Report no. changed (Mar 2006): SM-209-1-UU

SACLANTCEN SM-209

Atlantic Inflow Experiment, GIN Sea Cruise '86

Data Report
Part I: Hydrography

T.S. Hopkins

The content of this document pertains to work performed under Project 04 of the SACLANTCEN Programme of Work. The document has been approved for release by The Director, SACLANTCEN.

Issued by:
Underwater Research Division

J. Hovem
Division Chief

intentionally blank page

SACLANTCEN SM-209

Atlantic Inflow Experiment, GIN Sea Cruise '86

Data Report
Part I: Hydrography

T.S. Hopkins

Executive Summary: This memorandum summarises the results of the Atlantic Inflow Experiment in the form of an oceanographic data report. Its purpose is to provide a complete data summary that serves as a reference for the experiment itself and for subsequent analysis of portions of the data pursuant to ASW applications.

Detailed sampling of the oceanographic environment provides information to researchers on three levels: exploration of the environment in both space and time frames not yet observed; confirmation of our understanding of the physical laws governing the ocean environment; and utilisation of these data and laws in quantitative assessments (models) that allow environmental prediction. Such descriptions and assessments of the ocean environment are a primary goal of ASW research.

The Atlantic Inflow Experiment was designed to provide information on the entrance of Atlantic waters to the Arctic Ocean through the Faeroe–Shetland Channel. The sampling design was unique and the instrumentation was more advanced technologically than that used in previous sampling in the area.

This report is divided into two parts, one covering shipboard sampling and the other sampling conducted from moored and free-floating instruments. Part I presents the observations taken from a CTD (Conductivity–Temperature–Depth instrument) which samples rapidly these and other variables as it is lowered through the water, transmitting data to a computer system on board. On return to the surface, the CTD records time-averages of these variables at selected depths where attached water bottles take samples of water for the analysis of further variables.

intentionally blank page

Report no. changed (Mar 2006): SM-209-1-UU

Atlantic Inflow Experiment, GIN Sea Cruise '86

Data Report
Part I: Hydrography

T.S. Hopkins

Abstract: An investigation of the inflow of North Atlantic surface water into the Greenland–Norwegian–Iceland Sea has been undertaken as a major observational component of SACLANTCEN's GIN Sea Project. Included in this data report are the hydrographic results of the *Tydeman* (NL) Cruise conducted between 26 May and 30 June 1986. Pressure, temperature, conductivity, dissolved oxygen, and light transmittance were recorded via in-situ sensors on a CTD and water samples for the analysis of salinity, dissolved oxygen, nitrate, nitrite, silicate, chlorophyll, phaeophytin, particulate organic carbon, oxygen-18, tritium, phytoplankton, and the heavy metals of iron, chromium and nickel were taken from selected depths using a Rosette sampling system. This report summarises the method of data acquisition and reduction and it presents a selection of the results in plots and tables.

Keywords: Atlantic inflow o Denmark Strait o Faeroes Channel o GIN Sea o Greenland–Iceland–Norwegian seas o hydrography o Icelandic Current o Nordic Sea o Norwegian Current o oceanography

Contents

Acknowledgement: We wish to thank the Ocean Engineering and Computer Departments for their assistance in the preparation and implementation of the cruises and to the Captain, officers and crew of the *Tydeman* (NL) for their excellent support and spirit during the cruise.

1

Introduction

1.1. GIN SEA PROJECT

The GIN Sea observational programme was initiated to acquire an extensive set of oceanographic data in the Greenland–Iceland–Norwegian Sea from which state-of-the-art quantitative analyses could be conducted to serve the purposes of SACLANT/NATO and the NATO scientific communities. In conducting the field experiments, an attempt is being made to employ as many techniques as feasible in order to maximize the potential for interpretive assesment. To achieve this, the observational programmes employ a high-quality core of standard instrumentation (CTD, current meters) together with new or experimental instrumentation (acoustic profilers, doppler current, subsurface floats, meteorological satellite buoys) and with an augmented biochemical sampling (chemical tracers, planktonic observations). Both the experimental instrumentation and biochemical sampling open avenues of collaboration with other research institutes and extend the potential for utilization of the latest techniques in interpretative analysis. The data obtained from the moored and floating instrumentation will be presented in Part II of this data report.

The SACLANTCEN GIN Sea Project has proposed to conduct two major observational experiments: the Atlantic Inflow Experiment in 1986–87 and the Icelandic Boundary Current Experiment in 1988–89. The first deals with the water mass input to the GIN Sea via the Faeroe–Shetland Channel and its subsequent transitions northward within the Norwegian Current System. The second deals with the large-scale forcing controlling the Icelandic Current which transports waters of the Denmark Strait to the Faeroes Channel and which establishes the dynamic boundary forming the Iceland–Faeroe Front. The two experiments are designed to provide a substantial database and a more complete physical understanding of this important region.

1.2. ATLANTIC INFLOW EXPERIMENT

The Arctic Ocean draws in the North Atlantic surface waters in large quantities, ~ 4–8 Sv. Most of this inflow derives from a portion of the North Atlantic Current which enters over the Wyville–Thompson Ridge and through the Faeroese Channel. Smaller inflows arrive via the Iceland–Faeroe Ridge and the Denmark Strait. Virtually all of the salt and heat input to the Arctic Ocean enters with this input. Although considerable observational effort has been spent in attempting to quantify this input, the results have not been particularly consistent nor have they been in accord with the input values deduced from thermohaline balances of the Arctic Ocean (see Hopkins, 1988). In part these results have been explained by the historical necessity to rely on the dynamic method, with its uncertainty of an unknown reference level, i.e. Tait (1957). The more recent use of current meters has provided better direct information on the flow field (i.e. Dooley and Meincke, 1981), but a comprehensive data set does not yet exist that provides a satisfactory description of the inflow and its temporal variability. A review of the observational attemps to establish this inflow and its general relevance to the Arctic Ocean oceanography can be found in Hopkins (1988).

The GIN Sea Project has undertaken the observational task of enhancing the body of data concerning the behavior of this input water within the southern portions of the GIN Sea (Norwegian Sea) in order that the interface between this water mass and the Arctic Waters can be better described. As mentioned above, we have called this observational effort 'The Atlantic Inflow Experiment'. This data report summarizes the data from the 1986 expedition, which concentrated on the Faeroese Channel region. The cruise also served as an introductory cruise in an engineering sense, that is, in the sense of deploying SACLANTCEN hardware into northern waters for the first time.

1.3. COLLABORATION

The GIN Sea Project is unclassified and open to collaboration with oceanographic research institutions of NATO member nations. This policy intends to encourage participation and scientific exchange within the NATO community. In both the hydrography and mooring phases of the GIN Sea Cruise '86 was assisted by collaborating Institutes, summarized as follows:

(1) *Institute of Oceanographic Sciences (UK)*

- participation of I. Waddington and G. Phillips
- deployment of IOS moorings 1, 2, and 3 (J. Gould, principal investigator)
- loan of two Aanderaa current meters for SACLANTCEN mooring 1

(2) *Dutch Royal Navy Hydrographic Office (NL)*

- participation of M. Scheffers
- administrative support

(3) *Stazione Zoologica di Napoli (IT)*

- participation of M. Ribera
- loan of fluorometer, centrifuge, and vacuum pump

(4) *Istituto Scienze Ambientali Marine (IT)*

- participation of P. Povero
- loan of filter apparatus for POC and heavy metal analysis

(5) *Deutsches Hydrographisches Institut (FRG)*

- participation of Z. Vogel

(6) *University of Bergen (NR)*

- phytoplankton sample counts (T. Johannessen)
- oxygen-18 sample analysis (E. Jansen)

(7) *Institute of Environmental Physics, University of Hieldleberg (FRG)*

- tritium sample analysis

(8) *Netherlands Institute for Sea Research (NL)*

- additional silicate analysis (J. van Bennekom)

2

Cruise track

The cruise hydrography consisted of a sequence of CTD/Rosette and XBT casts. The casts of Leg I (Fig. 1) were taken in support of the mooring deployments and to obtain some preliminary information in the Faeroe–Shetland Channel. The casts of Leg II (Fig. 2) were organized into a series of transects. The sequence of transects directed northwest–southeast across the inflowing North Atlantic Water intented to satisfy the primary observational objective: that of monitoring the changes in the incoming North Atlantic Water through the Faeroe–Shetland Channel and into the southern Norwegian Sea. The station spacing was irregular, being closer over large gradients in bottom depth and/or in water properties. One particular transect across the Faeroe–Shetland Channel was taken three times to investigate the variability over the timescale of days. Other transects were taken across the Faeroe Bank Channel, the opening to the North Sea, and across the Icelandic Current to provide information on the lateral inputs/outputs to the Norwegian Atlantic Water Mass. Finally, a time series sequence of stations was taken to explore higher frequency variability at a location near the incoming core of North Atlantic Water within the Faeroe–Shetland transect.

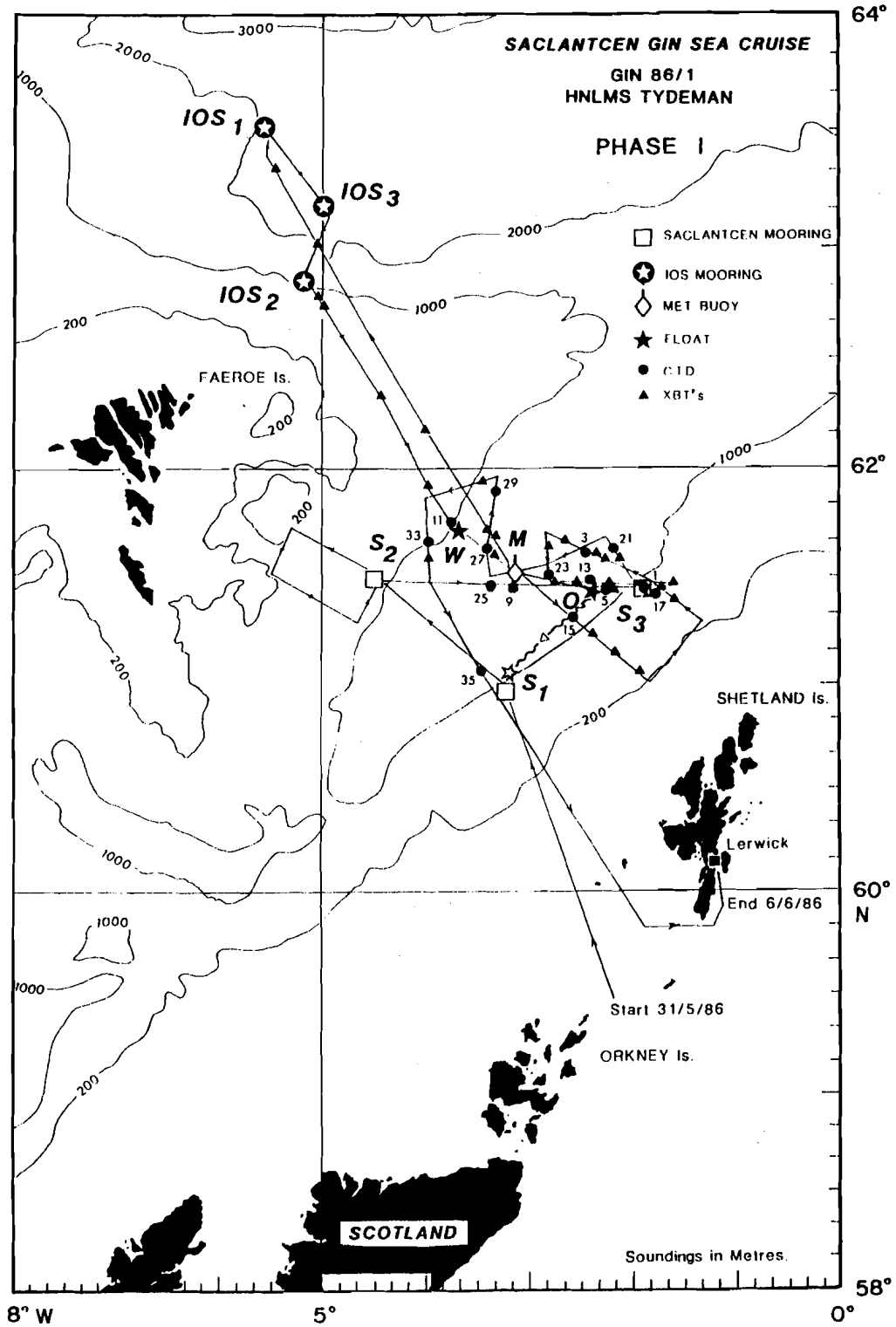

Fig. 1. Cruise track of Leg I.

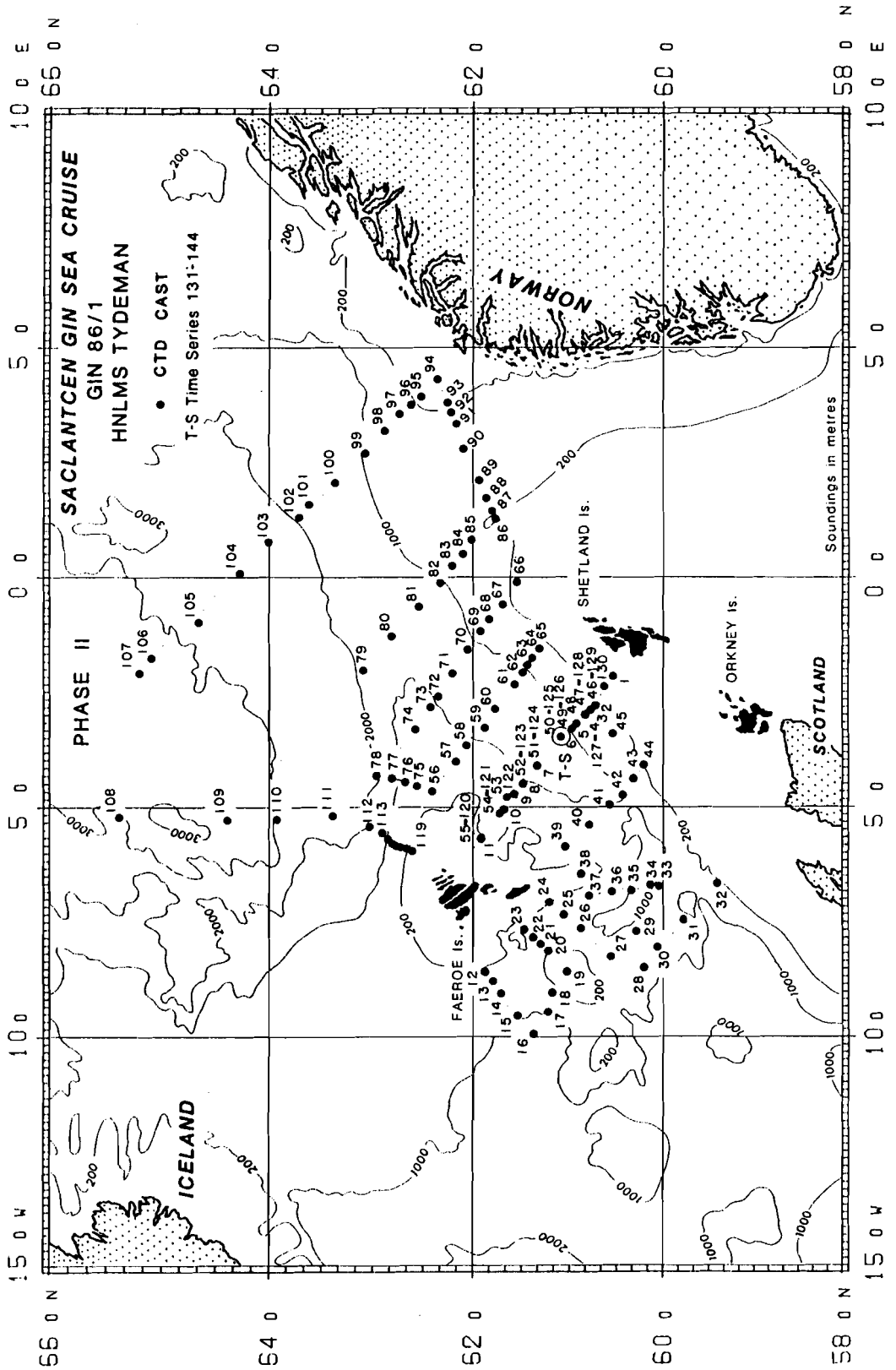

Fig. 2. Cruise track of Leg II.

3
Methods

3.1. DATA ACQUISITION

CTD/Rosette Hydrographic stations, as indicated in Figs. 1 and 2, consisted of sampling via the lowering of a CTD/Rosette package. This package was too large to be deployed through the starboard hydrographic hatch of the *Tydeman (NL)* so it was lowered from the forward A-frame by fairleading the cable along the starboard passageway from the midships hydrographic winch. While this arrangement was convenient with regard to the Rosette work, since the forward operating deck is accessible through a large hydraulic door to the wet hall and the chemical laboratory, it did produce cable related problems due to the number of blocks and the small-diameter curvatures imposed at several points.

The CTD package was a Neil Brown Mark III conductivity–temperature–pressure (CTD) probe equipped with a Beckman-dissolved Oxygen Sensor and Sea Tech., Inc. 25-cm-path transmissometer. Data from the CTD package were collected on descent, at about 1 m/s, and constituted a 'downcast'. On ascent, or 'upcast', a General Oceanics Rosette with 12 5-l Niskin bottles, was used to collect water at selected depths. At each bottle depth, the CTD/Rosette system was allowed to equilibrate for 1 min followed by 1 min of data collection before the bottle was closed by the CTD operator. The CTD/Rosette underwater system was placed in a circular stainless steel frame. The CTD data signal went through a Niel Brown Mark III deck unit to a HP-21 MX computer and was recorded on magnetic tape.

In the case of the time-series station, the CTD/Rosette was lowered in a downcast to 600 m on the hour for 13 h. After each lowering the CTD/Rosette was left on acquisition at 600 m for 20 min and then brought to the surface in an upcast taking 6 bottle depths.

Shipboard data A shipboard computer (HP-21M20) connected on-line to various sensors provided a print-out and magnetic tape recording of the ship's position, water depth, sea surface temperature, wet/dry air temperatures, and wind vector. The header information for the listed casts was entered manually at the time of the cast.

Water samples At least two salinity and two or more oxygen samples were drawn from every cast for calibration puposes. Nutrient samples were drawn from every bottle depth. Chlorophyll samples were drawn from the top 4 to 5 bottles. For more than half of the stations samples were taken for particulate organic carbon, carbohydrates, and heavy metal analyses. At selected stations, additional samples were drawn for phytoplankton counts, oxygen-18, tritium, and silicate analyses.

3.2. CTD DATA REDUCTION

Processing The data stream was interfaced from the NBIS Deck unit to a Hewlett-Packard (HP) 21 MX computer and stored on an HP 7906 disk. In the acquisition mode, the data were converted to engineering units and written to an HP 7970C 9-track magnetic tape in standard data blocks of 527 words (15 for header and 512 for data). At the same time, the raw temperature and the calculated salinity were plotted versus calculated depth on a CALCOMP 565 plotter. In between stations the data were re-read from the disk to provide a depth-averaged print-out of depth, potential temperature, salinity, density, potential density, sound velocity, opacity, oxygen concentration, and oxygen saturation.

The post-cruise data reduction involved reading the raw data tapes into the UNIVAC 1100 computer and processing with the SACLANTCEN MINIFILING system. The data were first ordered in pressure by deleting all data samples having a reversal in pressure. These were replaced with interpolated values so that the original sampling density (in time) was preserved. Next a time response correction was applied to the temperature data, in which the response time was 320 ms. As a result of the faster response of the conductivity sensor and of the above time-response filter, the conductivity data displayed a more accurate profile of vertical structure than did the temperature data. This discrepancy causes spikes in the calculation of salinity. To minimize this spiking the pressure, temperature, and conductivity data were all treated with an equally-weighted running-mean filter, and in addition the conductivity data were shifted in adavance by four sampling intervals ($\frac{1}{8}$ s) to adjust to the lag in the temperature. The salinity data were corrected for calibration and then other variables were calculated utilizing the standard algorithms from Fofonoff and Millard (1983) and then averaged to 1 m intervals. A greater vertical interval for averaging was employed for the summaries included in this Data Report.

Calibration The salinity data were adjusted according the results of the salinity analyses done on the bottle samples. The resulting salinity offsets varied slightly for the primary CTD unit (CTD2) because of repeated openings of the pressure case during the cruise. The second CTD unit (CTD1) had a greater offset. The corrections are listed in Table 1.

Table 1
Salinity offsets used

Instrument	Stations	ΔS (ppt)[a]
CTD2	1–65	0.008
	66–74	0.023
	81–88	0.003
	94–144	0.001
CTD1	75–80, 89–93	$(68 - 4.4T) \times 10^{-3}$

[a] $\Delta S = S_{\mathrm{CTD}} - S_{\mathrm{bottle}}$; T in °C.

3.3. CHEMICAL ANALYSES

Dissolved oxygen Sample bottles were volume calibrated (~ 75 ml). The Winkler method of analysis was used. Samples were fixed immediately and titrated later with an automated burette (DOSIMAT). Blanks were run once a day, approximately every 10 stations.

Nutrients Nutrient samples were prefiltered on a Whatman GF/F filter using a syringe equipped with a swinnex filter support and analyzed soon after using an ALPKEM Rapid Flow Analyzer. The procedure for silicate analysis followed that described by Strickland and Parson (1968) using the absorption value at 820 nm in a 10-mm flow cell; while that for nitrate/nitrite followed a modified procedure of Grasshoff (1970) using an absorption at 540 nm and a 10-mm flow cell.

Chlorophyll Chlorophyll and phaeophytin concentrations were measured fluorometrically using a Turner Designs Model 110 fluorometer. Water sample volumes of either 200 ml or 500 ml, depending on the sample depth, were filtered through a Whatman GF/F glass-fiber filters. The filters were then finely ground in a 10 ml tissue-grinder with 90% neutral acetone, centrifuged, and left for 20–24 h under refrigeration and 0 °C for complete pigment extraction prior to observing their fluorescence.

Particulate organic carbon One liter samples of seawater were filtered on precombusted (4 h at 450 °C) glass-fiber filters (Whatman GF/C). After filtration the filters were dried at 60 °C for 3 h and were stored in a freezer until post-cruise laboratory processing. There, the filters were dried at 60 °C, placed in acid-washed aluminium boats, and then burned in a Carlo Erba Elemental Analyzer Model 1106. A solution of cyclohexanone was used as a standard.

Oxygen-18 Oxygen-18 samples were drawn from selected stations and depths into

500-ml double-capped plastic bottles and the analysis was done by the Geology Department, University of Bergen.

Special chemistry The results of the following special-chemistry analyses were not yet available at the time of printing but may be obtained on request:

- Tritium samples were drawn into 1-l stoppered glass bottles for analysis at the Institute of Environmental Physics, University of Heidelberg. The samples were left to cure for one year prior to analysis.
- Heavy-metal samples, iron, chromium and nickel were taken for later analyses at the Chemical Department of University of Genova using the method of atomic absorption.

Phytoplankton Water samples for phytoplankton species counts were drawn into 250-ml bottles and preserved with 10 ml of a 40% neutral Formaldehyde solution. The analysis of a selection from 24 stations was done by Aquabotanikk, Bergen, and the results are available on request.

4

Data presentation

The data presented herein were prepared immediately prior to the dismantling of the Center's UNIVAC system and replacement by a VAX 8600 system (November 1986). As a result, certain minor corrections and inconsistencies that were discovered subsequently could not be corrected but are noted in Appendix A.

Subsequent to the preparation of this report the new VAX data-reduction software became operational. New data listings will be available on request, along with the various water sample analyses mentioned as not included in this version.

The appended data are presented in Appendices A, B, and C, of which only A is attached. Appendices B and C contain the individual station down-and upcast data summaries, respectively; these have a restricted distribution and are available on request.

References

Dooley, H.D. and Meincke, J. Circulation and water masses in the Faeroese Channels During Overflow '73. *Deutsche Hydrographische Zeitschrift*, **34**, 1981: 41–54.

Fofonoff, N.P. and Millard, R.C., Jr. Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Papers in Marine Science*, **44**, 1983.

Grasshoff, K., Ehrhardt, M. and Kremlig, K. (eds.) Methods of Seawater Analysis. Weinheim, Verlag Chemie, 1983.

Hopkins, T.S. The GIN Sea. Review of physical oceanography and literature from 1972, SACLANTCEN SR-124. La Spezia, Italy, SACLANT Undersea Research Centre, 1988.

Strickland, R.R. and Parson, T.R. A Practical Handbook of Seawater Analysis. *Bulletin of the Fisheries Research Board of Canada*, **167**, 1968: 1–311.

Tait, J.B. Recent oceanographical investigations in the Faeroe-Shetland Channel. *Proceedings of the Royal Society of Edinburgh*, **64(A)**, 1957: 239–289.

Appendix A

Transect contours

Potential temperature and salinity contours of the various sections from Leg II are presented in Figs. A1–A17.

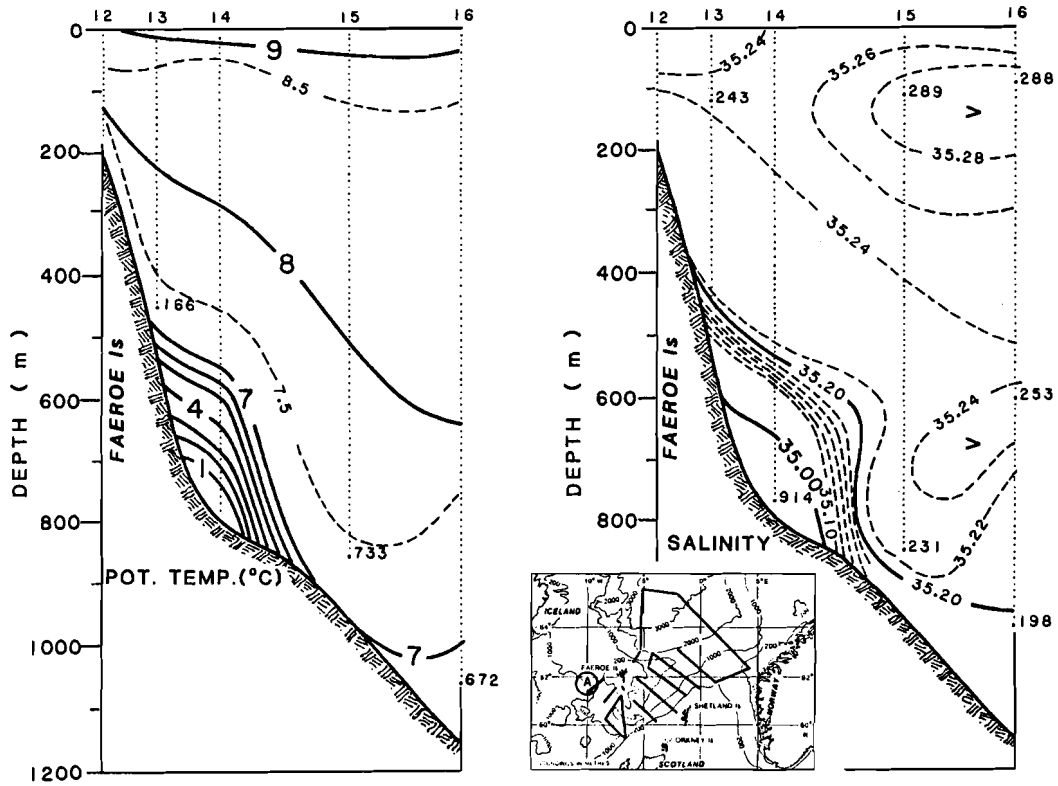

Fig. A1.

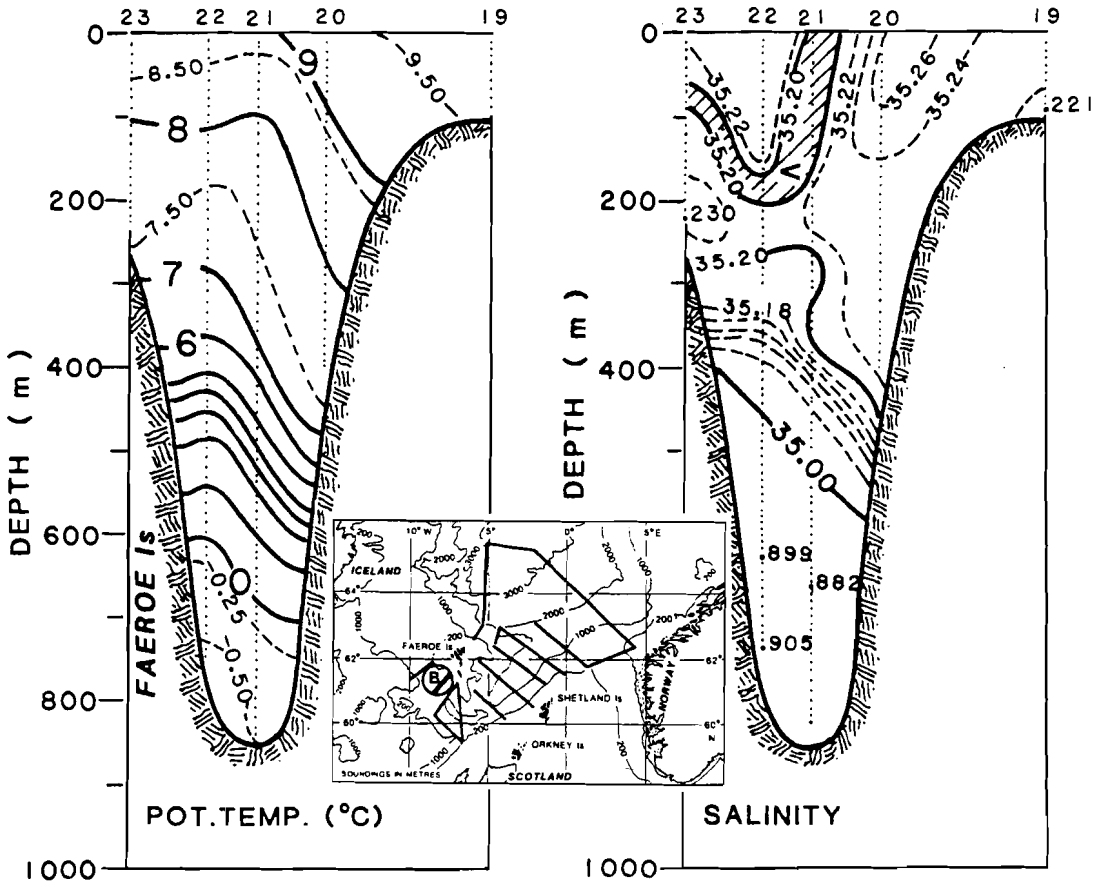
23 22 21 20 19
0
200
400
600
800
1000
DEPTH (m)
FAEROE Is
POT.TEMP. (°C)
SALINITY
ICELAND
FAEROE Is
SHETLAND Is
ORKNEY Is
SCOTLAND
SOUNDINGS IN METRES
.899
.882
.905
221
230

Fig. A2.

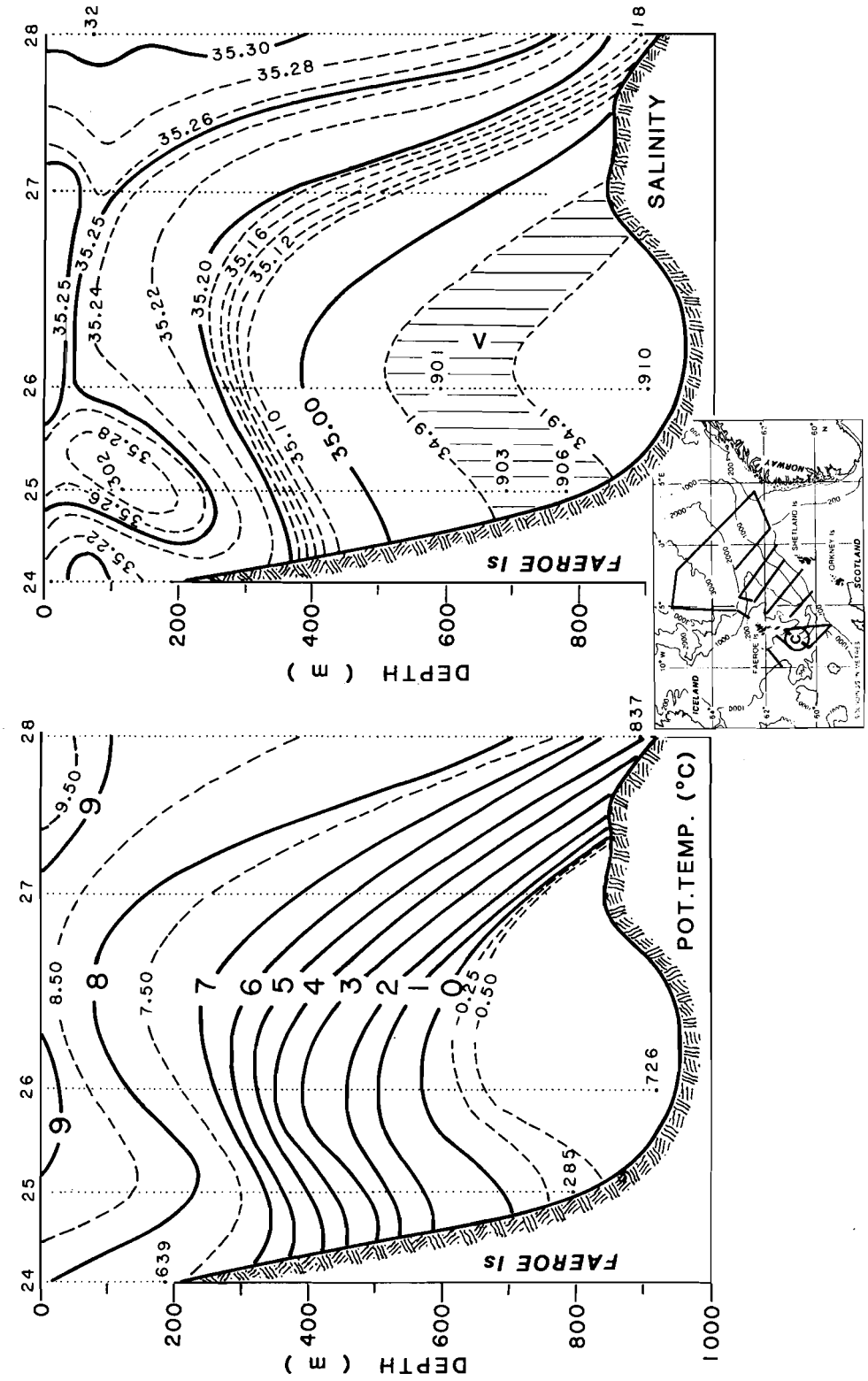
SALINITY
POT.TEMP. (°C)
DEPTH (m)
FAEROE Is
ICELAND
SCOTLAND
SHETLAND Is
ORKNEY Is
FAEROE Is

Fig. A3.

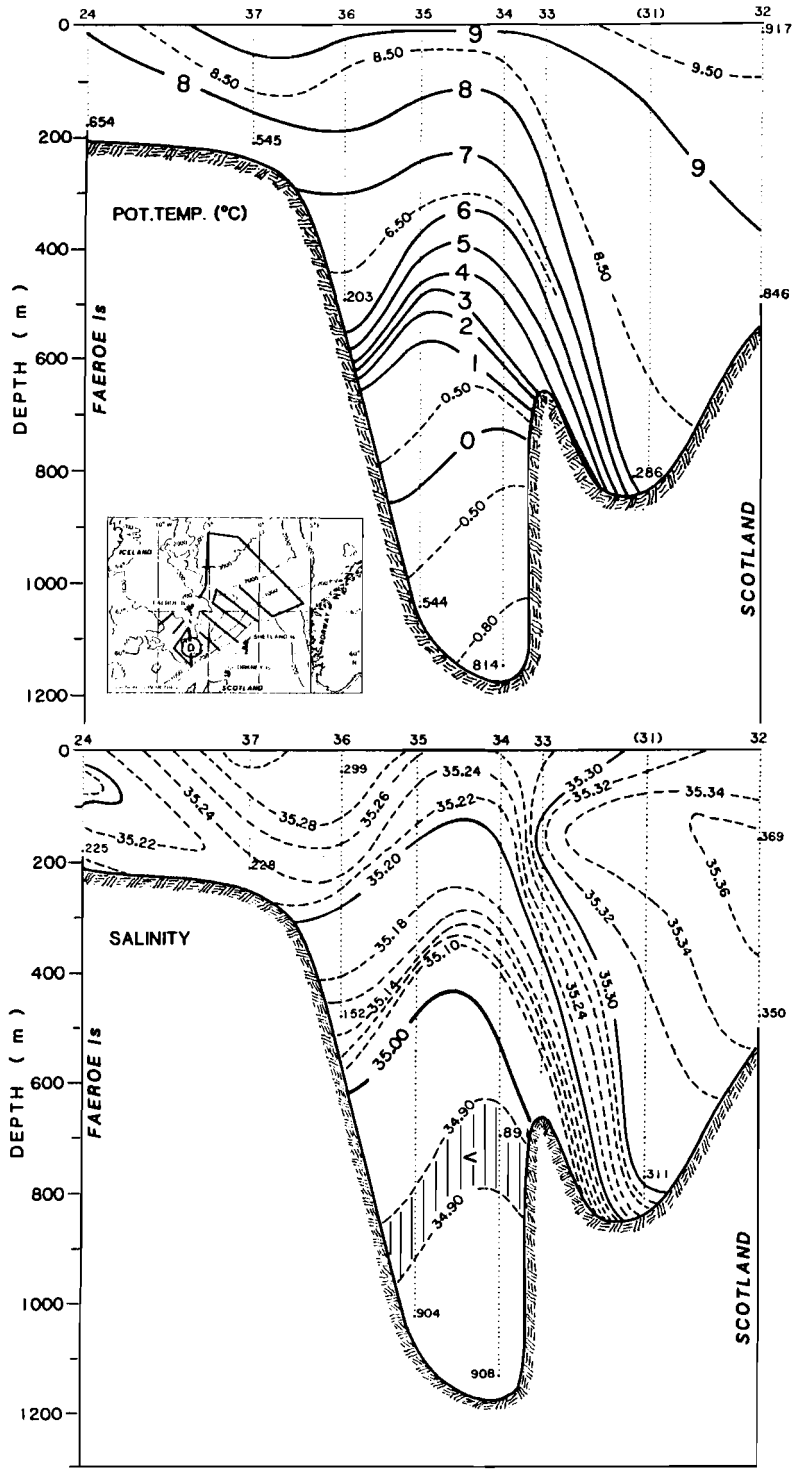
POT.TEMP. (°C)
SALINITY
DEPTH (m)
FAEROE Is
SCOTLAND
ICELAND
SCOTLAND

Fig. A4.

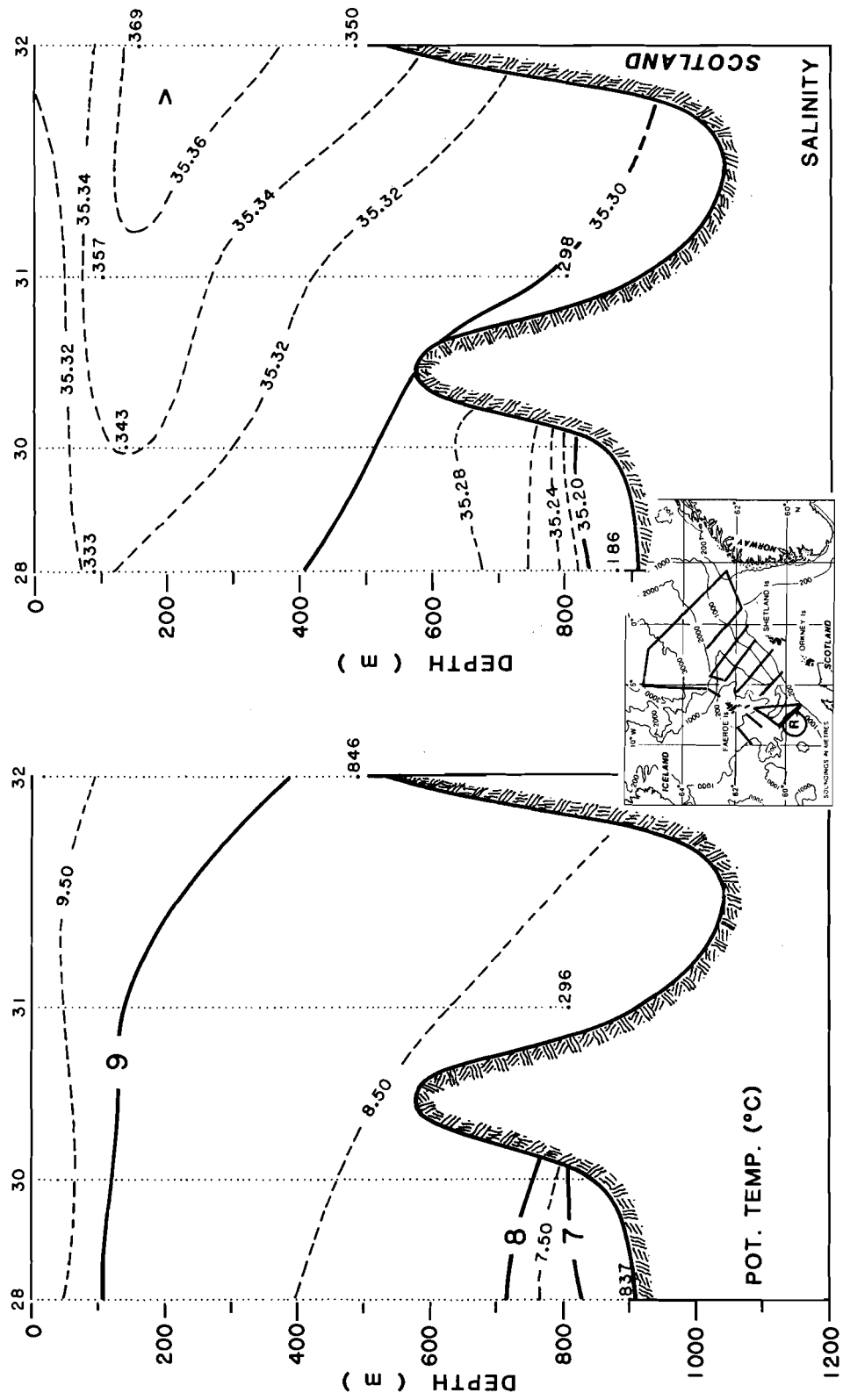
SALINITY
SCOTLAND
DEPTH (m)
POT. TEMP. (°C)
35.36
35.34
35.32
35.30
35.28
35.24
35.20
9.50
8.50
7.50
NORWAY
SHETLAND Is
ORKNEY Is
SCOTLAND
FAEROE Is
ICELAND

Fig. A5.

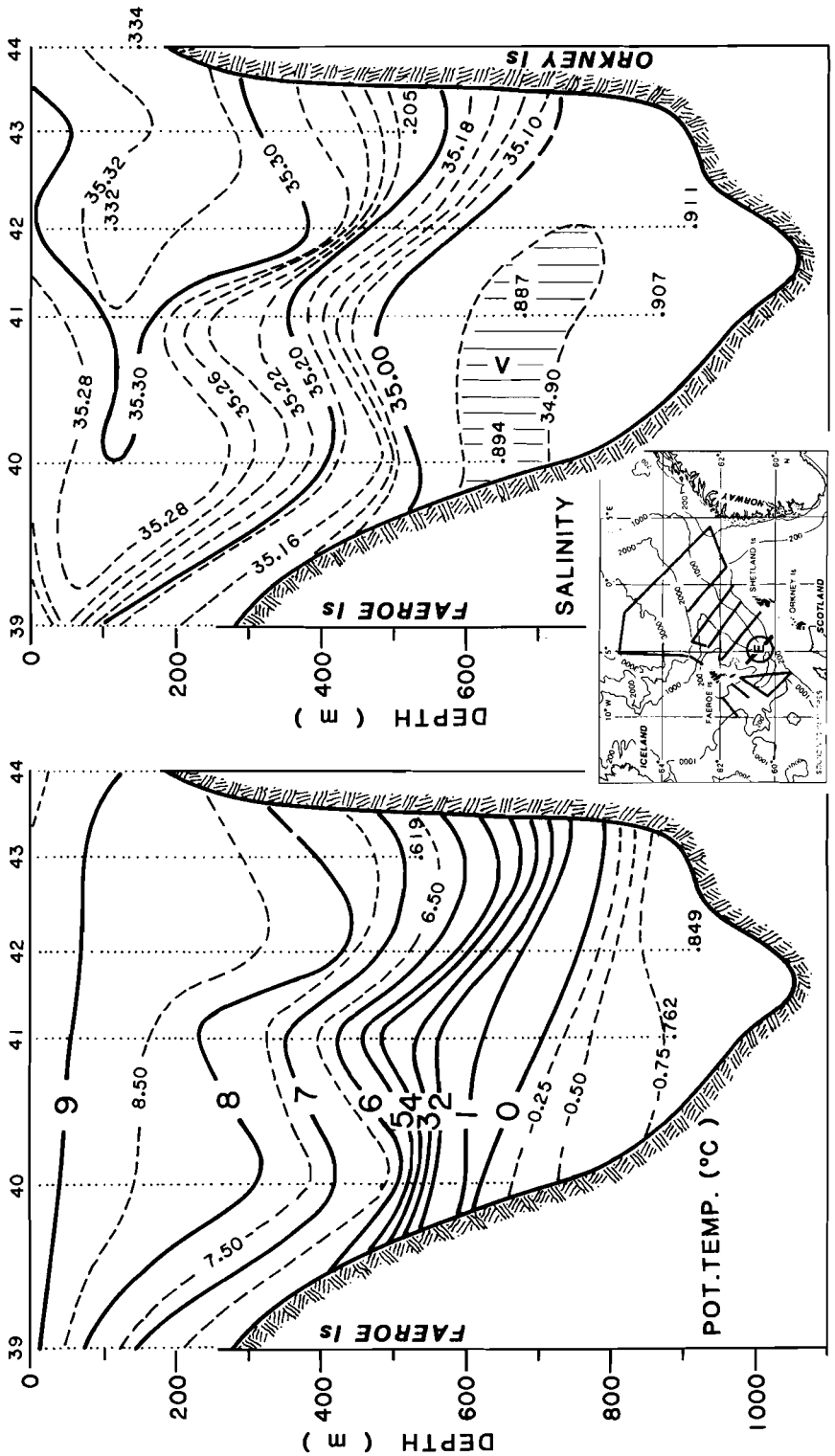
SALINITY
ORKNEY IS
FAEROE IS
DEPTH (m)
POT.TEMP. (°C)
SHETLAND IS
ORKNEY IS
SCOTLAND
NORWAY
ICELAND
FAEROE IS

Fig. A6.

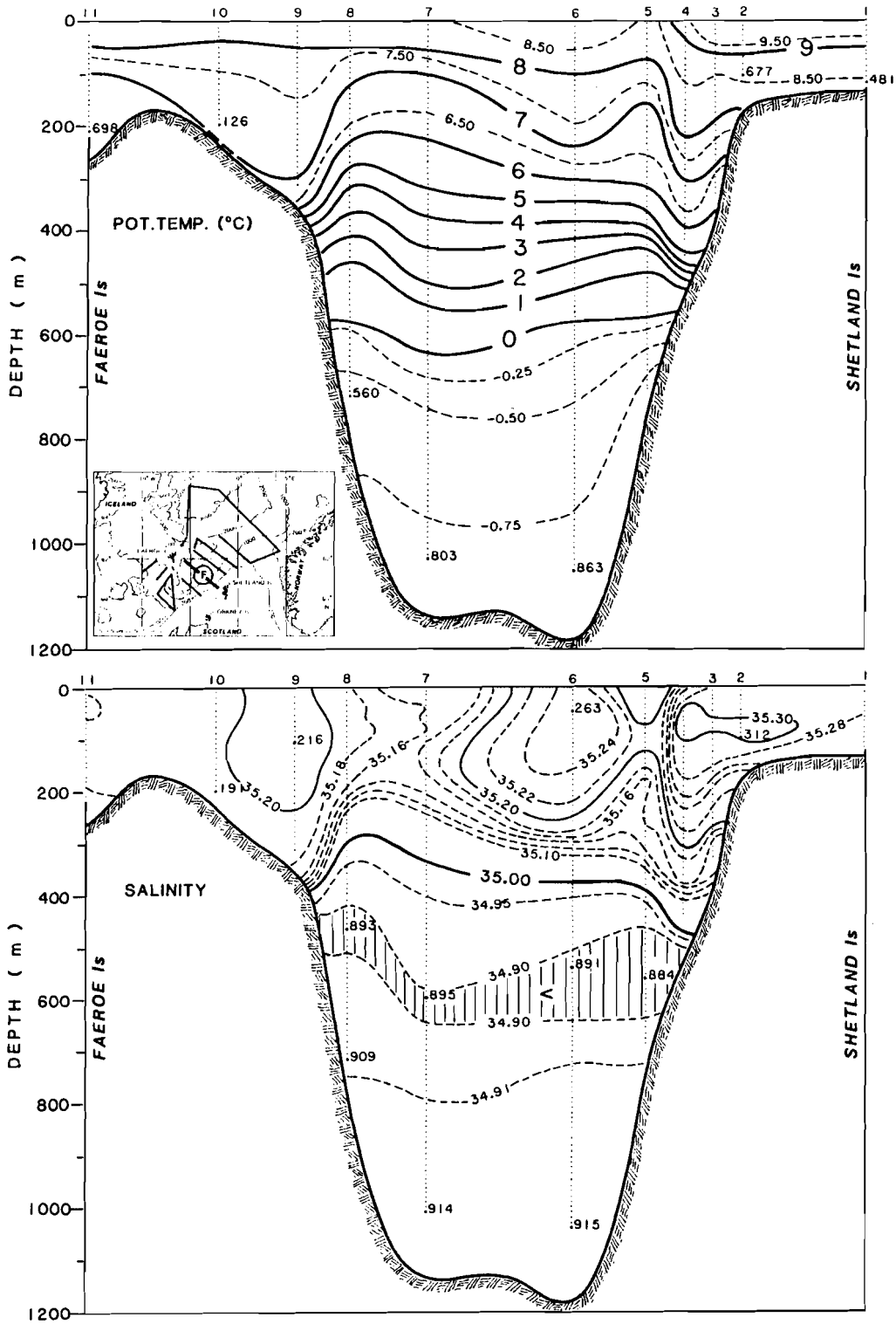
POT.TEMP. (°C)
SALINITY
DEPTH (m)
FAEROE Is
SHETLAND Is
ICELAND
SCOTLAND
8.50
7.50
6.50
9.50
9
8
7
6
5
4
3
2
1
0
-0.25
-0.50
-0.75
35.30
35.28
35.24
35.22
35.20
35.18
35.16
35.10
35.00
34.95
34.90
34.91

Fig. A7.

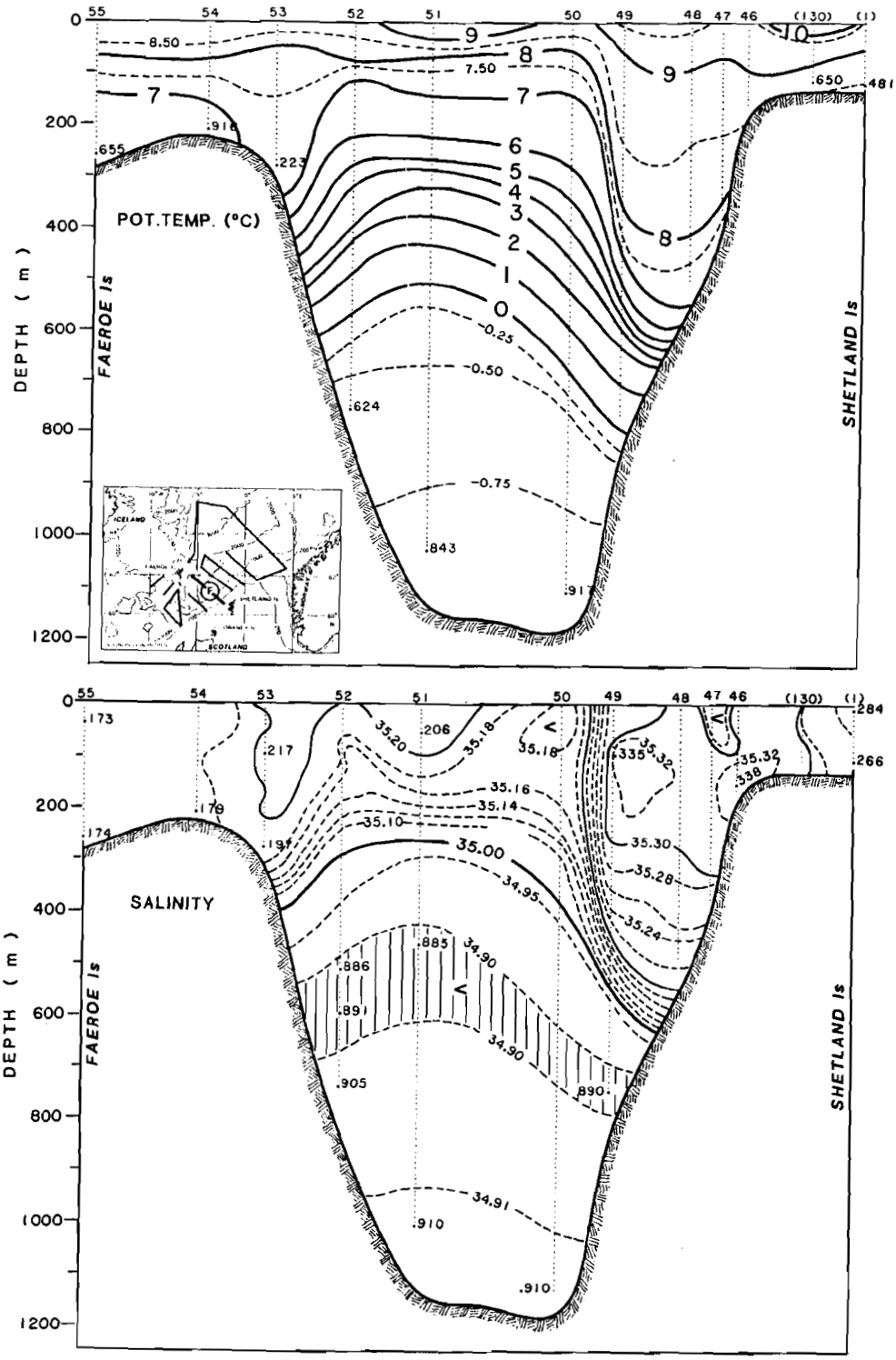
POT.TEMP. (°C)
SALINITY
DEPTH (m)
FAEROE Is
SHETLAND Is
ICELAND
SCOTLAND

Fig. A8.

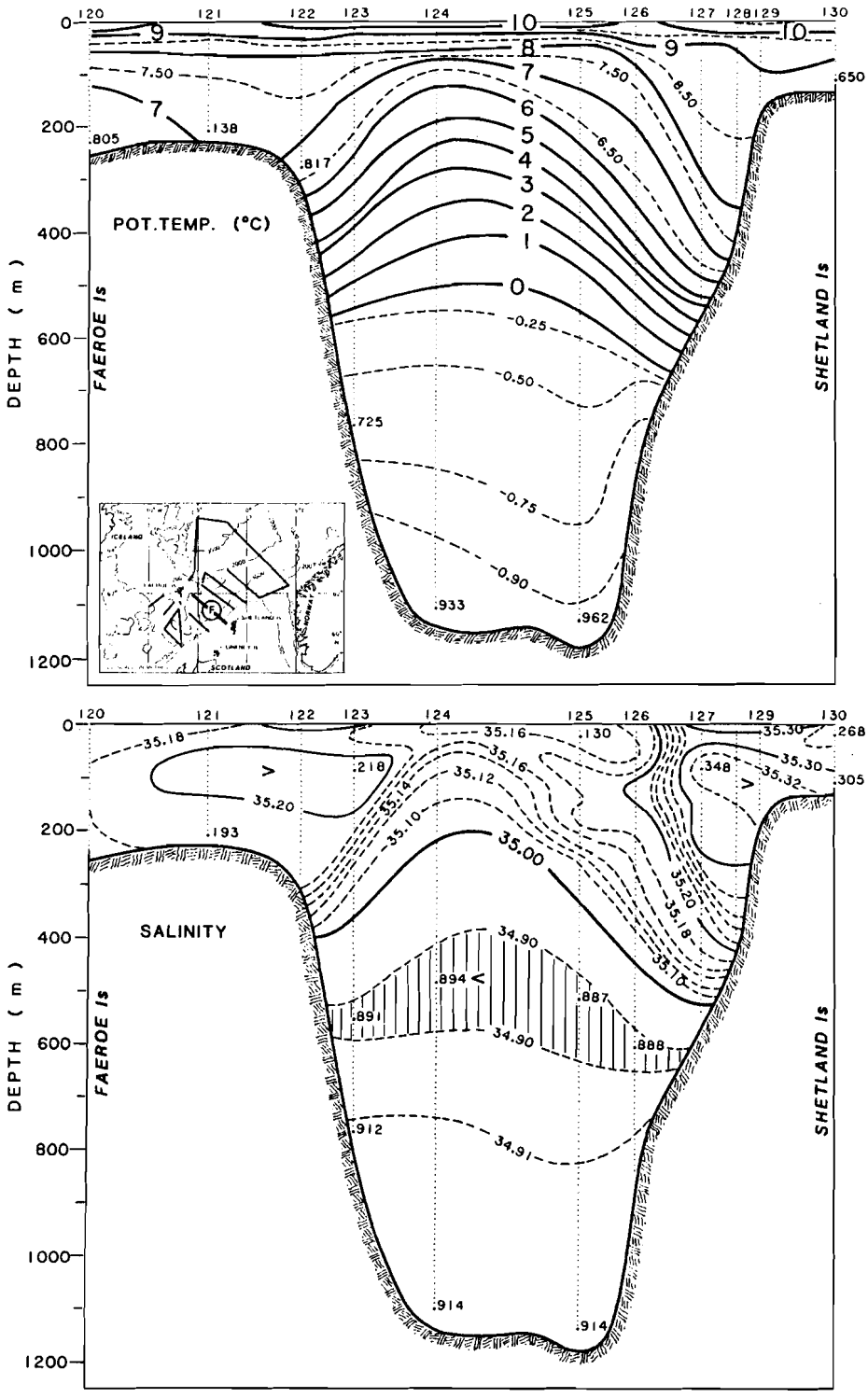
POT.TEMP. (°C)
SALINITY
DEPTH (m)
FAEROE Is
SHETLAND Is
ICELAND
SCOTLAND

Fig. A9.

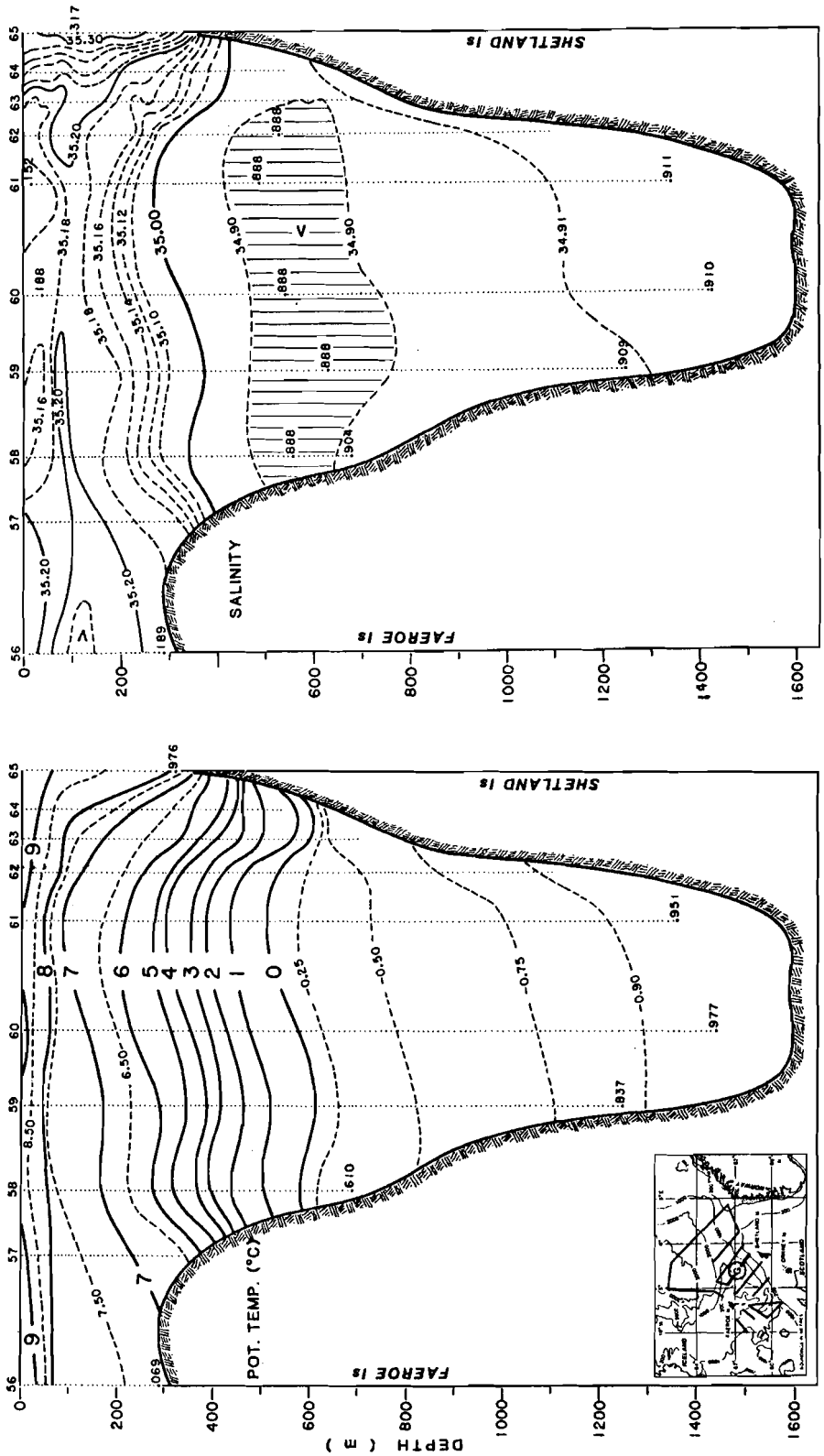
SHETLAND Is
FAEROE Is
SALINITY
35.00
34.90
34.91
35.10
35.12
35.16
35.18
35.20
POT. TEMP. (°C)
DEPTH (m)
0
200
400
600
800
1000
1200
1400
1600

Fig. A10.

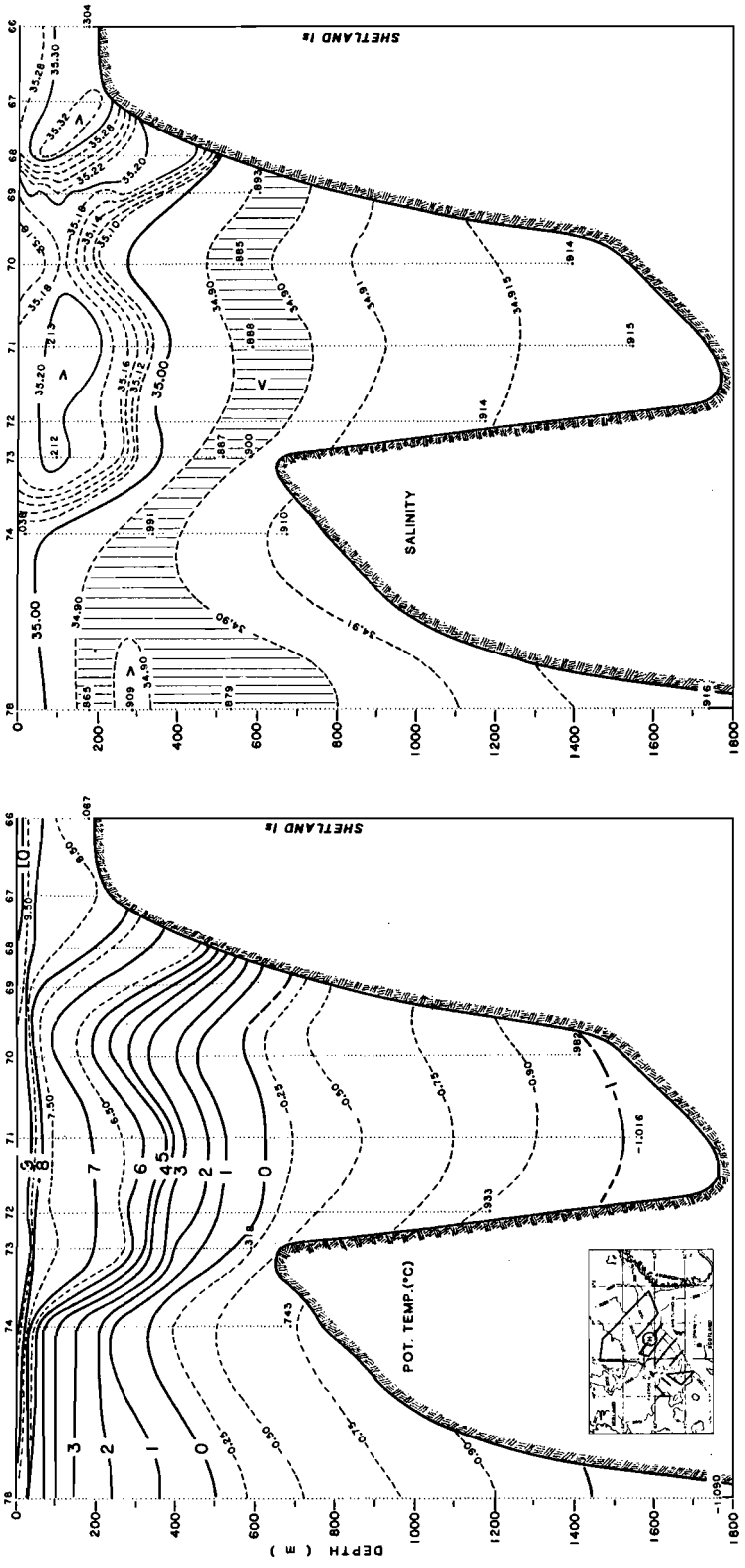

Fig. A11.

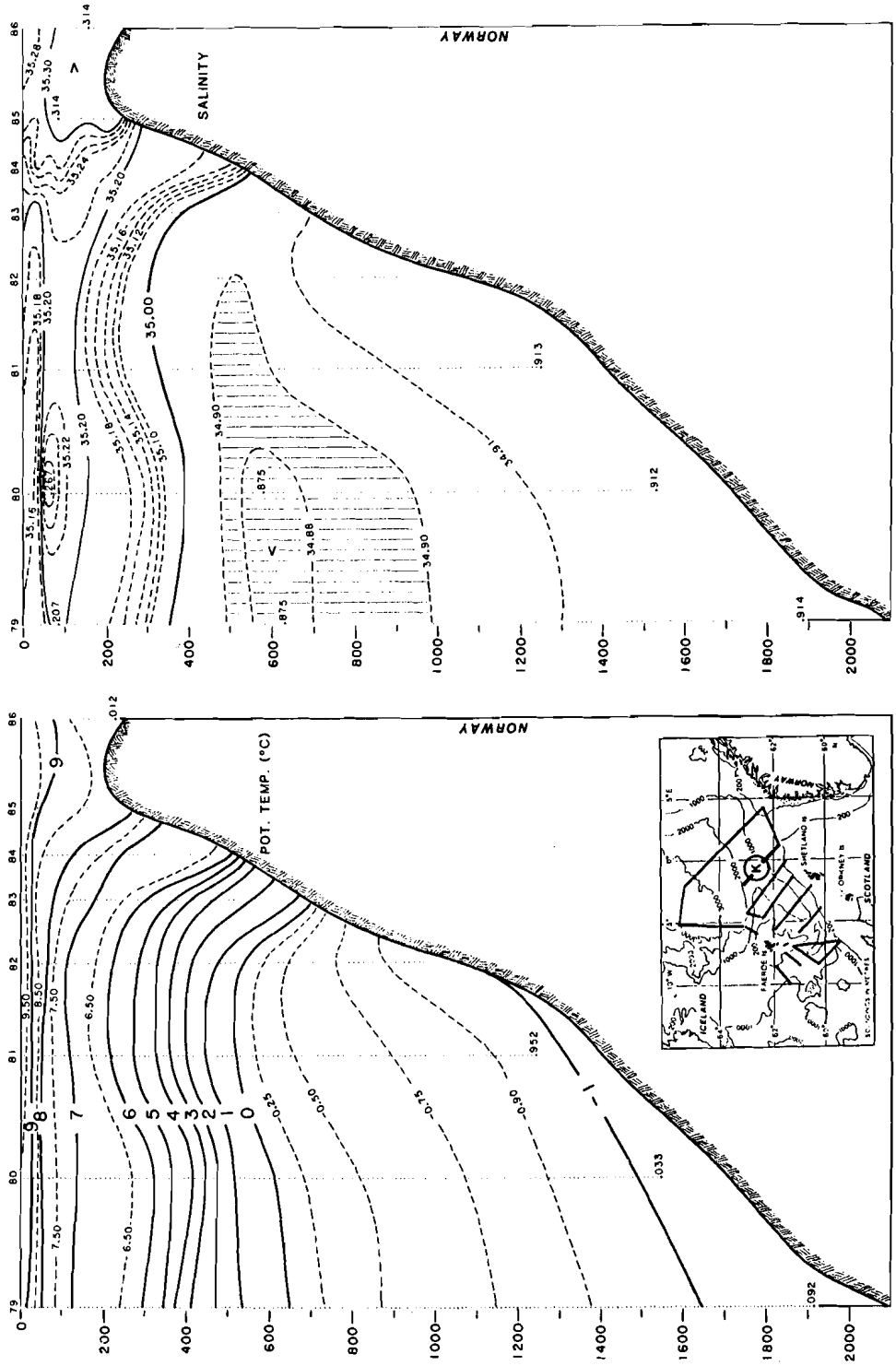
NORWAY
SALINITY
35.00
34.90
34.88
NORWAY
POT. TEMP. (°C)
ICELAND
SCOTLAND
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Fig. A12.

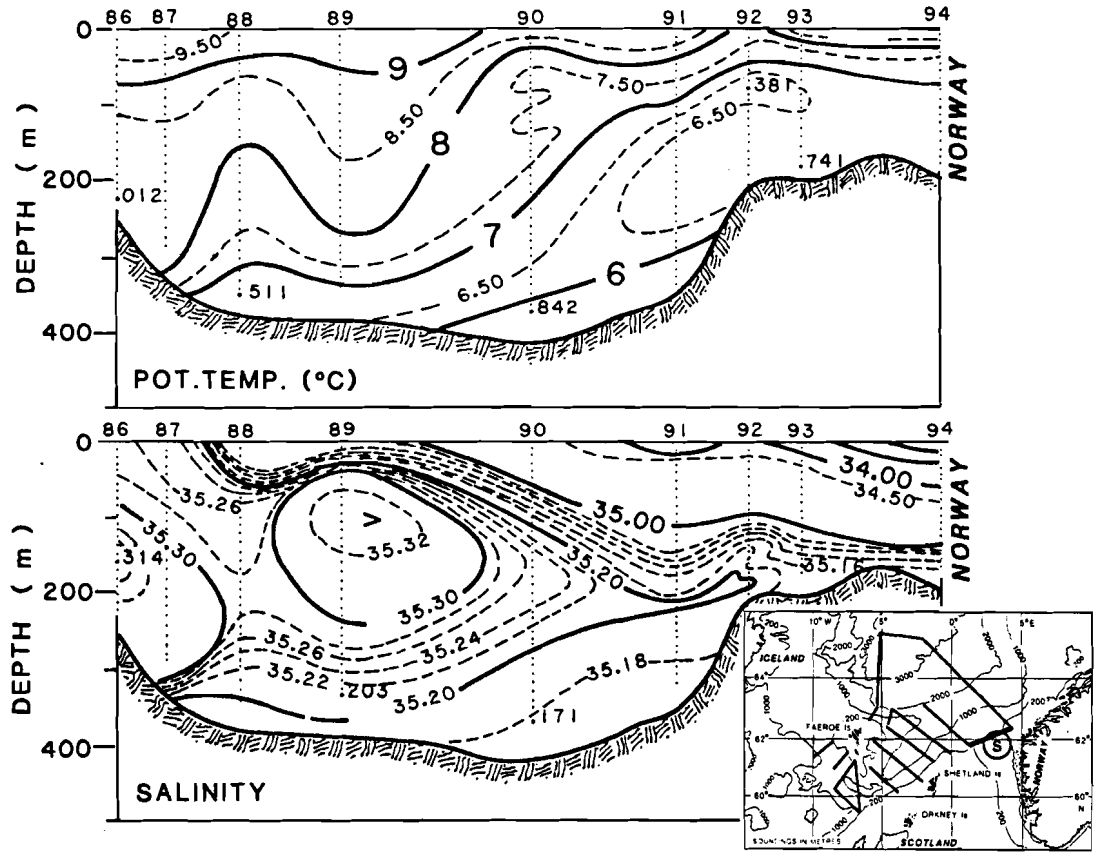
86 87 88 89 90 91 92 93 94
0
200
400
DEPTH (m)
NORWAY
9.50
9
8.50
8
7.50
7
6.50
6
.381
.741
.012
.511
.842
POT.TEMP. (°C)
34.00
34.50
35.00
35.26
35.32
35.30
35.24
35.22
35.20
35.18
.314
.205
.171
SALINITY
ICELAND
FAEROE IS
SHETLAND IS
ORKNEY IS
SCOTLAND
NORWAY

Fig. A13.

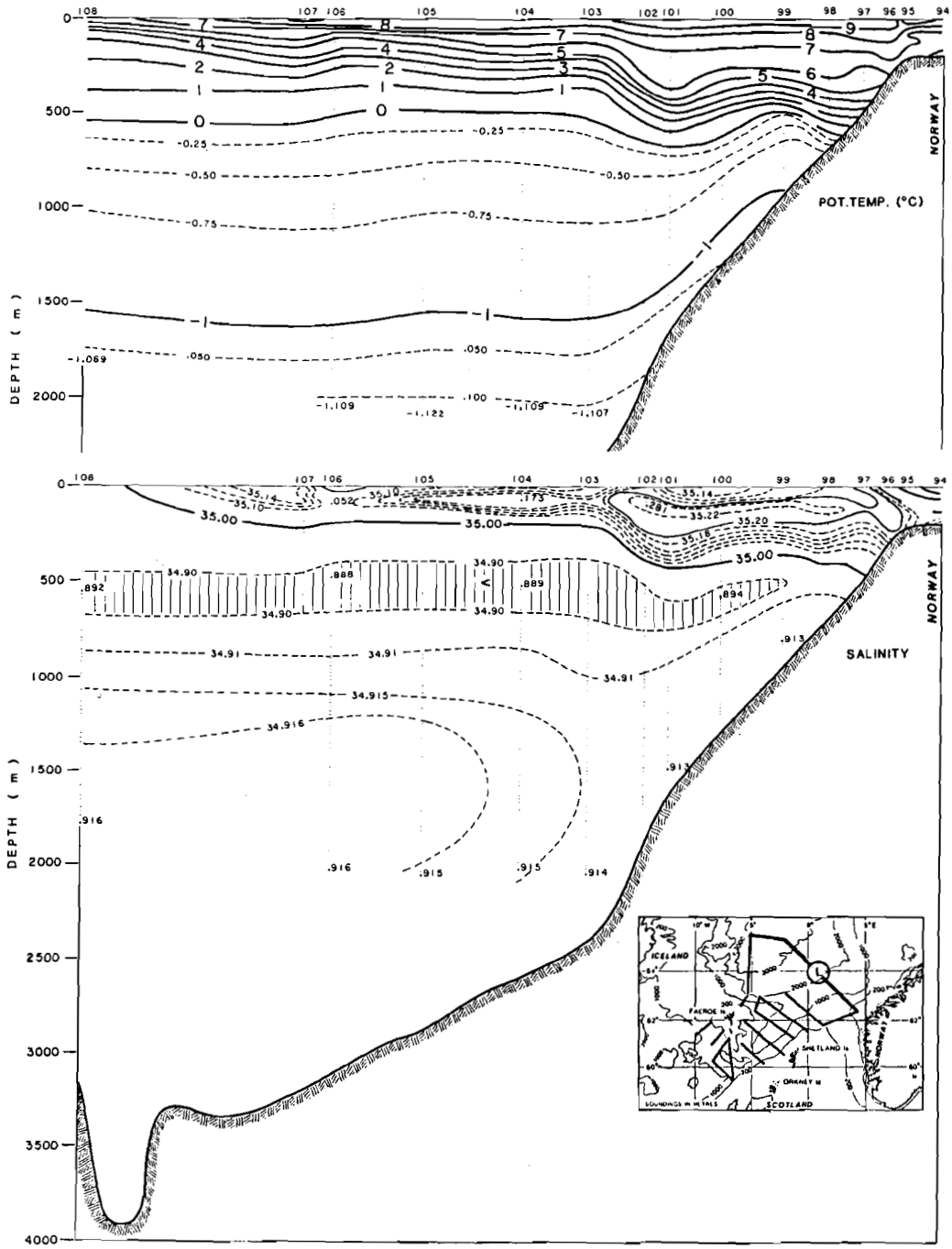
POT.TEMP. (°C)
SALINITY
NORWAY
DEPTH (m)
ICELAND
FAEROE
SHETLAND
ORKNEY
SCOTLAND

Fig. A14.

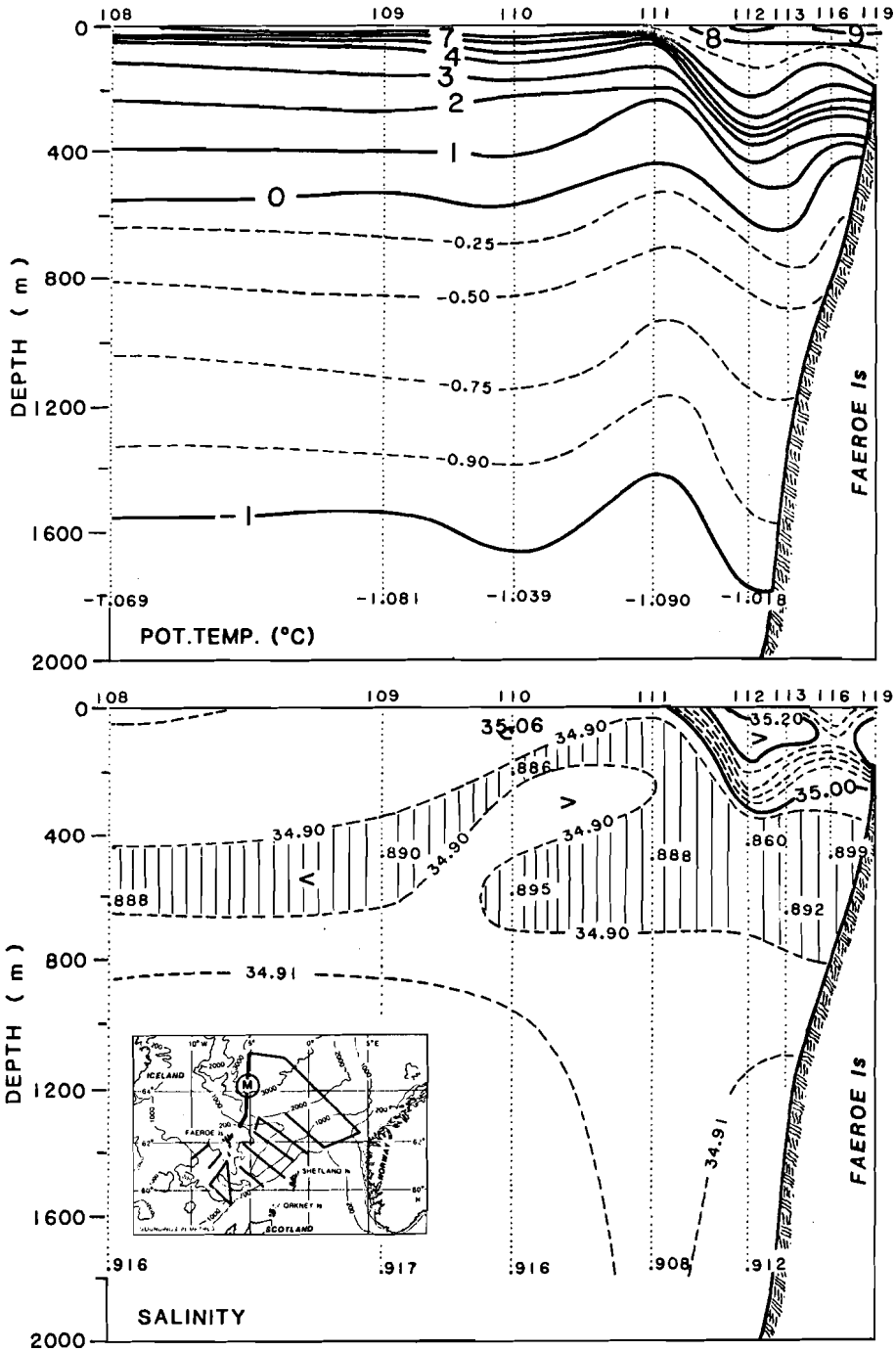
108
109
110
111
112 113 116 119
0
400
800
1200
1600
2000
DEPTH (m)
7
4
3
2
1
0
-0.25
-0.50
-0.75
-0.90
-1
8
9
FAEROE Is
-1.069
-1.081
-1.039
-1.090
-1.018
POT.TEMP. (°C)
35.06
34.90
886
35.20
35.00
890
888
895
860
899
892
34.91
ICELAND
FAEROE Is
SHETLAND Is
ORKNEY Is
SCOTLAND
916
917
916
908
912
SALINITY

Fig. A15.

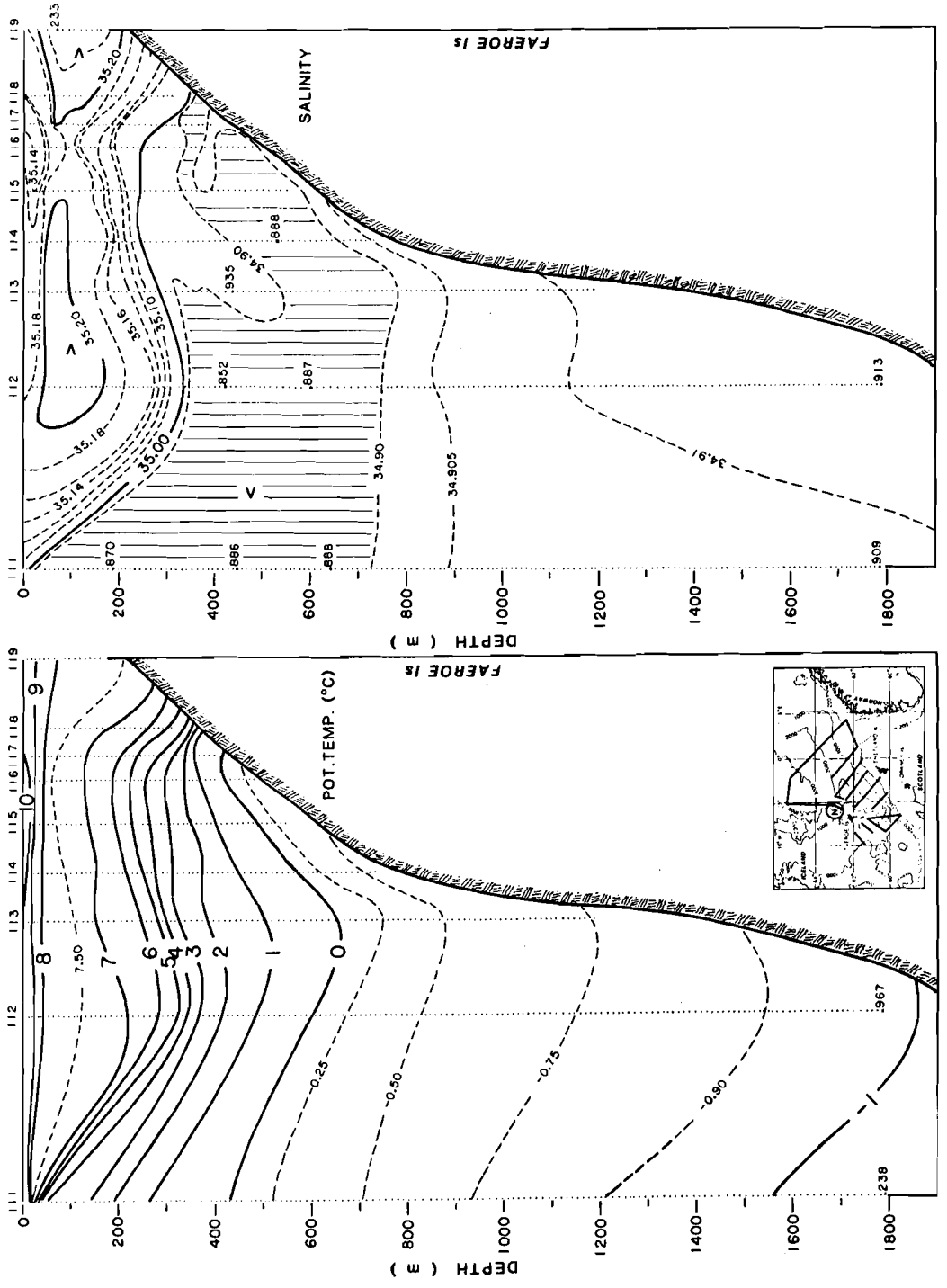

Fig. A16.

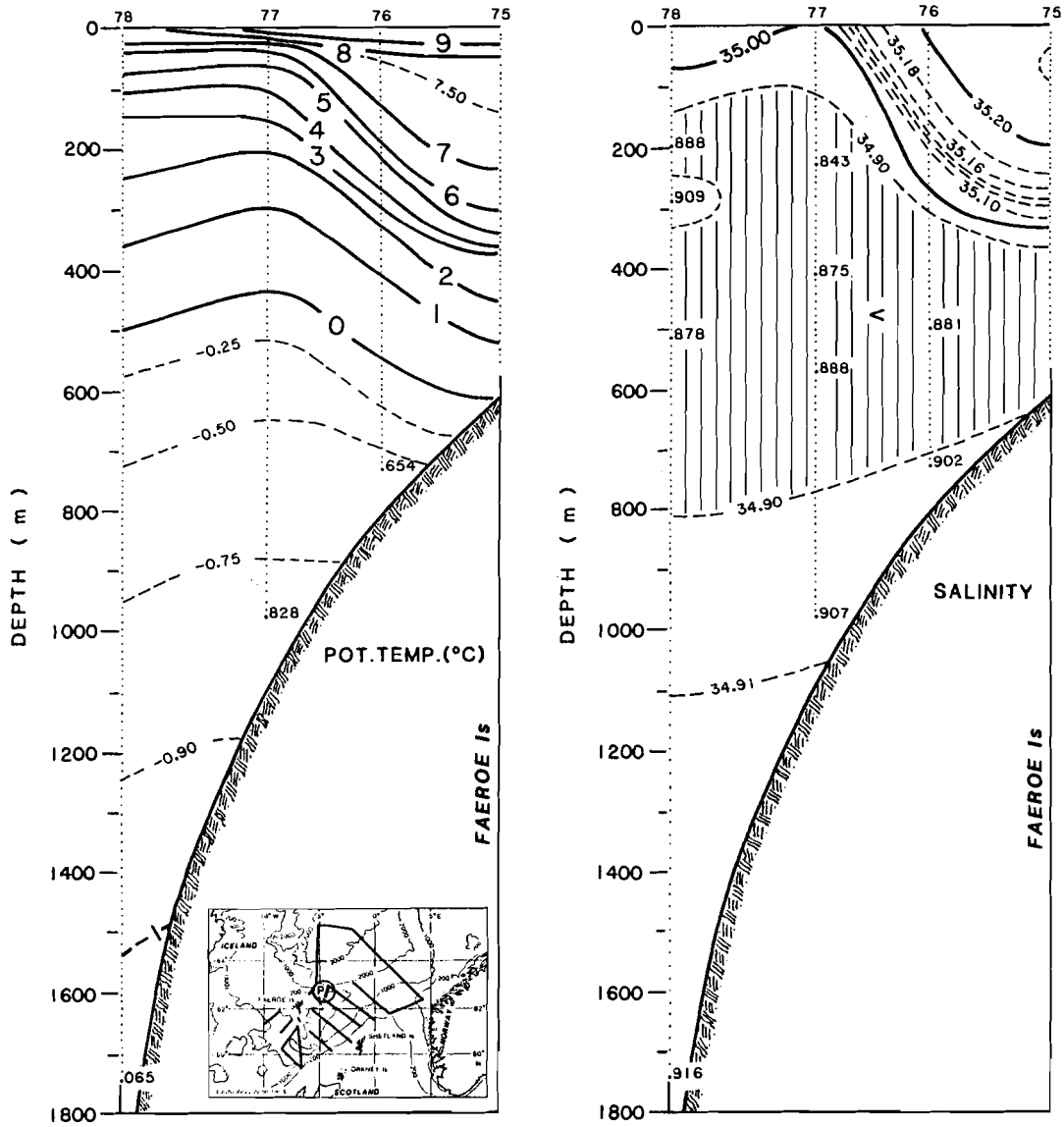
78
77
76
75
0
200
400
600
800
1000
1200
1400
1600
1800
DEPTH (m)
POT.TEMP.(°C)
SALINITY
FAEROE Is
9
8
7
6
5
4
3
2
1
0
7.50
-0.25
-0.50
-0.75
-0.90
.654
.828
.065
35.00
35.18
35.20
35.16
35.10
34.90
34.91
.888
.909
.843
.875
.878
.888
.881
.902
.907
.916
ICELAND
SHETLAND Is
ORKNEY Is
SCOTLAND

Fig. A17.