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Formation of nutrient rich bottom water in the eastern part of the Barents Sea.

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Abstract

During yearly routine observations of hydrography, nutrients and plankton in the Barents Sea we have observed a distinct anomaly in the distribution of the nutrients silicate and nitrate in near bottom water in an area off the west - southwest coast of Novaya Zemlya and in the eastern Barents Sea as a whole.

Three areas are distinguished:

- The first area represents the deeper parts of the north and central eastern parts of the Barents Sea with bottom depths from 200 to 350 m. Here the observed concentrations of silicate are in the range from 8 to 12 $\mu mol \cdot l^{-1}$.
- The second area represents the south-eastern Barents Sea with bottom depths from 50 to 100 m, with silicate concentrations from 6 - 9 $\mu mol \cdot l^{-1}$.
- The third area is found in the fairly shallow waters, with depths from 100 - 170 m, off the central west coast of Novaya Zemlya having silicate values from 10 to over 20 $\mu mol \cdot l^{-1}$. Highest silicate value of 21,8 $\mu mol \cdot l^{-1}$ and the corresponding nitrate value of 15,7 $\mu mol \cdot l^{-1}$ were observed at a depth of 165 m in mid- september 1994.

These high values are in contrast to most of the silicate values found in the Barents Sea, where the bottom water contains from 6 to 7 $\mu mol \cdot l^{-1}$ silicate. The silicate anomalies are also reflected in the molar ratio of silicate to nitrate. In the western and central bottom water of the Barents Sea this ratio is about 0,5, while in the bottom water with elevated silicate concentrations this ratio is from 0,7 to 1,5.

Most interesting is the high values in the shallow areas off the central west coast of Novaya Zemlya. The water masses with especially high silicate content have salinities less than 34,85 and temperatures below - 0,5 °C. A possible source for these high silicate values may be the water masses of the North-Eastern Kara Sea where we have observed silicate values above 50 $\mu mol \cdot l^{-1}$ in the surface water.

Introduction

The yearly routine fisheries surveys in the Barents Sea of the Institute of Marine Research (IMR) include extensive observations of hydrographic parameters, i.e. CTD measurements. In some of the cruises sampling for nutrients measurements and plankton studies are carried out as well. The data from the plankton surveys including the nutrient observations are, in the first hand, presented as internal reports (in Norwegian) of IMR.

This paper refers to data from water samples collected for nutrient measurements during the plankton surveys of 1994, 1995 and 1996 (Hassel *et al.*, 1995, Johannessen *et al.*, 1996 and Hassel *et al.*, 1997). Some of the nutrient data, in particular the silicate data, from the eastern Barents Sea showed elevated levels compared to data from the western and central Barents Sea. Since some of these concentrations were more than three times as high as the "normal" near bottom silicate concentrations of the Barents Sea, it was at first almost concluded that there was some analytical errors producing the specially high silicate values. But our analytical QA procedures (Hagebø, 1993), however, confirmed the values. Furthermore these elevated data were allocated to distinct areas and were observed for all the three years in question.

Rey & Skjoldal (1987) have described consumption of silicate by sedimenting diatom blooms in the Barents Sea, a process which could contribute to elevated concentrations of silicate in the near bottom water due to remineralization. Their observations were made at hydrographic sections in the Central Barents Sea i.e.: from 74° 30′ N to 78° N between 31° 30′ E and 34° 30′ E (in June 1983 and June 1984) and at a section from 74° 00′ N to 76° 20′ N along 45° E (in June 1984). While they report near bottom concentrations of silicate for the western sections between 6 and 7 $\mu mol \cdot L^{-1}$, the concentrations at their easternmost section amounts to above 8 $\mu mol \cdot L^{-1}$.

The specially high silicate concentrations observed further east and presented in this paper amount to more than 20 $\mu mol \cdot L^{-1}$. These observations open for other speculations about the origin of the high silicate concentrations. Midttun (1985) has discussed the formation of dense bottom water in the Barents Sea and especially in the areas where we found the high concentrations of silicate. Midttun (1985) demonstrate the formation of the dense bottom water, how it is formed on the shallow bank area off the west coast of Novaya Zemlya and drained down into hollows and depressions.

Materials and methods

Fig. 1 show the stations occupied in the eastern Barents Sea in 1994, 95 and 96. Fig. 2 presents examples of the horizontal distribution of silicate, nitrate and density in the near bottom water of the eastern Barents Sea.

The water samples for nutrient analysis were collected from Rosette-water bottles mounted on the CTDs of the actual research vessels. 20 ml samples from standard depths were added 1 ml chloroform and stored in a refrigerator in polyethylene scintillation bottles (Hagebø & Rey, 1984). The samples were transported to IMR where they were analyzed according to our standard analytical procedures (Føyn *et al.* 1981). The data were then reported in tables from each cruise (Hassel *et al.*, 1995, Johannessen *et al.*, 1996 and Hassel *et al.*, 1997).

In addition to the samples from the Barents Sea a few water samples for nutrient determination were collected during the joint Norwegian - Russian expedition to the Kara Sea in 1992 (Føyn & Semenov, 1992). The samples were stored and analyzed according to Hagebø & Rey (1984) and Føyn *et al.* (1981).

Results and discussion

Three types of water masses have elevated silicate concentrations;

a) one type representing the deeper parts of the eastern Barents Sea i.e. depressions and hollows where Midttun (1985) located dense bottom water and visualized by Loeng (1991),
b) the second water mass is located as the bottom water of the shallow area in the South-East Barents Sea, i.e. the Pechora Sea,
c) the third type of water is found in relatively shallow and restricted areas on the shelf off the west coast of Novaya Zemlya.

a) The dense bottom water formed over shallow areas as described by Midttun (1985), especially for the eastern part, and by Quadfasel *et al.* (1992) for the Central Barents Sea, will flow down into the deeper parts of the eastern basin of the Barents Sea. According to Loeng *et al.* (1992) this eastern basin may occasionally be almost filled with this dense water. Most of this bottom water leaves the Barents Sea through the strait between Novaya Zemlya and Frans Josef Land (Loeng *et al.*, 1992). Loeng *et al.* (1992) also states that the outflow may vary considerably from year to year with major outflows. This variation in outflow indicate a certain stagnation in these dense bottom water masses over a longer period allowing for an increase in their nutrient content.

Loeng (1991) may be interpreted in a way that these major outflows of dense bottom water take place every six to seven year. Which can explain the increase in nutrient content due to stagnation allowing for longer periods of remineralization processes. The typical molar ratio between silicate and nitrate of 0,5, is not found in these bottom water masses. The representative silicate : nitrate molar ratio found in the water below 200 meters, from our observations, is 0,7. This shows that there is a surplus of silicate in these bottom waters. This surplus can be explained by the observations described by Rey & Skjoldal (1987) of resting spores of the diatom *Chaetoceros socialis* transporting silicate downwards. If these diatom spores with a high load of silicate are trapped in the dense bottom water the remineralization may change the ratio of dissolved silicate to nitrate in these particular water masses, and thereby explain the increase in silicate concentration.

The normal bottom concentrations of silicate in the western part of the Barents Sea, consisting of mainly Atlantic water, are from 6 to 7 $\mu mol \cdot L^{-1}$, while we observed the silicate concentrations in the dense bottom water to be between 8 to 12 $\mu mol \cdot L^{-1}$.

b) In the shallow areas, bottom depths from 50 - 100 m, of the South-East Barents Sea we observed ratios for silicate to nitrate of from 1 to 1,1 all over the area, with silicate concentrations from 6 to 9 $\mu mol \cdot L^{-1}$. These ratios of 1 to 1,1 for silicate to nitrate were observed in the near bottom water east of 44° E. Further to the west along 70° N at 43° E the ratio had changed to 0,6, which is approaching the "normal" ratio of 0,5 found in the central and western Barents Sea. Observation depths ranged from 60 to 80 m. This area also called the Pechora Sea is influenced by the Pechora River and this may explain the surplus of silicate. The salinity of the bottom water, from 34,4 to 34,6, where we observed the silicate anomaly do not indicate a pronounced fresh water influence. According to Rudels *et al.*, (1991) the input of silicate from the Arctic rivers to the Arctic oceans is comparable to that of the Atlantic Water, and may explain the elevated levels. But we have no observations of silicate concentrations closer to the river mouth and for the river water itself, therefor further studies or new data have to be presented before we can draw any conclusions about the silicate anomaly in the bottom water of this shallow part of the Barents Sea.

c) More intriguing are the observed silicate concentrations of more than 15 $\mu mol \cdot L^{-1}$ at depths of 150 m amounting to as much as 21,8 $\mu mol \cdot L^{-1}$ at the bottom depth of 165 m. The corresponding nitrate concentration of 15,7 $\mu mol \cdot L^{-1}$ gives a molar ratio for silicate to nitrate of 1,4. The location of this station was 74° 49′ N and 51° 19′ E. In the bottom water of the station closest to the coast (74° 50′ N and 53° 44′ E) the same ratio for silicate to nitrate of 1,4 is found although the concentrations are lower (14,1 $\mu mol \cdot L^{-1}$ for silicate and 10,2 $\mu mol \cdot L^{-1}$ for nitrate) and the depth was 215 m.

Unfortunately our observation-net of stations was not aimed at the silicate anomaly and consequently the data-sets are not detailed enough to map the areas with elevated concentrations of silicate. Therefor only questions can be raised about the formation/source of the water masses with the high silicate levels. The Kara Sea may probably be a source for these specially elevated silicate concentrations.

From the very few water samples collected for nutrient analysis in the Kara Sea in 1992 (Føyn & Semenov, 1992) we know that the surface water of some areas of the Kara Sea have high silicate concentrations. Firstly there is the area influenced by the river Ob with surface salinities between 8 and 10 and corresponding silicate values of about 42 $\mu mol \cdot L^{-1}$. The surface water at the 11 stations worked in the Kara Sea during the joint Norwegian - Russian expedition (Føyn & Semenov, 1992) was characterized by almost depletion of nitrate. At some stations surface concentrations for silicate were measured in the range from 40 to over 55 $\mu mol \cdot L^{-1}$ with corresponding salinity values from 15 to 27. In fact at one station in the north-west central part we measured a silicate concentration for the surface water to be 55,3 $\mu mol \cdot L^{-1}$ with a corresponding salinity of 27,5.

Visual observations (Føyn, pers.com.) of eddies completely filled with timber logs in the middle of the Kara Sea may indicate that envelopes of surface water may be formed. Observations at the south-east shores of Novaya Zemlya in 1993 and 94 by Føyn (pers. com.) concluded that there was only small amounts of driftwood on land. Consequently the huge amount of driftwood that are discharged from the rivers Ob and Yenesei and observed in the north-western central part of the Kara Sea is most likely to be transported out of the Kara Sea between Novaya Zemlya and Frans Josef Land. If such transport take place in an envelope of water created by the eddies other constituents like silicate may be transported more or less unmixed as well.

If surface water from the north-western Kara Sea flows out of the Kara Sea through the strait between Novaya Zemlya and Frans Josef Land and follows the western coast of Novaya Zemlya southwards as a counter current, in an intermediate layer, then it may be possible to explain the elevated concentrations of silicate. In the water masses where we observed the silicate anomaly we also observed temperatures from 0° C to -1,0° C, salinity between 34,85 and 34,90 and nitrate concentrations around 15 $\mu mol \cdot L^{-1}$. This indicate a lesser probability that these intermediate water masses originate from The Kara Sea surface water.

The fact that we observe the elevated silicate concentrations in the shallower part of the shelf area and not in the nearby depressions indicate also that the formation of this water is not comparable to the formation of dense bottom water as described by Midttun (1985). It is furthermore not likely that the sedimenting processes of diatoms as described by Rey & Skjoldal (1987) will create the high observed concentrations of silicate only in some small restricted areas where the actual water mass certainly can not be stagnant for a sufficient long period allowing a remineralization of this magnitude.

Conclusion

Three different bottom water masses in the eastern Barents Sea are distinguished due to their elevated concentrations of silicate compared to the concentrations in the rest of the Barents Sea and due to the different molar ratio of silicate to nitrate compared to bottom water ratios in other parts of the Barents Sea.

The main water mass with a silicate anomaly is the dense bottom water of the eastern basin of the Barents Sea. The elevated silicate concentrations may be explained by remineralization of sedimented diatoms in a stagnant water mass. A stagnation which may last for several years.

For the two other distinguished water masses where we observed a silicate anomaly we do not have enough data to conclude about the sources and formation of these water masses.

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