FiskDir. Skr. Ser. HavUnders., 17: 501–519

INFLUENCE OF BOTTOM TOPOGRAPHY ON THE CIRCULATION AT THE CONTINENTAL SHELF OFF NORTHERN NORWAY

By

SVEIN SUNDBY
Institute of Marine Research, Bergen, Norway

ABSTRACT

SUNDBY, S. 1984. Influence of bottom topography on the circulation at the continental shelf off northern Norway. *FiskDir. Skr. Ser. HavUnders., 17: 501–519.*

The three banks Sveinsgrunnen, Malangsgrunnen and Nordvestbanken, which lie off the coast of northern Norway, are separated by troughs. Synoptic hydrographic surveys and data from satellite-tracked buoys drogued in the mixed layer, show that the botton topography strongly influences the distribution of water masses and current pattern. Coastal water above the banks circulates in a clockwise direction, while Atlantic water intruding in the troughs circulates in a anticlockwise direction. This circulation pattern influences the transport and spreading of cod eggs from the spawning grounds which are sited between the banks and the coastline. The eggs are, for the most part, distributed throughout the Coastal water on the banks, while only small numbers are found in the Atlantic water in the troughs. The circulation in the investigated area probably favours mixing of the Coastal and Atlantic water masses. Moderately stratified concitions occur in the period from June to September. During this period, the influence of the bottom topography seems to be less pronounced. However, Atlantic water does flow into the trough Malangsdjupet during stratified conditions.

INTRODUCTION

The continental shelf topography off northern Norway is dominated by a number of relatively small and well-defined banks separated by troughs (Figs. 1 and 2). The topography is thus expected to influence the circulation of the Coastal current. In this area the Coastal current is an important carrier of pelagic eggs and larvae, and consequently the bottom topography may also influence the transport and spreading of eggs and larvae.

EIDE (1979) clearly demonstrated the influence of the larger Haltenbanken at the Norwegian continental shelf off mid-Norway. The bank induces a Taylor column reaching the surface during relatively homogenous conditions, while the upper layers during summer stratification are released from the Taylor column below. The aim of this study is to investigate whether the bottom topography of the area, shown in Fig. 2, also influences the general circulation

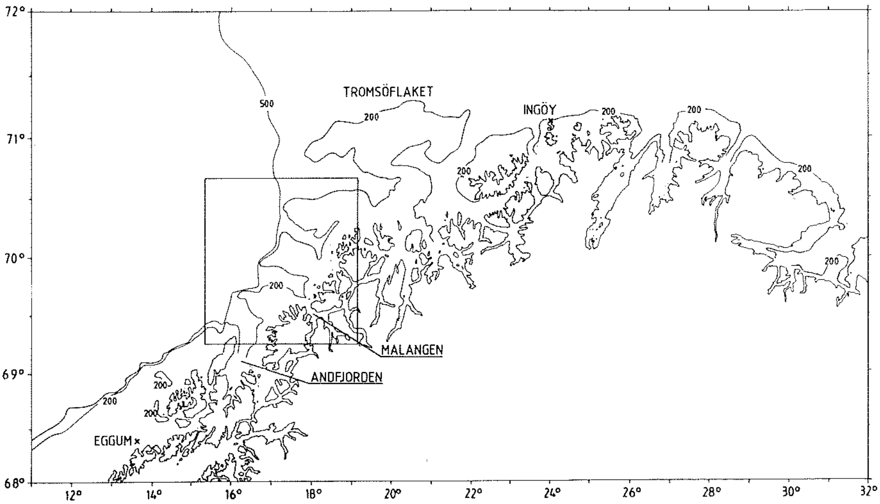

Fig. 1. The coast of northern Norway. The investigated area is within the frame.

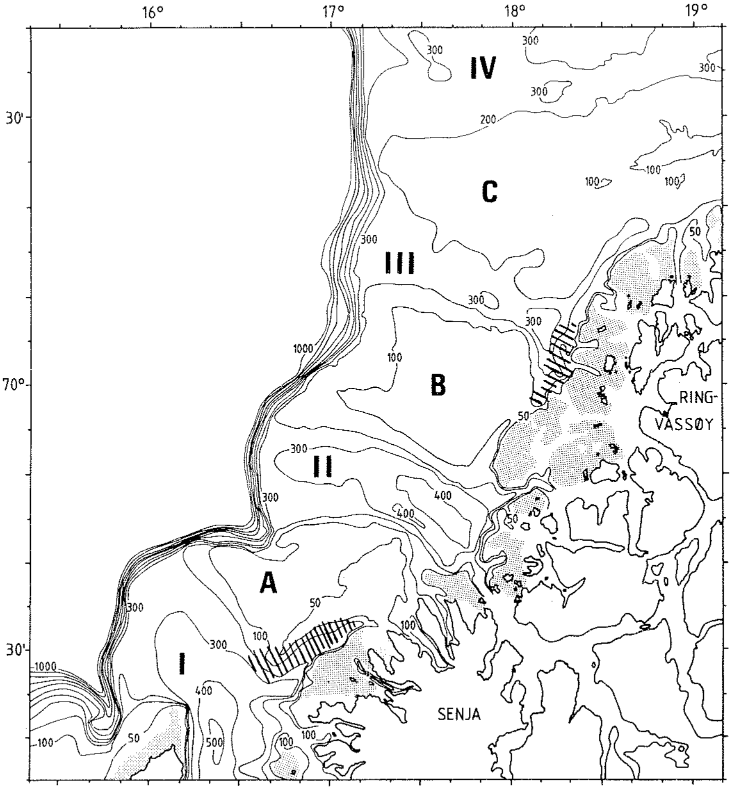

Fig. 2. Bottom topography of the continental shelf within the investigated area (depths in meters). Banks: A) Sveinsgrunnen, B) Malangsgrunnen, C) Nordvestbanken. Troughs: I) Andfjorddjupet, II) Malangsdjupet, III) Malangsgrunnen–Nordvestbanken Trough, IV) Tromsøflaket Trough.

of the area. However, it must be stated that both topography and the general oceanographic conditions are somewhat different from those at Haltenbanken. This is discussed later.

The large-scale features of the hydrography off the coast of northern Norway during summer are described by LJØEN (1962). The general current features are described by SÆTRE and LJØEN (1971). SUNDBY (1976) has described the general hydrographic conditions of the Coastal current off northern Norway in more detail. KISLYAKOV (1964) has studied the general circulation of the Atlantic current and the Norwegian current at Tromsøflaket and in the adjacent coastal waters. These investigations are all too large-scaled, however, to reveal the possible influence of the bottom topography of the continental shelf on the hydrographic and current conditions. Current measurements have been made with moored Aanderaa current meters at three positions of the inner part of Malangsgrunnen during the years 1973–1975 (SÆTRE 1973, EIDE 1974, 1975, 1976). Like the other measurements, these do not reveal effects of the bottom topography.

TOPOGRAPHY

The contiental shelf topography between Andøya and Fugløya, off the coast of northern Norway (Figs. 1 and 2), consists of three banks separated by throughs. Outside, the shelf edge slopes steeply towards the deep basin of the Norwegian Sea. The southernmost bank, Sveinsgrunnen (A), is the shallowest, with a mean depth of 61 m. Malangsgrunnen (B) is somewhat deeper, with a mean depth of 91 m. The norhernmost bank, Nordvestbanken (C), is the deepest, with a mean depth of 139 m. Malangsgrunnen is relatively flat, while Sveinsgrunnen and Nordvestbanken slope slightly towards the shelf edge.

The four troughs, Andfjorddjupet (I), Malangsdjupet (II), Malangsgrunnen–Nordvestbanken Trough (III), and Tromsøflaket Trough (IV) have sills close to the shelf edge. The sill depths vary from 230 to 270 m. All three banks are partially separated from the coastline by small and narrow trenches. The shaded areas in Fig. 2 indicate shallow waters with depths varying between 0 and 20 m. Large parts of this area contain vast numbers of skerries. The border of this shaded area probably acts as a secondary coastline for the coastal current.

MATERIALS

The hydrographic data are mainly taken from the four quasisynoptic surveys indicated in Table 1. During the same cruises, Juday net hauls were also made, from 50 m depth to the surface, to sample cod eggs and larvae. On three of the surveys, two ARGOS-buoys were also released, drogued with a sail at 30-m

Table 1. Four quasi-synoptic surveys specifically designed to study the influence of bottom topography. A = Sveinsgrunnen, B = Malangsgrunnen, C = Nordvestbanken, I = Andfjorddjupet, II = Malangsdjupet, III = Malangsgrunne–Nordvestbanken Trough, IV = Tromsøflaket Trough.

Time	Ship	Number of hydrographic stations	Number of Juday net hauls	Drogues	Area covered (see Fig. 2)
5–7 May 1980	«Johan Hjort»	68 C.T.D.	68	0	I, A, II, B, and partly III and C.
29 April–1 May 1981	«Johan Hjort»	65 C.T.D.	61	2 ARGOS-buoys drogued at 30 m depth	I, A, II, and B
2–4 May 1981	«Johan Hjort»	43 C.T.D.	43		I, A, II, B and III
17–20 April 1982	«G.O. Sars»	86 C.T.D.	86	2 ARGOS-buoys drogued at 30 m depth	I, A, II, B, III, C, and IV

depth. Location of the buoys was made by satellite roughly nine times each day.

Fig. 3 shows the station grid used. Some additional stations between the sections, which differ in position from cruise to cruise, are not shown is this figure. On the first cruise, only the inner parts of Nordvestbanken and adjacent troughs were covered; on the second and third, Nordvestbanken was not covered.

In addition to the four major surveys, data from eight minor surveys, covering only parts of the area, are also studied. These cruises were designed for purposes other than to study the influence of bottom topography. However, the stations are located so that they appear to give some indication of the distribution of the water masses in relation to troughs and banks.

Table 2 gives an overview of the minor surveys. The stations from the first six surveys were taken by Nansen casts and only at depths varying between the surface and 30 m. At some of the stations only salinity was measured. These data are, therefore, presented in horizontal maps at different depths.

ANNUAL VARIATIONS OF THE VERTICAL DENSITY STRUCTURE

Vertical stratification is an important factor in modifying the influence of bottom topography on the circulation of the upper layer. Thus the general vertical density structure and the annual variations are described.

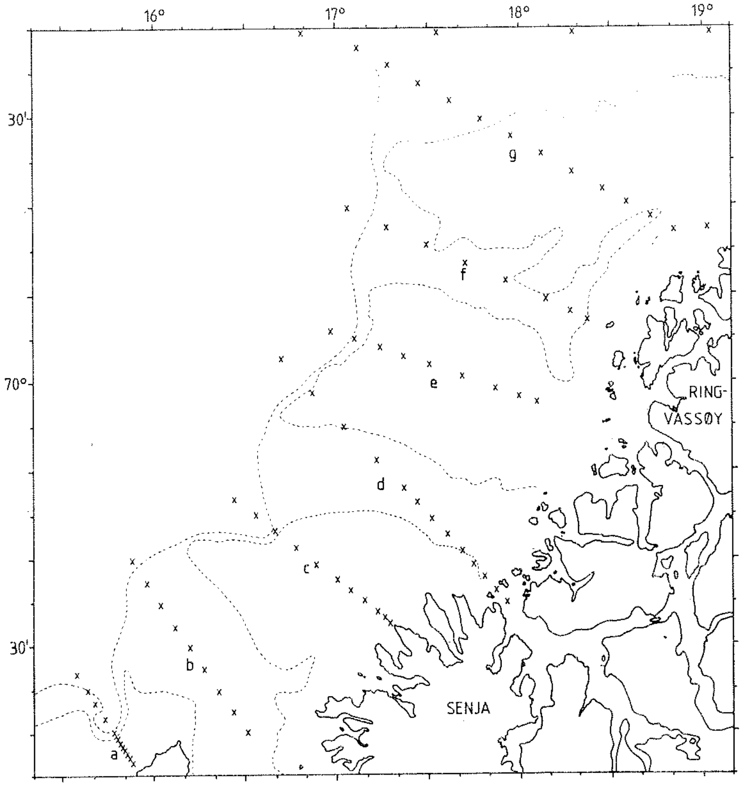

Fig. 3. Station grid used for the major cruises. In addition to these fixed stations, some stations were taken inbetween the sections for each cruise.

Table 2. Eight quasi-synoptic minor surveys. A = Sveinsgrunnen, B = Malangsgrunnen, C = Nordvestbanken I = Andfjorddjupet, II = Malangsdjupet, III = Malangsgrunnen–Nordvestbanken Trough, IV = Tromsøflaket Trough.

Time	Ship	Number of hydrographic stations	Area covered (see Fig. 2)
9–10 May 1974	«Johan Hjort»	20 Nansen casts	I, A, II, B, and III
14 April 1975	«G.O. Sars»	13 Nansen casts	I, A, II, and B
10–11 May 1975	«Johan Hjort»	11 Nansen casts	A, II, B, and III
22–25 June 1975	«G.O. Sars»	12 Nansen casts	A, II, B, III and C
31 July–1 August 1975	«G.O Sars»	12 Nansen casts	A, II, B, III and C
12–13 October 1975	«G.O. Sars»	9 Nansen casts	A, II, B, III and C
19–21 March 1980	«G.O. Sars»	7 C.T.D.	II, B, and partly III, C and IV
19 August 1982	«G.O. Sars» «Johan Hjort» «Michael Sars»	16 C.T.D.	I, A, II, B, III, C

There exists no fixed hydrographic station to show the annual variations of the vertical density structure within the investigated area. However, at Eggum farther south and at Ingøy to the north (Fig. 1) long time series records of hydrography exist. Both stations describe well the Coastal water off northern Norway. Fig. 4 shows isopleths of the squared Brunt-Vaisälä frequency, N^2, from Eggum for the mean year (1936–82) and from Ingøy for the mean year (1936–43 and 1968–82). The figure indicates that the stability in general decreases from south (Eggum) to north (Ingøy). During winter, the stability is very low throughout the water column ($N^2 < 3 \times 10^{-5}$ s^{-2}). Stratification starts in June, reaching maximum values of $N^2 \approx 2\text{–}3 \times 10^{-4}$ s^{-2} in Juli for the upper 20 m. The stability then rapidly drops, reaching «winter conditions» already in early October. Thus the summer stratification is of shorter duration than farther south at the Norwegian continental shelf.

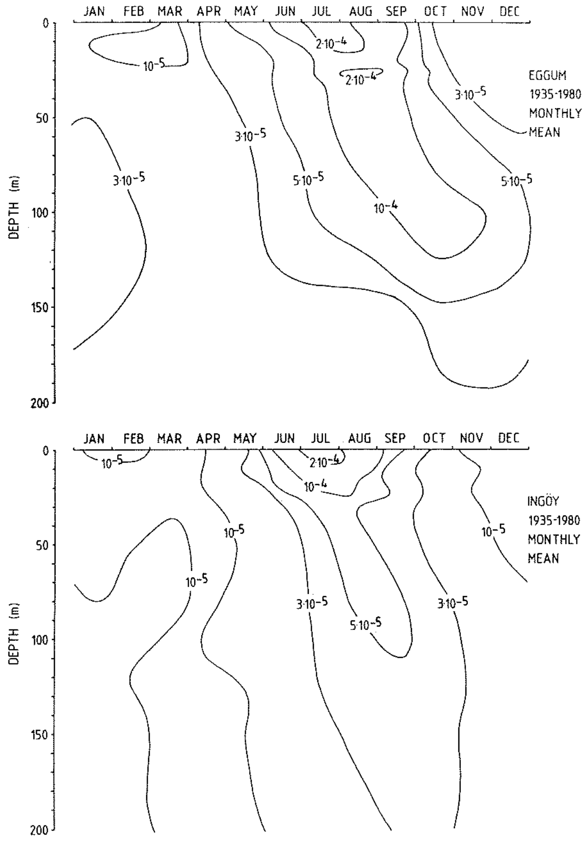

Fig. 4. Isopleths of the squared Brunt-Vaisälä frequency, N^2, for the mean year for the fixed stations Eggum and Ingøy (positions of these stations are shown in Fig. 1).

The four major surveys were all conducted in the middle period of spring (Table 1). At this time of year, the vertical conditions are relatively homogeneous. Only at some few nearshore stations is a slight temperature increase observed in the upper 5–10 m. Five of the eight minor surveys were also conducted at a time of year when homogeneous conditions prevailed; namely, in October, March, April, and May. One survey was conducted towards the end of June. At that time, the upper layer was only weakly stratified. Only the two cruises of 31 July–1 August 1975 and 19 August 1982 (Table 2) were conducted during well-developed stratified conditions.

THE FOUR MAJOR SURVEYS

HYDROGRAPHY

The four major surveys were all conducted at nearly the same time of year, within a three-week period in April or May. Therefore, the general hydrographic conditions are expected to be similar for all four surveys. Characteristic features of the season are the following. The static stability of the water column is low. The squared Brunt-Väisälä frequency, N^2, was approximately $1–2\times10^{-5}$ s^{-2} from sea surface to the bottom. The density gradient was largest from 30 to 50 m depth.

Fig. 5 shows some density profiles for each of the sections for each survey. Only at the innermost stations of section d (Fig. 3) was a significant stratification of the upper 30 m observed. Here the squared Brunt-Väisälä frequency, N^2, reached $2–4\times10^{-4}$ s^{-2}. It is evidently a local feature due to outflow of low-salinity fjord water.

There is a strong relation between salinity and temperature of the Coastal water at this time of the year. Fig. 6 shows temperature-salinity or T–S plots for all stations for each of the years. Three types of water are present:

1. Northern Norwegian Coastal water, NNC, which is found close to the coast.
2. Atlantic water, A, with the core just outside the shelf break.
3. Norwegian Sea deep water, ND, which is present in the deep basin of the Norwegian Sea.

The water mass represented by the line A–ND only occurs at greater depths off the shelf break. Inside the shelf break the water mass A–NNC is present. Because of the close relationship between temperature and salinity, the horizontal distribution patterns of temperature and salinity are roughly similar. Therefore, only maps of the temperature distribution are presented.

Figs 7, 8, 9 and 10 show the temperature distribution at 20 m depth for the four synoptic surveys. The distribution at this depth is a good representation of the hydrography of the upper 50 m. As already mentioned, Nordvestbanken (area C in Fig. 2) was fully covered only in 1982. All situations show similar

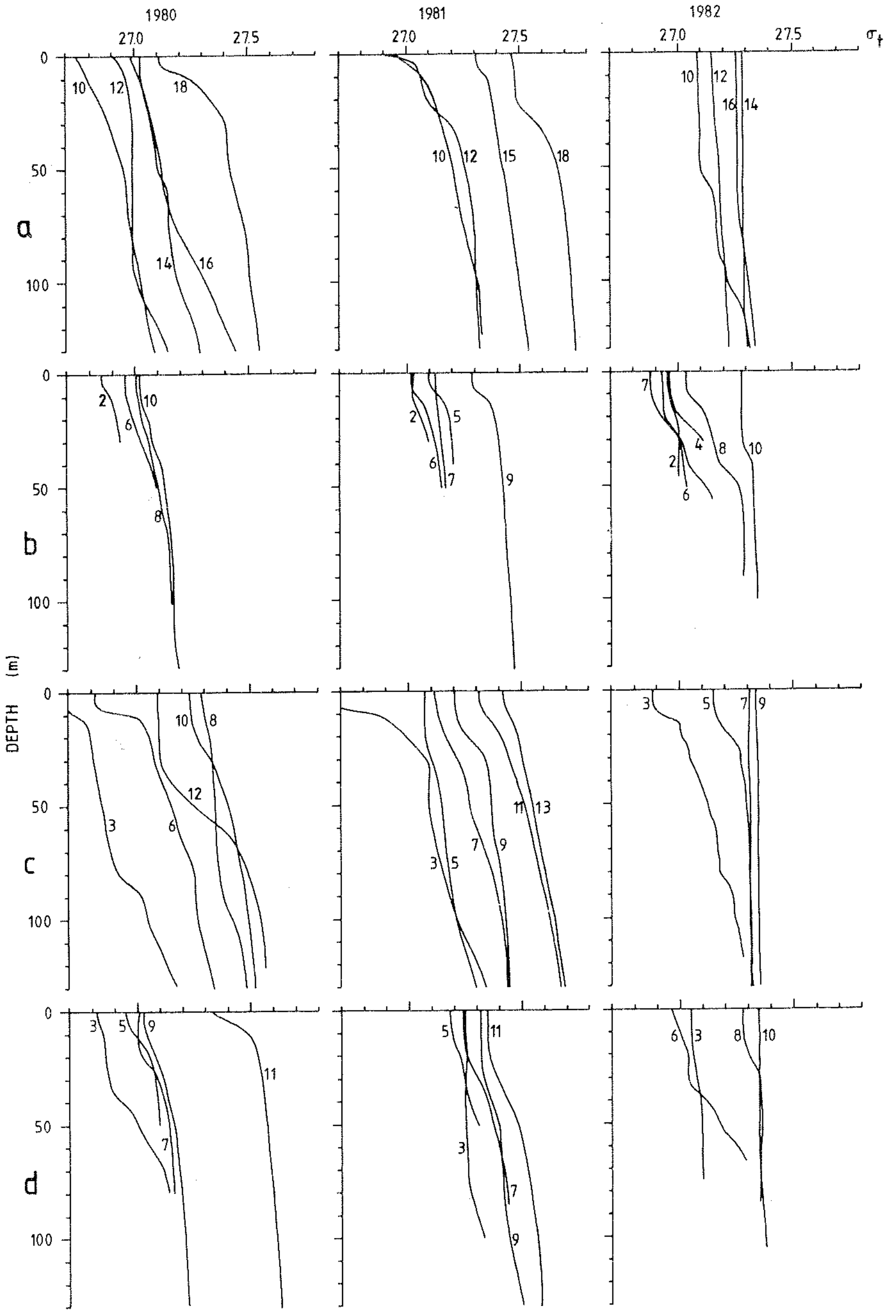

Fig. 5. Density profiles, σt, for selected stations in the sections b, c, d, and e (see Fig. 3) for synoptic surveys in May 1980, May 1981 and April 1982.

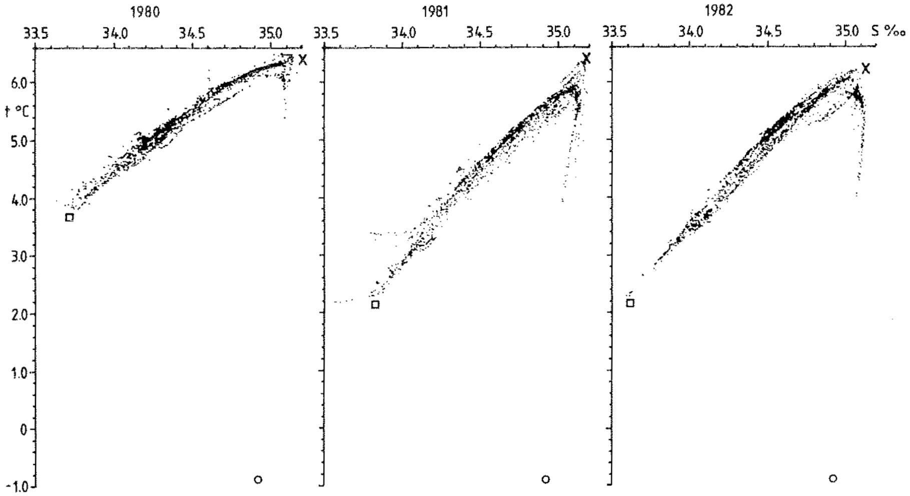

Fig. 6. Temperature-salinity characteristics of water masses during winter off northern Norway. □: Northern Norwegian Coastal water (NNC), x: Atlantic water (A), o: Norwegian Sea Deep water (ND).

features. The cold Coastal water spreads out over the banks, and the warmer Atlantic water intrudes into the intervening troughs. The main front between the Atlantic and Coastal water masses is located at the shelf break. However, it also intrudes into the troughs. In particular, at the northern edge of Sveinsgrunnen (A in Fig. 2), which faces Malangsdjupet (II in Fig. 2), the front was strong during the surveys, indicating a strong inflow of Atlantic water in Malangsdjupet.

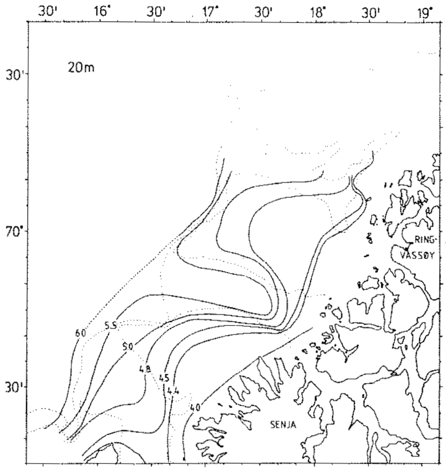

Fig. 7. Temperature distribution at 20 m depth, 5–7 May 1980.

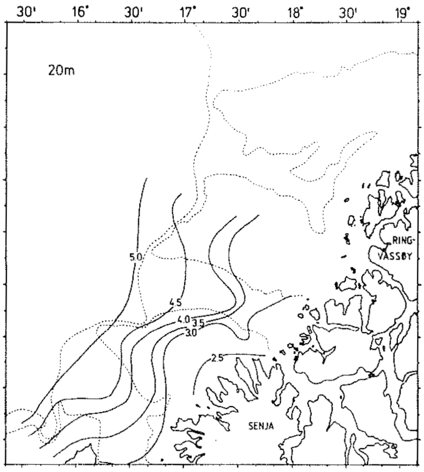

Fig. 8. Temperature distribution at 20 m depth, 29 April–1 May 1981.

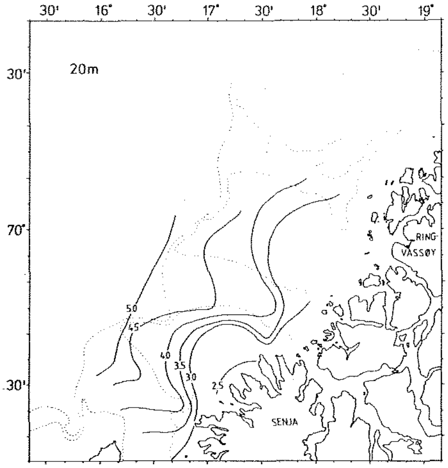

Fig. 9. Temperature distribution at 20 m depth, 2–4 May 1981.

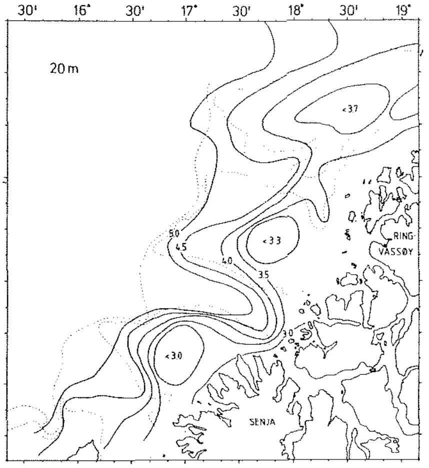

Fig. 10. Temperature distribution at 20 m depth, 17–20 April 1982

The hydrography of the upper layer for the 1982 survey differs in one way from the other surveys: A temperature minimum, hence also salinity and density minima, exists above the banks, appearing through the closed isotherms in Fig. 10. This did not occur during the three first surveys (Figs 7, 8 and 9), when the temperature monotonically decreased from the shelf edge to the coastline. These different hydrographic features may indicate slightly varying bank circulations. While the first feature indicates closed streamlines, and consequently, the presence of a vortex, the second feature indicates that the circulation merely decribes a bend around the banks.

SATELLITE-TRACKED DROGUES

During the two quasi-synoptic surveys in 1981, two satellite-tracked buoys (the ARGOS system), drogued with sail at 30 m depth, were released. The buoys were positioned on the average nine times each day. The trajectories of the buoys are shown in Fig. 11. The buoys were released 18 km apart, but both on the same 200 m isobath. They drifted more or less along the 200 m isobath around Sveinsgrunnen. Then they crossed Malangsdjupet (II) and turned towards the northwest, and crossed the 200 m isobath at an angle of about 45 degrees. Crossing the western part of Malangsgrunnen (B), their speed was considerably reduced, especially that of the easternmost drogue. During 58 hours of drift, this drogue described four clockwise loops, most probably indicating semidiurnal tidal movements. Table 3 shows mean, maximum, and minimum speeds of the drifting buoys in different subareas (see Fig. 2). It indicates that the speed is higher at the shelf edge than above the banks. This is

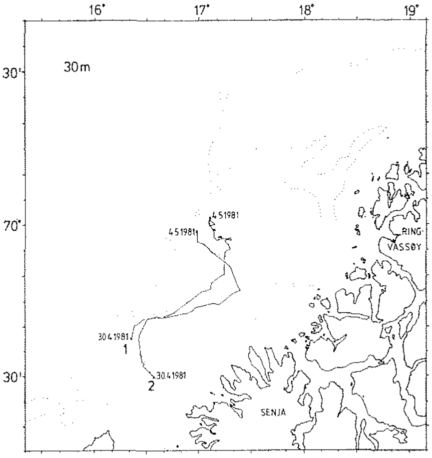

Fig. 11. Trajectories of two ARGOS-buoys, 30 April–4 May 1981

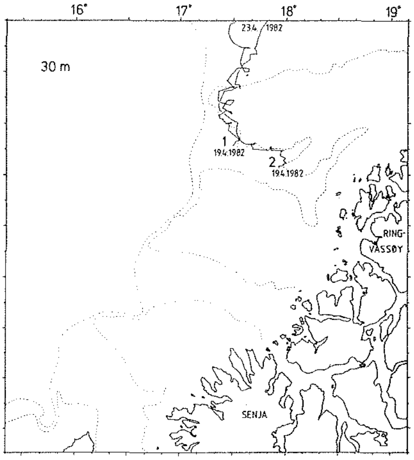

Fig. 12. Trajectories of two ARGOS-buoys, 19–23 April 1982.

Table 3. Mean, maximum and minimum speeds, cm/s, of drifting buoys 30 April–4 May 1981, and hours of drift within the subareas. A = Sveinsgrunnen, II = Malangsdjupet, and B = Malangsgrunnen.

Buoy number	Subarea											
	A				II				B			
	Speed			Hours	Speed			Hours	Speed			Hours
	Mean	Max	Min		Mean	Max	Min		Mean	Max	Min	
1	29	43	14	30	21	38	14	24	15 (7*)	31	2	58
2	21	50	9	76	27	32	9	24	21	35	14	12

* indicate «residual» drifting speed, i.e. fluctuations due to tidal movements are subtracted.

particularly clear at Malangsgrunnen (B). Here the residual current of buoy 1 was only 7 cm/s, while the speed of buoy 2 farther out towards the shelf edge was 21 cm/s. One radartracked drifting buoy, which was released at the shelf edge to the west of Malangsgrunnen (B) during the recovery of the two satellite buoys, drifted northwards at a speed of about 40 cm/s. This indicates a considerable current shear between the shelf edge and the banks. It is also noted that the trajectories appearing in Fig. 11 are remarkably parallel to the temperature and salinity isolines of the upper layer (Figs 8 and 9).

During the survey in 1982, two satellite-tracked drogues were released 18 km apart at the southern edge of Nordvestbanken. They were drogued at 30 m depth. The trajectories are shown in Fig. 12, and Table 4 shows drift velocities of the buoys. The drift patterns are similar to those of the first experiment with respect to the bottom topography (Fig. 11). The buoys drifted around the bank, and the trajectories in Fig. 10 are parallel to the isotherms. However, the semidiurnal clockwise loops are more pronounced here. As shown in Table 4, the speed is lower than during the first drift experiment (Table 3).

Table 4. Mean, maximum and minimum speeds, cm/s, of drifting buoys 19 April–23 April 1982, and hours of drift within the sub areas. C = Nordvestbanken, IV = Tromsøflaket Trough.

Buoy number	Sub area							
	C				IV			
	Speed			Hours	Speed			Hours
	Mean	Max	Min		Mean	Max	Min	
1	16 (13*)	49	2	50	20 (18*)	60	1	45
2	18 (17*)	77	1	74	14	42	1	23

* indicate «residual» drifting speed, i.e. fluctuations due to tidal movements are subtracted.

DISTRIBUTION OF PELAGIC EGGS

The Arcto-Norwegian cod spawns during March and April at certain locations near the coast of northern Norway. The eggs are mainly confined to the upper 50 m, depending on the conditions of vertical mixing (Solemdal and Sundby 1981, Sundby 1983). Within the present investigated area, spawning occurs mainly at the slope of the southern part of Sveinsgrunnen and

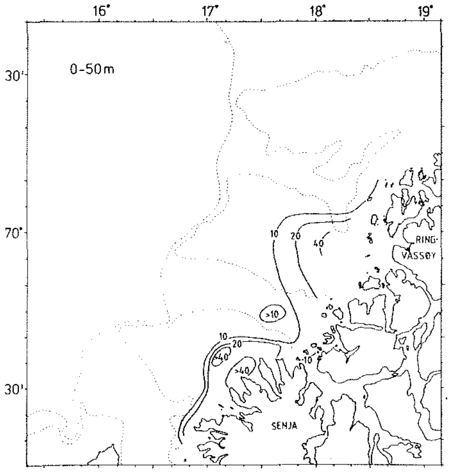

Fig. 13. Distribution of cod eggs of the upper layer. 0–50 m depth, 5–7 May 1980. Numbers/m^2 surface.

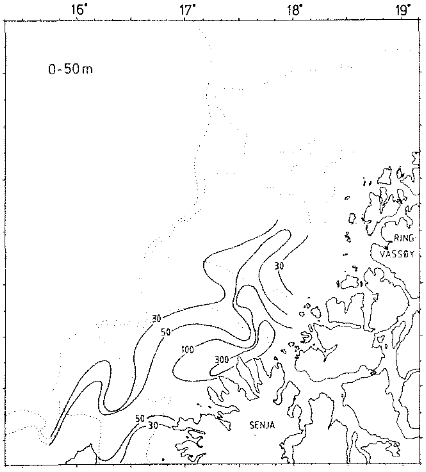

Fig. 14. Distribution of cod eggs of the upper layer, 0–50 m depth, 29 April–1 May 1981. Numbers/m^2 surface.

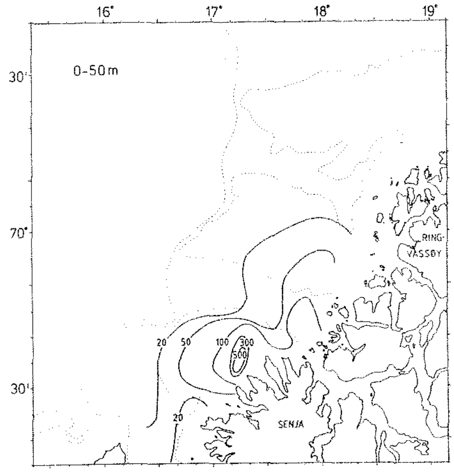

Fig. 15. Distribution of cod eggs of the upper layer, 0–50 m depth, 2–4 May 1981. Numbers/m² surface.

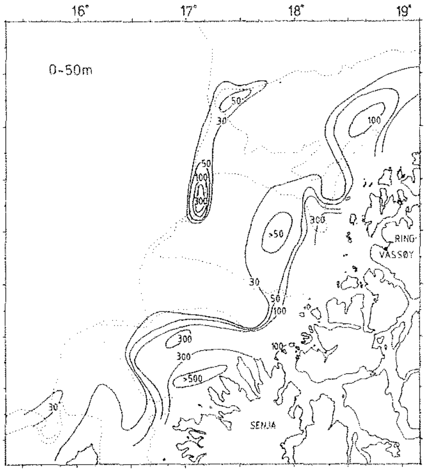

Fig. 16. Distribution of cod and haddock eggs of the upper layer, 0–50 m depth, 15–17 April 1982. Numbers/m² surface.

between Malangsgrunnen and the coast. The shadings in Fig. 2 indicate the main spawning grounds of cod. Spawning occurs to a lesser extent in a larger area along the slopes of the bank, but the precise location of the spawning varies from one year to the next.

Figs 13, 14, 15 and 16 show the distribution of pelagic eggs from the four surveys. In Figs 13, 14 and 15 all stages of the eggs are included, hence some may be as old as 20-days. However, the greater number are younger than 7 days. In Fig. 16 only eggs younger than 7 days are included. This figure contains two separate fields of egg distribution. Cod eggs have been identified in the nearshore field, which spreads out above the banks. Most of these are believed to come from the two spawning grounds shaded in Fig. 2. The other egg field, extending along the shelf edge, is determined by electroforetic techniques to contain mainly eggs of haddock (JARLE MORK, personal communication). The haddock spawns at the shelf edge off northern Norway. The exact locations of haddock spawning are not known, but the stage of the eggs in this particular case indicates that spawning occurred at the locations of highest concentration, i.e., at the western edge of Malangsgrunnen. In Figs 13, 14 and 15 only cod eggs are believed to be present. The main features of the cod egg distribution are similar in all four cases: the distribution spreads out in the Coastal water, above the banks, while close to the shore, in the troughs, it is contracted. This indicates a circulation of the upper layer corresponding to that of the water masses (Figs 7–10) and the trajectories of the ARGOS-buoys (Fig. 11).

THE EIGHT MINOR SURVEYS

Five of the surveys were conducted during relatively homogeneous conditions. The horizontal distributions of salinity or temperature are shown in Figs 17, 18, 19, 20 and 21. Because of the sparseness of stations, the isolines are much more uncertain in these cases than for the major surveys. However, the results from these surveys also indicate that the water above the banks is less saline and colder than the water above the troughs.

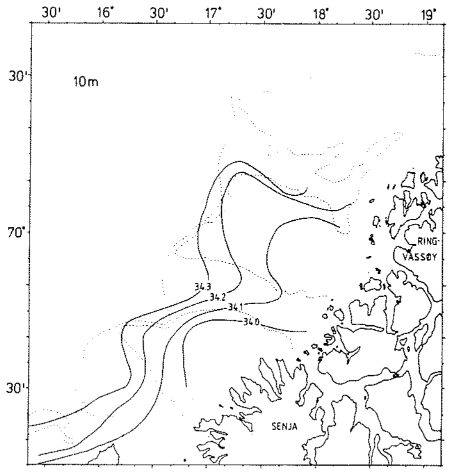

Fig. 17. Salinity at 10 m depth, 9–10 May 1974

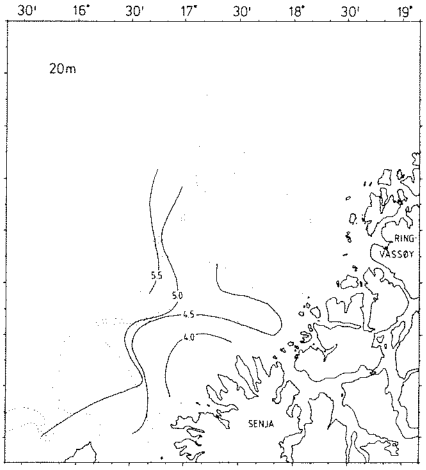

Fig. 18. Temperature at 20 m depth, 14 April 1975.

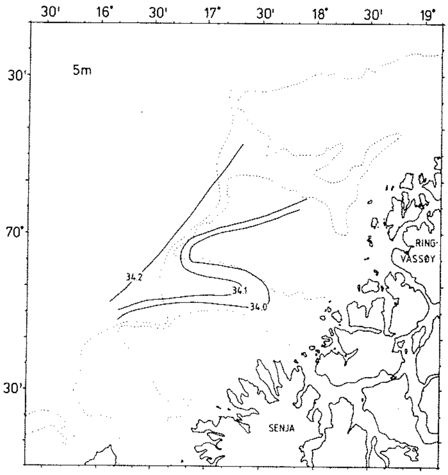

Fig. 19. Salinity at 5 m depth, 10–11 May 1975.

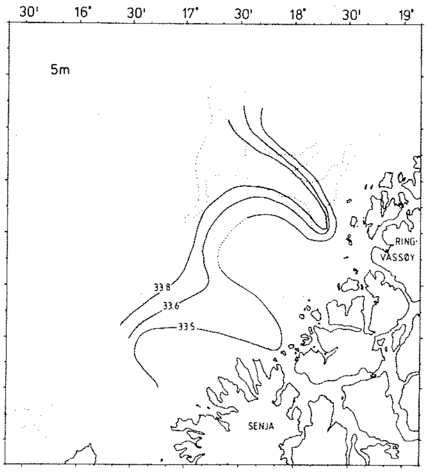

Fig. 20. Salinity at 5 m depth, 12–13 October 1975.

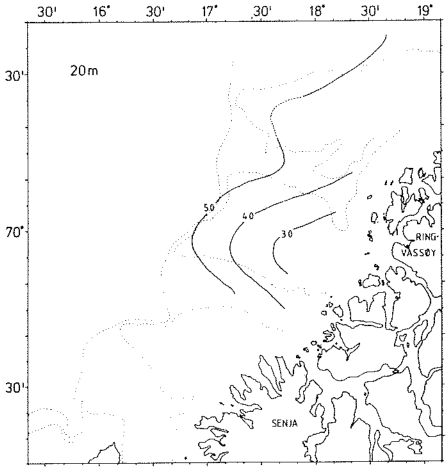

Fig. 21. Temperature at 20 m depth, 19–21 March 1980.

Figs 22, 23 and 24 show the horizontal distributions of salinity from the surveys during summer conditions. Fig. 22 shows the distribution at 5 m depth on 22–25 June 1975. Only moderate stratification was developed at that time. Again, only the station at the mouth of Malangen (see Fig. 1) shows stratification which occurs in the upper 20 m.

Fig. 23 shows the salinity distribution at 5 m depth 31 July – 1 August 1975. Stratification was developed as shown by the vertical density profiles in Fig. 25.

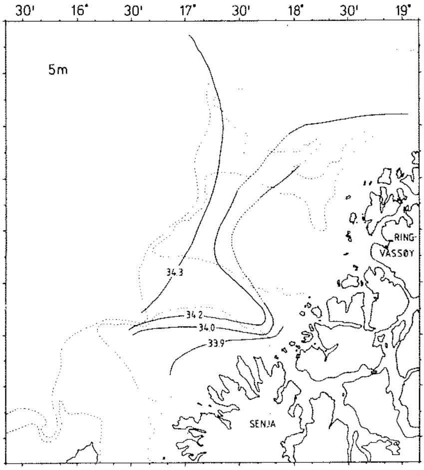

Fig. 22. Salinity at 5 m depth, 22–25 June 1975.

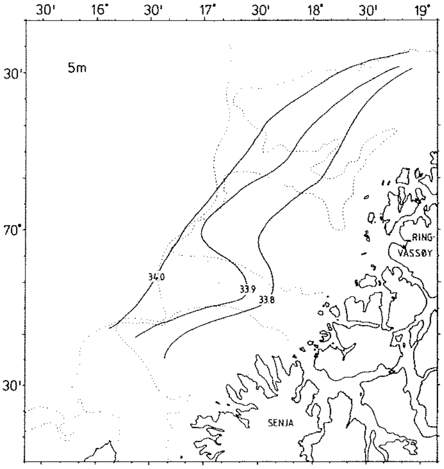

Fig. 23. Salinity at 5 m depth, 31 July–1 August 1975.

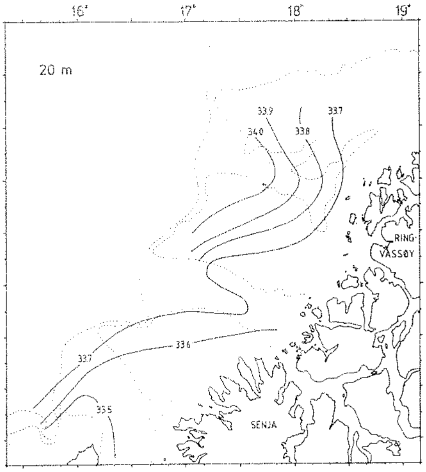

Fig. 24. Salinity at 20 m depth, 19 August 1982.

The squared Brunt-Väisälä frequency of the upper 50 m is 1–3×10^{-4} s^{-2}. This value corresponds well with those of the mean year shown in Fig. 4. Nevertheless, more saline water is also present for the stratified situation above Malangsdjupet (II in Fig. 2) showing the presence of Atlantic water.

The last survey, on 19 August 1982, was also conducted during well-stratified conditions, as shown in Fig. 25. The squared Brunt-Väisälä frequency is 2–4×10^{-4} s^{-2}. Fig. 24 shows the salinity distribution at 20 m depth. It indicates intrusion of more saline water in Andfjorddjupet (I in Fig. 2) and Malangsdjupet (II in Fig. 2). However, this also seems to flush the western part of Malangsgrunnen (B in Fig. 2).

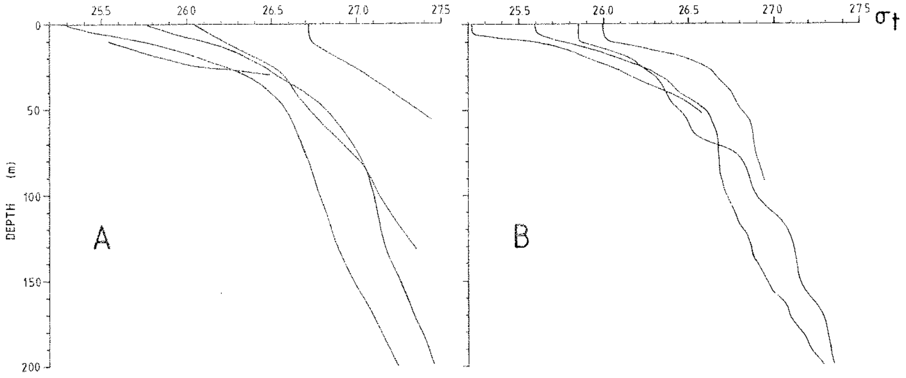

Fig. 25. Density profiles, σ_t, for selected stations at surveys during stratified conditions. A) 31 July–1 August 1975. B) 19 August 1982.

DISCUSSION

The results from the presented surveys, demonstrate that the distribution of the water masses and the horizontal circulation throughout the water column are highly influenced by the bottom topography. The features seem to be permanent during the homogeneous conditions which occur in the period from October to May. However, the features are definitely not identical for the different surveys. The intrusion of the Atlantic water into Malangsdjupet (II in Fig. 2) was stronger during the major cruises of 1980 and 1982 (Figs 7 and 10) than during those of 1981 (Figs 8 and 9). The intrusion of Atlantic water into Andfjorddjupet (I in Fig. 2) also seems to vary. It is most probably caused by short time variations. This is supported by the results from the two major surveys of 1981, which were conducted with an interval of only two days. The intrusion of Atlantic water into Andfjorddjupet (I) and Malangsdjupet (II) increased during this period of time. This is also confirmed by the trajectories of the drifting buoys. Buoy no. 1, which crossed Malangsdjupet (II) on 1 May, had a straighter trajectory across Malangsdjupet than buoy no. 2 which crossed Malangsdjupet on the 3 May.

The variations described above may contribute to the mixing of Atlantic and Coastal water masses. In general, the temperature of the Coastal water decreases northwards during the winter. However, in the investigated area it increases with northerliness. This appears most clearly in Fig. 10. It may be caused partly by the outflow of cold water from Andfjorden, but mainly it must be due to mixing of Atlantic and Coastal water.

Although few data are available for stratified conditions, which occur from June to September, these data indicate that Atlantic water invariably intrudes into Malangsdjupet (II in Fig. 2). However, the inflow of Atlantic water into the Malangsgrunnen-Nordvestbanken Trough is less regular (III in Fig. 2). During the survey 31 July–1 August 1975 (Fig. 23) this inflow was slight, but during the survey 19 August 1982 the inflow was pronounced. There are also winter situations where the Atlantic inflow into the Malangsgrunnen-Nordvestbanken Trough is slight. It must therefore be concluded that the inflow of Atlantic water into this trough is less stable than the Atlantic inflow into Malangsdjupet.

As pointed out in the Introduction, Eide (1979) has demonstrated the influence of the obstacle Haltenbanken off the mid-Norwegian coast. He discussed the conditions for a topographically trapped vortex above the bank. For the homogeneous case, closed streamlines will form when the dimensionless product h_0R^{-1} of the fractional height, h_0, of the obstacle and the inverse Rossby number, R^{-1}, exceeds a number between 2 and 4, depending upon the shape of the obstacle. This was outlined by Huppert (1975). For Haltenbanken Eide (1979) estimated h_0R^{-1} to about 50. For Sveinsgrunnen, Malangsgrunnen, and Nordvestbanken the number is respectively about 13, 11 and 9.

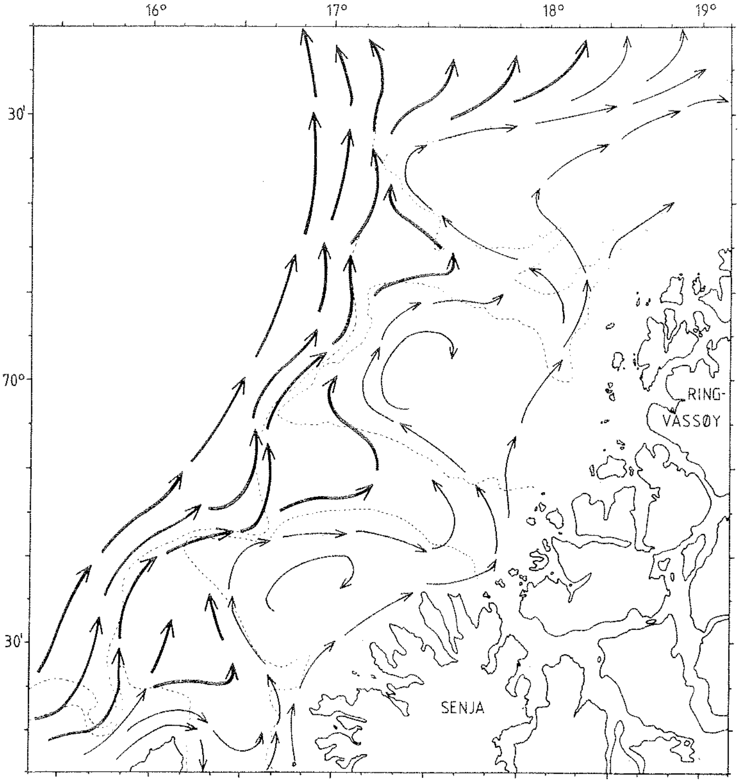

Fig. 26 Tentative map of the circulation in the upper layer during homogeneous conditions, i.e. October–May. Thin arrows: Coastal Water. Heavy arrows: Atlantic Water.

Thus, in the homogeneous case the conditions for formation of closed streamlines should be present for all three banks. However, it must be pointed out that the topographical formations here are not equivalent to Haltenbanken which rises from a relatively wide and flat seabed. In the investigated area, the high-velocity Atlantic current flows northwards along the shelf edge, which coincides with the western slopes of the banks. The Atlantic current may therefore influence the flow of the Coastal water above the banks. Since the inflow of Atlantic water into the troughs may oscillate, and the instrusion of Atlantic water seems to be maintained during stratified conditions, the topographical influence may be generated by dynamics of the Atlantic current rather than by Taylor columns og the coastal water.

Different explanations for the pulsation of the Atlantic water into the troughs may be advanced. A simple explanation, which is probably obvious, is found in the balance between the Coriolis- and centrifugal-forces of the Atlantic current.

In this case the current velocity along the shelf edge and the current velocity into the troughs should vary inversely. The characteristic shelf-edge speed is about 50 cm/s which corresponds to a radius of the inertial circle of about 4 km. The radii of curvatures of the banks vary from 3 to 5 km. Thus, the speed of the shelf current could be an important parametre describing intrusion into the troughs.

Based on the hydrograpic data, the current drogues, and data on cod eggs, a tentative map of the mean current circulation of the upper layer is drawn (Fig. 26). These features represent the period from October to June. During stratified conditions from June to September it is expected that the topographically dependent current features are less pronounced. However, the inflow of Atlantic water into Malangsdjupet also seems to be present, from the bottom to surface, during summer.

REFERENCES

EIDE, L.I 1974. Current measurements on Malangsgrunnen. *Report 2. River and Harbour Laboratory, University of Trondheim, Trondheim 1974*:1-6. 137 figs. [In Norwegian].

EIDE, L.I. 1975. Current measurements on Malangsgrunnen. *Report 3. River and Harbour Laboratory, University of Trondheim, Trondheim 1975*:1-6. 155 figs. [In Norwegian].

EIDE, L.I. 1976. Current measurements on Malangsgrunnen. *Report 4. River and Harbour Laboratory, University of Trondheim. Trondheim 1976*:1-3. 26 figs. [In Norwegian].

EIDE, L.I. 1979. Evidence of a topographically trapped vortex on the Norwegian continental shelf. *Deep Sea Res., 26* (6A): 601–621.

HUPPERT, H.E. 1975. Some remarks on the initiation of inertial Taylor columns. *J. Fluid Mech., 67*: 397–412.

KISLYAKOV, A.G. 1964. The horisontal circulation of the waters on the border between the Norwegian Sea and the Barents Sea. *Trudy polyar. nauchno-isled. Inst. morsk. ryb. Khoz. Okeanogr., 16*: 183–194. [In Russian].

LJØEN, R. 1962. The waters of the western and northern coasts of Norway in July–August 1957. *FiskDir. Skr. Ser. HavUnders. 13*(2): 1–39.

SOLEMDAL, P. and SUNDBY, S. 1981. Vertical distribution of pelagic fish eggs in relation to species, spawning behaviour and wind conditions. *Coun. Meet. Int. Coun. Explor. Sea, 1981* (G:77): 1–27. [Mimeo.]

SUNDBY, S. 1976. Oseanografiske forhold i området Malangsgrunnen–Fugløybanken–Tromsøflaket. En oversikt. *Fisken og Havet Ser. B, 1976* (1): 1–53.

SUNDBY, S. 1983. A one-dimensional model for the vertical distribution of pelagic fish eggs in the mixed layer. *Deep Sea Res., 30* (6A): 645–661.

SÆTRE, H.J. 1973. Current measurements on Malangsgrunnen. *Report 1. River and Harbour Laboratory, University of Trondheim, Trondheim 1973*:1-6. 42 figs.

SÆTRE, R. and LJØEN, R. 1971. The Norwegian coastal current. *Proc. of the first international conference on port and ocean engineering under Arctic conditions. University of Trondheim, 1971*: 514–536.

Received 21 November 1983
Printed 28 August 1984