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HYDROGRAPHIC CONDITIONS IN THE ICELAND SEA IN LATE WINTER 1971, 1975 and 1982

by

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ABSTRACT

This paper deals with hydrographic observations in the Iceland Sea in late winter 1971, 1975 and 1982. Main emphasis is laid on water mass characteristics as regards deep water formation, their variability, and possible reasons and consequences of the observed variability.

The observations in 1971 revealed that both the classical model of cooling at the sea surface and the double diffusion model could be valid for deep water formation not only in the Greenland Sea but also in the Iceland Sea. Due to lower salinities in the surface layer as well as in the intermediate layer in 1975 than in 1971, conditioning for deep water formation in the Iceland Sea were less favoured in 1975 than in 1971.

The 1982 observations in the Iceland Sea revealed changed water mass characteristics from 1971 and 1975. The Intermediate Water in 1982 was colder and less saline with salinity below 34.90 compared with 34.93-34.94 in 1971 and 1975; thus no intermediate salinity maximum was observed in 1982. Also the Bottom Water was in 1982 less saline (<34.92) than in 1971 and 1975 (>34.92), but slightly warmer too ($\theta > -1.0°C$ versus $< -1.0°C$) and thus slightly less dense.

These results from the Iceland Sea in February 1982 may be the first reported showing a decrease in density in deep water accompained with the salinity anomaly of the late seventies in the northern North Atlantic and the Subarctic Sea.

Introduction

The waters bounded by Iceland, Greenland and Jan Mayen are known as the Iceland Sea (Fig. 1). The region has much in common with the neighbouring Greenland and Norwegian Seas, including an interplay between Atlantic and polar influences which not only makes the region lively and variable but also provides its importance to the weather and climate of north-western Europe. The most outstanding publications dealing with the Iceland Sea are those of Stefánsson (1962) and Swift (1980; see also Swift et al. 1980 and Swift and Aagaard 1981).

The cyclonic current system and the different water masses in the Iceland and Greenland Seas are indicated in a XBT section between northeast Iceland and Spitzbergen carried out in August 1972 (Fig. 2)

In February 1971 hydrographic investigations were carried out in the Iceland and Greenland Seas (Fig. 1). The main purpose of these investigations was to study the late winter distribution of salinity in the East Icelandic Current northeast of Langanes (Malmberg 1984) and in the Jan Mayen Polar Current northeast of Jan Mayen. The observations were a part of a study of ice conditions in the sea north of Iceland. The hydrographic conditions in the area in the Greenland Sea where deep bottom water formation is supposed to take place were also investigated. In February 1975 (Iceland Sea Project; Swift 1980) and 1982 (Deep Water Project of ICES) again hydrographic investigations were carried out in the Iceland Sea on sections between northeast Iceland and Jan Mayen (Fig. 3). The present paper deals with these investigations from late winter 1971, 1975 and 1982 mainly as regards water mass characteristics and their variability, and possible reasons and consequences of the observed variability.

Material

Figs. 1 and 3 show the location of the hydrographic stations dealt with in this paper. The data collected are kept on file at the Marine Research Institute in Reykjavík. The data are based on standard hydrographic observations with water bottles and reversing thermometers (Hydro- Bios and Gohla, Kiel). The salinity was determined by conductivity (Australian Auto-Lab Salinometer in 1971 and 1975 and a Guildline Salinometer in 1982, using IOS standard seawater and Unesco International Oceanographic Tables). Reported oxygen values were determined by Winkler titration.

Results and discussion

The main results of the investigations in 1971 were the following (Malmberg 1983):

1. The t-s diagrams from the Iceland and Greenland Seas were similar (Figs. 4,5), showing only the slight but not insignificant differences in the water mass characteristics (Table 1). The main water masses are (see Stefánsson 1962, Lee 1963, Carmack and Aagaard 1973, Swift and Aagaard 1981): a) relatively cold and low saline water in the surface layer in the southern parts of the seas (East Icelandic Current and Jan Mayern Polar Current; Fig. 2), b) relatively warm and saline intermediate waters below the cold and low saline waters, and c) cold and saline deep or bottom water in the deepest and central parts of the seas, more or less connected with the upper layers in these seas of cyclonic current systems (Fig. 2).

2. As regards the observations from the Greenland Sea in 1971 it should be repeated here (Malmberg 1983) that a salinity of 34.874 was reached in the surface layer of the northernmost station in the Greenland Sea (Figs. 1, 5, 6; stat. 139 at long 0°, 75°N). As far as known to the first author of this paper in 1983 this was the highest winter salinity observed in the area. Norwegian investigations in 1958 revealed similar values (Odd H. Sælen, pers. comm.). This value of 34.874 is still slightly too low to allow surface water to sink to greater depths by cooling at the

sea surface. It was however stated (Malmberg 1983), that the homogeneity in salinity and sigma-Θ from near surface layers down to the deepest observations at 3500 m (34.87-34.90 and 28.08-28.09) indicates a deep reaching convection with formation of deep or bottom water prior to the observation time. After that some lateral advection of less saline water may have taken place in the surface layers. The oxygen values of the northernmost stations in the Greenland Sea (Fig. 1) were also relatively high and homogenous from surface layers to the deepest observations at 3500 m (7.75-7.40 ml/L or 93-89%). Farther south (stat. 135, 137 in Figs. 1, 5, 6), in the intermediate layer below the cold surface layer of the Jan Mayen Polar Current, the observed salinity distribution also permits water mass transformation involving double diffusion and deep vertical convection in the very homogenous study area (Carmack and Aagaard 1973).

3. In the Iceland Sea in February 1971 the salinity in surface layers south of Jan Mayen (Fig. 7) was indeed high enough (34.92-34.94) to permit the water to sink by cooling (Stefánsson 1962, Swift and Aagaard 1981), but the vertical temperature distribution did not however reveal such conditions to greater depths since the temperature decreased with depth, ca. 1°C from the sea surface down to bottom (sigma - Θ of 28.05-28.09), and neither did the oxygen distribution show such conditions (Fig. 8). Further south, at station 124, relatively high oxygen values were found from the sea surface (8.0 ml/L, > 95%) to bottom (7.25 ml/L, > 88%). This might indicate a degree of vertical convection in the area, possibly in connection with low temperatures in the surface layers and high salinities in the intermediate water with salinity values of about 34.94 (Fig. 7, lateral advection and diffusion; Carmack and Aagaard 1973).

4. Thus the hydrographic data obtained in the Iceland Sea and in the Greenland Sea in late winter 1971 showed the generally known features of permanent net cyclonic circulation in these seas accompained by a doming of isopycnals on a hundred of km length scale (Figs. 2, 6, 7). These

conditions are believed to be important in the production of deep water in the Greenland Sea at least. The data revealed that both the classical model of cooling (Helland-Hansen and Nansen 1909) at the sea surface and the double diffusion model (Carmack and Aagaard 1973) could be valid for deep water formation not only in the Greenland Sea, but also in the Iceland Sea. Also small scale and/or non-stationary cyclonic circulation (eddies, chimneys) together with physical processes like intense winter cooling at the surface and water mass transformation involving double diffusion in intermediate waters could lead to vertical convection or deep water formation (Killworth 1979). Primarily, this deep water may be formed in the Greenland Sea and the Norwegian Sea where its presence and characteristics maintain secondary conditions for deep water formation in the Iceland Sea.

5. The investigations in the Iceland Sea in late winter 1975 (Swift 1980, Swift and Aagaard 1981, Malmberg 1984) again revealed the three above mentioned water masses (Table 1, Figs. 9, 10). The low-saline and cold water in the surface layers was now slightly fresher (<34.80) than in 1971 (<34.90). The intermediate water was above 0°C in temperature along the whole section between Northeast Iceland and Jan Mayen contrary to 1971 (Fig. 7), but both colder and less saline in the southern and northern parts of the section. The bottom water was in 1975 similar in temperature ($\Theta < -1.0°$) as in 1971 and so was the salinity, though with slightly higher values (>34.92) in the southern part of the area than in the northern one (< 34.92). This may indicate a different origin of the deep water, the former being Norwegian Sea Bottom Water and the latter Greenland Sea Bottom Water (Aagaard et al. 1985). Due to lower salinities in the surface layer as well as in the intermediate layer in 1975 than in 1971 conditioning for deep water formation in the Iceland Sea can be considered still less favoured in 1975 than in 1971.

6. The observations in February 1982 in the Iceland Sea revealed changed water mass characteristics from 1971 and

1975 except for the surface layer (Table 1, Figs. 11, 12). The Intermediate Water in 1982 was colder and less saline with salinity below 34.90 compared with 34.93-34.94 in 1971 and 1975; thus no intermediate maximum in salinity was observed. The potential temperature in the intermediate layer in 1982 was below 0°C instead of 0-1°C in 1971 and 1975. However, the Bottom Water was in 1982 less saline (< 34.92) than in 1971 and 1975 and slightly warmer ($\Theta > -1.0$°C versus $\Theta < -1.0$°C). It was thus slightly less dense, possibly indicating effects of the low-saline Intermediate Water on the Bottom Water.

These conditions of the Intermediate and Bottom Water in the Iceland Sea in February 1982 may be coupled to the so-called mid-seventies salinity anomaly (Dooley et al. 1984, Dickson and Blindheim 1984, Dickson et al. 1984), i.e. a decrease in salinity observed in the northern North Atlantic and the European Subarctic Sea in the late seventies. It may either be directly connected to an increased outflow of Polar Water from the European Arctic and Subarctic Seas during the late sixties (Dickson et al. 1984, Malmberg 1985, 1986) or indirectly through atmospheric variations (Dooley et al. 1984, Gammelsröd and Holm 1984, Dickson et al. 1975, Malmberg and Svansson 1982), traced from the Denmark Strait (1968) to Labrador (1972) and from there back to the coasts of Europe (1976) and into the European Subarctic Sea (1979-1981; see also Aarkrog et al. 1983).

As previously shown (Dickson and Blindheim 1984), not only a decrease in salinity was observed during these years, but also a cooling found place in the European Subarctic Sea so densities remained close to normal. This is also true for the Intermediate Water in the Iceland Sea in 1971, 1975 and 1982 (Table 1; densities around 28.03-28.04), but in the Deep or Bottom Water a slight <u>increase</u> in temperature was observed in 1982 compared with the findings in 1971 and 1975, together with a <u>decrease</u> in salinity, leading to a slight <u>decrease</u> in density (28.08 versus 28.09) of the

Bottom Water (Figs. 9, 11). These conditions should lead to a decrease both in salinity and temperature of the Denmark Strait Overflow which consists of 80-90% of Intermediate Water partly formed in the Iceland Sea (Swift et al. 1981, Ross 1984), which again is in accordance with findings by Swift (1984). He reported a decrease in salinity of 0.02 and in temperature of 0.15°C in deep waters of the North-East Atlantic. The same was stated by Swift (1984) as regards the Iceland-Scotland overflow water. This overflow consists of Norwegian Sea Deep or Bottom Water at least in the Faroe-Shetland Channel but more of intermediate waters farther north on the Iceland-Faroe Ridge (Stefánsson 1967, Meincke 1978).

On the other hand the results of the investigation in the Iceland Sea, dealt with in this paper, show a decrease in salinity of approximately 0.01 of the Bottom Water from 1971, 1975 to 1982 but a slight increase in potential temperature of 0.01° C and hence a decrease in density of 0.01. Thus the data from the Iceland Sea in February 1982 may possibly be the first reported showing a decrease in density in deep waters accompanied with the salinity anomaly of the late seventies.

7. A data series from spring in deep waters east of Iceland (Fig. 14) reveals the same trend (Fig. 13). The data are from 600 m depth and cover the period 1975-1984. The locality can be regarded as upstream for the flow of Deep or Bottom Water along or across the Iceland-Faroe Ridge and through the Faroe-Shetland Channel. It is evident from the series that a freshening of 0.02 took place in the Deep Water at this location east of Iceland together with a decrease in density. There was not as clear a trend in temperature at this location and only of secondary importance to the density. During this period, which may be coupled to the seventies salinity anomaly in the Subarctic Sea, the hydrobiological conditions in North Icelandic waters also changed to the most unfavourable primerly due to a cold arctic water mass ($t=1-3°$; $S \sim 34.8$) dominating in North Icelandic waters in spring 1981-1983

contrary to the usual Atlantic and/or polar influence in the area (Fig. 15).

Conclusion

It can be concluded that both the classical model of cooling at the sea surface and the double diffusion model could be valid for deep water formation in the Iceland Sea in late winter 1971, but these conditions were less favoured in 1975 due to lower salinities in the surface layer as well as in the intermediate layer than in 1971.

The 1982 observations in the Iceland Sea revealed changed water mass characteristics from 1971 and 1975, the Intermediate Water was colder and less saline and no intermediate salinity maximum was observed. Also the Bottom Water was in 1982 less saline than in 1971 and 1975, but also slightly warmer and thus slightly less dense. The results from the Iceland Sea in February 1982 may be the first reported showing a decrease in density in deep water accompained with salinity anomaly of the late seventies in the northern North Atlantic and the European Subarctic Sea.

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Table 1a. Water masses in the Iceland Sea in February 1971, 1975 and 1982.

	1971		1975		1982	
	t°C	S	t°C	S	t°C	S
Surface water	< - 0.5	< 34.9	< -0.5	< 34.8	-0.5	< 34.8
Intermediate water	0-1	34.94	0-0.2	34.93	< 0	34.90
Deep and bottom water	~ -1	> 34.92	~ -1	~ 34.92	> -1	< 34.92

Table 1b. Water masses in the Greenland Sea in February 1971.

	t°C	S
Surface water	< - 1.5	34.87
Intermediate water	0-1.5	34.95
Deep and bottom water	- 1.3	34.90

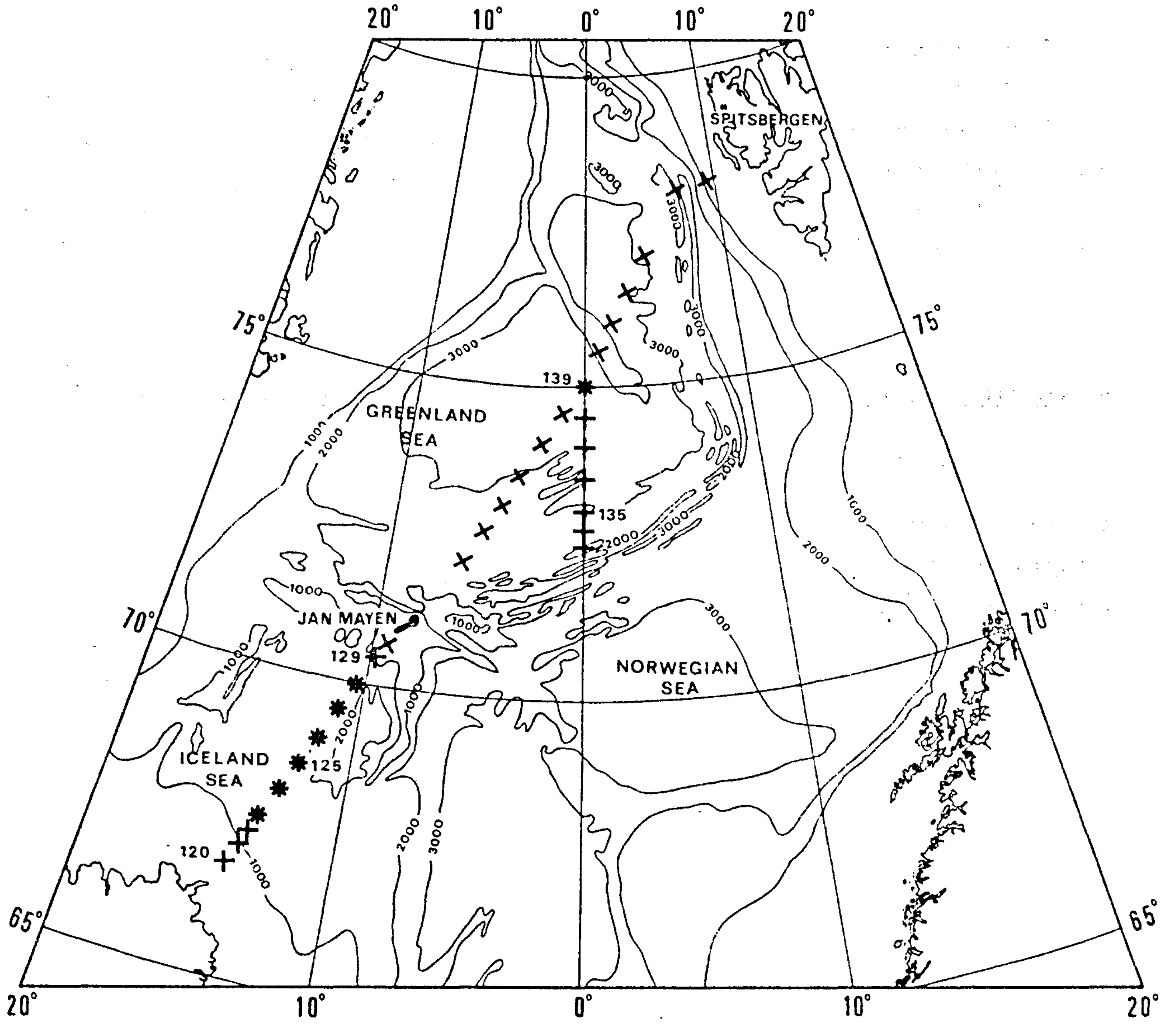

Figure 1. Location of hydrographic stations in the Iceland and Greenland Seas carried out on R/V Bjarni Sæmundsson in February 1971 (+), and a XBT section carried out in August 1972 (X). (Malmberg 1983)

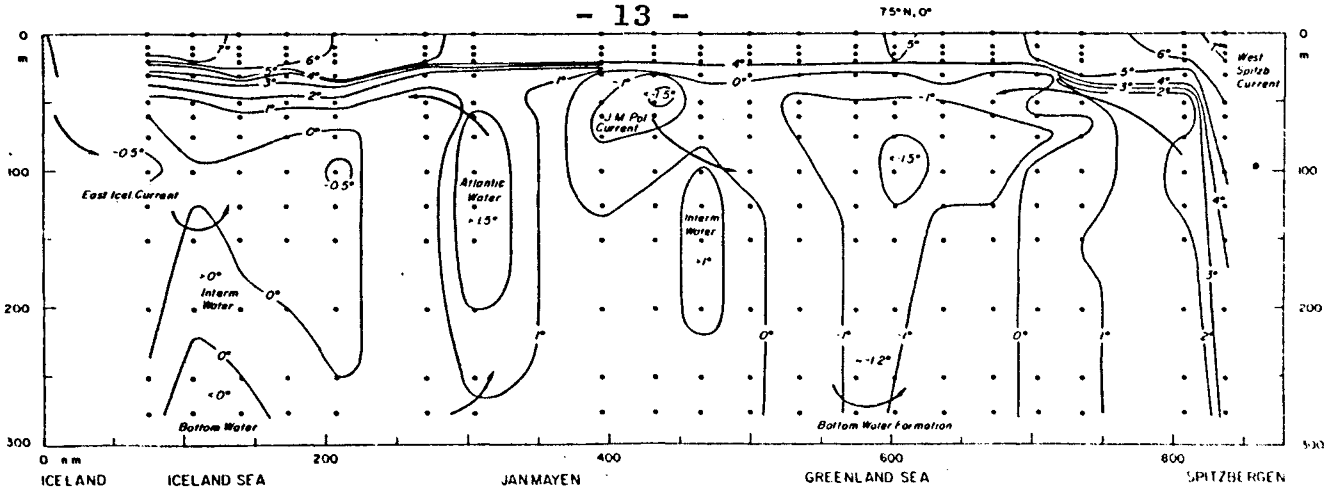

Figure 2. Temperature distribution in a XBT section from Iceland to Spitsbergen from August 1972. The cyclonic current systems and the different water masses in the Iceland and Greenland Seas are indicated. For location see Fig. 1. (Malmberg 1983).

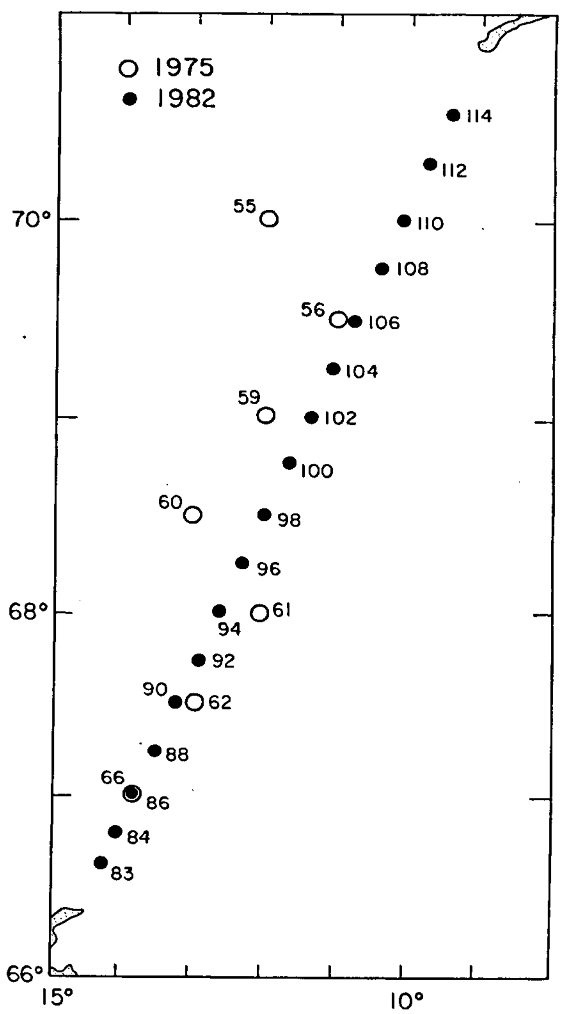

Figure 3. Location of hydrographic stations in the Iceland Sea carried out on R/V Bjarni Sæmundsson in February 1975 and 1982.

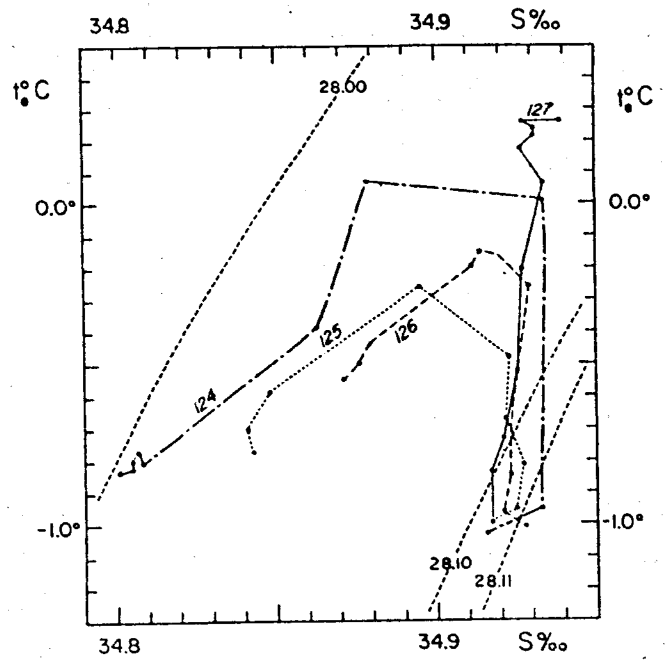

Figure 4. Potential temperature - salinity diagrams at selected stations in the Iceland Sea in February 1971. For location see Fig. 1. (Malmberg 1983).

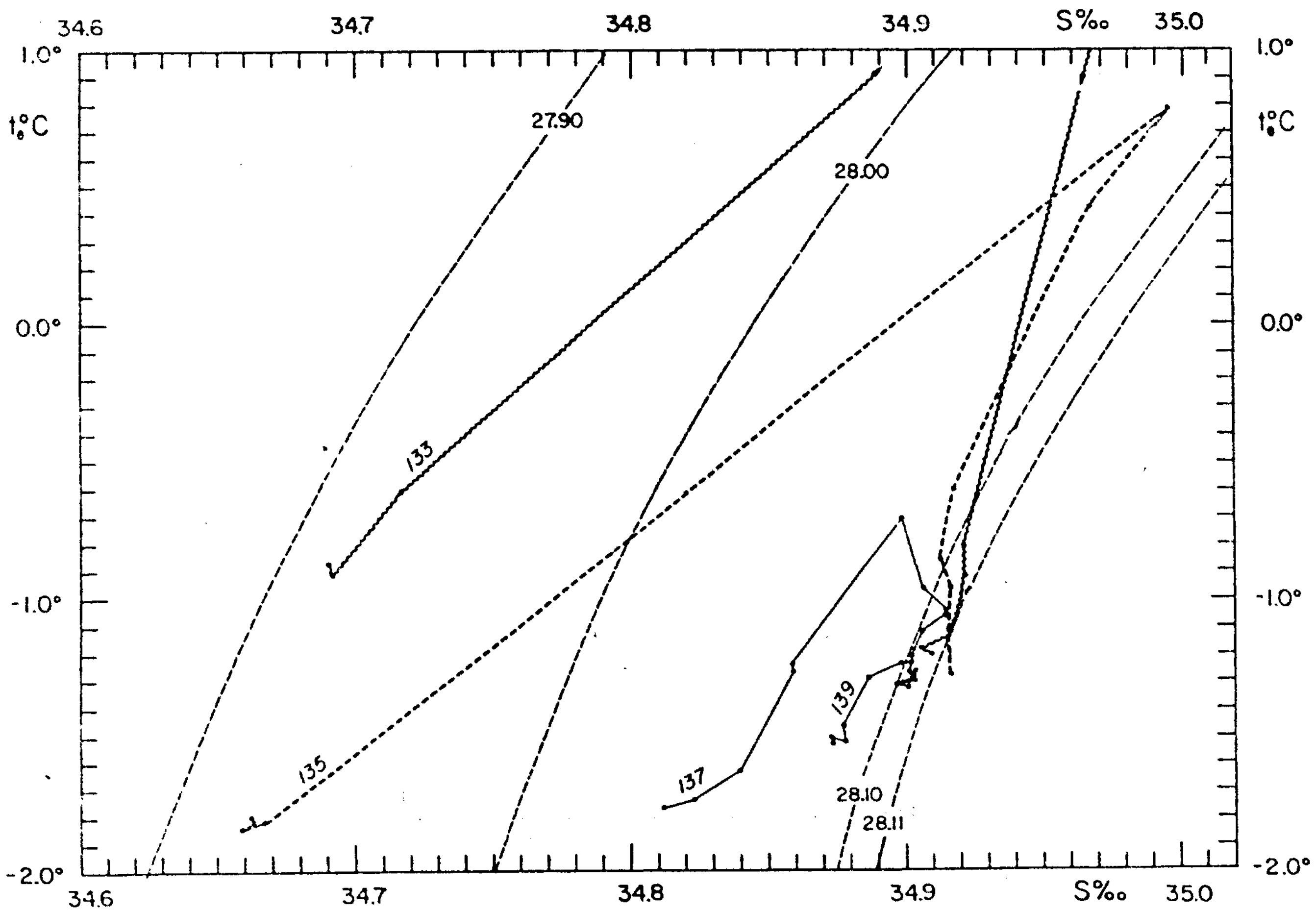

Figure 5. Potential temperature - salinity diagrams at stations in the Greenland Sea in February 1971. For location see Fig. 1. (Malmberg 1983).

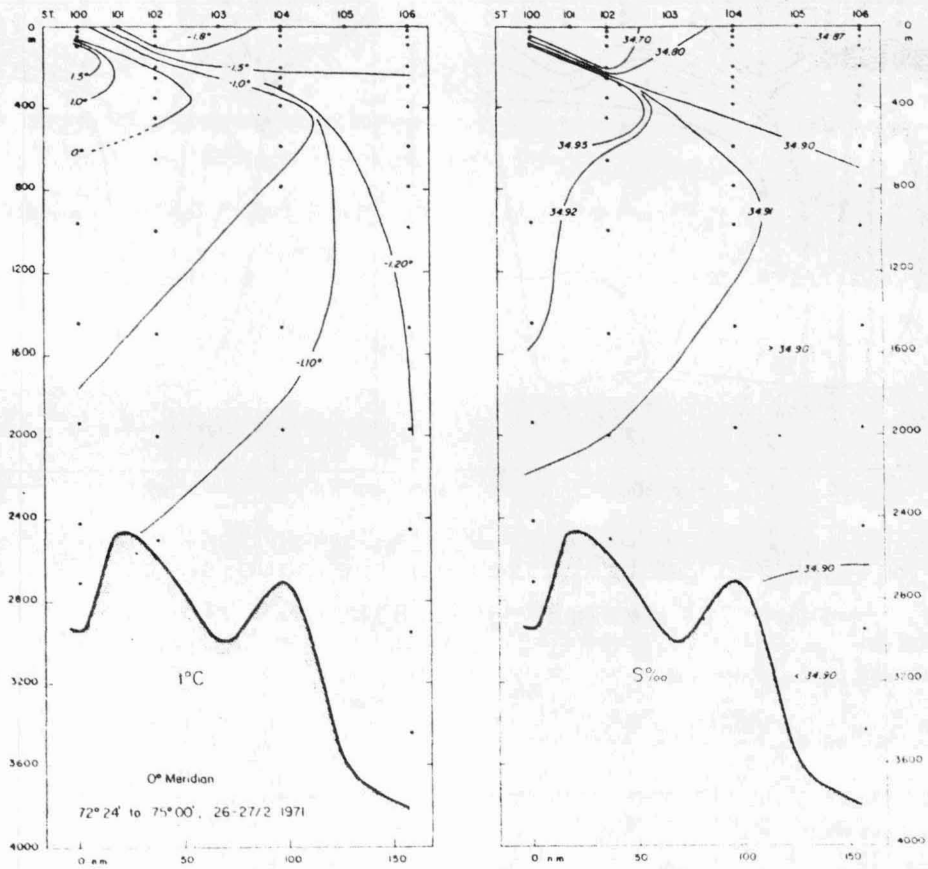

Figure 6. Temperature and salinity distribution in a section along the 0° meridian from 72°24'N to 75°00'N in the Greenland Sea in February 1971. For location see Fig. 1. Notice differences in cruise stat. numbers here used and consecutive stat. numbers used elsewhere in this paper. (Malmberg 1983).

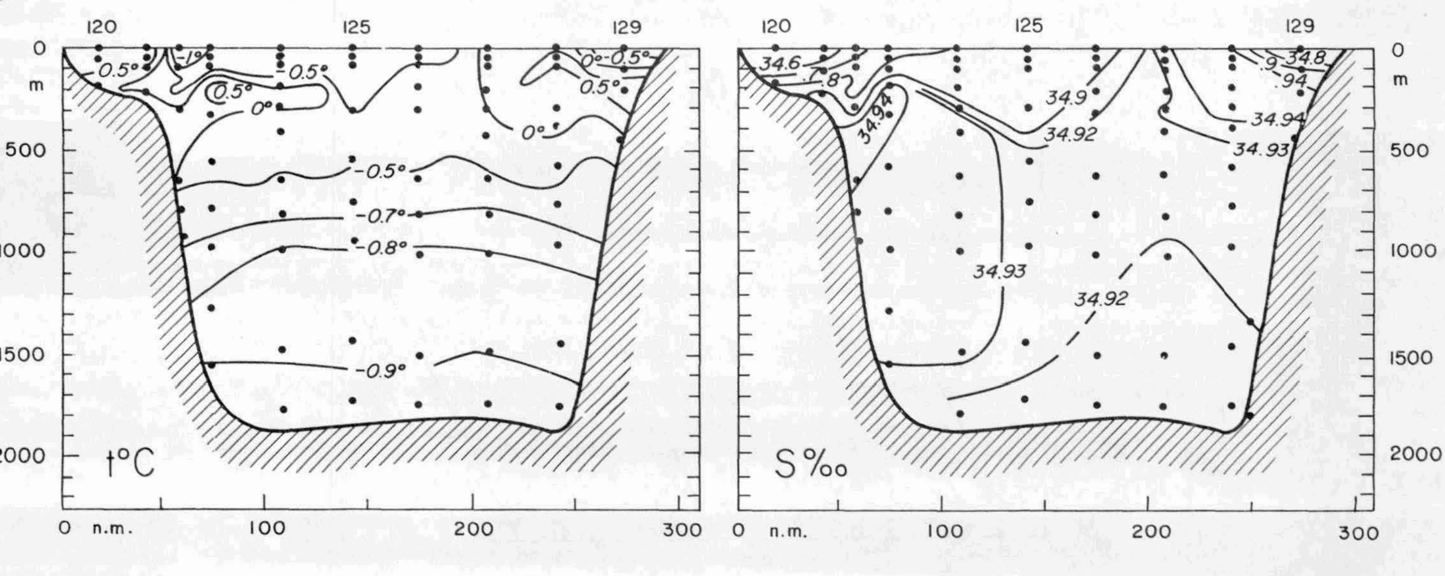

Figure 7. Temperature and salinity distribution in a section between Iceland and Jan Mayen in February 1971. For location see Fig. 1. (Malmberg 1983).

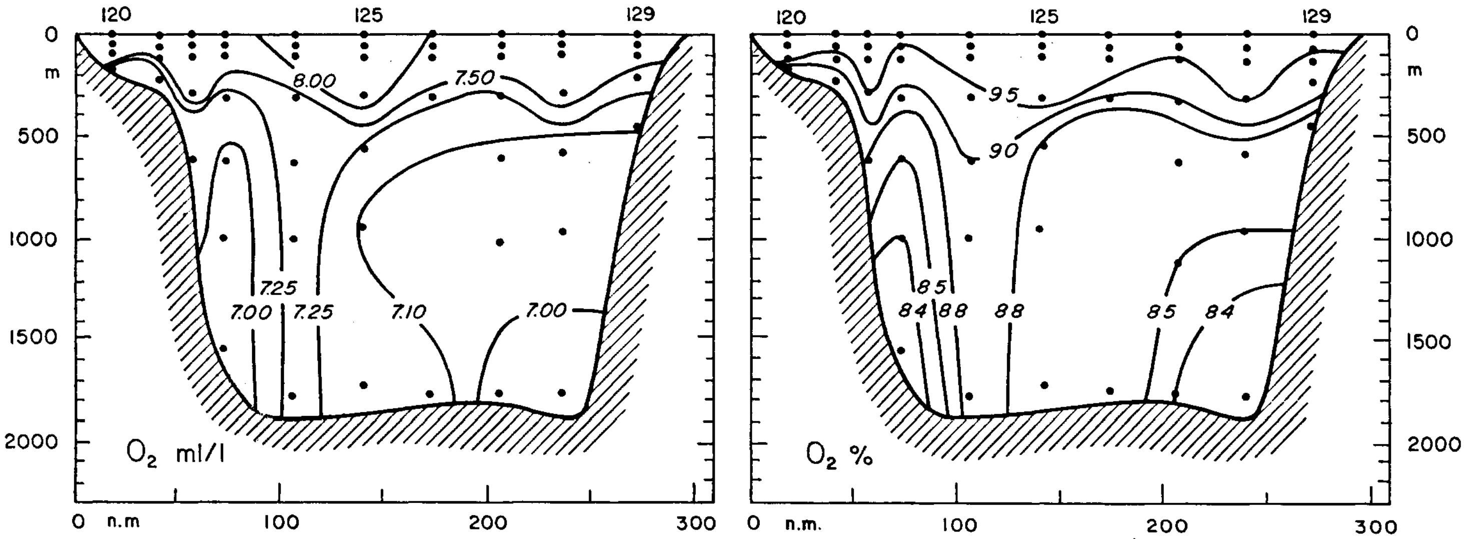

Figure 8. Oxygen distribution in the same section as shown in Fig. 7. (Malmberg 1983).

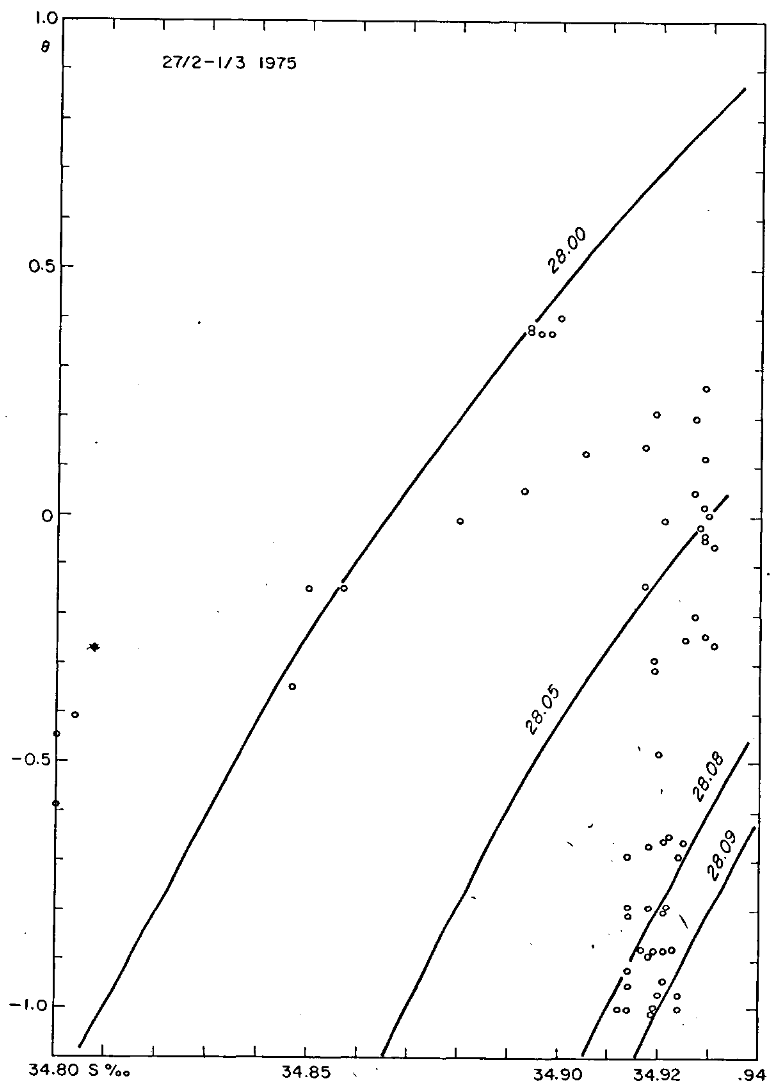

Figure 9. Potential temperature - salinity diagrams at selected stations in the Iceland Sea in February 1975. For location see Fig. 3.

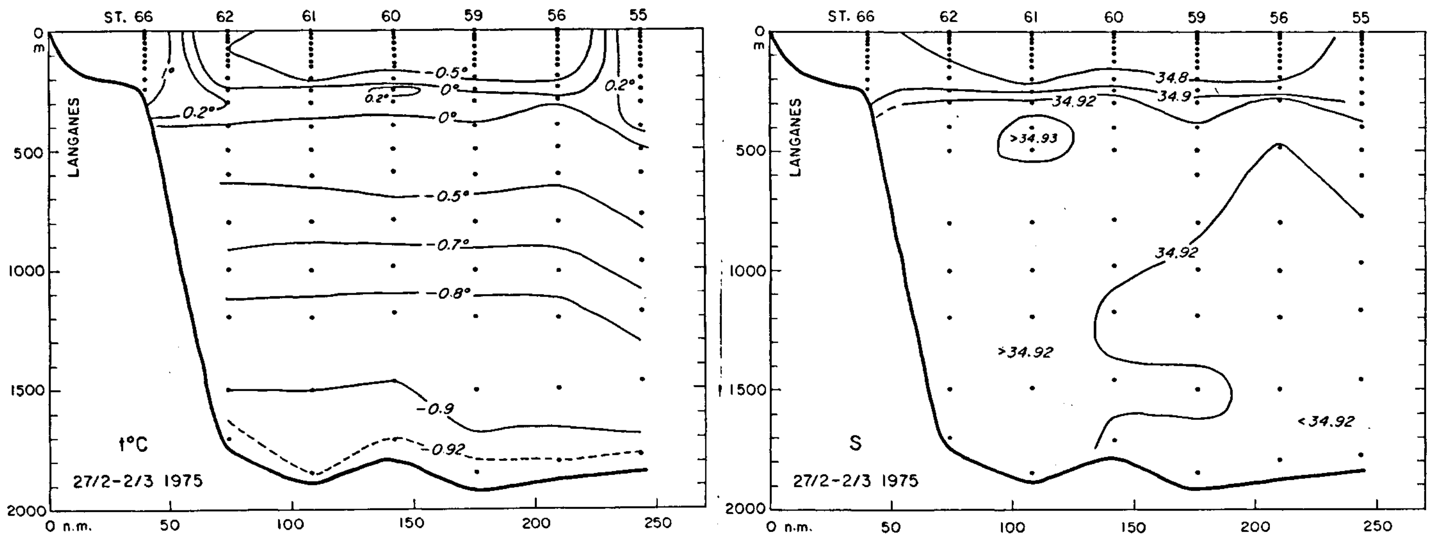

Figure 10. Temperature and salinity distribution in a section between Iceland and Jan Mayen in February 1975. For location see Fig. 3.

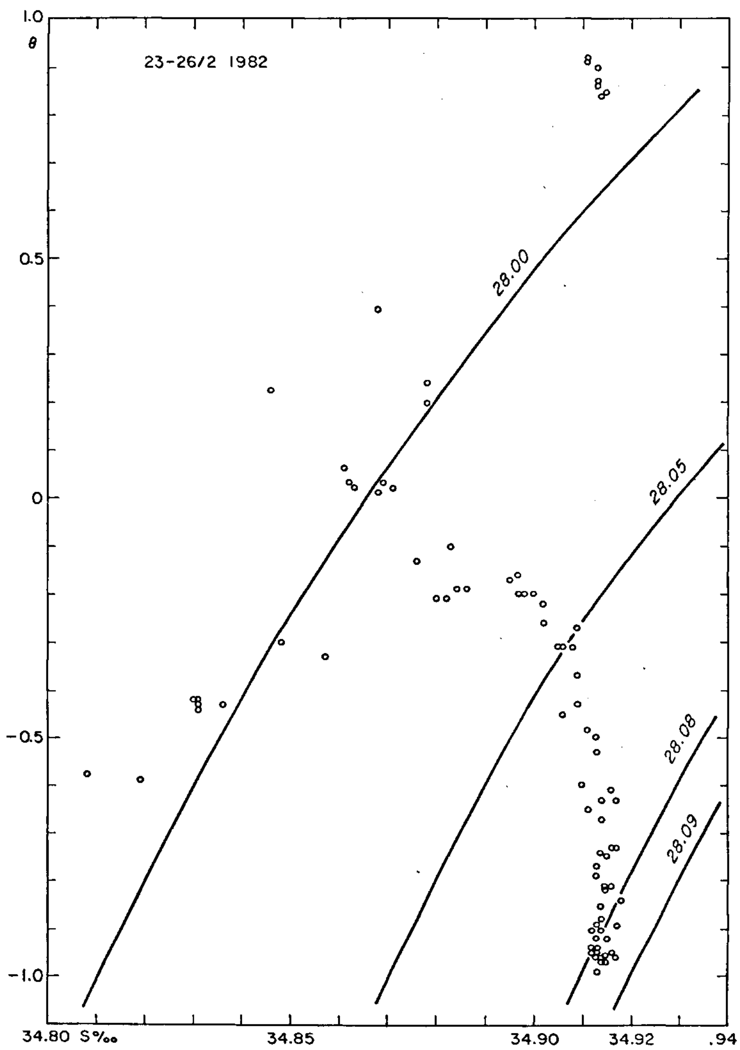

Figure 11. Potential temperature - salinity diagrams at selected stations in the Iceland Sea in February 1982. For location see Fig. 3.

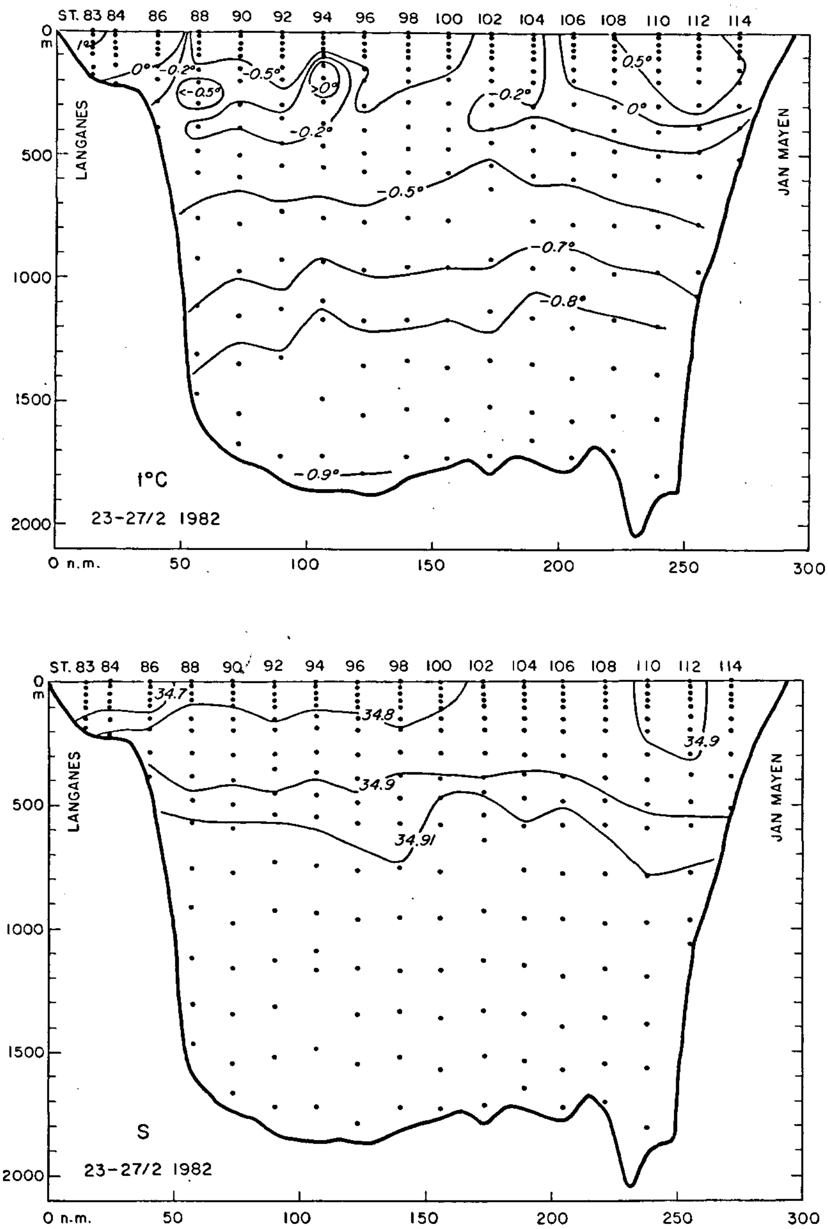

Figure 12. Temperature and salinity distribution in a section between Iceland and Jan Mayen in February 1982. For location see Fig. 3.

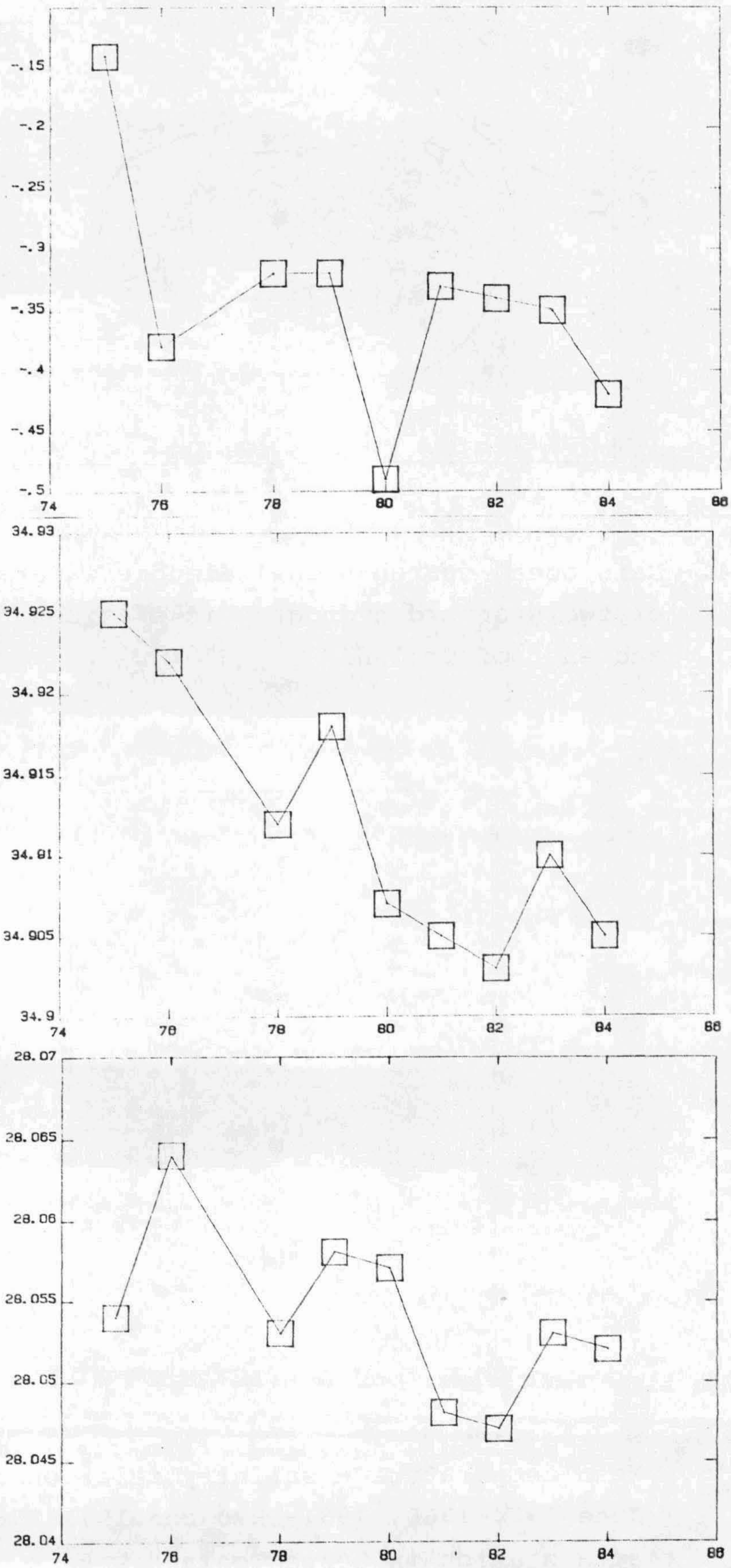

Figure 13. Temperature, salinity and density in June 1975-1984 at 600 m depth east of Iceland. For location see Fig. 14.

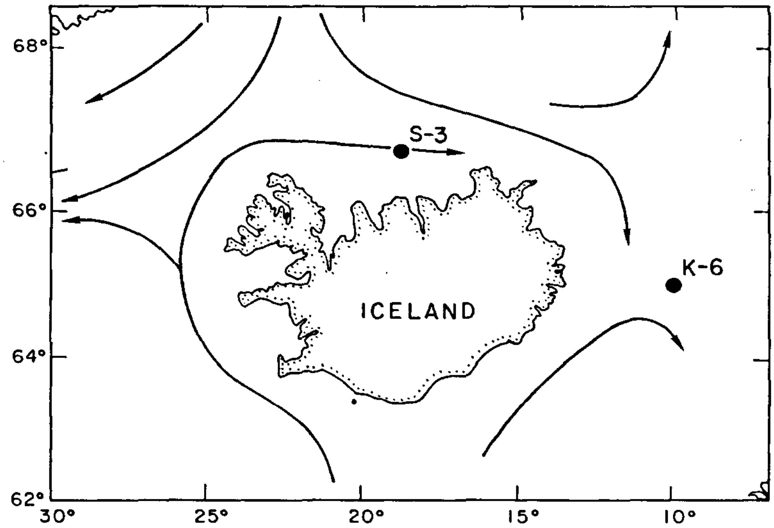

Figure 14. Main ocean currents in Icelandic waters and location of two standard hydrographic stations north of Iceland and east of Iceland.

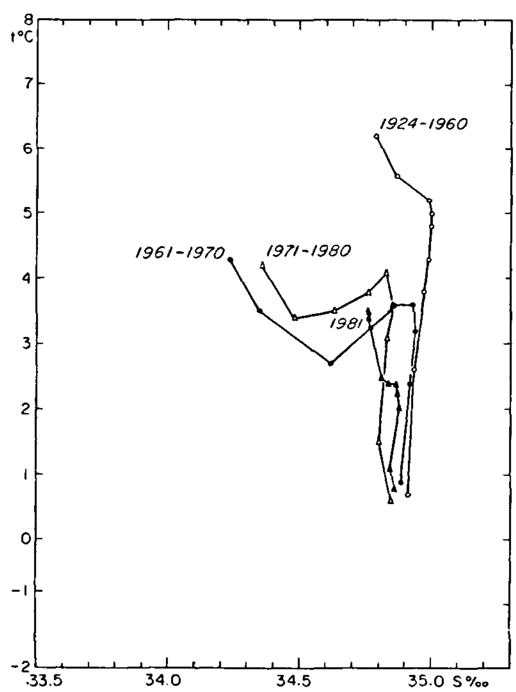

Figure 15. Mean temperature - salinity relationships in May-June 1924-1960, 1961-1970 and 1971-1980 and in 1981 at a station in North Iceland waters. For location see Fig. 14. (Malmberg and Svansson 1982).

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