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ARCTIC INTERMEDIATE WATER IN THE NORWEGIAN SEA

by

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ABSTRACT

Two types of intermediate water propagate into the Norwegian Sea from the Iceland and Greenland seas. North Icelandic Winter water flows along the slope of the Faroe-Iceland Ridge towards the Faroes . The distribution of this intermediate water is limited to the southern Norwegian Sea.

The second type intrudes between the bottom water and the Atlantic water, and can be traced as a slight salinity minimum over the entire area of the Norwegian Sea. There seems to be along-isopycnal advection of this water type along the arctic front from both the Iceland and Greenland seas. Although the salinity minimum is less distinct along the slope of the continental shelf than in the western Norwegian Sea, this intermediate water acts as an isolating layer between the deep water and the Atlantic water.

INTRODUCTION

Since the beginning of the century it has been known that Arctic Intermediate water (AIW) flows with the East Icelandic Current into the southwestern Norwegian Sea. Helland-Hansen and Nansen (1909) described a tongue of water with low temperature and salinity between 34.86 and 34.90 along the slope of the Faroe-Iceland Ridge. They concluded that it follows the cyclonic movement of the southern Norwegian Sea and that it comes from the deeper layers of the East Icelandic Current, being Arctic water of the kind which occurs near the slope of the Iceland platform.

Meincke (1978) described the distribution of low salinity intermediate water around the Faroes and ascribed its major component to the North Icelandic winter water. This water mass was defined by Stefansson (1962) who concluded that it is formed on the North Icelandic shelf during winter. This is one of several modifications of intermediate water found in the Iceland Sea. Swift and Aagaard (1981) studied water mass formation in the Iceland Sea and defined several types of AIW. The propagation of these water masses beyond the Iceland Sea is not fully described. Characteristics of the intermediate water along the slope of the Faroe Iceland Ridge and its distribution into the Faroe-Shetland Channel has been fairly well elucidated. In the central Norwegian Sea, Leinebø (1969) found evidence of an intermediate salinity minimum associated with a maximum in oxygen content between 600 and 800 m depth at Ocean Weather Station M and suggested the area between Iceland and Jan Mayen as its origin. In addition to this, little attention has been given to AIW in the Norwegian Sea Basin. The present paper gives some information on its properties and distribution.

DATA

The work is based on data from the years 1980, 1982 and 1985, collected by research vessels from the Institute of Marinr Research, Bergen. Some of the stations from 1980 were worked with reversing water bottles, while the rest were worked with Brown CTD-systems. Obserwations were made to 1000 m or deeper. In 1985 samples for salinity calibration were collected at every station with a General Oceanics rosette sampler. In the other years a reversing water bottle was used for calibration, and samples were not collected at all stations. The absolute accuracy of the salinity data from 1985 is better than 0.01 while it is more uncertain in the other years. The data from 1982 were, however, collected by three vessels and agree in salinity to within 0.01 in the deep water. The salinity samples were determined on Australian Industria salinometers.

According to calibrations in the laboratory the temperature sensors of the CTD-systems were stable during the observation periods with an accuracy to within 0.005^{0}C. During the cruises CTD temperature readings were checked against reversing thermometers.

Also, the pressure sensors were calibrated only in the laboratory. According to specifications given by the producer of the calibration pressure gage, the accuracy of these calibrations were 0.1% of the total pressure

WATER MASSES

Atlantic water (AW) in this area is traditionally defined as any water with salinity greater than 35.0. The TS-relationship of the present data set indicates that a salinity of 35.0 is associated with a temperature of 2^{0}C.

Norwegian Sea deep water (NSDW) is colder than -0.5^{0}C and its salinity is 34.92.

North Icelandic Winter Water (NIWW) has, according to Stefansson (1962), usually a temperature range from 2^0 to 3^{0}C and a salinity of 34.85-34.90, but may be somewhat variable in composition. Accordingly, Martin (1976) and Dooley et al. (1984) have described time variations in this water mass, and Meincke (1978) defined NIWW, as observed in the Faroe Area in summer 1977, to be water with salinity less than 34.78 and temperature above 3.0^{0}C.

Arctic Intermediate water (AIW) in the Norwegian Sea is found in a layer between the AW and the NSDW and has a temperature range from -0.5^0, to $+1.0^0C$ and salinities between 34.87 and 34.91. AIW in the Iceland Sea, which is its origin, has according to Stefansson (1962) temperatures between 2^0 and 3^0C and a salinity range from 34.8 to 35.0. Swift and Aagaard (1981) defined three types of intermediate water in the Iceland Sea: "upper AIW", with temperature less than 2^0C and salinity in the range 34.7 to 34.9; "lower AIW", with temperatures in the range 0^0 to 3^0C and salinity greater than 34.9; and Polar Intermediate water (PIW), colder than 0^0C with a salinity in the range 34.4 to 34.7.

None of the above definitions covers the characteristics of the AIW in the Norwegian Sea. Some data from the Iceland Sea and the southern Greenland Sea, observed in August 1985, may be used to illustrate the properties of this intermediate water in its formation area. Fig 1A shows the TS-relationship at the stations in the western and northern parts of the Iceland Sea and the southern Greenland Sea which are indicated in the figure. Typical for all these stations is an intermediate maximum both in temperature and salinity, ranging up to 2^0C and 34.96, respectively. This is in agreement with the "lower AIW" defined by Swift and Aagaard (1981). However, between this maximum and the bottom water, there is a slight salinity minimum in the range 34.89-34.91, associated with temperatures between -0.5 and $+0.5^0C$.

At stations in the central Iceland Sea shown in Fig. 1B, there is no such salinity maximum in the TS-relationship. The intermediate layer on top of the deep water is only indicated by a slight temperature maximum ranging between -0.3^0 and $+0.1^0C$. The envelope of the TS-plot for these stations is entered in Fig. 1A and shows that the AIW in the central Iceland Sea is colder and fresher than the AIW further to the west and north. In 1980 (Fig. 9) also the intermediate water in the frontal area north of Jan Mayen had properties similar to those shown in Fig. 1B. The maximum temperatures were only slightly above 0^0C and the associated salinities were in the range from 34.87 to 34.90.

According to the terminology of Swift and Aagaard (1981), this water may be a mixture of "lower AIW", PIW and NSDW. It may also have been formed in the central Iceland Sea by cooling and convection during the winter. In either case, this intermediate water mass is found in areas bordering on the Norwegian Sea both in the Iceland and Greenland Seas and may be defined by the temperature range -0.5^0 to $+1.0^0C$ and salinities in the range 34.87 - 34.91.

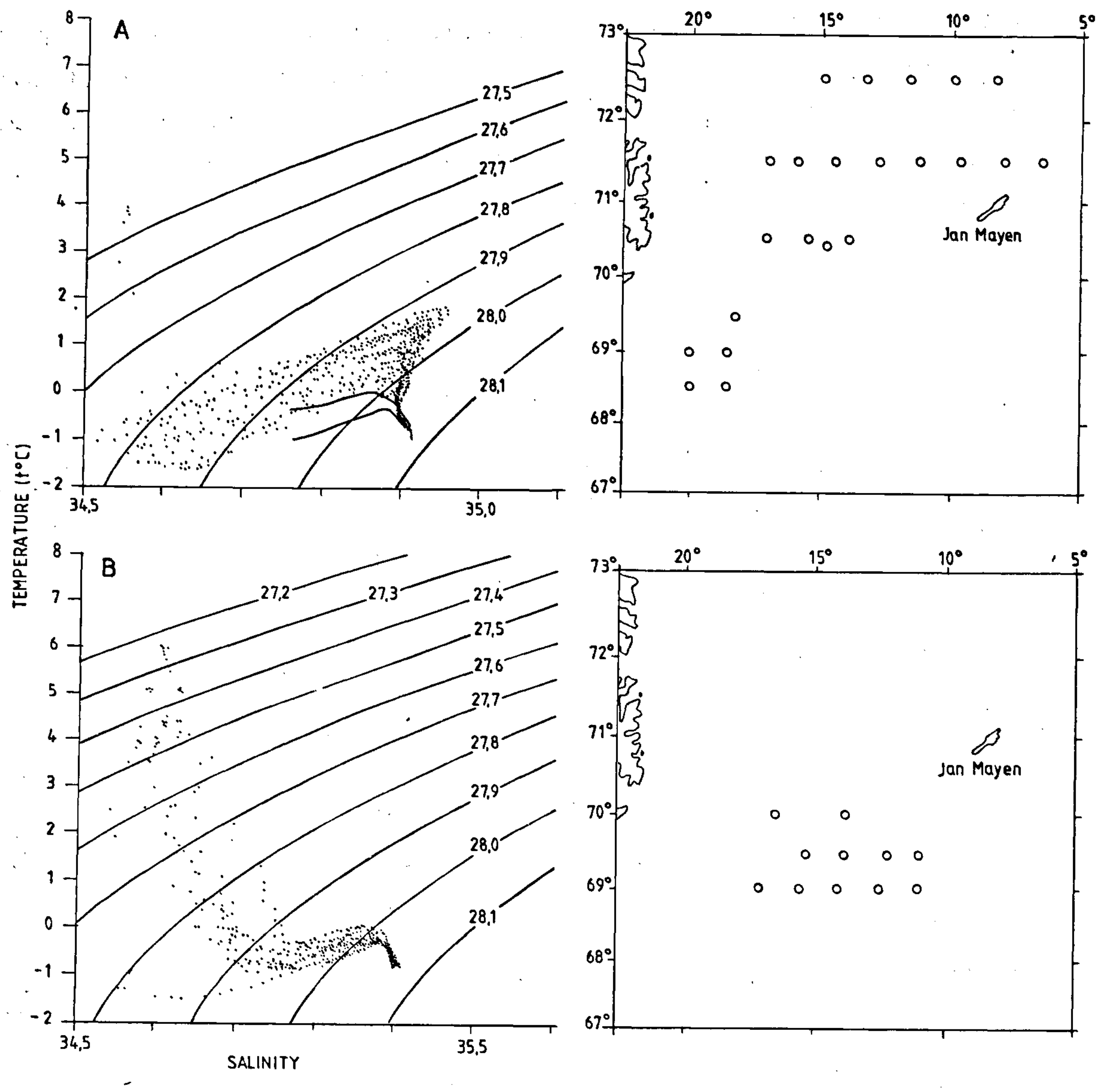

Figure 1. TS-relationship in the Iceland Sea and southern Greenland Sea in August 1985. Positions of stations are shown. The envelope of the TS-plot for the central Iceland Sea, B, is entered in A.

DISTRIBUTION OF THE ARCTIC INTERMEDIATE WATER.

Fig. 2 shows TS-relationships from four CTD-stations in the Norwegian Sea. All of them are from August 1982 and as shown in the figure, they were widely separated. The observations from the station near 64^0N, which is symbolized by open rings, showed two salinity minima. In the upper one at 200 m, the temperature was about 2.5^0C and the salinity below 34.88. This is associated with NIWW and was observed only on some stations in the southwestern part of the area. The second salinity minimum at a temperature around 0^0C, which is due to AIW, was observed at all four stations and shows that this water is widely distributed in the Norwegian Sea Basin.

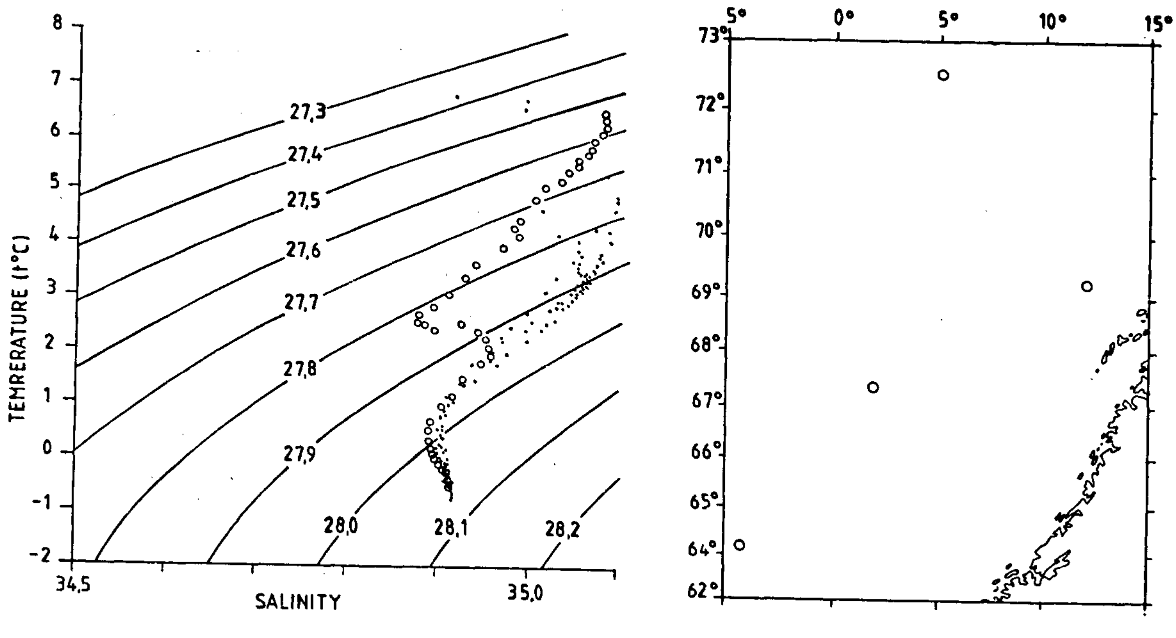

Figure 2. TS-relationship and positions of four stations from August 1982. The station near 64^0N is symbolized by open rings.

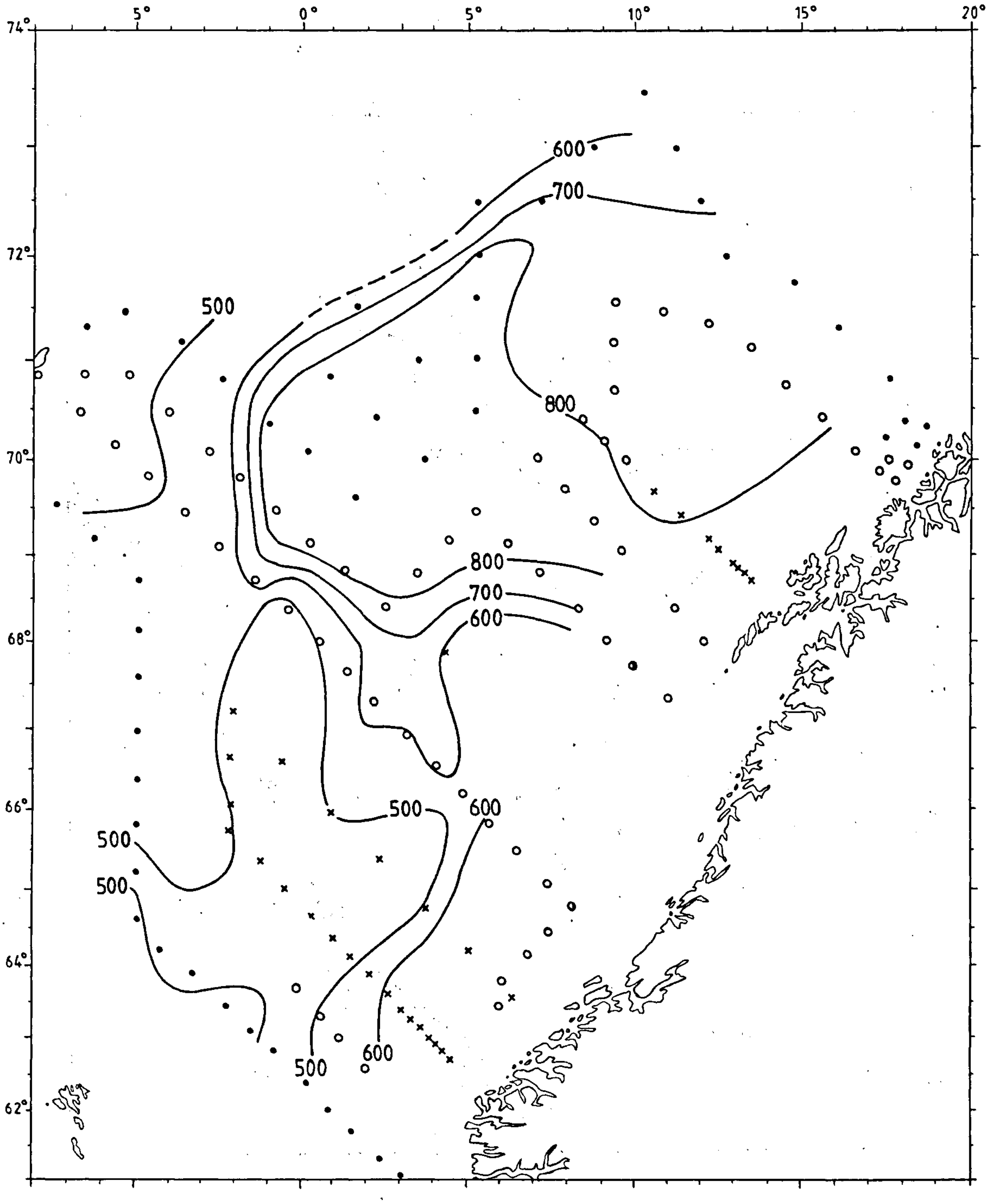

Figure 3. Depth of the minimum salinity in the Arctic Intermediate water in August 1982. Positions of observations are indicated with different symbols for the three vessels participating in the survey.

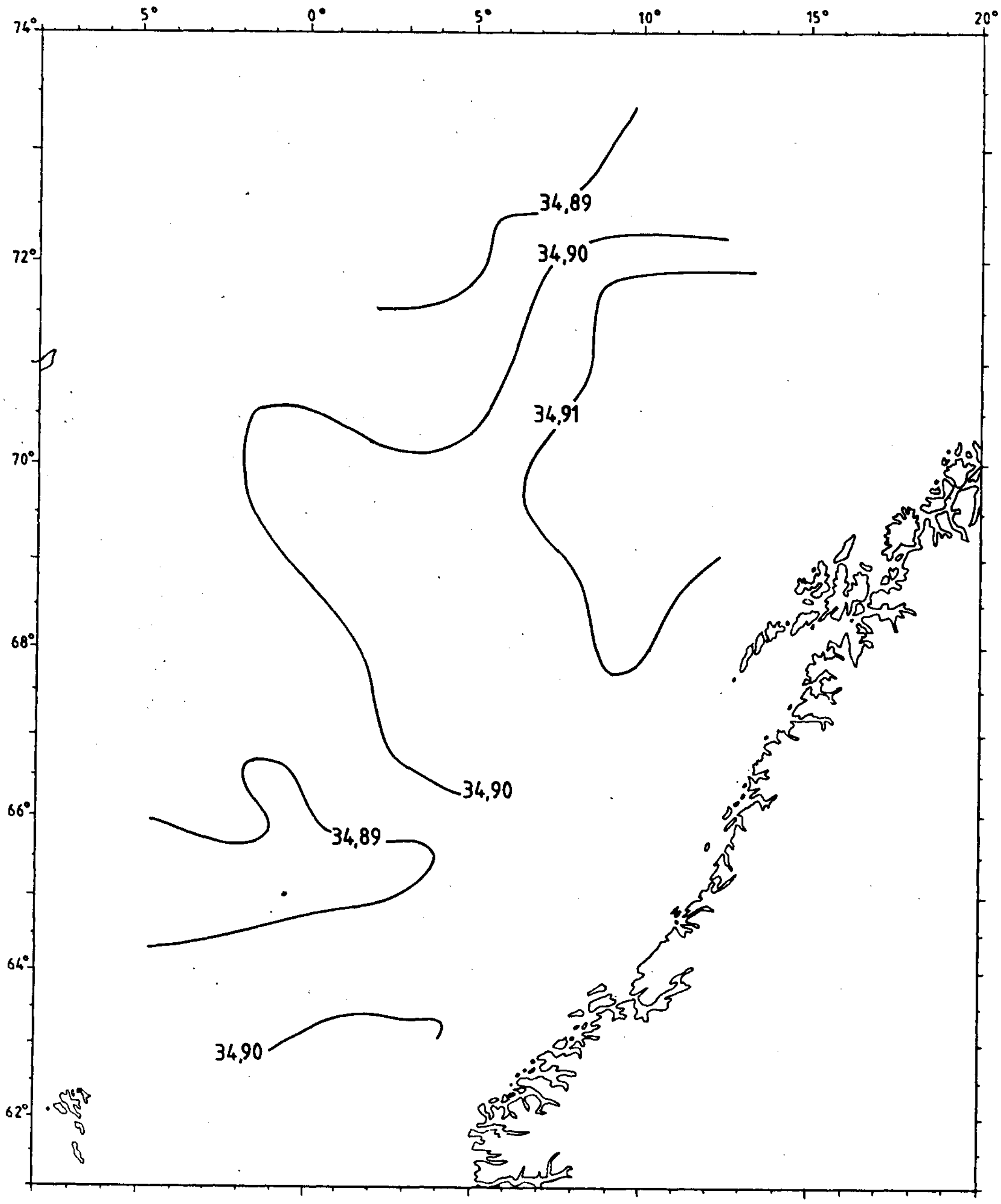

Figure 4. Distribution of the minimum salinity in the Arctic Intermediate water. Observation grid as in Fig.3.

In August 1982 most of the Norwegian Sea was covered with a grid of CTD-casts to 1000 m depth. Based on these data the depth of the salinity minimum in the AIW is shown in Fig.3. To the south and west there were areas where its depth was less than 500 m, and in general it was shallower than 600 m south of approximately 68^0N, except along the slope of the Norwegian shelf. Between northern Norway and Jan Mayen there was a wide area where its depth was greater than 800 m. Except towards the north and northeast, the layer of the minimum salinity descended rather abruptly around this area.

The minimum salinities are shown in Fig. 4. The areas with salinities below 34.89 to the northeast of the Faroes and along the Arctic front to the northeast of Jan Mayen, coincide with the areas where its depth was less than 500 m. Generally there was a salinity increase towards the north and east, and in an area off northern Norway there were salinities above 34.91. But even in this area a slight salinity minimum was observed between the AW and the NSDW.

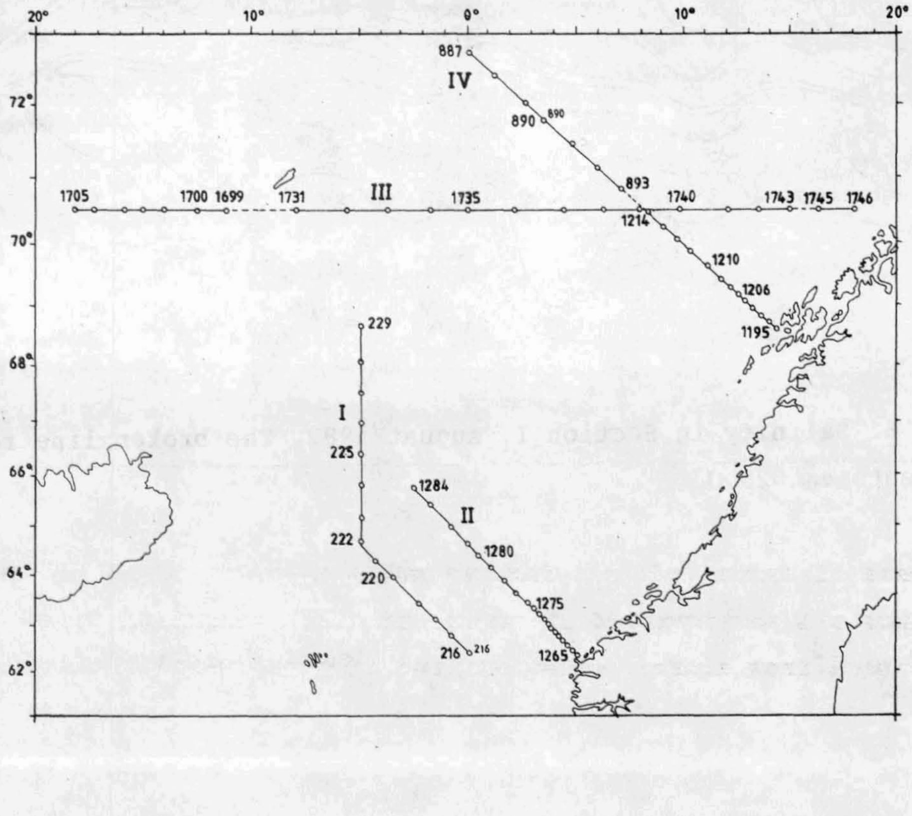

Figure 5. Positions of the sections shown in Figs 6 - 9.

The vertical salinity structure is illustrated in four sections covering the area as shown in Fig.5. In Section I, from August 1982, which is shown in Fig. 6, there was a tongue of low salinity water under the AW off the North Sea continental slope. Within this tongue there were two cores of water with salinity below 34.9 at depths about 200 and 300 m. This water had temperatures between 2^0 and 3^0C, indicating that this low salinity was due to intermixing of NIWW. AIW was observed along the whole section in a layer with salinity below 34.91 from depths varying between about 400 and 600 m. Its minimum salinity was below 34.9 except in the area close to the slope where the intermediate layer was very narrow. Elsewhere in the section its vertical extent was about 300.

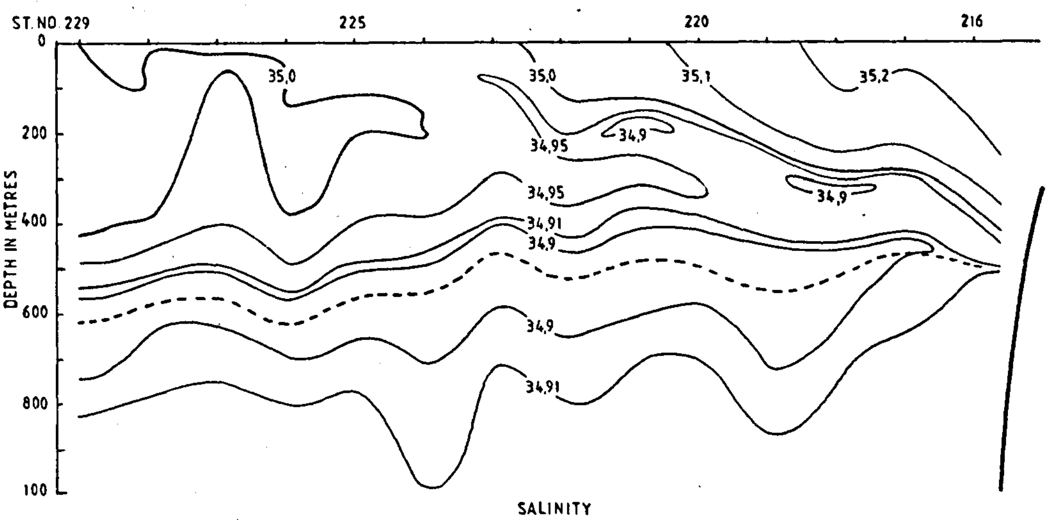

Figure 6. Salinity in Section I, August 1982. The broken line represents σ_θ =28.0.

In Section II further to the northeast (Fig. 7), the influence of NIWW was hardly traceable. Only in the tongue with salinity below 34.95 in its northwestern part, was there a slight salinity minimum around 200 m depth. The layer with AIW was also observed across this section, but its contraction towards the continental slope was more pronounced here than in Section I.

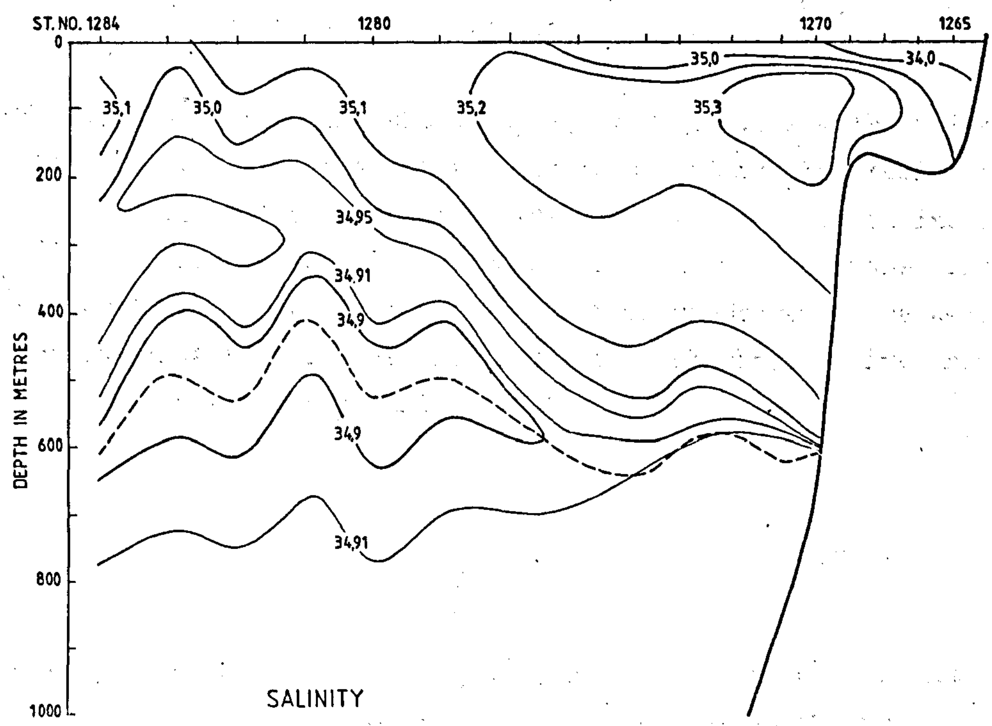

Figure 7. Salinity in Section II, August 1982. The broken line represents σ_θ = 28.0.

Section III (Fig. 8) shows the temperature and salinity distribution in August 1985 across the Iceland and Norwegian Seas along 70°30'N. The intermediate temperature maximum in the Iceland Sea was indicated by temperatures above 0°C between 100 and 500 m depth to the west of the Jan Mayen platform. The highest temperatures in this layer were observed at about 150 m depth, ranging from +0.2°C near Jan Mayen to +1.6°C at station 1704. The Arctic front is indicated by descending isolines both in temperature and salinity between stations 1733 and 1734 (1° to 3°W). Characteristic of the area west of the front is the great volume of homogeneous water with AIW properties. The contin-

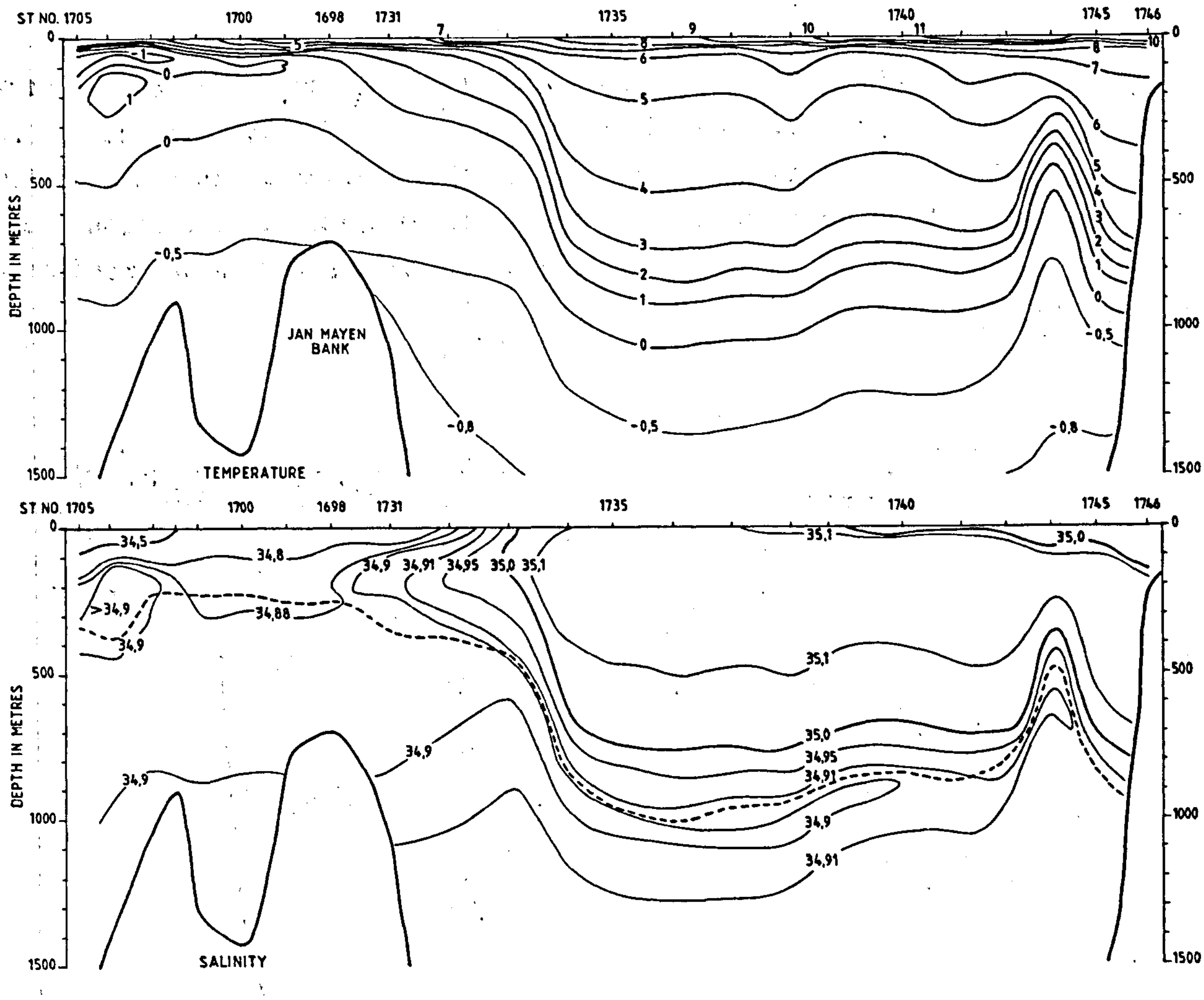

Figure 8. Temperature and salinity in Section III, August 1985. The broken line represents $\sigma_\theta = 28.0$.

uation of this water into the Norwegian Sea is clearly indicated by the intermediate layer with salinities below 34.91 across the Norwegian Sea Basin almost to the continental slope. The greatest depth of the layer with salinities below 34.9 in this section was between 1000 and 1100 m, 100-200 m deeper than in 1982 (Fig.3).

Section IV which was observed in August 1980, is shown in Fig. 9 to illustrate the conditions in the frontal area to the northeast of Jan Mayen, where the Arctic front is topographically fixed to Mohns Ridge, from Jan Mayen to approximately 74^{0}N, 9^{0}E. In this section the isolines descended very steeply from the surface layer to depths of 700-900 m. Also here the AIW, identified by salinities below 34.9, extended from depths of 100-300 m on the cold side of the front to 700-900 m

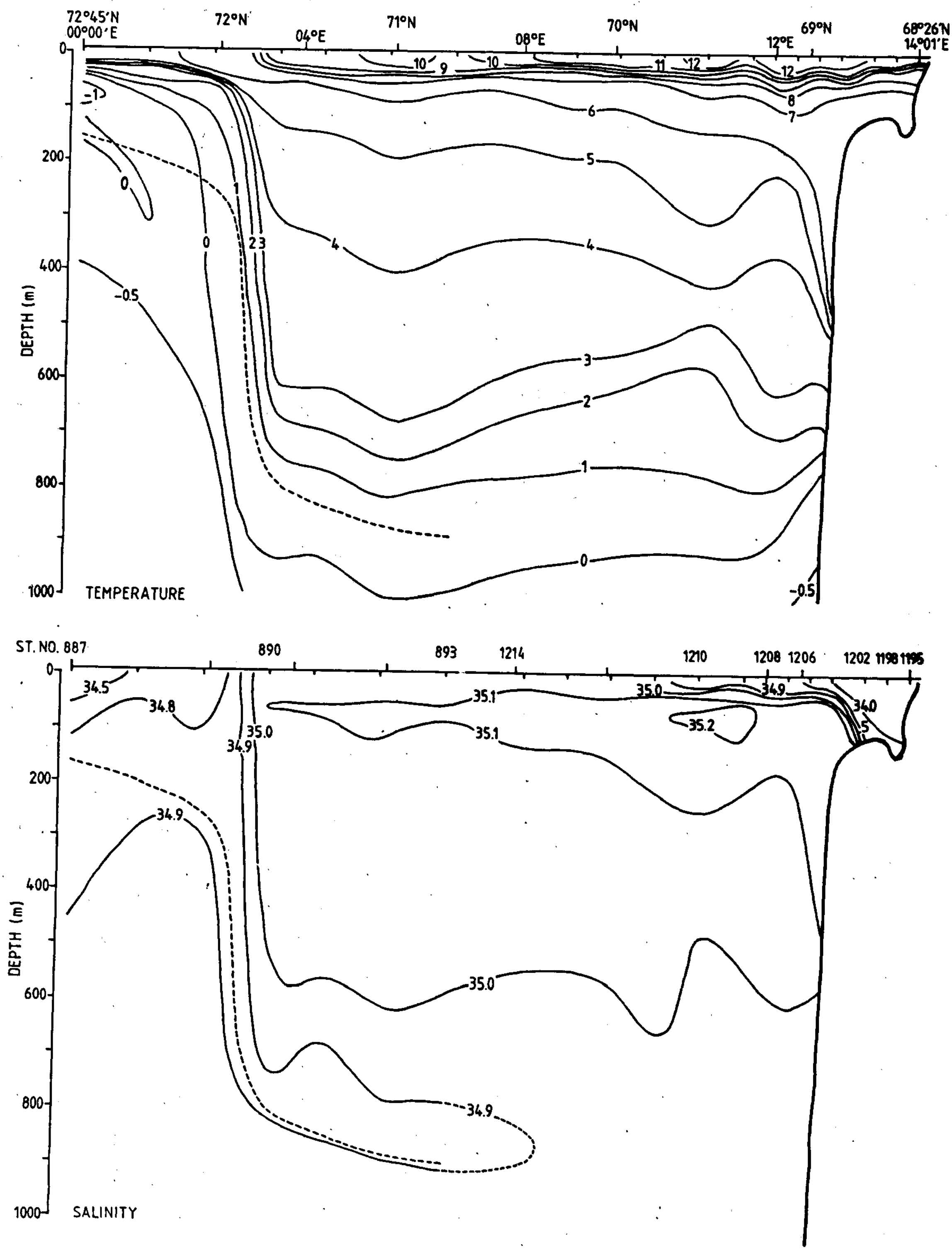

Figure 9. Temperature and salinity in Section IV, August 1980. The Broken line represents σ_θ= 28.0.

depth in the Norwegian Sea. The eastward extent of the AIW could not be fixed in this section because its southeastern part (Stations 1195-1214) was observed with reversing water bottles at standard depths. This also demonstrates the reason for the little attention given to this intermediate water before CTD-observations became available.

The broken line which is entered in the sections, represents the σ_θ value of 28.0. All the sections show that the AIW spreads into the Norwegian Sea at approximately this density level. This is also indicated by the TS-relationship in Fig. 2.

DISCUSSION

The area with salinities below 34.89 between 64^0 and 66^0N indicates that AIW flows into the southern Norwegian Sea in the deeper layers of the East Icelandic Current. It may be questioned to what extent the inflow of AIW is restricted to this area or whether there is downwelling also along the front further north. If the area between Iceland and Jan Mayen is the only route, the main flow would probably be found off the slope of the Iceland shelf. Due to mixing, it would then get less distinct while propagating northwards. The AIW has, however, about the same properties in the northwestern Norwegian Sea as in its southern areas. Moreover, it is observed at shallower depths in the frontal area north of Jan Mayen than further south (Fig. 9). It is therefore likely that downwelling of AIW takes place along the front also north of Jan Mayen.

It is also likely that the warm portion of the AIW north of Jan Mayen, with temperature and salinity above $+1.0^0$C and 34.91, respectively, is involved in the downwelling. This is, however, difficult to distinguish from mixtures of AIW and AW in the Norwegian Sea.

The northward salinity increase shown in Fig.4, is most probably a result of mixing of AIW with AW nad NSDW as the distance from the source of the AIW increases. The relatively short distance from the front to the area with salinities above 34.91 to the northeast of Jan Mayen may be suggestive of another reason for the relatively high salinity in the area off northern Norway. The dynamic topography of the 1000 decibar level relative to 2000 decibars based on IGY-data in this area, indicates soutward movement along the continental slope (Eggvin, 1961). If this movement exists, more saline bottom water from the Barents Sea may be transported southward from the Bear Island Channel which is its main route into the Norwegian Sea. This bottom water has about the same density as the AIW and salinities in the range 34.9-35.05 (unpublished data). It will therefore sink into the same layers as the AIW and give rise to increased salinity. As yet there are, however, no observations which can confirm such a distribution of the outflow from the Barents Sea.

A comparison of the minimum salinities in the AIW in Section III and, for example, those entered in Fig. 4, indicates year-to-year variations in the properties of the AIW. Time variations observed in the Iceland Sea (Malmberg, 1969 and 1984) are in favour of such fluctuations. Similarly, the difference in TS-relationships between 1980 and 1985 in the frontal area north of Jan Mayen clearly demonstrates time variations in the AIW in the zone bordering on the Norwegian Sea. It is therefore likely that the AIW may be influenced by such fluctuations throughout its distribution area. The quality of the present data is, however, not high enough to indicate anything definite about such variations within the Norwegian Sea which in salinity may be of the order of 0.01 or less.

The most important role of the AIW in the Norwegian Sea is probably its isolating effect between the AW and the NSDW, prohibiting direct mixing of these two water masses. The only place with direct contact between AW and NSDW is possibly along the slope of the continental shelf.

REFERENCES

DOOLEY, H.D., J.H.A. MARTIN and D.J. ELLETT. 1984. Abnormal hydrographic conditions in the Northeast Atlantic during the 1970s. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 185: 179-187.

EGGVIN, J. 1961. Some results of the Norwegian Hydrographical Investigatins in the Norwegian Sea during the IGY. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 149: 212-218.

LEINEBØ, R. 1969. Influence of intermediate water at Weather Ship Station M (66^{0}N 2^{0}E) in the Norwegian Sea. Universitetet i Bergen, Geofysisk Institutt: 9 pp., 3 Figs.

MALMBERG, S.A. 1968. Hydrographic changes in the waters between Iceland and Jan Mayen in the last decade. Jøkul, 19: 30 - 43.

MALMBERG, S.A. 1984. Hydrographic conditions in the East Icelandic current and sea ice in north Icelandic waters, 1970 - 1980. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 185: 170 - 178.

MARTIN, J.H.A. 1976. Long term changes in the Faroe-Shetland channel associated with intrusions of Iceland-Faroe ridge water during the period 1955-1975. ICES CM 1976/:22.: 10 pp (mimeo).

MEINCKE, J. 1978. On the distribution of low salinity intermediate waters around the Faroes. Dt. hydrogr. Z., H. 2.: 50 - 64.

STEFANSSON, U. 1962. North Icelandic Waters. Rit. Fiskid. 3: 269 pp.

SWIFT, J.H. and K. AAGAARD. 1981. Seasonal transitions and water mass formation in the Iceland and Greenland seas. Deep Sea Res., 28A (10): 1107 - 1129.