MODERN BENTHIC FORAMINIFERAL BIOFACIES ACROSS THE NORTHERN NORTH SEA

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Foraminiferal distributions along a transect across the northern North Sea have been investigated in 11 surface sediment samples. Based on benthic calcareous foraminifera, four biofacies are defined; the *Cibicides lobatulus*, the *Bulimina marginata*, the *Elphidium excavatum* and the *Cassidulina laevigata* biofacies. The *Cibicides lobatulus* biofacies is found in areas with coarse grained sediments and high energy regime. The *Bulimina marginata* biofacies is found in an area with shifting hydrography and the development of a thermocline. All tests of *Elphidium excavatum* found in the *Elphidium excavatum* biofacies are considered reworked. The *Cassidulina laevigata* biofacies is located in connection with Atlantic water in the Norwegian Channel. The same distribution pattern is found for the agglutinated fauna. The distribution of planktonic specimens reflects the inflow of Atlantic water along the Norwegian Channel and on the Fladen Ground. A total number of 147 benthic species were recognized in the samples.

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INTRODUCTION

Investigation of Recent foraminifera forms the basis for environmental interpretation of fossil faunas. It is therefore important to have knowledge about the modern foraminiferal distribution when paleoenvironmental research is being carried out in an area. Knowledge about Recent foraminifera faunas can also be of importance for detecting changes in the marine environment (Alve & Bernhard 1995).

The aim of this study was to determine the modern benthic foraminiferal distribution in a transect across the northern North Sea and discuss the relationship to hydrography, organic carbon content, oxygen content and sediment distribution. The study was concentrated on the calcareous species since these will be used later in studies of stratigraphical data. Also, the planktonic and the agglutinated fauna have been investigated to determine their faunal distribution patterns in the North Sea.

The foraminiferal distributions in the northern North Sea have previously been investigated by Jarke (1961) who described five major benthic assemblages in surface sediments from the northern North Sea. A more detailed investigation was carried out in the Norwegian Channel and Skagerrak by Qvale & Van Weering (1985). Murray (1991) compiled data from the North Sea on the basis of Jarke's investigation and his own analysis. Sejrup & al. (1981) investigated benthic foraminiferal distributions in the northeastern part of the North Sea and the adjacent slope.

HYDROGRAPHY

The hydrography of the northern North Sea is characterised by an inflow of Atlantic water (AW) moving southwards along the Norwegian Channel (Furnes & al. 1986). Fig. 1 shows southern part of the AW inflow. This water enters the Skagerrak where it mixes with other, less saline watermasses from the Baltic region and Kattegat, turns cyclonic and returns following the Norwegian coast (NCW = Norwegian coastal water) towards the north (North Sea Task Force 1993d).

Another inflow of Atlantic water (AW(west)) is found east of Shetland, flowing southwards (Svendsen & al. 1991). The AW(west) turns east at about 58° N and forms a gyre around the Fladen Ground (Fig. 1). The inflow of AW(west) varies seasonally (Turrell & al. 1992). The AW(west) cools during winter (CAW = Cooled Atlantic water) and flows along with the Atlantic water in the Norwegian Channel into the Skagerrak (Svendsen & al. 1991). The offshore areas in the northern North Sea are stratified in summer with a thermocline between 30 and 50 m water depth (North Sea Task Force 1993a). The stratification

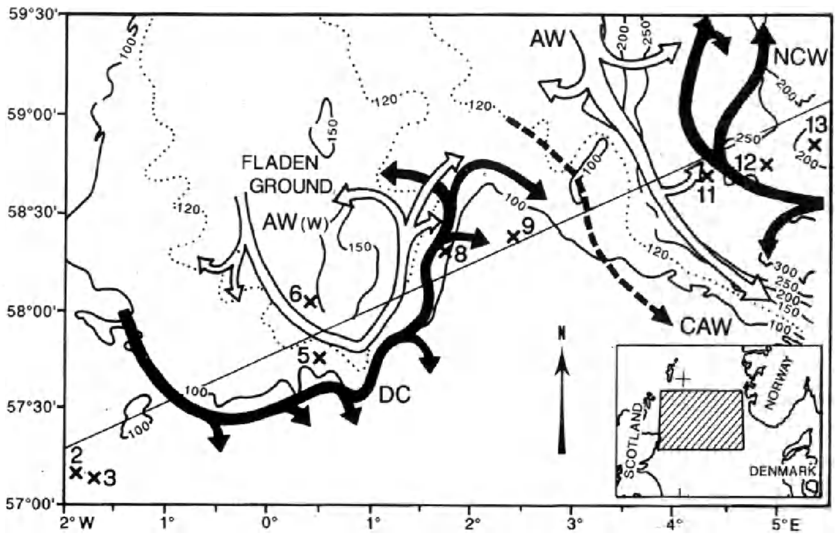

Fig. 1: Location map showing sample stations and major current system. The black straight line is the transect line used in Fig. 5. AW(w): Atlantic water (west), AW: Atlantic water; DC: Dooley Current; CAW: cooled Atlantic water; NCW: Norwegian coastal water. (Modified from Svendsen & al. 1991). Stns 1 and 4 are located north and south of the hatched area on the inset map, their locations are; 1: 60°38.02'N, 03°43.26'E and 4: 56°16.25'N 00°45.99'E.

breaks down in autumn due to strong winds. South of the AW(west) flows the Dooley Current (DC) which is a continuation of the Fair Isle Current (FIC) (mixture of coastal water and Atlantic water, Svendsen & al. 1991). The watermasses close to the Scottish coast are well mixed throughout the year because of strong tidal currents which prevent stratification in the water column.

Table 1. Position of stations.

Station	Latitude	Longitude
1	60°38.02' N	03°43.26' E
2	57°07.00' N	01°54.00' W
3	57°04.12' N	01°44.93' W
4	56°16.25' N	00°45.99' E
5	57°44.06' N	00°36.49' E
6	58°04.01' N	00°33.01' E
8	58°23.80' N	01°43.98' E
9	58°28.93' N	02°28.26' E
11	58°41.48' N	04°13.89' E
12	58°45.48' N	04°51.03' E
13	58°47.98' N	05°16.16' E

MATERIAL AND METHODS

Eleven surface sediment samples (Fig. 1, Table 1) were collected with a boxcore sampler (0.30 x 0.30 m) in April 1991 during a cruise with research vessel *Håkon Mosby*, University of Bergen. The top few centimetres (ca 2 cm) of sediments in the boxcore were sampled for foraminifera analysis. A few samples contained core top water after the boxcore sampler was retrieved on deck and it was drained off without sieving. Half of the surface area of the boxcore, i.e. 0.045 m^2 was sampled. Immediately after collection, ethanol and Rose Bengal were added to the samples (except Stn 12). In the laboratory the samples were wet sieved prior to drying. The sieve sizes used were 63 µm, 125 µm and 1,0 mm and the 125 µm -1,0 mm fraction was utilized for foraminiferal analysis. In samples with high sand content the foraminifera were separated from the sediment by using a heavy liquid CCl_4.

In each sample at least 300 specimens of agglutinated, 300 specimens of calcareous and 300 specimens of planktonic foraminifera were counted comprising only dead individuals. Few living (stained) benthic specimens (max. 60 specimens per 100 g dry sediment) were observed in the samples (Fig. 4, Table 5).

Interpretations of shallow marine paleoenvironments are commonly based on the knowledge of modern foraminiferal distribution. In many cases there is a difference between the modern assemblage found in the surface sediment and the fossil assemblage, due to post mortem processes. Many researchers (e.g. Murray 1982; Scott & Medioli 1980) have therefore questioned when to use living, dead or total (living + dead) assemblages as a base for paleoenvironmental reconstructions. To investigate the ecological demands of species, the living assemblage must be used, while in paleoenvironmental investigations the dead or total assemblage resembles the fossil assemblage better and should therefore be applied. In this study the dead assemblage distribution (probably representing several decades of accumulation) is discussed relative to present environmental parameters. The dead benthic assemblage is considered to represent both infaunal and epifaunal species which arises due to mixing within the sediment (Corliss & Chen 1988). The agglutinated foraminifera have not been used in the definition of biofacies because most commonly the specimens disintegrate soon after death (Murray 1991) and thus seldom occur in investigations carried out on core material. Therefore, a general picture of the modern calcareous foraminiferal distribution is more useful in paleoenvironmental applications.

The determination of total organic carbon (TOC) was performed at the University of Bergen using a LECO Carbon Determinator E-12.

RESULTS

Results from analysis of foraminifera in the 11 samples are given in Tables 3-5; only species with abundances higher than 1 % and occurring in at least two or more samples are

Table 2. Species list.

Adercotryma glomeratum (Brady, 1878)
Bulimina marginata d'Orbigny, 1826
Cassidulina laevigata d'Orbigny, 1826
Cibicides lobatulus (Walker & Jacob, 1798)
Elphidium excavatum (Terquem, 1875)
Glomospira spp.
Haplophragmoides bradyi (Robertson, 1891)
Hyalinea balthica (Schröter, 1783)
Lagenammina sp.
Melonis barleeanus (Williamson, 1858)
Reophax subfusiformis Earland, 1933
Saccammina spherica G. O. Sars, 1871
Stainforthia fusiformis (Williamson, 1858)
Trifarina angulosa (Williamson, 1858)
Uvigerina mediterranea Hofker, 1932
Verneuilina media (Höglund, 1947)
Neogloboquadrina pachyderma (Ehrenberg, 1861)
Globigerina bulloides d'Orbigny, 1826
Globigerina quinqueloba Natland, 1938
Globigerinata glutinata (Egger, 1895)
Globigerinata uvula (Egger, 1861)
Globorotalia inflata (d'Orbigny, 1839)

Table 3. The percentage distribution of 23 agglutinated benthic species with frequencies higher than 1 % and occurring in at least two samples. Stn 9 shows number of agglutinated specimens counted.

Species/Stations	1	2	3	4	5	6	8	9	11	12	13
Adercotryma glomeratum	3	-	-	2	-	6	9	-	1	1	-
Ammolagena clavata	1	-	-	-	-	-	-	-	1	-	-
Cribrostomoides crassimargo	-	-	-	-	-	5	0.5	-	-	-	-
C. kosterensis	-	1	-	-	-	-	1	-	-	-	1
C. nitidum	3	-	-	-	-	-	-	-	0.3	3	-
C. subglosa	2	-	-	-	-	-	-	-	4	-	-
Dorothia pseudoterris	3	-	-	-	-	-	-	-	-	-	-
Eggerella scabra	-	9	6	-	1	-	0.5	-	-	-	-
Glomospira spp.	3	0.3	-	-	-	-	-	-	6	8	4
Haplophragmoides bradyi	19	0.3	-	-	-	-	3	-	22	16	5
Karreriella sp.	2	2	-	-	-	1	-	-	-	-	-
Lagenammina sp.	-	-	-	3	-	15	7	-	-	-	-
Recurvoides trochamminiforme	3	-	-	-	-	-	-	-	-	2	-
Reophax guttifera	2	-	-	-	-	-	-	-	5	8	-
R. scorpius	-	-	-	-	-	-	-	*4*	-	-	-
R. subfusiformis	1	3	2	6	-	-	28	-	1	-	-
Saccammina spherica	7	-	-	-	-	0.3	-	-	5	12	-
Textularia bocki	-	2	-	-	15	0.3	-	-	-	-	10
T sagittula	-	5	-	14	34	-	2	*1*	-	-	45
Textularia sp.	-	62	88	55	45	-	-	*1*	-	-	-
Trochammina cf. *rotaliformis*	9	1	-	-	-	-	-	-	-	5	-
T. globigeriniformis	3	-	-	-	-	-	-	-	3	-	-
Verneuilina media	28	9	-	2	3	58	37	*6*	33	11	9
Indeterminata	6	2	-	12	-	6	3	-	6	7	6
No. of specimens counted per sample	343	364	372	105	222	296	217	12	302	313	217
No. of specimens per 100 g sediment	3900	1000	6500	150	4400	6700	500	30	3600	6100	8200

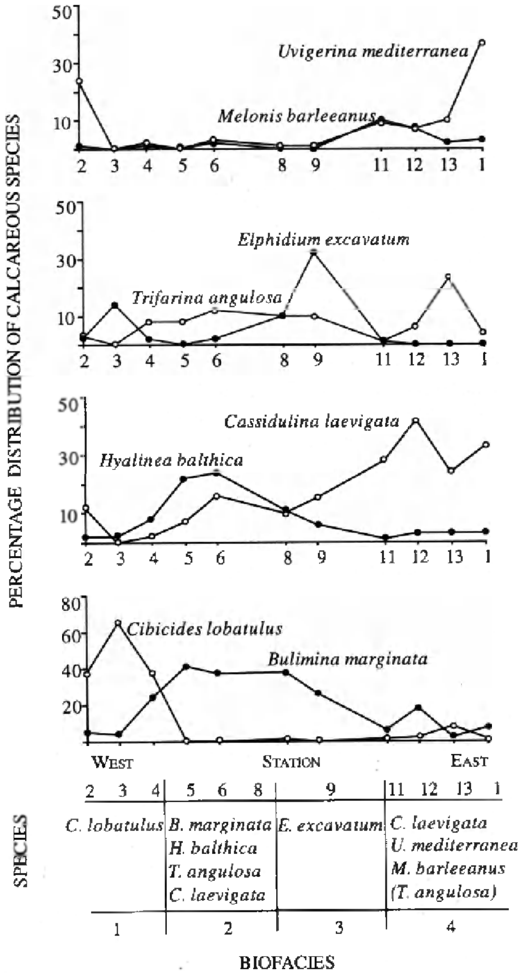

Fig. 2: The percentage distribution of the most common calcareous species at each station. Also shown are the common species and stations included in each biofacies. *Trifarina angulosa* and Stn 13 are marked with parentheses ( ) in biofacies 4 because this sample is distinct from the *Cassidulina laevigata* -biofacies.

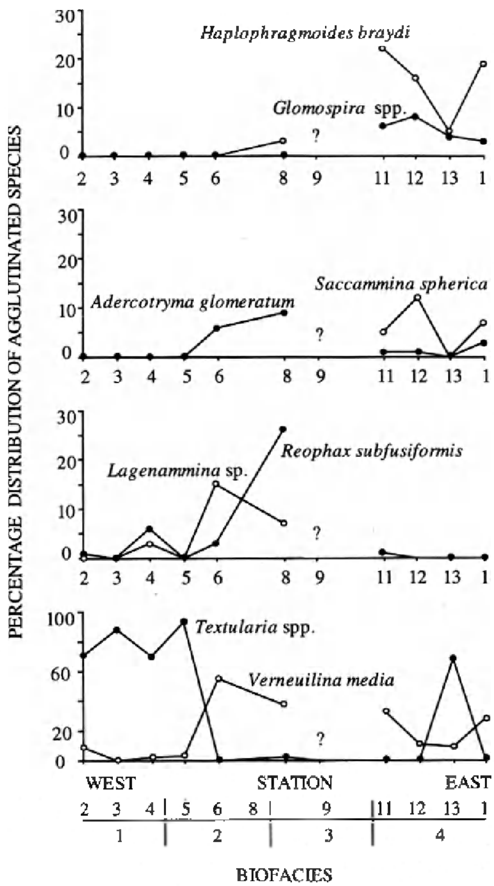

Fig. 3: The percentage distribution of the most common agglutinated species at each station. The questionmark (?) at Stn 9 indicates that percentage calculations were not carried out due to a low number (12) of agglutinated specimens.

shown. A total of 147 benthic species was found representing 59 genera. Only foraminifera species mentioned in the text are listed in Table 2. The foraminiferal tests are generally well preserved except for at Stns 5 and 3 where some specimens are abraded. The distribution of the most common benthic calcareous and agglutinated species is shown in Figs 2 and 3. The calcareous species shown in Fig. 2 represent, on average, 84 % (ranging from 58-96 %) of the specimens counted in each station. The dominating species are: *Cibicides lobatulus*, *Bulimina marginata*, *Hyalinea balthica*, *Trifarina angulosa*, *Cassidulina laevigata*, *Elphidium excavatum*, *Uvigerina mediterranea* and *Melonis barleeanus*. Based on these benthic calcareous species four biofacies are defined and given informal names after the most common species within the biofacies.

BIOFACIES

The *Cibicides lobatulus* biofacies (Stns 2, 3, and 4): This biofacies is dominated by *Cibicides lobatulus* (37-65 %) (Fig. 2). Stns 2 and 3 represent the *Cibicides lobatulus* biofacies located in coastal areas near Scotland. Stn 4 is located further to the south and outside coastal areas. Other species at Stn 2 include *U. mediterranea* (24 %), *C. laevigata* (12 %) and *B. marginata* (4 %). At Stn 3 other frequent species are *E. excavatum* (9 %), *S. fusiformis* (7 %) and *B. marginata* (4 %). Stn 4 has *B. marginata* (24 %), *T. angulosa* (8 %) and *H. balthica* (8 %) as more frequent species. The agglutinated fauna is dominated by *Textularia* spp. (70-88 %) (Fig. 3).

The *Bulimina marginata* biofacies (Stns 5, 6, and 8): *Bulimina marginata* (37-41 %) dominates the assemblage located on the Fladen Ground together with *H. balthica* (24-11 %), *C. laevigata* (7-16 %) and *T. angulosa* (8-12 %) (Fig. 2). The agglutinated fauna is dominated by *Textularia* spp. (more than 90 %)at Stn 5 while Stns 6 and 8 are dominated by *Verneuilina media* (37-55 %). Other frequent agglutinated species are *Lagenammina* sp. (7-15 %), *Adercotryma glomeratum* (6-9 %) and *Reophax subfusiformis* (26 %) at Stn 8 (Fig. 3).

The *Elphidium excavatum* biofacies (Stn 9): The *Elphidium excavatum* biofacies is only represented by one station and located west of the Norwegian Channel at approximately 58° N. *Elphidium excavatum* (32 %) is the dominating species. Other frequent species were *B. marginata* (26 %), *C. laevigata* (15 %) and *T. angulosa* (10 %). There were few signs of worn foraminifera tests and few living (stained) specimens were found (Table 5). No living (stained) specimens of *E. excavatum* were found. The agglutinated fauna is almost absent (30 specimens per 100 g sediment, Fig. 4; Table 3) in the *Elphidium excavatum* biofacies and the number of calcareous specimens is low (2 000 specimens per 100 g sediment) compared with the other stations (Fig. 4, Table 4).

Table 4. The percentage distribution of 25 calcareous benthic species with frequencies higher than 1 % and occurring in at least two samples.

Species/Stations	1	2	3	4	5	6	8	9	11	12	13
Astrononion gallowayi	-	-	-	-	-	-	-	-	1	-	1
Bolivina skagerrakensis	3	1	-	-	-	-	-	-	14	5	1
Bulimina marginata	7	5	4	24	41	37	38	26	5	18	2
Cassidulina laevigata	33	12	-	2	7	16	10	15	29	42	24
C. obtusa	-	1	2	0.3	2	-	1	-	0.4	-	3
Cibicides bertheloti	-	0.3	-	-	-	-	-	-	3	4	1
C. lobatulus	1	37	65	37	0.3	-	1	1	1	2	8
C. pseudoungerinaus	0.3	2	-	1	-	0.3	-	-	-	3	1
C. refulgens	1	-	-	-	-	-	-	-	6	4	1
Cibicides sp. 1	0.3	0.3	-	-	-	0.3	-	-	-	2	2
Elphidium excavatum	-	2	9	2	1	2	10	32	1	-	-
Epistominella spp.	-	1	-	-	1	-	0.3	-	0.4	1	1
Fissurina spp.	-	-	1	-	1	1	0.3	1	-	3	1
Hanzawaia concentrica	-	-	-	1	-	-	-	-	0.4	1	1
Haynesina sp.	-	-	1	1	-	-	-	-	-	-	-
Hyalinea balthica	3	2	2	8	22	24	11	6	1	3	3
Melonis barleeanus	3	1	-	1	0.3	2	1	-	10	7	11
Oolina spp.	0.3	-	1	0.3	0.3	-	-	-	-	1	1
Pullenia bulloides	1	1	-	-	-	-	1	-	3	2	-
P. subcarinata	0.3	-	-	-	-	-	-	-	3	3	-
Sphaeroidina bulloides	1	1	-	-	-	-	-	-	-	-	-
Stainforthia fusiformis	-	-	7	2	8	-	14	5	-	-	-
Trifarina angulosa	4	3	-	8	8	12	10	10	1	6	23
T. fluens	-	1	-	1	2	-	-	0.3	1	-	-
Uvigerina mediterranea	37	24	-	2	3	3	1	1	10	7	10
Indeterminata	-	-	-	4	1	-	1	-	0.4	1	2
No. of specimens counted per sample	338	297	277	302	307	391	335	318	267	283	348
No. of specimens per 100 g sediment (x 100)	519	670	275	22	690	1000	130	17	188	194	985

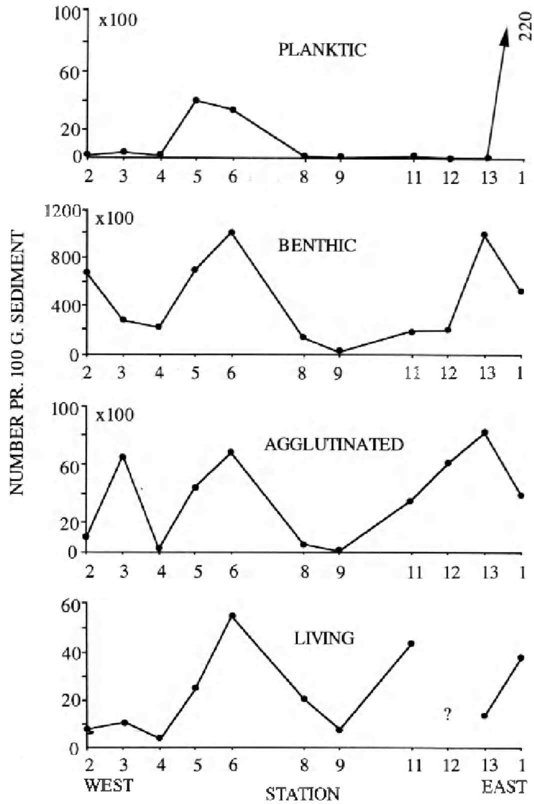

Fig. 4: The calculated number of planktonic, benthic, agglutinated and living (stained) specimens per 100 g dry sediment. The questionmark (?) at Stn 12 indicates that number of living (stained) specimens was not investigated at the station because the sample was not stained.

The *Cassidulina laevigata* biofacies (Stns 11, 12, 13, and 1): The *Cassidulina laevigata* biofacies is located in the Norwegian Channel. *Cassidulina laevigata* (24-42 %) is the dominating species at all stns except 1 which is dominated by *U. mediterranea* (37 %) (Fig. 2). Other common species are *Bolivina skagerrakensis* (1-14 %), *U. mediterranea* (7-10 %), *B. marginata* (2-18 %) and *M. barleeanus* (3-11 %). Stn 13 differs from the stations in the Norwegian Channel in its high content of *T. angulosa* (23 %). The agglutinated fauna is dominated by *Verneuilina media* (9-33 %) and *Haplophragmoides bradyi* (5-22 %) with *Glomospira* spp. (3-8 %) and *Saccammina spherica* (5-12 %) as frequent species, however, *S. spherica* was not found at Stn 13. The agglutinated fauna at Stn 13 contrasts with samples in the Norwegian Channel with its high content of *Textularia* spp. (68 %) (Fig. 3).

LIVING (STAINED) FORAMINIFERA

Very few living (stained) individuals were recovered in the samples (max. 60 per 100 g sediment) compared with other studies from the North Sea area. Conradsen (1993) found an average of ca 400 living (stained) per 100 g sediment in Kattegat using the fraction between 0,1 and 1,0 mm. Murray (1985) calculated a standing crop of 3500 per 30 cm^2 using the > 63 µm fraction in the North Sea. This number is difficult to compare with the results presented here since the 125 µm - 1,0 mm fraction has been used. In this study standing crop calculations on the 125 µm - 1,0 mm fraction yielded values between 315 and 15 per 30 cm^2.

There are several possible explanations for the low number of living (stained) foraminifera. The sampling method (boxcore) and the loss of core top water does not provide a perfect sample of the water/sediment transition. Also, the reproduction of foraminifera may vary seasonally and thereby less living foraminifera would be found at certain periods through the year. These samples were collected in April. Also, more recent studies show that living (stained) foraminifera can be found down to several centimetres in the sediment (e. g. Corliss & Emerson 1990; Alve & Bernhard 1995) implying that some living specimens would be lost when sampling only the top few centimetres.

As the number of living (stained) foraminifera is low there is considerable uncertainty in describing areas with post mortem changes regarding reworking of tests of Holocene age. However, the overall pattern and biofacies in the dead foraminifera are reflected in the living (stained) fraction, with the exception of the *Elphidium excavatum* biofacies (Table 5).

PLANKTONIC FORAMINIFERA

The number of planktonic specimens per 100 g sediment is shown in Fig. 4. The planktonic fauna is dominated by *Neogloboquadrina pachyderma* (dextral) (35-84 %). Additional species are *Globigerina bulloides* (10-43 %), *G. quinqueloba* (1-17 %), *Globigerinata glutinata* (1-3 %), *G. uvula* (1-19 %), *Globorotalia inflata* (0-2 %) and *Neogloboquadrina pachyderma* (sinistral) (1-16 %).

The highest numbers of planktonic foraminifera are located in the northern part of Norwegian Channel and central part of Fladen Ground, which are influenced by Atlantic water. Although the Atlantic water continues its flow southwards in the Norwegian Channel (Fig. 1), the number of planktonic specimens decreases. The low number at Stn 13 is explained by its position close to the Norwegian coast which is influenced by low salinity water from the Norwegian coastal water (abbreviation NCW in Fig. 1). The low number at Stns 11 and 12 may reflect the discontinuity of Atlantic water in the southern part of the Norwegian Channel (FURNES & al. 1986) where the stations are located.

DISCUSSION AND CONCLUSIONS

In this study four biofacies were defined. Their relation to the hydrography and sediment distribution strongly reflects some of the Recent processes in the North Sea but also earlier events (e.g. changes in sea-level and climate) are of major relevance for our understanding of Recent processes.

The biofacies found here represent both infaunal and epifaunal species according to MURRAY (1991). A general trend found in this study is that areas with coarse sediment and/or strong currents show a dominantly epifaunal assemblage (*Cibicides lobatulus* biofacies) while areas of fine grained sedimentation show mainly an infaunal assemblage (*Bulimina marginata* biofacies and *Cassidulina laevigata* biofacies). In addition to substrate, this trend can also be related to variation in percent organic carbon which is an important factor in epifaunal and infaunal species distribution patterns (CORLISS & CHEN 1988).

The *Cibicides lobatulus* biofacies is found in Scottish coastal areas (Fig. 6) influenced by fairly strong current activity which keeps the water mixed throughout the year and prevents sedimentation of fine grained material. Both *C. lobatulus* and *Textularia* live attached to a hard surface substrate which means they can survive in areas with stronger currents and in sediments containing sand

Table 5. Number of living (stained) specimens counted.

Species/Station	2	3	4	5	6	8	9	11	13	1
Polymorphinidae	1	-	-	-	-	-	-	-	-	-
Textularia sp	1	-	-	1	-	-	-	-	2	-
T. sagittula	1	-	-	-	-	-	-	-	-	-
T. bocki	1	-	-	-	-	-	-	-	-	-
T. earlandi	1	-	-	-	-	-	-	-	-	-
Eggerella scabra	-	-	-	-	-	-	-	-	-	-
Nonionella grateloupii	-	-	-	-	-	-	-	-	-	-
Cibicides lobatulus	-	2	-	-	-	-	-	-	-	-
Bolivina sp.	-	1	-	-	-	-	-	-	-	-
Verneuilina media	1	-	1	1	1	2	1	-	-	-
Bulimina marginata	1	1	-	9	9	2	-	5	1	-
Trifarina angulosa	-	2	-	2	-	2	2	-	-	-
Nonionella turgida	-	3	-	1	1	12	-	-	-	-
Cibicides bertheloti	-	-	-	-	1	-	-	-	1	-
Cassidulina laevigata	-	-	-	3	-	-	-	-	-	-
Hyalinea balthica	-	-	-	2	1	-	-	-	-	-
Ammonia beccarii	-	-	-	2	-	-	-	-	-	-
Stainforthia fusiformis	-	-	-	-	1	-	-	-	-	-
Reophax sp.	-	-	-	-	2	-	-	-	-	-
Lagena mollis	-	-	-	-	1	-	-	-	-	-
Uvigerina mediterranea	-	-	-	-	2	-	-	-	-	3
Epistominella vitrea	-	-	-	-	-	-	-	2	-	-
Loxostomum porrectum	-	-	-	-	-	-	-	-	1	1
Melonis barleeanus	-	-	-	-	-	-	-	-	1	-
Pullenia bulloides	-	-	-	-	-	-	-	-	-	1
Globobulimina turgida	-	-	-	-	-	-	-	-	-	1
Pullenia subcarinata	-	-	-	-	-	-	-	-	-	1
Adercotryma glomeratum	-	-	-	-	-	-	-	-	-	1
No. of specimens counted per sample	7	12	1	21	19	18	3	7	6	8
No. of specimens per 100 g sediment	9	13	2	26	54	20	7	44	38	14
No. of specimens per 30cm	105	180	15	315	285	270	45	105	120	90

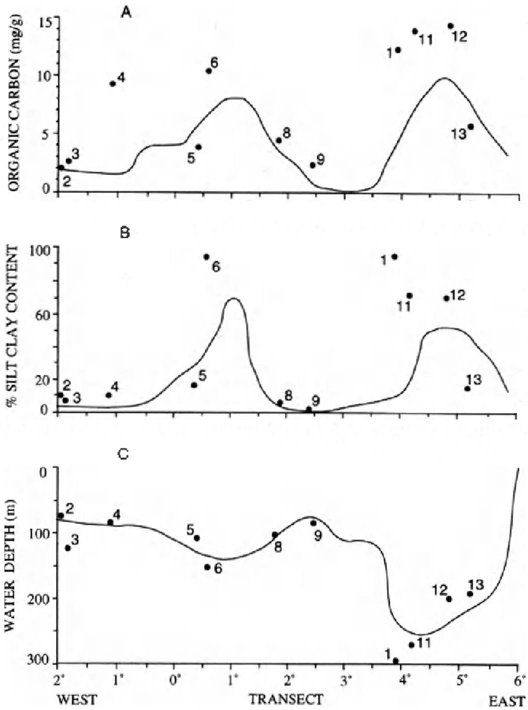

Fig. 5: Based on data from NORTH SEA TASK FORCE (1993a) the black solid curves were constructed to show a general distribution of organic carbon content, silt clay content and water depth along the transect line (Fig. 1). The measurements performed at each station are represented by the black solid circles.

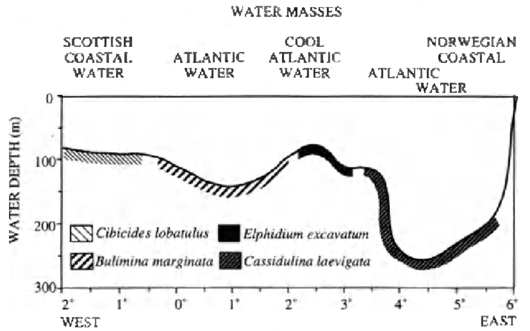

Fig 6: The four recognized biofacies based on calcareous species and major currents along the transect.

and gravel (VILKS & DEONARINE 1987; MURRAY 1991; CONRADSEN 1993). The dominance of *C. lobatulus* and *Textularia* spp. in coastal areas with strong current activity, and thereby a coarse grained substrate, are in agreement with previous work. Stn 4 is not influenced by Scottish coastal water but the fauna resembles that in Stns 2 and 3. The grain size distributions are quite similar to Stns 2 and 3 (Fig. 5) and the area is influenced by tidal currents. These are however, weaker (30-40 cm s^{-1}) than tidal currents located west of Scotland and England (ca 60 cm s^{-1}) (NORTH SEA TASK FORCE 1993c). Stn 4 is located under a less turbulent regime which may explain the minor differences in the fauna.

The *Bulimina marginata* biofacies is located on Fladen Ground where AW (w) and the DC prevail (Fig. 1). The *Bulimina marginata* biofacies seems to be connected with the seasonally changing watermasses on the Fladen Ground with temperature around 8° C (temperature range for DC and AW (w) is 7.7-9.0° C) and normal salinity (salinity range is 34.9-35.3 ‰). The difference in temperature and salinity between the two watermasses appears insignificant enough to have any effect on the foraminiferal distribution. The development of a thermocline in the Fladen Ground area may affect the bottom environment due to the trapped CAW water during the summer. The stagnant water lowers the oxygen level (NORTH SEA TASK FORCE 1993b) allowing species which tolerate lower oxygen concentrations to prevail. *B. marginata* has been found in areas of depleted oxygen (QVALE & VAN WEERING 1985). However, measurements of oxygen in the sediments will be necessary to confirm this.

B. marginata has also been associated with fine grained sediments and high organic carbon content in the sediments (MURRAY 1991; CONRADSEN 1993). The area is, in general, subject to fine grained sedimentation but no obvious relationship between the abundance of *B. marginata* and the fine grained substrate and/or high organic content was found. However, as mentioned before *B. marginata* is an infauna and is likely to be related to organic carbon content and oxygen content (CORLISS & CHEN 1988; ALVE & BERNHARD 1995).

The agglutinated fauna is dominated by *V. media* in the Fladen Ground area. This indicates that *V. media* prefer a fine grained substrate and normal salinity. The same was also observed by ALVE & NAGY (1986) for *V. media* in the Oslofjord area. The agglutinated fauna at Stn 5 differs from that occurring at other stations in the *Bulimina marginata* biofacies (Fig. 3). The reason for this is unknown.

The other area of fine grained sedimentation is the Norwegian Channel which is occupied by the *Cassidulina laevigata* biofacies. The *Cassidulina laevigata* biofacies is associated with the inflow of Atlantic water in the Norwegian Channel (Fig. 6). Faunal differences between stns may be explained by the variation in the flow of Atlantic water in the Norwegian Channel (FURNES & al. 1986). Stn 1 has more specimens of *U. mediterranea* reflecting more stable conditions, that is, a more stable and continuous inflow of Atlantic water in the northern central part of the Norwegian Channel. This relationship is also reflected in the high number of planktonic specimens at Stn 1 compared with the other Norwegian Channel stations (Fig. 4). Stn 13, located close to the Norwegian coast has a different faunal composition with higher content of *T. angulosa* and *Textularia* spp. The station is located within the outflow of Norwegian Channel water which varies in temperature and salinity and has a higher current speed than the Atlantic water flowing into the Norwegian Channel (NORTH SEA TASK FORCE 1993d). *T. angulosa* is associated with coarser grained sediments and strong bottom currents (MACKENSEN & al. 1985). The high abundances of *T. angolusa* and *Textularia* spp. reflect the change in hydrography and substrate across the Norwegian Channel. Whether it is the hydrographic or substrate change or other factors that cause the faunal differences is not possible to establish in this study; it may be a combination of both.

The agglutinated fauna in the *Cassidulina laevigata* biofacies is, in general, dominated by *V. media*, *H. bradyi* and *Glomospira* spp. *H. bradyi* and *Glomospira* spp. seem to be confined to the Norwegian Channel (Fig. 3) where the organic carbon content is highest (Fig. 5). SEN GUPTA & MACHAIN-CASTILLO (1993) found *H. bradyi* and *Glomospira charoides* adapted to environments with low oxygen content. The relationship between organic carbon and low oxygen content in the sediment is beyond the scope of this paper but *H. bradyi* and *Glomospira* spp. seems adapted to environments with high organic carbon and/or low oxygen in the sediment.

The two areas (Fladen Ground and central Norwegian Channel) influenced by Atlantic water are also the areas with the greatest abundance of planktonic foraminifera.

E. excavatum has been found in several studies of surface sediment samples in the North Sea and Kattegat area (SEJRUP & al. 1981; QVALE & VAN WEERING 1985; MURRAY 1992; CONRADSEN 1993). In these previous studies it is found to be either living (stained) in shallow water or reworked from older deposits. Investigation of Recent samples also suggests that post mortem transport of *E. excavatum* occurs frequently in the North Sea (MURRAY 1992). In the present study, tests of *E. excavatum* are considered reworked from older deposits. Late glacial (13 000-12 000 years BP) and older deposits with occurrences of *E. excavatum* are found beneath the thin Holocene sediment layer across the entire northern North Sea (JANSEN & al. 1979). A ^{14}C-date could be used to test if the *E. excavatum* found in this study is of Late glacial age. Other species found at the station are regarded as tests of Holocene age. It is difficult to state whether the tests are, in fact, reworked or if they live in situ, due to the low number of living (stained) specimens.

Reworking of Holocene tests is difficult to detect because of small changes of the fauna through this period. Even in areas where sedimentation does occur the sedimentation rate is low and therefore a relatively large number of dead tests has accumulated compared to living (stained) specimens (Fig. 4). However, except for the *E. excavatum* biofacies, the living (stained) species reflect the same faunal pattern as the dead species, implying that reworking is insignificant.

The distribution pattern of agglutinated species is comparable to the calcareous biofacies suggesting that the same environmental factors affect the agglutinated fauna.

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