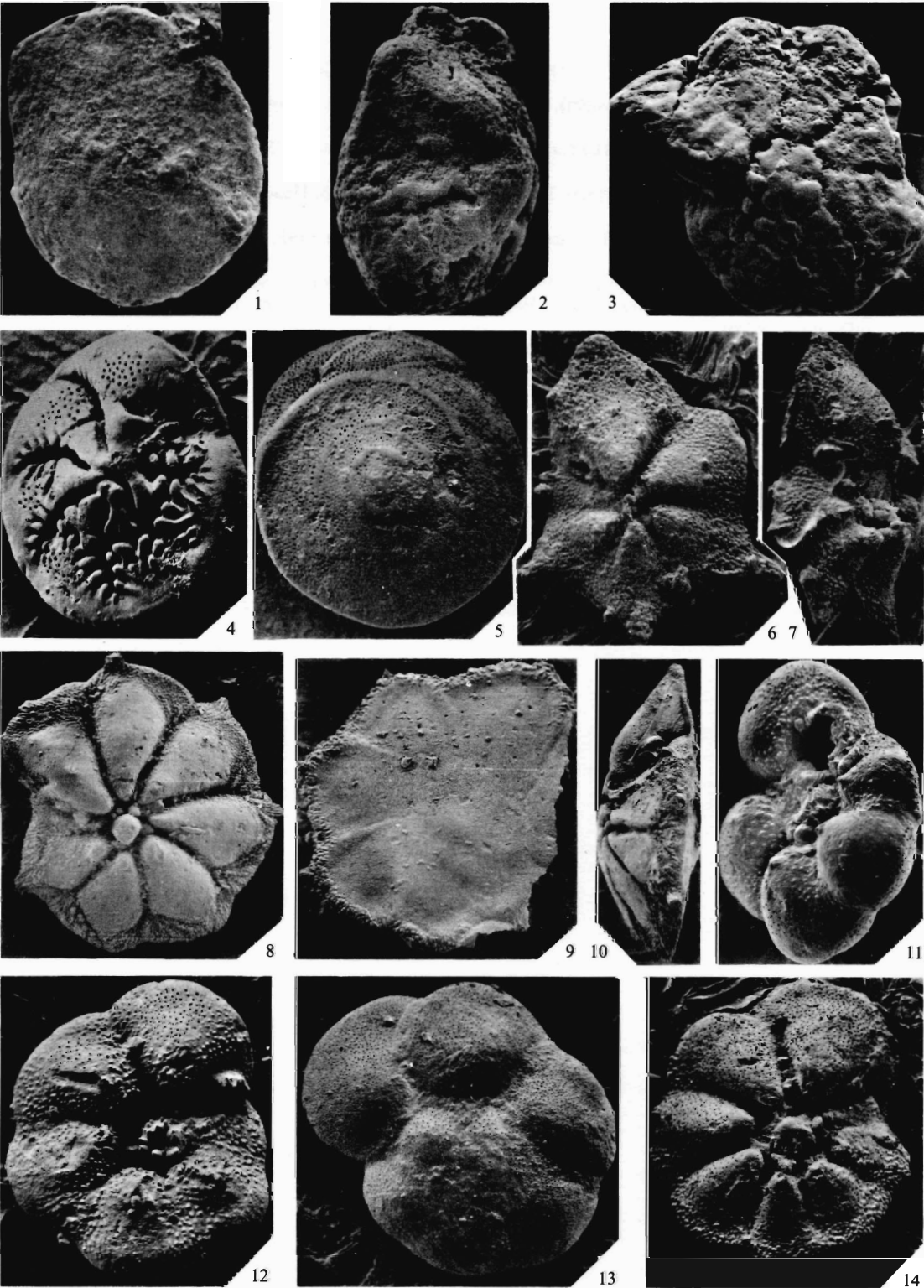
EXPLANATION OF PLATE 10

- Fig. 1. *Baggina parisiensis* (d'Orbigny), sample F132, Grignon, Middle Lutetian, $\times 175$. (Specimen lost.)
Figs. 2, 3. *Glabratella ubiqua* (Le Calvez), P49265–49266, sample W116, Whitecliff Bay, Bracklesham Beds.
2, $\times 215$; 3, $\times 207$.
Figs. 4–6. *Asterigerina bartoniana* (Ten Dam), P49267–49269, Barton-on-Sea, Barton Clay, Bed E. 4, $\times 162$;
5, $\times 220$; 6, $\times 175$.
Figs. 7–9. *Epistomaria rimosa* (Parker and Jones), P49270–49272, sample F131, Grignon, Middle Lutetian.
7, $\times 100$; 8, $\times 103$; 9, $\times 60$.
Figs. 10, 11. *Epistomaria separans* Le Calvez, P49273–49274, sample F133, Grignon, Middle Lutetian.
10, $\times 93$; 11, $\times 80$.
Figs. 12–14. *Rotalia discoides* d'Orbigny, P49278–49279, sample F141, Hauteville, Lutetian. 12, $\times 46$;
13, $\times 53$; 14, $\times 54$.



EXPLANATION OF PLATE 11

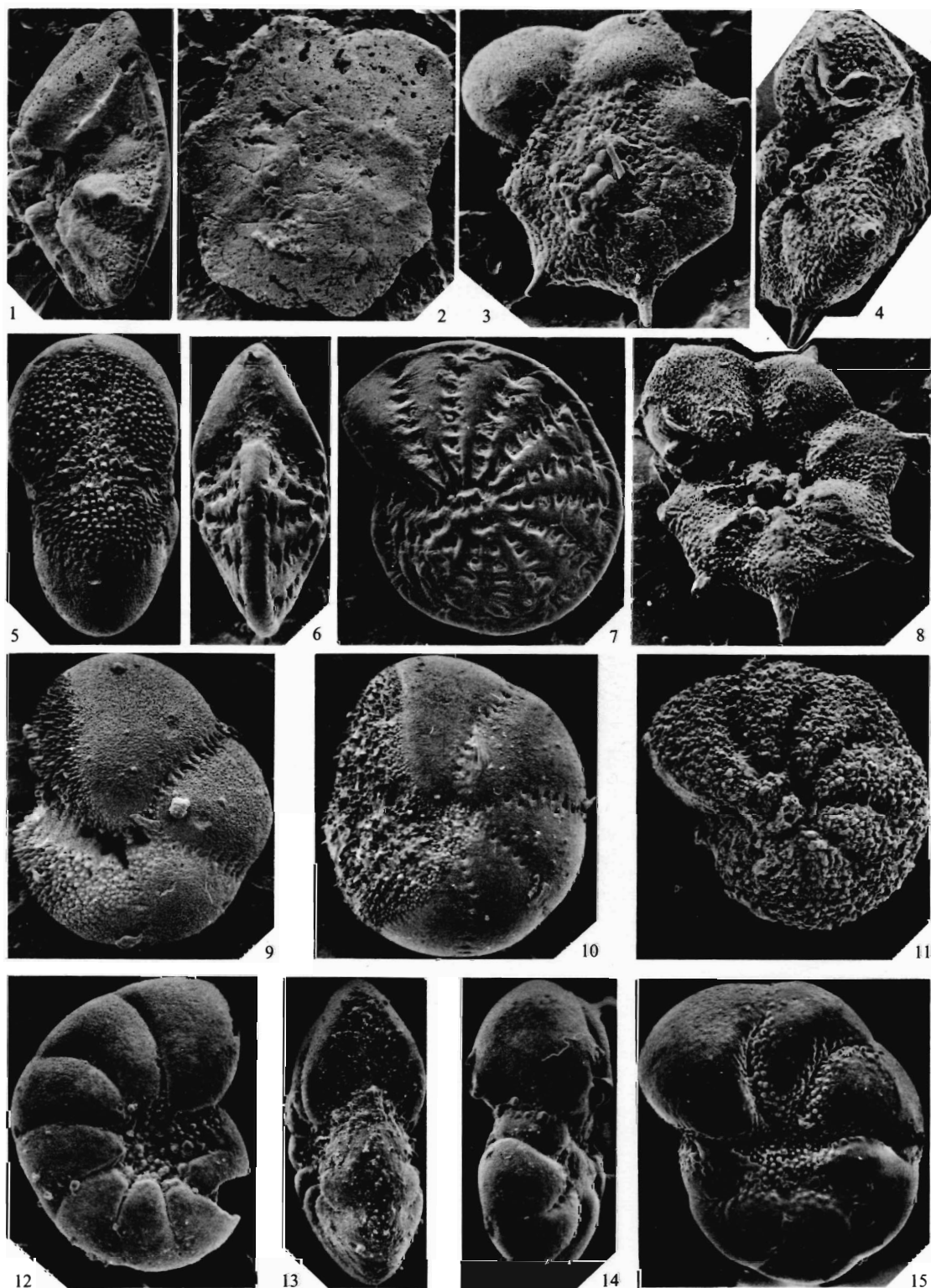
- Figs. 1-3. *Rotalia lithothamnica* Uhlig, P49280-49282, sample SB528, Western Approaches, Upper-Middle Eocene. 1, $\times 68$; 2, $\times 76$; 3, $\times 45$.
- Figs. 4, 5. *Rotalia trochidiformis* (Lamarck), P49283, sample F134, Grignon, Middle Lutetian. 4, $\times 42$; 5, $\times 45$.
- Figs. 6, 7. *Pararotalia armata* (d'Orbigny), P49284-49285, sample S1, Selsey, Fisher Bed 21, Bracklesham Beds. 6, $\times 100$; 7, $\times 120$.
- Figs. 8-10. *Pararotalia audouini* (d'Orbigny), P49275-49277, sample 1535, Whitecliff Bay, Middle Headon Beds. 8, $\times 72$; 9, $\times 70$; 10, $\times 50$.
- Figs. 11-13. *Pararotalia curryi* Loeblich and Tappan, P49286-49288, sample 2056, Colwell Bay, Middle Headon Beds. 11, $\times 240$; 12, $\times 180$; 13, $\times 110$.
- Fig. 15. *Pararotalia inermis* (Terquem), P49289-49291, sample F132, Grignon, Middle Lutetian, $\times 130$.



MURRAY and WRIGHT, *Rotaliina*

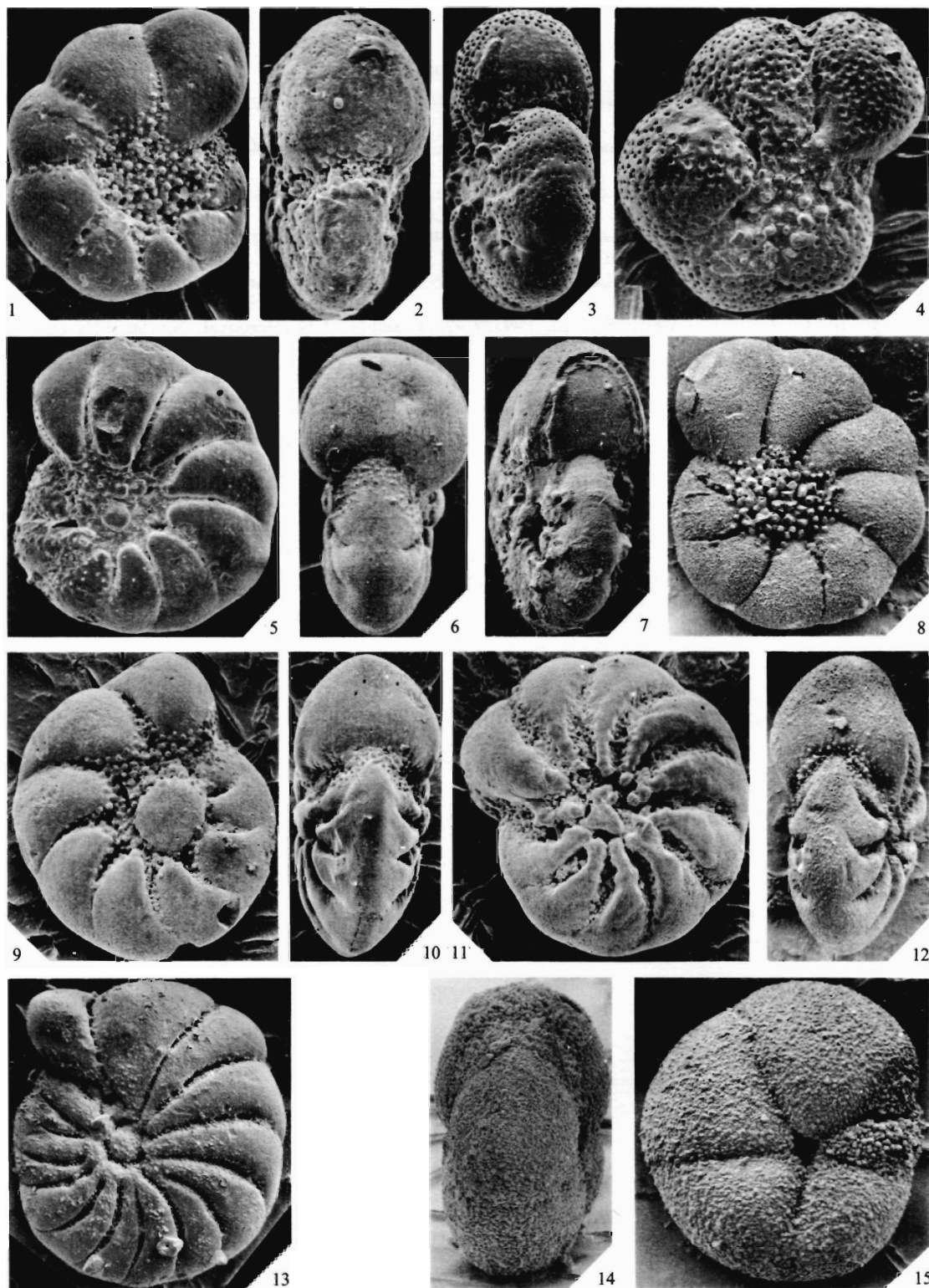
EXPLANATION OF PLATE 12

- Figs. 1, 2. *Pararotalia inermis* (Terquem), P49289–49291, sample F132, Grignon, Middle Lutetian. 1, $\times 130$; 2, $\times 118$.
- Figs. 3, 4, 8. *Pararotalia spinigera* (Le Calvez), P49292–49294, sample F105, Sables d'Auvers, Le Guépelle. 3, $\times 123$; 4, $\times 130$; 8, $\times 103$.
- Figs. 5, 9. *Elphidium hiltermanni* Hagn, P49297–49298, sample 1375, Headon Hill, Middle Headon Beds. 5, $\times 290$; 9, $\times 260$.
- Figs. 6, 7. *Elphidium costiferum* (Terquem), P49295–49296, sample F141, Hauteville, Lutetian. 6, $\times 106$; 7, $\times 100$.
- Fig. 10. *Elphidium latidorsatum* (Reuss), P49299, sample B100, Barton-on-Sea, Barton Clay, Bed E, $\times 150$.
- Fig. 11. *Elphidium subcarinatum* (Egger), P49300, sample 1685, Corneilles-en-Parisis, Marnes à Huîtres inférieures, $\times 280$.
- Figs. 12, 13. *Protelphidium* sp. 1, P49303–49304, Barton-on-Sea, Barton Clay, Bed E. 12, $\times 310$; 13, $\times 250$.
- Figs. 14, 15. *Protelphidium* sp. 2, P49301–49302, sample F66, Chavençon, Ludian. 14, $\times 340$; 15, $\times 260$.



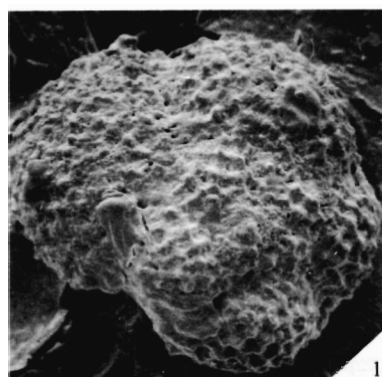
EXPLANATION OF PLATE 13

- Figs. 1, 2. *Protelphidium* sp. 3, P49305-49306, sample F124, Ézanville, Ézanville Formation. 1, $\times 305$; 2, $\times 380$.
- Figs. 3, 4. *Protelphidium* sp. 4, P49308-49309, sample 2056, Colwell Bay, Isle of Wight, Middle Headon Beds. 3, $\times 270$; 4, $\times 340$.
- Figs. 5, 6. *Protelphidium* cf. *P. roemeri* (Cushman), P49307, sample 2051, Colwell Bay, Isle of Wight, Middle Headon Beds. 5, $\times 255$; 6, $\times 190$.
- Figs. 7, 8. *Nonion graniferum* (Terquem), P49310-49311, sample 1676, Argile à Corbules de Frépillon, Cormeilles-en-Parisis. 7, $\times 130$; 8, $\times 180$.
- Figs. 9-13. *Nonion laeve* (d'Orbigny), P49312-49315. 9-11, sample F10, Monte de Magny, Cuisian. 9, $\times 152$; 10, $\times 174$; 11, $\times 178$. 12-13, sample 1676, Cormeilles-en-Parisis, Argile à Corbules de Frépillon. 12, $\times 170$; 13, $\times 110$.
- Figs. 14, 15. *Nonion parvulum* (Grzybowski), P49316-49317, sample 1681, Cormeilles-en-Parisis, Marnes à Huitres supérieures. 14, $\times 225$; 15, $\times 170$.

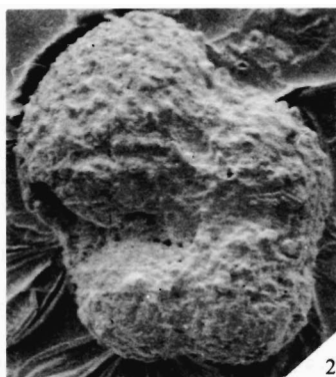


EXPLANATION OF PLATE 14

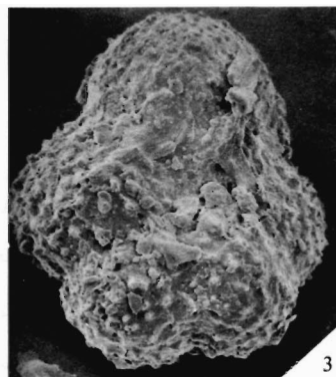
- Figs. 1, 2. *Turborotalia esnaensis* (Le Roy), P49320-49321, sample W27, Whitecliff Bay, London Clay. 1, $\times 270$; 2, $\times 190$.
- Figs. 3, 6. *Turborotalia perclara* (Loeblich and Tappan), P49318-49319, sample SW20, Swanwick, London Clay. 3, $\times 270$; 6, $\times 370$.
- Figs. 4, 5. *Globigerina aquiensis* Loeblich and Tappan, P49324-49325. 4, sample W27, Whitecliff Bay, London Clay, $\times 175$. 5, sample SW15, Swanwick, London Clay, $\times 175$.
- Figs. 7, 8. *Globigerina* cf. *G. angustiumbilitata* Bolli, P49322-49323, sample 1535, Whitecliff Bay, Middle Headon Beds. 7, $\times 400$; 8, $\times 400$.
- Figs. 9, 11, 12. *Eponides polygonus* Le Calvez, P49326-49328, sample F49, Marquemont, Lutetian. 9, $\times 90$; 11, $\times 87$; 12, $\times 89$.
- Figs. 10, 13. *Eponides toulmini* Brotzen, P49329-49331, sample F24, Hérouval, Niveau d'Hérouval. 10, $\times 155$; 13, $\times 147$.



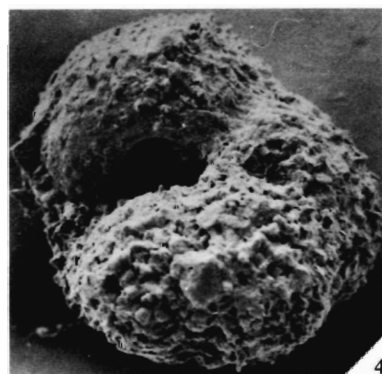
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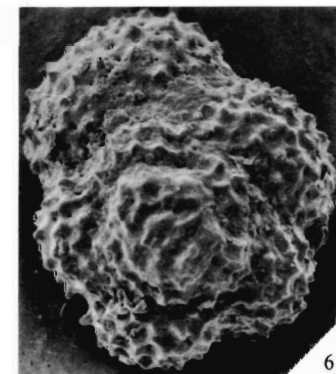
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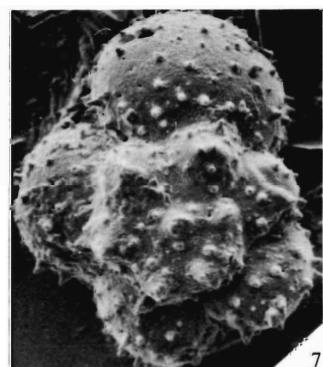
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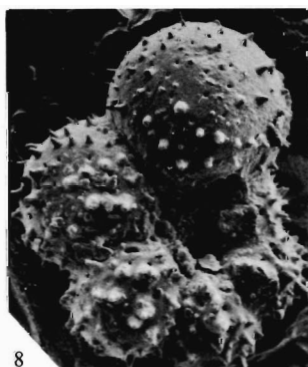
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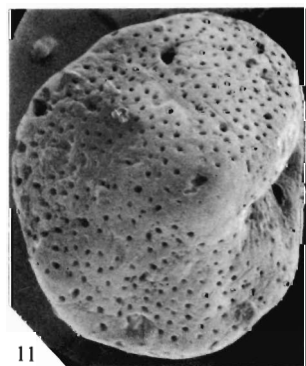
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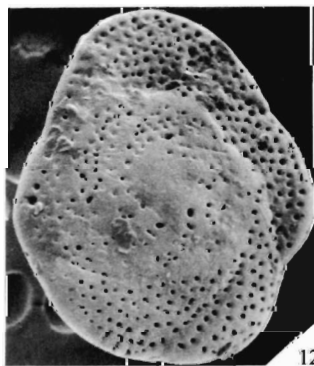
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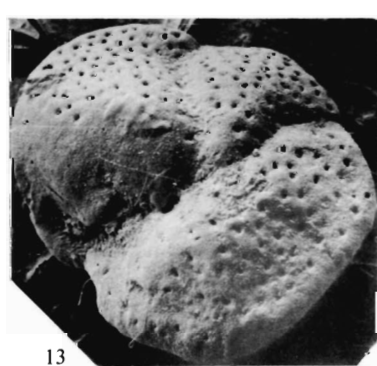
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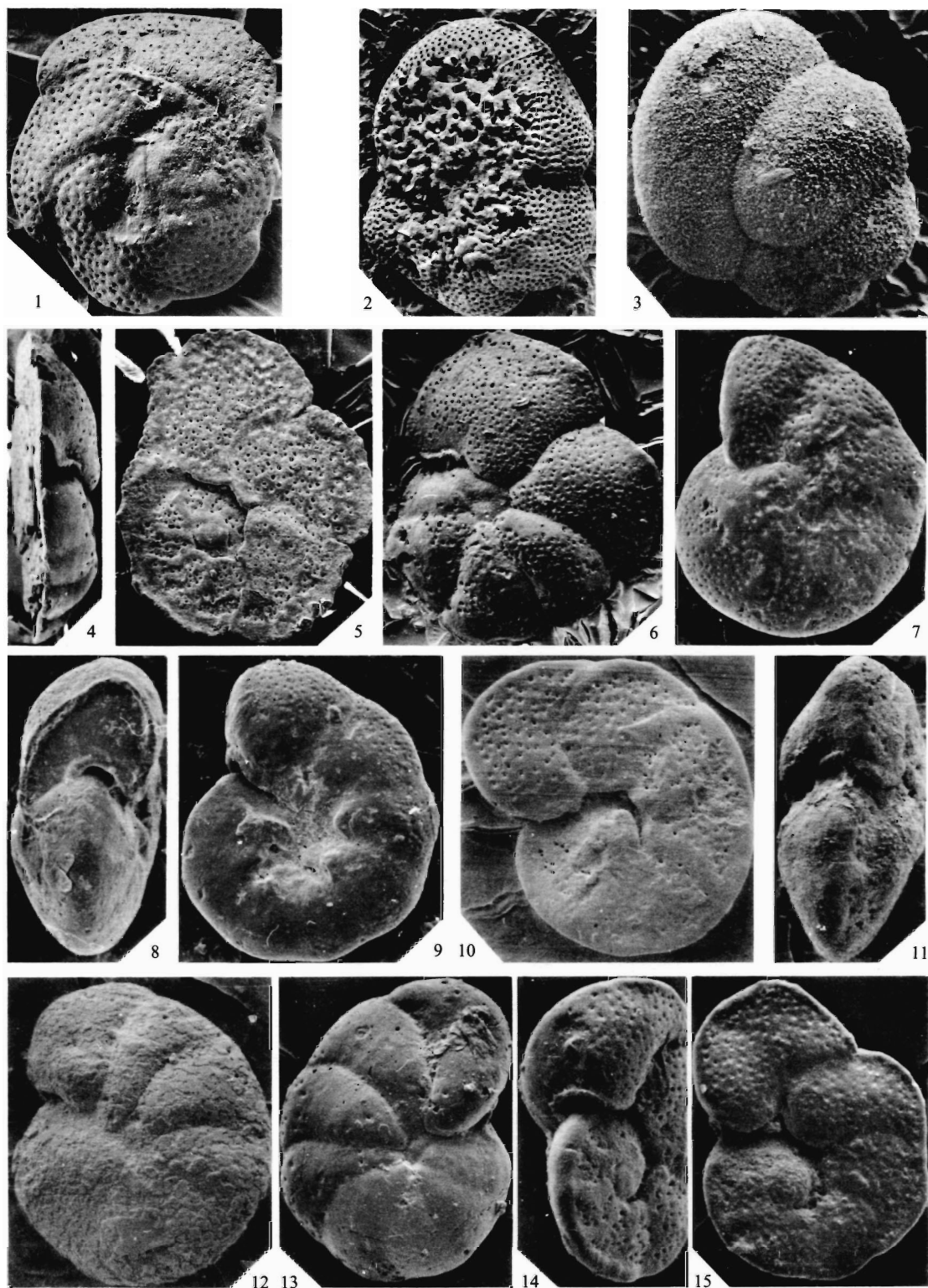
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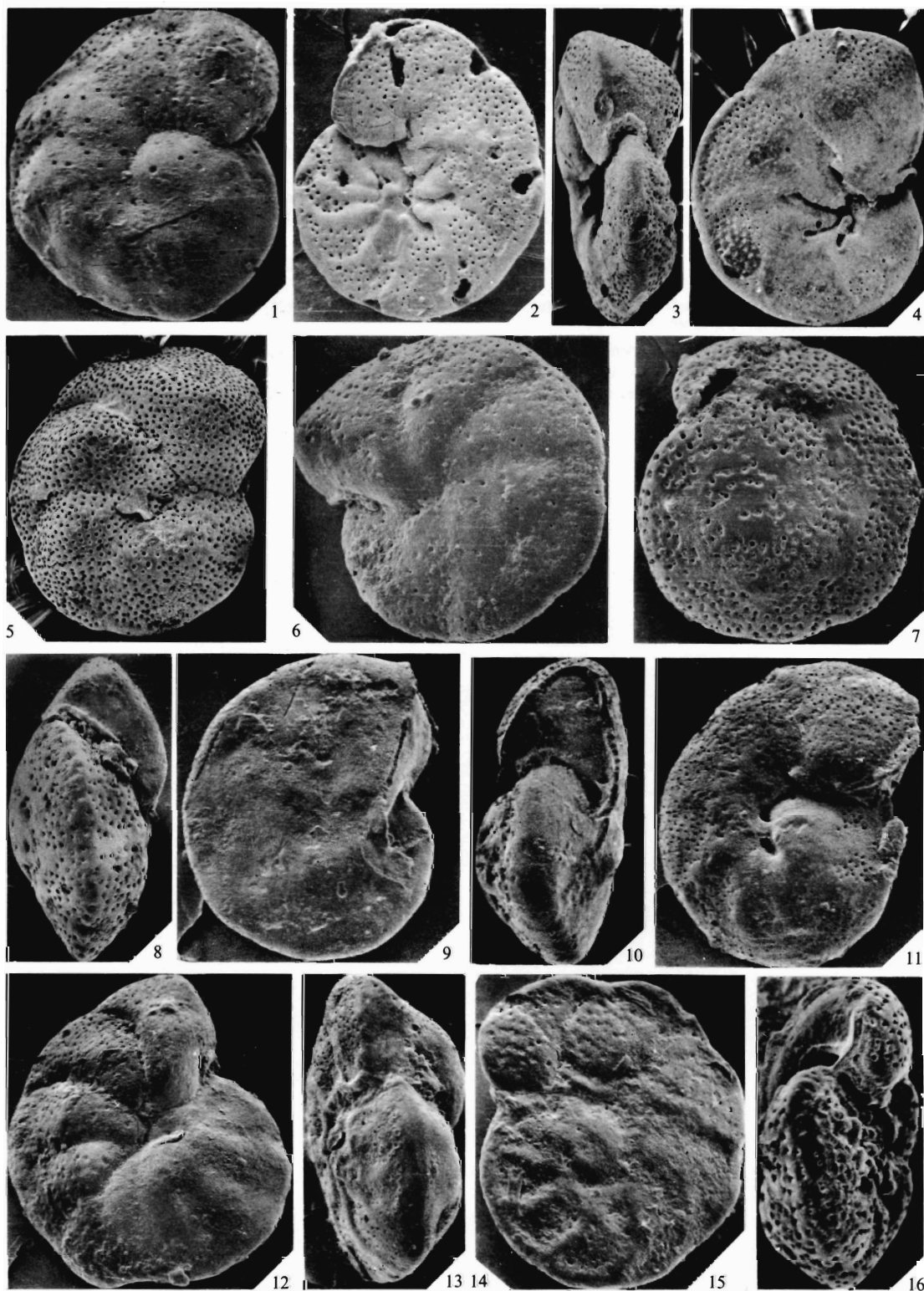
EXPLANATION OF PLATE 15

- Fig. 1. *Eponides toulmini* Brotzen, P49329-49331, sample F24, Hérrouval, Niveau d'Hérrouval, $\times 136$.
Figs. 2, 3. *Neocribrella globigerinoides* (Parker and Jones), P49332-49333. 2, sample F134, Grignon, Middle Lutetian, $\times 135$. 3, sample F32, Chaumont-en-Vexin, Lutetian, $\times 72$.
Figs. 4-6. *Cibicides carinatus* (Terquem), P49334-49336, sample F42, Liancourt, Middle Lutetian. 4, $\times 80$; 5, $\times 73$; 6, $\times 85$.
Figs. 7-9. *Cibicides cunobelini* Haynes, P49337-49339, sample A4, Alum Bay, London Clay. 7, 8, $\times 150$; 9, $\times 125$.
Figs. 10-12. *Cibicides fortunatus* Martin, P49340-49341, sample 1322, Alum Bay, Barton Clay. 10, $\times 210$; 11, 12, $\times 150$.
Figs. 13-15. *Cibicides lobatulus* (Walker and Jacob), P49342-49344, sample F105, Le Guépelle, Auversian. 13, $\times 120$; 14, $\times 145$; 15, $\times 150$.



EXPLANATION OF PLATE 16

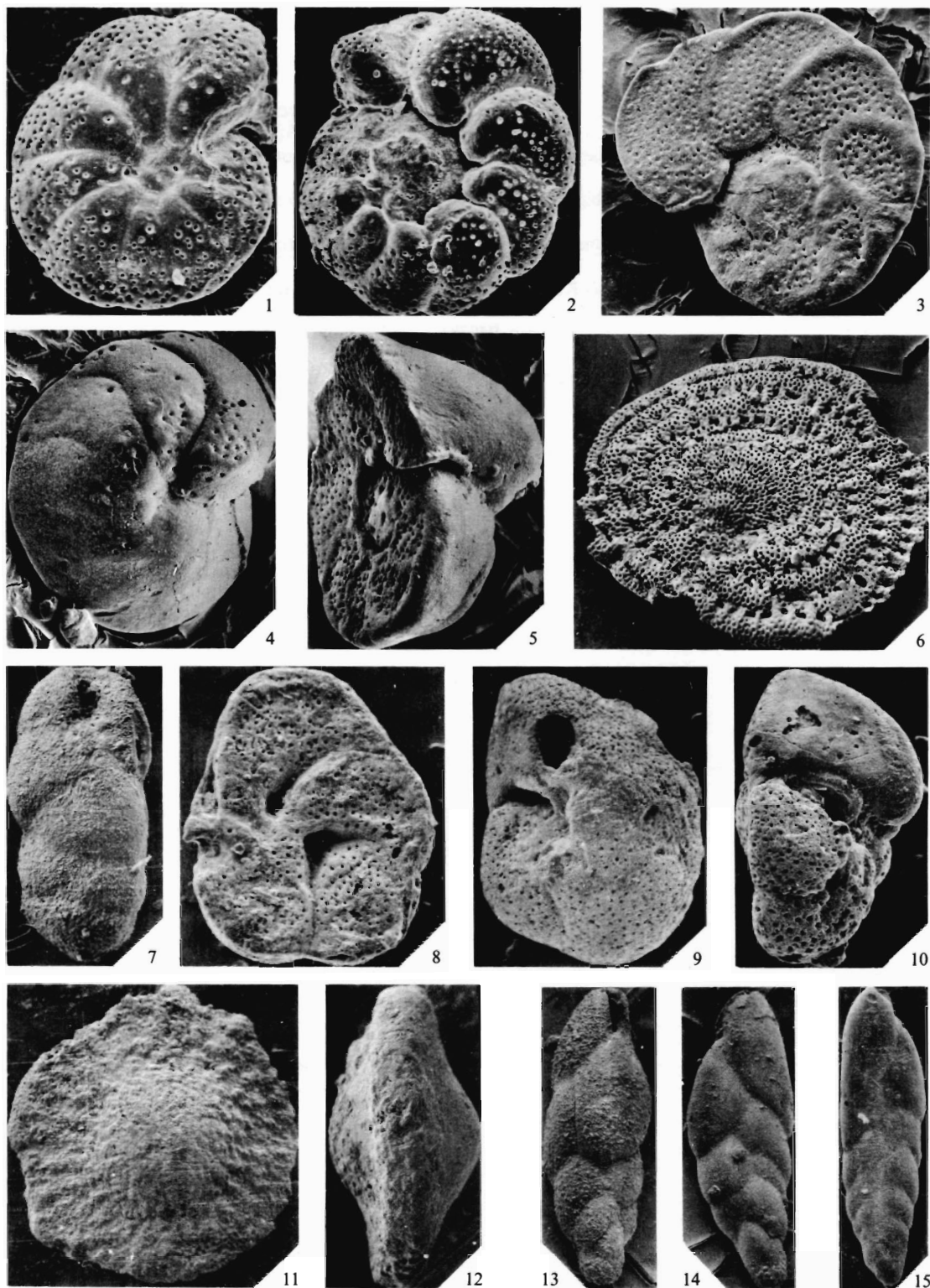
- Figs. 1, 2. *Cibicides mauricensis* Howe and Roberts, P49345-49346, sample F14, Mont de Magny, Cuisian. 1, $\times 142$; 2, $\times 114$.
- Figs. 3-5. *Cibicides productus* (Terquem), P49347-49348, sample F31, Chaumont-en-Vexin, Lutetian. 3, $\times 134$; 4, $\times 140$; 5, $\times 127$.
- Figs. 6-8. *Cibicides pygmeus* (Hantken), P49349-49350, sample 1316, Alum Bay, Barton Clay. 6, $\times 160$; 7, $\times 145$; 8, $\times 150$.
- Figs. 9-11. *Cibicides simplex* Brotzen, P49351-49353, sample A2, Alum Bay, London Clay. 9, $\times 168$; 10, $\times 130$; 11, $\times 165$.
- Figs. 12-14. *Cibicides tenellus* (Reuss), P49354-49355, sample W93, Whitecliff Bay, Bracklesham Beds, Beds XIV-XVII. 12, $\times 109$; 13, 14, $\times 120$.
- Fig. 15. *Cibicides ungerianus* (d'Orbigny), P49356, sample F59, Le Ruel, Auversian, $\times 160$.



MURRAY and WRIGHT, Rotaliina

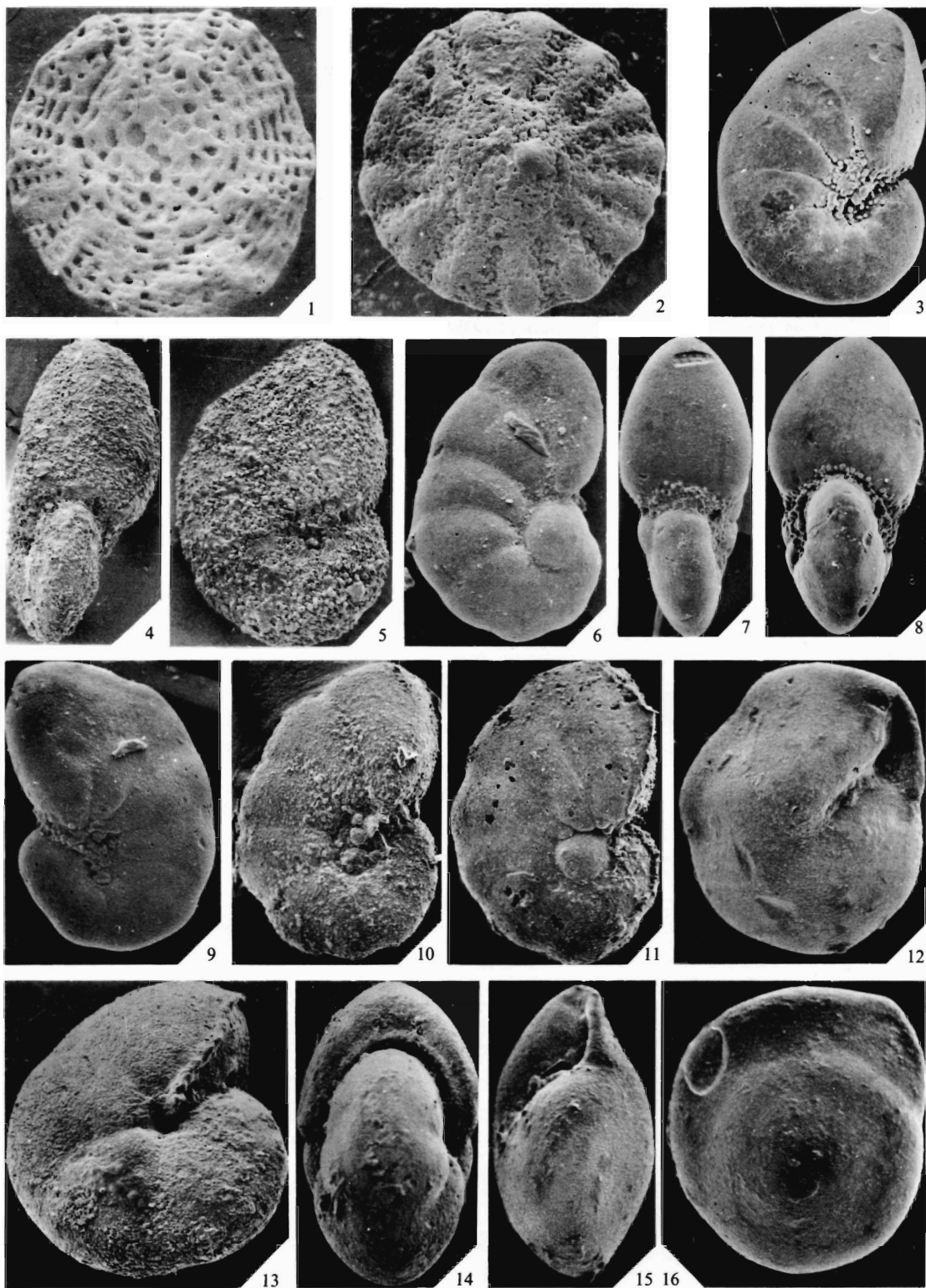
EXPLANATION OF PLATE 17

- Figs. 1, 2. *Cibicides ungerianus* (d'Orbigny), P49356-49357, sample F59, Le Ruel, Auversian. 1, $\times 130$; 2, $\times 97$.
- Figs. 3-5. *Cibicides westi* Howe, P49358-49360, sample F10, Mont de Magny, Cuisian. 3, $\times 176$; 4, $\times 173$; 5, $\times 178$.
- Fig. 6. *Cycloloculina eocenica* (Terquem), P49361, sample F131, Grignon, Lutetian, $\times 78$.
- Fig. 7. *Caucasina coprolithoides* (Andreae), P49362, sample 1551, Whitecliff Bay, Isle of Wight, Bembridge Marl, $\times 170$.
- Figs. 8-10. *Gyroidinella magna* Le Calvez, P49363-49365, sample F31, Chaumont-en-Vexin, Lutetian. 8, $\times 96$; 9, $\times 93$; 10, $\times 83$.
- Figs. 11, 12. *Linderina brugesi* Schlumberger, P49366-49367, sample SB74/1, Western Approaches, Upper-Middle Eocene. 11, $\times 80$; 12, $\times 73$.
- Figs. 13, 14. *Fursenkoina schreibersiana* (Czjzek), P49368-49369, sample 1681, Cormeilles-en-Parisis, Marnes à Huîtres supérieures. 13, $\times 130$; 14, $\times 112$.
- Fig. 15. *Fursenkoina vicksburgensis* (Cushman), P49370, sample 1681, Cormeilles-en-Parisis, Marnes à Huîtres supérieures, $\times 106$.



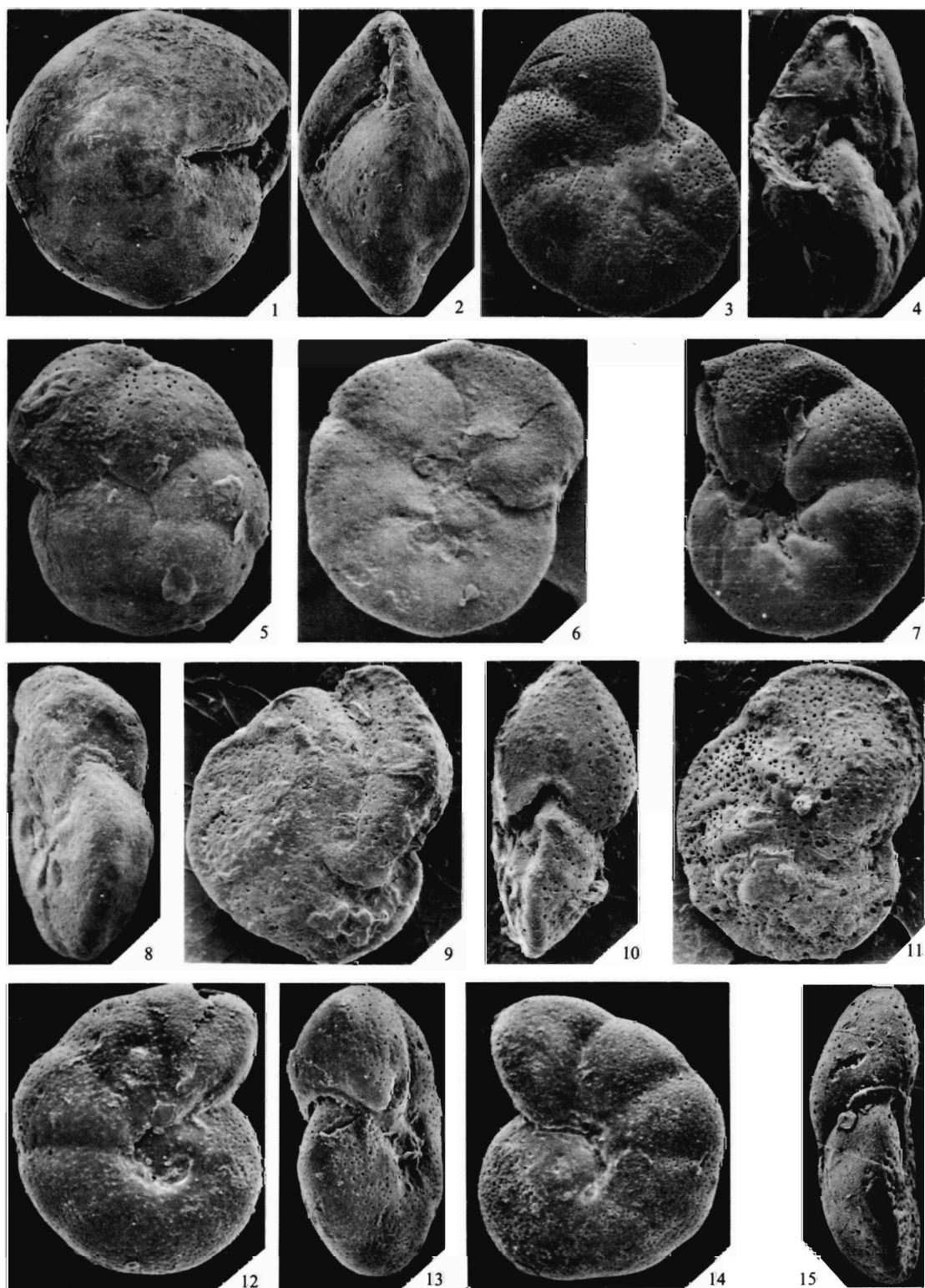
EXPLANATION OF PLATE 18

- Fig. 1. *Sphaerogypsina globulus* (Reuss), P49371, sample SB1082/2, Western Approaches, Eocene, $\times 40$.
Fig. 2. *Halkyardia minima* (Liebus), P49372, sample SB106/4, Western Approaches, Eocene, $\times 114$.
Figs. 3, 8. *Florilus commune* (d'Orbigny), P49373–49374, sample F10, Mont de Magny, Cuisian. 3, $\times 130$; 8, $\times 126$.
Figs. 4, 5. *Florilus elongatum* (d'Orbigny), P49375–49376, sample F1, Mont de Magny, Cuisian. 4, $\times 94$; 5, $\times 98$.
Figs. 6, 7, 9. *Nonionella spissa* Cushman, P49377–49379, sample F107, Ermenonville, Auversian. 6, $\times 240$; 7, $\times 220$; 9, $\times 240$.
Figs. 10, 11. *Nonionella wemmelensis* Kaasschieter, P49380, sample 1691, Cormeilles-en-Parisis, Calcaire de Sannois. 10, 11, $\times 250$.
Figs. 12, 15, 16. *Alabamina wilcoxensis* Toulmin, P49381–49383, sample F34, Chaumont-en-Vexin, Lutetian. 12, $\times 180$; 15, 16, $\times 166$.
Figs. 13, 14. *Pullenia quinqueloba* (Reuss), P49386–49387, sample W24, Whitecliff Bay, London Clay. 13, $\times 200$; 14, $\times 170$.



EXPLANATION OF PLATE 19

- Figs. 1, 2. *Alabamina obtusa* (Burrows and Holland), P49384-49385, sample W24, Whitecliff Bay, London Clay. 1, $\times 120$; 2, $\times 150$.
- Figs. 3, 4, 7. *Anomalinoides acuta* (Plummer), P49391, sample F14, Mont de Magny, Cuisian. 3, $\times 105$; 4, $\times 130$; 7, $\times 110$.
- Figs. 5, 6, 8. *Anomalinoides acuta* (Plummer) var. *anomalinoides* (Ten Dam), P49392-49394, sample F9, Mont de Magny, Cuisian. 5, $\times 210$; 6, $\times 190$; 8, $\times 106$.
- Figs. 9-11. *Anomalinoides auris* (Le Calvez), P49395-49397, sample F27, Chaumont-en-Vexin, Lutetian. 9, $\times 103$; 10, $\times 137$; 11, $\times 115$.
- Figs. 12-14. *Anomalinoides nobilis* Brotzen, P49401-49403, sample W26, Whitecliff Bay, London Clay. 12, $\times 166$; 13, $\times 230$; 14, $\times 180$.
- Fig. 15. *Anomalinoides ypresiensis* (Ten Dam), P49398, sample F24, Hérouval, Cuisian, $\times 112$.



EXPLANATION OF PLATE 20

- Figs. 1, 2. *Anomalinoides ypresiensis* (Ten Dam), P49399-49400, sample F24, Hérrouval, Cuisian. 1, $\times 164$; 2, $\times 124$.
- Figs. 3, 5, 6. *Cibicidoides proprius* Brotzen, P49404-49406, sample A7, Alum Bay, London Clay. 3, $\times 160$; 5, $\times 109$; 6, $\times 118$.
- Figs. 4, 7. *Melonis affine* (Reuss), P49407-49408, Barton-on-Sea, Barton Clay, Bed E. 4, 7, $\times 146$.
- Figs. 8-10. *Gyroidina angustiumblicata* Ten Dam, P49388-49390, sample A7, Alum Bay, London Clay. 8, $\times 205$; 9, $\times 280$; 10, $\times 230$.
- Fig. 11. *Robertina ovigera* Cushman and Parker, P49413, sample F21, Hérrouval, Niveau d'Hérrouval, $\times 130$.
- Figs. 12-14. *Pulsiphonina prima* (Plummer), P49409-49411, sample SW17, Swanwick, London Clay. 12, $\times 340$; 13, $\times 520$; 14, $\times 240$.
- Fig. 15. *Robertina germanica* Cushman and Parker, P49412, Barton-on-Sea, Barton Clay, Bed E, $\times 155$.

