RECENT FORAMINIFERA FROM THE FIRTH OF CLYDE

THESIS

presented for the degree of

Master of Science

at the

University of Glasgow

by

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December 1974

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ABSTRACT

Seventy-four samples were collected from the central part of the Firth of Clyde; sixty-five of these yielded Foraminifera. The distribution of the dead specimens was examined by cluster analysis, using Jaccard's coefficient. This indicated the presence of eight thanatotopes which were principally controlled by type of sediment and depth of water. Living Foraminifera were common in samples collected from less than 25 m. depth, and were found to be related to the four dead thanatotopes. Living Foraminifera were rare in deeper water (30 - 115 m.) so it was not possible to recognize the four thanatotopes established from the dead Foraminifera. The deeper water Foraminifera are entirely dominated by E. sca bra, but this species is virtually absent in shallow water.

Abstract

Seventy-four samples were collected from the central part of the Firth of Clyde; sixty-three of these were collected with a Van Veen Grab, the remainder with a 10 cm sq. tray from intertidal sand flats. The sediment was analysed and divided into seven categories using the Wentworth scale: gravel, sandy gravel, gravelly sand, sand, muddy sand, sandy mud and mud. Sixty-five of the stations yielded Foraminifera, belonging to fifty species, of which thirteen were predominant, constituting 76% of the total population. Living individuals were rare except in the shallow water, but this may have reflected the method of sampling.

The distribution of the dead specimens was examined by cluster analysis, using Jaccard's Coefficient. This indicated the presence of eight thanatotopes which were principally controlled by type of sediment and depth of water. Four thanatotopes are characteristic of shallow water; one of these is from intertidal sand flats, the second from sands and gravels of about 1 m depth of water, the third from sandy sediments of average depth 14 m (range 5 - 45 m), the fourth from muddy sands of 12 - 16 m depth. The remaining four thanatotopes were from deeper water, average depth 44 m, with muddy sediments. Diversity is greatest in shallow water sands and gravelly sands (1 - 45 m), and the distribution of living species in the shallow water can be correlated with the shallow water thanatotopes.

The dominant species of the areas is Egerella scabra. The species recorded are similar to those found in other places around the British Isles.

Introduction:

The sheltered central part of the Firth of Clyde is an ideal area for an investigation of the distribution of Recent Foraminifera. Within this region there is a great variety of sediments, while the depth ranges between 0 and 125 metres. Fifty species of living Foraminifera have been found, of which thirteen are regarded as being common. The distribution of the dead tests of these common species has been investigated by using cluster analysis, a method shown to be of great value in ecology and palaeoecology by many investigators. Living Foraminifera have generally proven to be too rare to allow an investigation of their distribution by statistical methods.

The physical and chemical factors that might have played a role in the Foraminiferal distribution in the area were studied; these factors were type of sediment, temperature, depth of water, salinity pH, and oxygen content.

Literature Review:

The earliest study of the distribution of the Foraminifera of the Firth of Clyde was that of David Robertson in 1877, with a further study in 1901. Since then, very little work has been done on the subject.

John Pirit started work on the Foraminifera, but was tragically drowned in 1962; his material is stored in the collections of the Hunterian Museum, and is available for study. The oceanography of the Clyde Sea area was comprehensively studied by Hugh Robert Mill (1889).

The relation of the plankton to some chemical and physical factors in the Clyde Sea area was studied by S. M. Marshall (1927).

H. B. Moore (1930) determined the phosphate and nitrogen contents in the muds throughout the area. In 1931 Moore made another comprehensive study of the mud of the Clyde Sea area, its chemical and physical conditions, rate and nature of sedimentation and fauna.

In recent years various members of the Scottish Marine Biological Association and the Institute of Geological Sciences have investigated the general oceanography of the area. This has included the sediments, the factors controlling their distribution, and the relation between sedimentary environments and the biological associations found in them. C. E. Deegan et al. (1973) published an important report dealing with the superficial deposits of the Firth of Clyde and its sea lochs.

Location of the area:

The area sampled is the central part of the Firth of Clyde, bounded by latitudes $55°56'$ N and $55°43'$ N and by longitudes $4°52'$ W and $5°5'$ W (Fig. 1). The area consists mainly of three tracts. The first is an isolated one, lying between Bute and Cumbrae, and belonging to the Arran Basin. The second is the Bute Plateau which extends from the north of Great Cumbrae to Toward Point and Rothesay Bay. The surrounding shores of this part are low and sandy, with no streams. Through this, the northern part of the Arran Basin joins the Dunoon Basin, which makes the third part of the sampling area. This third part lies between coastlines in a straight narrow trough, running from the north end of Great Cumbrae to the line joining Cloch Point and Gantocks Point. The eastern side of this part is deeper than the west.

The sampling area is relatively sheltered, the predominant sediments being mud and sandy mud in deep channels, while sand and gravel are found in the shallow water. The average depth is approximately
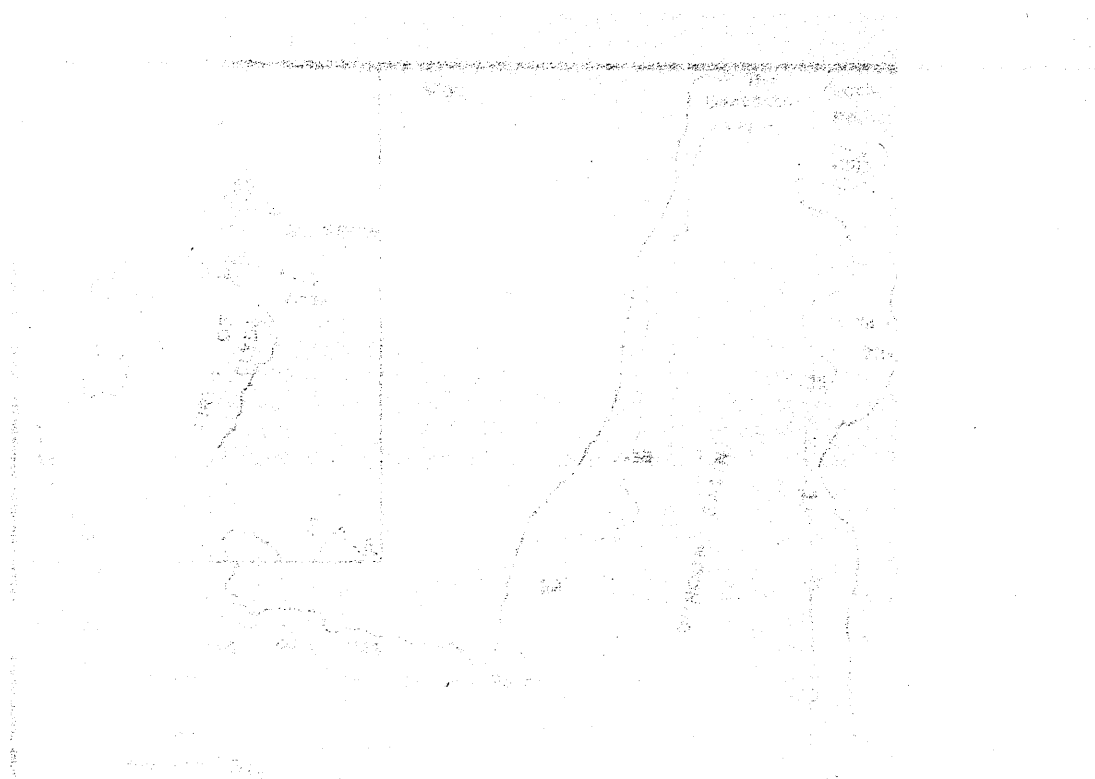
Fig. 1

The area studied and location of stations.
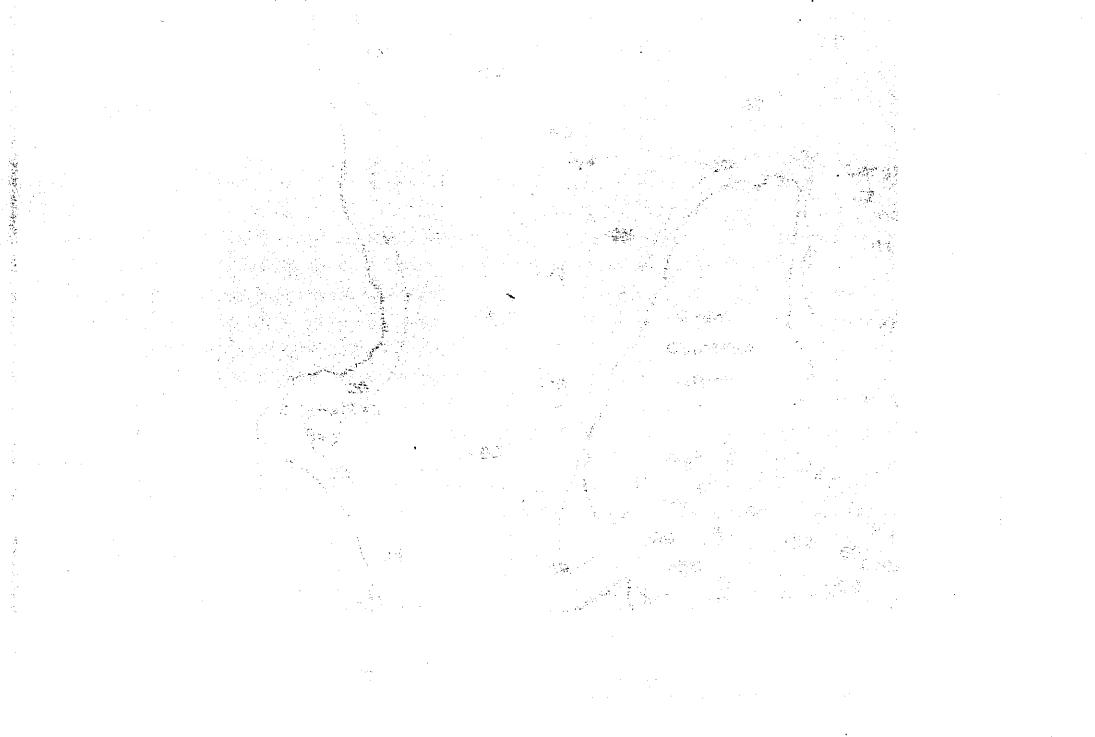
Fig. 1
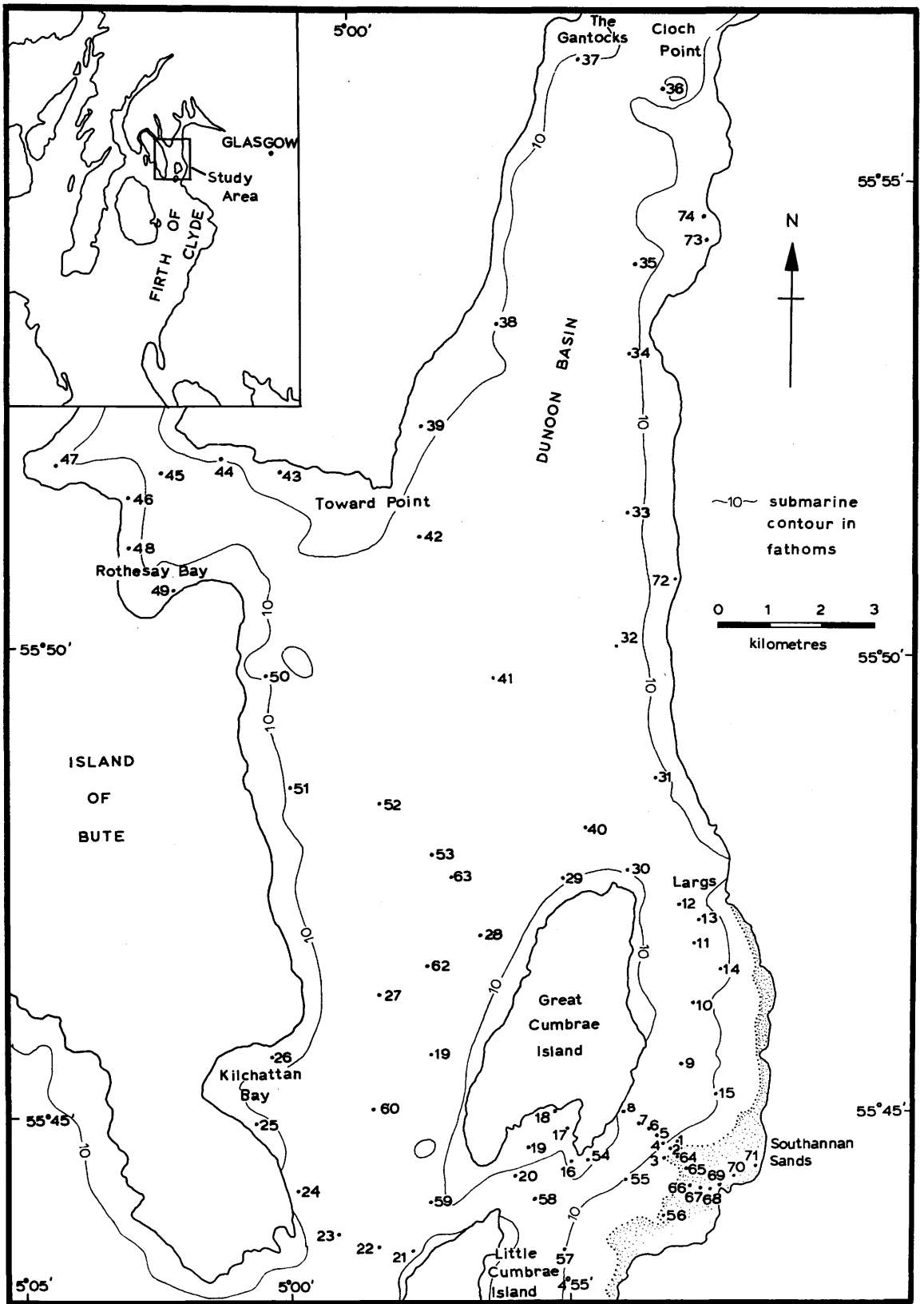
60 metres.

Materials and Methods:

Seventy-four samples were collected from the area described above, between 25th May 1973 and 5th May 1974 (Fig. 1). Sixty-three of these sampls were collected by means of a Van Veen Grab from aboard the 'Mizpah', the boat of the Marine Biological Station of Millport. The remaining eleven samples were 10 cm. square surface samples collected from the shore using a tray of dimensions 10 x 10 x 2 cms. All the samples were stored in plastic bags without the addition of preservatives because the samples were processed in the laboratory within a few days of collection. The locations of the samples taken from aboard the 'Mizpah' were determined by taking compass bearings with a prismatic compass.

The salinity and temperature of the surface and the bottom water were determined at thirty-three stations. Appendix (Table 1 & 2). Fourteen samples of the bottom water were collected with a Nansen bottle, pH and oxygen content were measured with a Lovibond 1000 compatator, using Cresol red and Winkler's Method. These measurements were taken within a few hours of collecting the samples. Appendix (Table 3). The depth of water at each sampling station was determined by echo sounding. Appendix (Table 4).

For the foraminiferal analysis a measured weight of 250 gm. of wet sediment was washed over 20 and 200 mesh sieves in order to remove the gravel and very fine grained particles. The residue was stained in Rose Bengal for one hour (Walton, 1952), then rewashed over a 200 mesh sieve to remove the surplus stain, and finally, dried at 60°C. To facilitate counting and to save time, the Foraminifera were concentrated by slowly adding the dried cool sediments to carbon tetrachloride, the Foraminifera float-

ing on its surface being collected by carefully passing the solution
through a filter paper. The sediment residues were checked to assure
that complete separation had taken place. As most of the samples con-
tained a high concentration of dead Foraminifera, it was found necess-
ary to divide them into smaller fractions, ranging from 1/2 to 1/16
of the sample.

To obtain percentages of various species, at least 250 Foramini-
fera were counted in each sample. The total population counted in all
the samples was found to belong to 50 species, dead Foraminiferal
counts being 48,947 and living ones 1,576. Of the 50 species, 13 were
predominant, constituting 76% of the total population and occurring
in 18 - 58 samples; these 13 species in order of abundance were:
Eggerella sca·bra, Textularia sagittula, Bulliminella elegantissima,
Ammonia beccarii, Elphidium articulatum, Rosalina globularis, Elphidium
crispum, Elphidium excavatum, Quinqueloculina seminulum, Elphidium
magellanicum, Cibicides lobatulus, Bulimina marginata and Reophax
fusiform. The remaining 37 species comprised 24% of the total popu-
lation; twenty of them occurred in 5 - 18 samples, while the remain-
ing seventeen were very rare and occurred in less than five samples.

The sediments were analysed by sieving of weighed amounts of wet
sediment using 18 and 200 mesh sieves. According to the Wentworth
See DAVIS
scale (1971.) the fraction retained above the 18 mesh sieve was gravel,
shells and pebbles, the fraction retained above the 200 mesh sieve was
sand, and the fraction that passed through the two sieves was mud.
The sediments were grouped into seven groups according to the percent-
age weight of their different components in the following way:

1. gravel sediment   : 'gravel > 80%
2. sandy gravel sediment   : gravel > sand > 10% > mud
3. gravelly sand sediment : sand > gravel > 10% > mud

6

4. sandy sediment : sand > 80%

5. muddy sand sediment : sand > mud > 10% > gravel

6. muddy sediment : mud > 80%

7. sandy mud sediment : mud > sand > 10% > gravel

Appendix (Table 4).

CHAPTER 2

Quantitative Distribution Analysis of the Dead Fauna

Kaesler (1966) was the first to use quantitative techniques to analyse the distribution of organisms. Using cluster analysis he re-evaluated the foraminiferal biofaces of Walton (1955) and ostracodal biofaces of Benson (1959) from Todos Santos Bay, Mexico. Many researchers have since used cluster analysis in ecological studies.

The aim of the present study was to determine patterns of association between species in the Clyde area. This involves the determination of biofacies and biotopes. Kaesler (1966) defined biofacies as "a group of organisms found together and presumably adapted to environmental conditions in their place of occurrence, such groups differing from the contemporary assemblages, found in different environment". He defined biotope as "an area of relatively uniform environmental condition, evidenced by a particular fauna in the area and presumably adapted to environmental conditions existing there". Using these definitions it is possible to make plausible assumptions that can be used to explain the distribution patterns of the assemblages of the Foraminifera of the study area.

Several coefficients of association have been used in previous investigations (Cheetham and Hazel, 1969). Two of these were considered, the Jaccard Coefficient and the Sokal and Michiners Coefficient. Jaccard's Coefficient is determined from the following equation:-

$$Sj = \frac{a}{a + b + c}$$

When comparing two species, a is the number of stations in which they occur together, b is the number of times one species occurs without

the other, and c is the number of times the other species is found
without the first; when comparing two stations, a is the number of
species in common, b is the number of species present in station 1
but not in station 2, and c is the number of species in station 2 but
not in station 1.   (Cairns & Kaesler 1969)

The Sokal and Michiners Coefficient is given by:-

$$Ssn = \frac{a + d}{n}$$

Where a is the number of cases in which the two compared items are
both present, d is the number of times both are absent, and n is the
total number of comparisons. (Kaesler 1966)

The important difference between the two coefficients is that
the Jaccard Coefficient ignores negative matches, whereas the Sokal
Coefficient gives equal weight to both negative and positive matches.

In theory, all the species present in the area should be con-
sidered in the statistical analysis. Because the coefficients used
simply compare the presence or absence of species in samples, it is
impossible to determine whether a very rare species is truly absent
from a station. Thus it is common practice to consider only the
common species. Furthermore, ecological conditions are probably best
reflected by the distribution of abundant species. Thirteen species
are considered to be common, as previously stated. Nine of the seventy-
four stations sampled were barren, leaving sixty-five to be considered.

The stations were compared with each other by Q mode analysis
(= biotope), and the species by R mode analysis (= biofacies). The
information was computed using the two coefficients mentioned above,
considering firstly dead specimens and secondly living specimens.
The small number of living specimens led to a high absence rate, and
proved impossible to compute. With the dead specimens, Jaccard's
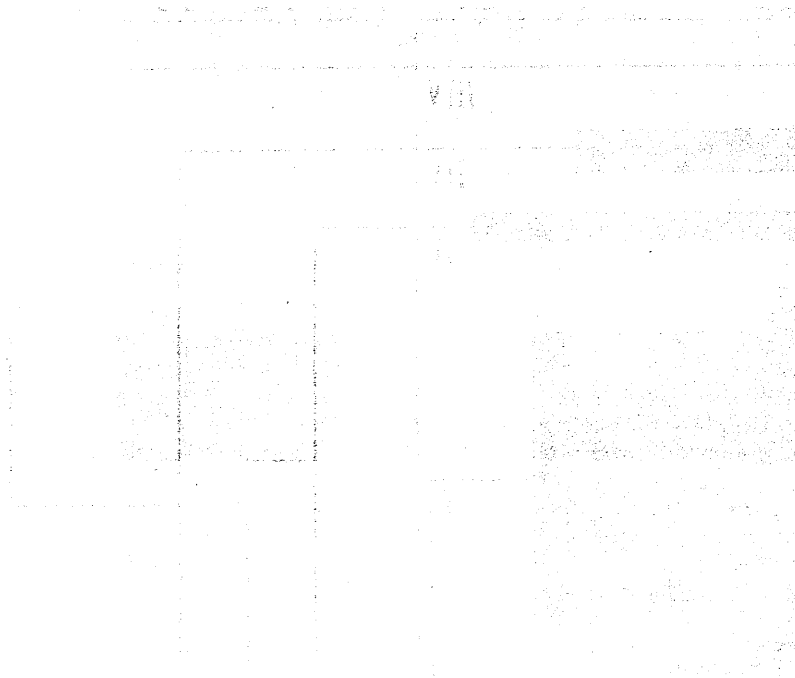
Fig. 2

Dendrogram (UPGMA) based on Jaccard Coefficient

of association computed from occurrence data of

species of Foraminifera.   Q Mode.

Fig. 2

JACCARD COEFFICIENT
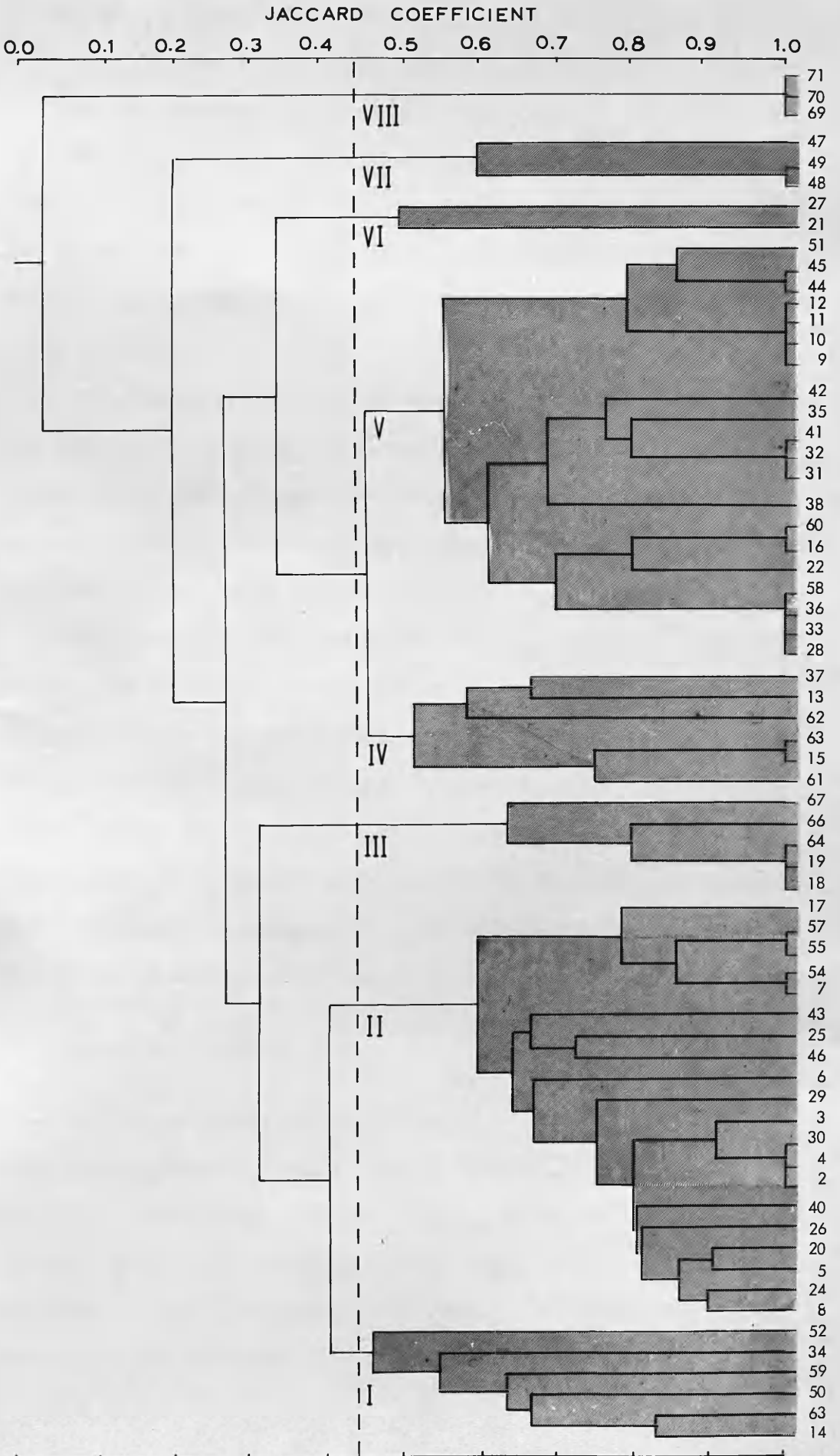
Coefficient proved to be more satisfactory for interpretation, and so is the only result considered here. The results for the Q mode analysis are presented as a dendogram (Fig. 2).

The R mode (biofacies) were determined by using Jaccard and Sokal Coefficients, but the results were unsatisfactory and did not show distinct clusters. This was expected, because of the small number of species involved in the study. For this reason a dendogram is not included.

The advantages and disadvantages of the cluster method have been discussed by Kaesler (1966) and many other investigators (e.g. Brooks, 1973). For further details the reader is referred to these works. However, no other suitable method could be used in the interpretation of these results.

The computation of the data and the construction of the dendogram in this study were carried out by using a computer program written by Bonham - Carter (1967) and modified by R. Cumberland in the Department of Geology, Glasgow University, for use in the ERec 379/158 digital computer. All the data used in this study and the modified computer programme are stored in the Department of Geology of the University of Glasgow and can be obtained from there upon request. The diversity of the faunas is indicated by use of the α index; see Murray (1973) for a discussion of this method.

The Foraminiferal Thanatotopes

The following assemblages have been determined from the distribution of dead tests. Therefore it is more correct to call them thanatotopes rather than biotopes (Brooks, 1973). Eight thanatotopes have been recognized at the 0.47 level. This level has been chosen because it allows the recognition of distinct clusters. The shaded portions on the dendogram (Fig. 2) represent the author's interpreta-

tion, which, of course, is not the only one possible.

Thanatotope I:

This is represented by six stations: 14, 53, 50, 59, 34, and 52. The sediment is sandy mud, the average depth is 44 metres, with a range of 25-65 m. The major species occurring in this thanatotope, in order of abundance are:

		percentage	Range
1.	Eggerella scarbra	59%	29 - 79
2.	Elphidium excavatum	12%	6 - 25
3.	Bulimina marginata	9%	3 - 17
4.	Elphidium magellanicum	7%	4 - 19
5.	Buliminella elegantissima	5%	6 - 25

The characteristic feature of this thanatotope is the high percentage of E. scarbra and the presence of some other species in moderate abundance.

Thanatotope II:

This comprises a major part of the cluster and is represented by the following stations: 8, 24, 5, 20, 26, 40, 2, 4, 30, 3, 29, 6, 46, 25, 43, 7, 54, 55, 57 and 17. The average depth of the water is 14 metres, ranging between 5 - 45 m. the sediment consisting of sand and gravelly sand.

The major species characterizing this thanatotope according to their abundance are the following:

		percentage	Range
1.	Eggerella scarbra	19%	1 - 50
2.	Textularia sagittula	15%	2 - 55
3.	Elphidium crispum	12%	1 - 71
4.	Rosalina globularis	8%	2 - 32
5.	Cibicides lobatulus	7%	1 - 29

6.	Quinqueloculina seminulum	6%	1 - 17
7.	Elphidium excavatum	6%	4 - 26
8.	Elphidium magellanicum	5%	1 - 23
9.	Elphidium articulatum	5%	1 - 28
10.	Ammonia beccarii	4%	1 - 58

This is characterized by many features, differing from Thanatotope I in type of sediment, shallower depth of water, low percentage of E. scabra, and a higher diversity (α = 3-9). The sediment type is important for this thanatotope because muddy samples from similar depths belong to different thanatotopes.

Some of the species were found to be clinging to vegetation, stones, and shells, indicating subjection to strong current agitation (Murray 1973).

Thanatotope III:

This is represented by five stations. Stations 64, 66 and 67 were in the intertidal sand flats of Southannan Sands and were collected with a 10 cm. sq. tray. Stations 18 and 19 were in Millport Bay, water depth 1 m., sediment sand mixed with gravel. They were collected with a Van Veen Grab.

The major species occurring in this thanatotope are:

			Range
1.	Elphidium crispum	38%	12 - 67
2.	Elphidium articulatum	25%	7 - 60
3.	Ammonia beccarii	14%	2 - 28
4.	Cibicides lobulatus	5%	1 - 13
5.	Rosalina globularis	4%	5 - 10

The main feature is the absence of E. scabra and T. sagittula which were found to be present in thanatotope II. The presence of E. crispum, E. articulatum and A. beccarii in high percentages, and

the presence of C. lobulatus and R. globularis in low percentages
compared with Thanatotope II, are indicators that Thanatotope III
is subject to moderate and quiet current agitation. The diversity
here is low and ranges between $\alpha = 1$ and $\alpha = 4$.

Thanatotope IV:

This is represented by six stations, three of them (61, 62, and
63) located on the west side between Great Cumbrae and the Island of
Bute, two of them (13 and 47) located on the east side of Great Cumbrae,
and the last one (37) located in the north-west of Dunoon Basin. The
average depth of these stations is 42 metres ranging from 12 - 54 m.,
and the sediments collected from them were predominantly sandy mud.

The main species represented in this thanatotope are:

			Range
1.	Eggerella scarbra	84%	76 - 98
2.	Ammonia beccarii	6%	1 - 15
3.	Buliminella elegantissimi	4%	7 - 8

This is similar to Thanatotope I in being characterized by deep
water and sandy mud sediments, but differs from it in the greater
dominance of E. scarbra and the rarity of E. excavatum and B. marginata.
The diversity is very low, ranging from $\alpha = 1$ to $\alpha = 2$.

Thanatotope V:

This is represented by twenty stations, twelve of which are
from three main areas; the first group represented by sampling
stations 31, 32, 33, 41, and 42 is located in the middle of the Dunoon
Basin. The second group represented by sampling stations 36, 35, and
38 is located in the north of the Dunoon Basin. The last group repre-
sented by sampling stations 9, 10, 11, and 12 is located near Largs
at the eastern side of Great Cumbrae. The remaining eight sampling

stations 44, 45, 51, 60, 16, 22, 28, and 58 are scattered at different

localities. The average depth of water in this thanatotope is 42

metres, ranging between 25 - 78 m. and the sediments are a mixture

of mud and sandy mud.

The main species represented are:

		percentage	Range
1.	Eggerella scarbra	75%	39 - 89
2.	Buliminella elegantissima	5%	1 - 33
3.	Ammonia beccarii	5%	1 - 9
4.	Elphidium excavatum	3%	6 - 20
5.	Reaphax fusiforms	3%	1 - 13

The main features of this thanatotope are the presence of E.

scarbra in very high percentage; the presence of R. fusiforms, which

is only found in this thanatotope; the absence of all Elphidium

species except E. excavatum; and the absence of Q. seminulum. The

diversity in this thanatotope is very low and ranges from $\propto$ = -1 and

$\propto$ = 3.

Thanatotope VI:

This is represented by two stations, 21 and 27, from depths of

35 m. and 98 m. respectively. The sediment is a sandy mud. They

cluster together because E. scarbra is the only Foraminifera present.

Thanatotope VII:

This consists of three stations 49, 48, and 47 located at Roths

Bay and Kames Bay along the west side of the sampling area. The depth

of water is 12, 15, and 16 m. respectively, the sediment is muddy sand.

The main species represented in this thanatotope are:

1.	Buliminella elegantissima	52%	40 - 59
2.	Eggerella scafbra	34%	40 - 29

3.   _Elphidium_ _magellanicum_   5%   5-6

This thanatotope is dominated by two species, but the remark-
able point is the high percentage of B. _elegantissima_ compared with
the other thanatotopes having the same type of sediment. As this
thanatotope is from shallow water, it suggests that this species is
controlled by depth of water, preferring shallow water and muddy sand
sediment. The diversity in this thanatotope is very low, $\propto$ = -1 to
$\propto$ = 2.

Thanatotope VIII:

This is represented by stations 69, 70, and 71, located in the
intertidal zone. Samples were obtained from these stations by the
known area tray and were found to be clean sand.

This thanatotope is dominated by E. _articulatum_ (97%). This
species seems to be confined to the intertidal flat zone, living on
the surface of the sediment.

Summary Discussion:

Referring to the afore mentioned thanatotopes, it is possible
to reach the following conclusions:

1.   Thanatotopes II, III, VII, and VIII are characterized by rela-
tively shallow water. Thanatotope VIII is from sandy intertidal flats;
Thanatotope II from sand and sandy gravels of between 5 and 45 m.
depth; Thanatotope III from sands and gravels of about 1 m. depth;
and Thanatotope VII from muddy sands of 14 m. depth. Thus a combina-
tion of depth and sediment explain the differences between these
thanatotopes.

2.   Thanatotopes I, IV, and V have similar faunas and are all domin-
ated by E. _scabra_. They are found in similar environments: mud and

muddy sands, with an average depth of 42 - 44 m., but ranging between 12 - 78 m. Other factors such as pH, salinity, temperature, and water oxygen content are also similar. They have been separated into three thanatotopes because they form distinct clusters in the dendogram. It is possible, however, that because of the small number of stations sampled, Thanatotopes I, IV, and V are merely part of a continuous variation within a single thanatotope.

3.   Thanatotope VI, consisting of two stations only, may also belong with Thanatotopes I, IV, and V.

4.   E. scabra is the commonest species found in the area. It is present in all thanatotopes, apart from Thanatotopes III and VIII, and dominates faunas from deeper waters.

5.   The main conclusion of this study is that the distribution of the dead fauna is controlled by two factors: type of sediment, and depth of water. The importance of the substratum is seen in Thanatotope II: some stations belonging to this come from fairly deep water, up to 45 m. This depth is more characteristic of Thanatotopes I, IV, V, and VI; but the sediment is a sand, not a mud as in the latter thanatotopes. Substratum is also important in Thanatotope VII, muddy sand in shallow water, 14 m. deep; this differentiates it from the other shallow water thanatotopes. On the other hand, Thanatotope VII also illustrates the importance of depth: it is this which distinguishes it from Thanatotopes I, IV, V, and VI which come from similar sediments in deeper water. Depth is the important factor in separating Thanatotopes II, III, and VII. (see Fig. 3)
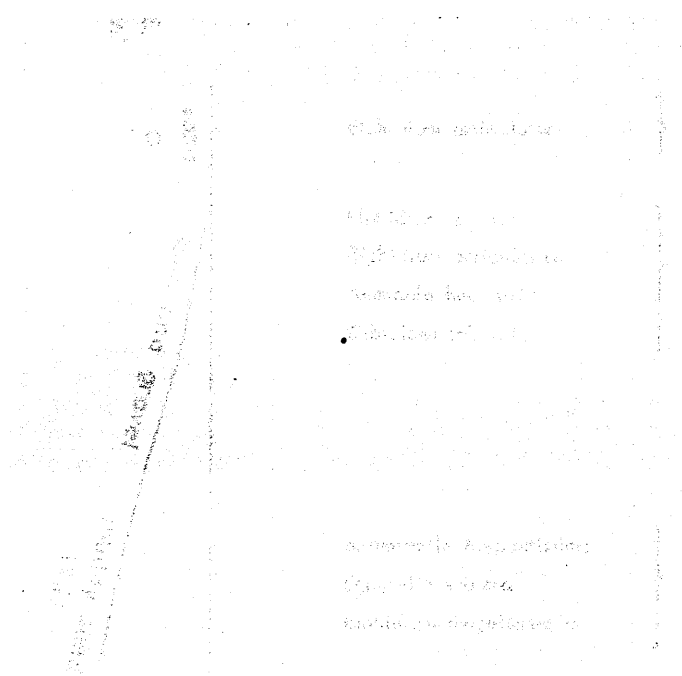
Fig. 3

The relationship between

thanatotopes, type of sediment

and depth of water.

Fig. 3

AVERAGE
DEPTH (m)

sand — 0

sand and gravel — 1

muddy sand and sands and gravel (VI) (II)

14

sandy mud and mud

42-44

Elphidium articulatum } THANATOTOPE VIII

Elphidium crispum
Elphidium articulatum
Ammonia beccarii
Cibicides lobatulus } THANATOTOPE III

Buliminella elegantissima
Eggerella scarbra
Elphidium magellanicum } THANATOTOPE VII

Eggerella scarbra
Textularia sagittula
Elphidium crispum
Rosalina globularis
Cicbicides lobatulus
Quinqueloculina seminulum
Elphidium excavatum
Elphidium magellanicum
Elphidium articulatum } THANATOTOPE II

Eggerella scarbra
Elphidium excavatum
Bulimina marginata
Elphidium magellanicum
Buliminella elegantissima } THANATOTOPE I

Eggerella scarbra
Ammonia beccarii } THANATOTOPE IV

Eggerella scarbra
Buliminella elegantissima
Ammonia beccarii } THANATOTOPE V

Eggerella scarbra } THANATOTOPE VI

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CHAPTER 3

Living Foraminifera

This chapter is an attempt to determine the ecological factors important in controlling the distribution of living Foraminifera in the study area. The rarity of living Foraminifera makes any statistical approach difficult. Various methods were tried in order to relate the distribution of the living fauna with the dead fauna (chi-square, cluster analysis), but all attempts proved unsatisfactory. So a non-statistical approach has been adopted. The following figures indicate the number of dead and living Foraminifera.

48,947 dead specimens

1,576 living specimens

Appendix Table 5.

For the thirteen common species the figures are:

37,430 dead specimens

1,350 living specimens

Appendix Table 6.

Ecological factors:

(1) salinity:

The salinity of surface and bottom water was determined at thirty-three stations (Appendix Table 1). The average for the surface water is 32°/oo and for the bottom water 33°/oo, with slight variations between stations. There is very little annual variation, or geographical variation, so salinity does not appear to be a controlling factor in the foraminiferal distribution. It should be borne in mind however, that most of the species have been recorded from a wide range of salinities (Murray 1968, 1970).

(2) temperature:

The lowest bottom water temperature were recorded in March,

with a temperature of 6.4°C, the highest was 9.4°C in December. Appendix Table 2 shows that there was little change in temperature between different depths at the same time of the year. It is thought that temperature has little bearing on the distribution of the Foraminifera.

(3) pH:

The range encountered (8 - 8.7) is well within the limits tolerated by the majority of organisms; Moore (1931) also found little variation in pH. Thus this factor is not considered important. Appendix Table 3.

(4) oxygen content:

The oxygen content of the bottom water was analysed at fourteen stations. The results range from 5.6 to 8.3 ml./l., with lower values in deeper water, and the higher values in shallow water where current action predominates. However, even the lowest value indicates a totally adequate supply of oxygen, so it seems unlikely that this affects the distribution of the Foraminifera.

It may be important to consider the oxygen content in the sediment; unfortunately this was not possible in the present study. Moore in 1931 made a comprehensive study of the chemical nature of the mud in the Clyde Sea area, including the nitrogen, phosphate, Ph, and oxygen content. Appendix Table 3.

(5) type of sediment and depth of water:

These two are the main physical factors upon which the thanatotopes were established, and which were responsible for the distribution of the dead fauna (Chapter 2). This same conclusion had been reached by Robertson (1877). The L/D ratios and the distribution of the living fauna are also greatly influenced by these two factors. Thanatotopes II, III, VII, and VIII from shallow sandy sediments are characterized by a high L/D ratio (Appendix Table 5). There is a general correlation

between the distribution of the living and dead forms within these thanatotopes. In deeper muddier waters, however, the L/D ratio (Appendix Table 5) is very low and it is not possible to recognize in the living Foraminifera the thanatotopes established by the dead fauna. From the living Foraminifera it is only possible to recognize a single fauna from deeper (ave. 42 - 44 m.) muddy sediments. It may be that the low numbers of living specimens from deep water prevents the recognition of distinct faunas.

Factors that might have distorted the L/D ratio:

(1) Reworking of fossils:

Reworking of fossil tests from previous environments could give a high proportion of dead tests. In the context of the Firth of Clyde, the possible fossil tests would be Pleistocene in age (Goodlet, 1970). In this study it seems unlikely that fossil material has been collected, for the following reasons:

(a) The surface sediments deposited recently have a thickness varying from 0 - 10 cm. in the shallow water, with greater thickness in the deeper water (Deegan et al. 1973). It is unlikely that the Van Veen Grab used in sampling could have penetrated to the Pleistocene sediments.

(b) Most of the species represented in the eight thanatotopes, including the thirteen common species, are still living in the area. Even the species that were not represented by living specimens had tests in a good state of preservation which makes it unlikely that they have been reworked from previous environments.

(2) Transportation:

The high percentage of dead Foraminifera in the deep water could perhaps be attributed to transportation of tests from shallower

water. This seems unlikely though, because the common shallow water

species such as T. sagittula, Q. seminulum, R. globularis, C. lobatulus

and Elphidium species except E. excavatum, are absent from the deep

water thanatotopes. The well-preserved tests of the deep water species

is further evidence against transportation.

(3) The sampling method:

    It is well known that most living forms are restricted to the

top one centimetre of the sediment. The samples from the boat were

collected with a Van Veen Grab. This grab collects sediments from

several centimetres depth, thereby incorporating a vast number of

dead specimens. Its closure was not always perfect so that washing

of material took place during transit to the surface. Finally, the

sediments were emptied into plastic basins resulting in a great deal

of disturbance and mixing of the sediment. Thus it was impossible to

sample only the top layer of the sediment, and because of this the

samples contained a much higher proportion of dead tests, compared

with those collected from the surface sediment of the intertidal flat

zone by using the known area method which gave a very close correla-

tion between the living and dead fauna (Table 5). It is also known

that the Van Veen Grab goes in deeper in muds than in sands, and this

may account for lower L/D ratios in the muds.

(4) Rate of sedimentation:

    Rate of sedimentation could exert an influence on the proportion

of the living and dead tests. This was discussed by Walton (1955),

who devised a formula which could be applied in such cases:

$$L/D = \frac{\text{Living population}}{\text{Dead population}} \times 100$$

    In the present study this formula showed that the L/D ratios

vary from 0 where no living species were encountered, to a maximum of

24

38. The low ratio represents the thanatotopes coming from the deep water, and the high ratio represents those coming from the shallow water (Appendix Table 5).

This might be taken to suggest that faster sedimentation occurs in shallow water than in deep water. Moore in 1931 had reached this conclusion concerning the rate of sedimentation in the Clyde area. However, the greater thickness of surface sediment in the deep waters compared with the shallow waters as reported by Deegan et al. (1973) would suggest the opposite. Murray (1973, p.14) pointed out the difficulties in comparing L/D ratios with rate of sedimentation; the conclusions noted here do not suggest a simple relationship between these two.

<u>Summary and Conclusion:</u>

From the study of the foraminiferal content, and examining the sediments of the seventy-four samples, which were collected from the central part of the Firth of Clyde, the following points could be drawn:-

(1)   The sediment which floors the area can be classified into seven divisions according to the grain size and the percentage of the different grain sizes. These divisions are gravel, sandy gravel, gravelly sand, sand, muddy sand, sandy mud, and mud.

(2)   The total population of the Foraminifera was found to belong to fifty species, thirteen of them were predominant, constituting 76% of the total population. (Appendix Table 6). The additional thirty-seven species comprised 24% of the total population.

(3)   From counting the total population and observing the Foraminifera which are present in the sample, the living individuals showed a very low abundance compared with the dead, particularly in water greater than 25 m. depth; this could be attributed to the following:

(a)   The lack of oxygen in the sediments, particularly in the mud which comes from the deep water (Moore 1931).

(b)   The sampling method (Van Veen Grab).

(4)   Cluster analysis using Jaccard's Coefficient indicates eight thanatotopes amongst the sixty-five stations yielding Foraminifera. Nine stations were barren, their sediment being gravel.

(5)   The distribution of living Foraminifera from shallow water could be related to the four shallow water thanatotopes recognized in the dead specimens; it was not possible to correlate the living specimens from deeper water with the four deep water thanatotopes recognized from dead specimens; only one general deep water fauna

could be recognized.

(6)   The two main factors responsible for the distribution of the dead and living Foraminifera are type of sediment and depth of water. The oxygen content of the sediment may also be of importance.

(7)   The main species dominating waters more than about 30 m. deep is E. sca:bra.

(8)   The diversity is generally low, showing a relationship to the type of sediment and depth of water; thanatotopes representing the shallow water sands and gravelly sands (II and III) showed a high diversity (range from $\alpha = 4$ to $\alpha = 9$) compared with those from the deep water muddy sediments, which have a low diversity (range from $\alpha = -1$ to $\alpha = 4$).

(9)   The species recorded from the area showed a high degree of similarity to those found in other places around the British Isles. (e.g. Plymouth region, Murray 1965), (Christchurch Harbour, Murray, 1968), (Western Approaches to the English Channel, Murray, 1970), and (Cardigan Bay, Haynes, 1973).

SYSTEMATICS

The nomenclature of Murray (1971) has been followed in this report. Since the publication of Murray's work an important study by Haynes (1973) has appeared, which differs from Murray in certain respects. Haynes created a new genus _Eggerelloides_, genotype _E. scabra_. Thus the species referred to here as _Eggerella scarbra_ should be called _Eggerelloides scarbrum_. _Elphidium articulatum_ and _E. excavatum_ have often been confused. As stated by Murray, they inhabit distinct environments and a close study of the test easily separates the two. This is borne out in the present study; _E. articulatum_ is found on sandy tidal flats, _E. excavatum_ having a much wider range. The species here described as _E. articulatum_ is probably synonymous with a new species described by Haynes as _E. williamsoni_, and _E. excavatum_ may be Hayne's _E. selseyense_ (Heron-Allen & Earland). However, this introduces taxonomic problems beyond the scope of this work, so, as stated before, the usage of Murray has been followed.

APPENDIX

Table 1. Salinity of surface and bottom waters in each of the
          different sampling sites.

Station Number	Surface salinity ($^{\circ}/oo$)	Bottom salinity ($^{\circ}/oo$)
31	33.0	33.5
32	32.2	33.5
33	32.0	33.5
34	32.7	33.9
35	33.5	33.5
36	32.5	33.3
37	32.5	33.4
38	32.7	33.6
39	32.5	33.2
40	31.2	33.0
41	31.2	33.0
42	31.6	33.1
43	31.4	33.0
44	31.4	32.0
45	31.0	33.0
46	30.8	32.2
47	30.5	32.2
48	31.0	32.0
49	31.0	32.0
50	31.4	33.0
51	30.5	33.3
52	32.0	33.6
53	31.5	33.2
54	32.8	32.9
55	33.0	33.2
56	32.9	33.0
57	32.8	32.0
58	32.8	33.0
59	32.8	33.4
60	32.7	32.5
61	32.4	33.2
62	32.7	33.4
63	32.8	33.2
Average	32	33

Table 2. Surface temperature, deep temperature, and depth of water in the different sampling sites.

Station Number	Surface temp.($^{\circ}$C)	Bottom temp.($^{\circ}$C)	Depth of water (m)	Date of Measurements
31	8.6	9.6	40	
32	8.6	9.8	35	
33	8.4	9.8	70	
34	9.6	9.8	65	
35	9.0	9.9	75	3/12/73
36	9.8	9.9	25	
37	9.8	10.0	35	
38	9.8	9.9	30	
39	9.8	9.9		
40	6.8	7.0	38	
41	6.3	6.7	47	
42	6.3	6.7	39	
43	6.3	6.4	5	
44	6.3	6.8	34	
45	6.3	7.0	50	
46	6.2	6.5	13	3/ 3/74
47	6.2	6.5	12	
48	6.2	6.7	15	
49	6.2	6.7	16	
50	6.2	6.6	25	
51	6.2	6.7	42	
52	6.2	6.5	60	
53	6.2	6.6	34	
54	8.0	8.0	8	
55	8.2	7.6	32	
56	8.9	8.0	3	
57	8.3	7.4	45	
58	8.4	7.6	30	8/ 5/74
59	8.4	7.6	35	
60	8.2	7.4	78	
61	8.4	7.8	54	
62	8.6	7.6	42	
63	8.2	7.4	43	
Average temp.	7.7	7.8		

Table 3. pH and oxygen content.

Station Number	pH	Oxygen content ml/l
23	8.2	6.2
28	8.1	6.2
30	8.1	5.6
40	8	6.9
42	8	6.9
44	8	6.9
48	8	6.9
51	8	6.9
55	8	8.3
57	8	8.3
59	8	8.2
64	8.3	8.3
66	8.4	8.3
69	8.4	8

Table 4. Type of sediments, depth of water, and the sampling
devise used in collecting samples from the different
sampling sites

Station Number	Type of sediment	Depth of water (m)
1	Sand	4
2	Sand	16
3	Sand	10
4	Sand	25
5	Sand	37
6	Gravelly sand	33
7	Sand	26
8	Sand	14
9	Mud	25
10	Mud	43
11	Mud	45
12	Mud	44
13	Mud	46
14	Sandy mud	45
15	Sandy mud	30
16	Mud	24
17	Sand	10
18	Sand	4
19	Gravelly sand	2
20	Gravelly sand	10
21	Sandy mud	35
22	Sandy mud	65
23	Muddy sand	115
24	Gravelly sand	35
25	Gravelly sand	25
26	Sand	12
27	Sandy mud	98
28	Sandy mud	48
29	Gravelly sand	11
30	Gravelly sand	19
31	Sandy mud	46
32	Mud	35
33	Mud	70
34	Sandy mud	65
35	Sandy mud	75
36	Sandy mud	25
37	Mud	35
38	Sandy mud	30
39	Gravel	5
40	Gravelly sand	38
41	Sandy mud	47
42	Sandy mud	39
43	Gravelly sand	5
44	Mud	34
45	Mud	50
46	Gravelly sand	13
47	Muddy sand	12
48	Muddy sand	15
49	Muddy sand	16
50	Sandy mud	25

Table 4

(Continued)

Station Number	Type of sediment	Depth of water (m)
51	Sandy mud	42
52	Mud	60
53	Sandy mud	34
54	Sand	8
55	Sand	32
56	Sand	3
57	Sand	45
58	Sandy mud	30
59	Sandy mud	35
60	Sandy mud	78
61	Sandy mud	54
62	Mud	42
63	Sandy mud	43
64*	Sand	0
65*	Sand	0
66*	Sand	0
67*	Sand	0
68*	Sand	0
69*	Sand	0
70*	Sand	0
71*	Sand	0
72*	Sand	0
73*	Gravel	0
74*	Sand	0

* These samples were collected from the intertidal zone using the known area method. All the other samples were collected by the Van Veen Grab.

Table 5. Number of living and dead Foraminifera, L/D ratio, type
of sediment, and the depth of water in each of the
sampling stations related to the thanatotopes.

Thanato-tope Number	Station Number	No. of Living Foram.	No. of Dead Foram.	L/D	Type of Sediment	Depth of Water (m)
I	14	0	316	0	M	45
	53	10	257	4	SM	34
	50	32	1005	3	SM	25
	59	4	329	1	SM	35
	34	4	252	2	SM	65
	52	0	180	0	SM	60
II	8	44	1974	2	S	14
	24	53	416	10	GS	35
	5	12	348	3	S	34
	20	33	629	5	GS	10
	26	6	289	2	S	12
	40	7	1165	1	GS	38
	2	12	150	8	S	16
	4	96	2106	5	S	25
	30	60	1145	5	GS	19
	3	13	40	32	S	10
	29	10	281	4	GS	11
	6	5	184	3	GS	33
	46	54	1297	4	GS	13
	25	26	469	6	GS	25
	43	40	1666	2	GS	5
	7	33	5355	1	S	26
	54	7	197	4	S	8
	55	20	424	5	S	32
	57	25	386	6	S	45
	17	8	249	3	S	10
III	18	10	198	5	GS	4
	19	62	984	5	GS	2
	64	8	53	15	S	0
	66	61	470	13	S	0
	67	2	25	8	S	0
IV	61	0	130	0	SM	54
	15	1	418	0	SM	30
	63	0	125	0	SM	43
	62	0	155	0	M	42
	13	0	861	0	M	46
	37	0	112	0	M	35

Thanato-tope Number	Station Number	No. of Living Foram.	No. of Dead Foram.	L/D	Type of Sediment	Depth of Water (m)
V	28	0	233	0	SM	48
	33	0	65	0	M	70
	36	0	59	0	SM	25
	58	2	378	0	SM	30
	22	37	680	5	SM	65
	16	0	212	0	M	24
	60	16	331	5	SM	78
	38	1	227	0	SM	30
	31	2	280	0	SM	40
	32	0	245	0	M	35
	41	0	380	0	SM	47
	35	5	229	2	SM	75
	42	0	343	0	SM	40
	9	10	1948	0	M	25
	10	48	5669	1	M	43
	11	32	6238	1	M	45
	12	0	746	0	M	44
	44	36	895	4	M	34
	45	10	765	1	M	50
	51	39	599	7	SM	42
VI	21	19	726	3	SM	35
	27	0	80	0	SM	98
VII	48	95	629	1	MS	15
	49	60	730	8	MS	16
	47	323	840	38	MS	12
VIII	69	25	230	10	S	0
	70	33	300	10	S	0
	71	25	250	10	S	0
Total		1,576	48,947			

N.B.   S stands for sand, MS for muddy sand, SM for sandy mud, M for mud, and GS for gravelly sand.

Table 6 . Total counts of living and dead Foraminifera collected
in all the sampling stations.

Species	No. of living	No. of dead
Eggerella scabra	178	16155
Textularia sagittula	48	5331
Buliminella elegantissima	410	2656
Ammonia beccarii	154	1989
Elphidium articulatum	180	1957
Rosalina globularis	57	1713
Elphidium crispum	136	1559
Elphidium excavatum	40	1393
Quinqueloculina seminulum	50	1234
Elphidium magellanieum	40	1210
Cibicides lobatulus	28	965
Bulimina marginata	24	904
Reophax fusiforms	5	364
Total	1,350	37,430

PLATES

Numbers refer to catalogued numbers of Hunterian Museum.

L = maximum length; D = maximum diameter.

All measurements are in millimetres.

Suborder TEXTULARIINA

1. Reophax fusiform (Williamson)
   L = 0.57, x 75   P750

2. Reophax scottii (Chaster)
   L = 0.63, x 65   P751

3. Reophax scorpiurus (Montfort)
   L = 0.47, x 85   P752

4. Ammoscalaria pseudospiraliss (Williamson)
   L = 0.76, x 75   P753

5. Ammoscalaria runiana (Heron, Allen and Earland)
   D = 0.47, x 85   P754

6. Miliammina fusca (Brady)
   L = 0.68, x 75   P755

7. Cribrostomoides jeffreysii (Williamson)
   D = 0.38, x 150 P756

8. Trochammina ochracea (Williamson)
   D = 0.40, x 120 P757

9. Eggerella scabra (Williamson)
   L = 0.86, x 65   P758

10. Textularia sagittula (Defrance)
    0.6,   x 75   P759

11. Textularia pseudorugosa (Lacroix)
    L = 0.8,   x 80   P760

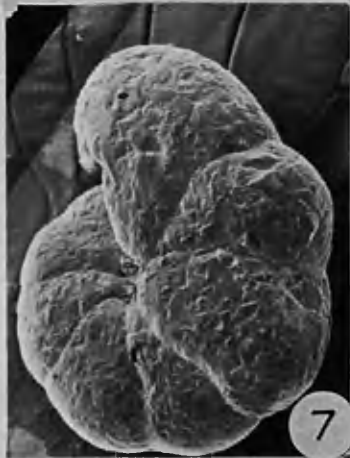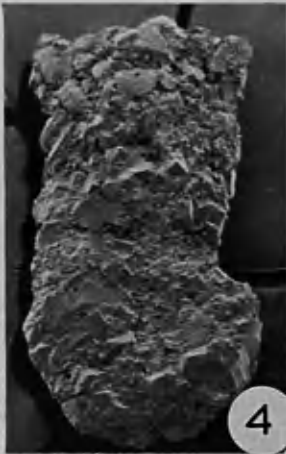12. Textularia earlandi (Parker)
    L = 0.7,   x 65   P761

PLATE 1

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Suborder MILIOLINA

1. Cyclogyra involvens (Reuss)
   D = 0.24,   x 150   P762

2. Quinqueloculina seminulum (Linné)
   L = 1,   x 60   P763

3. Quinqueloculina bicornis (Walker and Jacob)
   L = 0.8,   x 35   P764

4. Spiroloculina excavata (d'Orbigny)
   L = 0.74,   x 70   P765

5. Spiroloculina cf. S.rotunda (d'Orbigny)
   L = 0.97,   x 38   P766

6. Miliolinella subrotunda (Montagu)
   L = 0.44,   x 70   P767

7. Triloculina sp. (d'Orbigny)
   L = 0.7,   x 65   P768

8. Pyrgo williamsoni (Silvestri)
   L = 0.7,   x 65   P769

9. Pyrgo depressa (d'Orbigny)
   L = 0.45,   x 70   P770

PLATE 2

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Suborder ROTALIINA

1. Amphicoryna cf. A.scalaris (Batsch)
   L = 0.38,   x 170   P771

2. Dentalina subarcuata (Montagu)
   L = 0.9,   x 43   P772

3. Polymorphina acuta (d'Orbigny)
   L = 0.71,   x 70   P773

4. Lagena interrupta (Williamson)
   L = 0.43,   x 140   P774

5. Lagena substriata (Williamson)
   L = 0.56,   x 80   P775

6. Lagena sulcata (Walker and Jacob)
   L = 0.33,   x 160   P776

7. Lagena semistriata (Williamson)
   L = 0.4,   x 150   P777

8. Lagena clavata (d'Orbigny)
   L = 0.56,   x 65   P778

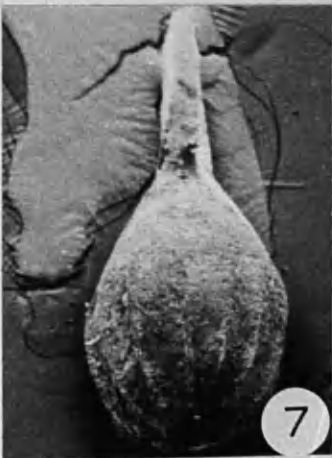9. Lenticulina peregrina (Schwager)
   L = 0.72,   x 65   P779

PLATE 3

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Suborder ROTALIINA

1. Globulina gibba (d'Orbigny)
   L = 0.66,   x 80   P780

2. Oolina hexagona (Williamson)
   L = 0.23,   x 150   P781

3. Fissurina lucida (Williamson)
   L = 0.24,   x 150   P782

4. Oolina squamosa (Montagu)
   L = 0.21,   x 170   P783

5. Fissurina orbignyana (Seguenza)
   L = 0.5,   x 140   P784

6. Buliminella elegantissima (d'Orbigny)
   L = 0.31,   x 160   P785

7. Brizalina spathulata (Williamson)
   L = 0.18,   x 80   P786

8. Bulimina gibba/elongata (Fornasina and d'Orbigny respectively)
   L = 0.36,   x 180   P787

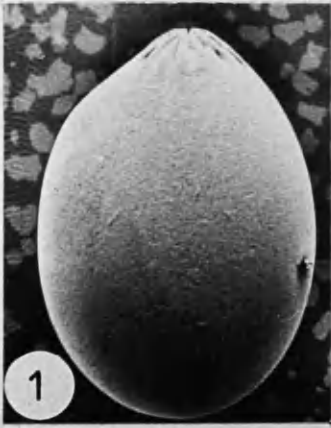9. Bulimina marginata (d'Orbigny)
   L = 0.49,   x 85   P788

PLATE 4

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Suborder ROTALIINA

1. **Elphidium articulatum** (d'Orbigny)
   D = 0.52,   x 85   P789

2. **Elphidium excavatum** (Terquem)
   D = 0.39,   x 130   P790

3. **Elphidium crispum** (Linnè)
   D = 0.66,   x 65   P791

4. **Cribroelphidium sp.** (Cushman and Bronnimann)
   D = 0.53,   x 80   P792

5. **Planorbulina mediterranensis** (d'Orbigny)
   D = 0.3,   x 140   P793

6. **Elphidium magellanicum** (Heron Allen and Earland)
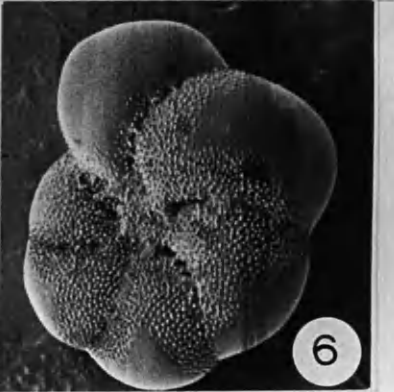   D = 0.34,   x 160   P794

PLATE 5

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Explanation of Plate 6

Suborder ROTALIINA

1. *Rosalina globularis* (d'Orbigny)
   D = 0.42,   x 75   P795

2. *Asterigerinata mamilla* (Williamson)
   dorsal view, L = 0.39,   x 130   P796

3. *Ammonia beccarii* (Linnè)
   ventral view, D = 0.66,   x 65   P797

4. *Asterigerinata mamilla* (Williamson)
   lateral view, L = 0.39,   x 130   P798

5. *Ammonia beccarii* (Linnè)
   dorsal view, D = 0.66,   x 65   P799

6. *Cibicides lobatulus* (Walker and Jacob)
   dorsal view, D = 0.64,   x 85   P800

7. *Cibicides lobatulus* (Walker and Jacob)
   ventral view, D = 0.64,   x 85   P801

8. *Cibicides pseudoungerianus* (Cushman)
   ventral view, D = 0.52,   x 70   P802

PLATE 6

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