THE PALAEOECOLOGY OF THE FORAMINIFERA OF THE CHALK MARL

by T. P. BURNABY

ABSTRACT. The frequencies of benthonic foraminifera from twenty-seven samples from the Chalk Marl at Barrington, Cambridgeshire, have been used in constructing a discriminant function which gives a relative measure of the depth of water of the Chalk Marl sea.

THE work here described was carried out in 1950–2, at a time when most of the references cited below had not yet been published. Hence the nature of the plan of work, which was to make a detailed investigation of a single short stratigraphical profile, to develop a suitable quantitative technique, and to evaluate the degree of accuracy of the results. This, though limited in scope, was felt to be a worth-while preliminary to possible future regional palaeogeographical studies, such as that since carried out by R. P. S. Jefferies on the *plenus* Marls of the Turonian (this volume).

The Chalk Marl in Messrs. Eastwood's cement quarry at Barrington is, except for intermittent talus slopes, completely exposed from the Cambridge Greensand at the base to the Burwell Rock at the top. The management's permission having been obtained, twenty-seven samples of chalk were collected from twenty-three different levels in the 90-foot thickness of the *Schloenbachia varians* Zone. Each sample was a discrete lump of chalk and not an aggregate of chippings from an extended vertical surface, the object of study being the actual death assemblages of foraminifera. The penalty incurred in this procedure is, of course, that species occurring abundantly in thin bands but not elsewhere will probably be missed.

About 200 c.c. of chalk from each sample was disaggregated in water, using a shaking machine and four rubber bungs in the glass jars to act as mill-balls, and yielded in the washings from a few thousand to tens of thousands of benthonic foraminifera in the size fraction 1 mm.–0·2 mm. Owing to the presence of some 15–30 per cent. of clay in the Chalk Marl, disaggregation is particularly easy, and no boiling or other treatment is necessary to yield clean undamaged tests. The Burwell Rock is more difficult.

Standard sample counts of from 1,000 to 1,500 specimens were carried out on the benthonic foraminifera in the size fraction 1 mm.–0·2 mm. A specially designed two-stage rotary sample splitter was used to divide the dry sieved washings from a given sample into random subsamples, the accuracy of counting being checked by the χ^2 test. The results of about twenty such tests showed conclusively that the sample counts are as accurately repeatable as random sampling will allow, provided that the specified size limits of the material are not changed. It has also to be remembered that only a single observer was being tested. Some χ^2 tests were also made with data from duplicated extraction processes from a single Chalk Marl sample, the repeatability of the extraction process being thus checked. No significant discrepancies were found. Strongly significant χ^2 values were obtained from five replicated samples collected a few feet apart horizontally at the same level (samples 2/7A–E).

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The main results are summarized in the accompanying distribution chart (text-fig. 1). Altogether 49 species were distinguished, of which 44 were regularly recorded in the sample counts. The actual total number present, as estimated by fitting a negative binomial to the observed distribution, could well be about 60: this allows for those species which may have escaped unobserved in thin bands not sampled or, if very rare, in the actual samples. It will be seen that the general aspect of the fauna is fairly constant throughout the section, nearly all the more abundant species, and some of the rarer ones as well, being present at all levels sampled. Arenaceous species represent about half the fauna in terms of individuals and about one-third in terms of species. The zonal index-fossil, *Textulariella cretosa*, is absent from three samples in the first 10 feet of the section. The distinctive Cenomanian species *Cibicides formosa* occurs sparsely in samples 1/13 and 2/7A–E and nowhere else, its maximum level of abundance being 12 per mil.

In warm subtropical seas at the present day, a large proportion of arenaceous individuals and species is characteristic of the faunas occurring in depths of from 5 to 50 fathoms (see, for example, Bandy 1956, charts 5–7). In addition to the arenaceous forms there is often a striking diversity of genera and species of other families in this range of depths (Lowman 1949, p. 1956). The Lagenidae would not be so abundant in this depth range at the present day as they are in the Chalk Marl fauna, but it is well known that in the Mesozoic the Lagenidae were much more widely distributed than they are now, and the principal Chalk Marl genus, *Lenticulina*, is frequently found today at 50 fathoms and less. The principal apparent anomaly concerns the planktonic species, which were not included in the sample counts but which are very abundant in the Chalk Marl. Formerly this might have been taken as indicating a depth of two or three hundred fathoms or more; but recent work has shown that a large proportion of planktonic individuals is by no means unusual in comparatively shallow water. Thus Bandy (1956) records 70 per cent. planktonic forms at a little over 40 fathoms off St. Petersburg, Florida, and Bandy and Arnal (1957) record 25 per cent. planktonic forms at 10 fathoms at two stations off the west coast of Central America.

It will be understood that the palaeoecology of Cretaceous foraminifera is a very different proposition from the comparatively straightforward approach which is possible in the case of the Tertiary. The faunas have been much changed through extinctions and fresh evolutionary speciation, and we are forced to rely upon comparisons of related genera, rather than of species. A further difficulty has been that, until recently, ecological studies of living foraminifera have tended to concentrate upon temperate and cold-water faunas, which have no affinities with the Chalk Marl fauna; indeed at the time the present work was begun it was found that the only reports having any real relevance were the classic papers of Norton (1930) and Lowman (1949).

Fortunately, geological evidence of conditions of deposition of the Chalk Marl is not lacking: the Cambridge Greensand at the base clearly represents a shallow-water phase when the bottom sediments were winnowed by currents, and at the top of the section the Burwell Rock equally clearly represents a time of shallow-water conditions. It is a fair inference that the period of time intervening, during which 90 feet of Chalk Marl was deposited, represents an environment in which the water was somewhat deeper. We have therefore to seek for Chalk Marl foraminifera whose vertical distribution-patterns possess marked peaks or troughs, which might suggest that their relative abundance was governed by the changing environment. The four species *Arenobulimina*

(*Hagenowella*) *anglica*, *Textularia subconica*, *Tritaxia pyramidata* s.l., and *Gyroidinoides nitida*, are particularly noteworthy in this respect, as may be seen from text-fig. 1. Now it is interesting that the living species *Valvulina oviedoiana*, which is perhaps the closest living relative of the Chalk Marl *Arenobulimina* spp., is at the present day largely confined to very shallow warm water, from 0 to 5 fathoms in the West Indies (Norton 1930).

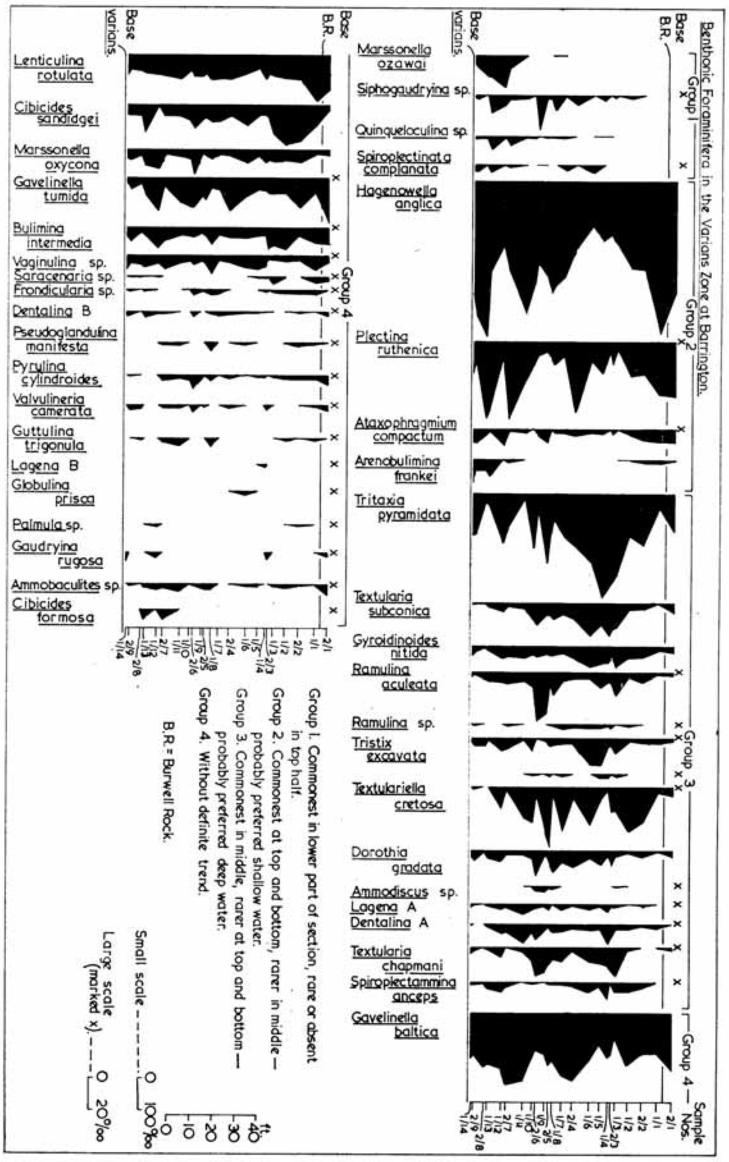
Textularia today is characteristically a genus whose species prefer a depth of the order of 20 fathoms, though naturally among the many living forms there are numerous exceptions. As a rough generalization it would be correct to say that they are relatively uncommon in very shallow water or at depths much below 100 fathoms. (See, for example, Norton 1930; Lowman 1949, figs. 13, 15, and 17; Walton 1955, figs. 20–21; Bandy 1956, charts 1–7; Bandy and Arnal 1957, table 1.)

Living species of *Gaudryina* in which a large part of the test is triserial and triangular in cross-section, resembling in this respect the extinct genus *Tritaxia*, occur mostly in moderately deep water, from 50 to 500 fathoms. Of fourteen Recent species listed by Cushman (1937) none are recorded from depths of less than 17 fathoms. Two Californian species listed by Walton (1955) occur at depths of between 12 and 120 fathoms. Bandy and Arnal (1957) report *G. atlantica* at depths ranging from 30 to 57 fathoms. It is arguable that the Cretaceous *Tritaxia* is not more closely related to these Recent species than is implied by its inclusion in the same family, but in any case the present-day bathymetric distribution of the Verneuilinidae is much the same as that of *Gaudryina*. We conclude, therefore, that *Tritaxia pyramidata* s.l. most probably preferred a moderately deep-water habitat.

Gyroidina (including *Gyroidinoides*) is a deep-water form at the present day. The shallowest occurrences I have found recorded are at 60 fathoms in the Gulf of Mexico (Norton 1930, Lowman 1949). It is common at abyssal depths (Bandy 1953, p. 171 and table 1).

Now, if it is conceded that the relative abundance of the four Chalk Marl species, *Hagenowella anglica*, *Textularia subconica*, *Tritaxia pyramidata*, and *Gyroidinoides nitida*, was governed largely by the depth of water, then the immediate conclusion will be drawn that there was a deep-water phase in the deposition of the Barrington Chalk Marl, culminating at a horizon about 60 feet above the base of the section, where the depth of water was perhaps 50–100 fathoms. At the commencement and end of Chalk Marl time, the sea appears to have been only about 5 fathoms deep. It seems to have remained fairly shallow while the first 40 feet of the Chalk Marl was laid down, although conditions then appear to have been extremely unsettled. The same four species show clearly enough by their change in relative abundance the shallowing of the sea during the last phase of Chalk Marl deposition, represented by the topmost 25 feet of the section below the Burwell Rock.

It is possible to make use of the observed frequencies in the samples of the foraminifera in constructing a cinematic record of the changes in depth of the Chalk Marl sea, not by purely subjective assessment but by statistical analysis of the data. The basic idea is to obtain a suitably weighted average of the percentages of the four species at any given horizon, the value of which serves as a measure of the former depth of the sea at that horizon. The weighted average, known as a discriminant function, is of course expressed in arbitrary units which must be assumed to be simply proportional to the depth in fathoms.



TEXT-FIG. 1. Distribution chart of the Chalk Marl benthonic foraminifera. Data from Table 2, reduced to frequencies per mil.

Essentially the same method has already been employed by N. M. Curtis, Jr. (1955) in plotting an oscillation chart of the changes in depth of the Eocene sea in a section in the Weches formation in Texas. His discussion of the palaeoecology is naturally not confined to the two abundant depth-sensitive species, *Quinqueloculina claiborniana* and *Siphonina claibornensis*; however, it seems clear from his remarks below his fig. 2 that the oscillation chart shown thereon has been constructed by taking, at each sampling point, a simple average of the percentage frequencies of the two species, with weighting coefficients $(-1, 1)$, as a measure of the depth.

The procedure adopted for the four Chalk Marl species was as follows. From the frequencies per mil. (x_{jk} specimens) of the jth species in the kth sample, were subtracted the values of a five-point moving average representing the trend-line of the species concerned, giving the residuals (i.e. deviations from trend)

$$z_k = x_k - \tfrac{1}{9}(1, 2, 3, \ldots)(x_{k-2} \ldots x_{k+2}).$$

The 4×4 matrix of residual variances and covariances for the four species was then calculated, having elements w_{ij} such that

$$w_{ij} = \frac{1}{N-4}(z_{ik}\, z^{jk}),$$

the alternate sub- and superscript ${}_{ik}{}^{jk}$ denoting summation over the range of k, which in this case is from $k = 3$ to $k = N-2$, since the moving average does not cover the first and last two samples. There are 23 horizons sampled, but only $19 = N-4$ terms in the mean products, w_{ij}, the 16 values of which are as follows:

	Gyroidinoides	*Textularia*	*Tritaxia*	*Hagenowella*
Gyroidinoides	73·6	51·2	63·7	−155·5
Textularia	51·2	159·2	−18·2	−282·4
Tritaxia	63·7	−18·2	2324·7	−851·1
Hagenowella	−155·5	−282·4	−851·1	2234·7

This residual dispersion matrix can be regarded as giving the variances and covariances within a generalized thin stratum of Chalk Marl roughly 10 feet thick.

The next step is to select—subjectively—on general geological grounds which will now be apparent, two small groups of samples representing deep-water and shallow-water conditions respectively. Group DW comprised Nos. 1/6, 1/5, 1/4, 2/3, and 1/3, and Group SW Nos. 1/14, 2/9, 2/8, 1/13, and 1/1. As a defence against possible criticism, it may be remarked that the precise choice of particular samples makes little difference to the results, since the residual dispersion matrix is not thereby affected. The mean frequencies per mil. from the two groups of samples were calculated, and from them the set of differences $d_i = \bar{x}_{iDW} - \bar{x}_{iSW}$ was obtained.

$$(d_i) = \begin{bmatrix} 36{\cdot}2 \\ 83{\cdot}0 \\ 204{\cdot}0 \\ -236{\cdot}0 \end{bmatrix} \begin{array}{l} \textit{Gyroidinoides} \\ \textit{Textularia} \\ \textit{Tritaxia} \\ \textit{Hagenowella}. \end{array}$$

The discriminant function was then calculated in the usual way (see, for example, Rao 1952, p. 254) by solving the set of four simultaneous equations

$$\lambda_j w^{ij} = d_i$$

the solutions obtained being

$$\lambda_j = (0{\cdot}0535,\ 0{\cdot}508,\ 0{\cdot}0888,\ -0{\cdot}00393)$$

and the discriminant function is thus

$$X = 0{\cdot}0535x_1 + 0{\cdot}508x_2 + 0{\cdot}0888x_3 - 0{\cdot}00393x_4$$

where the variates $x_1 \ldots x_4$ are the frequencies per mil., in any one sample of Chalk Marl, of the four species of *Gyroidinoides*, *Textularia*, *Tritaxia*, and *Hagenowella*. Values of X so calculated have the smallest possible residual variance relative to their variance between samples from deep and shallow water.

The mean values $\bar{X}$ for the deep-water and shallow-water groups of samples, when differenced, give the value of the statistic known as D^2. We have

$$\bar{X}_{DW} - \bar{X}_{SW} = 70{\cdot}77 - 8{\cdot}01 = 62{\cdot}76 = D^2.$$

The square root of D^2 gives the standard error of the value of X for a single sample, which is therefore $\sqrt{(62{\cdot}76)} = 7{\cdot}922$.

It is interesting to note that the standard deviation of X can be estimated directly from the five replicated samples, Nos. 2/7A–E. From the five values of X (see Table 1) we obtain in the usual way $s_X = 6{\cdot}15$, with 4 degrees of freedom, which shows that the previous result is of the right order of magnitude.

Returning to the Chalk Marl sea, it is clear that we do not know, nor can we discover directly, what value of X corresponds to a particular depth in fathoms. But if we care to postulate that the value of X is linearly related to the depth of water, and assign the notional depths of 50 and 5 fathoms to the deep-water and shallow-water groups, we can set up the equation

$$Y_k - 5 = (50-5)(X_k - \bar{X}_{SW})/(X_{DW} - \bar{X}_{SW})$$

where Y_k is the depth in fathoms corresponding to the value of X_k for the kth sample. Most of the Chalk Marl samples will now be found to lie somewhere in the range 5 to 50 fathoms which we had previously concluded to be about right. Since we now have the value of the constant of proportionality between X and Y, we can determine the standard error of Y: it is

$$s_Y = s_X(45)/(62{\cdot}76) = 45/\sqrt{(62{\cdot}76)} = 5{\cdot}680 \text{ fathoms.}$$

(Note. A standard deviation can only be put to practical use by performing at least one further arithmetical operation upon it: four figures are therefore quoted, out of courtesy to readers—not because it is thought to represent anything but an order of magnitude.)

The values obtained for the depth Y for the twenty-three sampled horizons in the Barrington Chalk Marl are given in Table 1. Also shown are the heights in feet of the sampling points above the base of the formation, the total number of benthonic foraminifera extracted per c.c. of chalk, and (measured for 16 samples only) the percentage of insoluble mineral residues present in the chalk.

There is a rather sharp drop in the insoluble fraction at around 50 feet above base,

TABLE 1

Sample	*Height (ft.) above base*	*X*	*Y (fathoms)*	*Forams/c.c. chalk*	*% insol. residue*
Group SW	. .	8·01	5·0		
Group DW	. .	70·77	50·0		
2/1	90·0	25·91	17·8	17·1	8·2
1/1	84·5	3·00	1·4	26·3	20·3
2/2	77·5	22·83	15·6	26·7	. .
1/2	70·5	22·14	15·1	35·5	13·8
1/3	65·5	63·64	44·9	34·0	18·1
2/3	63·5	66·35	46·8	43·3	. .
1/4	62·5	81·21	57·5	. .	13·1
1/5	59·5	68·43	48·3	46·3	16·8
1/6	56·0	74·53	52·7	47·0	17·3
2/4	46·5	41·44	29·0	30·8	. .
1/7	42·0	31·49	21·8	41·1	23·9
1/8	39·0	32·61	22·6	21·6	21·2
2/5	35·5	30·42	21·1	33·9	. .
1/9	34·5	40·38	28·2	21·2	26·6
2/6	30·0	41·82	29·2	25·9	. .
1/10	29·0	41·89	29·3	21·5	23·5
1/11	26·0	12·51	8·2	34·6	25·9
2/7	17·0	13·74	9·1	80·0	. .
1/12	15·0	29·30	20·3	73·7	19·7
1/13	9·0	7·68	4·8	149·0	30·4
2/8	7·5	1·58	0·4	168·0	. .
2/9	2·5	12·71	8·4	122·0	26·6
1/14	2·0	15·08	10·1	158·0	24·4
2/7A	17·0	12·23	8·0	98·6	
B	,,	15·93	10·7	115·0	
C	,,	21·17	14·4	. .	
D	,,	4·79	2·7	26·7	
E	,,	17·51	11·8	. .	

Explanation of Table 1. The Chalk Marl section at Barrington. Serial numbers of the samples, their heights above the base of the formation, values of the discriminant X, the assumed equivalent depths of water Y, the numbers of benthonic foraminifera (larger than 0·2 mm. diameter) per c.c. of undisaggregated chalk, and the percentages by weight of mineral residue insoluble in HCl. At the head of the table are given the mean values of X and the assumed values of Y for Group SW (the four samples from 2 to 9 feet above base plus sample 1/1), and Group DW (the five samples from 56–66 feet above base). The five replicated samples 2/7A–E were collected a few feet apart horizontally at the same level, ± a few inches either way.

and it is tempting to associate this with the rapid increase in Y to over 50 fathoms, as though the coastline were receding in consequence of a general rise in sea-level. The next sharp drop in the insoluble fraction occurs at 90 feet, in the topmost sample which is from the Burwell Rock. The value of Y of 17·8 fathoms for this sample is, however, almost certainly not to be relied on, since from the abundance of shell-debris in the washings, and the battered appearance of the foraminifera, it is obvious that there has been sedimentary reworking of the material. The topmost sample but one, at 84·5 feet, which is still within the Chalk Marl, gives a value of Y of only 1·4 fathoms, and I would conjecture that the true depositional environment of the Burwell Rock was even shallower than this.

In the lowest part of the section, from 0 to 20 feet above the base, the number of foraminifera in unit volume of chalk is exceptionally high. The simplest explanation is that this reflects an exceptionally low net sedimentation rate, the numbers of foraminifera living and reproducing per unit area of sea-floor supposedly remaining roughly constant. The values of Y recorded in this part of the section indicate irregular and pronounced fluctuations in depth, the average being about 10 fathoms but with occasional very shallow episodes. Under these conditions it would not be surprising if the sedimentary record were somewhat condensed. That the Barrington section is condensed is suggested also by the much greater thickness of the Chalk Marl elsewhere; e.g. 120 feet in Oxfordshire, while bore-hole records near Cambridge also seem to indicate thicknesses greater than 90 feet.

It now becomes interesting to examine the behaviour of some of the other species of foraminifera, in the light of the above results. *Lenticulina rotulata* is an abundant species which apparently was affected very little by the disturbed conditions in the first 20 feet of the section. It thus appears reasonably certain that the hypothesis of a low net sedimentation rate is correct, since otherwise we would have to suppose that the percentage of *Lenticulina* kept exactly in step with pronounced changes in the total number of foraminifera per unit area of sea-floor.

Quinqueloculina sp. and *Marssonella ozawai* are both confined to the lower part of the Chalk Marl. *Quinqueloculina* is common only in samples 1/13 and 2/7A, B, C, and E: it is rare in samples 2/8 and 2/7D. Present-day species of the genus are generally common in shallow-water inshore environments, and there are some that tolerate slightly brackish water. *Marssonella ozawai* has a more restricted stratigraphical range, which makes me reluctant to draw any inferences; but it may be worth noting that it is most abundant in sample 1/12, for which $Y = 20{\cdot}3$ fathoms and the per cent. insol. residue is 19·7, figures which stand out from the general trends of about 7 fathoms and 28 per cent. respectively at about that horizon (see Table 1).

Arenobulimina frankei occurs only in the lower 20 feet and the upper 20 feet of the section. It is absent from sample 1/12. It seems definitely to be a shallow-water species.

Plectina ruthenica is present throughout the section being most abundant in samples with a low value of Y.

Dorothia gradata, *Textulariella cretosa*, *Textularia chapmani*, *Ramulina* (two species) and *Tristix* (two species) and perhaps also *Spiroplectammina anceps*, show a preference for samples with a high value of Y.

Gavelinella baltica seems to have had no ecological preferences either way.

Lenticulina rotulata and *Cibicides sandidgei* are most abundant towards the top of the section. This may perhaps indicate a preference for fairly shallow, clear water, not too close inshore. Except in the lower 20 feet of the section, the tests of *Cibicides sandidgei* have a slightly convex spiral side (the umbilical side being, of course, strongly convex), whereas in the lower 20 feet of the section the spiral side is flat. In living forms such as *Cibicides lobatulus* the flat spiral side is known to function as an area of attachment, on which the animal creeps about over algal fronds, hydroids, bryozoa, and so on, which may grow on the bottom in shallow water in the photic zone.

An independent check on the depth of the Chalk Marl sea at Barrington, or failing that, on its temperature, is clearly highly desirable. There is none yet available for the Chalk Marl itself, but Lowenstam and Epstein (1954) give the results of a series of O^{16}/O^{18} analyses of Cretaceous fossils from a number of horizons and localities which include a belemnite and an oyster from the *subglobosus* Chalk of Hampshire ($T = 16{\cdot}9$ and 25·1° C. respectively), a Cenomanian belemnite from Bornholm ($T = 15{\cdot}4°$ C.), Albian belemnites from Jutland and their associated chalk ($T = 17{\cdot}3$ and 27·6° C. respectively), and a belemnite and an oyster from the Cenomanian of Hautrage, Belgium ($T = 16{\cdot}1$ and 27·6° C.).

It is highly satisfactory to find the same range of temperatures in the Gulf of Mexico at the present day at approximately the range of depths which we have inferred for the Chalk Marl, although, of course, the data relate to different horizons and localities and the absence of a discrepancy does not of itself constitute agreement. From data given by Bandy (1956) it appears that in the Gulf of Mexico a temperature range of 24–30° C. is characteristic of the bottom water at 5 fathoms, and a temperature range of 16–22° C. is characteristic of 50 fathoms.

Emiliani and Epstein (1953) have demonstrated the feasibility of determining O^{16}/O^{18} temperatures for fossil tests of Pleistocene foraminifera, but it would not necessarily be practicable to get results from Chalk foraminifera which differed significantly from the Chalk matrix. Contamination through recrystallization is thought to have introduced an error in at least some of the Cretaceous fossils studied (see Lowenstam and Epstein 1954, pp. 211 and 234). The high temperatures of the order of 30° C. determined for many specimens of the Chalk matrix appeared puzzling at the time; however, it is now known that the Chalk matrix consists of the skeletal disks of planktonic coccospheres (Black and Barnes 1959). The extremely detailed state of preservation of the coccoliths makes it seem unlikely that much, or indeed any, recrystallization has taken place in typical soft chalks of Cretaceous age, although enough carbonate from the coccoliths has doubtless gone into solution to provide an effective contaminant for other fossils. The presence in the Chalk—and in the Chalk Marl of Barrington (my own observations)—of rhabdoliths, which, unlike the coccoliths, are exclusively tropical in distribution at the present day, would make it surprising if the O^{16}/O^{18} analyses did not record fairly high temperatures.

It would be very interesting to make a study of the foraminifera from the sections in the Norwich Chalk for which detailed palaeotemperature records are given by Lowenstam and Epstein. It is possible that the Chalk Marl section described here would repay investigation by the oxygen isotope method, since the inferred range of depth should be sufficient to induce measurable changes in the temperature of the bottom water, though naturally a perfect correlation is not to be expected.

The author's collection is deposited in the Sedgwick Museum, Cambridge.

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2	1	1	1	2	1	2	*Total no. specimens observed*
3	3	2a	2b	2	1	1	
63½	65½	70½	—	77½	84½	90	
	1						12
	1	2	3	1		7	57
	6	9	8	5			118
88	74	21	32	18	1	31	1,395
15	18	2	3			2	192
08	260	146	191	202	50	128	5,457
		1					36
3						2	22
2			5				112
07	203	331	409	346	567	370	10,729
			2	6	8	1	311
3		7	1	9	9	9	117
17	4	24	31	24	40	37	821
53	20	8	10	20	1	14	889
34	33	40	51	46	11	14	1,065
							635
18	15	35	37	27	5	7	461
			1				308
61	61	104	115	103	176	117	2,601
3	7	9	15	16	8	8	170
	4		1		4	2	22
3	3	3	4	2	10	3	222
				1			3
	1	4		2	2		29
9	3	1	6	1			164
1			1	1	2	3	39
		1		2	1		16
6	10	1	2	2	4	2	179
	1						15
							1
2	2			1			76
							1
8	14	5		7	1	2	249
2		1	1				29
	1	2	3	2	2	6	58
		1	1		1		34
							4
14	11	15	20	6	12	10	286
3					1	3	35
29	63	38	43	36	13	23	1,151
50	78	207	249	171	152	193	6,114
11	10	8	17	23	11	30	385
							39
44	95	147	186	138	71	14	1,912
94	—1	173	448	218	163	038	36,571

' from the same field sample: samples 2/7A–E
were counted as 1 if more than half complete;

TABLE 2

Section	1	2	2	1	1	2	2	2	2	2	1	1	2	1	2	2	1	1	2	1	1	1	1
Sample	14	9	8	13	12	7A	7B	7C	7D	7E	11	10	6	9	5a	5b	8	7	4	6	5	4a	4
SPECIES Height above base, ft.	2	2½	7½	9	15	17	—	—	—	—	26	29	30	34½	35½.	—	39	42	46½	56	59½	62½	—
Ammodiscus sp.												1	3	3	2		2						
Ammobaculites sp.		1		3	4	5			5	1	5		1	3	6	4	3			1	1		
Spiroplectammina anceps (Reuss 1845)	2	1	1	6	10	2	1	2	4	3		1	2			2	2	2	2	8	2	27	10
Textularia subconica (Franke 1928)	8	5	2	14	41	8	4	10	1	11	28	61	84	46	65	43	57	44	61	115	86	195	141
Textularia chapmani Lalicker 1935	6	2		2	10		1		1		5	10	20	20	19	12	8	11	3	10	12		
Tritaxia pyramidata s.l. (Reuss 1863)	218	146	31	54	240	90	165	111	56	106	14	203	45	261	248	113	91	172	201	247	397	578	385
Spiroplectinata complanata (Reuss 1860)	5	5		6			1	2	2	2			1			1		4		5		1	
Gaudryina rugosa d'Orbigny 1840	10				5	1										1							
Siphogaudryina sp.	1	2		17	10	6	1	1	1	7	3		25	2	1	6	11	1	7		3		
Arenobulimina (*Hagenowella*) *anglica* Cushman 1936	553	495	589	446	306	285	354	162	344	219	544	386	290	353	637	404	379	362	257	160	222	323	226
Arenobulimina cf. *frankei* Cushman 1936	119	31	36	79			1	9	2	17													
Ataxophragmium compactum Brotzen 1936	12	10	3	2	15		3				3		5	10		1	2	2	5	2	4		
Plectina ruthenica (Reuss 1850)	29	13	58	67	13	59	46	34	45	57	29	15	10	7	18	10	15	11	56	13	24	10	5
Dorothia gradata (Berthelin 1880)	34	37	6	35	42	7	31	10	4	9	20	32	92	17	40	32	76	48	62	25	52	26	26
Marssonella oxycona (Reuss 1860)	27	31	23	74	94	5	13	22	9	22	29	33	95	15	39	24	33	21	27	52	26	86	36
Marssonella ozawai Cushman 1936	38	46	76	97	155	21	96	21	45	37							3						
Textulariella cretosa Cushman 1932		1			21		3		1		24	26	6	34	70	42	4	34	7	27	9	3	5
Quinqueloculina sp.	12	8	9	64	1	36	22	51	8	52	5	7	1	5	11	3	5	5			2		
Lenticulina rotulata Lamarck 1804	92	53	61	81	101	73	53	43	104	48	100	58	79	84	101	70	96	97	97	67	54	156	96
Marginulina sp.	2	1					2		4		8	11	10	5	15	12	9	6	14	5			
Saracenaria sp.	2	1	1		1			1													1	2	2
Vaginulina sp.	15	7	8	12	8	7	6	4	19	8	7	4	8	4	7	7	12	3	5	9	10	14	10
Palmula sp.					2																		
Frondicularia sp.		1		1					1			1	3	1		2	4	2				2	2
Dentalina A	3			3	8	6	3	4		9	15	7	11	5	4	2	7	5	4	5	4	29	10
Dentalina B	4	2		4	2	1			3				4				1	4	2	1	1		2
Pseudoglandulina manifesta (Reuss 1851)						2		1	1	1	1				1		4			1			
Tristix excavata (Reuss 1863)	3	6	6	1	12	6	5	6	6	9	1	9		2	11	2	5	4	5	18	20	9	6
Tristix B												1	1		1	1		1			2	5	2
Quadratina sp.																						1	
Lagena A	4	1		1	4	2			2	4	11	4	4	1	10			3	1	3	1	9	6
Lagena B																						1	
Ramulina aculeata (d'Orbigny 1840)	4	1	4	7	9	13	10	4	3	4	8	10	34	29	11	5	15	6	4	3	10	8	10
Ramulina B		1					8		2							2	1	3	2	2	2	2	
Pyrulina cylindroides (Roemer 1838)		1				2		9	1	4	2	3	9	2		1	3		2		1	1	1
Guttulina trigonula (Reuss 1845)			1				5	4			6				14	1							
Globulina prisca Reuss 1863							2													2			
Bulimina intermedia Reuss 1845	11	10	3	8	19	14	8	13	2	8	7	7	8	4	10	6	12	6	10	8	7		17
Valvulineria allomorphinoides (Reuss 1860)		3	2			6		1	2		3		6			4			1				
Gyroidinoides nitida (Reuss 1845)	41	22	5	18	61	54	18	22	17	34	48	29	36	28	42	36	28	25	49	68	61	96	68
Gavelinella baltica Brotzen 1942	226	147	211	256	273	341	141	165	292	201	278	171	133	149	282	202	173	241	262	178	119	274	199
Gavelinella cf. *tumida* Brotzen 1942	6	9	5	17	31	17	2	1	1	1	21	22	22	14	20	19	8	10	26	14	9		
Cibicides formosa Brotzen 1945				10		3	7	5	3	11													
Cibicides cf. *sandidgei* Brotzen 1936	53	41	50	138	1	56	12	23	59	23	49	58	84	56	70	56	60	60	37	74	41	72	44
Totals, 1,000+	540	141	191	523	499	128	024	−259	050	−92	274	170	132	160	755	126	129	193	209	123	183	930	309

Explanation of Table 2. Observed frequencies (actual numbers of specimens counted) in the size fraction 1 mm.–0·2 mm. Samples nos. 2/5a, b, 1/4a, b, 1/2a, b, are duplicated 'throughp are replicated field samples. Also present in small numbers: *Bullopora sollasi* (Chapman 1892), *Lenticulina* B, *Frondicularia* B, *Nodosaria* sp., and *Nodosarella* sp. Fragmentary specime otherwise as 0.