International Council
for the Exploration of the Sea

C.M. 1984/C:17
Hydrography Committee

Formation of heavy bottom water in the Barents Sea

by

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Abstract

Formation of heavy bottom water through rejection of brine during ice freezing is a regular phenomenon in the Barents Sea, particular on the Novaya Zemlya shelf, but also observed in other shallow localities of the sea.

Water with temperature around $-1^{\circ}C$ and salinity above 34.95 is found moving eastwards on the southern side of the Novaya Zemlya-Franz Josef Land Channel which communicates with the Polar Sea. The relative high salinity is a result of admixture from heavy water formed during the freezing process.

Introduction

Recently Swift, Takahashi and Livingston (1983) in discussing formation of the deep water of the Arctic Ocean (Polar Sea) conclude traditionally that the main sources are deep water from the Norwegian and Greenland Seas through the Fram Straith. But since the salinity of these deep waters are not exceeding 34.92 a third saline water supply is required to obtain the salinity of the Arctic Ocean deep water which is higher. The authors suggest that the Barents Sea is the likely source of dense saline water to the Arctic Ocean. This view is supported from measurements of radionuclides in the different watermasses.

Also Aagaard (1981) considers the formation of the so-called lower deep water of the Arctic Ocean with salinities higher than 34.92. This water has to be augmented by a salt source probably to be found in the Atlantic water or on the shelves. Aagaard sees two possibilities, one is cooling of Atlantic water with high enough salinity, the other is brine rejection during the freezing process. The latter has to occur in selected areas on the adjoining shelves. As an example Aagaard refers to an observation made on the open shelf in the Chukchi Sea near bottom as high as 34.99 and freezing temperature, but regard this as exceptional for this area.

However, high salinities formed by ice freezing are not exceptional occurrences in the Barents Sea. Already Nansen (1906) took notice of the early observations of the famous Russian scientists dr. Knipowitch, dr. Breitfuss and Admiral Makarow (Knipowich 1905) together with the results from Amundsens expedition with "Gjøa" and his own observations on the "Fram"-expedition (Nansen, 1906) in forming his theories on the formation of the bottom waters of the Northern Seas, including both the Norwegian Sea, the Barents Sea and the Polar Sea (Arctic Ocean). Nansen is examining the observations available from the Barents Sea and makes a point of the heavy water formed particularly in the eastern Barents Sea, notably on the Novaya Zemlya shelf, where for example Wollebæck onboard the Norwegian vessel

"Heimdal" in position 71°48'N, 49°38'E observed water with density σ_t = 28.33 (t = −1.80°C, S = 35.17). Nansen concluded that such a heavy water could only be formed by ice freezing and brine rejection. Nansen further believe that heavy water formed in the eastern Barents Sea can supply the bottom water of the Polar Sea through the deep channel between Novaya Zemlya and Franz Josef Land. Makarovs observations of low temperatures here (Knipowich 1905) supported this suggestion, but Makarov's salinity samples were not trustworthy enough to make a firm statement in the matter.

A similar process is also the basis for the bottom water formation in the Antarctic as first suggested by Mosby (1934). Mosby (1967) gives an instructive description of the process which are applied both to southern and northern oceans.

Since the question of heavy water formation and the processes of deep water production in the northern seas have again been brought into focus, it might be of interest to look at some newer observations from the Barents Sea of heavy water formation which can confirm the early observations and the conclusions drawn by Nansen (1906).

The Process

The formation of heavy water can be regarded as a process which takes place in two steps. First the density is increased from cooling of the water. This is a process which gradually becomes slower as the temperature is decreasing towards the freezing point.

The second step starts when formation of ice begins and brine is rejected to the water, whereby the density is increased because of the increasing salinity. Now the process of heavy water formation goes much faster. A rough calculation shows that the σ_t increase per unit energy loss (calories) becomes about ten times higher after ice formation has started.

Also the bottom depth is of importance for the process. In shallow areas where the vertical convection reach the bottom the heavy water formation goes faster. The heavy water now formed will sink along bottom slopes and fill into hollows and depressions in the sea bottom. Fig. 1 illustrates how the heavy water formation is expected to take place.

The northern and eastern Barents Sea belongs to the socalled marginal ice zone area, where ice is formed in winter and melts during the summer season. By delution from melting water a summer surface layer of low salinity is formed, covering the winter layer below which still remains with last winters quality of freezing temperature (or near) and corresponding salinity. This gives opportunity to estimate the amount of ice which have melted in summer. Estimations show that delution from melting of between 1.5 and 2 meter ice is the most common, but values corresponding to more than 2 m ice are often observed in the northernmost area of the Barents Sea.

Next years freezing will first refreeze the summer surface layer and renew the former years winter situation and then eventually continue to form still more ice than last year. In this northern area there are generally a netto heat loss from the sea through the year which means in average a greater heat loss in winter than received in summer. The ice thickness is therefore generally growing in the same water mass from winter to winter, until a certain thickness is obtained where the isolating effect of the icecover itself protect the water from higher heat loss. This leads to the assumption that the marginal ice zone being the greatest producer of heavy water since high production requires ice formation under minimal isolating conditions, i.e. fast ice growth. If in addition the surface layer and the ice is systematically transported away from the production locality the formation of heavy water will be maximum. The process can be regarded as a separator transferring salt from surface water to the deep water.

The area west of Novaya Zemlya

According to Nansen (1906) the heaviest water is formed on the Novaya Zemlya Bank. Since 1971 this area has some times been visited by the Norwegian research vessels "G.O. Sars" and "Johan Hjort" during their autumn cruises in the Barents Sea. In Table I are listed selected examples of temperature and salinity observations from the near bottom layer, normally about 10 metres above the bottom. We shall look closer at some of these examples.

In August 1972 "Johan Hjort" worked a short section along longitude 54°E between 74°30'N and 76°00'N. The location can be seen in Fig. 2 (section no. 1). Temperature salinity and density (σ_t) are shown in Fig. 3. The observations are from four stations with Nansen water bottles at standard depths taken to 10 m above bottom and with 30 miles between the stations. On the bank area in the northern part of the section bottom water with freezing temperature and salinity 35.09 are found. The upper 50 meter layer has been deluted by ice melting and somewhat warmed during the summer season. The mean salinity in the layer from surface to bottom is 34.75 at the northernmost station. If the content of salt in sea ice is 5 °/oo, melting of 158 cm ice would be enough to change the mean salinity from 35.09 to 34.75 in the whole 125 m deep layer. In the deep depression in 75°N the bottom water has salinity as high as 35.24 and temperature -1.88°C. This water has obviously been formed on a shallow bank area and drained down into the hollow where it was observed. In this hollow, between 74° and 76°N outside the west coast of Novaya Zemlya, heavy water has been observed several times (Tab. I, example no. 3, 4, 5, 8, 9, 10). The highest density was observed with CTD by "Johan Hjort" in 1981: $\underline{\sigma_t = 28.42}$ (Tab. I example no. 9). But also further south on the Novaya Zemlya coast heavy water originating from ice-freezing has occasionally been observed. Thus, in the area near the above-mentioned "Heimdal" station from 1900 (Nansen 1906), "Johan Hjort" observed in 1979 bottom water with salinity 35.07 and temperature below -1.80°C (Example 6 and 7 of Tab. I).

Spreading of heavy water from the Novaya Zemlya Bank

Heavy water from the bank area may spread further westwards along the bottom and into the deeper depression of the eastern Barents Sea with two basins more than 300 meter deep. In Fig. 4 are shown two sections running from the Novaya Zemlya Bank in 75°17'N, 52°00'E, one westward over the southern basin and the other running north over the northern basin (cfr. Fig. 2). Both sections show cold and saline bottom water originating from the bank area near Novaya Zemlya, but slightly mixed with warmer and less saline water from west flowing northwards along the slope. The observations are from 1979 when the inflow from west is regarded to be low and causing a rather cold regime in the water masses of the eastern Barents Sea.

In years of low activity in the north-running deep water current the effect of admixture from the sinking heavy bank water will increase and be more pronounced, even if the production of such heavy water itself is only at normal.

The area covered by the survey in 1979 did not extent eastward beyond 52°E and any eventually influence from heavy Barents Sea water to the deep water of the Polar Sea could not be shown this year. Effluxion has to pass over a ridge with silldepth probably about 250 metres located in position about 77°45'N, 55°–56°E.

In 1974 the Novaya Zemlya Bank was covered during a survey of "G.O. Sars". Observations from the bottom layer are shown in Fig. 5. The bank area itself is covered by water of salinity above 35.00 and near freezing temperature. At depths around 300 meters to the east of the ridge between Novaya Zemlya and Franz Josef Land the bottom water has this year salinity 34.97 and temperature about –1°C.

In 1971 and 1973 "G.O. Sars" worked the section along the 60°E meridian between Novaya Zemlya and Franz Josef Land. Cold and saline water is again found on the southern side of the channel with temperature about –1°C and salinity around 35.00 (Fig. 6).

This water is apparently moving eastwards through the channel communicating with the Polar Sea.

The Svalbard Bank area

Also on the Svalbard Bank area heavy water formed through brine rejection has been observed. Thus, in 1981 "G.O. Sars" observed in position 77°15'N, 19°34'E at 160 metres and 10 metres above bottom $t = -1.90^{\circ}C$, $S = 35.25$ and $\sigma_t = 28.40$. The heavy water will sink along the bottom and gradually mix with warmer and less saline water. This is illustrated in Fig. 7, showing T-S-diagrams from three stations at different depths along the track of the sinking bottom water.

Concluding remarks

The present paper does not intend to analyse the deep water formation of the Barents Sea in full scale. The purpose is to show that formation of heavy water through rejection of brine during ice freezing in this area is a more or less regular fenomenon particular on the Novaya Zemlya shelf, but also observed in other shallow localities.

It is further shown that water with temperature around $-1^{\circ}C$ and salinity above 34.95 is found moving eastwards on the southern side of the Novaya Zemlya-Franz Josef Land Channel which communicates with the Polar Sea. The relative high salinity is a result of admixture from heavy water formed during the freezing process.

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Table 1. Examples of bottom water observations west of Novaya Zemlya.

Example no.	Station		Instrument[x)]	Date	Position	Obs. Depth (m)	t°C	S°/oo
1	G.O. Sars	st.510	STD	28 Aug. 1971	76°30'N 56°00'E	100	÷1.83	35.06
2	Johan Hjort	st.537	NC	21 Aug. 1972	75°00'N 54°00'E	220	÷1.89	35.24
3	G.O. Sars	st.824	STD	5 Oct. 1973	75°00'N 53°40'E	230	÷1.79	35.13
4	G.O. Sars	st.805	STD	6 Oct. 1974	75°00'N 54°00'E	233	÷1.86	35.18
5	Johan Hjort	st.1013	CTD	20 Sep. 1977	74°00'N 51°00'E	225	÷1.92	35.24
6	Johan Hjort	st.1283	CTD	12 Sep. 1979	71°30'N 50°00'E	115	÷1.81	35.07
7	Johan Hjort	st.1284	CTD	12 Sep. 1979	71°00'N 51°00'E	115	÷1.83	35.07
8	Johan Hjort	st.1059	CTD	1 Sep. 1981	74°30'N 52°00'E	176	÷1.85	35.22
9	Johan Hjort	st.1061	CTD	2 Sep. 1981	75°15'N 54°00'E	216	÷1.83	35.27
10	Johan Hjort	st.1062	CTD	2 Sep. 1981	75°15'N 52°00'E	171	÷1.83	35.21

[x)] STD: Bissett-Berman System

NC: Nansen cast

CTD: Neil Brown System

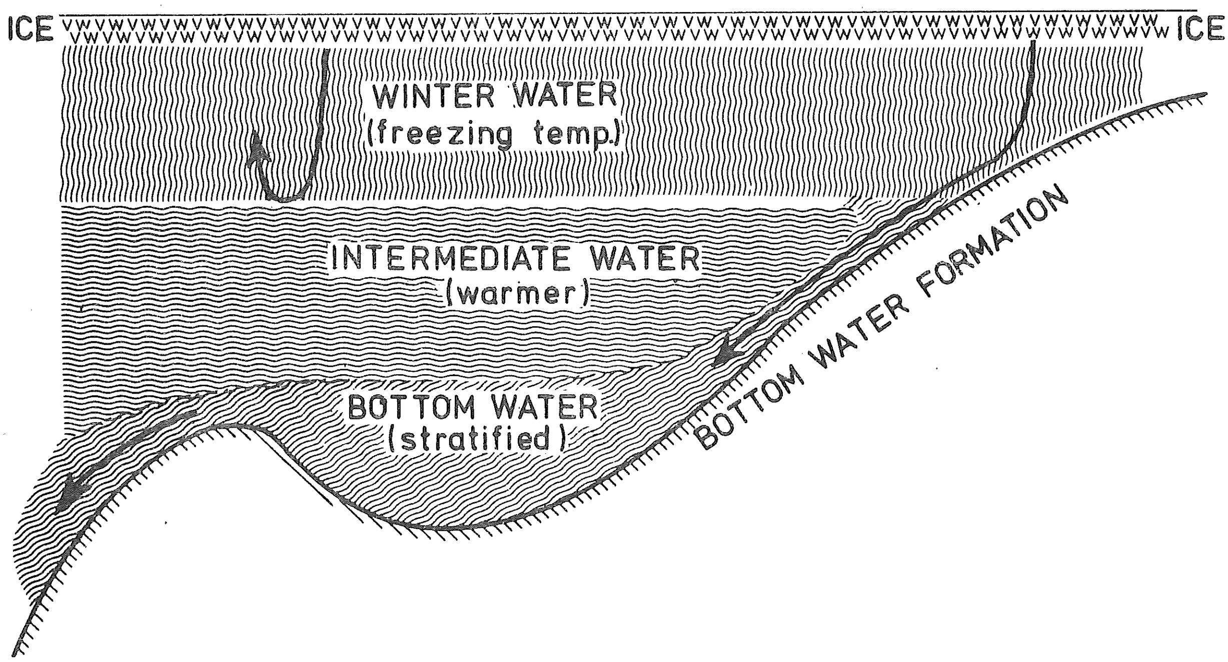

Fig. 1. Illustration of heavy water formation.

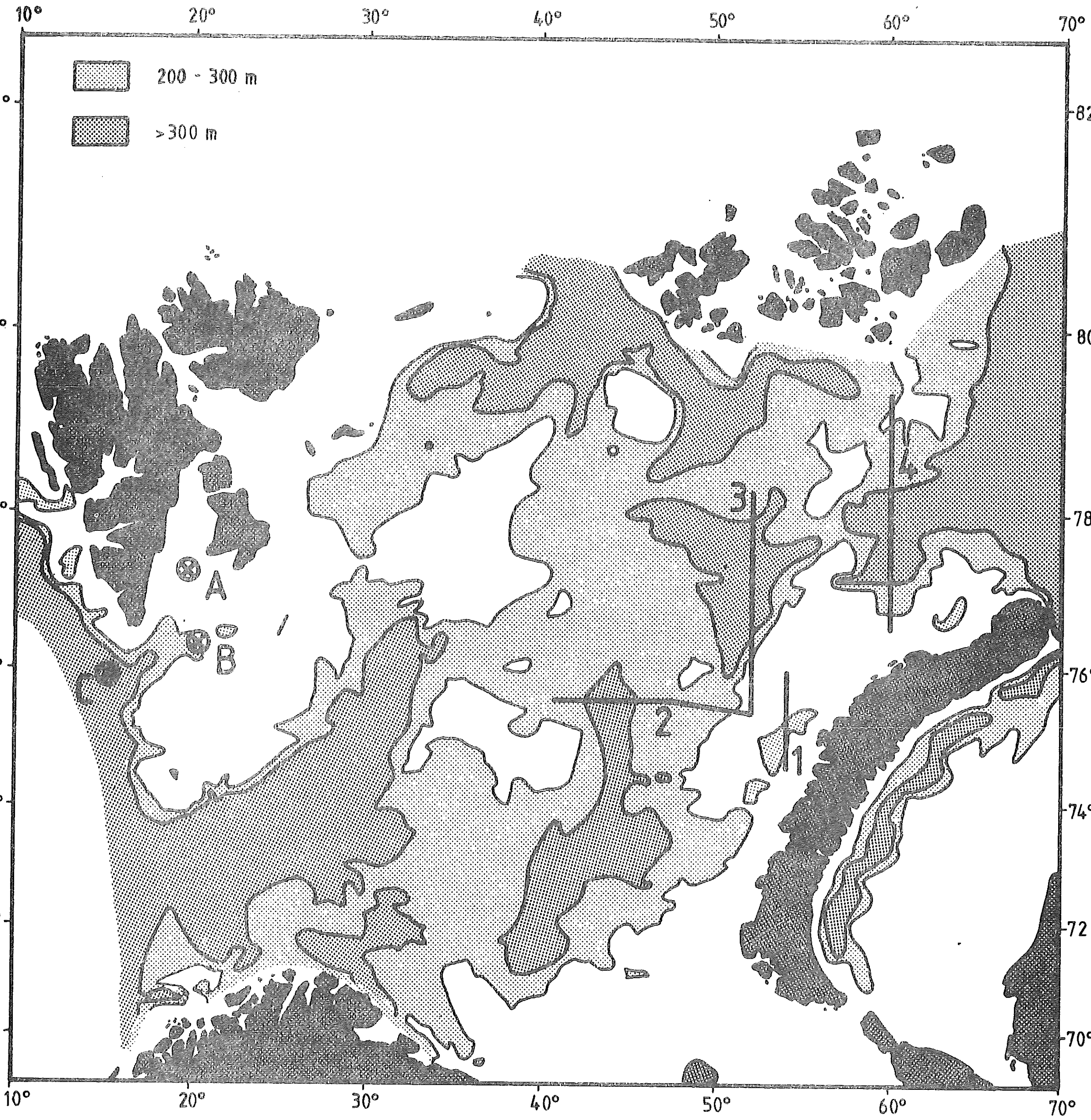

Fig. 2. Location of the sections and hydrographic stations.

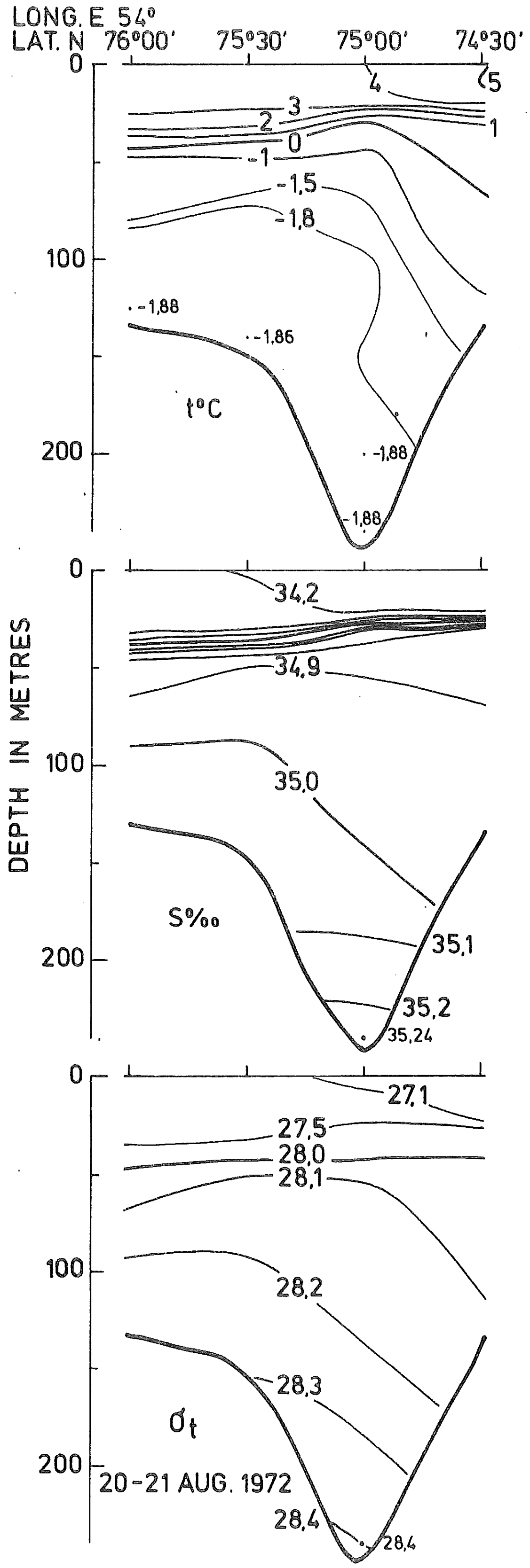

Fig. 3. Section 1. "Johan Hjort"
August 1972.

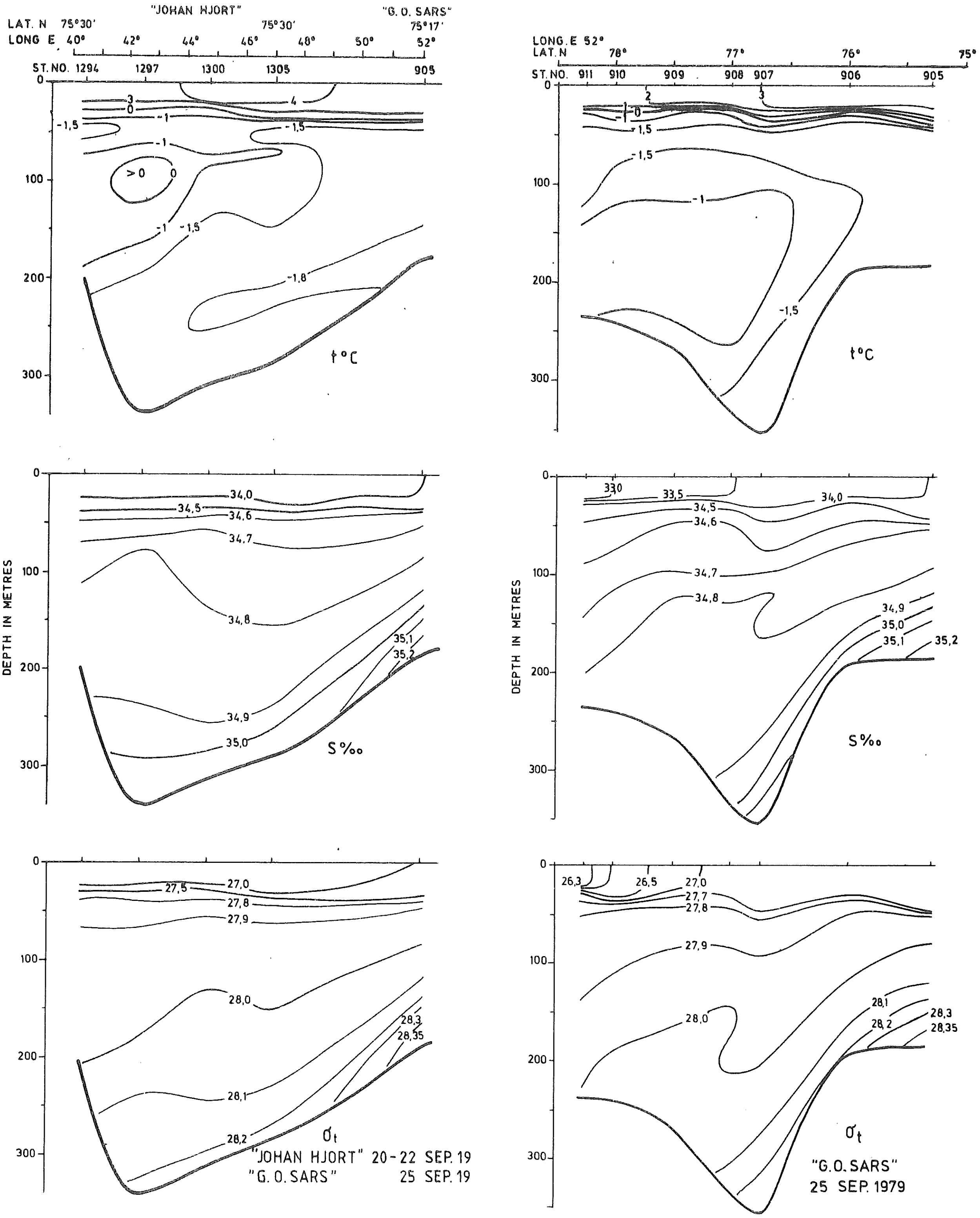

Fig. 4. Section 2 and 3 "G.O. Sars" and "Johan Hjort" September 1979.

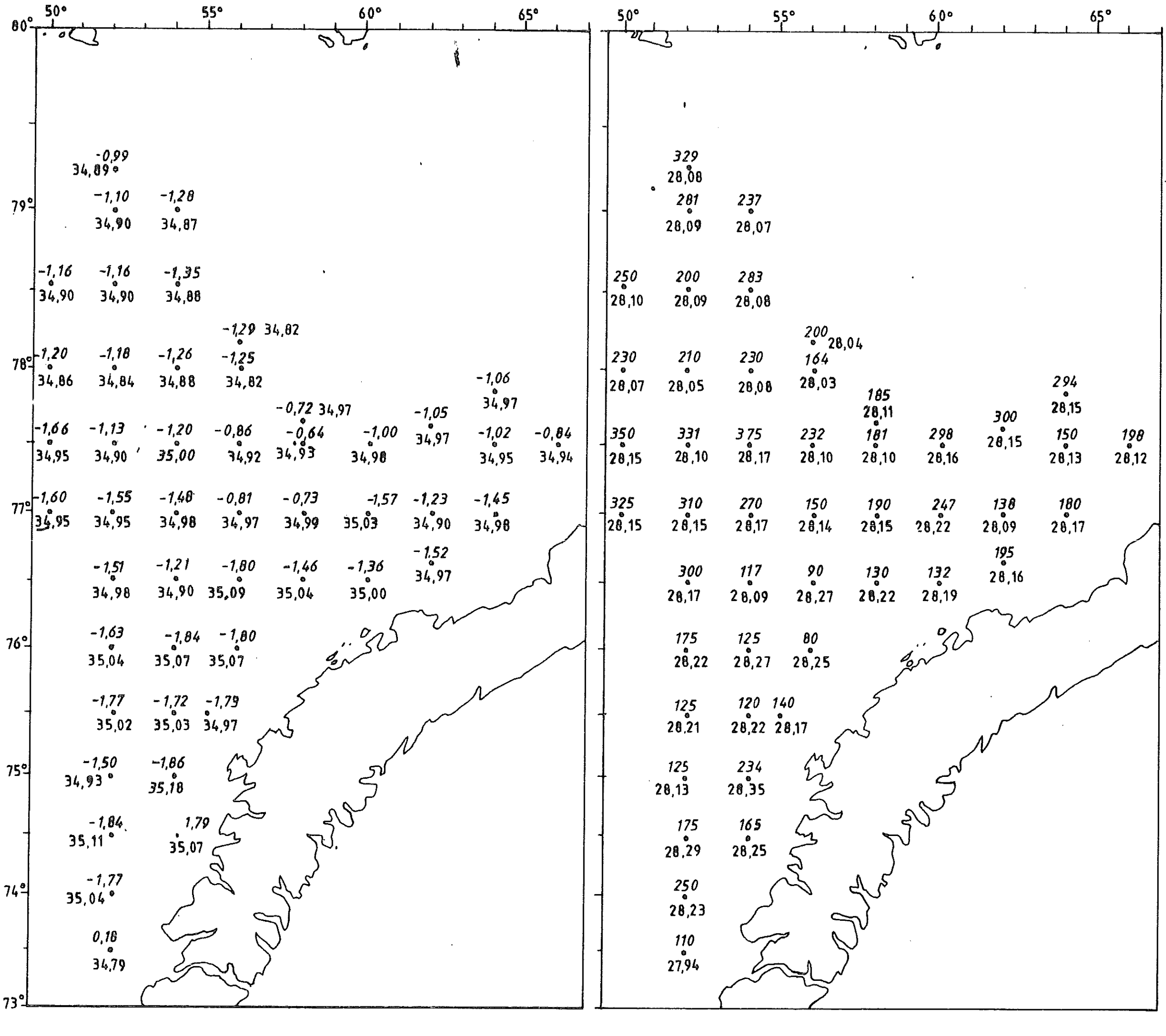

Fig. 5. "G.O. Sars" 1-15 October 1974. Left: Temperature and salinity of the bottom layer. Right: σ_t and observation depth.

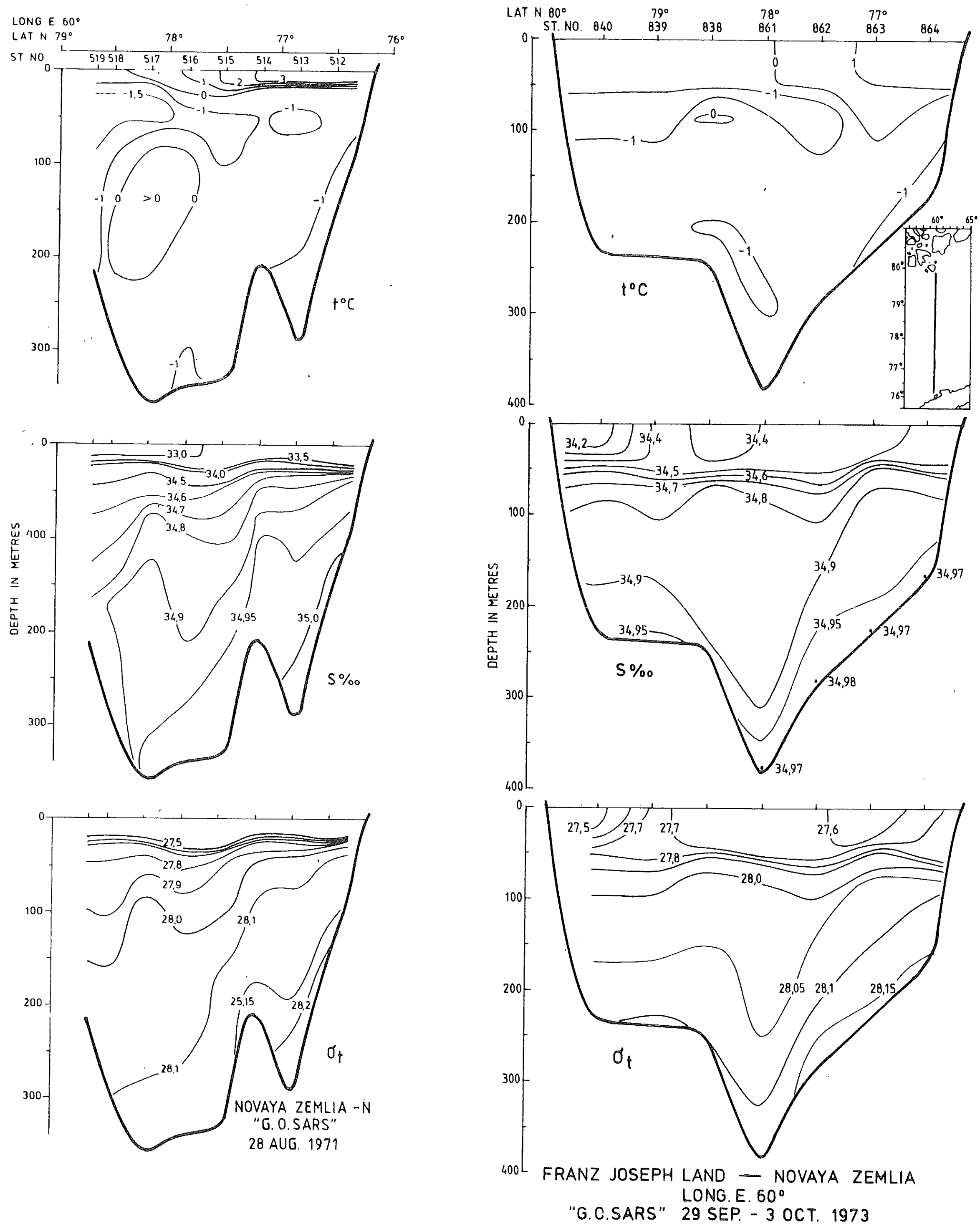

Fig. 6. Section 4 between Novaya Zemlya and Franz Josef Land along 60°E. Left: "G.O. Sars" 28 August 1971. Rigth: "G.O. Sars" 29 September-3 October 1973.

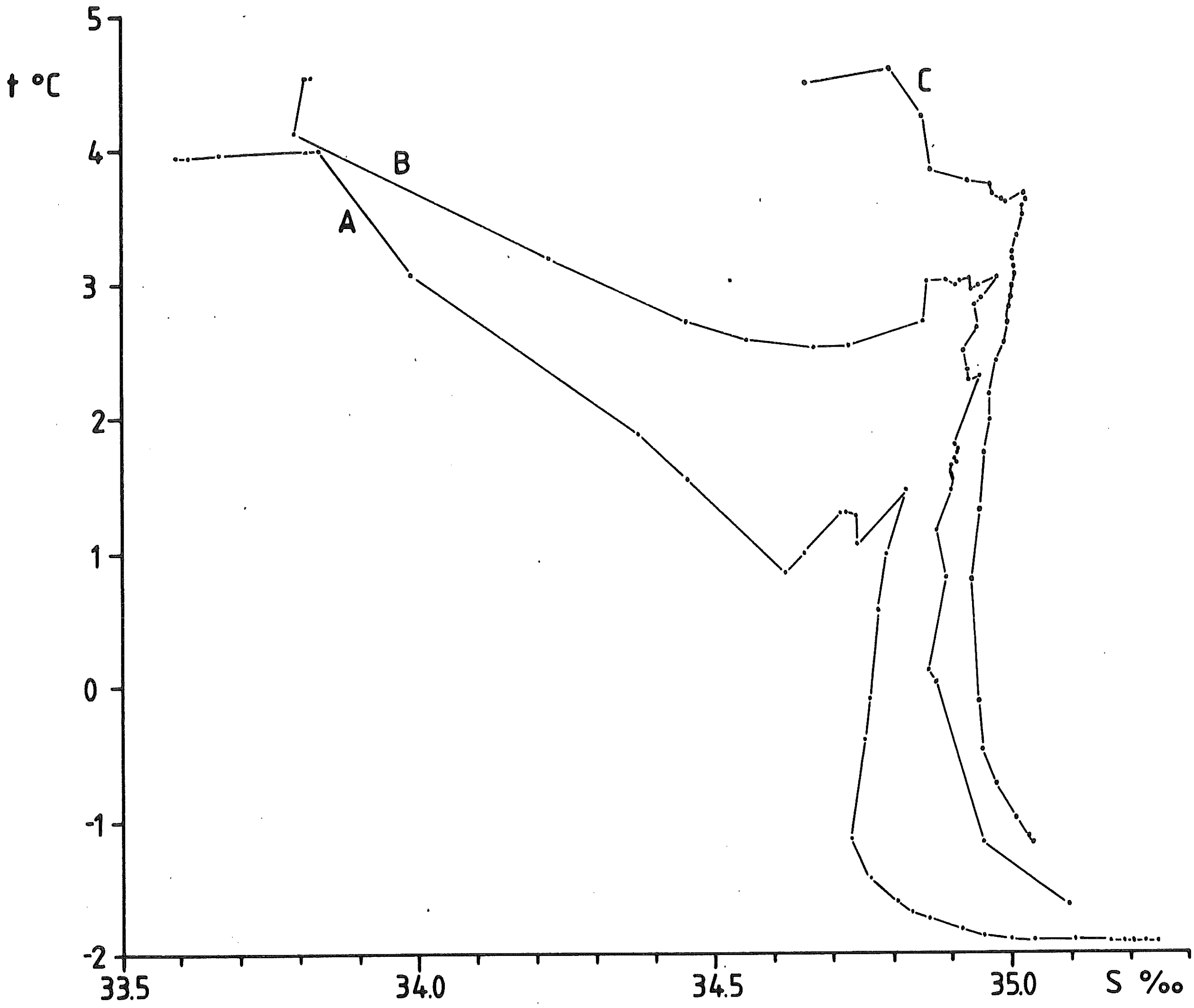

Fig. 7. A: "G.O. Sars" St. 805, August 1981 in 77°15'N 19°34'E, 0-160 m.
B: "G.O. Sars" St. 799, August 1981 in 76°20'N 19°59'E, 0-245 m.
C. "G.O. Sars" St. 659, September 1977 in 75°50'N 14°53'E, 0-363 m.