International Council for the Exploration of the Sea

C.M. 1978/C: 10

TS-Characteristics and Water Masses during Overflow '73

by

T.J. Müller
Institut für Meereskunde
Düsternbrooker Weg 20
D - 2300 Kiel
Germany

Summary: Some results from a TS-diagram analysis of Overflow '73 data are presented in terms of distributions of concentrations of water masses contributing to the overflow through the Denmark Strait and across the Iceland-Faroe-Shetland ridge. The main contribution to the overflow comes from the Norwegian Sea Deep Water (NS), which is found in high percentages on the Atlantic flanks of the ridges down to the deeper parts of the Atlantic basins. The following intermediate waters have been observed south of the ridges and thus also contribute to the Overflow: Arctic and Polar Intermediate Water (AI and PI) in the Denmark Strait region and a mixture of North Icelandic Winter Water and Arctic Intermediate Water (NI/AI) for the whole Iceland-Faroe-Shetland region. A further cold ($-0{,}5^{\circ}$ C) and low salinity (34,70 $^{o}/oo$) intermediate water was found on the Icelandic side of the Iceland-Faroe-Ridge. According to Meincke (1978) it is recognized as East Icelandic Winter Water (EIW).

Introduction

In August/September 1973 an international investigation of the overflow of cold arctic and subarctic waters across the submarine ridges between Greenland, Iceland, the Faroes and the Shetlands was untertaken. Since then several reports have been published presenting current measurements and hydrographic sections (see ICES list of Overflow '73 contributions, available at ICES, Copenhagen).

The aim of this paper is to give some general information about the characteristics of the water masses, found in that area, their vertical distribution and their spreading across the ridges in terms of volume percentages. The method of calculating these is described in Hermann (1967) and Meincke (1978). More detailed information based on the whole set of hydrographic data from this expedition will be presented elsewhere (Meincke et al., 1978).

Since the Reyjkjanes ridge is a natural border for two different regimes of the overflow to look at, the Iceland-Greenland ridge and the area from Iceland to the Shetlands will be considered now separately.

Greenland-Scotland overflow

The water masses that have been found to contribute to the overflow across this ridge have been described by Stefansson (1962). The most dense one is Norwegian Sea Deep water (NS, $T \leq -0{,}5^{\circ}$ C , S = 34.92 $^{\circ}/oo$), which occurs as near bottom overflow. Two intermediate waters maybe defined: First Arctic Intermediate water (AI, T = 1° C , S = 35.00 $^{\circ}/oo$) which is formed by cooling of Atlantic inflow water and mixing with NS far further north. At the entrance to the ridge region it is found in about 250 - 400 m depth on the Greenland side. Secondly, Polar Intermediate water (PI) with low temperature ($T \leq 0^{\circ}$ C) and salinity ($S \leq 34.70$) has been reported by Stefansson (loc. cit., p. 91) and

Gade et al. (1965). It is formed further north by direct mixing of Polar Water (P), and NS with small amounts of AI. These arctic waters interact with inflowing North Atlantic water (NA) from the Irminger current and the Irminger Sea water (IS, T = 4° C , S = 34.98 °/oo) in the deeper parts of the Atlantic side. Figures 2 and 3 show TS-diagrams of selected stations of R.V. Hudson on and north of the sill region(stations and sections see figure 1). The shapes of the curves show nearly undisturbed NA below summer heated P just south of the sill (stat. 194) and on the Icelandic shelf (stat. 84). Except of stat. 84 all other stations show large amounts of PI with T $\leq$ - 1° C. , S = 34.50 °/oo, and AI. Pure NS is only found north of the sill (stat. 84, 86, 89). Similar TS-curves of that area are shown in Gade et al. (loc. cit.).

As an illustration for the clearly seperated water masses, sections of NS, AI and PI north of the sill region are drawn in figures 5 a) - 5 c). The cores of AI and PI are found at the western flank of the channel at 500 m and 150 m depth, thus pressing NS to greater depths on this side. PI is confined to a thin layer of 30 - 50 m for the 70 % value at 150 m depth. When passing the sill the cores of NS, AI and PI deepen rapidly (figure 6).

Figure 4 shows the TS-relation of R.V. Hudson station 141, far south of the sill, but within the core of the outflow. Thick layers of Labrador Sea water (LS, T = 3.98, S = 34,88) and IS lie below NA. Here the mixing occurs mainly between IS and NS and small amounts of PI in a thin bottom layer. Note that contributions of AI can no longer be identified, and have to be included to the NS. All three arctic water masses may pass the sill and contribute to the overflow. This is revealed from maps of horizontal distributions of NS, AI and PI as obtained by data of R.V. Hudson from 22.8. - 1.9.1973 (figures 7 a) - 7 c)). The core of NS (with small amounts of AI) is found at 1800 m depth in a narrow band at the western flank of the continental slope. Very small amounts of PI, together with admixtures of pure

P are also observed at this depth, whereas AI cannot be traced so far.

Iceland-Faroe-Shetland overflow

Stefansson (1962, pp. 128) reported two main sources for the overflow across the Iceland-Faroe ridge. The first is the Norwegian Sea Deep water (NS, $T \leq -0.5^{\circ}$ C., $S = 34.92$ ‰) as near bottom overflow. The second one is the north Icelandic winter water (NI), which forms in winter along the North Icelandic shelf by mixing and cooling of the Irminger current with Polar water, together with small amounts of Arctic Intermediate water (AI). The characteristics of this mixture NI/AI are usually defined by $T = 3^{\circ}$ C , $S = 34.88$ ‰. Figures 8 and 9 b show location and TS-curves of R.V. Meteor stations 180 and 181 north of the central Iceland Faroe ridge. Obviously stat. 180 is just south of the Polar front. Both TS-curves intersect at the definition point of NI/AI. The core of NI/AI deepens towards the southwest below the North Atlantic water.

In both curves the connection of NI/AI and NS is not a straight line, but slightly deformed to lower salinity and temperature. Meincke (1978) reported similar shapes of TS-curves and defined a water mass, EIW with $T \leq 1.5^{\circ}$ C , $S \leq 34.63$ ‰, speculating that it orginated from the East Icelandic current. Stefansson (loc. cit., p. 124) noted a water mass with similar characteristics which forms in late winter at the surface northeast of Iceland towards Jan Mayen. This water might be the physical and geographical origin of the cold and fresh water. For the Overflow '73 data the characteristics $T \leq -0.5$, $S \leq 34.70$ ‰ for EIW fit better to the data, especially to that of R.V. Bj. Saemundsson (see Meincke et al., loc. cit.). But since no EIW was observed on the southwest flank of the ridge or at the entrance to the Faroe-Shetland channel, it will not be considered any longer in this context.

Only NI/AI and NS contribute to the arctic inflow into the Faroe-Shetland channel (figure 10 c). Note that clearly two types of North Atlantic water can be distinguished, pure (NA $T \leq 9^{o}$ C , $S \leq 35.32$ $^{o}/oo$), which represents the northward inflow of Atlantic water along the shelf of the Shetlands, and modified (MNA, $T \leq 8.5^{o}$ C , $S \leq 35.24$ $^{o}/oo$) which orginates from inflow towards the arctic north of the Faroes and returns to the Atlantic basin round the Faroes, loosing slightly its characteristics (Meincke, 1978).

Well away from the crest areas, R.V. Shackleton station 223 (figure 10 a) represents a TS-characteristic, that is undisturbed by short fluctuations. The shape of the TS curve is characteristic for this area and also found at all deeper stations during Overflow '73 of Shackleton and Challenger (see Meincke et al., 1978). LS and IS stand for a mixture of Labrador-Sea water and Irminger-Sea water which cannot be distinguished any longer so far from their origin. The slight increase of NA below 1550 m depth represents the fact, that NS had been in direct contact with NA before the mixture of both reached the level to flow below LS/IS. No NI/AI can be distinguished in this region.

Figure 10 shows the northeast-southwest distribution of NS, NI/AI and EIW across the central Iceland-Faroe ridge. There is a considerable high amount of NS found on the southwest flank. As will be explained later this is a result of the Faroe-bank outflow rather than overflow across the ridge. Only NI/AI of the intermediate waters is found on the southwest flank. This result corresponds to a section of Meincke (1978).

Figures 11 a), b) now show the horizontal distribution of NS and NI/AI in the whole region as revealed from quasisynoptic sections of several ships, 24.8. - 28.8.1973. The whole bottom layer of the Faroe-Shetland and Faroe-bank channels consits of pure NS > 90 %. This overflow can be followed to the cross ridge section, mentioned above (figure 11 a)) with NS > 70 % and towards the Icelandic shelf with NS > 50 % at a level of ~ 700 m. It should be noted, that according to Meincke (1978) parts of the NS filling the Faroe Shetland channel seems to return towards to Norwegian Sea.

There is no evidence for strong overflow of NS across the central part of the ridge. Indeed the rather constant value of ~ 30 % of NS seems to support the idea of strong horizontal mixing between Atlàntic and Arctic waters above the crest (Meincke 1978). The second most important contribution of NS-overflows is found southeast of Iceland. A similar picture as for NS is found for the distribution of NI/AI, but with lower concentrations. Note that the overflow across the Wyville Thompson ridge seems to be non-zero in both NS (> 30 %) and NI/AI (> 10 %).

Acknoledgements: Helpful advices have been given by K. Aagaard, S.-A. Malmberg and J. Meincke. The study was supported by the Deutsche Forschungsgemeinschaft.

References

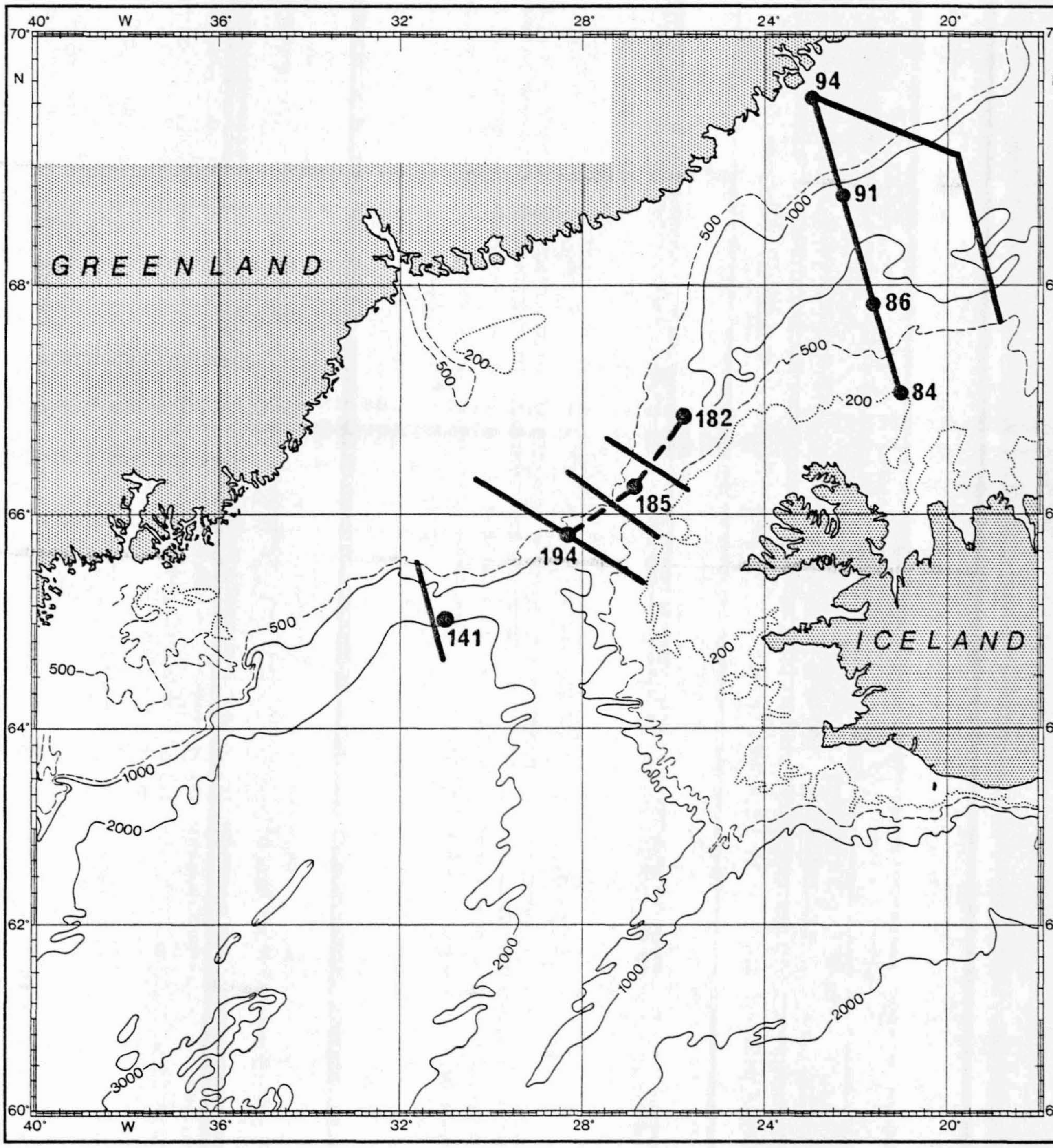
Hermann, F. (1967): The TS-diagram analysis of the water masses over the Iceland-Faroe-Ridge and in the Faroe Bank Channel. Rapp. P.v.-Cons. Expl. Mar. 157, 139 - 149.

Gade, H.G., S.-A. Malmberg, U. Stefansson (1965): Report of the Joint Icelandic-Norwegian Expedition to the Area between Iceland and Greenland 1963. Preliminary Results. NATO Subcom. Oceanogr. Res., Techn. Rep. No. 22.

Meincke, J. (1978): On the Distribution of Low Salinity Intermediate Waters around the Faroes. Dtsch. Hydr. Z. 31, 50 - 64.

Meincke, J., T.J. Müller and G.A. Becker (1978): Overflow '73: The Distribution of Water Masses on the Greenland-Scotland-Ridge in August/ September 1973 (Data report to appear in Ber. Inst. Meeresk. Kiel).

Stefansson, U. (1962): North Icelandic Waters. Rit. Fisk., Vol. III.



<u>Fig. 1:</u> Section Index Map for the Iceland-Greenland-Ridge 22.8. - 1.9.1973, R.V. Hudson.
Depths in m. Numbers indicate stations referred to in the text and other figures. Section 182 - 194 (broken linie) was run 16.9. - 18.9.1973, station 141 obtained 6.9.1973.

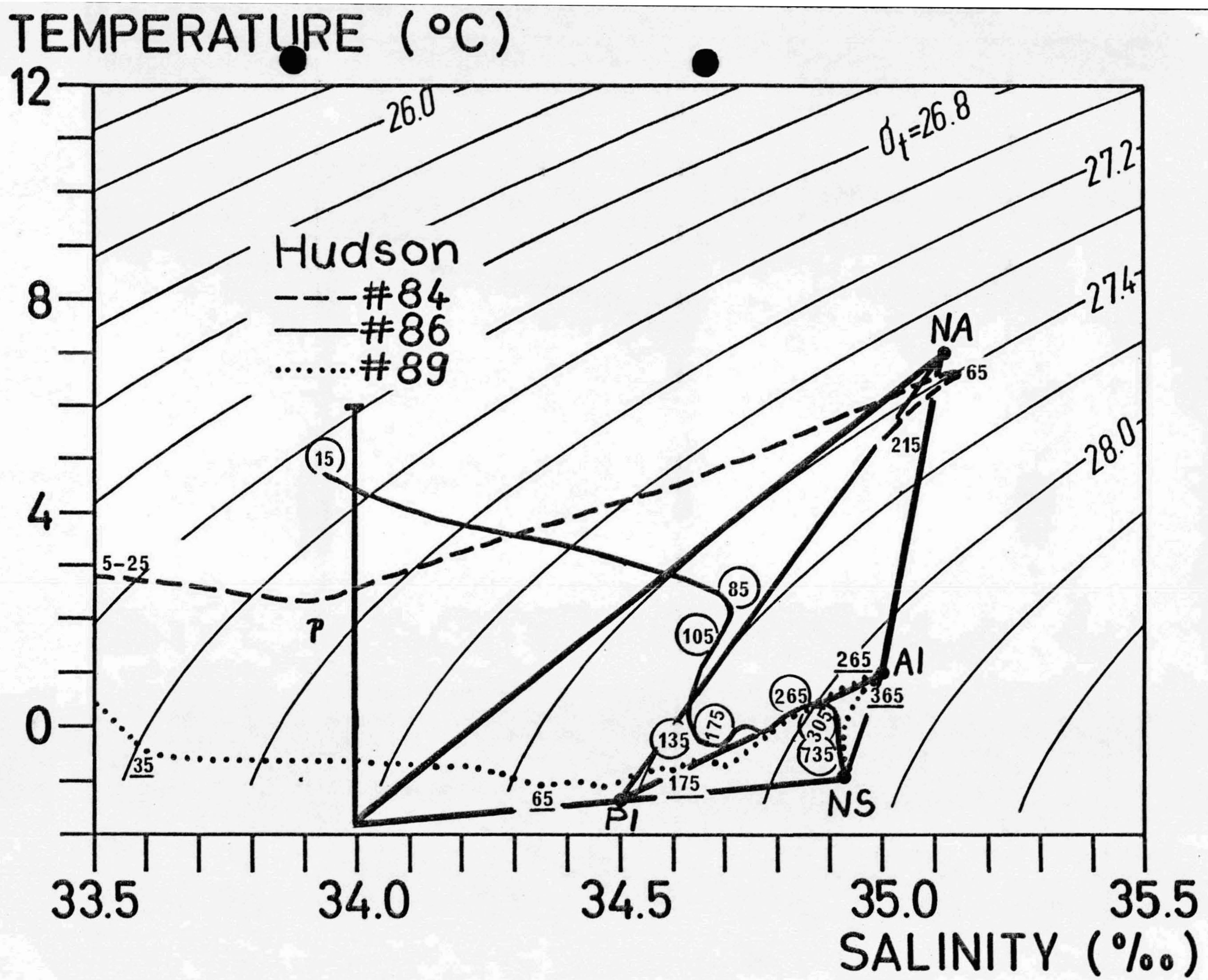


Fig. 2: TS-diagrammes of Hudson-stations 84, 86, 89, numbers at TS-curves indicate observed depths. Water masses are defined in the text.

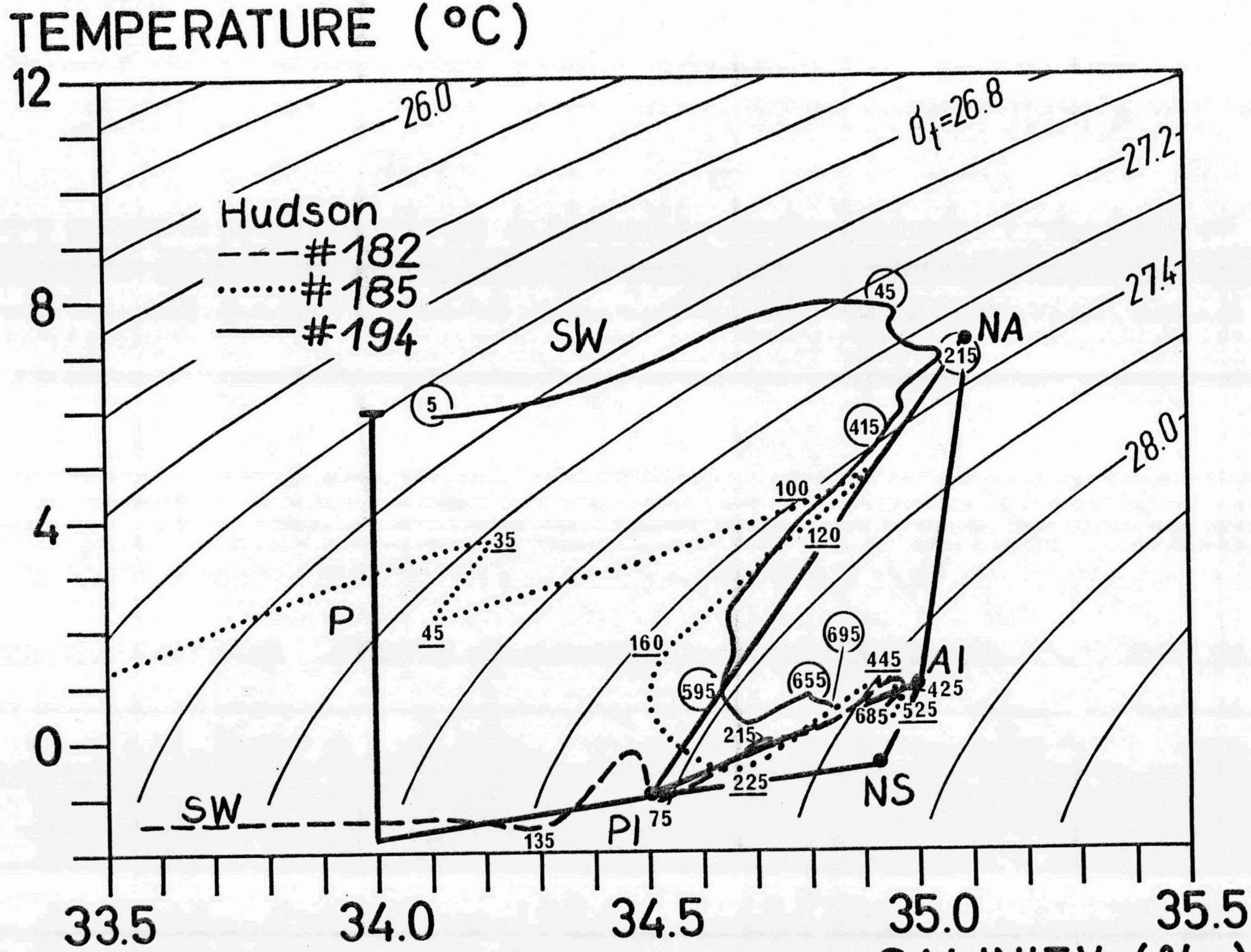


Fig. 3: TS-diagramme of Hudson-stations 182, 185, 194 just north (182), on the sill (185) and just south of the sill. Numbers indicate observed depths. Water masses are defined in the text.

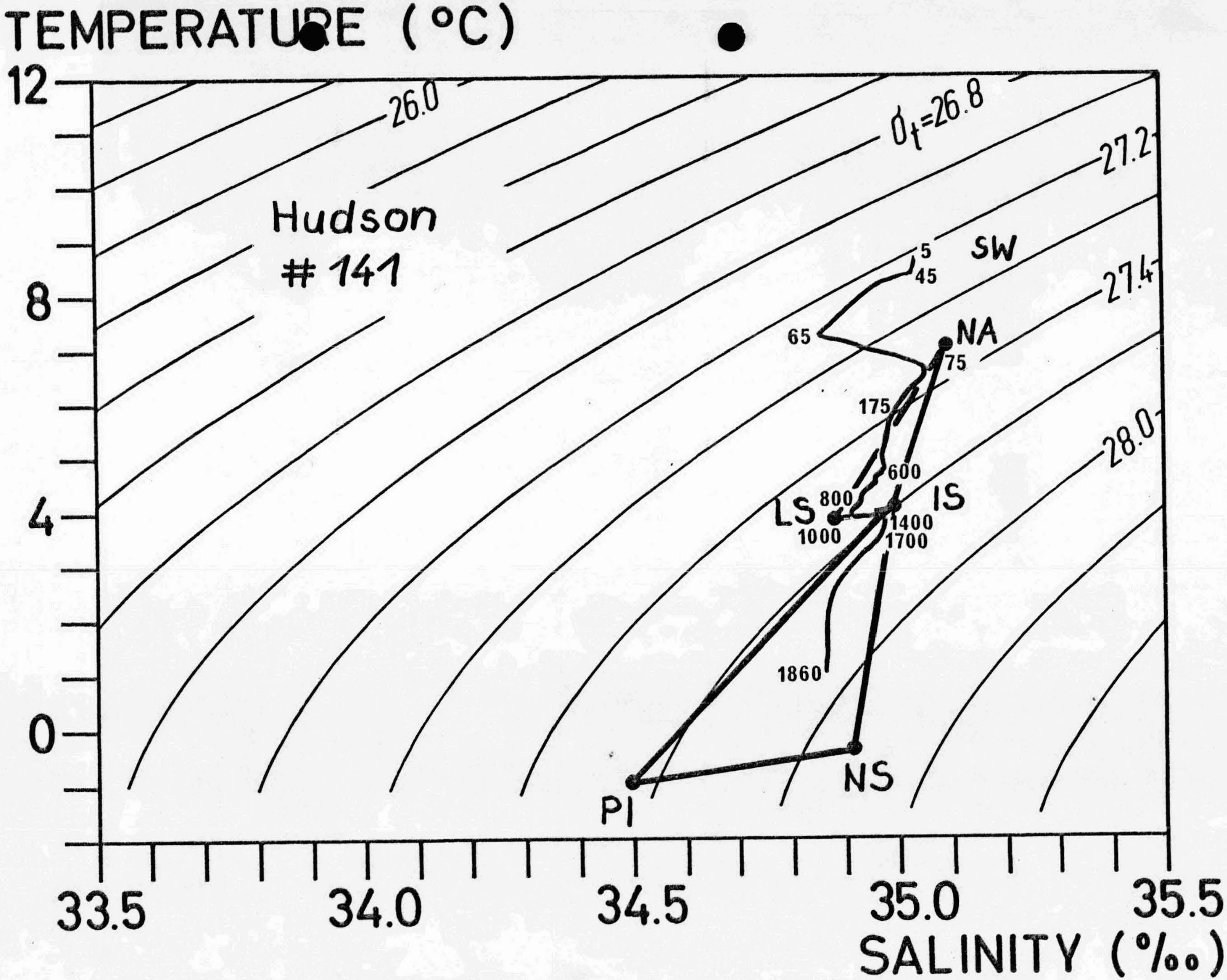


Fig. 4: TS-diagramme of Hudson-station 141 well south of the sill. Numbers indicate observed depths. Water masses are defined in the text.

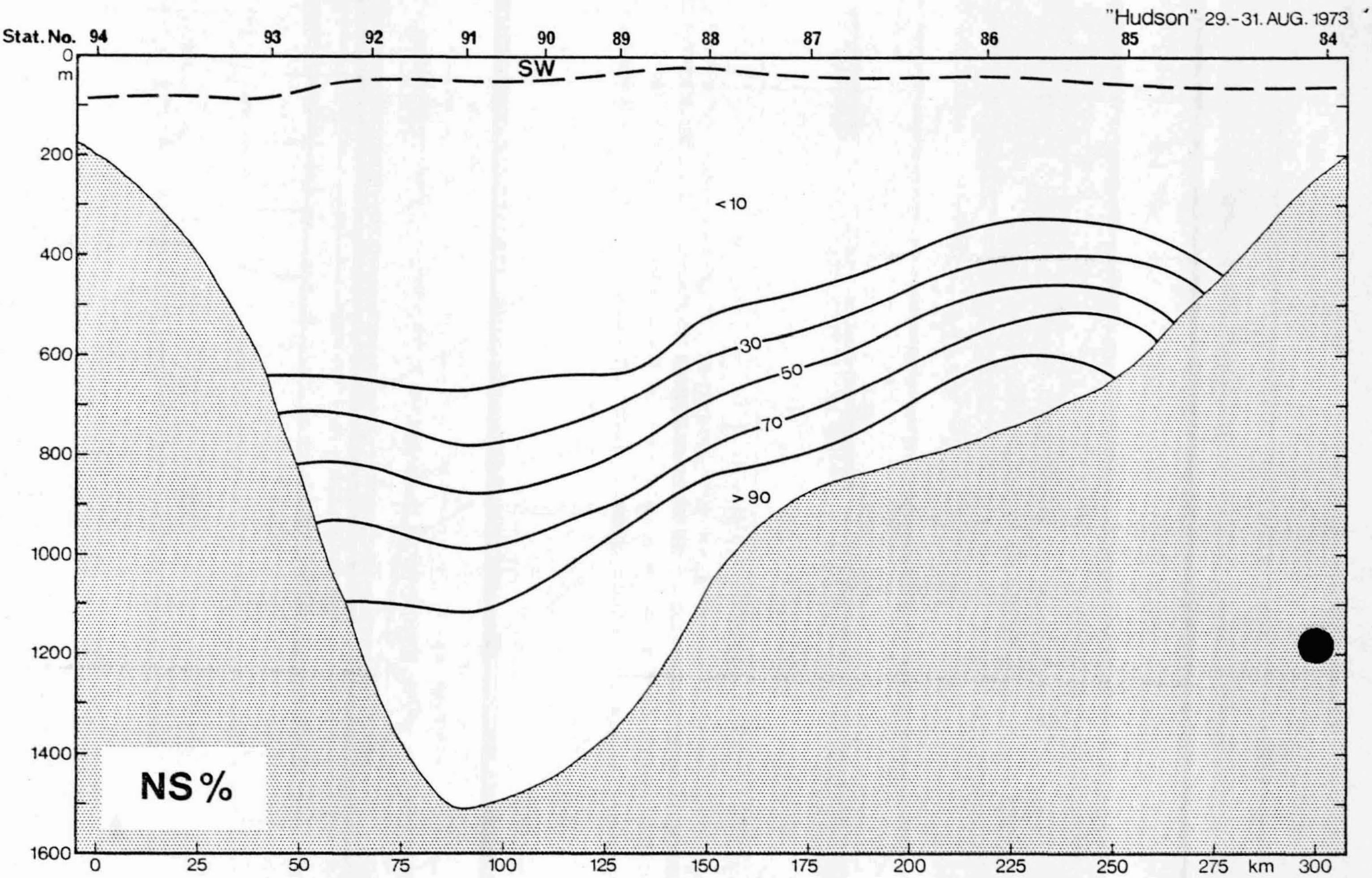
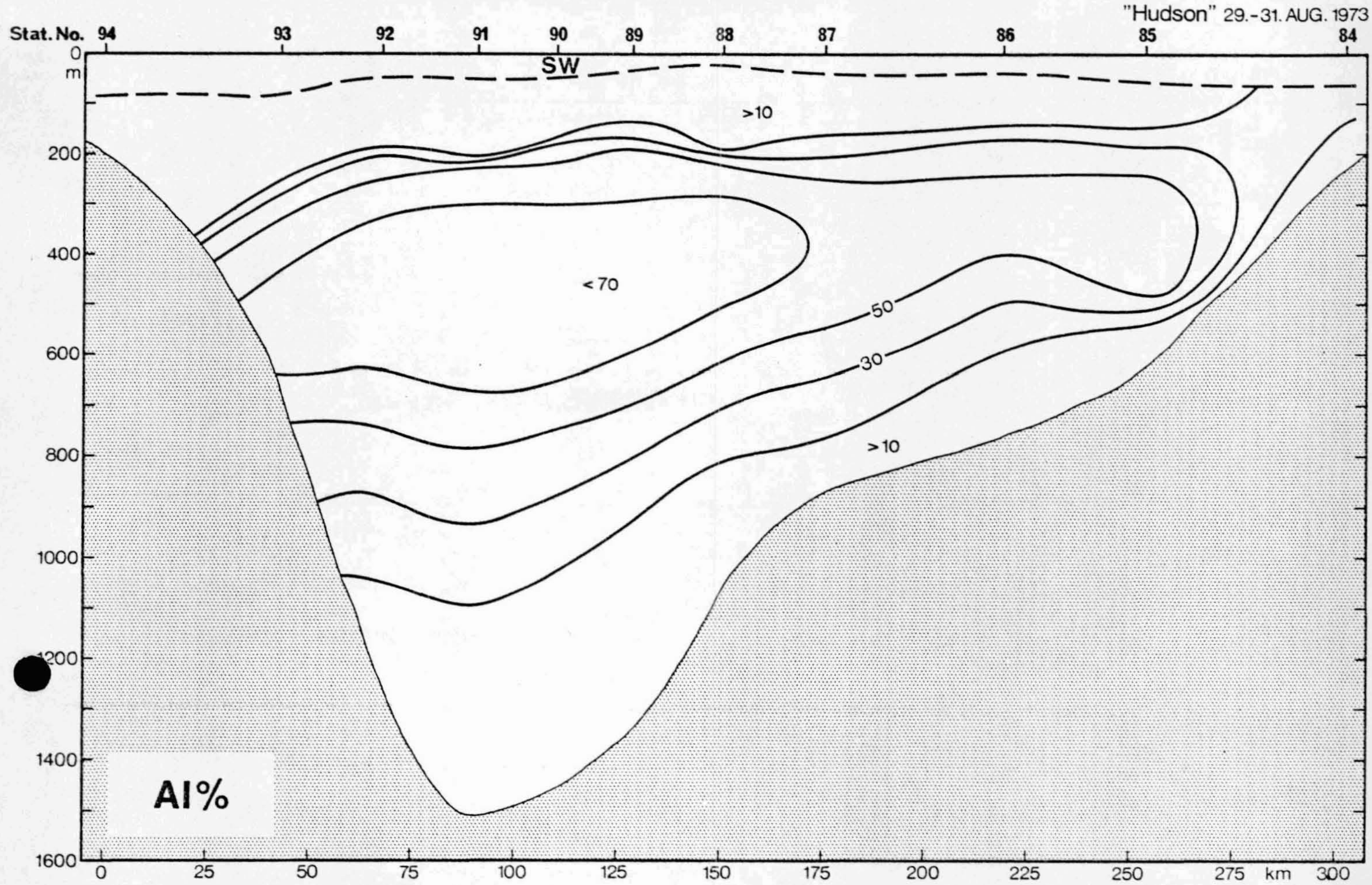


Fig. 5: Distribution of water masses between stations 84 and 94 of Hudson
a) Norwegian Sea Deept Water (NS)
b) Arctic Intermediate Water (AI)
c) Polar Intermediate Water (PI)



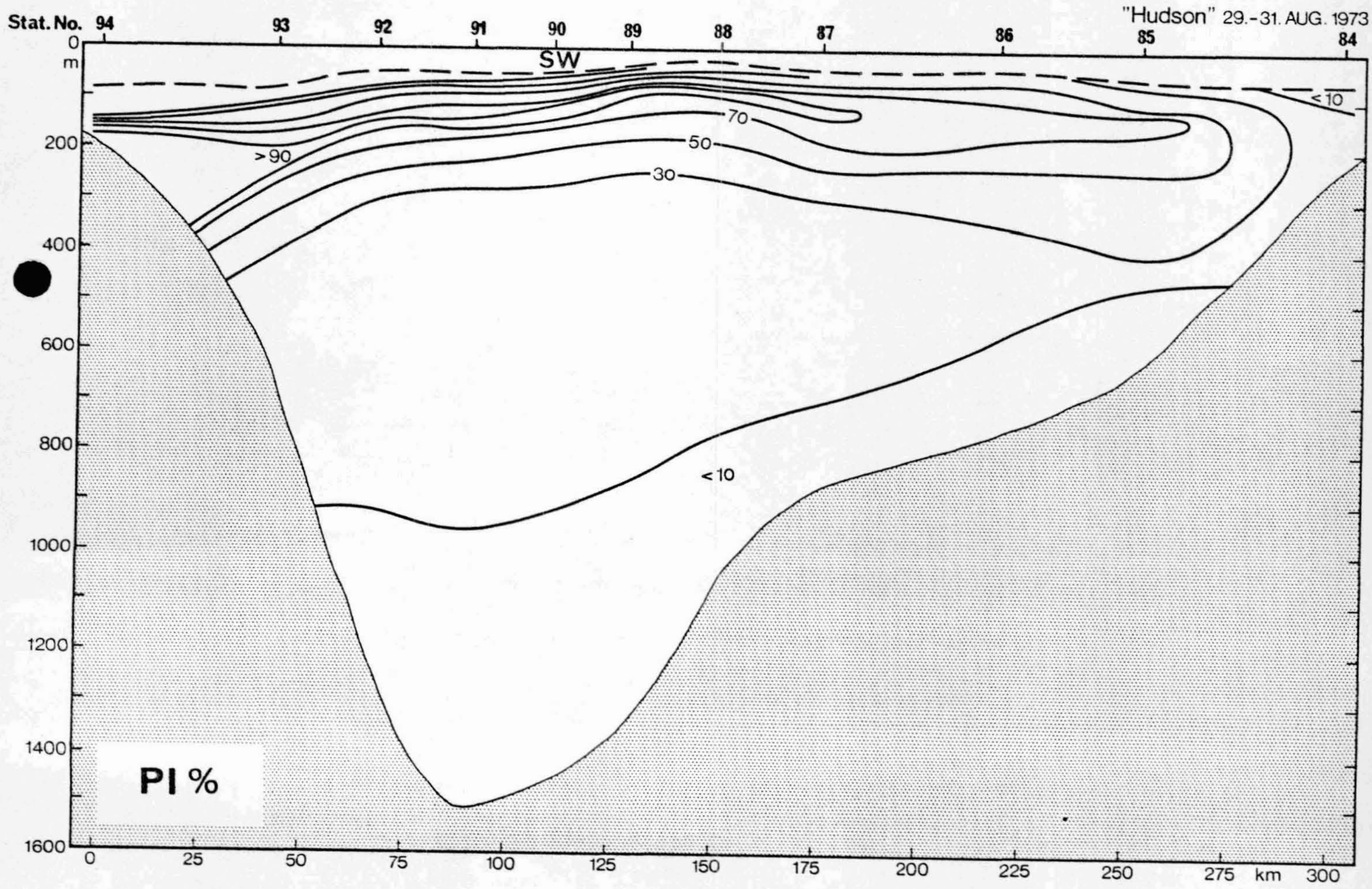


Fig.5b,5c cont'd

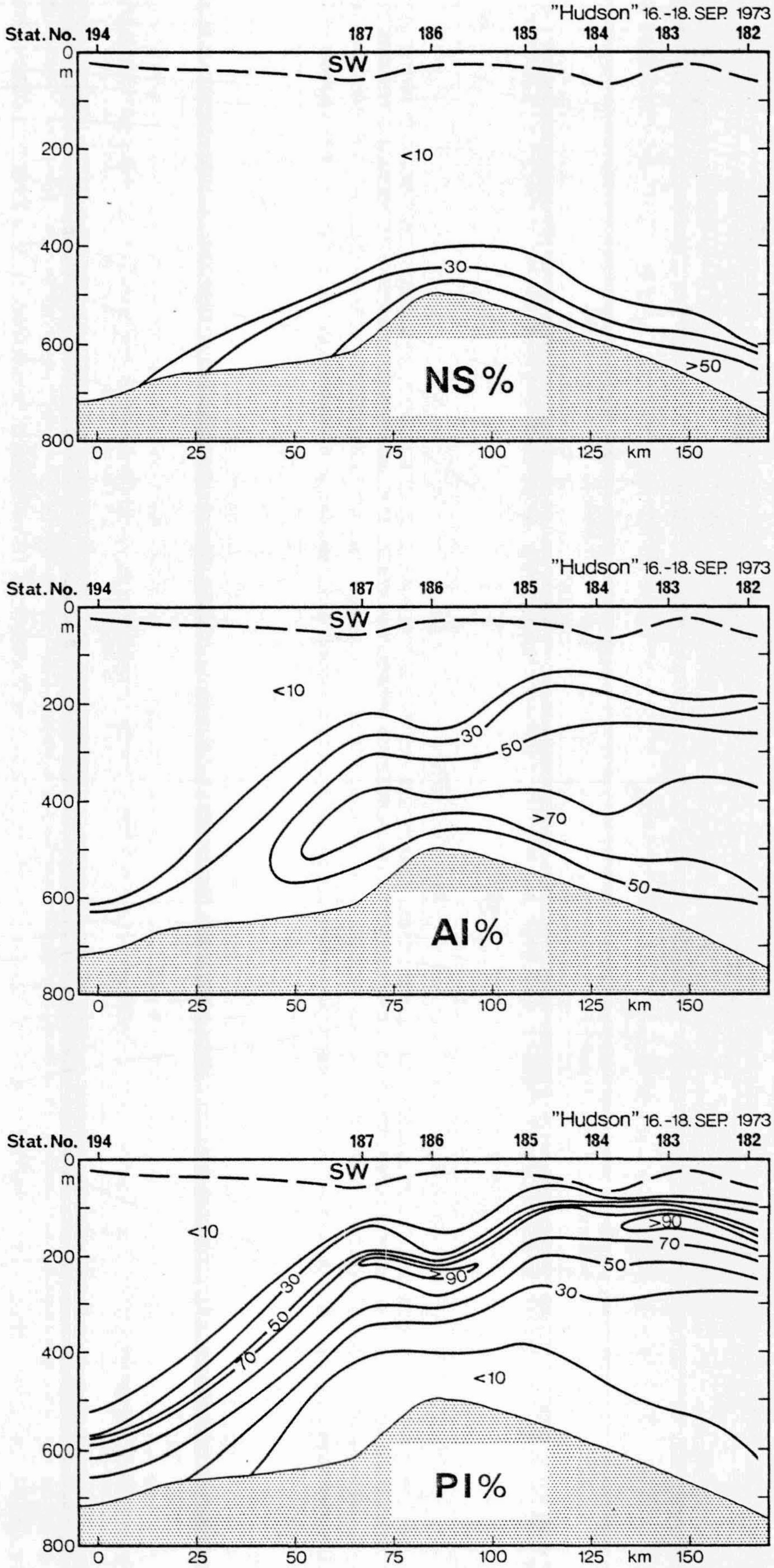


Fig. 6: Deepening of Norwegian Sea Deep Water (NS), Arctic Intermediate (AI) and Polar Intermediate Water (PI) from the northeast (stat. 182) to the southwest (stat. 194) across the sill.

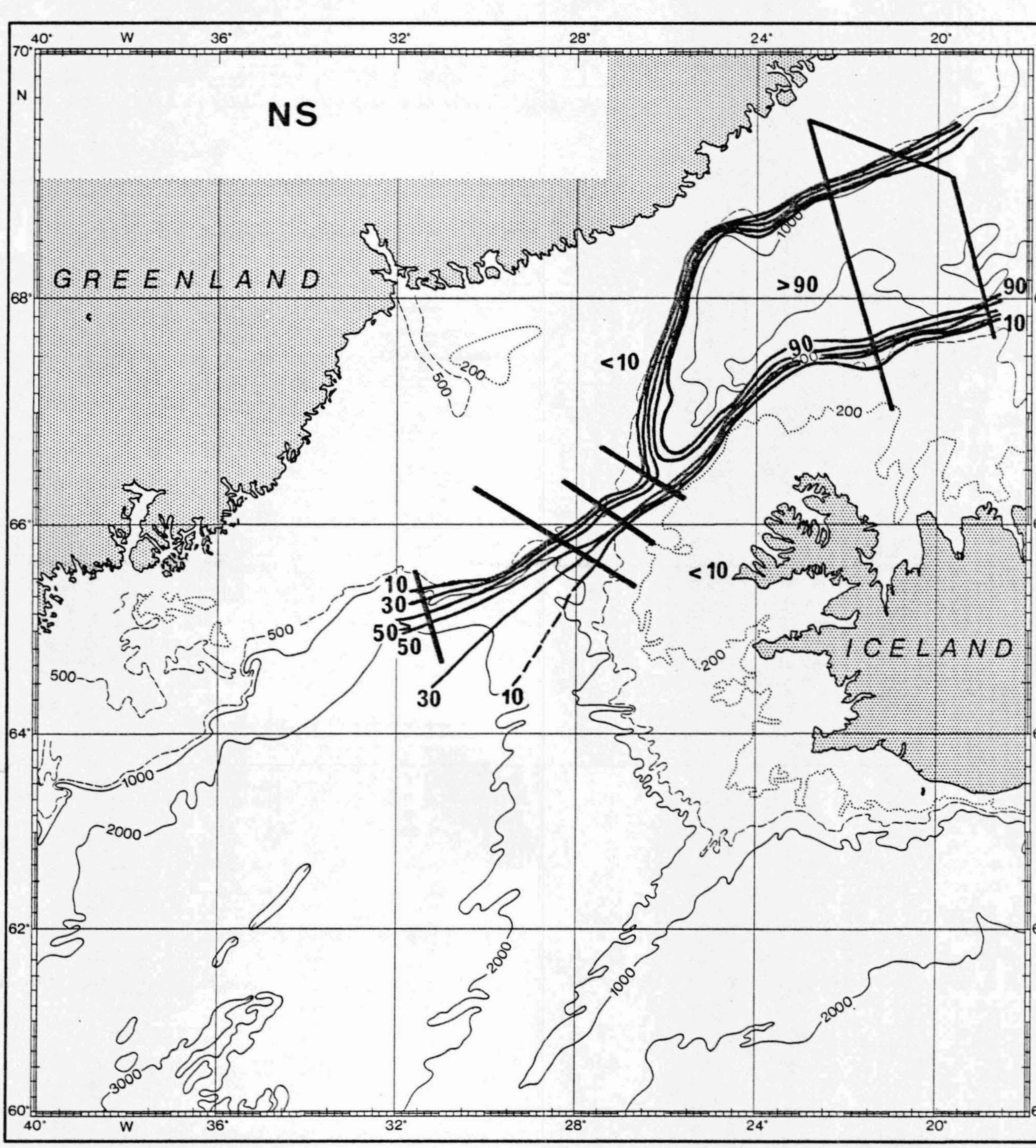


Fig. 7: Horizontal distribution of water masses in the Denmark strait
a) Norwegian Sea Deep Water (NS)
b) Arctic Intermediate Water (AI)
c) Polar Intermediate Water (PI)

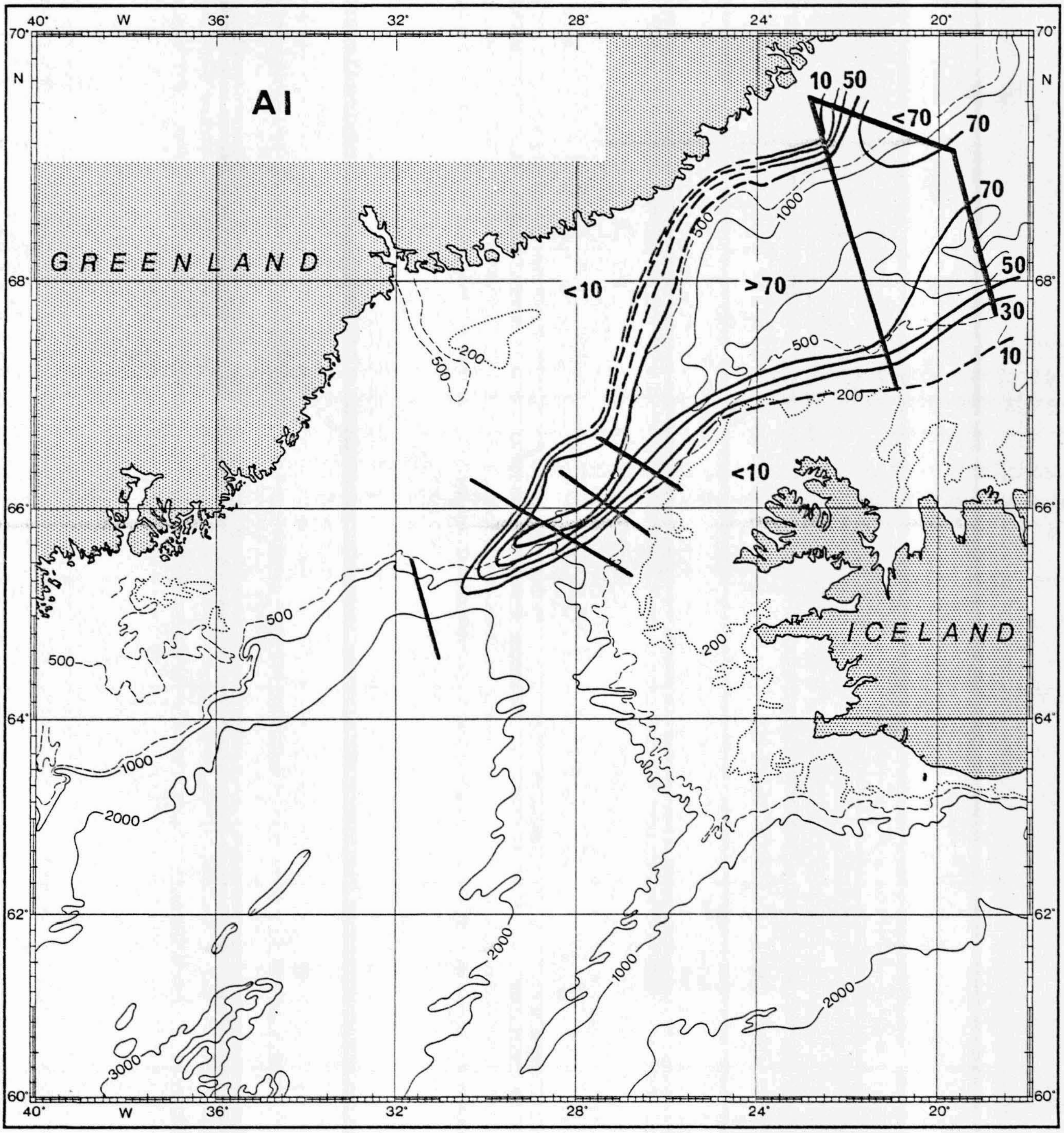

AI
GREENLAND
ICELAND
10 50
<70
70
70
50
30
10
<10
>70
<10
500
1000
200
2000
3000
40°
W
36°
32°
28°
24°
20°
70°
68°
66°
64°
62°
60°
N

Fig. 7b cont'd

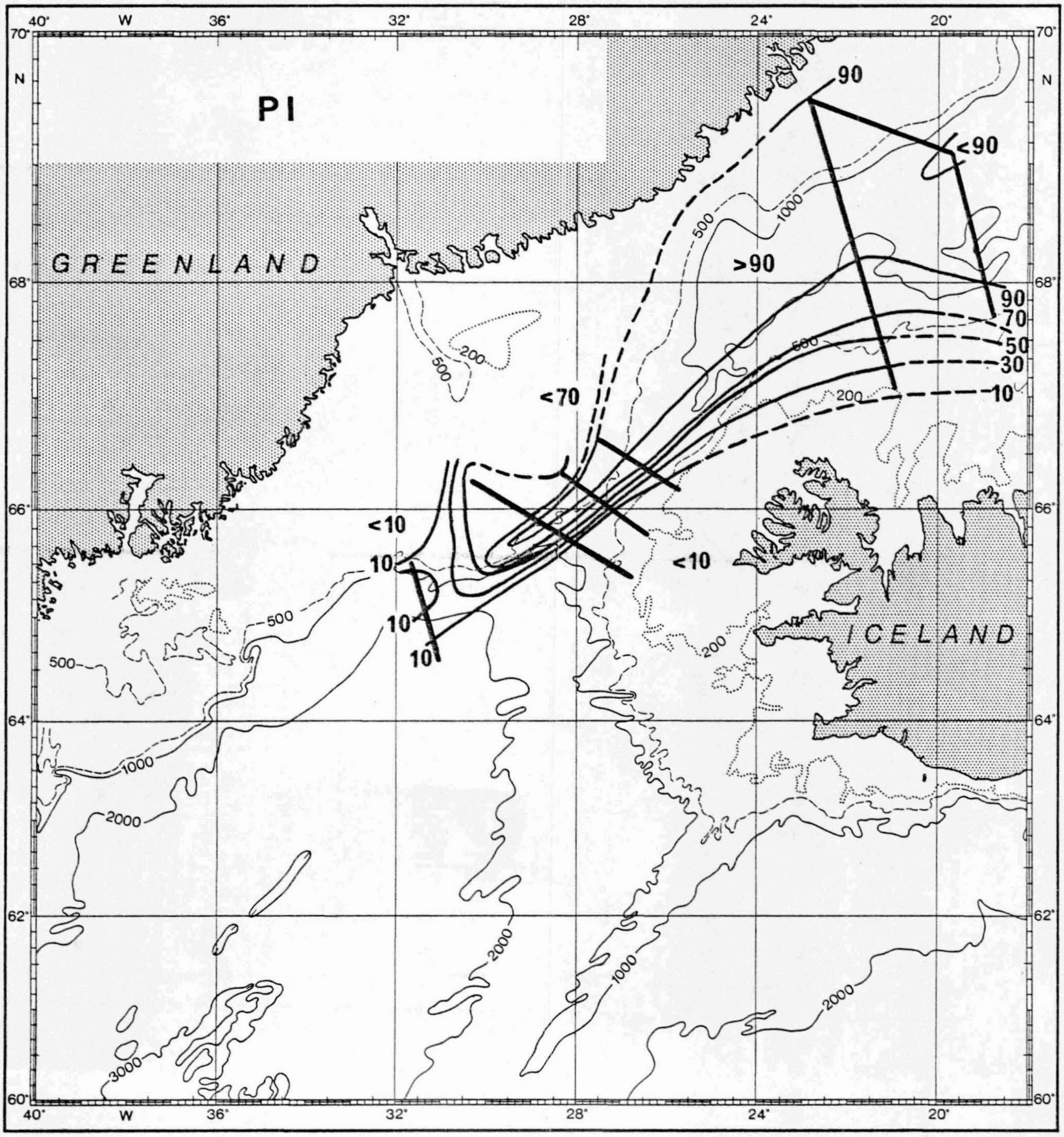
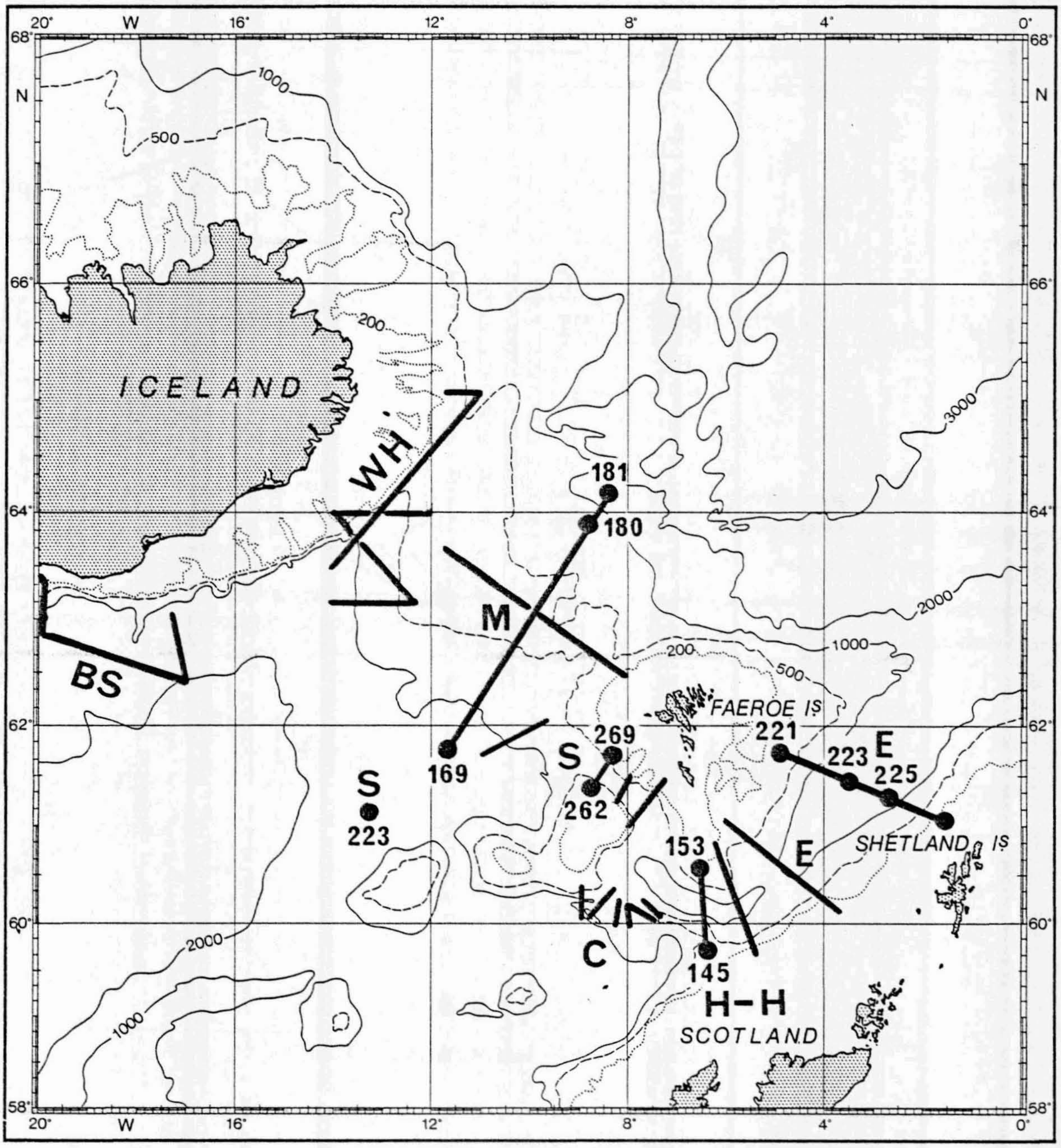

PI
GREENLAND
ICELAND
90
<90
>90
90
70
50
30
10
<70
<10
10
10
10
<10
40°
W
36°
32°
28°
24°
20°
70°
N
68°
66°
64°
62°
60°
500
1000
200
2000
3000

Fig. 7c cont'd



<u>Fig. 8:</u> Section Index Map for the Iceland-Faeroe-Shetland area, 24.8. - 28.8.1973. Depths in m. letters refer to the ships:

C Challenger
E Explorer
H-H Helland-Hansen
WH Walter Herwig
M Meteor
S Shackleton
BS Bjarni Seamundson.

Numbers indicate stations referred to in the text and other figures.

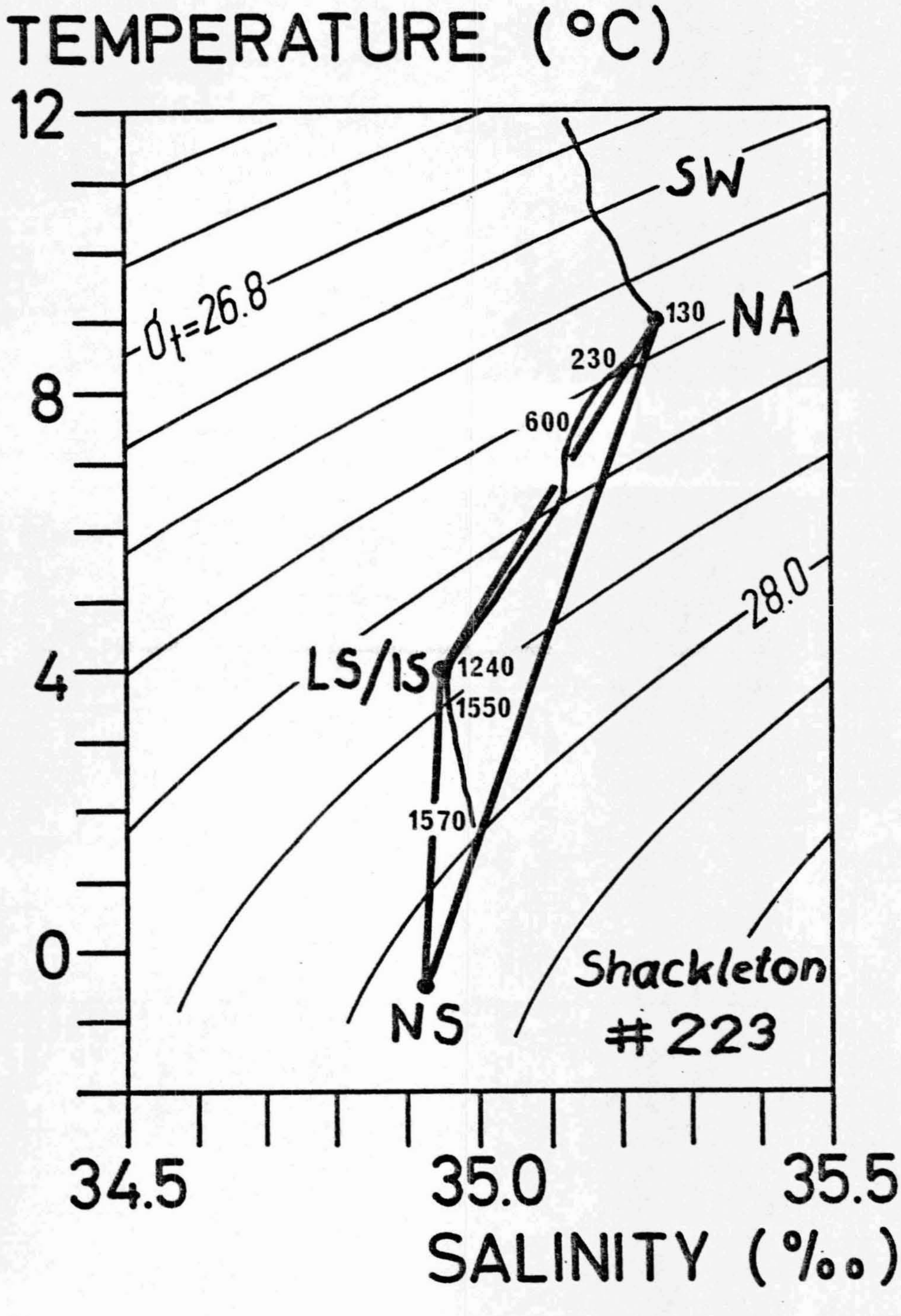


Fig. 9: Examples of TS-diagrammes from the Iceland-Faroe-Shetland area

a) far south of the ridge (Shackleton, stat. 223)
b) north of the ridge (Meteor, n.stat. 180, 181)
c) at the entrance of the Faroe Shetland Channel (Explorer stat. 223, 225) Note the two different types of Atlantic Water: Pure (NA) and modified (MNA).

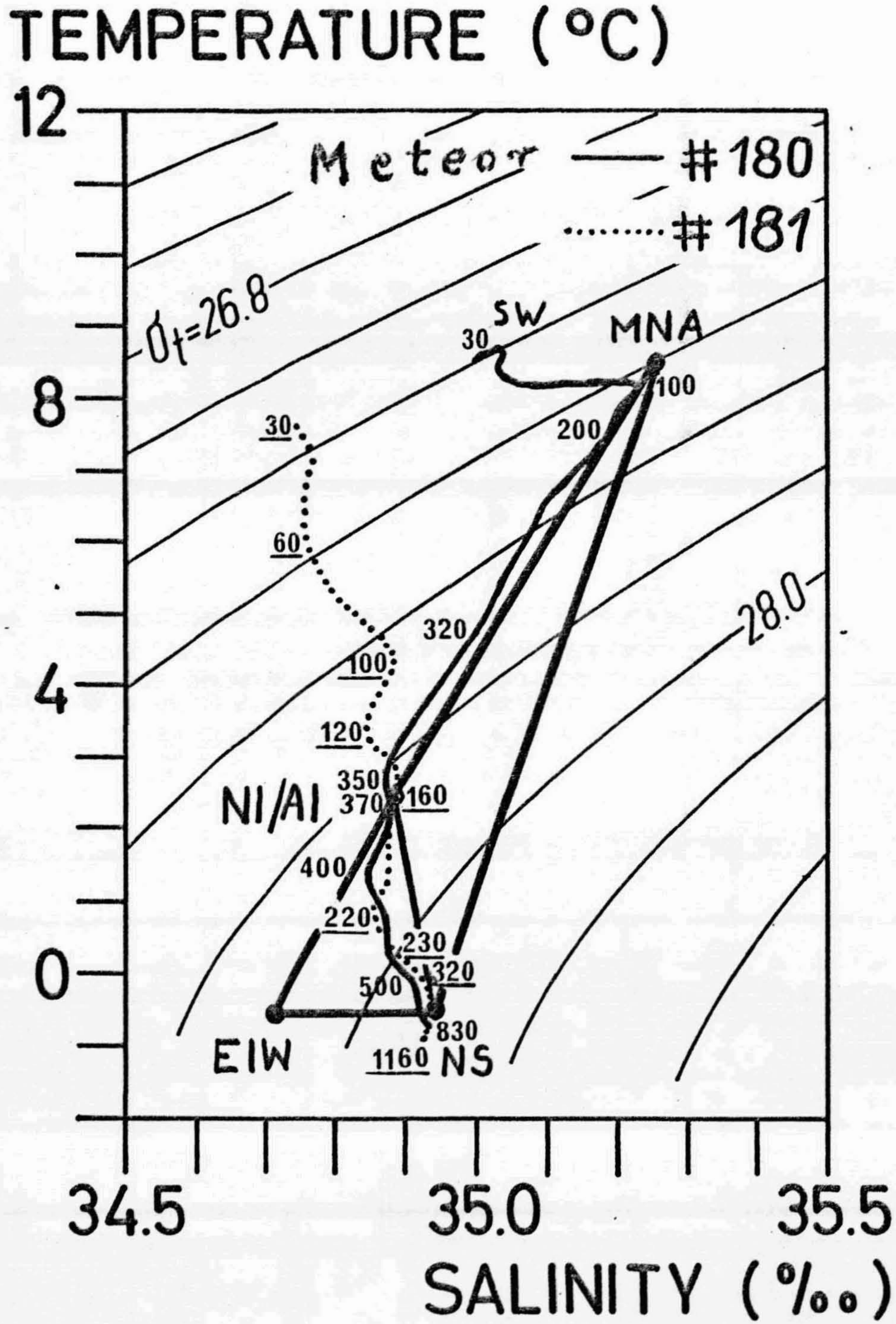


Fig.9b cont'd

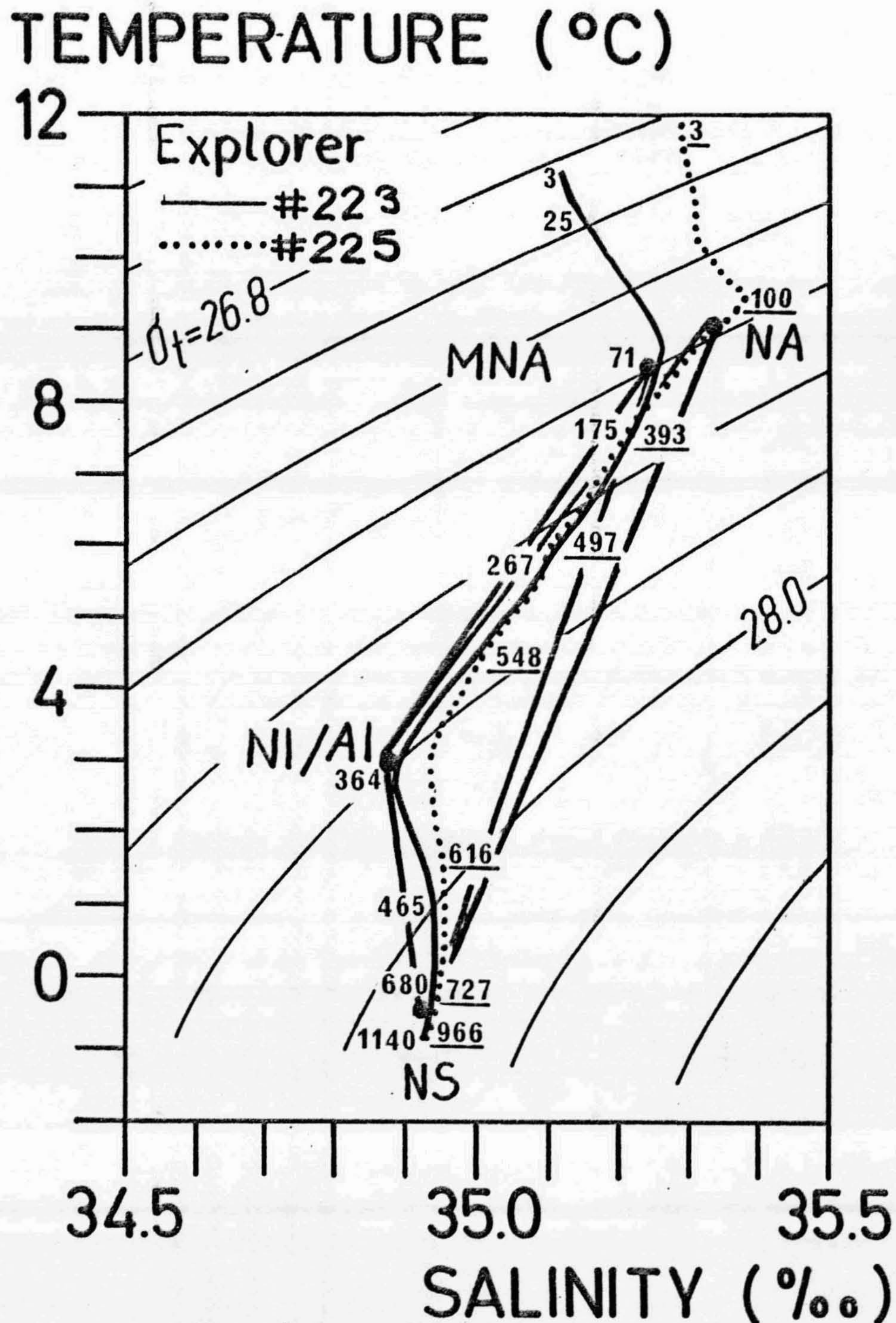


Fig.9c cont'd

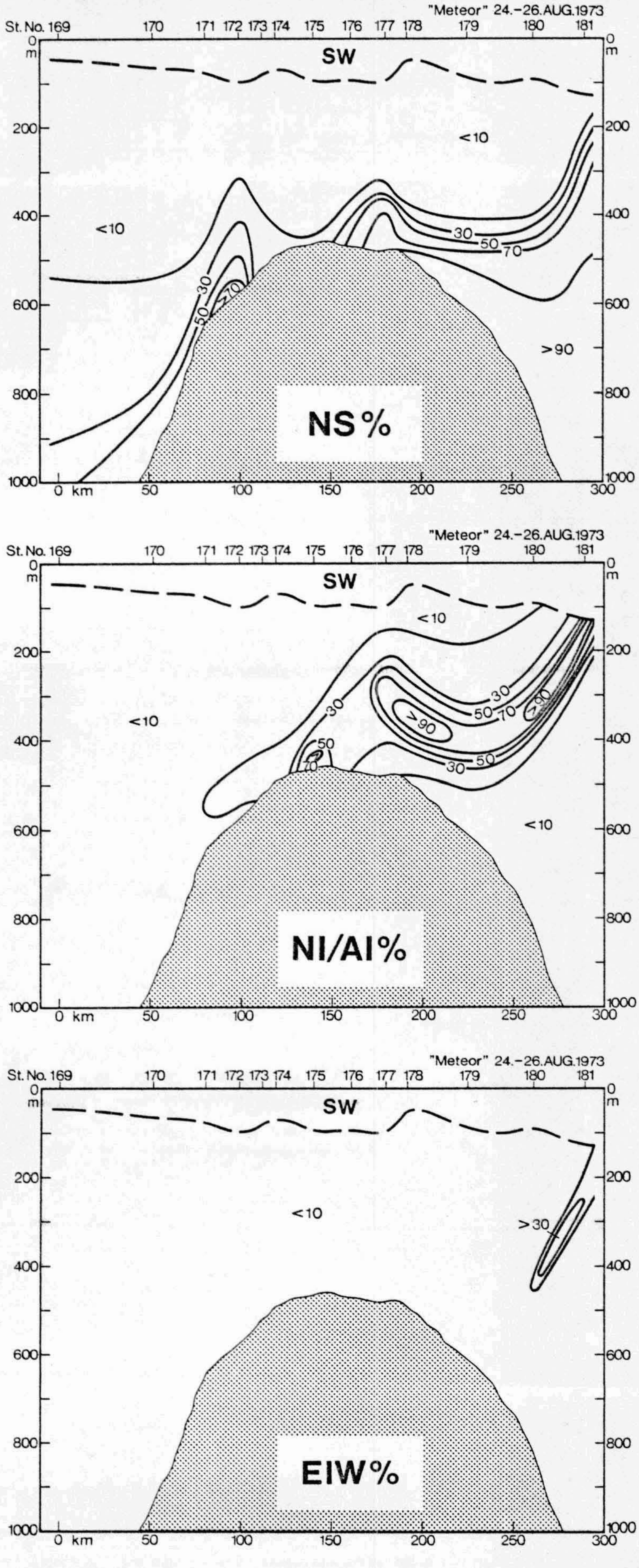


Fig. 10: Distribution of water masses across the Iceland-Faeroe-Ridge

a) Norwegian Sea Deep Water (NS)
b) North Icelandic Winter/Arctic Intermediate Water (NI/AI)
c) East Icelandic Winter Water (EIW)

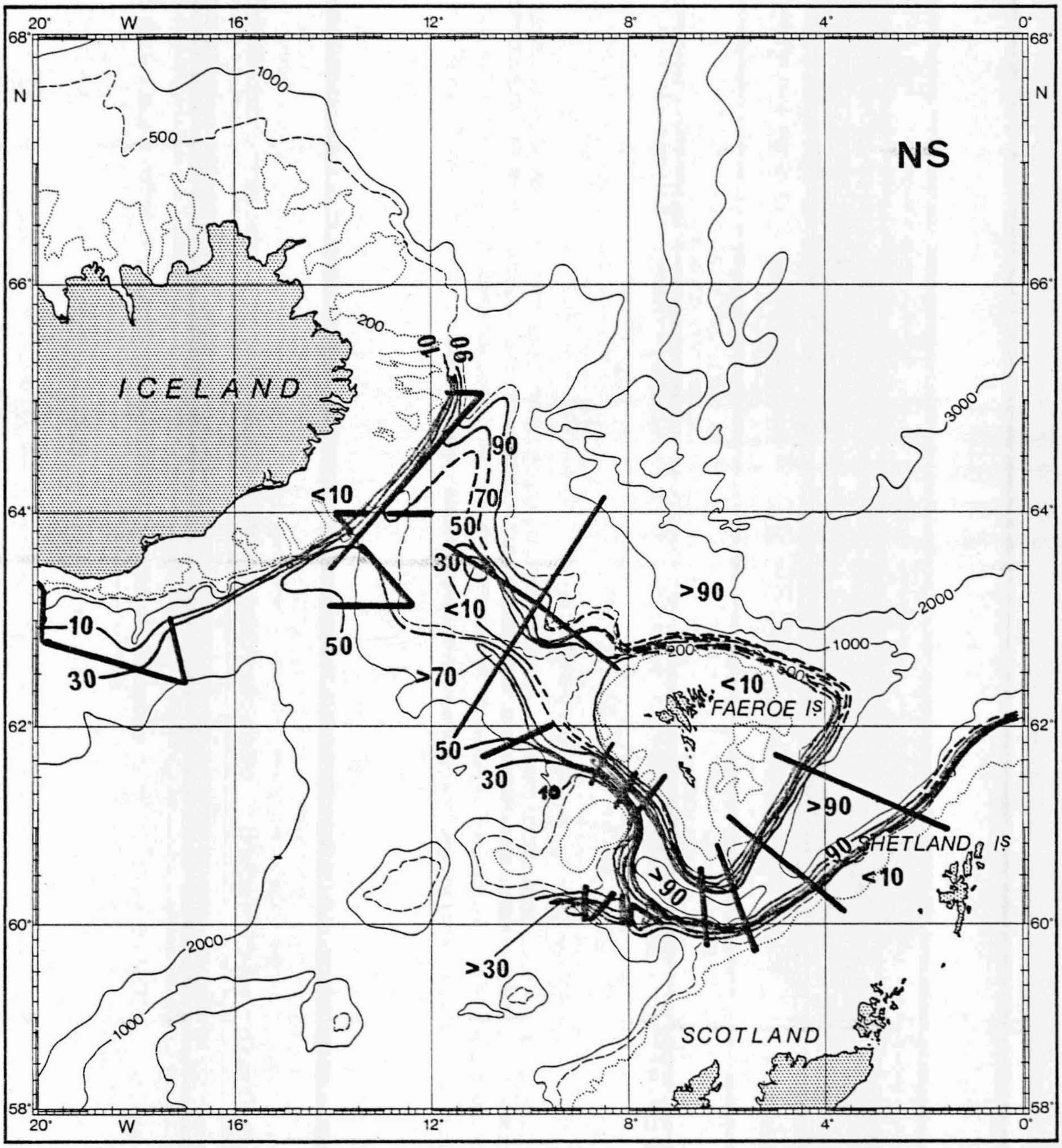


Fig. 11: Horizontal distribution of water masses in the Iceland-Faeroe-Shetland region

a) Norwegian Sea Deep Water (NS)
b) North Icelandic Winter/Arctic Intermediate Water (NI/AI)

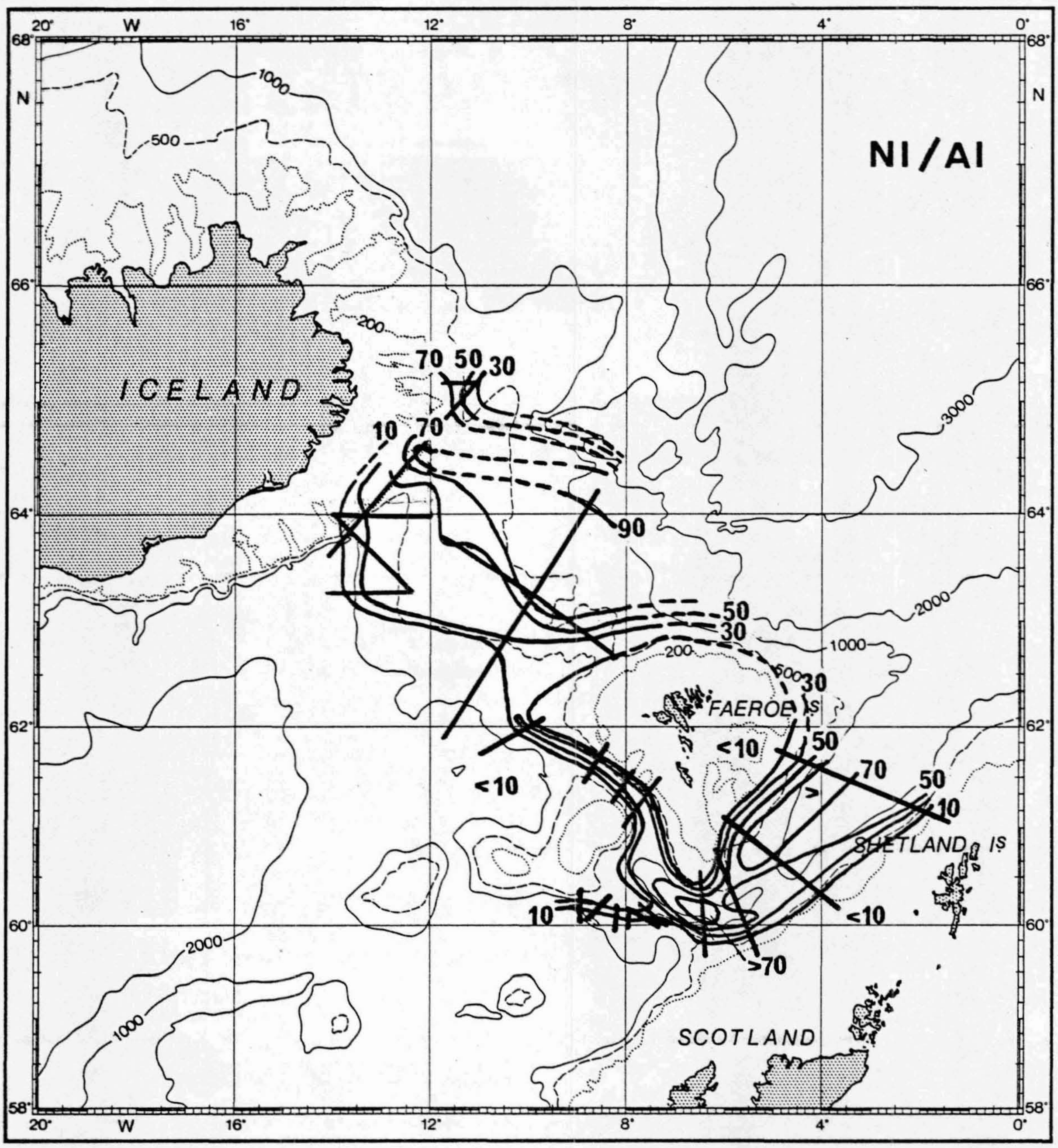


Fig.11b cont'd