# Distribution of benthic foraminifers in surface sediments along the Norwegian continental shelf between 62° and 72°N

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Seventy surface sediment samples from the Norwegian continental shelf north of 62°N have been studied to map the distribution of benthic foraminifers. Most of the samples contain a large portion of poorly preserved benthic foraminifers, and only samples with a large proportion of well preserved shells have been taken into account. The benthic foraminiferal assemblages are characterized by normal marine, heavy shelled species. *Trifarina angulosa* and *Cibicides* spp. account for more than 50% of the assemblage in most samples. The maximum occurrence of *T. angulosa* is in water depths between 250 m and 375 m, while the *Cibicides* maximum is found to be somewhat shallower. *Uvigerina peregrina* is an important constituent of the assemblages in the southern part of the study area.

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Previous studies have shown that benthic foraminifer distribution is controlled by the physical and chemical properties of the watermasses (e.g. salinity, temperature, oxygen, supply of nutrients and the substrate), properties that may vary independently of water depth (Streeter 1973, Schnitker 1974, 1979, 1980, Lohmann 1978, Corliss 1979, Streeter & Shackleton 1979, Miller & Lohmann 1982 and many others).

Up to now no complete survey of the distribution of benthic foraminifer shells along the Norwegian continental margin has been carried out, although smaller areas have been studied in great detail (e.g. Kihle 1971, Vorren et al. 1978, Nagy & Ofstad 1980, Sejrup et al. 1981, Hald & Vorren 1984, Mackensen et al. 1985).

An extensive study of foraminifers on the deeper parts of the margin and in the Norwegian Sea has been published by Mackensen (1985). This study completes the mapping of recent benthic foraminifer distribution along the Norwegian continental margin. The southern part has been published by Qvale & van Weering (1985).

## Environmental setting

### *Physiography and sediments*

The Norwegian continental shelf north of 62°N is characterized by variations in depth and bears the features of a formerly glaciated area. The surface is irregular with troughlike depressions, which often represent continuations of fjords, cutting across and along the shelf (Fig. 1). These troughs have been formed by glacial erosion of the underlying rocks. Off Møre, water depths are mostly less than 200 m, while further to the north, off Trøndelag, Nordland and Troms, depths are between 200 and 500 m, but with local shallower banks. Around the Lofoten Islands water depths are usually less than 200 m.

Most of the shelf, except for smaller areas close to the coast where the bedrock crops out, is covered by Quaternary sediments of varying thickness (Holtedahl & Bjerkli 1975, 1982, Vorren et al. 1978, Elverhøi 1979, Rokoengen et al. 1979), which overlie Precambrian-Silurian crystalline rocks and sediments of Mesozoic and Tertiary age.

The surface sediments on the Norwegian continental shelf between 62°N and 72°N fall into four categories (Holtedahl & Bjerkli 1975): 1) till, mainly composed of material derived from the adjacent mainland, 2) till, mainly composed of material derived from the Mesozoic and Tertiary bedrock on the continental shelf, 3) lag deposits from 1 and 2, and 4) secondarily transported sand and finer material winnowed from 1 and 2. The lag deposits occur mainly in the shallow areas, while the transported material is deposited in the

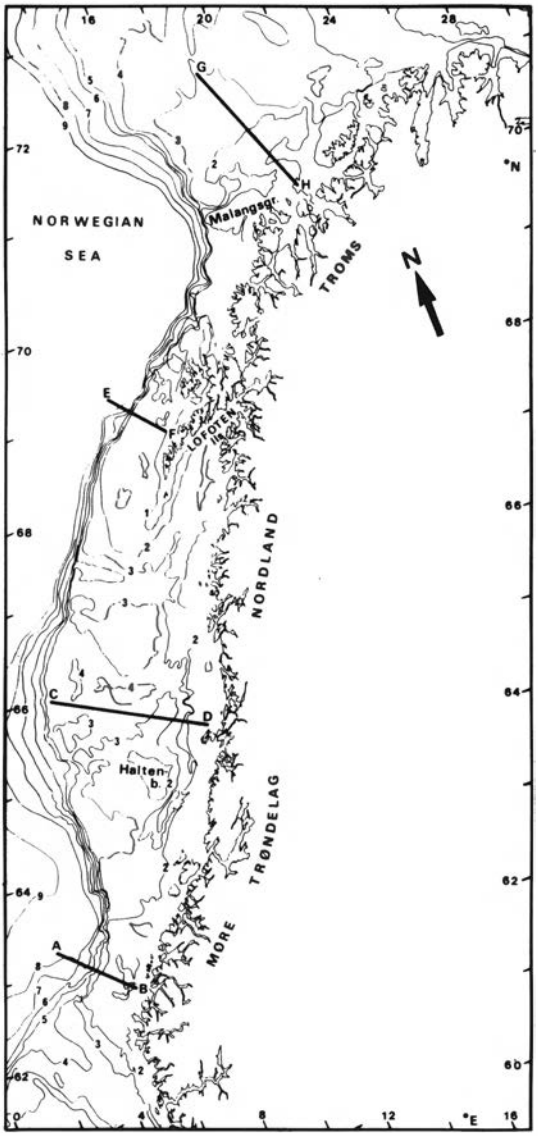


*Fig. 1.* Bathymetric map of the study area. Depth contours are in 100 m. The solid lines A-B, C-D, E-F and G-H indicate the positions of the S- and T-profiles shown in Fig. 3.

depressions and at greater depths along the slope. The winnowing of the shallow areas started when the Atlantic water encroached upon the Norwegian west coast close to 10,000 years B.P. (Sejrup et al. 1980, Jansen et al. 1983, Sejrup et al. 1984a). During the Holocene there has been very little supply of material from the mainland (Holtedahl & Bjerkli 1975, Elvsborg 1979) due to the prevailing current and transport direction, which is along the coast, and because the major part of the river transported sediments are trapped in the fjords. Thus, recent sedimentation of the shelf takes place only locally, in the depressions and deeper parts of the study area. In areas where deposition takes place, the sedimentation rates are low. On the continental shelf off Troms, Hald & Vorren (1984) found average thicknesses of the Holocene deposits of 10–30 cm (and often less) on the banks, and about 3 m in the troughs. A surface sediment lithofacies map covering the entire Norwegian continental shelf was published by Holtedahl & Bjerkli (1975).

## *Hydrography*

Two distinct water masses dominate the study area: Atlantic water of the Norwegian Current (NC) and coastal water of the Norwegian Coastal Current (NCC). Both currents flow northwards roughly parallel to the Norwegian coast (Fig. 2).

The NC water is characterized by salinities of less than 35‰ and greater, and is part of the North Atlantic Drift system.

The NCC is characterized by salinities of < 35‰, and overlies the NC water as a westward thinning wedge, reaching the bottom only very near to the coastline. Its width varies due to season and weather conditions, but on average it stretches 100 km from the coast (Leinebø 1973). The NCC originates in the Skagerrak from Baltic water and North Sea water brought into the Skagerrak by the Jutland Current, and is mixed with fresh water runoff from the Norwegian mainland (Tomczak 1968, Sætre 1973). The salinity of the NCC water increases towards the north (Fig. 3), due to mixing with Atlantic water (Sætre 1973).

Bottom current velocities are usually high, as is also reflected in the surface sediment distribution (see above). At Haltenbanken, 42 cm $s^{-1}$ has been measured 5 m above the seabed (Eide 1978). At Malangsgrunnen, current velocities 5 m above the bottom were measured at 64 cm $s^{-1}$ (Eide 1978). Measurements carried out at 300 m water depth off Troms in August-September 1978 revealed current velocities around 30 cm $s^{-1}$ (Lie 1978). The current directions are influenced by wind and tides, but the average transport and current directions are northward along the coast (Sætre et al. 1979). Due to the irregular topography, eddies are formed, especially in the shallow bank areas (Fig. 2).

The temperatures and salinities of the bottom

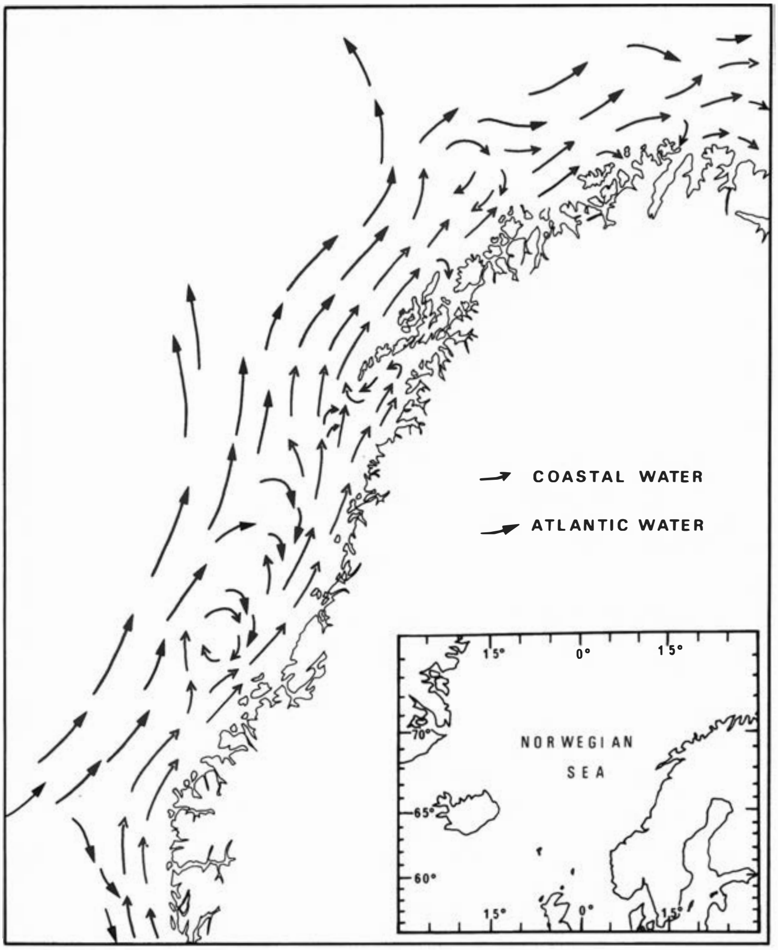


*Fig. 2.* Main currents and watermasses along the western Norwegian continental shelf (after Sætre & Ljøen 1972). Inset shows the location of the sections shown in this figure.

water are rather constant throughout the study area (Fig. 3). The bottom water temperatures are around 6–7°C, except in the northernmost part, where they are slightly lower (5–6°C) (Anonymous 1976). Surface temperatures vary due to seasonal changes. Bottom water salinities deviate little from 35‰ along the entire shelf (Fig. 3). South of Træna (66°N) surface salinities are around 32–33‰, but increase towards the north due to gradual mixing with Atlantic water (Sætre 1973).

The coastal water is rather poor in nutrients, but a continuous inflow of the nutrient rich Atlantic water into the productive layers of the Norwegian Coastal Current initiate extensive phytoplankton blooms, especially in the bank areas (Føyn & Rey 1981).

To summarize, the study area can be characterized as a normal marine shelf environment with small variations in temperature and salinity of the bottom waters with a strong current regime.

## Methods

The 70 samples studied were selected to give as good coverage as possible of the shelf area north of 62°N (Fig. 4). Samples were available from most of the shelf, except between latitude 66 and 67°N, and east of 21°E longitude. The water depths range from 100 to 735 m, but most samples were taken between 200 and 400 m. Most of the material was retrieved by a grab or box corer, from which the surface layer (upper 3-5 cm) was removed. Six of the samples represent the top (upper 3 cm) of gravity cores. Most of the samples were not dyed, only a small number (12) had been treated with rose Bengal.

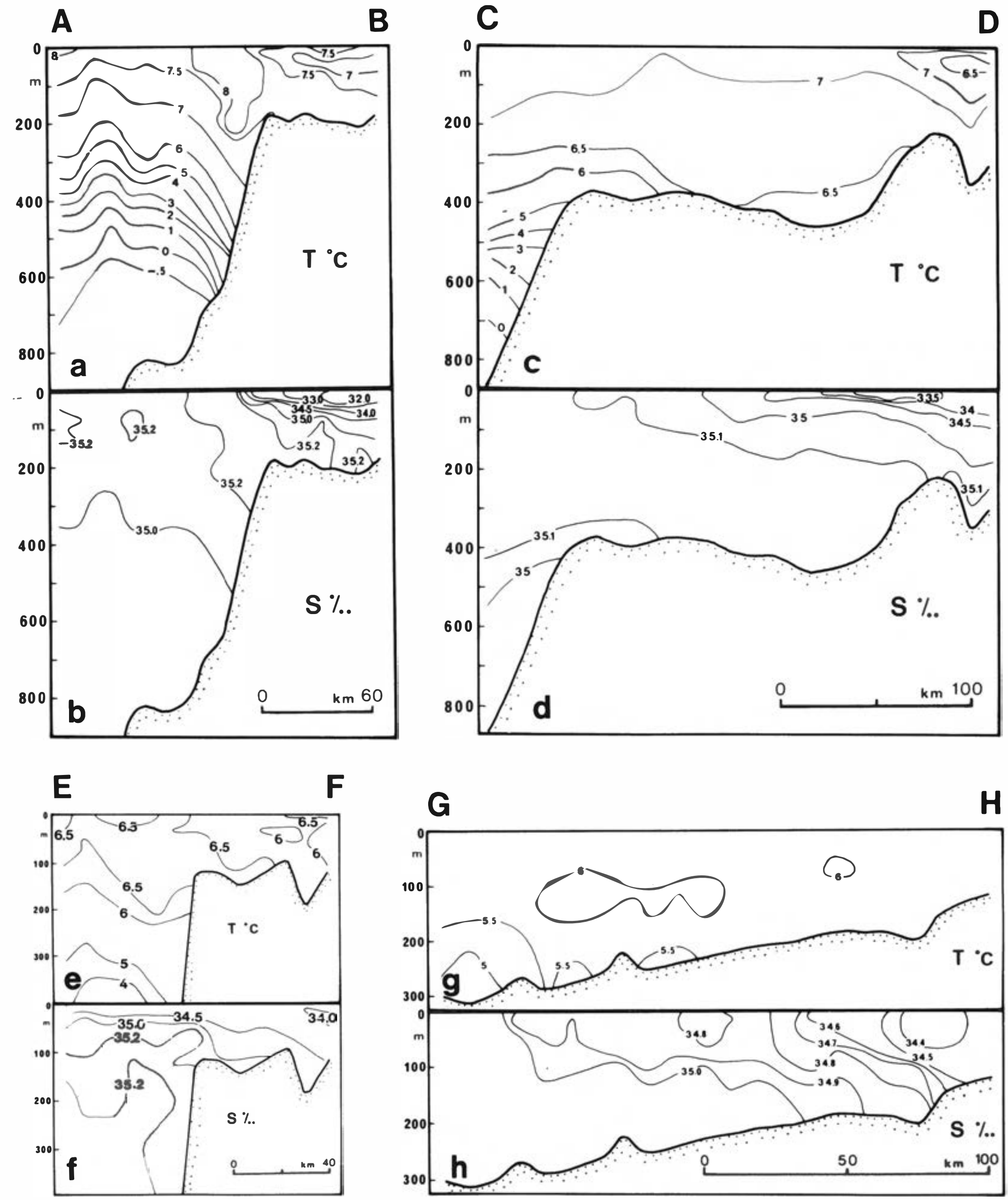


*Fig. 3.* Four selected sections across the Norwegian continental shelf showing average temperatures (in °C) (a, c, e, g) and salinities (‰) (b, d, f, h). For locations of the sections, see Fig. 1. Data from Anonymous (1976).

The samples were dried, weighed and washed through sieves with 1 mm, 0.150 and 0.063 mm mesh sizes.

The foraminifers were studied in the size fraction 0.15–1.00 mm so that the results were directly comparable to other studies of foraminifers in the Norwegian Sea (e.g. Kellogg 1973, 1976).

The samples were examined and the foraminifers counted, except in samples which contained a significant amount of clearly reworked material

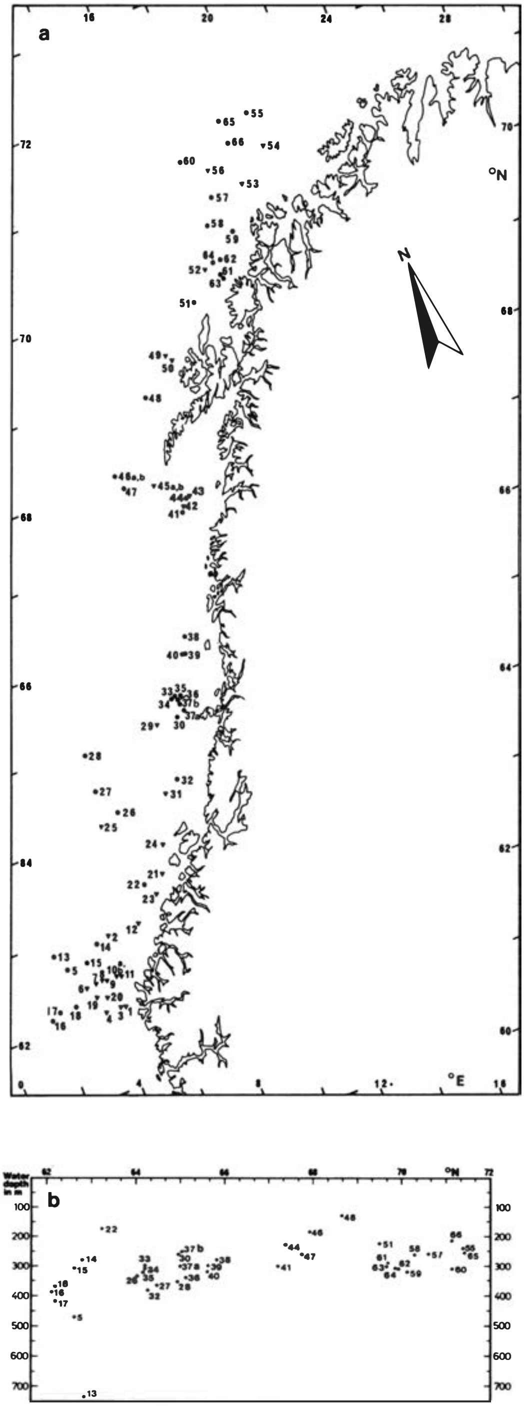


*Fig. 4.* a) Map showing the sample locations. Samples indicated with dots have been counted, while in those indicated with triangles the composition of the assemblage has been estimated visually. b) Samples (indicated by dots in Fig. 4a) plotted against water depth and latitude.

(see below). At least 150 (in samples strongly dominated by one or two species), and usually more than 300 specimens of benthic foraminifers were counted in each sample (Table 1). Only the benthic foraminifers are dealt with in this paper; the distribution of planktic foraminifers have been described and discussed in earlier papers (Qvale & Thiede 1980, Qvale 1981). The relative frequencies of the most abundant species of benthic foraminifers have been plotted on maps (Figs. 5–7). For taxonomy of the species discussed, see Table 2.

## Distribution of benthic foraminifers

Most of the samples contain a considerable amount of sand-sized material and have a variable clay content (see Table 3). A number of the samples, especially from the southern part of the study area, contain pebbles and larger fragments. The content of foraminifers is also variable and the preservation of the shells is poor in many samples. The foraminiferal shells and other calcareous biogenic particles, such as ostracods, echinoderm skeletal elements and bivalves, are often strongly corroded and the pores and cavities filled with sediment or minerals (especially glauconitic minerals). The proportion of fragmented shells is high, and the fragments are often rounded. This poorly preserved material probably represents older, transported or reworked material. The occurrence of Arctic (or cold water) benthic foraminifers in certain samples may indicate reworking of the underlying glacial deposits. Most of the poorly preserved shells, however, may have accumulated more or less in situ, but due to the overall low sedimentation rates they have been exposed on the sea-bed for a long time. The high number of benthic foraminifers in the sediment probably reflects a small supply of terrigenous material rather than a large production of foraminifers. Samples which contain a large portion of only poorly preserved foraminiferal shells have not been counted, but a visual estimate of the assemblages was made. The distribution maps thus present the counts from only 39 (indicated by dots in Fig. 4) of the samples studied. Most of the uncounted samples (indicated by triangles in Fig. 4) are located on the shelf between 62° and 64°N.

It is also doubtful if the assemblages found in the counted samples reflect the living fauna. As

*Table 1.* Foraminiferal counts of the 39 samples. Minor species have been included in textulariids, miliolids and rotaliids, respec-
(only small portion of fragments/corroded shells), A: moderate, and P: poor (considerable portion of fragments/corroded shells)

| | 5 | 13 | 14 | 15 | 16 | 17 | 18 | 22 | 26 | 27 | 28 | 30 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Astrononion gallowayi* | | 3 | | | 1 | 1 | 1 | 2 | | | | | 2 | 2 | | | |
| *Bolivina spp.* | 2 | | | | 1 | 1 | 9 | | | | | | 1 | | | 1 | |
| *Bucella spp.* | | | 1 | | 2 | | 1 | | | | | | | | | | |
| *B. frigida* | | | | | | | | | | | | | | 9 | | | |
| *Bulimina marginata* | | | 1 | 3 | 9 | 10 | 36 | 3 | 1 | 1 | | 5 | 10 | 8 | 5 | 1 | 7 |
| *Cassidulina laevigata* | 16 | 100 | 48 | 10 | 87 | 70 | 65 | 28 | 1 | 5 | 11 | 2 | 27 | 98 | 28 | 9 | 32 |
| *C. obtusa* | 23 | | | | 3 | | | 23 | | | 1 | 4 | 4 | 4 | | | 19 |
| *C. reniforme* | 29 | 52 | 2 | | 1 | | | 8 | | | 1 | | 13 | 1 | 7 | 10 | |
| *Cibicides spp.* | 25 | 2 | 91 | 123 | 16 | 11 | 3 | 32 | 6 | 6 | 6 | 10 | 34 | 14 | 28 | 34 | 24 |
| *C. boueana* | 7 | | 7 | 3 | | 6 | 5 | 15 | 1 | 10 | 5 | 7 | 7 | 3 | 13 | 3 | 13 |
| *C. lobatulus* | 4 | 1 | 21 | 64 | 2 | 3 | | 49 | | | 2 | | 6 | 11 | 13 | 10 | 42 |
| *C. pseudoungerianus* | 15 | | 4 | 7 | 2 | 3 | 3 | 49 | | 1 | | | 16 | 12 | 4 | 2 | 15 |
| *C. refulgens* | 6 | | 19 | 51 | 1 | 3 | 3 | 14 | | | 1 | 3 | 3 | 5 | 7 | 5 | 14 |
| *Discanomalina pseudopunctata* | 1 | | 1 | 76 | | | | 9 | | | | 1 | 2 | | | 1 | |
| *Elphidium spp.* | 1 | | | 2 | | | | 3 | | | | | | 6 | 2 | | |
| *E. excavatum* | 1 | | 12 | 2 | 15 | 11 | 1 | 26 | | | 2 | | 6 | 18 | 1 | | |
| *Fissurina spp.* | 6 | 2 | 3 | 2 | | 1 | 4 | | | 1 | | | 3 | | | | 1 |
| *Hyalinea balthica* | | | 3 | 1 | 14 | 4 | 20 | 2 | 14 | 24 | 11 | 2 | 30 | 4 | 22 | 1 | 22 |
| *Islandiella spp.* | | 5 | | 1 | 2 | | | 9 | | 1 | | | 6 | 5 | | | 1 |
| *Lagena spp.* | | | | | | 2 | 1 | 1 | | | | | | | 1 | | |
| *Melonis barleeanum* | 6 | 117 | 7 | 2 | 6 | 10 | 27 | 3 | 6 | 3 | 3 | 8 | 25 | 8 | 16 | 5 | 11 |
| *Nonion labradoricum* | | | | | 3 | 2 | | 6 | | 4 | 1 | 1 | 31 | 18 | 3 | | |
| *Oolina spp.* | 1 | | 2 | 1 | | | 1 | 2 | | | | | 1 | | 2 | 1 | |
| *Pullenia bulloides* | 3 | 28 | 2 | 2 | 10 | 8 | 11 | | 1 | 1 | 3 | 1 | 4 | 16 | 2 | 1 | 2 |
| *P. subcarinata* | 6 | 1 | 2 | | 2 | | 4 | | | 3 | | 2 | 2 | 7 | 1 | 1 | 3 |
| *Rosalina spp.* | 6 | | | | 1 | | | 3 | | | | | | | | | |
| *Stainforthia loeblichi* | | | | | | | | | | | | | 3 | 1 | | | |
| *Textularia spp.* | | | | 8 | | | | | | | | | | | | | 2 |
| *T. sagittula* | 1 | | | | | | | 87 | | | | 1 | 26 | | | | |
| *Trifarina angulosa* | 121 | 3 | 82 | 20 | 131 | 100 | 31 | 61 | 29 | 29 | 44 | 91 | 138 | 86 | 135 | 31 | 135 |
| *T. fluens* | 7 | | 5 | 3 | 3 | 4 | | 11 | 2 | | 1 | 2 | 7 | 5 | | | 5 |
| *Uvigerina peregrina* | 7 | | 13 | 8 | 45 | 103 | 104 | 5 | 30 | 60 | 46 | 18 | 52 | 81 | 53 | 9 | 37 |
| Textulariids | 4 | | 11 | 11 | 1 | 6 | 2 | 1 | 5 | 4 | | 8 | 3 | 5 | 4 | 3 | 6 |
| Miliolids | | 2 | | 4 | | | 3 | 1 | | | | | 1 | 1 | | | |
| Rotaliids | 7 | | 15 | 11 | 11 | 13 | 5 | 17 | 3 | 8 | 3 | 4 | 11 | 5 | 8 | 2 | 6 |
| Total number of specimens | 301 | 316 | 352 | 417 | 369 | 372 | 340 | 474 | 99 | 161 | 141 | 170 | 474 | 433 | 355 | 130 | 397 |
| Diversity | 17 | 5 | 24 | 22 | 17 | 21 | 14 | 27 | 12 | 17 | 11 | 14 | 22 | 20 | 16 | 15 | 14 |
| Number of BF per g sediment | 903 | 321 | 340 | 673 | 1747 | 2184 | 513 | - | - | 1162 | 2214 | - | 1138 | 100 | 1643 | 2059 | 2960 |
| % BF of total foram. assemb. | 61.3 | 25.5 | 32.0 | 76.8 | 27.1 | 37.2 | 57.1 | 75.0 | 55.0 | 52.8 | 54.7 | 66.4 | 76.9 | 79.7 | 81.2 | 80.8 | 76.1 |
| Preservation | G | G | P | P | G | G | G | A | P | P | P | P | P | P | P | A | P |

mentioned earlier, a number of the samples (nos. 21–32) had been treated with rose Bengal, but only one living specimen was observed in these samples (*Ammolagena clavata,* attached to rock fragment). The absence of living specimens does not necessarily imply that few benthic foraminifers are living in this area. Due to the strong currents many of the benthic foraminifers are attached to e.g. plants and rock fragments, and living specimens may therefore be absent in the size fraction studied. It may also be a result of the dying method; if the dying agent is added to the bulk sediment sample it may become too diluted to work sufficiently. The grab often disturbs the sediment surface which causes the samples to contain older subsurface material.

In 34 of the samples the benthic foraminifers constitute more than 50% of the total assemblage (Table 1). Planktic foraminifers are most important in the samples from the southernmost part of the study area. Diversities (calculated according to Walton 1964) are between 5 and 27 (Table 1), but in most samples the six to eight most abundant species constitute about 85% of the total assemblage. The important species are calcareous, normal marine, temperate forms, most of them with thick, heavy shells. Agglutinated species occur in low numbers, except in a few samples from the shelf off Møre. In one sample from this area *Textularia sagittula* constitutes 18% of the total benthic foraminiferal assemblage.

The dominant species throughout the area is *Trifarina angulosa.* Two frequency maxima occur, one south of 66°N and the other north of 68°N (Fig. 5a). Plotted against water depth and latitude it becomes apparent that the *T. angulosa* is most abundant in samples taken between 400 and 500 m water depth in the area south of 64°N, and between 300 and 400 m in samples from the area north of 64°N (Fig. 5b). The frequencies are low in samples from areas shallower than 250 m water depth; in the southernmost part of the study area tively. The diversities have been calculated according to Walton, 1964. The mode of preservation is indicated by G: well preserved

| 37a | 37b | 38 | 39 | 40 | 41 | 44 | 46a | 47 | 48 | 51 | 55 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 1 | | 12 | 1 | 1 | | 1 | 4 | 1 | 4 | 2 | 9 | | 4 | 9 | 5 | 1 | | |
| 1 | 1 | 2 | 1 | | | | | 7 | | 1 | | | 1 | | | | 2 | | 1 | | |
| | | | | | | | | | | | | | 1 | | | | | | | | |
| | | | | | | | 1 | | | | | | | | | | 9 | | 8 | | |
| 6 | 6 | 5 | 5 | 4 | 15 | 4 | 20 | 7 | | 1 | | | | | | 2 | 8 | 3 | 2 | | |
| 24 | 25 | 38 | 20 | 18 | 82 | 18 | 37 | 12 | 39 | 31 | 4 | 9 | 2 | 16 | 1 | 37 | 56 | 7 | 48 | 30 | 9 |
| 5 | 9 | 10 | 5 | 5 | 72 | | 16 | 1 | 12 | 16 | 11 | 5 | 9 | 5 | 1 | 22 | 8 | 6 | 16 | 39 | 37 |
| | | | | | 63 | | | 8 | | | | 9 | | 18 | 1 | | | 1 | 1 | | |
| 30 | 33 | 15 | 19 | 13 | 26 | 17 | 3 | 46 | 22 | 50 | 90 | 38 | 57 | 37 | 67 | 35 | 32 | 17 | 42 | 34 | 44 |
| 17 | 7 | 8 | 9 | 5 | | 8 | | | 4 | 3 | 6 | 1 | | | | 9 | 21 | 7 | 5 | | |
| 32 | 26 | 22 | 27 | 29 | 40 | 11 | 30 | | 96 | 26 | 71 | 5 | 19 | 11 | 15 | 26 | 26 | 17 | 11 | 39 | 21 |
| 9 | 13 | 11 | 8 | 10 | 12 | 5 | 10 | | 40 | 81 | 17 | 11 | 31 | 25 | 2 | | | 3 | | | 12 |
| 9 | 7 | 1 | 13 | 23 | 5 | | 24 | 1 | 25 | 6 | 1 | 2 | 9 | 11 | 18 | 121 | 26 | 18 | 80 | 126 | 119 |
| | | | 1 | | | | | | 39 | 9 | 13 | 1 | | 4 | 25 | 1 | | 3 | 1 | 2 | 6 |
| | | | | | | | 8 | 1 | 2 | 2 | | | 4 | 2 | | 8 | 8 | 9 | 6 | | 1 |
| 1 | 1 | 4 | 1 | | 50 | 6 | 1 | | 1 | 1 | 4 | | 60 | 1 | | | | | 1 | | |
| 2 | | 1 | | 1 | 1 | 1 | 2 | | 4 | 13 | 7 | 2 | 2 | 3 | | 5 | 1 | 10 | | 6 | 5 |
| 32 | 18 | 35 | 26 | 25 | 7 | 6 | 7 | 3 | 1 | | | | | | | | 23 | | 6 | | |
| 1 | | | 1 | | 22 | 1 | | | | | 1 | | 46 | | | 2 | | | | | |
| | | 1 | | | 2 | | 1 | | | | | | | | | | | | | | |
| 21 | 17 | 29 | 19 | 15 | 20 | 9 | 19 | 6 | 3 | 1 | 3 | 3 | 6 | 1 | | 1 | 50 | 10 | 26 | | 3 |
| | 2 | 7 | 3 | 2 | 48 | 3 | | | | | | | 14 | 4 | | 4 | 4 | 2 | 14 | | 3 |
| 1 | | 2 | 1 | | 5 | | 2 | | | | 1 | 2 | 2 | | | | 3 | 4 | | | |
| 5 | 2 | 8 | 3 | 2 | 7 | 2 | 6 | 2 | | | 3 | 4 | | | 3 | | 18 | 3 | 6 | 9 | 2 |
| 1 | 5 | 2 | 2 | 1 | 7 | 4 | 2 | 1 | | 2 | 2 | | | 10 | | | 6 | | | | |
| 1 | | | | | 2 | | | | | 5 | | 2 | 1 | | | 14 | | | | | |
| | | | | 1 | 22 | | | | | | | | 1 | | | | | | | | |
| | 2 | 1 | | 3 | 2 | | 1 | | 3 | 13 | | | | | | | | | | | |
| | | | | | | 4 | | | | | | 1 | | | | 10 | 1 | 3 | 3 | | 1 |
| 113 | 100 | 87 | 119 | 134 | 125 | 65 | 231 | 53 | 47 | 60 | 90 | 109 | 20 | 77 | 35 | 130 | 85 | 140 | 101 | 91 | 59 |
| 8 | 6 | 4 | 7 | 4 | 1 | 1 | 1 | 2 | 5 | 33 | 2 | 4 | 3 | 12 | 1 | 3 | | | | | |
| 55 | 79 | 57 | 85 | 84 | 33 | 12 | 7 | 4 | 1 | | 1 | | 1 | | | 1 | 21 | 7 | 2 | 14 | 4 |
| 6 | 10 | 6 | 8 | | 1 | 3 | 10 | 4 | | 3 | | 2 | | 4 | 8 | | 1 | | | 2 | 7 |
| | | | | | 2 | | | 2 | 2 | 7 | 1 | 1 | | 9 | 6 | 1 | 10 | | 3 | | |
| 1 | 3 | 5 | 3 | 7 | 12 | 3 | 7 | 11 | 8 | 9 | 3 | 8 | 10 | 9 | 8 | 1 | 2 | 17 | 48 | 17 | 22 |
| 382 | 374 | 363 | 389 | 386 | 696 | 184 | 447 | 171 | 355 | 377 | 336 | 223 | 316 | 268 | 181 | 451 | 431 | 292 | 432 | 409 | 357 |
| 14 | 16 | 20 | 17 | 14 | 20 | 17 | 22 | 20 | 15 | 22 | 14 | 17 | 18 | 17 | 14 | 13 | 18 | 18 | 13 | 10 | 19 |
| 1647 | 2625 | 2108 | 1892 | 1740 | 66 | 974 | 498 | 423 | 287 | 1016 | 549 | 2120 | 22 | 691 | 1532 | - | - | - | - | - | - |
| 84.4 | 88.4 | 79.3 | 87.2 | 77.2 | 82.7 | 87.6 | 84.8 | 91.4 | 84.9 | 76.8 | 54.2 | 53.1 | 90.0 | 83.2 | 67.5 | 66.4 | 71.2 | 44.7 | 82.4 | 62.4 | 70.3 |
| P | P | A | P | P | G | P | P | P | G | G | G | A | A | A | P | A | A | G | A | A | A |

*T. angulosa* occurs frequently between 375 and 500 m water depth. The state of preservation made identification of *Cibicides* spp. to species level difficult in many samples but *C. lobatulus* and *C. refulgens,* associated with *C. pseudoungerianus* and *C. boueana,* were found in all samples, though most numerous in the northernmost part of the study area (Fig. 6a). The frequencies

*Table 2.* Taxonomy (selected references) of the benthic foraminifers discussed.

*Ammolagena clavata* (Jones & Parker): Höglund, 1947, pl. 9, fig. 15.
*Cassidulina laevigata* d'Orbigny: Nørvang, 1958, pl. 9, figs. 27–31; Sejrup et al., 1981, pl. 1, Fig. 5.
*Cassidulina obtusa* Williamson: *Cassidulina crassa* d'Orbigny – Nørvang, 1958, pl. 8, figs. 20–23; *Cassidulina obtusa* Williamson – Sejrup & Guilbault, 1980, fig. 2, A-E.
*Cassidulina reniforme* Nørvang: *Cassidulina crassa* d'Orbigny – Feyling-Hanssen et al., 1971, pl. 7, figs. 18, 19; *Cassidulina reniforme* Nørvang – Sejrup & Guilbault, 1980, fig. 2, F-K.
*Cibicides boueana* (d'Orbigny): Kihle & Løfaldi, 1973.
*Cibicides lobatulus* (Walker & Jacob): Feyling-Hanssen et al., 1971, pl. 9, figs. 9–14.
*Cibicides pseudoungerianus* (Cushman): Barker, 1960, pl. 94, figs. 9a-c.
*Cibicides refulgens* Montfort Barker: 1960, pl. 92, figs. 7–9.
*Discanomalina semipunctata* (Bailey): Medioli & Scott, 1978, pls. 1–3.
*Elphidium excavatum* (Terquem): Murray, 1971, pl. 66, figs. 1–7.
*Hyalinea balthica* (Schröter): Feyling-Hanssen et al., 1971, pl. 9, figs. 7, 8.
*Melonis barleeanum* (Williamson): *Nonion barleeanum* – Feyling-Hanssen et al., 1971, pl. 9, figs. 15–18; *Melonis barleeanum* – Corliss, 1979, pl. 5, figs. 7–8.
*Pullenia bulloides* (d'Orbigny): Feyling-Hanssen et al., 1971, pl. 10, figs. 13,14.
*Trifarina angulosa* (Williamson): Murray, 1971, pl. 51.
*Textularia sagittula* Defrance: Murray, 1971, pl. 8.
*Uvigerina peregrina* Cushman: Feyling-Hanssen et al., 1971, pl. 7, figs. 9–11.

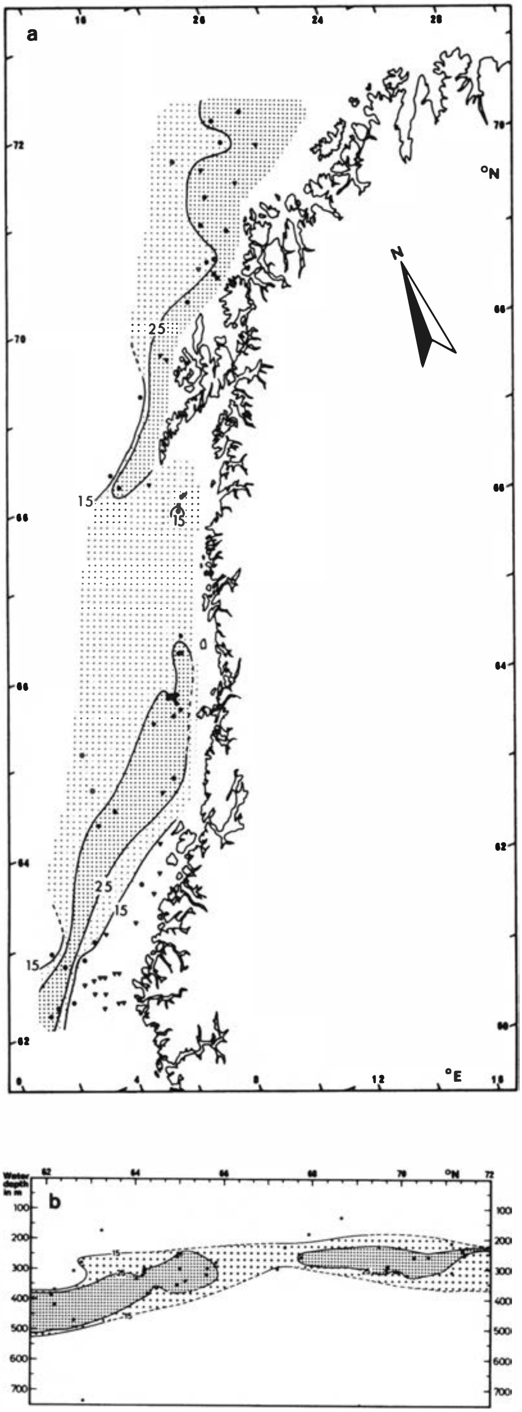


*Fig. 5.* Relative abundance (in % of the total benthic foraminiferal assemblage) of *Trifarina angulosa* in a) horizontal plot, and b) against water depth and latitude.

*Table 3.* List of samples, water depths, sediment type and the dominant species in each sample. The dominant species given constitute more than 50% of the total benthic foraminiferal assemblage. Those marked with an asterisk have only been visually estimated. Bul: *Bulimina marginata,* Cal: *Cassidulina laevigata,* Cib: *Cibicides* spp., Di: *Discanomalina semipunctata,* Hya: *Hyalina balthica,* Mel: *Melonis barleeanum,* Tex: *Textularia sagittula,* Tri: *Trifarina angulosa,* Uv: *Uvigerina peregrina,* PF: Planktic foraminifers, Cold: Arctic (cold water) species

| Station | Water depth (m) | Sediment | Dominant species |
|---|---|---|---|
| 1 | 143 | Gravel,pebbles | *Cib/Tri |
| 2 | 175 | Sand | *Cib/Di |
| 3 | 164 | Sandy/silty clay w/gravel | *Cib |
| 4 | 230 | Silty sand | *Uv |
| 5 | 471 | Sand | Tri/Cib |
| 6 | 315 | Silty sand w/pebbles | *Cib/Cal |
| 7 | 192 | Silty sand w/gravel | *Cib/Uv |
| 8 | 172 | Silty sand w/gravel | *Cib/Cal |
| 9 | 192 | Silty/sandy clay | *Uv/Bul/Cal |
| 10 a,b | 147 | Sand,shells | *Cib |
| 11 | 156 | Sand w/gravel & shells | *Di/Cib |
| 12 | 140 | Shell sand,gravel | *Di/Cib |
| 13 | 735 | Silty/sandy clay | Cal/Mel |
| 14 | 280 | Silty/sandy clay | Cib/Tri |
| 15 | 310 | Silty/sandy clay | Cib/Di |
| 16 | 388 | Silty/sandy clay | Tri/Cal |
| 17 | 420 | Silty/sandy clay | Uv/Tri/Cal |
| 18 | 370 | Silty/sandy clay | Uv/Cal/Bul |
| 19 | 210 | Sandy clay | *Uv/Tri |
| 20 | 170 | Silty/sandy clay | *Uv/Cib |
| 21 | 145 | Sand | *Di/Cib |
| 22 | 177 | Sand/gravel | Cib/Tex/Tri |
| 23 | 100 | Pebbly layer | *Di/Cib |
| 24 | 225 | Soft clay w/sand | *Uv/Cib/Hya |
| 25 | 320 | Morainic material | *Uv/Di |
| 26 | 335 | Soft clay | Uv/Tri/Hya |
| 27 | 365 | Silty caly | Uv/Tri/Hya |
| 28 | 355 | Clay w/sand | Tri/Uv |
| 29 | 212 | Morainic material | *Cib/Di |
| 30 | 260 | Sand,gravel,pebbles | *Tri |
| 31 | 318 | Morainic material | *Uv/Cib |
| 32 | 380 | Silty clay | Cib/Tri/Uv |
| 33 | 300 | Silty/sandy clay | Cal/Tri/Uv |
| 34 | 310 | Clayey sand | Tri/Cib |
| 35 | 320 | Sandy clay | Cib/Tri |
| 36 | 340 | Clayey sand | Tri/Cib |
| 37 a | 305 | Sandy clay | Tri/Cib/Uv |
| 37 b | 250 | Sandy clay | Tri/Cib/Uv |
| 38 | 280 | Silty/sandy clay | Tri/Uv/Cib |
| 39 | 300 | Silty/sandy clay | Tri/Uv/Cib |
| 40 | 320 | Silty clay | Tri/Uv/Cib |
| 41 | 300 | Silty clay w/shells | Cold/Tri |
| 42 | 215 | Silty sand w/gravel & shells | *Cib/Uv |
| 43 | 230 | Clayey/silty sand w/gravel & shells | Tri/Cib |
| 44 | 230 | Clayey/silty sand w/gravel | Tri/Cib |
| 45 a,b | 128 | Silty/clayey sand w/gravel & pebbles | *Cal/Cib |
| 46 a,b | 185 | Sandy/silty clay | Cib/Tri |
| 47 | 262 | Sandy/silty clay | Cib/Tri |
| 48 | 130 | Sand w/gravel & pebbles | Cib/Tri |
| 49 | 182 | Sandy geavel w/shells | *Cib/Tri |
| 50 | 207 | 1.5 cm sand o/silty clay | *Tri/Cib |
| 51 | 225 | Sand w/shells | Cib/Tri |
| 52 | 255 | Gravelly sand | *Cib/Tri |
| 53 | 270 | Silty sand w/gravel & shells | *PF |
| 54 | 161 | Sandy gravel w/shells | *Cib/Tri |
| 55 | 240 | Sandy/gravelly clay w/shells | Cib/Tri |
| 56 | 207 | Silty sand w/shells | *Cib/Di/Tri |
| 57 | 260 | Silty sand w/gravel | Tri/Cib |
| 58 | 263 | Gravelly sand w/shells | Cold/Cib |
| 59 | 320 | Silty sand w/shells | Cib/Tri |
| 60 | 314 | Sandy/silty clay | Cib/Tri/Di |
| 61 | 290 | Silty/sandy clay | Cib/Tri |
| 62 | 315 | Silty/sandy clay | Cib/Tri/Cal/Mel |
| 63 | 300 | Silty/sandy clay | Tri/Cib |
| 64 | 310 | Silty/sandy clay | Cib/Tri |
| 65 | 255 | Silty/sandy clay | Cib/Tri |
| 66 | 215 | Silty/sandy clay | Cib/Tri |

are > 10% in all samples from water depths shallower than 325 m (Fig. 6b).

*Uvigerina peregrina* occurs most frequently in the southern part of the study area (Fig. 7a), in samples between 325 m and 425 m water depths (Fig. 7b). This species has been found only in small numbers north of 66°N.

*Cassidulina laevigata* accounts for 5–10% of the total benthic foraminiferal assemblage in most samples, except in the four samples taken at the outlet of the Norwegian Channel, where it constitutes 19–32% of the assemblage. *Cassidulina obtusa* is found in many of the northerly samples.

*Melonis barleeanum* and *Pullenia bulloides* have also been found in most of the area, being most abundant in the deepest samples. *Hyalinea balthica* accounts for a few percent of the assemblages in the southern part of the study area, but is absent in most samples from the continental shelf off Troms. Locally *Discanomalina semipunctata* is abundant, up to 25% of the assemblage in certain samples.

# Discussion

The regionally dominant species of the study area, *T. angulosa* and *Cibicides* spp., are all well adapted to a strong current regime. Records of living *T. angulosa* indicate that this species requires a sandy to silty substrate (Mackensen et al. 1985, Mackensen 1985). The Norwegian continental shelf north of 62°N, which is mainly covered by sandy sediments (Holtedahl & Bjerkli 1975), should therefore provide excellent living conditions for *T. angulosa*. Recent studies of the distribution of foraminifers in the Norwegian Sea have also shown that *T. angulosa* is the dominant living species along the Norwegian continental margin in water depths between 300 and 800 m (Mackensen et al. 1985, Mackensen 1985). This depth distribution coincides with the lower boundary of the North Atlantic water.

*Cibicides* spp. have their maximum occurrence in slightly shallower water depths (Fig. 6) than *T. angulosa*. *Cibicides lobatulus*, and other *Cibicides* species live attached to plants, larger animals or rock fragments (Nyholm 1961) and may thus tolerate a stronger current regime. Living specimens of *Cibicides* are rare in dyed samples, even if there is a considerable portion of empty shells in the dead assemblage (Murray 1970). This does not necessarily imply that few *Cibicides* live in the area where the sample was taken; as they live attached to larger fragments or animals *Cibicides* spp. may be underrepresented in the size fraction which is normally used for foraminiferal studies. Most *Cibicides* species are also relatively large and thick shelled and not so easily transported

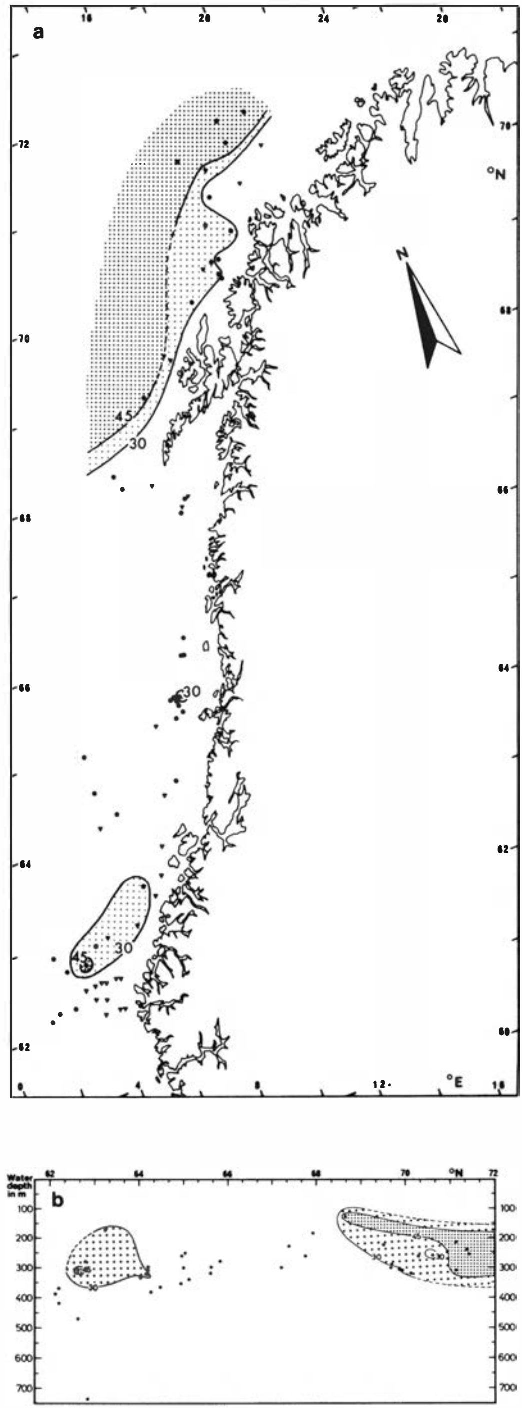


*Fig. 6.* Relative abundance (in % of the total benthic foraminiferal assemblage) of *Cibicides* spp. in a) horizontal plot, and b) against water depth and latitude.

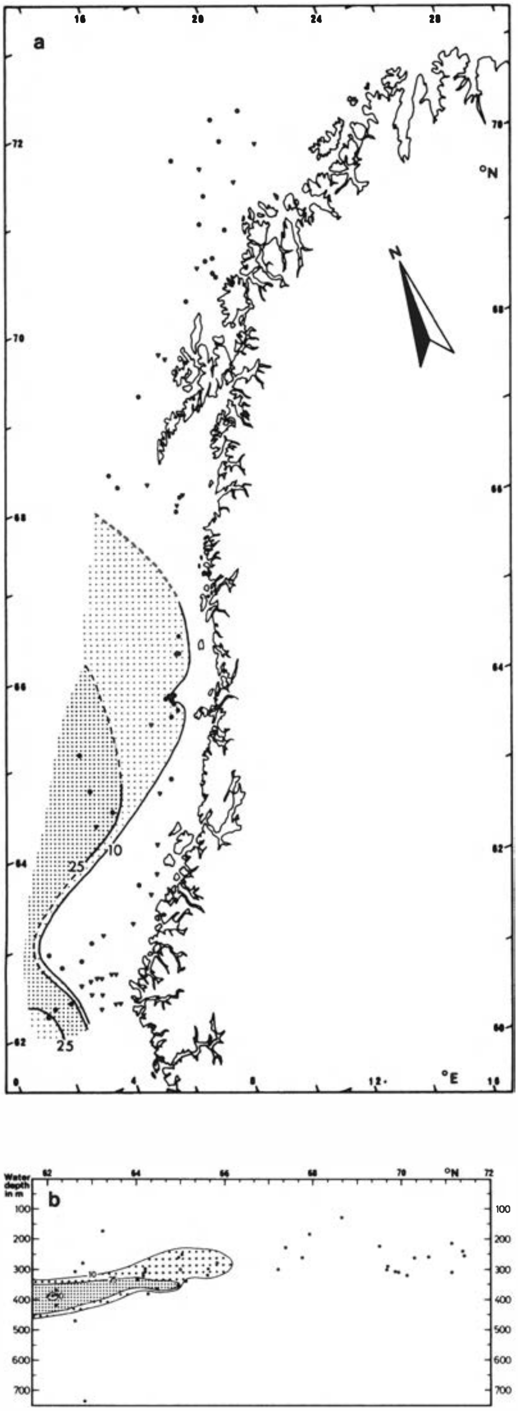

*Fig. 7.* Relative abundance (in % of the total benthic foraminiferal assemblage of *Uvigerina peregrina* in a) horizontal plot, and b) against water depth and latitude.

away from the areas as the smaller species. Their relative frequency may thus increase.

*U. peregrina* is the dominant species of the assemblage occurring in the deepest part of the Norwegian Channel off western Norway (Qvale & van Weering 1985). The southernmost samples in which *U. peregrina* is common (Fig. 7b) are located near the outlet of the Norwegian Channel, and represent the extension of this assemblage. *Uvigerina peregrina* requires quiet bottom conditions and a soft, fine-grained substrate (Foyn 1983). This explains the occurrence in the samples from the outer part of the continental shelf off Trøndelag (Fig. 7a). These samples are located in one of the areas where deposition of fine-grained material occurs (Holtedahl & Bjerkli 1982).

The more patchy distribution of the minor species is difficult to explain. *Cassidulina laevigata* is the dominant species on the North Sea plateau (Foyn 1983). According to Foyn (1983), this species tolerates unstable sedimentological and hydrographical conditions and should thus be able to inhabit the Norwegian continental shelf north of 62°N. It has also been found in small numbers in most samples.

*Discanomalina semipunctata* is locally abundant. This species lives, like *Cibicides,* attached to plants or larger animals. It has been found living in certain areas along the Norwegian continental margin (Mackensen 1985) and on the Iceland-Faeroe Ridge (Mackensen et al. 1985).

Local factors are apparently important in controlling the distribution of benthic foraminifers. However, the material in this study does not allow any detailed interpretations.

Even if the distribution of the main faunal elements can be explained by the present environmental conditions, it is doubtful whether the assemblages reflect the real living assemblage. Murray (1969, 1970) found very low similarities between living and dead assemblages on the continental shelf off the eastern United States and off southern England. He has also shown that the similarities between living and total foraminiferal assemblages are small in areas where the sedimentation rates are low (Murray 1982). The latter applies for most of the Norwegian continental margin north of 62°N. As mentioned earlier, only small amounts of material are supplied from the mainland. Most of the sediments originate from the shallowest part of the study area. Down to 300–400 m, currents are strong enough to erode and transport clay, silt and even sand sized material (Holtedahl & Bjerkli 1982), and this is deposited in local depressions on the shelf or deeper down on the slope. This will certainly affect the foraminiferal assemblages. In areas of erosion, only the largest and heaviest specimens will remain in situ, while the smaller ones will be transported and deposited in the troughs and depressions. The coarse material in the shallower areas represents winnowed glacial deposits (Holtedahl & Bjerkli 1975, Vorren et al. 1978, Hald & Vorren 1984). The erosion of the glacial deposits started at the beginning of the Holocene when the Atlantic water transgressed across the Norwegian continental shelf. The glacial deposits may contain a cold water foraminiferal assemblage, which could have been removed by erosion and redeposited. Cold water species such as *Cassidulina reniforme* and *Elphidium excavatum* contribute a few per cent of the assemblage in certain samples, especially from the deeper parts of the study area. The samples from areas where deposition takes place may thus contain a considerable contribution from allochthonous forms, and also boreal ones, which are not so easily identified as allochthonous.

The strong currents will also have a sorting effect on the assemblages. The smaller species will be easily removed while the heavier shells may remain in situ. This is evident from the samples studied, as the dominant species at shallow depths are large and heavy forms like *Cibicides* spp., *U. peregrina, D. semipunctata* and *T. angulosa.*

Due to slow sedimentation the shells may stay exposed on the seabed for a long time after death. The abundance of corroded shells in most samples and the infilling of glauconitic minerals in many of the foraminiferal shells indicate slow burial (Bjerkli & Østmo-Sæter 1973, Odin & Matter 1980). Low sedimentation rates also imply that the assemblages studied have probably been deposited over a long time span. Radiocarbon datings of the 10–20 cm interval in a core sampled on the shelf off Troms gave an age of 7030 ± 70 years BP, while the 15–30 cm and 10–30 cm intervals in two other cores from the same area gave 11,130 ± 110 and 13,310 ± 110 years BP, respectively (Rokoengen et al. 1979). By amino acid dating techniques (Sejrup et al. (1984b) revealed a Late Weichselian age of the 5–10 cm interval in cores from the shelf off Møre. In most samples, however, the assemblages are rather homogeneous and suggest that the environment has not changed considerably over the last few thousand years. This has also been pointed out by Hald & Vorren (1984). The present day conditions were established during the early Holocene with the incursion of the Atlantic water (Norwegian Current).

## Conclusions

A study of benthic foraminifers in surface samples from the Norwegian continental shelf north of 62°N has shown that the area is dominated by an assemblage with *Trifarina angulosa* and *Cibicides* spp. These species account for more than 50% of the total benthic foraminiferal assemblage in most samples. It is doubtful whether the *T. angulosa/Cibicides* assemblage reflects the living foraminiferal fauna. The study area is characterized by a strong current regime; erosion occurs in the shallower parts of the area, while material is deposited in local depressions and on the slope. The smaller species will probably be removed from the shallower areas. In the depositional areas, parts of the assemblage may be allochthonous. Due to low sedimentation rates in most of the area, the surface samples probably represent a long time interval. The results of this investigation should therefore be regarded as a rough indication of the real living fauna, and as background information for more detailed studies of the benthic foraminiferal distribution on the Norwegian continental shelf in the future.

Studies of the distribution of recent benthic foraminifers should be carried out on stained samples, especially in areas where sedimentation rates are low. In an area like the Norwegian continental shelf north of 62°N where bottom conditions are variable, the sampling stations should be selected very carefully. In high-energy environments where attached foraminifers are likely to be common, special attention should be paid to the study of rock fragments, plants and larger organisms on which foraminifers may grow.

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