# A Method of Classification of Samples into Groups of Similar Faunal Content and Its Application to Some Rocks from the Floor of the English Channel

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# A method of classification of samples into groups of similar faunal content and its application to some rocks from the floor of the English Channel

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A mathematical analysis is carried out of the presence or absence of individual species in the microfaunas of rock samples collected by coring in the English Channel with the purpose of classifying these samples into groups of similar ages. Application of this analysis to two groups of samples, one group of late Cretaceous age and one of Palaeogene age, has enabled a subdivision of each group to be made. These subdivisions are believed to be of temporal significance.

## 1. Introduction

The method to be described was developed to deal with a problem arising from the study of Eocene microfaunas extracted from some 80 core-samples collected in the western English Channel. For details of the geology of the area and of the distribution of these samples see Andreieff *et al.* (1975). The samples contain relatively rich suites of Foraminifera characteristic of shallow, warm seawater. No information was available about the relative age of the samples from the study of bedding sequences and the only guide was that obtainable from the contained microfaunas. Comparison was made between these microfaunas and those of the nearest well-documented and relatively complete successions on land; namely those of the Anglo–Paris–Belgian Basin. In that region a succession of occurrences of larger Foraminifera had been established (see Curry 1967, p. 446) and it had there been found in particular that *Asterocyclina stellata* (d'Archiac) appeared to be confined to Lower Lutetian levels, *Gyroidinella magna* Le Calvez and *Fabiania cassis* (Oppenheim) to the Middle or Upper Lutetian, *Linderina brugesi* (Schlumberger) to Upper Lutetian to Marinesian horizons and *Halkyardia minima* (Liebus) to the Marinesian and lowest Ludian. All of the above species occur in the Aquitaine, S.W. France, but their precise ranges there are not clearly established. Use of the succession of faunas observed in the Anglo–Paris–Belgian Basin thus seemed to be a promising means of dating the western Channel samples.

As work progressed it soon became apparent that the proposed method of correlation was not practicable because species, believed to be mutually exclusive in the Anglo–Paris–Belgian Basin, were found to occur together in individual Channel samples and this occurrence did not appear to result from reworking. For instance, *A. stellata* occurs with *H. minima* and *F. cassis* in sample 1633 and with *L. brugesi* in BL763. A preliminary examination of the species lists compiled in relation to the Channel samples does however suggest that their faunal content is not uniform. *H. minima* and *Discorbis discoides* (d'Orb.), for example, usually occur together, as does a group of species including *F. cassis*, *G. magna* and *Rotalia trochidiformis* Lk. However, at this stage it was realized that such groupings as do seem to occur might merely be the result of chance selection from a homogeneous series of populations. The purpose of the method to be discussed was to identify as many groupings as possible, to allocate species present to the appropriate group and to assess the probability that the pattern of groups so identified is not likely to be due to chance. The groupings having been identified, it was then possible to speculate on the nature of the controls which had produced them, as for instance of environment or age. Because the samples examined were very small (100 g or less) by the standards of investigation on land it was clear that absence of a species from a particular sample might be due to collection failure.

Table 1. Occurrence of selected species of Foraminifera in Channel samples

(For key to species see table 2.)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74† | × | × | × | × | × | . | × | × | . | × | . | × |
| 1053 | × | × | × | × | × | . | × | . | . | × | . | . |
| 1054 | . | . | × | × | . | . | × | . | . | . | . | . |
| 1043 | × | . | . | . | . | . | × | . | . | . | . | . |
| 1251 | × | × | . | . | . | × | . | × | × | . | . | . |
| 1252 | . | . | . | . | . | × | . | . | × | . | . | . |
| 1258 | . | . | × | × | . | . | . | × | . | . | . | . |
| 1255 | . | . | . | . | × | . | . | . | . | . | . | × |
| 1257 | . | . | × | × | . | . | × | . | . | . | . | . |
| 1254 | . | × | . | × | × | . | . | . | . | . | . | × |
| 72 | . | . | . | . | . | × | . | . | × | . | . | . |
| BT308 | × | × | × | . | × | . | . | . | . | . | . | . |
| 1114 | . | × | × | . | × | × | . | . | . | . | . | . |
| BL410 | × | . | × | × | × | . | × | . | . | × | . | × |
| BL532 | × | × | . | × | × | . | × | . | . | . | . | × |
| BL611 | × | × | × | × | × | . | × | . | . | × | . | × |
| BL763 | × | × | × | × | . | . | . | . | . | × | × | × |
| BL832 | × | × | × | × | × | . | × | . | . | . | . | × |
| BL910 | × | × | × | . | . | . | . | . | . | . | . | . |
| BLA | × | × | . | × | × | . | × | . | . | . | . | . |
| 465 | × | × | . | . | × | × | . | . | . | × | . | . |
| 468 | × | × | . | . | × | × | . | . | . | × | . | × |
| 469 | . | . | . | . | . | × | . | . | × | . | . | . |
| 451 | . | . | . | . | . | . | × | . | . | . | × | . |
| 517 | . | × | . | . | . | × | . | . | × | . | . | . |
| 458 | × | × | . | . | . | . | . | . | . | × | . | . |
| 1082 | . | × | . | . | . | × | . | . | . | . | . | . |
| C379 | × | . | × | × | . | . | . | × | . | . | . | . |
| C380 | × | × | . | . | . | . | . | . | . | . | . | . |
| C382 | . | . | . | × | . | . | × | . | . | . | . | × |
| C384 | × | . | . | × | . | . | . | . | . | . | . | . |
| C385 | . | . | × | × | . | . | × | × | . | × | . | × |
| C386 | . | . | . | × | . | . | × | . | . | . | . | . |
| U1602 | . | × | × | × | × | . | . | × | . | . | . | . |
| 828 | . | . | . | . | × | × | . | . | . | . | . | . |
| 1061 | × | × | . | . | × | × | . | . | × | . | . | . |
| G143 | . | × | . | × | . | . | . | . | . | . | . | . |
| 829 | . | . | . | . | . | × | . | . | × | . | . | . |
| 826 | × | × | . | × | × | × | . | . | . | . | × | . |
| 1106 | . | . | . | . | . | × | . | . | × | . | . | . |
| 1107 | × | . | . | . | . | × | . | . | . | . | . | . |
| 528 | . | . | . | . | . | × | . | . | × | . | . | . |
| 1633 | . | × | . | . | . | × | . | . | × | . | × | × |

For locations of sample sites see Andreieff *et al.* (1975).

† *Key to sample collectors*: BL, Boillot; BT, Best; C, Curry; G, Geomanche II; U, University College, London. No prefix: University of Bristol.

## 2. Analysis of relationship between pairs of species

The method used to discover associations depended on the examination of the occurrence of selected pairs of species to find out whether they occurred in association more often or less often than would be expected by pure chance. For this purpose 12 species were chosen, all of which were easy to identify, reasonably abundant and thought to have value as stratigraphical markers. They include those already mentioned plus *Fasciolites* cf. *bosci* (Defr.), *Orbitolites complanatus* Lk., *Rotalia papillosa* d'Orb., *Sphaerogypsina globulus* (Reuss) and '*Amphistegina*' *nucleata* Terquem. The occurrence of these species in 43 samples is listed in table 1. These samples were selected as having yielded at least two of the chosen species, plus some others in addition. The occurrence of pairs of species is recorded in table 2. This records, for example (top left of table), that species 1 (*F.* cf. *bosci*) occurs in 21 samples, species 2 (*O. complanatus*) in 23 samples, while both *F.* cf. *bosci* and *O. complanatus* occur in 16. A coefficient of association between the two species, as defined by Forbes (1907), has been calculated as 1.42.

The example which follows explains the method of analysis adopted by Forbes. If, in 40 samples, species A occurs in 20 cases and species B in 16 then, if the occurrences of A and B are independent of each other, A and B are most likely to occur together in $(20 \times 16)/40 = 8$ samples. If they are observed to occur together more often than this, say in 13 samples, it may be concluded that they tend to occur together; if less often, say in 5 samples, that they tend not to occur together. A measure of the two situations is expressed by Forbes' coefficient of association, which is given by the fractions $13/8 = 1.625$ and $5/8 = 0.625$ respectively, with a coefficient of association of 1 as the most likely result if the occurrences of the two species in a particular case are independent of each other.

It is true that single results such as those included in table 2 provide no more than an indication of the presence of a non-random relation and that they might occur by chance. An analysis of the situation can be made with the help of probability theory and this provides a means of assessing the reliability of the coefficients of association derived in the manner described. The theoretical background to this analysis is discussed by Brideaux (1971, p. 103), who quotes the necessary working formulae. Brideaux suggested that solutions of the problem for more than a few species-pairs will involve much calculation and developed a computer programme to provide these. However, the writer has found that with the aid of a Pascal triangle and a good pocket calculator such solutions can be obtained at the rate of several per hour. Unless therefore a very large number of computations is required, recourse to a computer is not essential.

Analysis carried out as above reveals that in the case quoted in the last but one paragraph the probability, A and B being independent of each other, of their occurring together in a specified number of samples is:

| 4 or less | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 or more |
|---|---|---|---|---|---|---|---|---|
| 0.012 | 0.041 | 0.114 | 0.207 | 0.252 | 0.207 | 0.114 | 0.041 | 0.012 |

(the probability distribution is symmetrical because 40, the total number of samples, is exactly twice 20, the number of occurrences of the more widely distributed of the two species considered). Thus the occurrence of 7, 8 or 9 is to be expected in two thirds of all cases and the addition of 6 and 10 brings the probability up to 90%. Records of 6 and 10 when 8 was the most likely will of course produce coefficients of association of 0.75 and 1.25 respectively.

There will thus be one chance in ten in the case chosen that a random relation between species A and B will produce coefficients outside the range 0.75 and 1.25 and there will in fact be one chance in 250 that the coefficients will be outside the range 0.5 and 1.5. Individual coefficients relatively near to 1 are not therefore a reliable indication that the relationship examined is not random. The standard error in the case under discussion can be calculated as 1.58 so the expected result can be written as $8 \pm 1.58$, with a coefficient of association of $1 \pm 0.20$. The standard error is, as would be expected, a progressively smaller fraction of the expected result as the latter rises. For example, if all the figures in the example are doubled the expected result is $16 \pm 2.19$, while if they are halved it is $4 \pm 1.12$. Results obtained when the expected number is very low are thus particularly unreliable.

To assess the degree of reliability of the coefficients of association included in table 2 a calculation was made in each case of the probability of getting the observed number of joint occurrences, or some more unlikely number (in the example, for instance, '5 or less' or '13 or more'). Those pairs whose probability of a random association are less than 10 %, 1 % and 0.1 % respectively are indicated in the table. The following species recorded a relatively large number of indications of non-random relations to other species: *R. trochidiformis*, *G. magna*, *L. brugesi*, *H. minima*, *S. globulus* and *D. discoides*.

Even when the coefficients of association between pairs of species are relatively near to 1 the degree of certainty provided by a group of such coefficients may be quite high. The example, of the group *F. cassis*, *L. brugesi* and *R. papillosa* is instructive in this respect. All of the individual correlations are greater than 1 but none is significant at the 10 % level. The probability of a random association between *L. brugesi* and *R. papillosa* (8 or more coincidences) is 0.152 while that between *F. cassis* and *R. papillosa* is 0.112. These results are independent of each other so the probability of the joint event is $0.152 \times 0.112 = 0.0170$. The probability of the occurrence of *L. brugesi* and *F. cassis* in isolation is 0.174. However, this probability is not independent of the other two. The expectation can be calculated of various occurrences in common of *L. brugesi* and *F. cassis*, given the observed occurrences together of *L. brugesi* and *R. papillosa* and of *F. cassis* and *R. papillosa*. It is:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 or 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 or more |
| 0.007 | 0.047 | 0.150 | 0.262 | 0.272 | 0.174 | 0.069 | 0.019 |

The observed occurrence is 6, and the probability of 6 or more is $0.174 + 0.069 + 0.019 = 0.262$. Thus the probability of the triple association is $0.152 \times 0.112 \times 0.262 = 0.00446$. To check the above calculation the expected distribution of *L. brugesi* with *R. papillosa* was calculated assuming the observed relations between *L. brugesi* and *F. cassis* and between *F. cassis* and *R. papillosa*. It is:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 or less | 4 | 5 | 6 | 7 | 8 | 9 | 10 or more |
| 0.020 | 0.076 | 0.176 | 0.256 | 0.241 | 0.149 | 0.061 | 0.021 |

The observed occurrence is 8 and the probability of 8 or more is 0.231. An alternative estimate of the probability of the triple relation can then be calculated as $0.174 \times 0.112 \times 0.231 = 0.00450$; a result which may be compared to the previous figure of 0.00446. It thus seems that the odds against the possibility that the triple association is a random one are of the order of 200 to 1.

### 3. Identification of groups of associated species

The observations that at least half of the species show non-random relations to one another and that multiple groupings can be identified as shown in the last section suggest that a series of groups might be identifiable. A cursory examination of table 2 shows a strong positive association (coefficient much higher than 1) between *H. minima* and *D. discoides* and some strong negative associations (coefficient much less than 1) between these species and several others. There is also a group including *R. trochidiformis*, *F. cassis*, *G. magna* and *S. globulus* within which the figures are consistently high. Coefficients for *F.* cf. *bosci*, *O. complanatus* and *A. stellata* are however mostly close to 1. The selection of groupings might seem in this situation to be rather subjective. To provide an objective analysis a method proposed by Mountford (1962) was adapted to use the coefficients in table 2 to form species into groups. Mountford's work dealt with woodland faunas. In this work he derived a coefficient of correlation (quite different from the coefficient used above) to measure the degree of similarity between faunas collected from different stations. Mountford considered the whole fauna and assessed similarities by comparing the number of species in common at pairs of stations with the total of species present at each. The basis of Mountford's method of reducing data is to select from the table of correlations the pair which shows the highest coefficient and then to rewrite the table having combined the results of the selected pair. From the rewritten table the next highest coefficient is then selected and a further pair is combined. The process is repeated, the table becoming smaller at each combination, until two terms only are left. A tree is then constructed whose branches join at the coefficients selected by the combinations. In table 2 the combination of species 6 and 9 produces the highest coefficient, 2.52. The mean of the coefficients of 6 and 9 with each other species in turn is thus substituted to form the first reduction table. A worked example of the relation 6/9 – 1 is given alongside the table. The calculations then proceed straightforwardly, except in reduction tables 7–10 where, in table 7 for example, weighting has to be introduced. When 3/8 is combined with 4/7/10/12 double weighting has to be given to the latter. The combination 3/4/7/8/10/12 – 11 is thus $(2 \times 0.96 + 0.36)/3 = 0.76$.

The results of the analysis are shown in table 3. It will first be noted that the occurrence of *A. stellata* is too infrequent and its pattern of associations too ill-defined to permit of any conclusion about its affiliations. The other species fall into two sharply defined groups comprising *H. minima* and *D. discoides* on the one hand and the remaining species on the other. The coefficient of association between these two groups of 0.48 indicates that they are strongly antipathetic. The remaining species also fall into two groups, with strong correlations between the left-hand six in the tree and somewhat weaker ones between the next three. Correlations between *F.* cf. *bosci* and *O. complanatus* and all other species are, as already stated, rather near to 1, which suggests that *F.* cf. *bosci* and *O. complanatus* occur as a component of most groups. The analysis suggests that possibly four different associations may be recognizable. They are:

4. *H. minima* with *D. discoides*.
3. As above, but with *Orbitolites* and *Fasciolites*.
2. *Orbitolites*, *Fasciolites*, with *R. papillosa* and perhaps rare members of groups 1 and 4.
1. *R. trochidiformis*, *L. brugesi*, *G. magna*, *F. cassis*, *S. globulus* and *A. nucleata*, with less common *Orbitolites* and *Fasciolites*.

TABLE 2

(*Key to species*: 1, *Fasciolites cf. bosci* (Defr.); 2, *Orbitolites complanatus* Lk.; 3, *Linderina brugesi* Schlumberger; 4, *Rotalia trochidiformis* Lk.; 5, *Rotalia papillosa* d'Orb.; 6, *Discorbis discoides* (d. Orb.); 7, *Gyroidinella magna* Le Calvez; 8, *Amphistegina nucleata* Terquem; 9, *Halkyardia minima* (Liebus); 10, *Sphaerogypsina globulus* (Reuss); 11, *Asterocyclina stellata* (d'Arch.); 12, *Fabiania cassis* (Oppenheim).)

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | total | 21 | 23 | 15 | 20 | 17 | 17 | 14 | 6 | 10 | 10 | 4 |
| | | 1.42″ | — | — | — | — | — | — | — | — | — | — |
| 2 | 23 | 16 | — | — | — | — | — | — | — | — | — | — |
| | | 1.23 | 1.12 | — | — | — | — | — | — | — | — | — |
| 3 | 15 | 9 | 9 | — | — | — | — | — | — | — | — | — |
| | | 1.13 | 1.03 | 1.72″ | — | — | — | — | — | — | — | — |
| 4 | 20 | 11 | 11 | 12 | — | — | — | — | — | — | — | — |
| | | 1.45′ | 1.54″ | 1.35 | 1.26 | — | — | — | — | — | — | — |
| 5 | 17 | 12 | 14 | 8 | 10 | — | — | — | — | — | — | — |
| | | 0.72 | 0.99 | 0.17″ | 0.13* | 0.89 | — | — | — | — | — | — |
| 6 | 17 | 6 | 9 | 1 | 1 | 6 | — | — | — | — | — | — |
| | | 1.17 | 0.80 | 1.64″ | 1.84* | 1.26 | 0* | | — | — | — | — |
| 7 | 14 | 8 | 6 | 8 | 12 | 7 | 0 | — | — | — | — | — |
| | | 1.02 | 0.93 | 2.38″ | 1.79′ | 0.84 | 0.42 | 1.02 | — | — | — | — |
| 8 | 6 | 3 | 3 | 5 | 5 | 2 | 1 | 2 | — | — | — | — |
| | | 0.61 | 0.75 | 0″ | 0* | 0.25′ | 2.52* | 0′ | 0.71 | — | — | — |
| 9 | 10 | 3 | 4 | 0 | 0 | 1 | 10 | 0 | 1 | — | — | — |
| | | 1.64′ | 1.31 | 2.00′ | 1.50′ | 1.52 | 0.50 | 1.84′ | 1.42 | 0′ | — | — |
| 10 | 10 | 8 | 7 | 7 | 7 | 6 | 2 | 6 | 2 | 0 | — | — |
| | | 1.02 | 1.40 | 0.71 | 1.07 | 0.63 | 1.26 | 0.77 | 0 | 1.10 | 1.10 | — |
| 11 | 4 | 2 | 3 | 1 | 2 | 1 | 2 | 1 | 0 | 1 | 1 | — |
| | | 1.19 | 1.24 | 1.43 | 1.61′ | 1.48 | 0.42′ | 1.79′ | 1.19 | 0.36 | 2.15′ | 0.90 |
| 12 | 12 | 7 | 8 | 6 | 9 | 7 | 2 | 7 | 2 | 1 | 6 | 1 |

*Probability*: less than 0.1(′), less than 0.01 (″), less than 0.001 (*).

Combine 6 and 9 (2.52)

| | 1 | 2 | 3 | 4 | 5 | 6/9 | 7 | 8 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1.42 | — | — | — | — | — | — | — | — | — |
| 3 | 1.23 | 1.12 | — | — | — | — | — | — | — | — |
| 4 | 1.13 | 1.03 | 1.72 | — | — | — | — | — | — | — |
| 5 | 1.45 | 1.54 | 1.35 | 1.26 | — | — | — | — | — | — |
| 6/9 | 0.67 | 0.87 | 0.08 | 0.06 | 0.57 | — | — | — | — | — |
| 7 | 1.17 | 0.80 | 1.64 | 1.84 | 1.26 | 0 | — | — | — | — |
| 8 | 1.02 | 0.93 | 2.38 | 1.79 | 0.84 | 0.56 | 1.02 | — | — | — |
| 10 | 1.64 | 1.31 | 2.00 | 1.50 | 1.52 | 0.25 | 1.84 | 1.42 | — | — |
| 11 | 1.02 | 1.40 | 0.71 | 1.07 | 0.63 | 1.18 | 0.77 | 0 | 1.10 | — |
| 12 | 1.19 | 1.24 | 1.43 | 1.61 | 1.48 | 0.39 | 1.79 | 1.19 | 2.15 | 0.90 |

*Example of working technique*

$6-1 = 0.72;\ 9-1 = 0.61;$

$$6/9-1 = \frac{0.61+0.72}{2} = 0.67.$$

Combine 3 and 8 (2.38)

| | 1 | 2 | 3/8 | 4 | 5 | 6/9 | 7 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 1.42 | — | — | — | — | — | — | — | — |
| 3/8 | 1.12 | 1.02 | — | — | — | — | — | — | — |
| 4 | 1.13 | 1.03 | 1.76 | — | — | — | — | — | — |
| 5 | 1.45 | 1.54 | 1.10 | 1.26 | — | — | — | — | — |
| 6/9 | 0.67 | 0.87 | 0.32 | 0.06 | 0.57 | — | — | — | — |
| 7 | 1.17 | 0.80 | 1.33 | 1.84 | 1.26 | 0 | — | — | — |
| 10 | 1.64 | 1.31 | 1.71 | 1.50 | 1.52 | 0.25 | 1.84 | — | — |
| 11 | 1.02 | 1.40 | 0.36 | 1.07 | 0.63 | 1.18 | 0.77 | 1.10 | — |
| 12 | 1.19 | 1.24 | 1.31 | 1.61 | 1.48 | 0.39 | 1.79 | 2.15 | 0.90 |

TABLE 2 (*cont.*)

Combine 10 and 12 (2.15)

| | 1 | 2 | 3/8 | 4 | 5 | 6/9 | 7 | 10/12 |
|---|---|---|---|---|---|---|---|---|
| 2 | 1.42 | — | — | — | — | — | — | — |
| 3/8 | 1.12 | 1.02 | — | — | — | — | — | — |
| 4 | 1.13 | 1.03 | 1.76 | — | — | — | — | — |
| 5 | 1.45 | 1.54 | 1.10 | 1.26 | — | — | — | — |
| 6/9 | 0.67 | 0.87 | 0.32 | 0.06 | 0.57 | — | — | — |
| 7 | 1.17 | 0.80 | 1.33 | 1.84 | 1.26 | 0 | — | — |
| 10/12 | 1.41 | 1.27 | 1.51 | 1.55 | 1.50 | 0.32 | 1.81 | — |
| 11 | 1.02 | 1.41 | 0.36 | 1.07 | 0.63 | 1.18 | 0.77 | 1.00 |

Combine 4 and 7 (1.84)

| | 1 | 2 | 3/8 | 4/7 | 5 | 6/9 | 10/12 |
|---|---|---|---|---|---|---|---|
| 2 | 1.42 | — | — | — | — | — | — |
| 3/8 | 1.12 | 1.02 | — | — | — | — | — |
| 4/7 | 1.15 | 0.91 | 1.55 | — | — | — | — |
| 5 | 1.45 | 1.54 | 1.10 | 1.26 | — | — | — |
| 6/9 | 0.67 | 0.87 | 0.32 | 0.03 | 0.57 | — | — |
| 10/12 | 1.41 | 1.27 | 1.51 | 1.68 | 1.50 | 0.32 | — |
| 11 | 1.02 | 1.40 | 0.36 | 0.92 | 0.63 | 1.18 | 1.00 |

Combine 4/7 with 10/12 (1.68)

| | 1 | 2 | 3/8 | 4/7 10/12 | 5 | 6/9 |
|---|---|---|---|---|---|---|
| 2 | 1.42 | — | — | — | — | — |
| 3/8 | 1.12 | 1.02 | — | — | — | — |
| 4/7/10/12 | 1.28 | 1.09 | 1.53 | — | — | — |
| 5 | 1.05 | 1.54 | 1.10 | 1.38 | — | — |
| 6/9 | 0.67 | 0.87 | 0.32 | 0.17 | 0.57 | — |
| 11 | 1.02 | 1.41 | 0.36 | 0.96 | 0.63 | 1.18 |

Combine 2 and 5 (1.54)

| | 1 | 2/5 | 3/8 | 4/7 10/12 | |
|---|---|---|---|---|---|
| 2/5 | 1.43 | — | — | — | — |
| 3/8 | 1.12 | 1.06 | — | — | — |
| 4/7/10/12 | 1.28 | 1.24 | 1.53 | — | — |
| 6/9 | 0.67 | 0.72 | 0.32 | 0.17 | — |
| 11 | 1.02 | 1.02 | 0.36 | 0.96 | 1.18 |

Combine 3/8 with 4/7/10/12 (1.53)

| | 1 | 2/5 | 3/4/7 8/10/12 | 6.9 |
|---|---|---|---|---|
| 2/5 | 1.43 | — | — | — |
| 3/4/7 8/10/12 | 1.23 | 1.18 | — | — |
| 6/9 | 0.67 | 0.72 | 0.22 | — |
| 11 | 1.02 | 1.02 | 0.76 | 1.18 |

Combine 1 with 2/5 (1.43)

| | 1/2/5 | 3/4/7 8/10/12 | 6/9 |
|---|---|---|---|
| 3/4/7 8/10/12 | 1.20 | — | — |
| 6/9 | 0.70 | 0.22 | — |
| 11 | 1.02 | 0.76 | 1.18 |

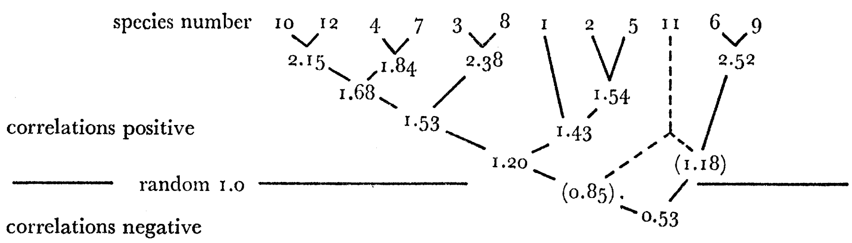
Combine 1/2/5 with 3/4/7/8/10/12 (1.20)

| | 1/2/3/4/5 7/8/10/12 | 6/9 |
|---|---|---|
| 6/9 | 0.38 | — |
| 11 | 0.85 | 1.18 |

Combine 6/9 with 11 (1.18)

| | 6/9/11 |
|---|---|
| 1/2/3/4/5 7/8/10/12 | 0.53 |

TABLE 3. TREE OF SIMILARITIES BASED ON THE ABOVE ANALYSIS




## 4. GEOLOGICAL INTERPRETATIONS OF FAUNAL PATTERNS

Samples belonging to groups 1 and 2 include 74, 1053, 1054, 1257 and 1258, together with perhaps all of the BL and C series, and may include 1254 and 468. All of these samples except 468 were taken at localities relatively close to Basement, either off the north coast of Britanny or near to the Banc des Langoustiers. Samples of groups 3 and 4 occur farther away from the present coast, as at 72, 1251, 1252; also in believed synclinal areas, as 469, 829, 1061, 1106. The faunal associations identified might characterize different environmental conditions or alternatively be the result of differences in age. The rock samples from which associations 1 and 2 were recovered seem to have been formed in conditions of rather higher energy than those of 3 and 4. Associations 1 and 2 might be correlated with nearshore conditions while 3 and 4 might indicate quieter and deeper water offshore. However, as associations 1 and 2 typify samples which are likely to be stratigraphically low (near to Basement) while associations 3 and 4 are found in what appear to be stratigraphically high situations, it seems most probable that the differences are due to difference in age.

A comparison of the four associations with the data in Curry (1967) and Le Calvez (1970) suggests that associations 1 and 2 are Upper Lutetian and that association 4 is Bartonian, association 3 being less certainly located. In the present context the Bartonian stage is taken to include the Auversian, Marinesian and Ludian substages. In the Aquitaine Basin, members of associations 1 and 2 occur especially in Upper Lutetian (including 'Biarritzian') beds, although *Orbitolites* ranges higher, being found, for example, in the Bartonian Calcaire de Blaye in company with *H. minima* and *D. discoides*. This latter occurrence also suggests that association 4 is not earlier than Bartonian. *H. minima* is known to occur in Oligocene beds (although *Orbitolites* is not) so that association 4 might in part be Oligocene. However, nothing in any of the marine faunas now under discussion positively suggests an Oligocene age, so all are here considered to be Eocene. As a working hypothesis therefore, samples with *Halkyardia*, with or without *Orbitolites*, but without any of the other species listed in association 1 are regarded as Bartonian. Those containing any combination of two or more species from association 1 are regarded as Upper Lutetian: any others are not dated more specifically than Middle or Upper Eocene. The results of this analysis have been used to date samples of appropriate age which are listed in Andreieff *et al.* (1975).

A similar problem to that posed by the Palaeogene samples occurred in studies of microfaunas from the Upper Chalk of the western English Channel. A good proportion of the samples included foraminiferids known in Maestrichtian beds of Denmark and Holland but not known from southern England or the Paris Basin, in which regions Maestrichtian beds are absent. It was clear that such samples were of Maestrichtian age, but could a further subdivision be made? To test this possibility an analysis was made of twenty samples and the occurrences of 23 species of foraminiferids within these samples were logged. Using the method described, it was found, as in the case of the Palaeogene samples, that natural groups of species were present. Details of this analysis also are given in Andreieff *et al.* The groupings found in the Maestrichtian samples are not so well defined as those in the Eocene ones. This is probably due to the rather small number of samples studied. As pointed out earlier, the smaller the number of samples, the less precise will be the analysis.

## 5. Conclusion

Although the method of analysis discussed was used to make age determinations, such analyses can be of value in situations where the age relations of a series of samples are known. Sequences of samples of apparently homogeneous beds such as those of the Oxford Clay or the London Clay show quite marked variations in their contained faunas. Analyses of these faunas, together with any other features which the samples exhibit, such as colour, grain-size and so forth, could in theory identify any associations, whether of species or of characters or both,



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which are present within them. Such associations would no doubt in part be controlled by differences in age, but might also be found to be linked with palaeoecological controls of some kind, or to conditions of preservation.

The value of the method appears to be that, once the data have been collected, it provides a method of analysis which is objective. The results of such analysis must of course be a matter of subjective interpretation.

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