

Benthic foraminifers in the Norwegian Channel: A comparison of Upper Quaternary and recent zonations

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The Upper Quaternary sequence can be divided into four distinct zones, each characterized by a certain benthic foraminifer species. Five different benthic foraminiferal assemblages characterize the surface sediments of the Norwegian Channel. The core and surface sediment data have been treated with the computer program THREAD, which describes the core faunas in terms of the surface assemblages. The consistency between the core fauna and the surface model is displayed in the communality values. Low values are believed to reflect depositional environments different from the present. A communality minimum occurs in the lowermost part of the core, while the upper part is characterized by generally higher values and two prominent maxima. The increase around the 675 cm level corresponds to 10,000 years B.P. when the area changed from being a near glacial, fjordlike basin to a temperate, open marine depositional environment. During parts of the Holocene the environment was similar to the present, the closest fit seen in the upper 50 cm of the core (last 800 years).

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Study of the distribution of benthic foraminifers in the surface sediments of the Norwegian Channel has shown that this area is characterized by five different assemblages (Qvale & van Weering 1985). Four of the assemblages apparently correlate with water mass characteristics.

Studies of a 10.7 m long gravity core retrieved from the southern flank of the Norwegian Channel have shown that the Upper Quaternary sediment sequence can be characterized by four distinct benthic foraminiferal assemblage zones (Nagy & Qvale 1985). The data sets from the two investigations mentioned represent an excellent basis to compare the late Quaternary foraminiferal zonation to the recent distribution. By sophisticated statistical methods (cf. below) the core faunas can be described in terms of the surface sediment assemblages. This enables us to explain better the zonation of the core and the environmental changes that have occurred during the deposition of the sediment sequence.

The Norwegian Channel

The Norwegian Channel is a prominent topographic feature in the North Sea, forming a depression bordering the southern coast of Norway. Maximum water depths (700 m) occur in the Ska-

gerrak (the eastern part of the Norwegian Channel), while off western Norway the depths are around 250 to 400 m.

The deep water mass (below 200 m) is stable with respect to temperature and salinity. The bottom water temperatures range from 6.5–7.5°C and the salinities are around 35‰ (Larsson & Rodhe 1979, Lee 1980). In the surface waters and in the surrounding shallow areas the hydrographical conditions are less stable. Seasonal variations in temperatures occur, and salinities are also variable due to changes in evaporation and fresh water runoff from the adjacent land areas.

Quaternary sediments of varying thickness cover the bottom of the Norwegian Channel (van Weering 1982, 1983). The thickest Holocene deposits are found in the Skagerrak (van Weering 1982). The surface sediments of the deeper parts of the Norwegian Channel are mostly fine grained (clay, silty clay), reflecting relatively quiet bottom water conditions. More coarse-grained sediments occur in the shallow areas north of Denmark and on the North Sea plateau west of the Norwegian Channel, where the currents are considerably stronger (Furnes & Sælen 1977, Larsson & Rodhe 1979).

The core studied penetrated Holocene and late Weichselian deposits on the southern flank of the Norwegian Channel (Fig. 1). The upper 7.8 m of

the core consisted of homogenous, dark greenish grey clay. Below 7.8 m the sediments were pale olive grey with bands of finely dispersed black sulfides and with a considerably higher content of sand-sized material. Pebble sized grains which bear all characteristics of ice-rafted material occurred in the sand fraction (Stabell et al. 1985).

Material and methods

The data used are the foraminiferal counts of 64 surface sediment samples from the Norwegian Channel (Qvale & van Weering 1985) and of 21 samples representing a 10.7 m long core through upper Quaternary sediments in the same area (Nagy & Qvale 1985). The water depth at the surface sample stations varies between 25 and 735 m; the bulk of the samples has been collected between 150 and 400 m water depth. The core was retrieved at 325 m water depth on the southern flank of the Norwegian Channel. A total of 32 species and species groups occurred in both data sets. Those present in only one of the data sets were grouped as "other species" (Table 1) to avoid changes in the relative frequencies of any species.

The raw data from the 64 surface samples were reduced to five factors using the computer program CABFAC (Klovan & Imbrie 1971). The program output is a varimax factor matrix which indicates the importance of each factor (here taken as equivalent to benthic foraminiferal species assemblage) in each sample, and a varimax factor score matrix which displays the importance of each variable (= benthic foraminiferal species) in each factor.

The computer program THREAD was used to describe the core in terms of the surface assemblages. THREAD is a matrix multiplication program which calculates a pseudofactor matrix from down core counts and the factor score matrix of the surface assemblages (generated by CABFAC). The degree to which the surface assemblage model fits the faunal data from the core can be seen in the communalities. The theoretical background for these calculations is explained by Imbrie & Kipp (1971).

Results and discussion

The factor analysis of the data from the surface sediment samples showed that the Norwegian

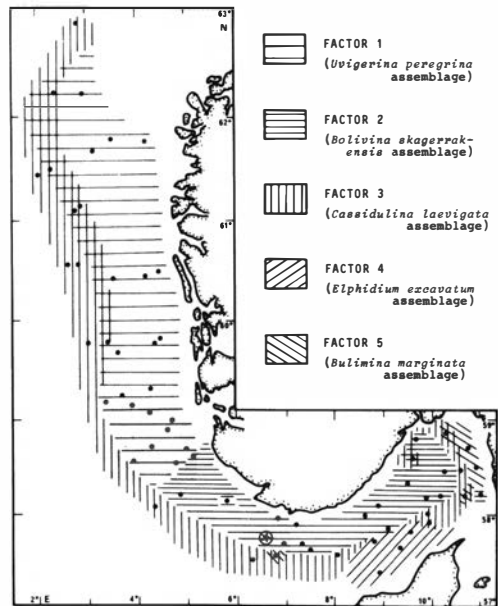


Fig. 1. Distribution of benthic foraminiferal assemblages (= factors) in the surface sediments of the Norwegian Channel. The shading indicates the area where the factor loadings are > 0.50. Dots indicate surface samples locations, the circled asterisk the position of core GIK 15530-4.

Channel is characterized by five different benthic foraminiferal assemblages (Fig. 1), each dominated by one species (Table 1). The first four assemblages are apparently related to certain water masses with known characteristics (Qvale & van Weering 1985).

Under the stable, deep water masses of the Norwegian Channel two different assemblages occur; off western Norway an assemblage characterized by *Uvigerina peregrina*, and in the Skagerrak and off southwestern Norway an assemblage dominated by *Bolivina skagerrakensis* (new name for *B. cf. B. robusta*, Qvale & Nigam 1985). The salinity and temperature of the deep water are similar throughout the Norwegian Channel, and other factors probably control the distribution of these assemblages. One possible explanation for the occurrence of the *U. peregrina* assemblage off western Norway may be the lower oxygen content of the bottom waters in this area (Ljøen 1962).

An assemblage dominated by *Cassidulina laevigata* occurs along the edge of the Norwegian Channel. The zone of maximum occurrence corresponds roughly to the transition zone between

Table 1. Varimax factor score matrix of the five factors found in the surface sediments of the Norwegian Channel. Significant species are underlined.

| VARIABLE | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 | FACTOR 5 |
|-----------------------------------|---------------|---------------|----------------|---------------|----------------|
| <i>Bolivina skagerrakensis</i> | -0.0380 | <u>0.9116</u> | 0.1731 | -0.0068 | 0.1874 |
| <i>Bulimina marginata</i> | 0.1006 | 0.1351 | 0.0257 | -0.0627 | <u>-0.9480</u> |
| <i>Cassidulina laevigata</i> | 0.2377 | 0.1702 | <u>-0.9270</u> | 0.0012 | <u>0.0313</u> |
| <i>Cibicides</i> spp. | 0.0615 | -0.0070 | <u>-0.0062</u> | 0.0052 | 0.0071 |
| <i>C. bertheloti</i> | 0.0050 | 0.0014 | -0.0003 | -0.0014 | -0.0008 |
| <i>C. boueana</i> | 0.0302 | -0.0067 | -0.0014 | 0.0036 | 0.0087 |
| <i>C. lobatulus</i> | 0.0324 | -0.0006 | -0.0141 | 0.0044 | 0.0083 |
| <i>C. pseudoungerianus</i> | 0.0142 | 0.0051 | -0.0018 | -0.0018 | -0.0003 |
| <i>C. refulgens</i> | 0.0209 | -0.0029 | 0.0014 | -0.0007 | 0.0013 |
| <i>Eggerella scabra</i> | -0.0047 | -0.0006 | 0.0061 | 0.1397 | -0.0091 |
| <i>Elphidium</i> spp. | -0.0041 | -0.0012 | -0.0080 | 0.0606 | 0.0035 |
| <i>E. excavatum</i> | 0.0013 | -0.0169 | -0.0110 | <u>0.9679</u> | -0.0610 |
| <i>E. incertum</i> | -0.0052 | -0.0022 | -0.0118 | 0.0200 | 0.0026 |
| <i>E. subarcticum</i> | -0.0010 | 0.0036 | -0.0003 | 0.0211 | 0.0050 |
| <i>Fissurina</i> spp. | 0.0069 | 0.0032 | -0.0059 | -0.0015 | -0.0014 |
| <i>Globobulimina turgida</i> | -0.0019 | 0.0922 | 0.0191 | 0.0252 | 0.0063 |
| <i>Hyalinea bathica</i> | -0.0076 | 0.1910 | -0.0708 | 0.0100 | -0.2105 |
| <i>Lagena</i> spp. | 0.0019 | 0.0048 | -0.0044 | 0.0046 | -0.0008 |
| <i>Melonis barleeana</i> | 0.1088 | 0.2439 | 0.0237 | -0.0235 | -0.0059 |
| <i>Nonion labradoricum</i> | 0.0086 | 0.0065 | -0.0098 | 0.0106 | -0.0294 |
| <i>Pullenia bulloides</i> | 0.0241 | 0.0930 | -0.0079 | -0.0135 | 0.0322 |
| <i>P. subcarinata</i> | 0.0246 | 0.0234 | -0.0099 | -0.0120 | 0.0125 |
| <i>Pyrgo williamsoni</i> | -0.0004 | 0.0022 | -0.0004 | 0.0003 | 0.0015 |
| <i>Quinqueloculina</i> spp. | -0.0009 | 0.0089 | -0.0017 | 0.0195 | 0.0116 |
| <i>Stainforthia loeblichii</i> | 0.0011 | 0.0002 | -0.0015 | 0.0039 | 0.0015 |
| <i>S. schreibersiana</i> | 0.0027 | 0.0003 | 0.0020 | 0.0009 | 0.0004 |
| <i>Trifarina angulosa</i> | 0.1946 | -0.0793 | -0.1520 | -0.0253 | 0.0823 |
| <i>Triloculina angusteorealis</i> | -0.0007 | 0.0039 | -0.0004 | -0.0003 | 0.0034 |
| <i>Uvigerina peregrina</i> | <u>0.9335</u> | -0.0332 | 0.2739 | 0.0080 | 0.0801 |
| Agglutinated sp. indet. | 0.0185 | -0.0079 | -0.0097 | 0.0182 | -0.0130 |
| Miliolids, indet. | 0.0194 | 0.0053 | -0.0020 | 0.0040 | 0.0057 |
| Rotaliids, indet. | 0.0135 | 0.0052 | -0.0125 | 0.0334 | 0.0075 |
| Other species | 0.0442 | -0.0041 | -0.0695 | 0.1660 | 0.0338 |

the hydrographically stable bottom water masses and the seasonally changing surface water. *Cassidulina laevigata* seems to tolerate rather unstable conditions with respect to both hydrography and sediments, and is the dominant living species on the North Sea plateau (Foyen 1983).

In the shallow, hydrographically variable area north of Denmark an assemblage with *Elphidium excavatum* occurs. *Elphidium excavatum* is common in arctic near-shore environments (Elverhøi et al. 1980, Vilks 1981), but it occurs also in more temperate areas characterized by seasonally variable hydrographic conditions, e.g. in the shallower part of the Oslofjord (Risdal 1964). *Elphidium excavatum* occurs frequently in glacial de-

posits and may therefore represent reworked material (Jansen et al. 1983, Mackensen et al. 1984). However, the specimens show no signs of transport and reworking. It is associated with typical shallow water forms, especially *Ammonia batava*, and other cold water indicators are absent. It is therefore assumed that *E. excavatum* represents in situ material.

The *Bulimina marginata* assemblage has a rather patchy appearance that is more difficult to explain. This species is common in Norwegian fjords with a large supply of organic carbon (Risdal 1963) and has also been found in other areas with similar conditions (e.g. Bandy et al. 1964, 1965). This, although not shown as a higher con-

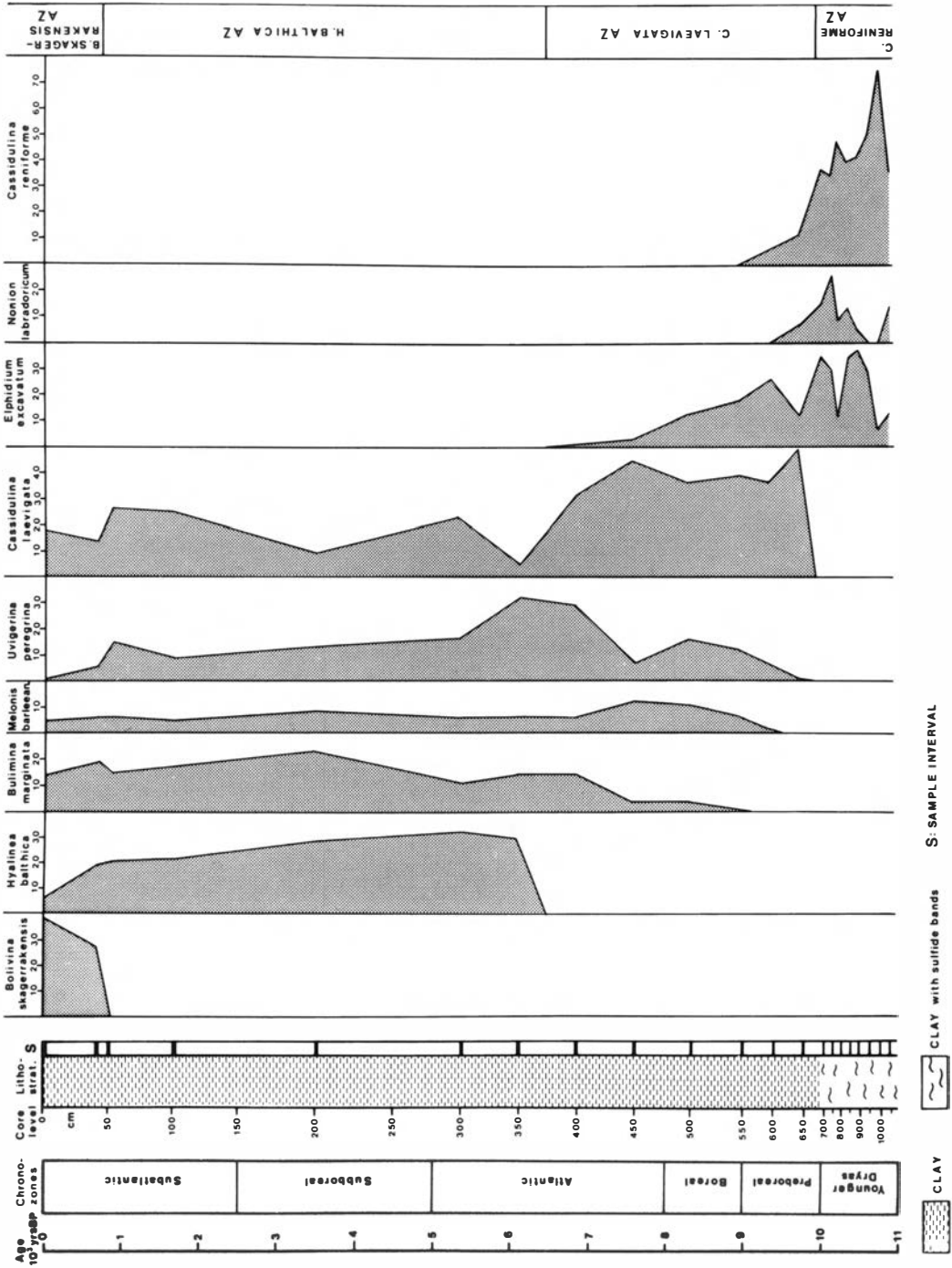


Fig. 2. Relative frequencies (% of total benthic foraminiferal assemblage) of the most important species in core GIK 15530-4 plotted against a time scale.

tent of C_{org} in the sediments, may explain the abundance of *B. marginata* along the Swedish west coast, but not the occurrence on the southern flank of the Norwegian Channel (Fig. 1).

The core studied, GIK 15530-4 (for location see Fig. 1), can be divided into four benthic foraminiferal assemblage zones, each designated by its dominant species (Fig. 2). The core has been dated by different techniques: radiocarbon (Stabell 1985 a), oxygen and lead isotopes (Erlenkeuser 1985, a, b), pollen (Henningsmoen & Høeg 1985) and magnetostratigraphic studies (Schönharting 1985). It was therefore possible to plot the foraminiferal distribution against a time scale (Fig. 2). Only the most important species have been shown in this figure. The assemblage zones are well defined with sharp boundaries due to rapid immigration of certain species.

The pseudo-factor matrix, which describes the core in terms of the surface sediment assemblages, has also been plotted against the time scale (Fig. 3). The communalities, which show how well each sample fits the model, vary throughout the core. If the sample fits the model without error, the communality is equal to 1.00, but values greater than 0.70-0.75 are considered as a good fit (e.g. Mudie et al. 1984). Communalities >0.70 have therefore been set off by shading in Fig. 3.

The communality curve shows three maxima where the values exceed 0.70; one in the upper 50 cm of the core, one between 75 and 200 cm (2 samples) and a third between 400 and 650 cm. Low communalities are most conspicuous in the lower part of the core, but there are also low values in samples between 375 and 225 cm and in the sample at 50-55 cm. Low communalities are believed to reflect environmental conditions different from the present.

The lowermost part of the core (1070-675 cm), corresponding to the most pronounced communality minimum, are characterized by cold water species (Fig. 2). This part was deposited before 10,000 years B.P., probably in a glacial, fjordlike environment (Stabell & Thiede 1985). The dominant benthic foraminifer is *C. reniforme*, associated with *E. excavatum*. *Elphidium excavatum* is an important constituent of the surface assemblage 4, and this assemblage thus describes part of the fauna in the lower part of the core (Fig. 3).

The core interval 650-400 cm, representing 10,000-6,500 years B.P., has apparently been deposited under conditions similar to those in parts

of the present day Norwegian Channel. The lower boundary of the communality maximum corresponds to the rapid immigration of *C. laevigata* (Fig. 2) and a more gradual increase in the frequencies of other boreal species. The immigration of temperate water species reflects the influx of warm Atlantic water after the retreat of the land ice (Nagy & Qvale 1985). It is also reflected by other microfossil groups (Bjørklund 1985, Dale 1985, Qvale 1985, Stabell 1985 b). The surface assemblage characterized by *C. laevigata* (factor 3) seems to describe the core fauna quite well. As mentioned above, *C. laevigata* apparently tolerates unstable conditions. After the rather drastic changes in environment at about 10,000 years B.P. it probably took some time to establish stable conditions. This may explain the abundance of *C. laevigata* in this interval.

The upper boundary of the communality maximum (Fig. 3) corresponds to the immigration of *Hyalinea balthica* (Fig. 2), which took place between 7,000 and 6,000 years B.P. There were two possible immigration routes, one by the inflow of the Atlantic water from the west, and one through the English Channel, which opened around 8,000 years B.P. (Jelgersma 1979). *Hyalinea balthica* is characterized as a boreal-lusitanian form (Nørvang 1945), and the abundance of this species may reflect the amelioration of the climate which took place during Atlantic time.

During Subboreal and early Subatlantic time the climate gradually approached that of the present. Conditions similar to that of today may explain the small communality peak in the samples at 200 and 100 cm. The core faunas from the time interval 6,500 to 1,000 years B.P. cannot be described by a single surface assemblage (Fig. 3), but factors 1, 2, 3 and 5 (the clearly boreal assemblages) each describe part of the fauna.

The upper 40 cm of the core fit well into the present day model, and lie within the *B. skagerrakensis* assemblage zone (factor 2) (Figs. 1, 3). The communality maximum in the top of the core is, however, set off by a minimum in the 50-55 cm sample. This minimum coincides with the rapid immigration of *B. skagerrakensis* at about 800 years B.P.. At present we have no explanation for this immigration, and we do not know from where the species came into the Skagerrak. Due to the confusion in the taxonomy of this species (Qvale & Nigam 1985), we know little about its distribution in time and space. With one exception it is known with certainty only from deposits of late Holocene age, and it is common only in

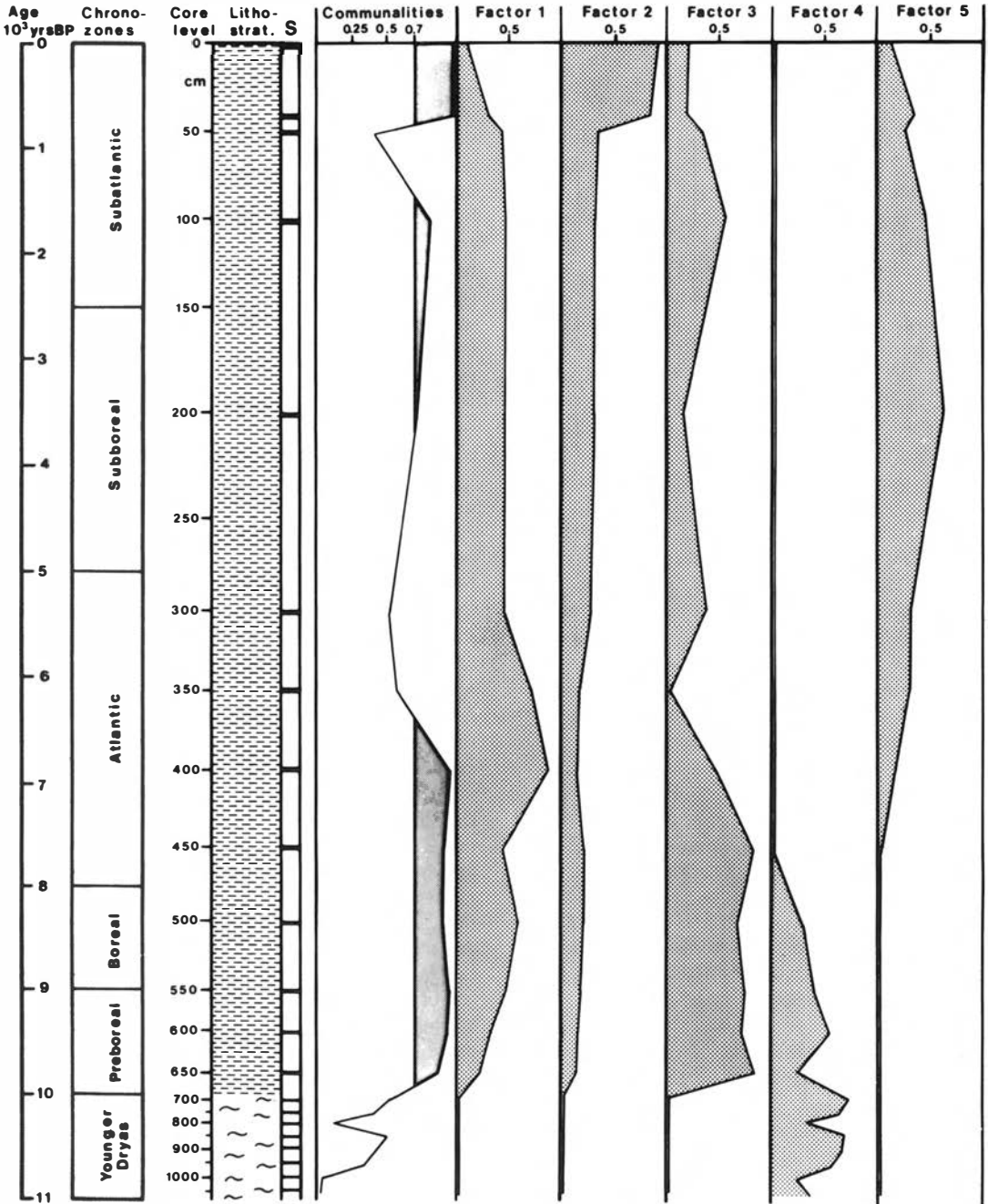


Fig. 3. Pseudo-factor matrix of core GIK 15530-4 plotted against a time scale. Communalities >0.70 have been set off by shading. For legend see Fig. 2.

the Norwegian Channel, especially in Skagerrak, and in the surrounding Norwegian fjords. In the Altafjord (North Norway) *B. skagerrakensis* has been found in sediments of middle (?) Holocene age, while it is absent in the recent deposits (Strand 1979). Whatever caused the immigration is, however, reflected in decreased communalities and indicates an environmental change.

The very rapid immigration into Skagerrak of certain benthic foraminifers is a very conspicuous feature (Fig. 2). According to the core data a maximum in the frequency of *Bolivina skagerrakensis* was reached within 80 years. The observed time interval is probably much too high due to large sample size (5 cm vertically) and mixing of the sediment by bioturbation.

Also the change from a fully glacial fauna to a fauna dominated by temperate species occurs over a short time interval, maximum 200 years. This is probably too high for the same reasons mentioned above.

Conclusions

The method of describing core faunas in terms of surface sediment assemblages is useful to compare fossil and recent environments. The similarity between fossil and recent assemblages is expressed quantitatively and is useful in interpretations of the depositional environment during the interval studied.

This method was applied to data from studies of benthic foraminifers in the surface sediments of the Norwegian Channel and in a core through upper Quaternary sediments from the same area. The stratigraphy of the core was well documented and therefore represented excellent material to test the method.

The communality values, which show how well the core faunas fit the model, vary considerably throughout the core. The lowest values occur in samples from the lower 375 cm of the core and reflect a depositional environment very different from the present day conditions. It thus confirms the results of the earlier core studies, which have shown that this part was deposited during the late Weichselian.

Three intervals of the core seem to represent conditions comparable to those of the modern Norwegian Channel. The lower and upper boundaries for the two most pronounced maxima coincide with the rapid immigration of certain benthic foraminifers.

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