# The water masses between Iceland and Greenland

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ABSTRACT

The hydrography of the area between Iceland and East Greenland is reviewed and the origin and fate of the different water masses discussed. The main features of the circulation are described. Special attention is paid to the Overflow and its composition with respect to Norwegian Sea Bottom Water and Intermediate water masses. The variabilities in the exchange of surface and intermediate waters are discussed and explained. Finally, the 1970's salinity anomalies in Icelandic waters are illustrated.

## INTRODUCTION

A submarine ridge, the Iceland-Greenland Ridge, extends from the Northwest Peninsula of Iceland to the East Greenland coast. The shortest distance across is about 275 km. Most part of the ridge is rather shallow, 300–400 m (Fig. 1). About 100 km west of the Northwest Peninsula a 40–50 km broad channel with depths exceeding 500 m cuts across the Iceland-Greenland Ridge. The sill depth is 600–650 m.

The gross features of the water exchange between the European Subarctic and the North Atlantic Ocean has been known for some time, mainly on the basis of studies carried out in the 50's and 60's (Dietrich 1957; Harvey 1961; Stefánsson 1962, 1968; Mann 1969; Malmberg et al. 1972; Stein 1974). However, the nature and the mechanism of this exchange and details concerning the water structure are far from being adequately understood.

This paper deals with the general hydrography of this area. Attention is paid to the overflow of bottom water across the Iceland-Greenland Rige, the water mass composition of the overflow and the near-surface flow of polar water into the northern North Atlantic.

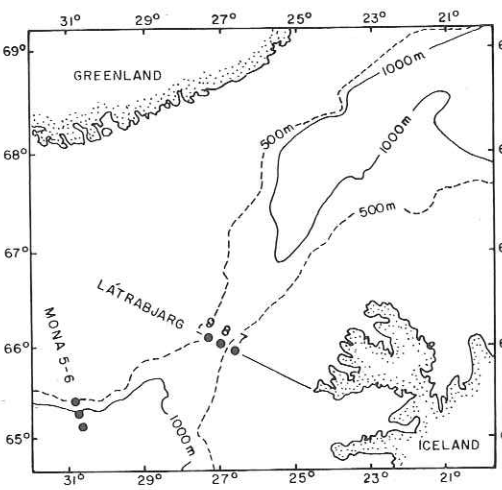



Fig. 1. Location of three stations on a standard hydrographic section on the sill of the Iceland-Greenland Ridge and other stations along the MONA 5–6 section in 1975–1976. (From Malmberg 1978b).

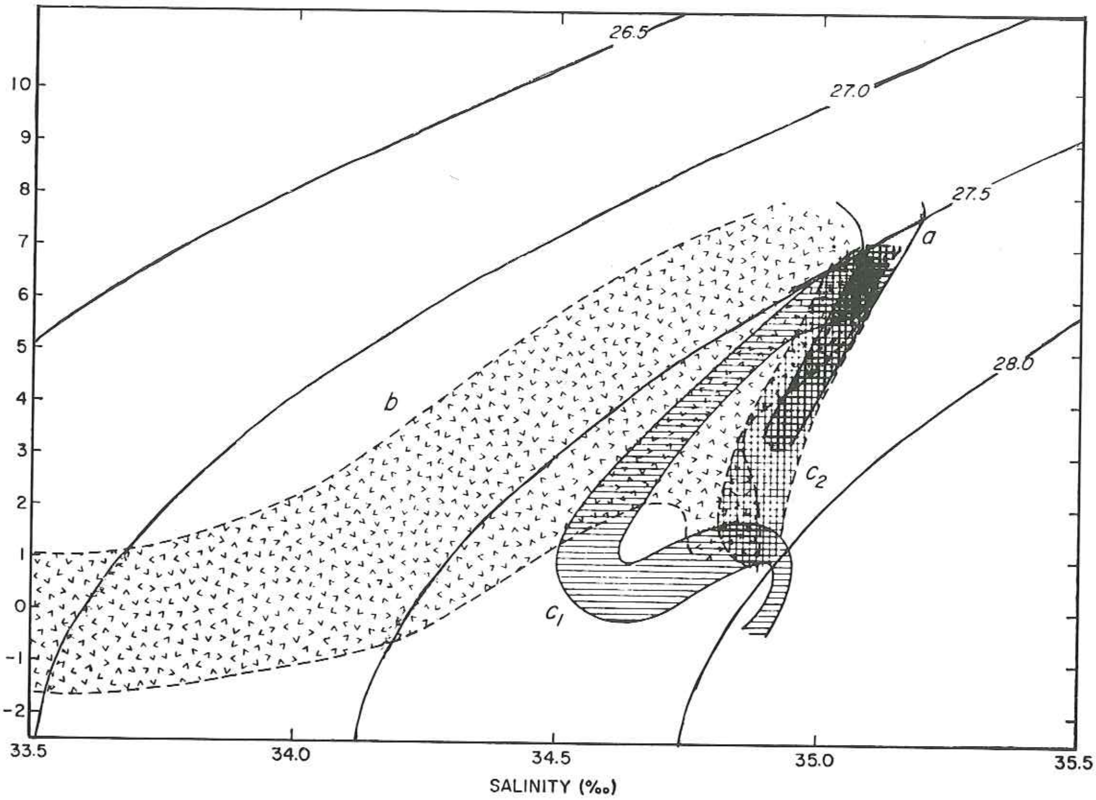



Fig. 2. Temperature and salinity relationships in the Iceland-Greenland Channel between 65° and 66°N. a) Between 100 and 2000 m in the trough region east of the Greenland continental slope. b) Below 50 m in the East Greenland shelf region. $c_1$) In the slope region east of Greenland and in the deepest part of the Iceland-Greenland Channel just south of the sill (66°N). $c_2$) In the slope region east of Greenland and in the deepest part of the northern Irminger Sea (65°–65°30′N). (From Stefánsson 1968).

## WATER MASSES

The main water masses in the area are the following (Fig. 2): a) warm and saline water of the Irminger Current on the eastern side of the Channel, b) Polar Water of the East Greenland Current with temperatures below 0° and salinity less than 34.5 in shallow waters on the west side of the Channel, c) a cold water often referred to as overflow of Norwegian Sea Bottom Water (NSBW; t<0°, S>34.9) in the deepest part on the western side of the Channel and d) an intermediate water mass with temperature of about 0–1° and salinity between 34.5 and 35.9 on the western slope between the shallow and deep water masses. This intermediate water consists of two different water masses, viz. Arctic Intermediate Water (AIW) with salinity 34.7–34.9 and temperature of 0–1°, and Polar Intermediate Water (PIW) with salinity below 34.7, even as low as 34.5, and temperatures below 0° (Fig. 3).

## SURFACE CURRENTS

The surface current system of the Iceland-Greenland Channel and the northern Irminger Sea is in general what could be expected from the bottom topography, with currents parallel to the coasts and land on the right hand side, consisting of two dis-

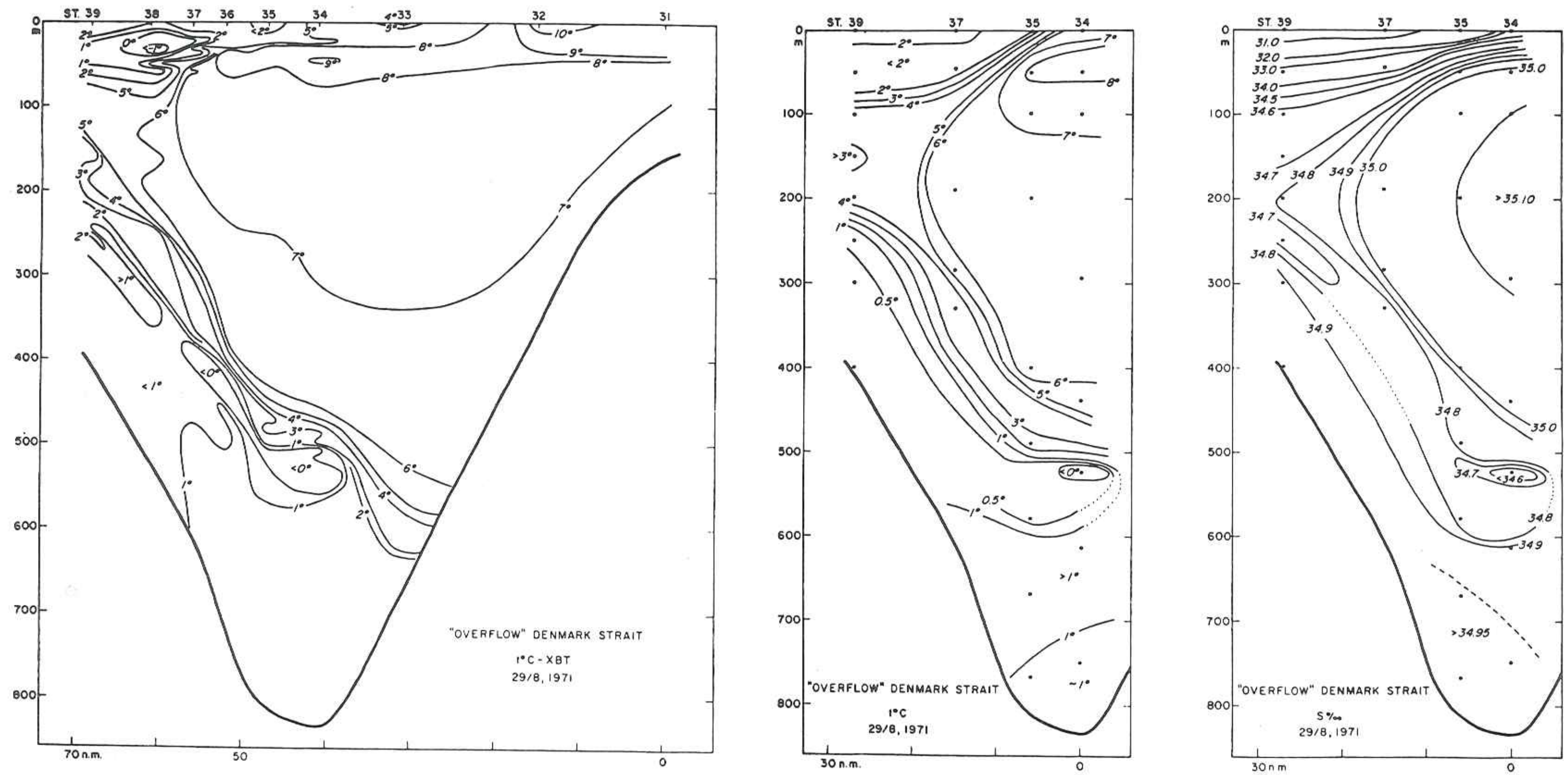



Fig. 3. Temperature and salinity distribution in a section through the Iceland-Greenland Channel (65°30′–66°00′N) in August 1971. (From Malmberg 1972).

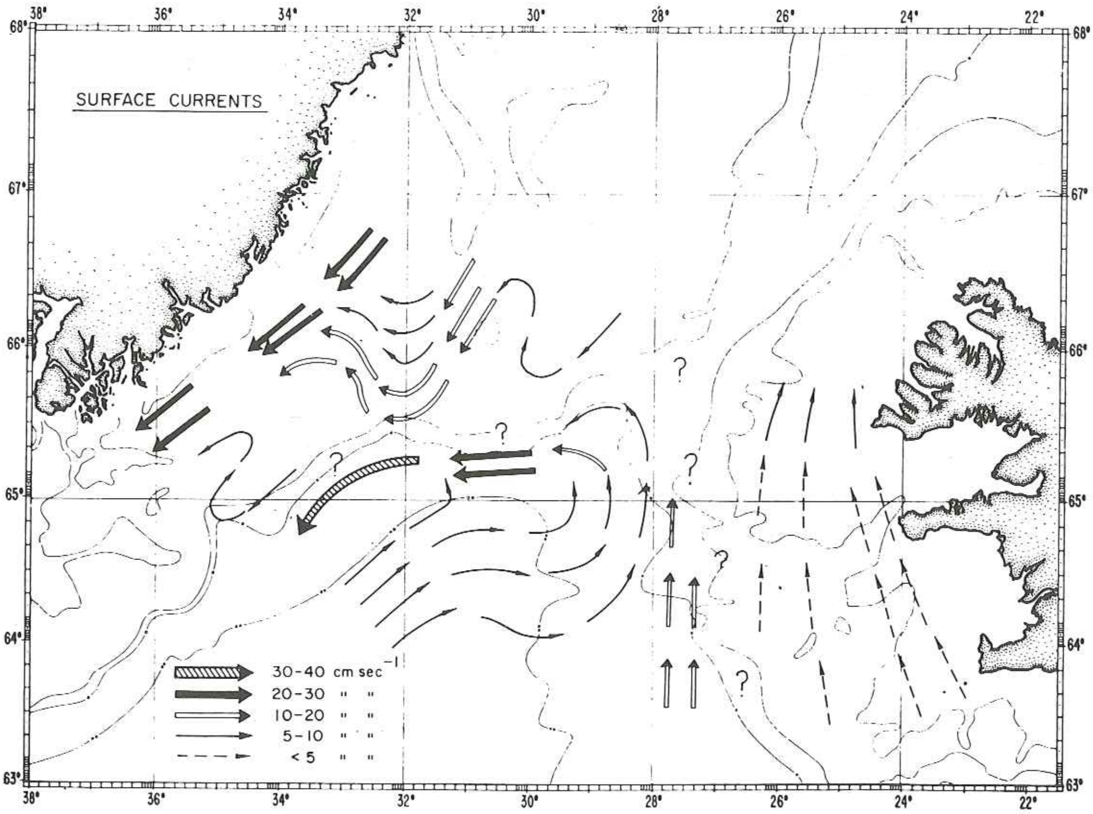



Fig. 4. Surface currents in the Northern Irminger Sea based on dynamical calculations from September 1963. (From Malmberg et al. 1972).

crete current bands, a shallow coastal current and a stronger flow along the slope (Fig. 4).

On the East Greenland shelf the southward flowing cold East Greenland Current is distinct, while a relatively slow northward flow is found in the Icelandic shelf area. In the deeper part of the region, inflow of the warm Irminger Current is found, partly into the North Icelandic region and partly along the East Greenland continental slope. The volume transport of the former has been estimated to be about 0.6 sv (Stefánsson, 1962). The main flow of the East Greenland Current north of the Iceland-Greenland Channel is along the slope on the shelf edge. In the Channel area the current enters the shelf, and south of the Channel it flows along the East Greenland coast, whereas the East Greenland branch of the Irminger Current is found in the slope area.

When dealing with volume transports of the East Greenland Current the difference in the location of the main flow north and south of the Channel must be taken into account, as well as admixture of the Polar Water with the water of the Irminger Current and the Intermediate Water.

The total southward volume transport across the whole East Greenland shelf south of the Channel including both Polar Water, Atlantic and Intermediate Water has been calculated to be 2.75 sv, whereas the transport of the main flow of the Polar Water itself has been calculated to be 1.0–1.6 sv (Malmberg et al. 1972).

## THE OVERFLOW ACROSS THE ICELAND-GREENLAND RIDGE

In his paper on links between deep water movements, climate and biological productivity Cooper (1955) predicted that the overflow across the Iceland-Greenland Ridge would take place intermittently in the form of boluses of cold water. His hypothesis was confirmed by direct observations (e.g. Harvey 1961, Worthington 1969). With the overflow '73 and Mona projects of ICES in the seventies (Anon. 1976; Ross 1977; Smith 1976; Aagaard and Malmberg 1978a, b) and the joint American-Icelandic Iceland Sea project in 1974–1975 (Swift 1980; Swift et al. 1980; Swift and Aagaard 1981) much knowledge was gained about this exchange of water, its variability and

TABLE 1

*Water mass composition of the near-bottom water of three hydrographic stations: 7,8 and 9 (see Fig. 1) in the Iceland-Greenland Channel during 1971–1977. AW: North Atlantic Water of the Irminger Current (T>6°C, S>35.0); AIW: Artic Intermediate Water (T = 0–1°C, S = 34.70–34.90); PIW: Polar Intermediate Water (T<0°C, S = 34.50–34.70); NSBW: Norwegian Sea Bottom Water (T<0°C, S = 34.90).*

| Year | Month | St. 7 (d~400 m) | | St. 8 (d~650 m) | | St. 9 (d~500 m) | |
|---|---|---|---|---|---|---|---|
| | | Water mass | Thickness (m) | Water mass | Thickness (m) | Water mass | Thickness (m) |
| 1971 | May | AW | | AW | | AW | |
| | August | NSBW | 50 | NSBW | 300 | AIW | 200 |
| 1972 | January | AW | | AIW | 150 | NSBW | 200 |
| | May | AW | | NSBW | 150 | AIW | 200 |
| 1973 | February | AW | | NSBW | 250 | — | — |
| | March | AW | | (PIW) | 100 | — | — |
| | June | AW | | NSBW | 25 | NSBW | 100 |
| 1974 | February | PIW | 100 | NSBW | 150 | NSBW | 250 |
| | May | AW | | NSBW | 150 | NSBW | 250 |
| | August | AW | | NSBW | 100 | NSBW | 150 |
| | Okctober | AW | | AIW | 300 | AIW | 150 |
| 1975 | February | AW | | AIW | 300 | AIW | 200 |
| | May | AW | | NSBW | 100 | — | — |
| | August | AW | | NSBW | 350 | NSBW | 250 |
| | November | — | | NSBW | 400 | NSBW | 150 |
| 1976 | February | AW | | NSBW | 300 | NSBW | 150 |
| | May | AW | | AW | | — | — |
| | August | AW | | NSBW | 250 | NSBW | 100 |
| | November | AW | | NSBW | 200 | NSBW | 100 |
| 1977 | January | AW | | AW | | NSBW | 150 |
| | February | AW | | NSBW | 50 | NSBW | 100 |
| | February | PIW | 50 | NSBW | 150 | — | — |
| | May | AW | | NSBW | 350 | NSBW | 200 |
| | August | AW | | NSBW | 150 | NSBW | 150 |
| | November | AW | | NSBW | 150 | NSBW | 150 |
| | Average: | AW: | 88% | AW: | 12% | AW: | 5% |
| | | NSBW: | 4% | NSBW: | 75% | NSBW: | 75% |
| | | PIW: | 8% | AIW: | 12% | AIW: | 20% |

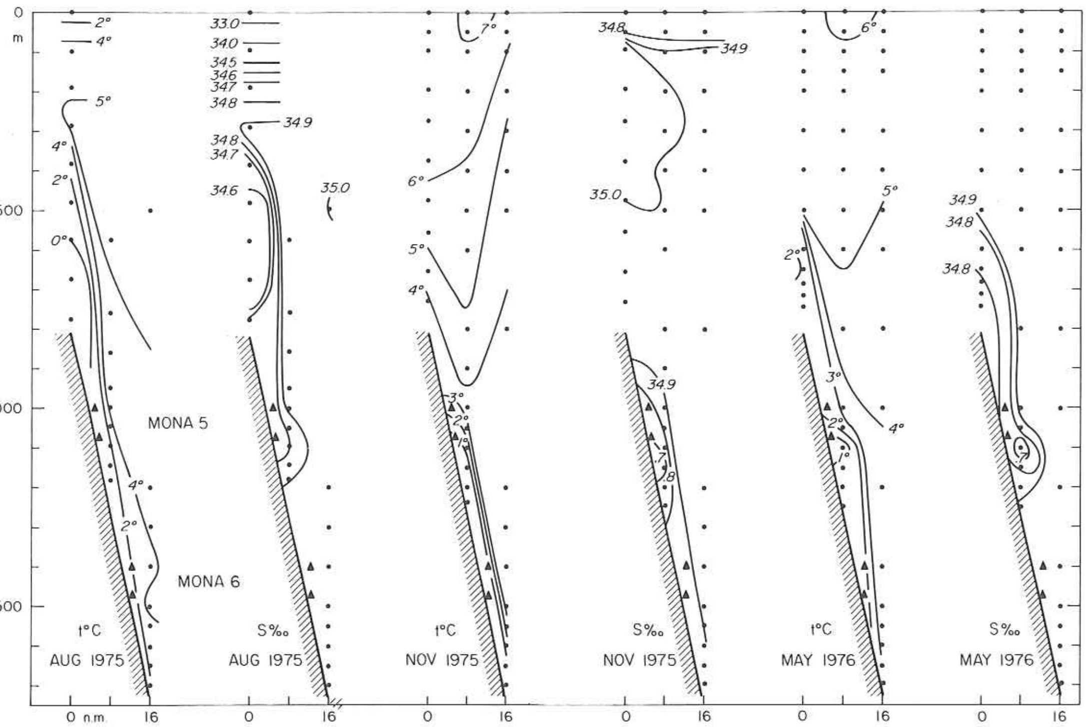



Fig. 5. Temperature and salinity distribution in a section along the MONA 5–6 section (see Fig. 1) in August and November 1975 and in May 1976. (From Malmberg 1978b).

complexity. The investigations were mainly directed at the overflow of cold water from the north across the Ridge into the deep and bottom layers of the Irminger Sea and the Labrador basin (Ross 1984; Swift 1984).

During annual and seasonal hydrographic investigations in 1970–1977 at the sill of the Ridge or just south of it (Fig. 1), NSBW was observed in 75% of the cases in the bottom layers with a thickness of as much as 100–200 m (Table 1). Year-long data from four recording instruments located near bottom at 1000–1500 m depth farther south on the East Greenland slope (Mona 5, 6; see Figs. 1 and 5) showed negative temperatures in the overflowing water less than 1% of the time (Aagaard and Malmberg 1978a, b). Such negative temperatures are a necessary, but not a sufficient indicator of NSBW because they can also reflect cold PIW. A concurrent record of salinity is required to determine the identity of the overflowing water. Such data were obtained by Ross (1977, 1984) during the overflow '73 experiment. Both the total overflow ($t<2°$) and the NSBW portion of this overflow ($t<0°$, $S>34.9$) has been estimated by Swift et al. (1980) and by Ross (1984). The total value was found to be respectively 2.3 sv and 2.9 sv. Of this only 10% and 17% respectively were identifiable as NSBW.

Indeed very few samples of NSBW have been recorded south of Denmark Strait, except immediately south of the sill.

It was concluded (Swift et al. 1980) that the component of the Iceland-Greenland Channel overflow of greatest significance is not NSBW but an intermediate water of arctic origin with salinity slightly under 34.9. This is supported by relatively high tritium values of about 5 T. U. observed in the overflowing water compared with low

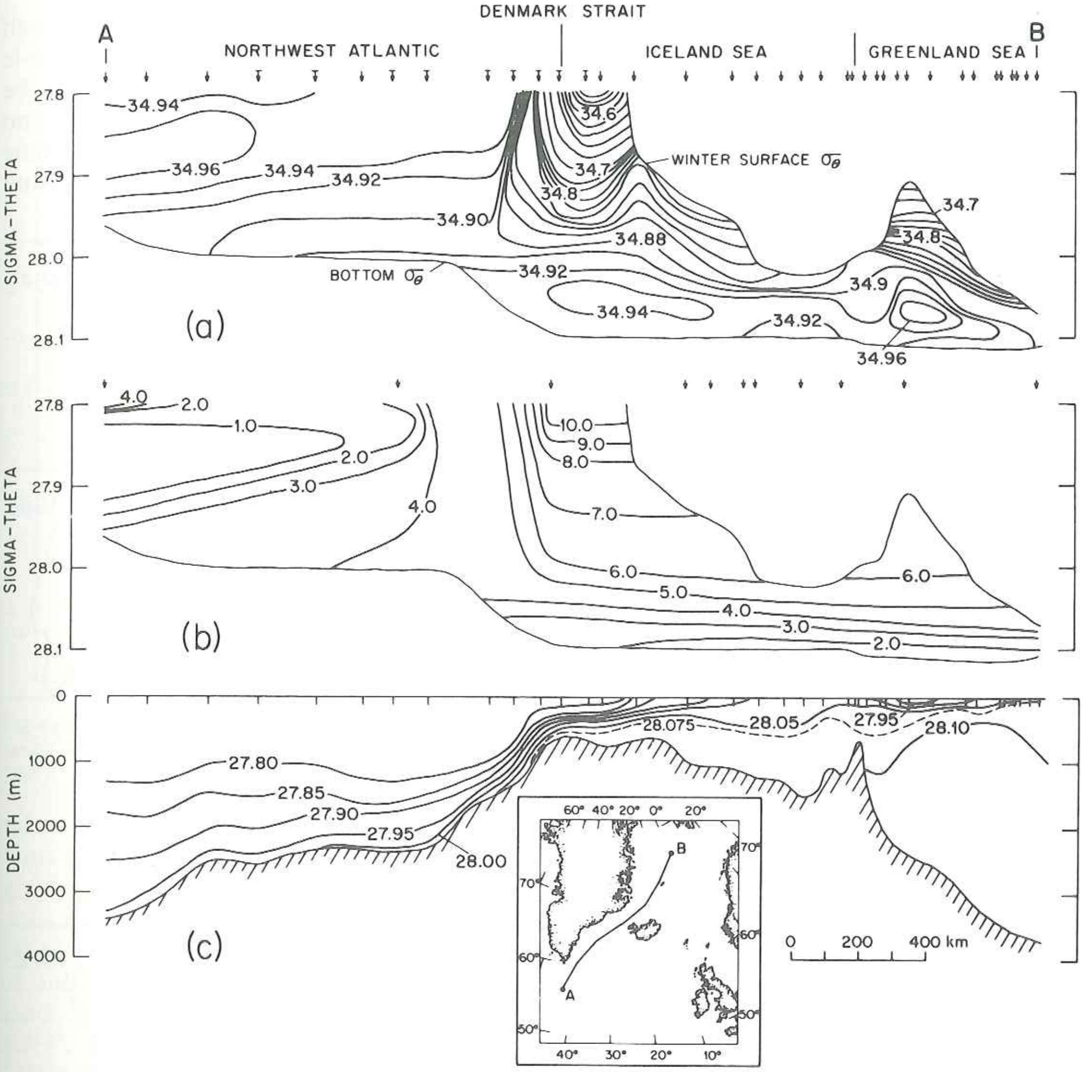



Fig. 6. a) Salinity in a sigma-theta section through the Iceland-Greenland Channel. Only values of sigma-theta greater than 27.80 are shown. b) Tritium in the sigma-theta section. c) Sigma-theta vs depth in the same section. (From Swift et al. 1980).

tritium values in the NSBW of about 1.5 T. U. (Fig. 6). The overflowing intermediate water is formed mainly in winter at the sea surface north of Iceland in the Iceland Sea and also farther north (Swift et al. 1980). Then there are still unsolved questions about what happens to the NSBW, frequently observed on the sill or even just south of it as mentioned above (Table 1).

## VARIABILITY IN THE EXCHANGE OF SURFACE WATERS

The relationship between oceanographical and meteorological variables in the shelf area north of Iceland has been investigated statistically for the period 1924–1965 (Stefánsson 1962; Stefánsson and Gudmundsson 1969). These studies have revealed that in ice-free years the hydrographical conditions at near-surface and intermediate depths are closely related to past meteorological conditions (N-S winds, air temperature) off the northwest coast of Iceland which largely control the influx of Atlantic water to the North Icelandic shelf area. However, in years with appreciable polar influence this relationship will be complicated and a simple correlation no longer holds. There is a need to re-examine this problem on the basis of a model that

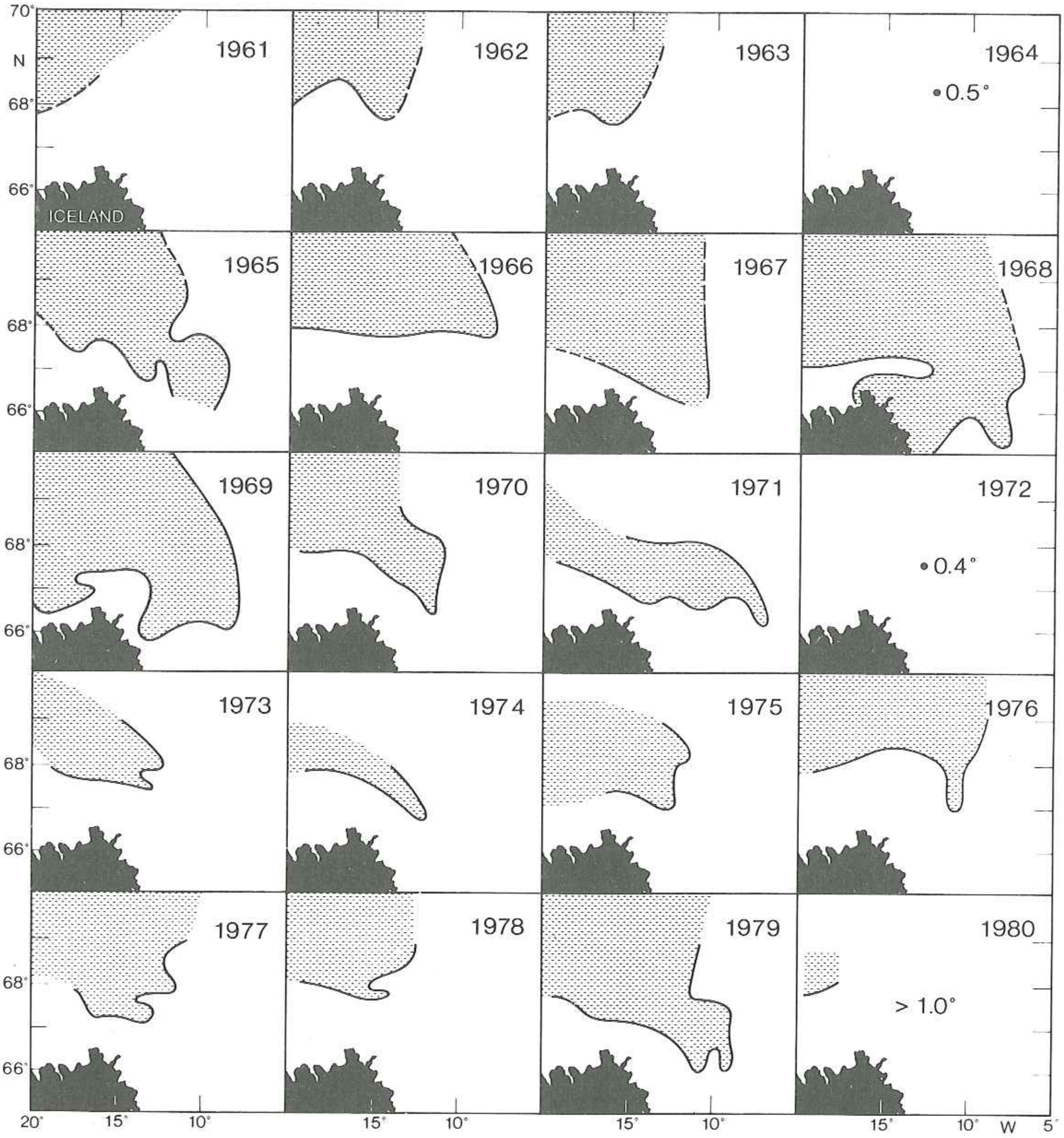



Fig. 7. The 0° isotherm at 50 m depth in the East-Icelandic Current northeast of Iceland in June 1961–1980. Within the shaded area the temperature was below 0°C. (From Malmberg 1984a).

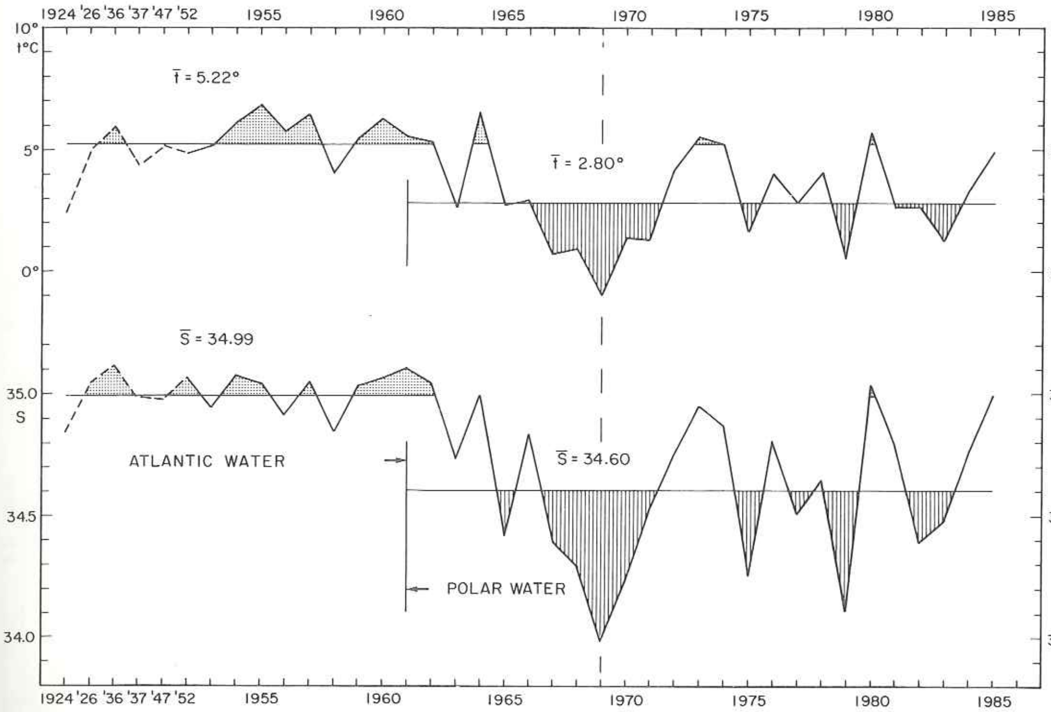


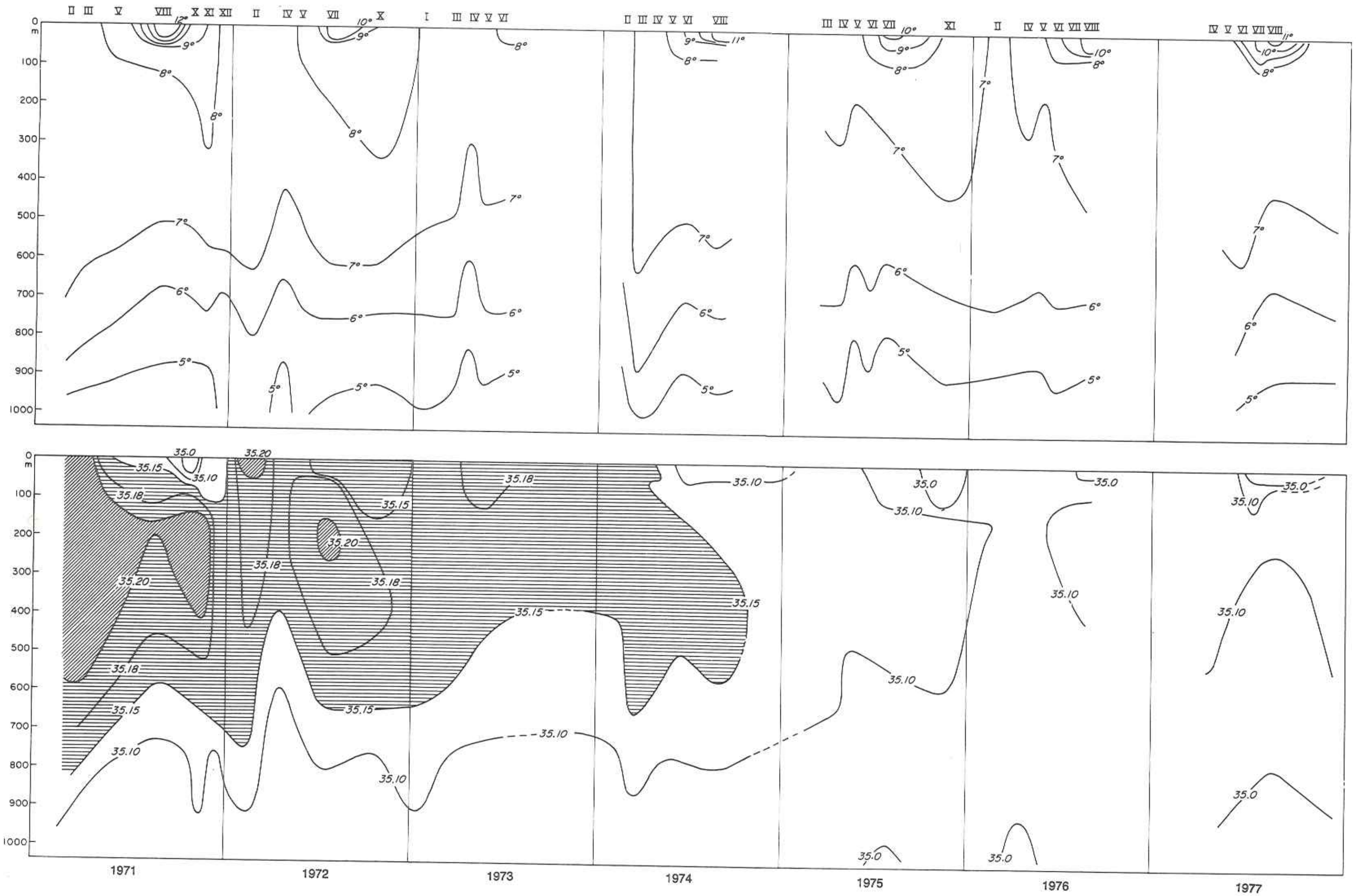

Fig. 8. Temperature and salinity, observed values and deviations, at 50 m on a hydrographic station in North Icelandic waters (S-3: 66°32′N, 18°50′W) in May-June 1924, 1926, 1936, 1937, 1947 and 1952–1985. (From Malmberg 1985).

takes into account the various current systems as well as meteorological and oceanographic processes.

In recent decades marked changes have taken place in the distribution of polar water and the extension of drift ice in the Iceland Sea (Fig. 7). While Atlantic Water (t>4°, S>35.0) was dominating in North Icelandic waters in spring during the period 1924–1964 (Stefánsson 1962), the late sixties were characterized by polar influence (Fig. 8). These changes were manifested by the appearance of sea ice and biological implications in North Icelandic Waters (Sigtryggsson 1972; Thórdardóttir 1977, 1984; Jakobsson 1980; Astthórsson et al. 1983; Malmberg 1985).

The changes were also linked to atmospheric pressure variations as well as to variations in the physical environment throughout the northern North Atlantic along the oceanic polar front from Spitzbergen to Newfoundland (e.g. Cushing and Dickson 1976; Dickson et al. 1975; Malmberg and Svansson 1982). This indicated a change or increase in the outflow of cold polar water from the Arctic and Subarctic Seas into the northern North Atlantic during these years (Malmberg et al. 1972; Dickson et al. 1984a, b).

The present author stated (Malmberg 1977) that "it is believed that in 1965–1970 great amount of polar water passed from the north through Greenland and Labrador waters into the general circulation system of the North Atlantic, from there flowing back mixed with Atlantic water from the south towards the European coasts. Thus the effects of the ice years in 1965–1970 may possibly still be found in Icelandic waters from a direction not generally expected".



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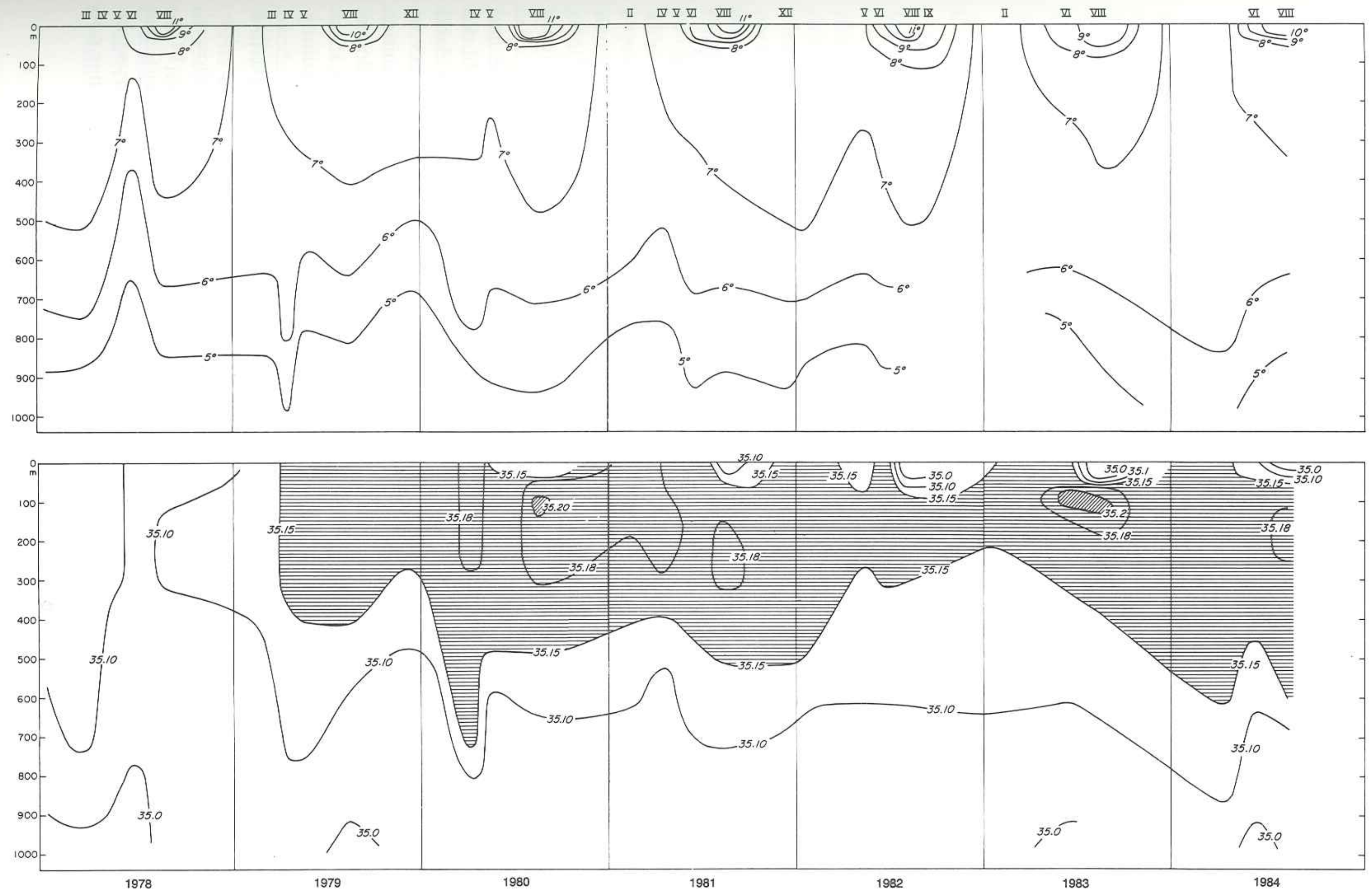


Fig. 9. Temperature and salinity isopleths at a hydrographic station on Selvogsbanki southwest of Iceland (63°00′N, 21°28′W) in 1971–1984. (From Malmberg 1984b).

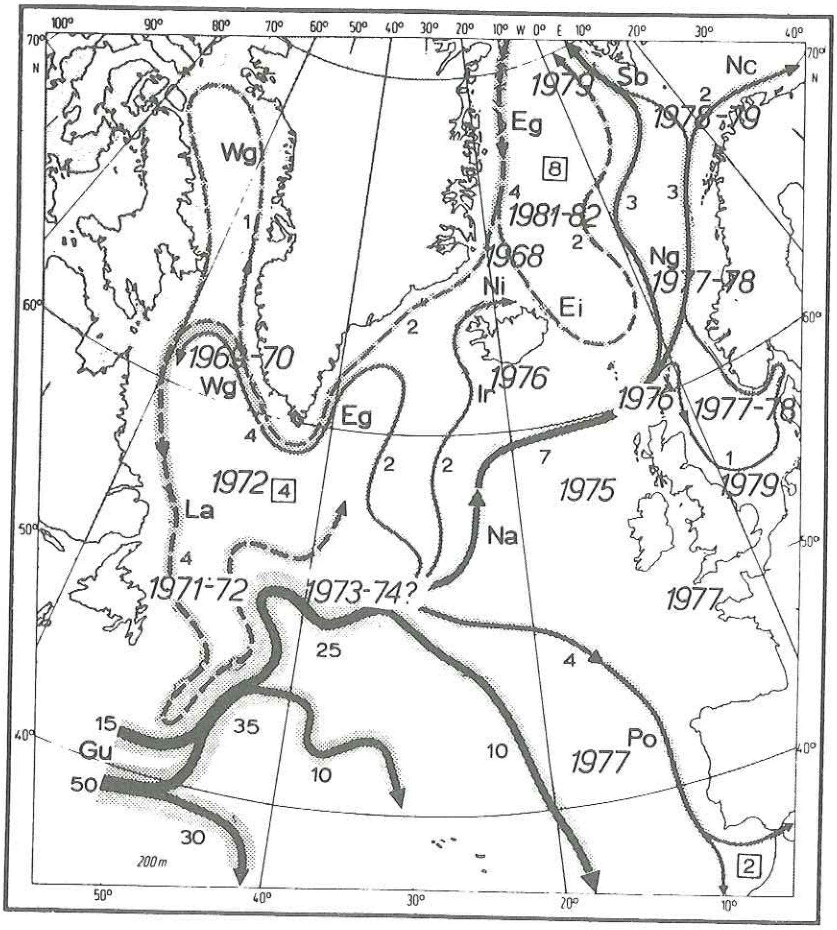


Fig. 10. Transport scheme for the 0-1000 m layer of the northern North Atlantic (Dietrich et al. 1975) with the dates of the 1970's salinity anomaly superimposed. (From Dickson et al. 1984b).

## THE 1970's ANOMALY IN ICELANDIC WATERS

Around 1976 relatively low salinities were observed in the North Atlantic water (t>6°, S>35.10) south of Iceland (Malmberg 1978a, 1984b), as was also reported for the waters west of Scotland (Ellett 1978). This anomaly, observed in the northern North Atlantic (Fig. 10), is the so-called "mid-seventies anomaly" (Dooley et al. 1984, Dickson et al. 1984a, b), a name given by the present Hydrographer of ICES, Dr. Harry D. Dooley.

Since 1970 more or less seasonal hydrographic observations have been carried out on standard sections in Icelandic waters. To illustrate the changes in temperature and salinity as a function of time and depth, the isopleths for one station south of Iceland are shown for the period 1970–1983 in Figure 9. It will be seen that salinities above 35.20 were observed at this station in 1971 and 1972, and values above 35.15 at least up to August 1974. In 1975 the salinity of the North Atlantic water was above 35.10, but in 1976 it was below 35.10, with a minimum of 35.08 in April 1976. The salinity showed a slight increase in 1977 followed by a secondary minimum in June 1978. Since then it has been increasing with the highest values of about 35.20 observed in 1980 and again in late 1983, but it has not quite reached the level of 1971–1972.

Thus it can be concluded that the "mid-seventies anomaly" in salinity was clearly observed in the waters south of Iceland. This lowering in salinity was also observed in the area west of Iceland and could be followed along the shelf on the east side of the Iceland-Greenland Channel to the North Icelandic region. However, in these northern waters the signal was less distinct and complicated by variable admixture of polar water in the surface layers.

## CONCLUDING REMARKS

It is evident that further investigations in the Iceland-Greenland Channel using modern techniques are badly needed to solve still unanswered questions about the exchange of water masses through the Channel, i.e. concerning the near bottom overflow, the variability in the polar component of the East-Greenland Current and finally the inflow of Atlantic water with the Irminger Current into North Icelandic waters. Such investigations are of obvious importance not only for a better understanding of Icelandic waters but also for gaining information on the exchange of water masses between the European Subarctic and the North Atlantic, and the subsequent effects on biological and climatic conditions in these northern waters. At this stage it seems appropriate to consider an *international effort* devoted to an extensive oceanographic study of the Iceland-Greenland Channel, making use of modern methods and high-precision instrumentation.

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