ICES STATUTORY MEETING 1993 C.M.1993/C:20

The North Atlantic Watercomponent of the West Greenland Current

by

Erik Buch

Royal Danish Administration of Navigation and Hydrography
Overgaden O. Vandet 62B
1023 Copenhagen K.

Abstract.

It has for many years been known that the West Greenland Current is composed mainly of two water masses originating from current systems outside the Davis Strait i.e. the East Greenland Current and the North Atlantic Current.

With regard to the North Atlantic current component it has always been referred to being a branch of the Irminger Current which just south of the Denmarks Strait turns south flowing alongside the East Greenland Current, rounding Cape Farewell to enter the West Greenland area, see Kiilerich (1943), Hermann (1967), Lee (1968) and Buch (1982, 1984,1985).

A more detailed analysis of the oceanographic observations from the standard sections along West Greenland reveal the presence of water with high temperatures but salinities below those of Irminger Water indicating inflow of water of North Atlantic origin but along other routes than the Irminger Water.

1. Introduction.

The waters off West Greenland are dominated by 4 - 5 water masses all formed outside the Davis Strait:

* In the surface layer close to the coast Polar Water is found. It is carried to West Greenland by the East Greenland Current.

* Below and west of the Polar Water we find water originating from the North Atlantic Current.

* At great depths Northeast Atlantic Deep Water and Northwest Atlantic Bottom Water are observed.

Recent years large research efforts in the North Atlantic and the Nordic Seas with improved observation technology have resulted in a detailed knowledge of the varity of water masses found in this area so that a rather specific temperature-salinity characteristic for each water mass can be given. A more detailed picture of the inflow of water originating from the North Atlantic Current to the West Greenland area can therefore be given, which is the topic of the present paper.

Kiilerich (1943) summarized the oceanographic observations made in the West Greenland area until World War II and defined Irminger Water (believed to be the only water component of Atlantic origin in the area) as water with:

Temperature:	3.5 - 5.0°C
Salinitiy:	34.75 - 35.00

Lee (1968) and Clarke (1984) have defined Irminger Water as a mixture of Irminger Sea Water, formed in the Irminger Sea during winter, and North Atlantic Water having the following T-S characteristics:

Temperature:	4.0 - 6.0°C
Salinity:	34.95 - 35.10

This different definition of Irminger Water, especially the increase of the lower salinity limit to 34.95, give reason to revaluate the presence of Irminger Water off West Greenland.

The present analysis is based on data collected by the Greenland Fisheries Research Institute on standard sections along West Greenland as well as the extensive dataset collected during the international NORWESTLANT programme in year 1963.

2. Inflow and distribution of Atlantic water.

The classic picture of the inflow of water of Atlantic origin to the West Greenland area is a component of the Irminger Current branching off towards East Greenland just south of the Denmarks Strait. This branch continues southwards along East Greenland running side by side and below the Polar Water in the East Greenland Current, rounding Cape Farewell and entering the West Greenland area.

Revised T/S-characteristics for the Irminger Water raise the following questions:

* Is Irminger Water the only water mass of Atlantic origin present off West Greenland?

* Is Irminger Water at all present in the area?

These two questions can be properly adressed using the extensive data material from the three field campains under the NORWESTLANT programme in 1963:

NORWESTLANT 1: 31 March - 9 May 1963
NORWESTLANT 2: 1 May - 18 June 1963
NORWESTLANT 3: 30 June - 3 August 1963

In Fig. 1 - 3 the horizontal salinity distribution at the surface and at 200 m during the three NORWESTLANT campains are shown, and Fig. 4 - 6 show selected vertical temperature and salinity sections along West Greenland from NORWESTLANT 3. It is seen that:

* During all three periods water with salinities above 34.95 enters the Davis Strait.

* The presence of Irminger Water off West Greenland is a subsurface phenomenon. Close to the continental slope Irminger Water is found in the depth interval 500 - 1100 m. Further offshore, especially in the southern part, it is found at shallower depths.

* Great differences in the horizontal distribution of Irminger Water between the three periods of observation are observed. Maps of the surface salinity distribution (Fig. 1 - 3) show a gradual retreat to the Irminger Sea, while at 200m a retreat is observed between NORWESTLANT 1 and NORWESTLANT 2 followed by an advance between NORWESTLANT 2 and NORWESTLANT 3. Vertical sections along West Greenland do, however, show the presens of water with salinities above 34.95 at depths greater than 500 m and further offshore compared to the two other NORWESTLANT surveys during the NORWESTLANT 2 survey, Lee (1968). The most northerly distribution of Irminger Water was observed during NORWESTLANT 3, where it was observed as far north as 66°N which is close to the sill between the Davis Strait and the Baffin Bay.

* Data from all three NORWESTLANT surveys (Lee, 1968) reveal that in the West Greenland area water with salinities above 34.95 have a temperature close to 4.5°C. It must however be noted that the three NORWESTLANT surveys were carried out during the first half of 1963 implying that the situation may be different during other seasons and in other years.

* On the vertical sections in Fig. 4 - 6 there is a layer between the surface layer (S < 34.5) and the Irminger Water having salinities between 34.5 and 34.95 and temperatures in the interval 2.5 to 4.5°C. This water is found beneath the cold, low saline Polar Water at depth greater than 150 - 200 m implying that the relatively high temperatures are not due to local atmospheric heating.

Using data from the three NORWESTLANT surveys in 1963 it has been demonstrated that Irminger Water enters the Davis Strait and that another water mass with temperatures indicating it must be of Atlantic origin is present at great quantities.

In the following the presence of these two water masses off West Greenland is analyzed more thoroughly using data collected by the Greenland Fisheries Research Institute over more than forty years allowing also seasonal and interannual variability to be investigated.

3. Irminger- and Sub-Atlantic Water.

The inflow of Atlantic water to the West Greenland area has a distinct annual period (Buch, 1985), which can be illustrated by the vertical distribution of temperature and salinity over a year (Nov. 1982 to Nov. 1983) at Fylla Bank st. 4 located just west of the Fylla Bank at 63°53'N, 53°22'W, Fig. 7. During spring and early summer the intensity is normally only appreciable at the southern parts i.e the Cape Farewell area (Buch, 1985), while further north the inflow is rather sluggish. In late summer the inflow begins to intensify and is consequently deflected towards the coast due to the action of the Coriolis force. The boundary between the warm and the cold water rises along the continental slope and reaches its highest level during winter. Additionnally Fig. 7. reveal a number of interesting features:

* Irminger Water (S > 34.95) is present only during wintertime that particular year.

* The period of maximum inflow is accompanied by an increase in temperature to above 5°C (some years even above 6°C). The water with maximum temperature has salinities between 34.5 - 34.85, i.e. the maximum temperature is not connected to the Irminger Water.

* Throughout most of the year there exists a layer between 200 and 400 meters with temperatures between 2.5°C and 4.5°C and salinities between 34.5 and 34.9. Below 400 m the temperature is always above 3°C and the salinity above 34.75 (Buch, 1990).

* During part of the year the salinity is below 34.9 in the entire water column.

Another way of illustrating the presence of different water masses of Atlantic origin is by constructing T/S-diagrams. Due to the seasonal variability of the inflow of Atlantic water plots have been prepared for each of the four seasons using observations from Fylla Bank st.4 and 5 from the years 1950 - 1988, Fig. 8 a-d, surface data (S<34.0) has been disregarded. All data are collected by the use of Nansen Bottles.

It is noticed that Irminger Water (S>34.95) has been observed every seasons and that the temperature of this water is close to 4.5°C. It is, however, striking to see how few observations of salinities above 34.95 that actually are made over a almost fourty year long observation period. This of course partly is due to the fact that the vertical spacing between the observation points is 100 - 200 m in the depth interval were Irminger Water is found because only bottle data is used. Another immediate explanation could be that Irminger Water does not reach the latitude of Fylla Bank every year. Buch (1982) prepared plots similar to Fig. 7 for each of the years 1970 - 79 (subseqent years are prepare as drafts) and they clearly show that it is far from every year that salinities above 34.95 is observed at Fylla Bank. It shall however be pointed out that the observation intensity has not been the same each year, so there may be years where Irminger Water has reached Fylla Bank without being observed. The data material nevertheless indicates the possibility that Irminger Water only occasionally enters the West Greenland area, and 1963 therefore may have been an unusual year with extremely high inflow of Irminger Water.

Fig. 8 shows that there troughout the year is a pool of data with salinities above 34.85 and temperatures around 4°C. It is natural to believe that the Irminger Water mixes with the surrounding water on its way towards West Greenland resulting in a decrease in temperature and salinity. We may therefore see the Irminger component of the West Greenland Current as a tongue-like flow of water, an impression confirmed by the temperature/salinity distribution given in the vertical sections given in Fig. 4 - 6. In the core temperatures are close to 4.5°C and salinities above 34.95, but at the outer limit the temperature has reduced to around 4°C and salinities to about 34.85. The core do apparently seldom reach far beyond Cape Farewell.

The increase in temperature towards the end of the year as revealed in Fig. 7 is clearly seen also in Fig. 8 and so is the fact that the rise happens in a water mass now believed <u>not</u> to be Irminger Water. Water with salinities above 34.5 is found at depths excluding the possibility of a temperature rise due to atmospheric heating. The high temperatures, especially during autumn, supports the assumption that the water with salinities in the interval 34.5 - 34.85 is originating from the North Atlantic Current. This water mass will be called "**SUB-ATLANTIC WATER**".

The question hereafter is: "From where does Sub-Atlantic Water enter the West Greenland area?"

The following hypothesis is proposed:

> *The warm water with salinities in the interval 34.5 - 34.85 observed along the continental slope off West Greenland at depths between 200 - 600 m originates from the area south - southwest of Cape Farewell where water with the true T/S characteristics are observed (see Fig.1 - 3). It is advected to West Greenland following a path as indicated by the streamlines shown in Fig. 9.*

The conditions shown in Figs. 1 - 3 and 9 are surface conditions, while Sub-Atlantic Water is observed at a depth below 200 m off West Greenland, but it is seen in Fig. 1 - 3 that water with the correct T/S - characteristic is found also at 200 m depth south of Cape Farewell.

Fig. 4 shows a vertical section of temperature and salinity south of Cape Farewell from the NORWESTLANT 3 survey. It appears that south of st. 43 a rather thick layer with salinities between 34.6 - 34.85 exists. Temperatures are above 4.5°C in a 50 - 100 m thick surface layer between st. 43 and st. 50, while south of station 51 the layer is 200 - 250 m thick. Observations from the same section during NORWESTLANT 1 and 2 show similar conditions, although with lower temperatures ($T < 2.5$°C), in a 200 - 250 m thick layer at a distance of 200 km south of Cape Farewell.

Clarke (1984) reported observations from a section between Cape Farewell and Flemish Cape taken in early 1978. North of the North Atlantic Current to about 200km south of Cape Farewell a 200 - 300m thick layer with $T > 2.5$°C and $S < 34.85$ was observed.

These observations indicate that the Sub-Atlantic Water may originate from the northern part of the North Atlantic Current. This water mass branches off towards west just east of Cape Farewell, rounds Cape Farewell and enters the Davis Strait. It may possibly be formed by mixing of water from the North Atlantic Current with water from the Labrador Current.

The high temperatures ($T > 4.0$°C) of the Sub-Atlantic Water during autumn and winter are primarily due to the high temperatures of the North Atlantic Current, but the heating of the surface layer during summer is also regarded important since a rise in temperature was rigistered between the three NORWESTLANT survey periods (lee, 1968). The lower temperatures the remaining part of the year may be due to winter cooling, presence of drift ice in the Labrador Current and perhaps reduced mixing with the North Atlantic Water.

4. Conclusions.

A thorough analysis of the extensive data material collected by the Greenland Fisheries Research Institute since 1950 and the data from the three NORWESTLANT surveys in 1963 have led to the following conclusions on the inflow of Atlantic Water to the West Greenland area:

* Irminger Water enters the West Greenland area in a tongue-like fasion. Temperatures are above 4°C and salinities above 34,85, in the core of the current temperatures are around 4.5°C and salinities above 34.95. The core of the current can be observed as far north as the submarine ridge between the Davis Strait and Baffin Bay (66°N) at depths of 500-1100 m, but the normal situation seem to be that the core of the current seldom flows far beyond Cape Farewell.

* The inflow of Irminger Water has previously been highly overestimated, because a strong inflow of warm water ($T > 5°C$) taking place every autumn has up to now been classified as Irminger Water. However, the major part of the inflowing warm water has salinities between 34.5 and 34.85 and thus does not fulfill the specifications of the Irminger Water.

* The high temperatures indicate that this water must originate from the North Atlantic Current. Water from the northern limit of the North Atlantic Current seem to have the right T/S-characteristics and it branches off towards the west in the area southeast - east of Cape Farewell, rounds Cape Farewell and enters the Davis Strait.

* This water mass, called **Sub-Atlantic Water,** is probably formed through mixing between water from the North Atlantic- and the Labrador Currents, occuring south - southwest of Cape Farewell where the two currents meet.

* The Sub-Atlantic Water are believed to enter the West Greenland area throughout the year because water with salinities in the given interval and temperatures above 2.5°C dominates at all seasons. The rise in temperatures late in the year may be due to solar heating of the surface layer in the area of formation, higher temperatures and less sea ice in the Labrador Current during summer.

The presence of Sub-Atlantic Water along the West Greenland continental slope can be considered a fact but its formation and it flow pattern towards West Greenland is of a more speculative nature based only on NORWESTLANT data. There is, therefore a need for further investigation and understanding of this matter. An immediate source of information for this purpose may be the data collected on the three WOCE sections approching Cape Farewell.

References.

Buch, E., (1982). Review of Oceanographic Conditions in Subarea O and 1 during the 1970-79 Decade. NAFO Scientific Council Studies no. 5, pp. 43-50.

Buch, E., (1984). Variations in temperature and salinity off West Greenland since 1970. NAFO Scientific Council Studies no. 7, pp. 39-45.

Buch. E., (1985). Seasonal and year to year variations of West Greenland waters in recent years. Rit Fiskideildar no.9 pp. 141-151.

Buch, E., 1990. A Monograph on the Physical Environment of Greenland Waters. Greenland Fisheries Research Institute Report. (Accepted for publication in "Meddelser om Grønland"), 405 pp.

Clarke, R.A., (1984). Transport through the Cape Farewell-Flemish Cap section. Rapp. P.v. Reun. Cons. int Explor. Mer. 185, pp. 120-130.

Hermann, F.C., (1967). Temperature Variations in the West Greenland Area since 1950. ICNAF Res. Doc. 67/59, 12 pp.

Kiilerich, A., (1943). The Hydrography of the West Greenland Fishing Banks. Medd. Komm. for Danmarks Fiskeri- og Havundersøgelser. Vol. II.

Lee, A.J., (1968). NORWESTLANT Surveys: Physical Oceanography. ICNAF Special Publ. no. 7, Part 1: 31-54, Part II: 38-159.

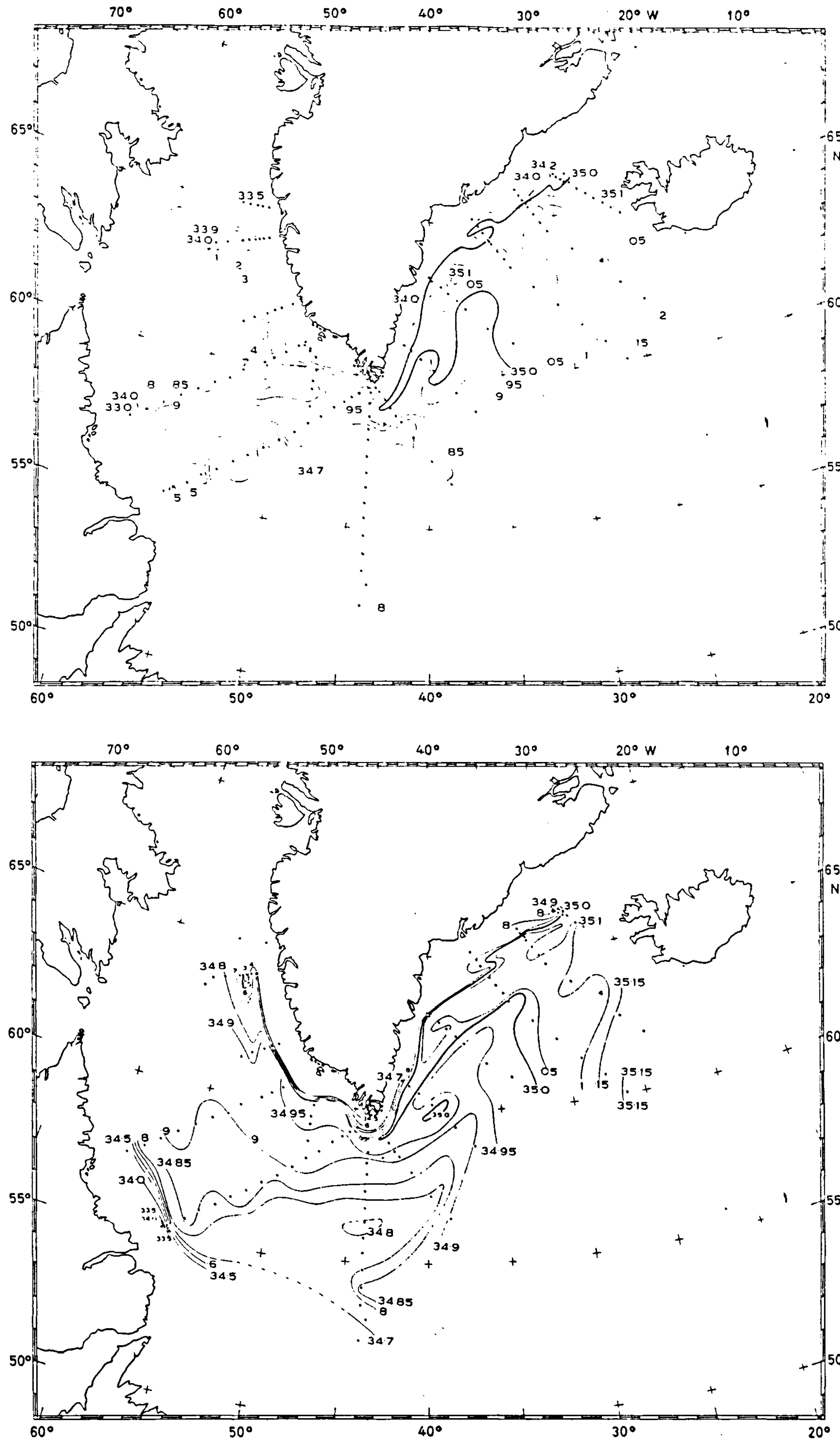

Fig. 1. Horizontal salinity distribution at the surface an at 200 m during the NORWESTLANT 1 survey. After Lee (1968).

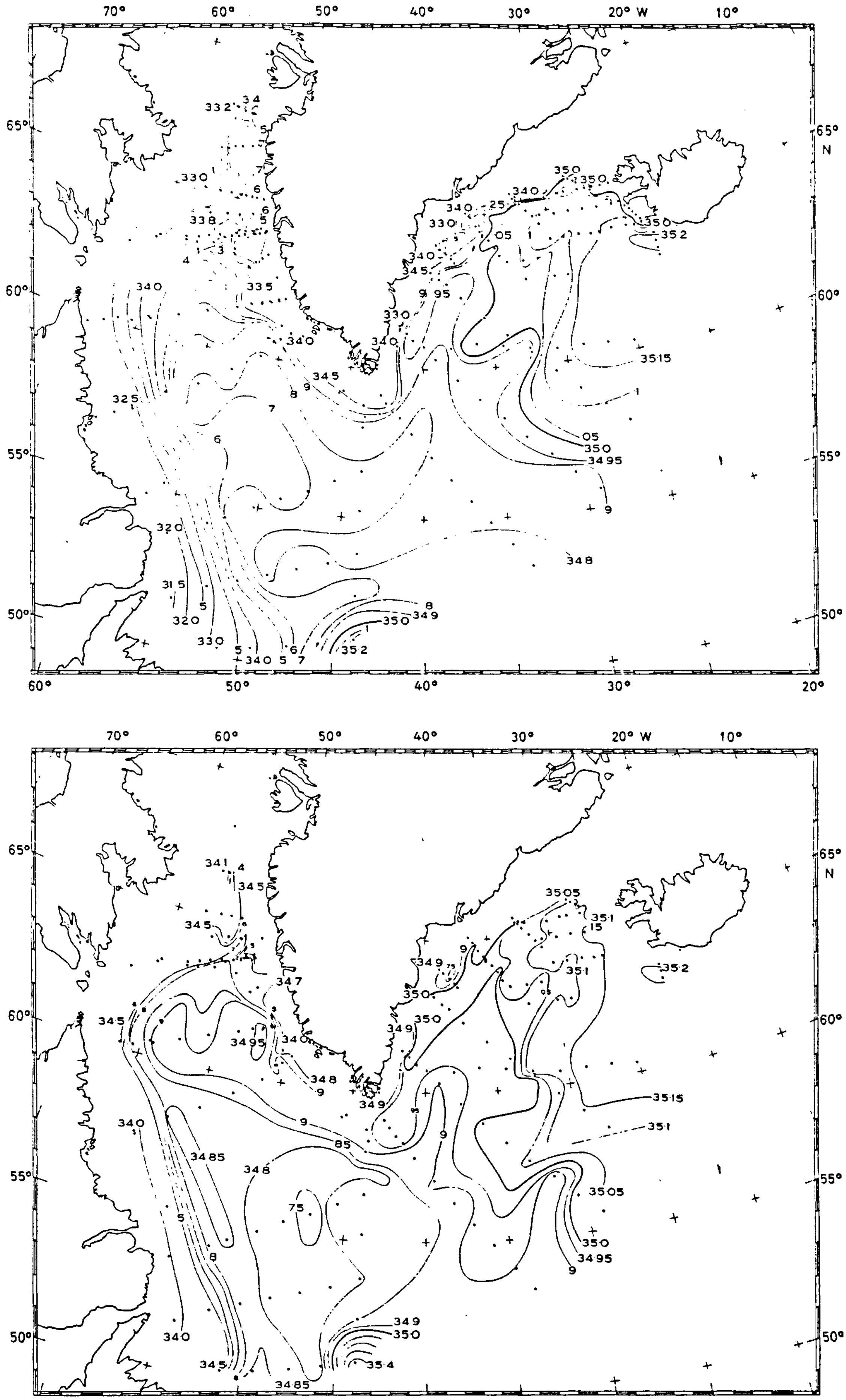

Fig. 2. Horizontal salinity distribution at the surface an at 200 m during the NORWESTLANT 2 survey. After Lee (1968).

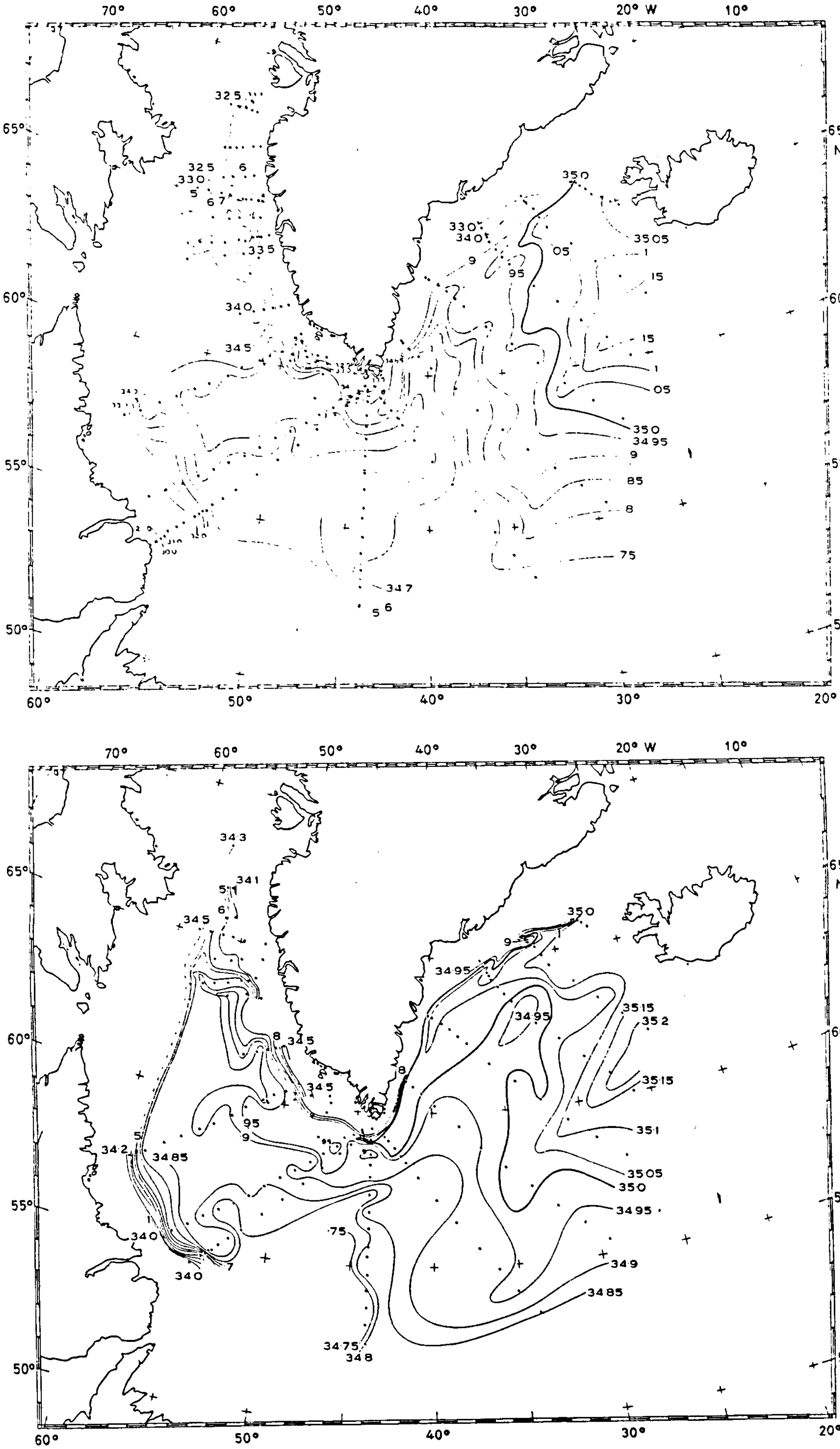

Fig. 3. Horizontal salinity distribution at the surface an at 200 m during the NORWESTLANT 3 survey. After Lee (1968).

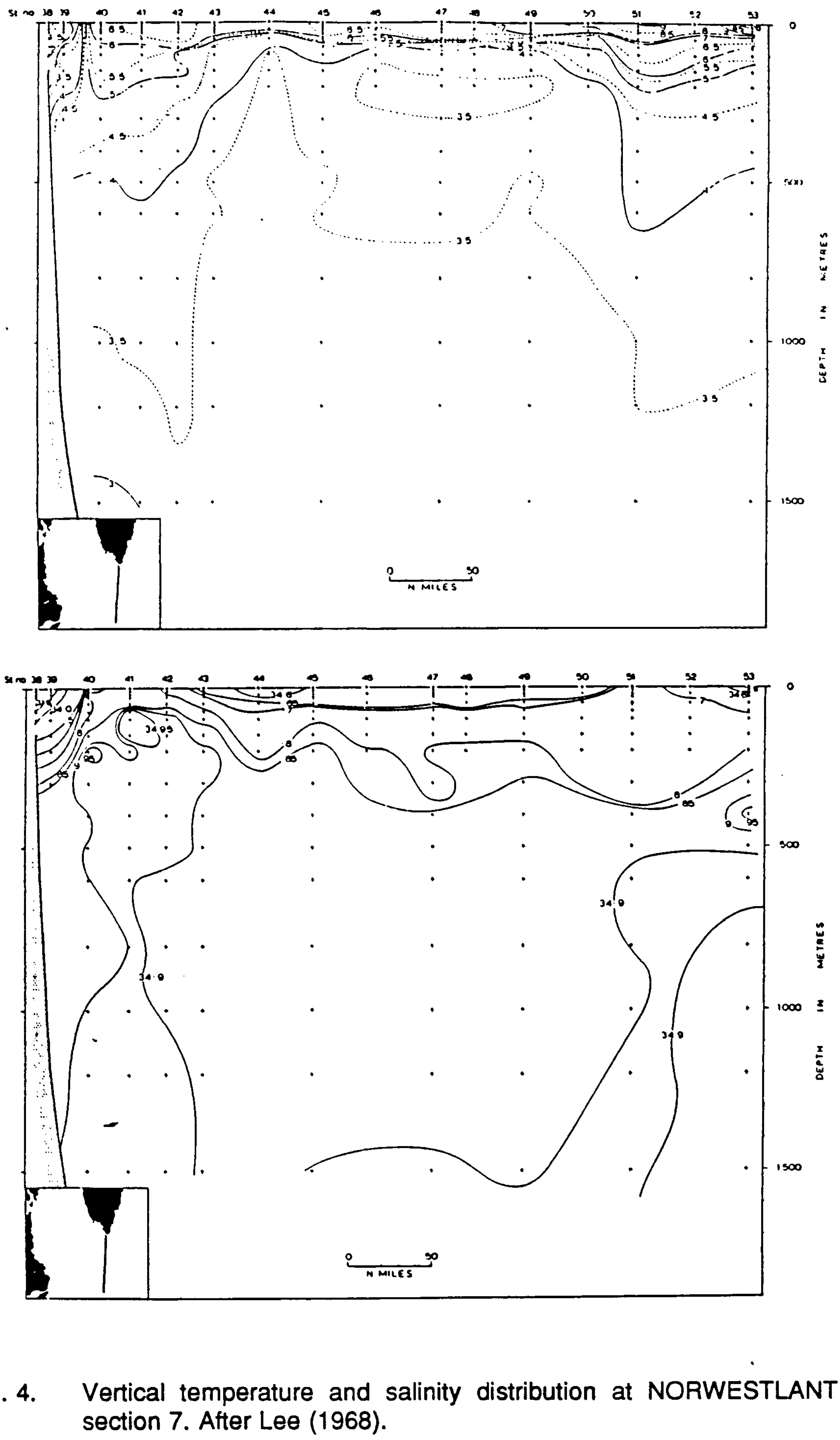

Fig. 4. Vertical temperature and salinity distribution at NORWESTLANT 3 section 7. After Lee (1968).

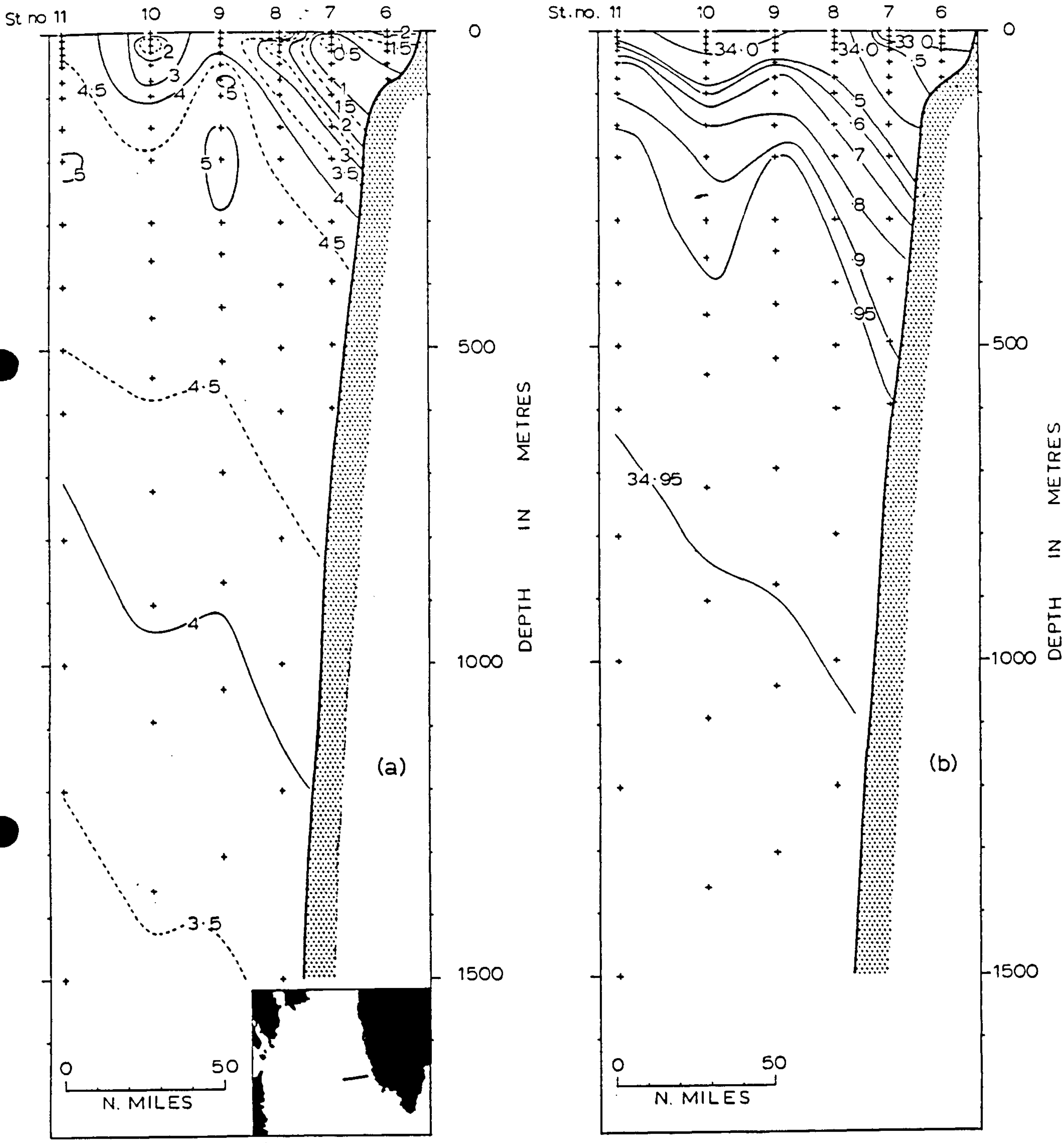

Fig. 5. Vertical temperature and salinity distribution at NORWESTLANT 3 section 10. After Lee (1968).

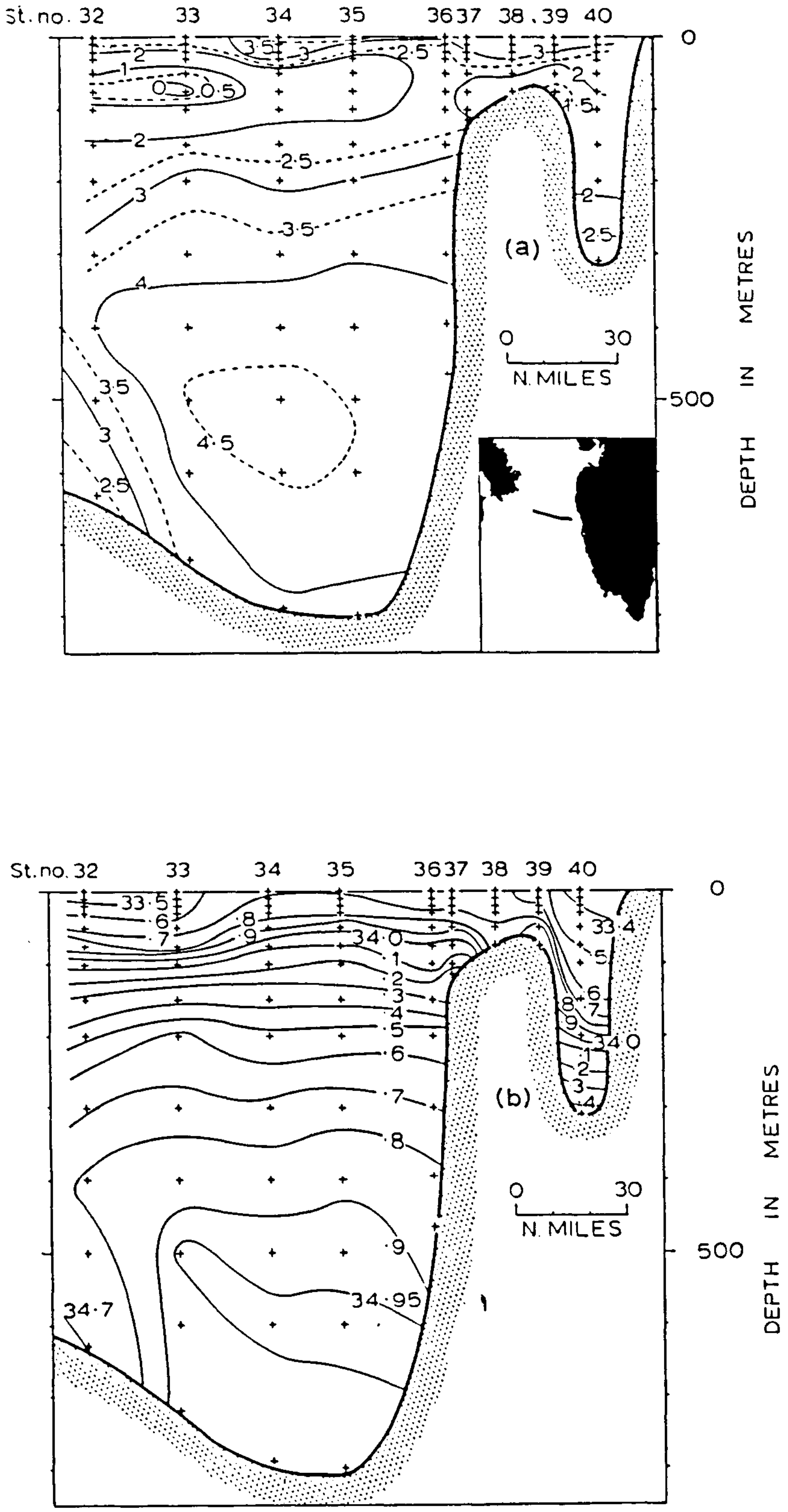

Fig. 6. Vertical temperature and salinity distribution at NORWESTLANT 3 section 13. After Lee (1968).

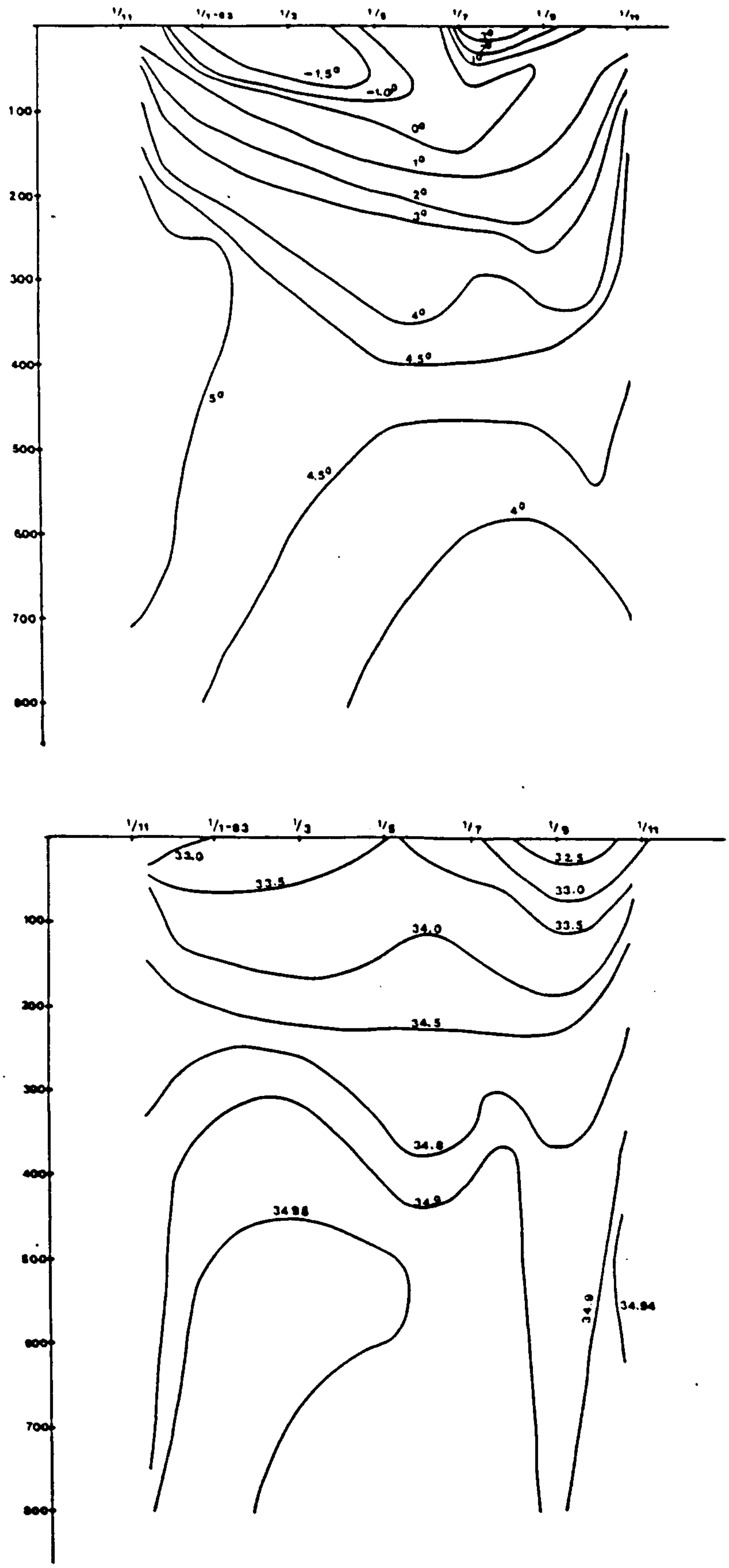

Fig. 7. Temperature and salinity distribution at Fylla Bank st. 4 from November 1982 to November 1983.

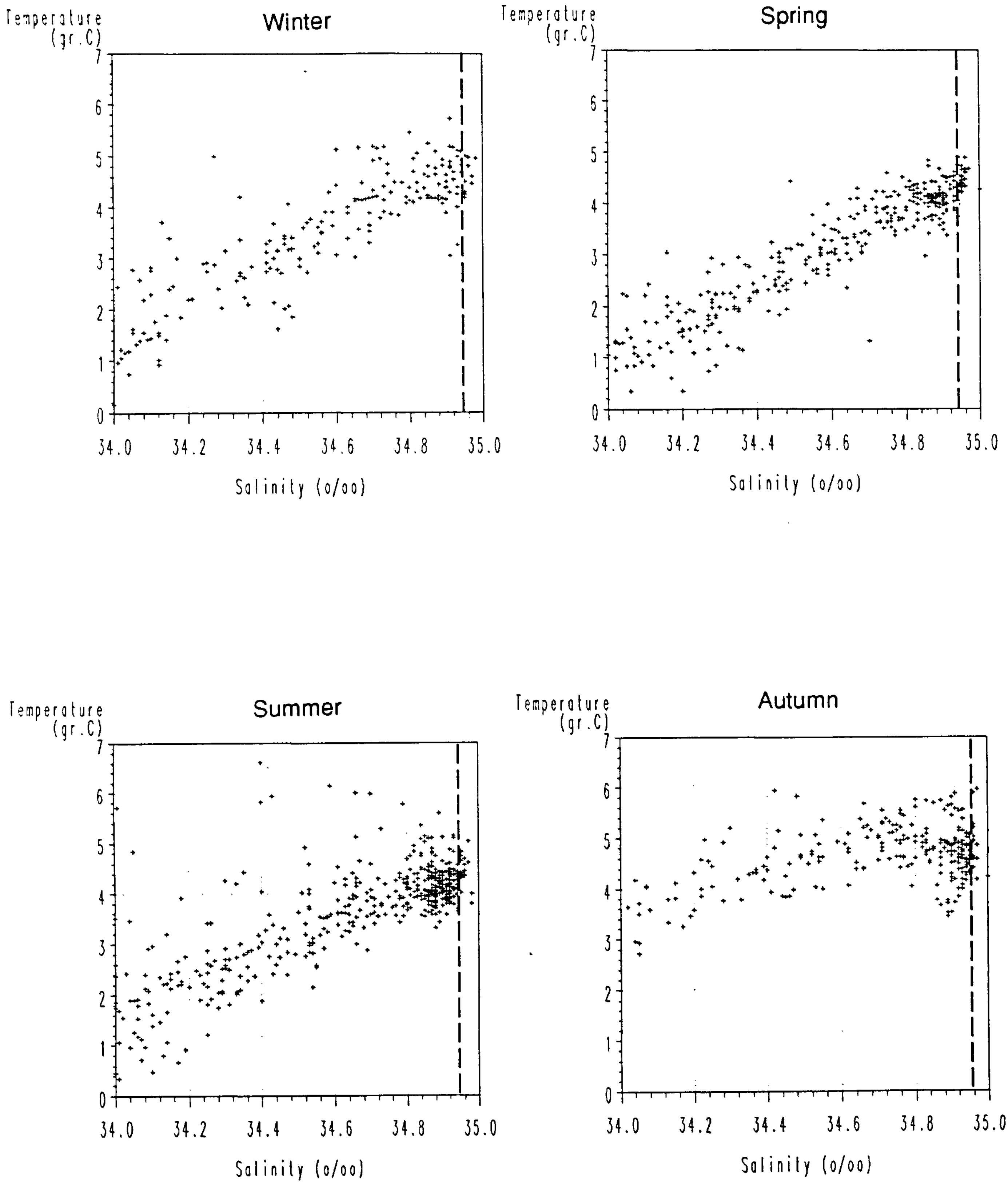

Fig. 8. Seasonal T-S plots using data from Fylla Bank st. 4 and 5 from 1950 - 1988.

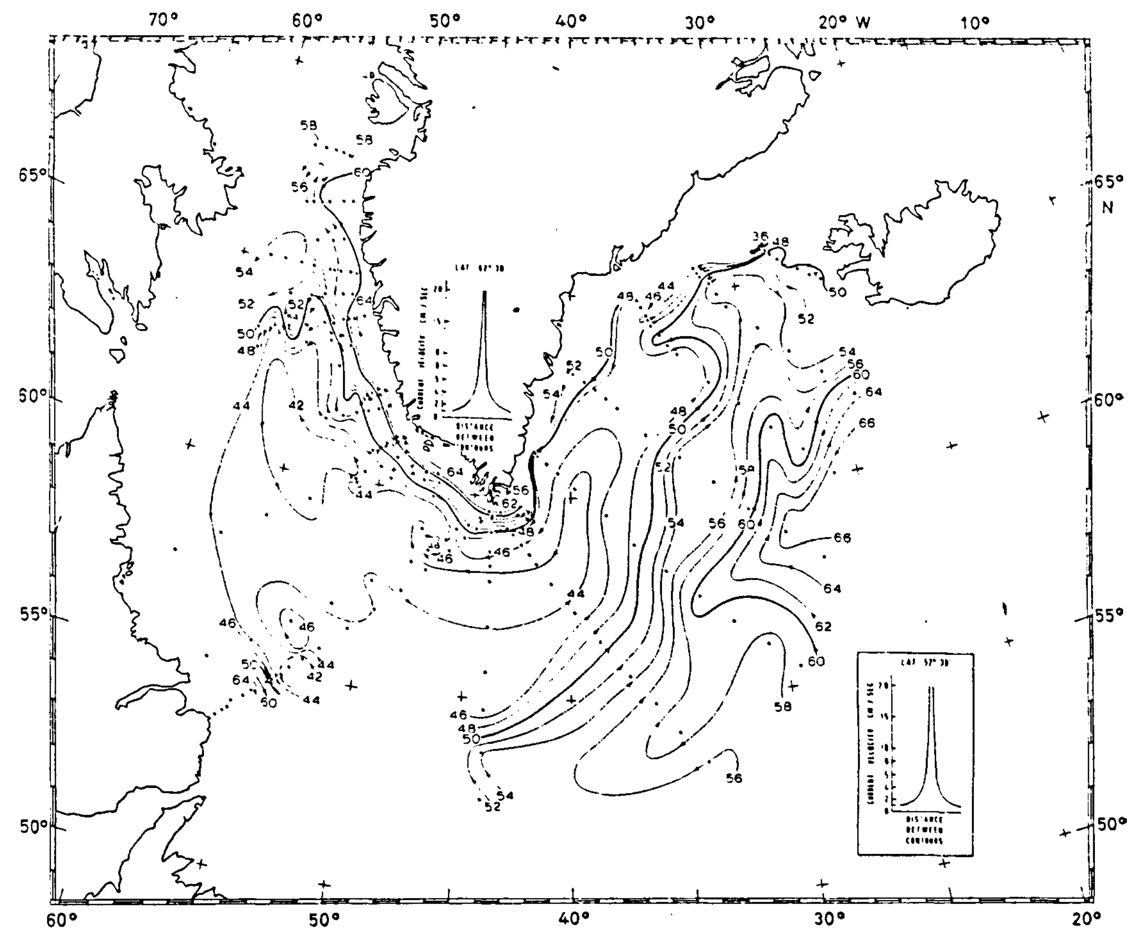

Fig.9. Dynamic topography of the sea surface relative to the pressure surface at 1000 m during NORWESTLANT 3. (Units: Dyn cms).