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Preliminary Assessment of the Physical Oceanography of the Labrador Sea during NORWESTLANT 2 1963

by

N. J. Campbell, J. R. N. Lazier and R. H. Loucks

B E D F O R D I N S T I T U T E O F O C E A N O G R A P H Y

D A R T M O U T H, N. S. - C A N A D A

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PRELIMINARY ASSESSMENT OF THE PHYSICAL OCEANOGRAPHY OF THE LABRADOR SEA DURING NORWESTLANT-2, 1963

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B.I.O. 64-3

also

ICNAF MEETING DOCUMENT XIV-54

April 1964

Introduction

Canada formally agreed to participate in the Norwestlant Surveys in 1962 at which time it was agreed that two ships would be made available for the Norwestlant-2 Survey. For the purpose of Canadian interests the southern sector of survey was expanded to meet other fisheries and oceanographic requirements. These data have been considered as an integral part of the work of CSS "Baffin" and CNAV "Sackville" in the ICNAF areas and have been made available to the participating nations of the Norwestlant Surveys. Concurrent with these surveys Canada and the United States agreed to a joint survey of the Labrador and Baffin coasts during the period these regions were ice covered. The United States Navy provided the USS "Atka" and agreed to occupy ICNAF stations located within the ice limits. Unfortunately the "Atka" was damaged while proceeding through heavy pack ice and only part of her program was achieved. However, the data resulting from her efforts have been made available and are incorporated in this report.

Survey Program

As near as possible the observational program as agreed to by the participants was followed with the exception of changes made to suit weather and ice conditions, Fig. 1. CSS "Baffin" was able to complete its program except for stations located in ice, but CNAV "Sackville" was seriously hampered by persistent heavy seas and winds off Cape Farewell. Two separate attempts were made to occupy the Cape Farewell-Hamilton Inlet section but a shortage of fuel and time thwarted both efforts. In addition, an entire cast of reversing bottles and thermometers was lost when

the wire parted on the first station.

As prearranged, "Baffin" was able to meet and work with the RIV "Dana" for biological studies and "Sackville" with the RIV "Anton Dohrn" at reference station A (Sackville station 9) for intercalibration studies.

Physical Observations

Serial observations of salinity and temperature were made at standard depths with one bottle placed as close to the bottom as possible. In the case of "Sackville" observations the maximum standard depth of observation was 1500 metres. Surface temperatures were measured in a bucket using a thermometer graduated in 0.10°C. Sea surface temperatures were monitored continuously while the ships were steaming.

Samples at depth were obtained with Knudsen reversing water bottles, with the interior parts Teflon coated. At 10 m depth a plastic sampling bottle manufactured by the National Institute of Oceanography was used in order to obtain a larger volume of water.

Aboard "Baffin" temperatures at depth were measured with deep sea reversing thermometers of German (Richter and Wiese) or English (Negretti and Zambra) manufacture. Protected thermometers were placed singly at depths down to 2000 m and paired at greater depths. An unprotected thermometer was used at each depth from 200 m to the bottom. On "Sackville" protected reversing thermometers were placed singly in the Knudsen bottles with unprotected thermometers at 100, 500 and at each standard depth

below 800 metres. On both ships temperatures were read by two individuals and corrections applied while steaming between stations, but rechecked once again in the laboratory.

Salinity Analyses

The salinity samples gathered by "Baffin" were determined with an inductive salinometer, Model 601 MKlll Serial No. 8, manufactured by Auto-Lab Industries, Sydney, Australia. These analyses were completed within one or two days of collection.

The "Sackville" salinity samples were determined on an NIO Conductivity Bridge No. 14 at the Bedford Institute of Oceanography. Corrections recommended by R. A. Cox and A. R. Folkard to the Auto-Lab and NIO determinations have been made to these observations.

Figures

The temperature and salinity data collected for ICNAF during the NORWESTLANT II survey by CSS "Baffin", USS "Atka", and CNAV "Sackville" have been plotted in vertical and horizontal sections. The sections used for the vertical plots (Fig. 16-55) are labelled on the track chart, Fig. 1. Two plots have been prepared for each cross section - surface to 100 metres and surface to the bottom. Horizontal distributions of temperature and salinity have been prepared for 0, 50, 100 and 200 metres, Fig. 2-9. The dynamic topographies of the surface relative to 1000, 500, 100 decibars are shown in Fig. 10, 11 and 12.

An attempt has been made to describe the broad features of the water masses and currents in the survey area. Remarks on the general circulation and division of water masses precede a

more detailed account of the main features.

General Circulation

The surface circulation in the Labrador Sea was summarized by Smith et al (1937) as follows:

> "The East Greenland Current and a western branch of the Irminger Current on rounding Cape Farewell are renamed the West Greenland Current which flows north-westwards. The West Greenland Current branches, part crossing Davis Strait Ridge into Baffin Bay and a part flowing westward, south of the Davis Strait Ridge and joining Arctic water flowing southward out of Baffin Bay to produce the Labrador Current."

This summary applies equally to the data and results presented in this report.

The dynamic topographies (Fig. 10-12) show the general cyclonic circulation and the intense boundary currents of surface waters in the Labrador Sea. The strong current on the east side of the sea is the West Greenland Current, while the Labrador Current is largely confined to the coastal regions of Baffin Island and Labrador. A branch of the West Greenland current swings westward as a slow drift joining the Labrador Current south of Davis Strait. In the southern part of the survey area the continuation of the Labrador Current is apparent (Fig. 12) while to seaward are found anticyclonic eddies. In the southeast corner of the survey area a strong northeast flow is evident, Fig. 10. The horizontal plots of temperature and salinity (Fig. 2-9) indicate that the northeast flow is transporting relatively warm high salinity water. It is probably the edge of the Atlantic Current (Smith et al 1937). The anti-cyclonic eddies to the north of the Atlantic Current transport the warm saline water northward in

the surface layers. The isotherms and isohalines on the horizontal plots (Fig. 2-9) parallel the dynamic contours closely.

The circulation below the surface layers in the Labrador Sea is generally cyclonic with velocities increasing above and below 1000 metres. Figure 13 represents the relative currents in section XXVI to "Baffin" station 2 with 1000 decibars taken as the level of no motion. The section shows the West Greenland Current in the upper right, with a strong northward flow at depth directly below the West Greenland Current. The Labrador Current and the southward flow of the deep water are not completely represented in the Figure.

Water Masses

The temperature and salinity characteristics of the water in the Labrador Sea have been divided into six groups labelled A to F. These groups, or water masses, are listed in the Table, under defining characteristics, and associated physical features. For example, water mass A, characterized by temperature and salinity maxima, is associated with the West Greenland Current. The temperature and salinity differences between water masses A to D are illustrated by the average T-S curve for "Baffin" Stations 13, 14 & 15 (Fig. 14). This T-S curve, although not typical of the whole Labrador Sea, represents a column of water in which the four water masses A to D appear in their "purest" form. Figure 15 shows the regions occupied by each of the water masses in section XXVI. Also shown are the average vertical temperature and salinity profiles for "Baffin" stations, 13, 14 and 15 which emphasize the distinguishing

TABLE

Water Mass	Characteristics temperature	salinity	Associated Feature
A - Irminger Atlantic	4°C.	34.92°/oo	West Greenland current, temp. & salinity max.
B - Intermediate	3.4	34.87	500 - 1500 metres in central Labrador Sea, salinity min.
C - Deep	2 - 3	34.92	2000 - 3000 metres, salinity maximum
D - Bottom	2	34.87	Below 3000 metres, temp. & salinity minimum.
E	2	<34.0	West Greenland Current, low temperature and salinity
F	2	<34.0	Labrador current, low temperature and salinity

features of each water mass. The surface water masses E and F are omitted from these Figures because the shelf areas are small in cross section. A seventh distinct water mass of high temperature, 10°C, and salinity, 35°/oo was observed in the upper 500 metres at "Sackville", station 1, (Fig. 2-9). It has not been considered as part of this summary owing to its local influence in the southern region.

West Greenland Current

The West Greenland Current which flows north from Cape Farewell to Davis Strait transports two distinct water masses. Adjacent to the Greenland coast and flooding the shelf area is

a cold low salinity water (water mass E). The offshore component is the Irminger-Atlantic water (water mass A) characterized by high temperature and high salinity. Near Cape Farewell the Irminger-Atlantic water is relatively small in cross section, but as it flows north it widens and branches to the west. Throughout its path the Irminger-Atlantic water lies below the surface. Thus the main influence of the Irminger-Atlantic water is felt in the northern central part of the Labrador Sea below the surface layer. Very little influence of this warm saline water is felt at the surface along the Greenland coast. The cold low salinity water which flows north with the West Greenland Current adjacent to the coast also tends to widen and join the general slow cyclonic circulation. This water overlies the warm Irminger water as it moves west, and thereby influences the surface waters of the northern central Labrador Sea in addition to the coastal regions of Greenland.

The vertical cross sections of temperature and salinity, section XXVI, Fig. 34 and 35, show the two water masses contained in the West Greenland Current at station 8, 9 and 10, above 800 metres. The core of the Irminger-Atlantic water is located at station 8 at a depth of about 250 metres. Toward the coast of Greenland at station 9 and 10 the cold low salinity water is encountered. The cross sections of temperature and salinity of the next section to the north, section XXVII, Fig. 38 and 39, show much the same situation. The Irminger-Atlantic water has spread out and moved farther offshore. The core of this water is at station 15 between 250 and 300 metres. The cold low-

salinity water occupies the coastal region but also spreads to the west at the surface and completely covers the warm saline Irminger-Atlantic water. In section XXVIII, Fig. 41 and 43, the Irminger-Atlantic water is seen to fill the entire cross section between the depths of 300 and 900 metres. This water is best defined by the 4°C isotherm on the temperature plot. The cold low-salinity water associated with the West Greenland Current still floods the coastal regions of Greenland but now shows to considerable depth on top of the Irminger water. In section XXIX, Fig. 44-47, the Irminger-Atlantic water can still be defined by the 4°C isotherm which lies between 300 and 600 metres. The depth of the basin at this latitude is decreasing toward Davis Strait and it is thought that most of the warm Irminger water has been deflected west and south before it reaches section XXIX. A small part of this water, however, seems to pass through Davis Strait into Baffin Bay, and can be picked up as relatively warm saline water in sections XXX and XXXI below 150 metres (Fig. 48-55).

The Labrador Current

The Labrador Current, which is confined to the upper waters along the Baffin Island and Labrador Coast, transports cold, low-salinity water south to the Grand Banks. The waters in the current originate in Baffin Bay, Hudson Strait and the surface waters of the Northern Labrador Sea. In sections XXI to XXIII (Fig. 16-27) and XXVI to XXXI (Fig. 32-55) the Labrador Current is shown by a pocket of cold low-salinity water in the upper waters adjacent to the coast. In the core of the current the water temperatures are generally below 0°C indicating Arctic origin.

The similarity of the offshore components of the West Greenland and Labrador Currents is evident in the horizontal distributions of temperature and salinity (Fig. 2-9). This similarity is consistent with the westward drift indicated by the dynamic topographies (Fig. 10-12).

Intermediate Water

The Intermediate Water (water mass B) has been defined as that water lying roughly between 500 and 1500 metres in the central regions of the Labrador Sea. In the northern parts of the Labrador Basin this water has temperature and salinity indicative of diluted and cooled Irminger-Atlantic water. This water mass is seen in sections XXI to XXIV (Fig. 16-31) and XXVI to XXVII (Fig. 32-37) as fairly homogeneous water of temperature 3.3 - 3.8°C and salinity 34.87 - 34.91°/oo between 500 and 1500 metres. The water at intermediate depths north of Section XXVII is still referred to as Irminger-Atlantic water. The Intermediate Water in the Labrador Sea appears to move slower than the waters either above or below. The relatively homogeneous water found at "Baffin" station 4 (Fig. 34 and 35) between 300 and 1500 metres is colder (3.32 vs 3.4 to 3.6°C) than the rest of the Intermediate Water, but has roughly the same salinity. This water is labelled water mass B in Fig 14 and 15 and may be due to convective cooling in winter of the diluted Irminger-Atlantic water. This cold component of the Intermediate Water is found in small amounts in sections XXVI, XXVII, and XXIII lying between the deep water and the warm component of the Intermediate Water. In the southern part of the survey area, the general movement of the intermediate

water is complicated by the anti-cyclonic eddies.

Deep Water

The deep water lies roughly between 2000 and 3000 metres and is characterized by a salinity maximum relative to the intermediate water above and the bottom water below (Fig. 35 and 39). The salinity of the deep water is near uniform but the temperature continues to decrease with depth, (Fig. 34 and 38). The origin of the water is not apparent from the data.

Bottom Water

The bottom water, characterized by low temperature and salinity relative to the deep water is confined to depths greater than 3000 metres (Fig. 34 and 35). Work done by Worthington (reported by Fuglister 1962) seems to indicate that this water has overflowed the Denmark Strait ridge and followed the depth contours around the southern tip of Greenland into the Labrador Sea.

Acknowledgement

The authors wish to express their appreciation to the officers and men of the USS "Atka", CSS "Baffin" and CNAV "Sackville", and the special assistance provided by the personnel participating in the survey and reduction of data. Special thanks are extended to A. B. Grant and M. E. MacLean who plotted all the data and organized its preparation.

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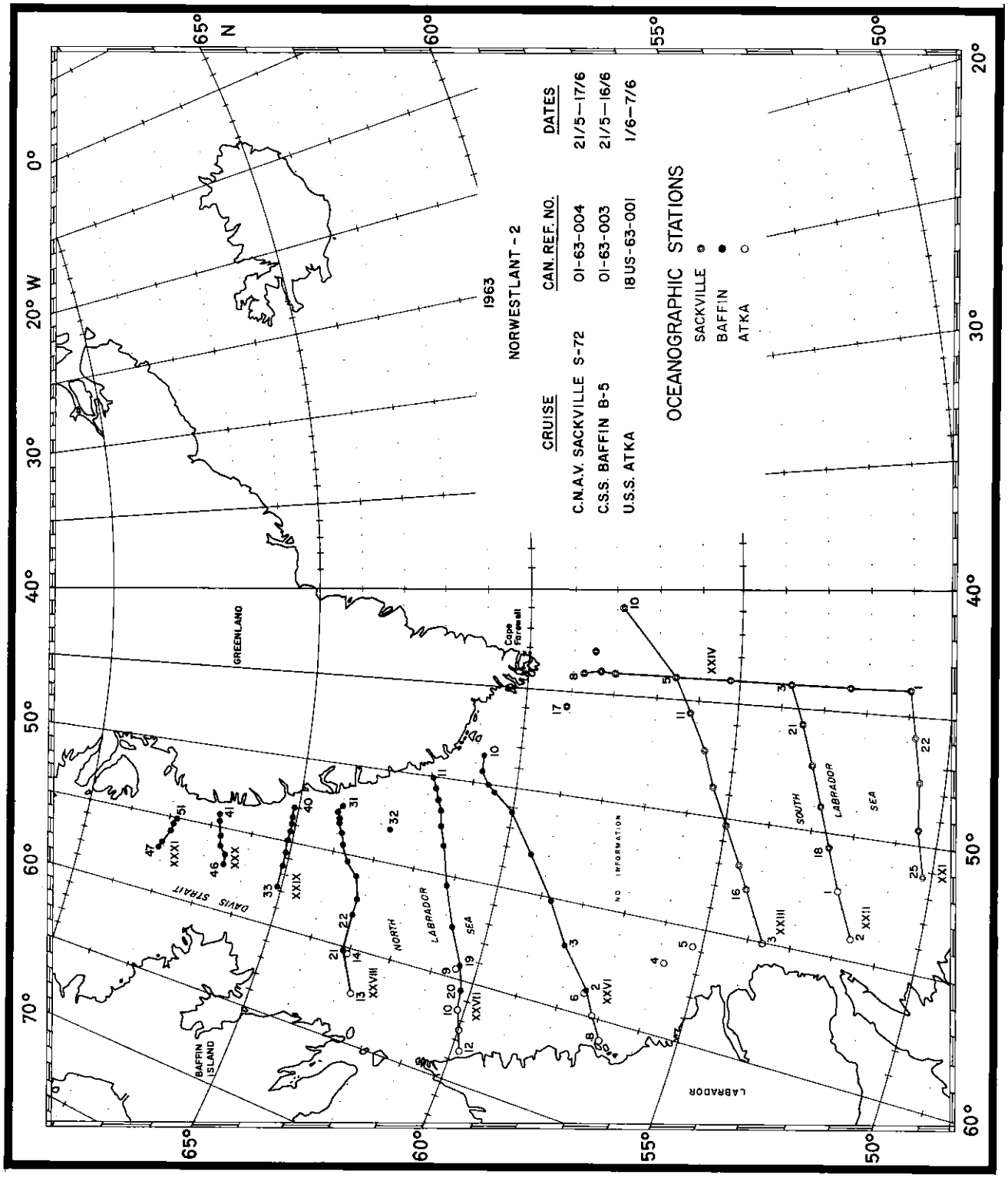
Fuglister, F.C. 1963

Department of Physical Oceanography, Annual Report 1962, Woods Hole Oceanographic Institution, Woods Hole, Mass., pp. 37-38.

APPENDIX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OCEANOGRAPHIC STATIONS
SACKVILLE
BAFFIN
ATKA
CRUISE
CAN. REF. NO.
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01-63-004
21/5—17/6
C.S.S. BAFFIN B-5
01-63-003
21/5—16/6
U.S.S. ATKA
IBUS-63-001
1/6—7/6
GREENLAND
BAFFIN ISLAND
LABRADOR
DAVIS STRAIT
NORTH LABRADOR SEA
SOUTH LABRADOR SEA
NO INFORMATION
Cape Farewell
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55°
50°
70°
60°
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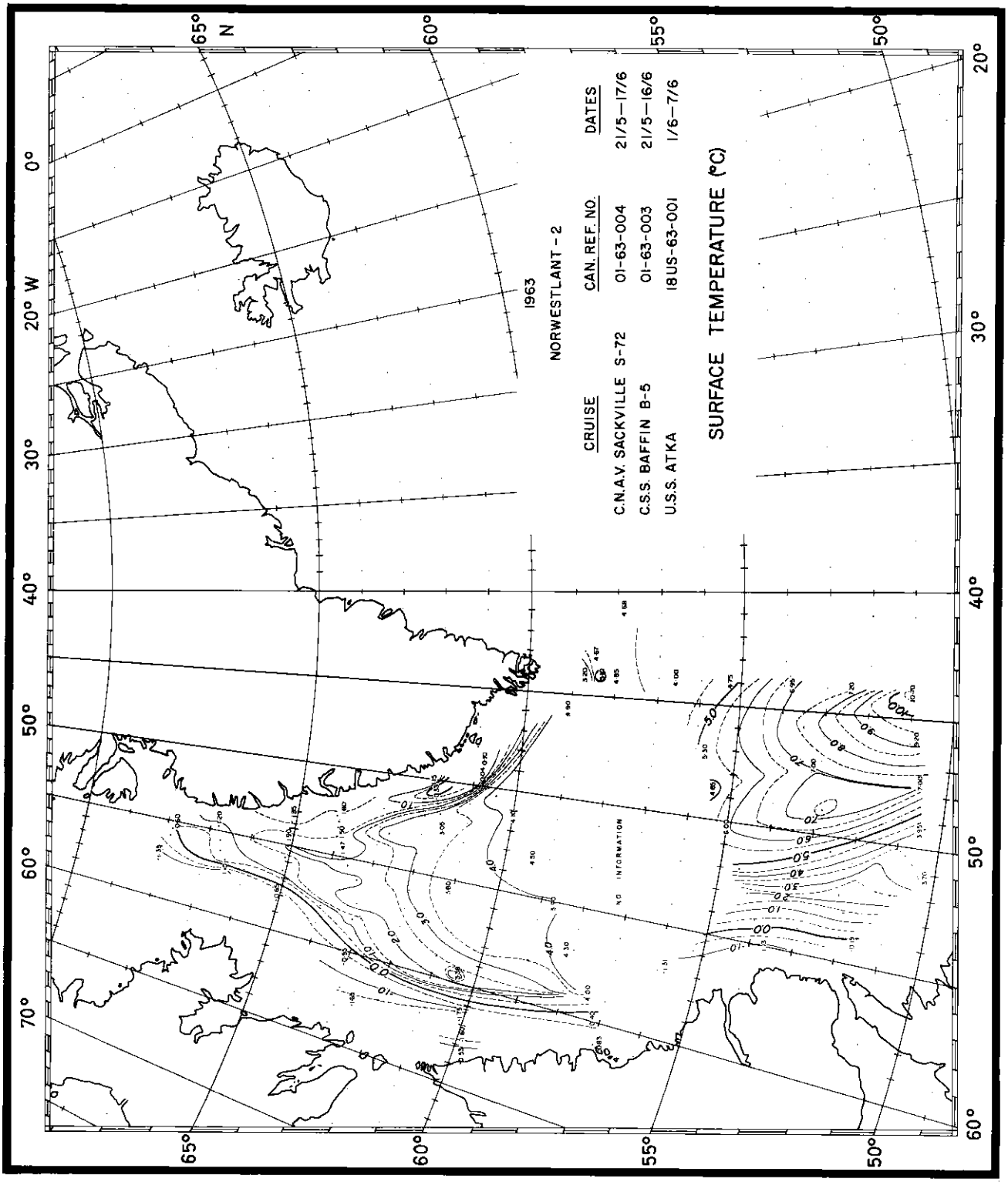
40°
30°
20° W
0°
20°

Figure 1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CRUISE
CAN. REF. NO.
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21/5—17/6
C.S.S. BAFFIN B-5
01-63-003
21/5—16/6
U.S.S. ATKA
18US-63-001
1/6—7/6
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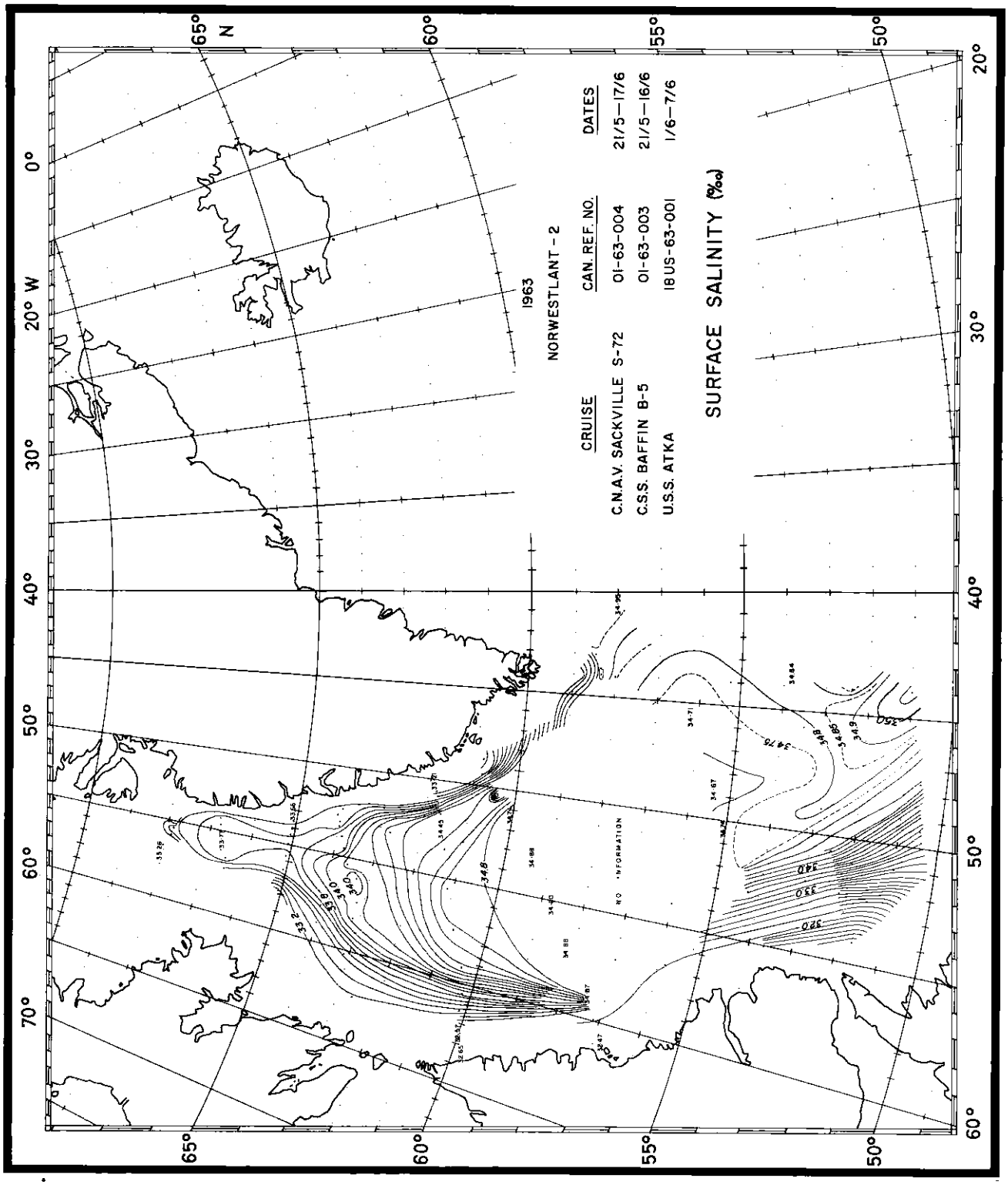
0°

Figure 2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01-63-003
21/5—16/6
U.S.S. ATKA
18US-63-001
1/6—7/6
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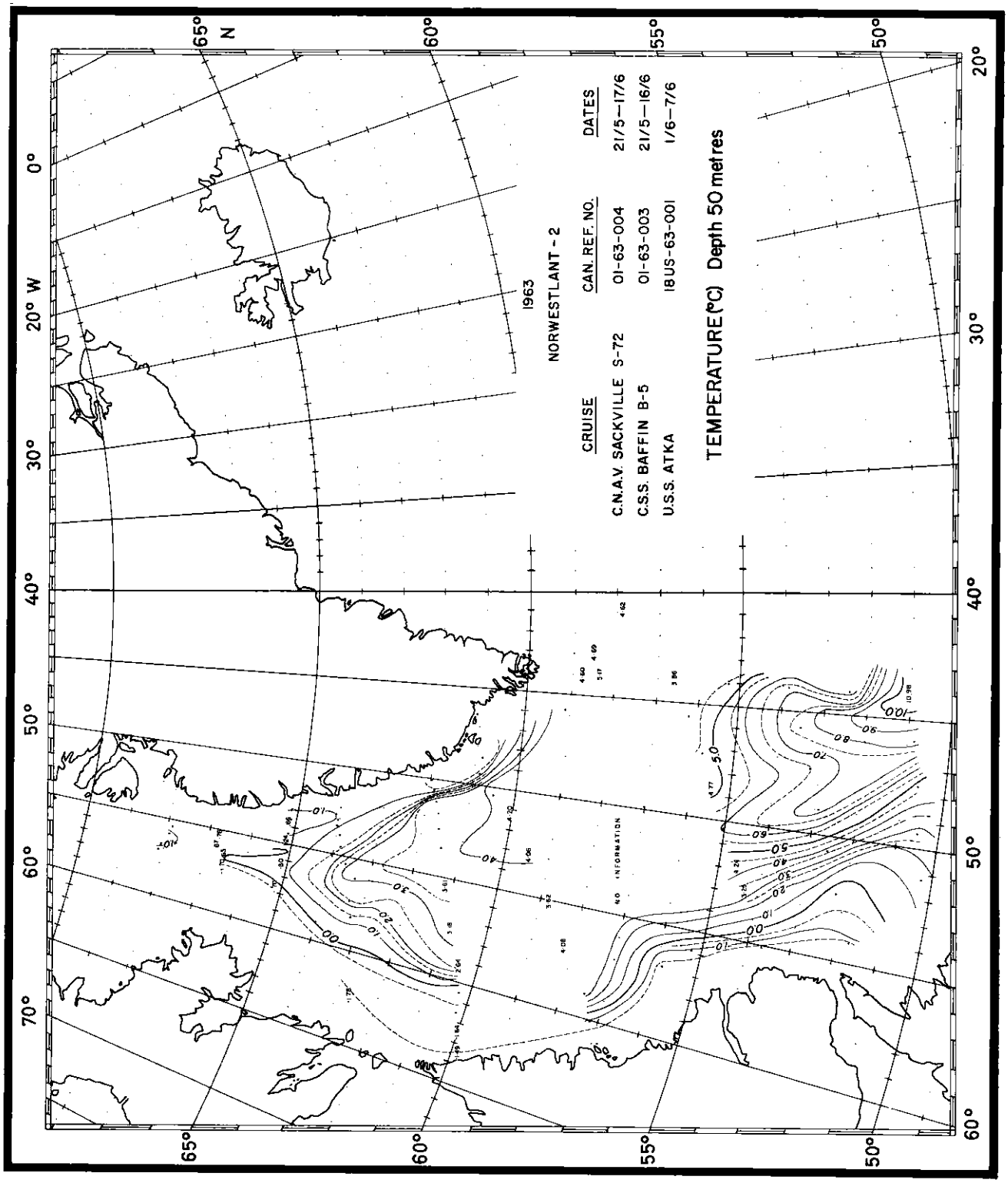
50°
60°
70°
65°
60°
55°
50°

Figure 3


TEMPERATURE(°C) Depth 50 metres
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21/5—17/6
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21/5—16/6
U.S.S. ATKA
18US-63-001
1/6—7/6
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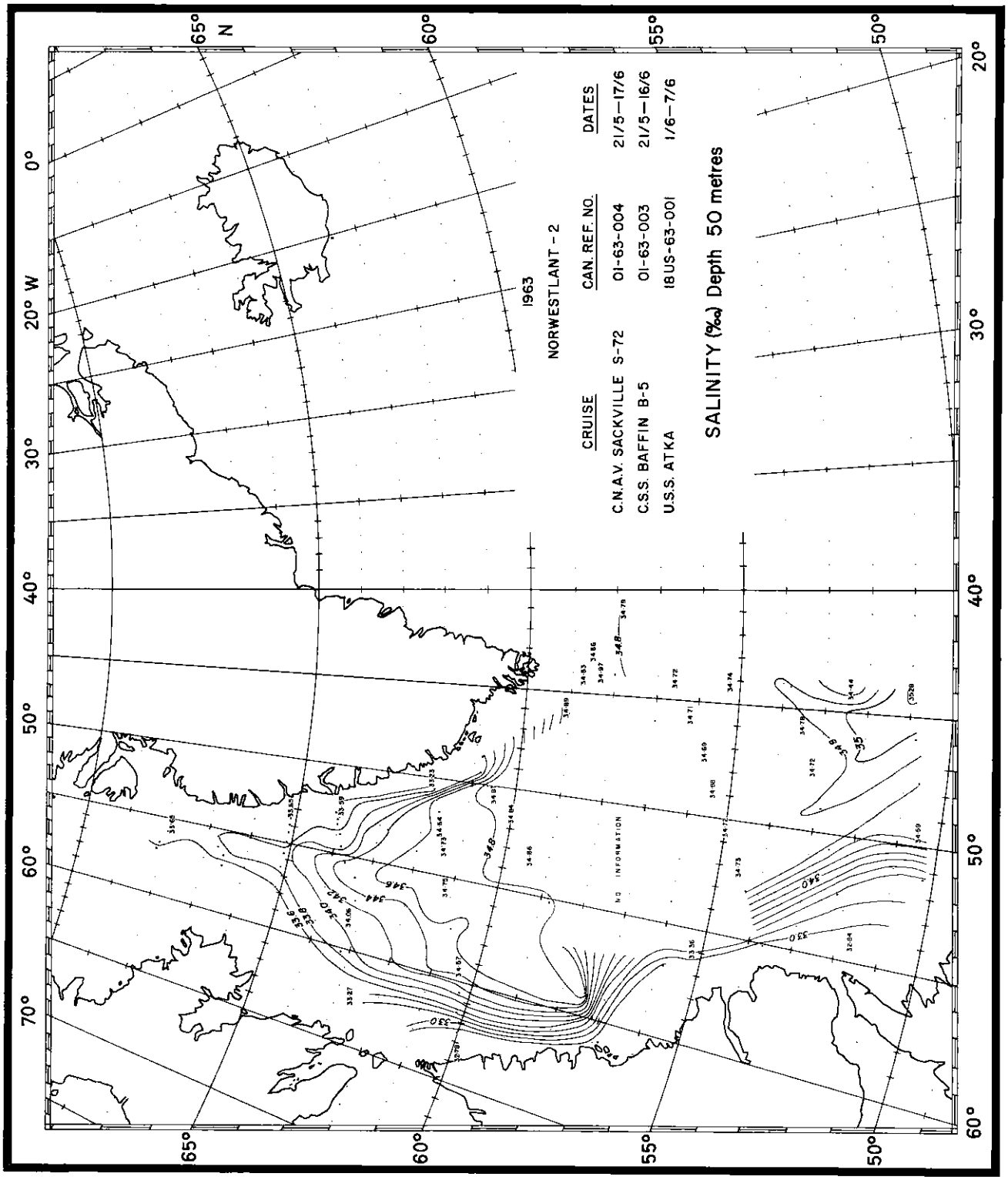
20°
0°
20° W
30°
40°
50°
60°
70°

Figure 4


SALINITY (‰) Depth 50 metres
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C.S.S. BAFFIN B-5
01-63-003
21/5—16/6
U.S.S. ATKA
18US-63-001
1/6—7/6
NO INFORMATION
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50°
60°

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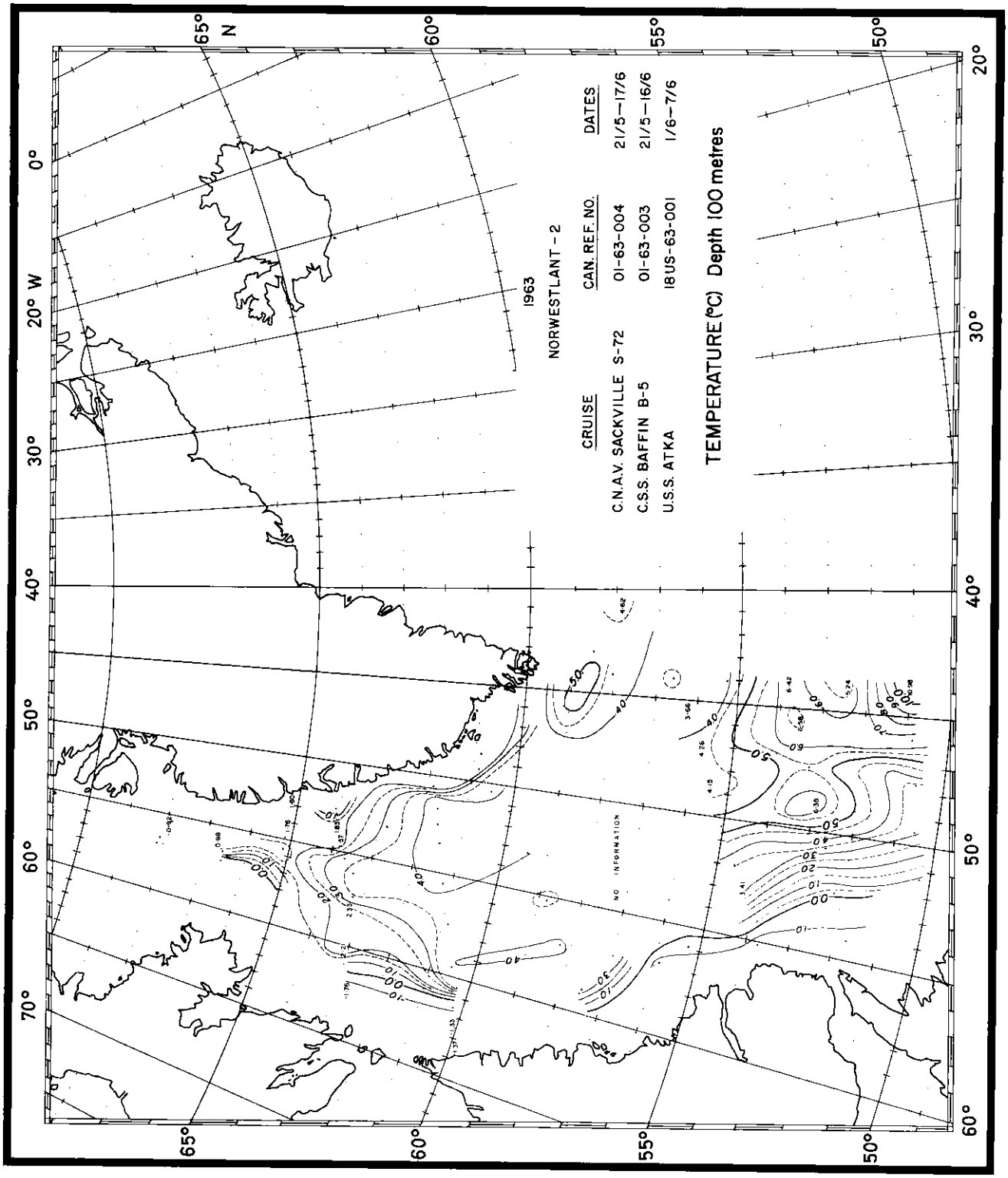
TEMPERATURE (°C) Depth 100 metres
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21/5—17/6
C.S.S. BAFFIN B-5
01-63-003
21/5—16/6
U.S.S. ATKA
18US-63-001
1/6—7/6
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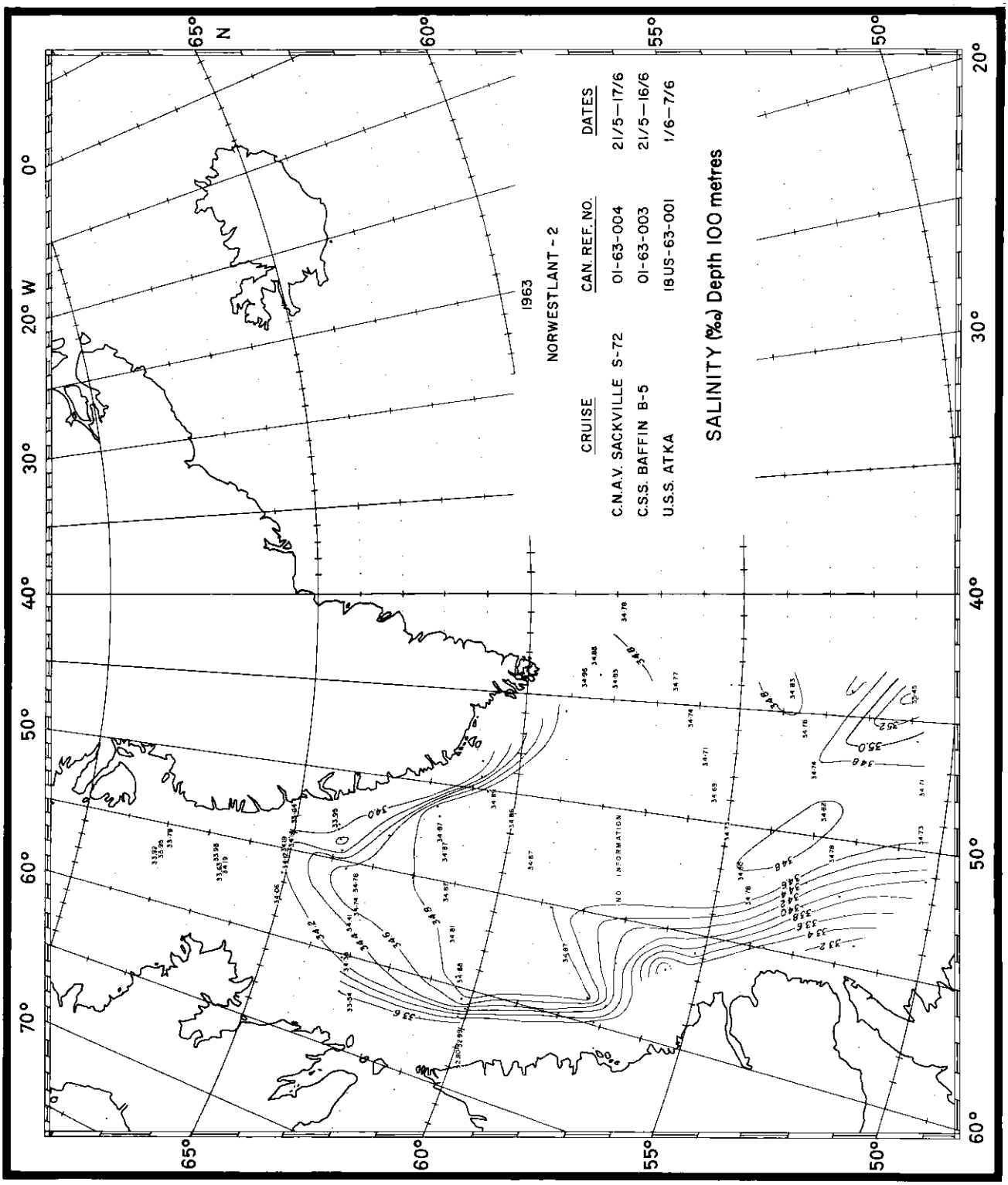
Figure 6


SALINITY (‰) Depth 100 metres
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21/5—16/6
U.S.S. ATKA
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1/6—7/6
NO INFORMATION
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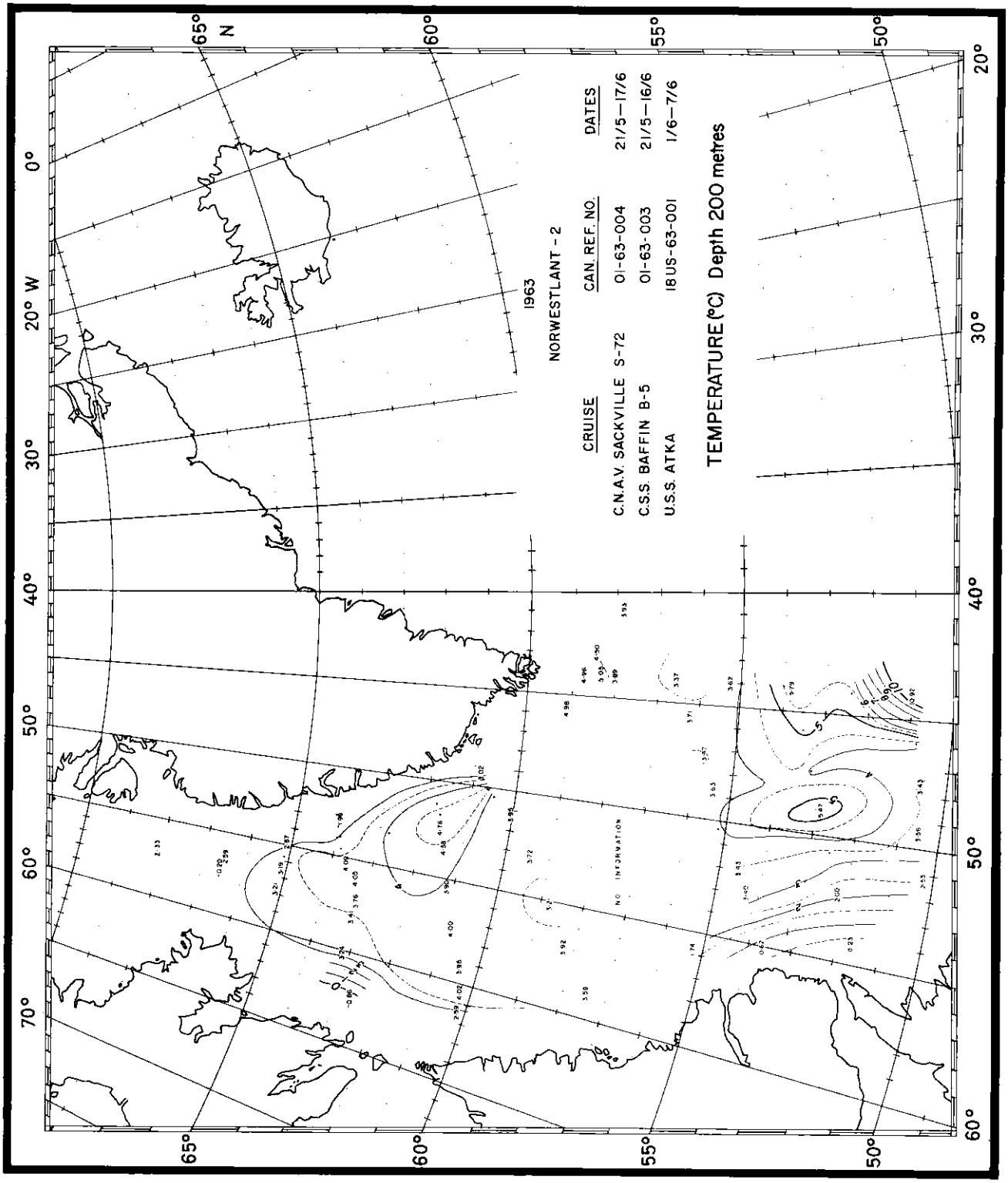
Figure 7


TEMPERATURE (°C) Depth 200 metres
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U.S.S. ATKA
18 US-63-001
1/6—7/6
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50°
60°
70°

Figure 8

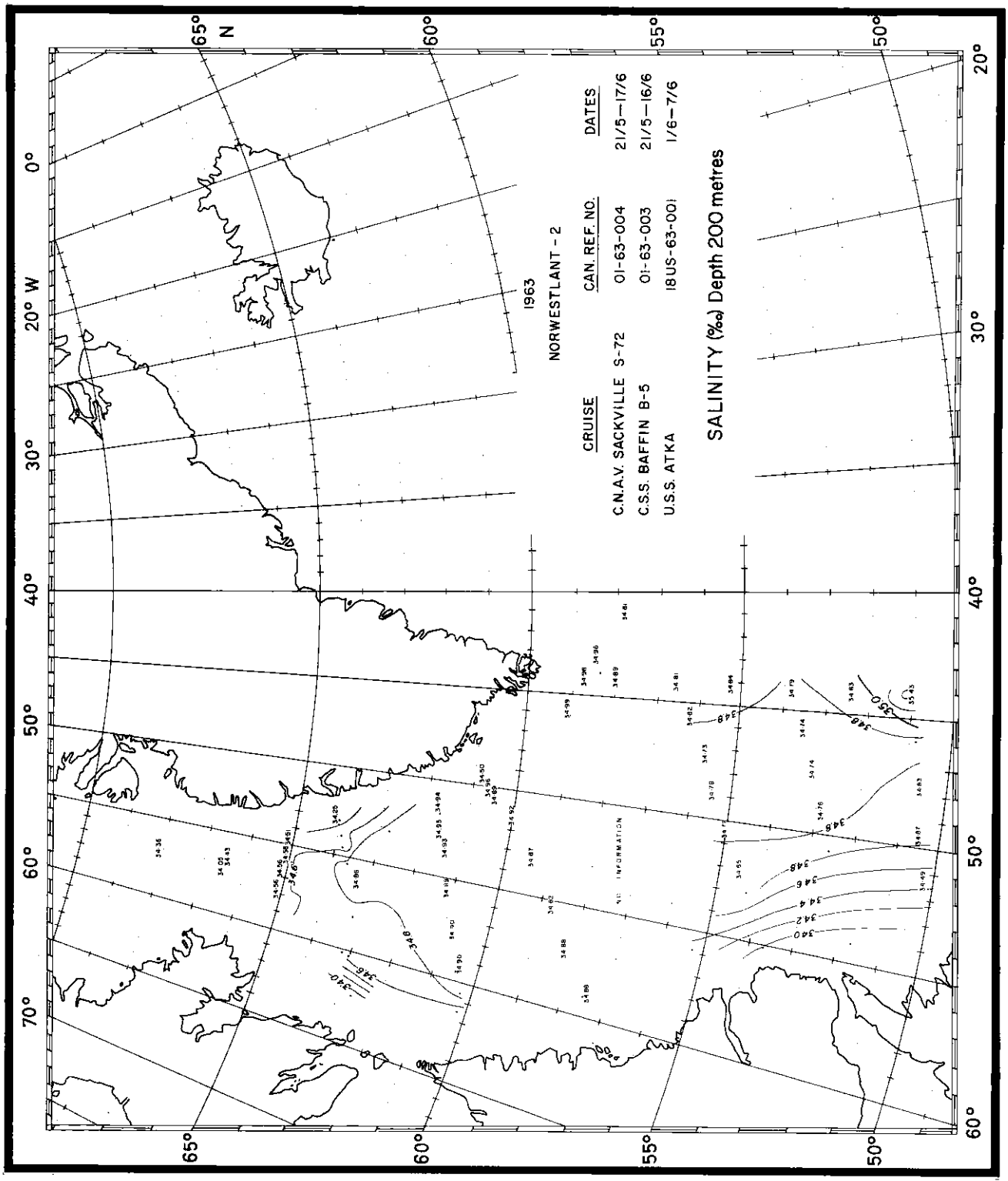
SALINITY (‰) Depth 200 metres
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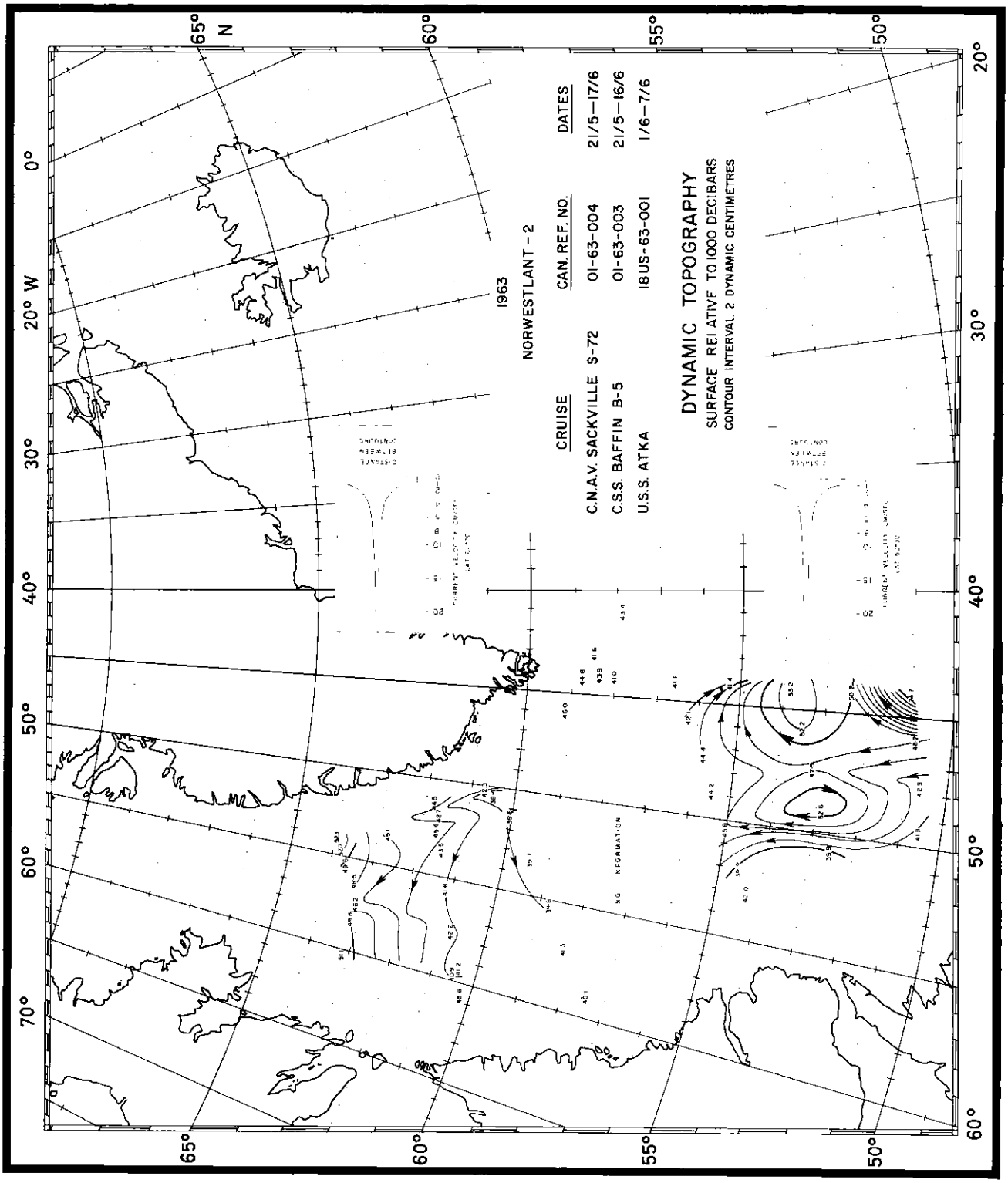
Figure 9


DYNAMIC TOPOGRAPHY
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18US-63-001
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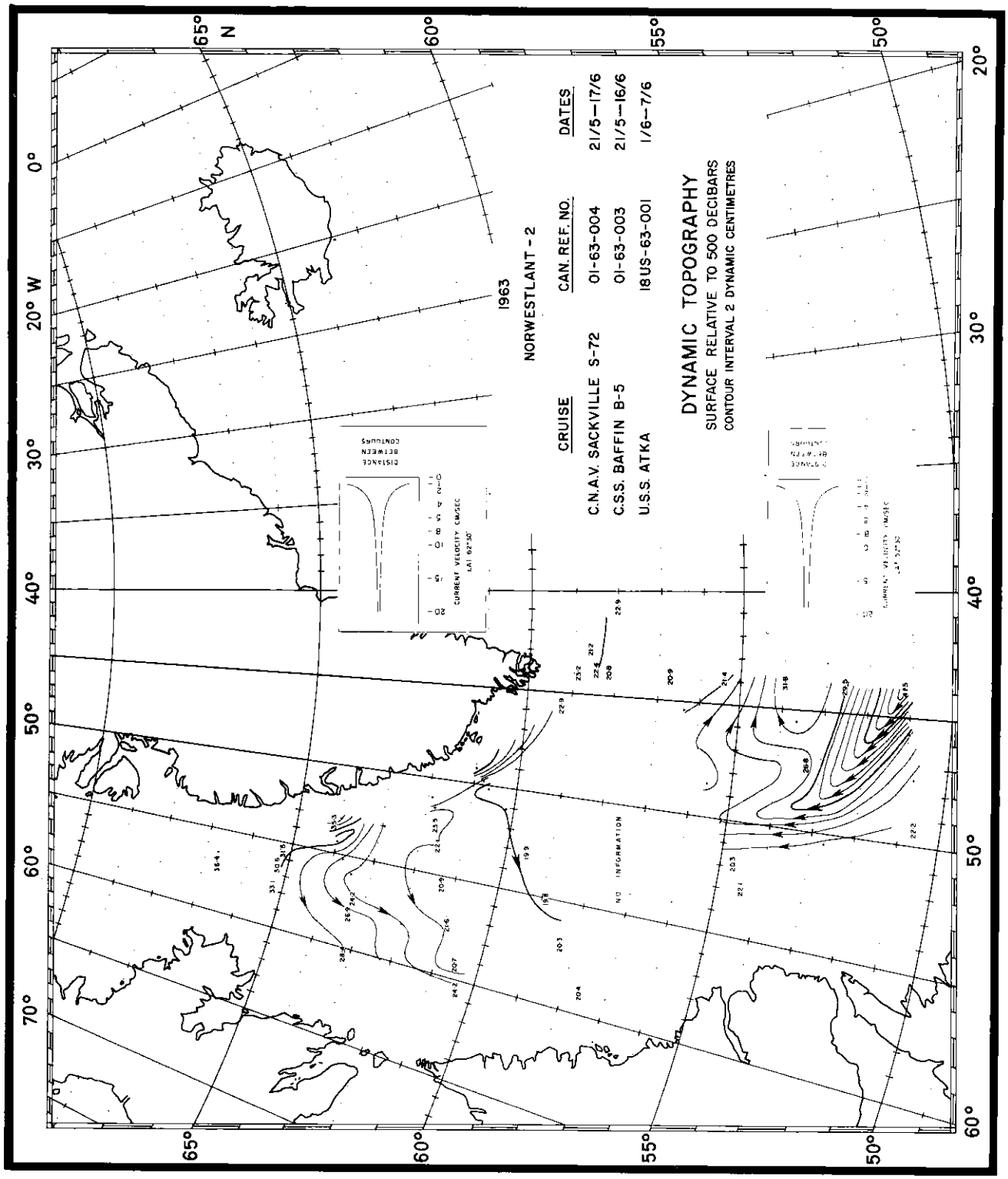
Figure 10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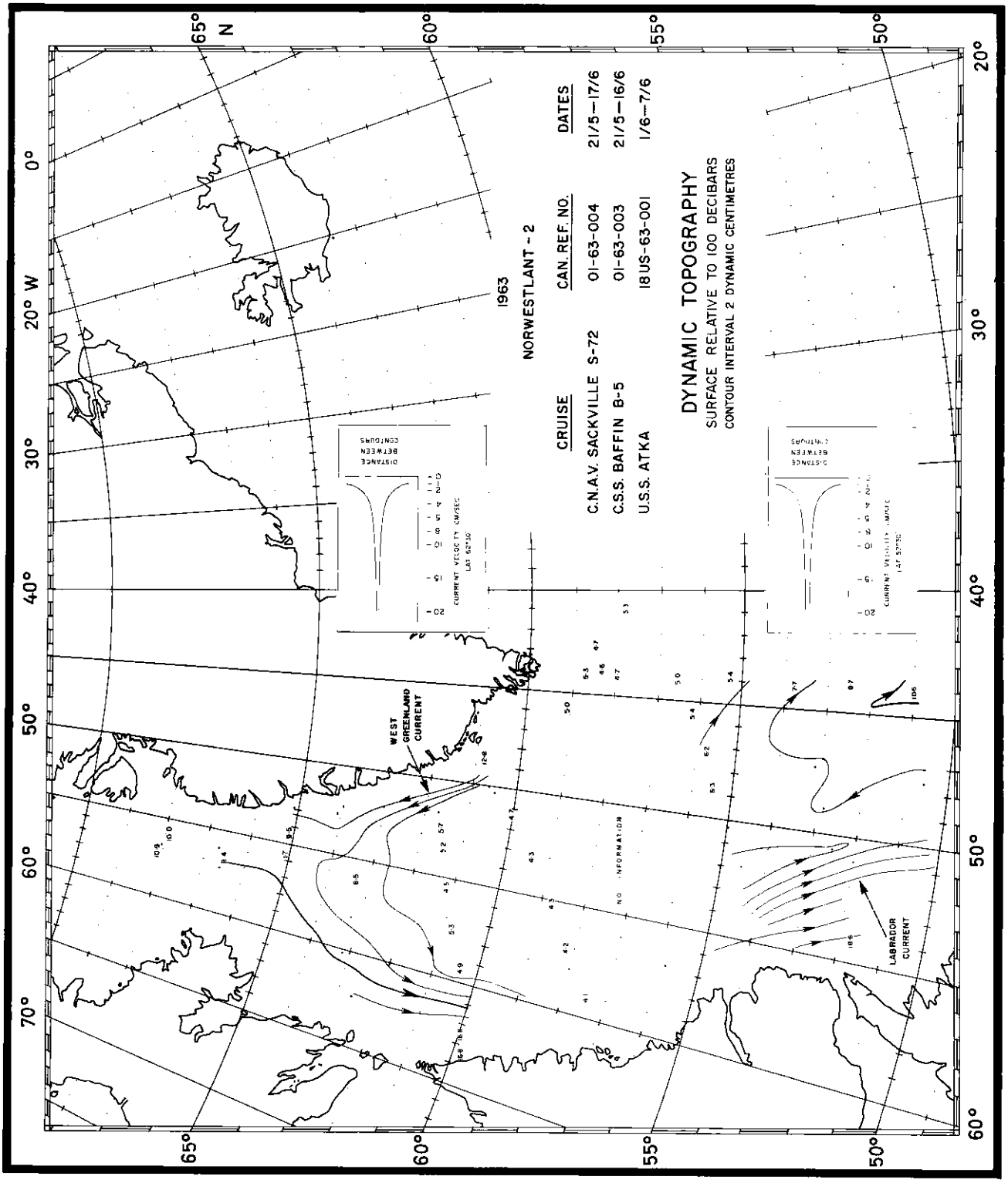
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CONTOUR INTERVAL 2 DYNAMIC CENTIMETRES
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U.S.S. ATKA
18US-63-001
1/6—7/6
WEST GREENLAND CURRENT
LABRADOR CURRENT
NO INFORMATION
65° N
60°
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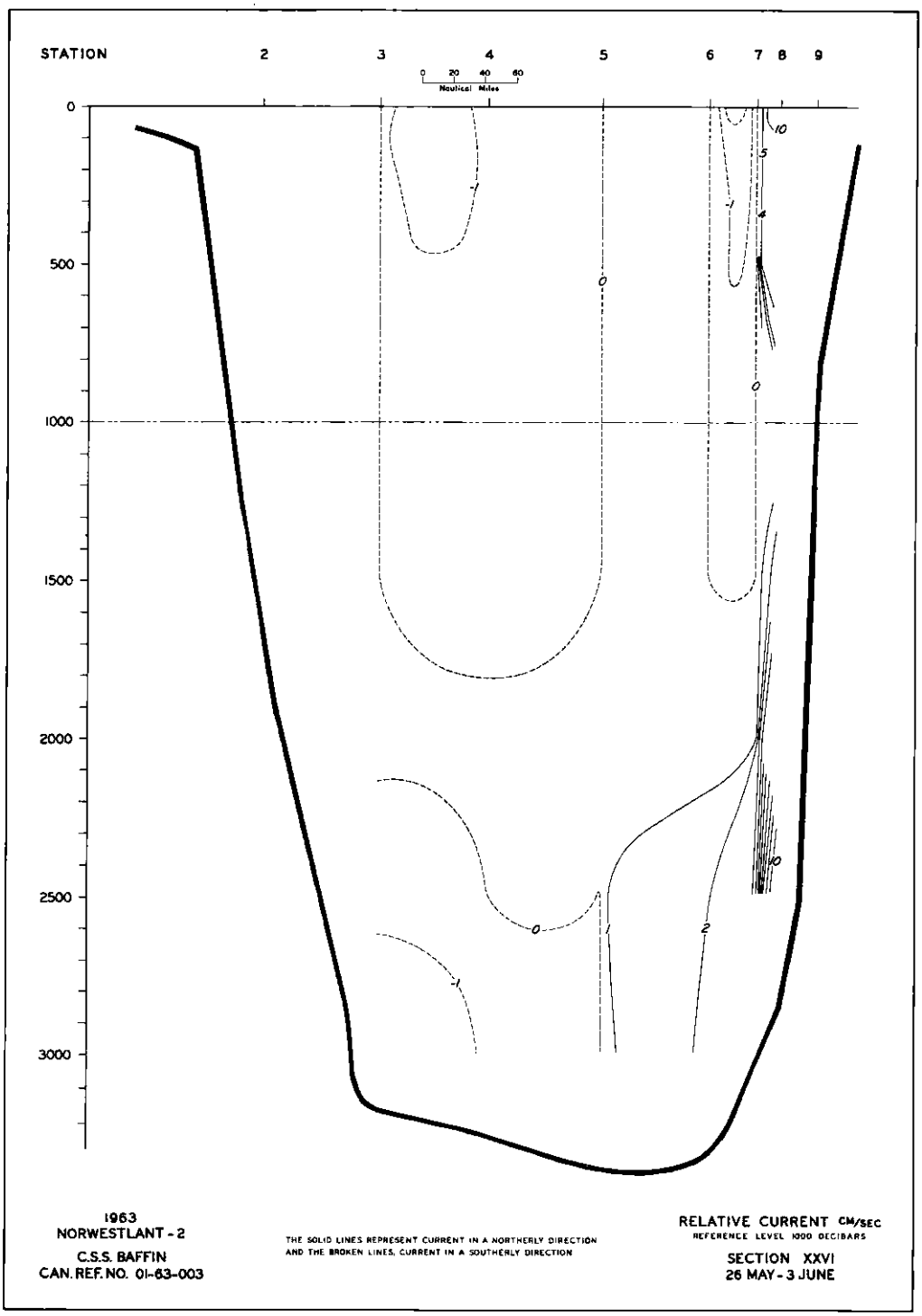
STATION
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60
Nautical Miles
0
500
1000
1500
2000
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3000
10
5
4
1
0
-1
2
1963
NORWESTLANT - 2
C.S.S. BAFFIN
CAN. REF. NO. 01-63-003
THE SOLID LINES REPRESENT CURRENT IN A NORTHERLY DIRECTION
AND THE BROKEN LINES, CURRENT IN A SOUTHERLY DIRECTION
RELATIVE CURRENT CM/SEC
REFERENCE LEVEL 1000 DECIBARS
SECTION XXVI
26 MAY - 3 JUNE

Figure 13

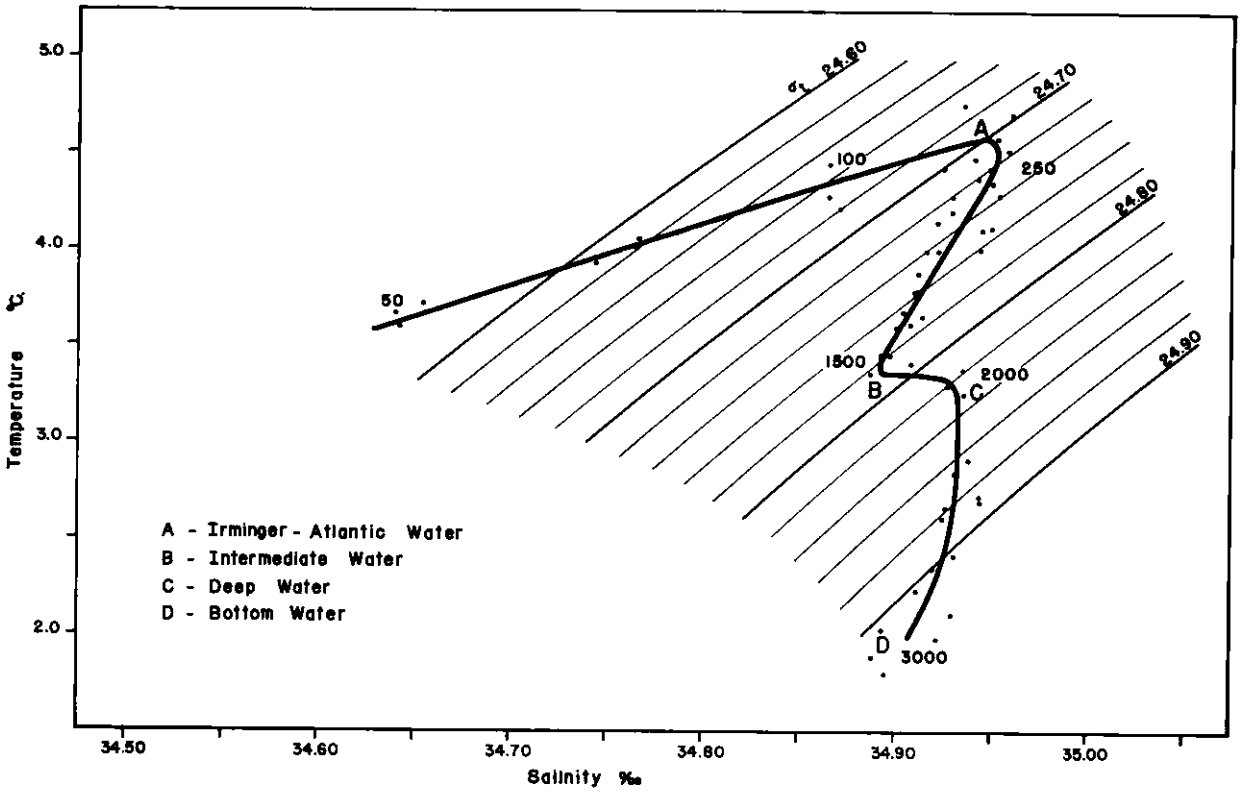

Figure 14 – Average T-S curve of Baffin stations 13, 14 and 15. Approximate depths in metres.

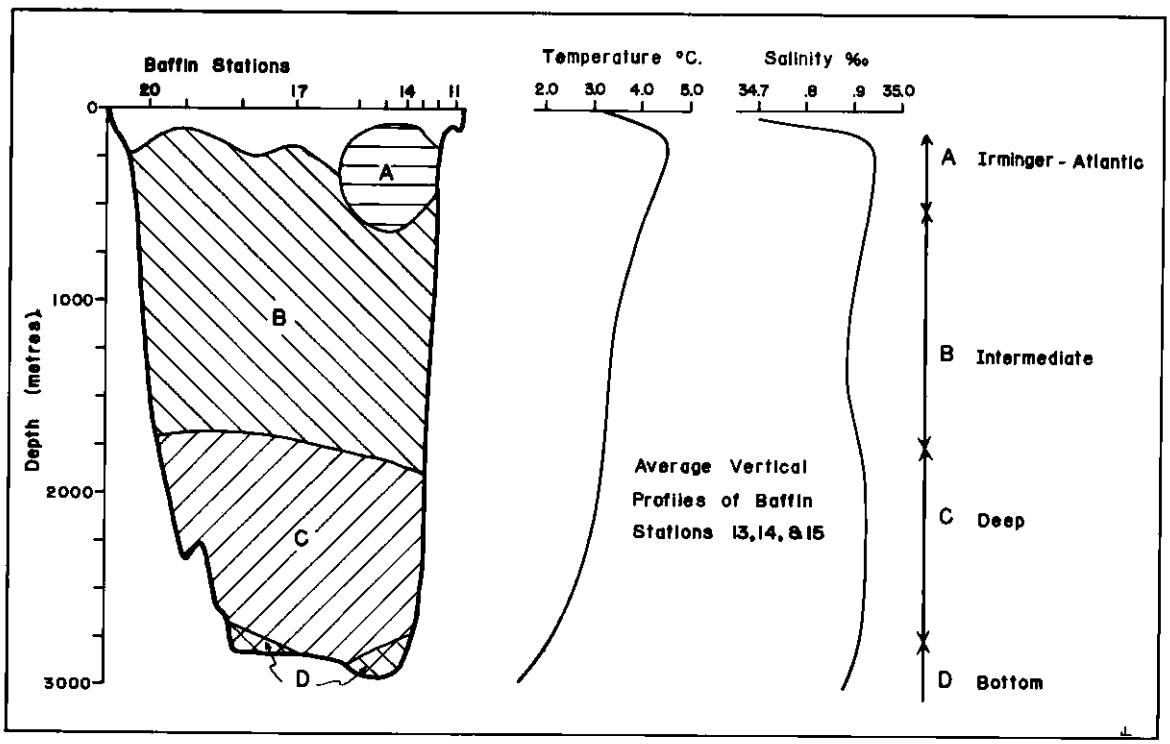

Figure 15 – Cross-section of Labrador Sea showing approximate regions occupied by water masses A to D. Also shown are the average vertical profiles of temperature and salinity of Baffin stations 13, 14 and 15.

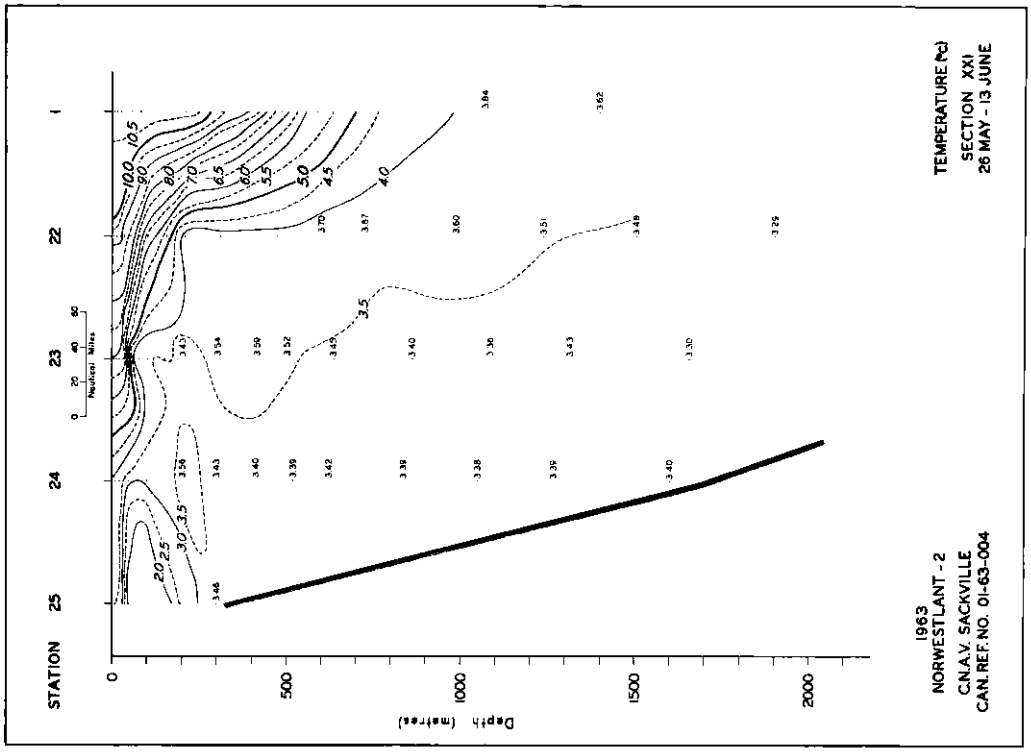

Figure 17

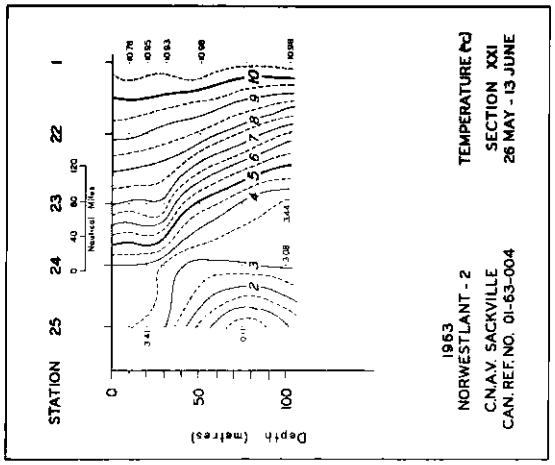

Figure 16

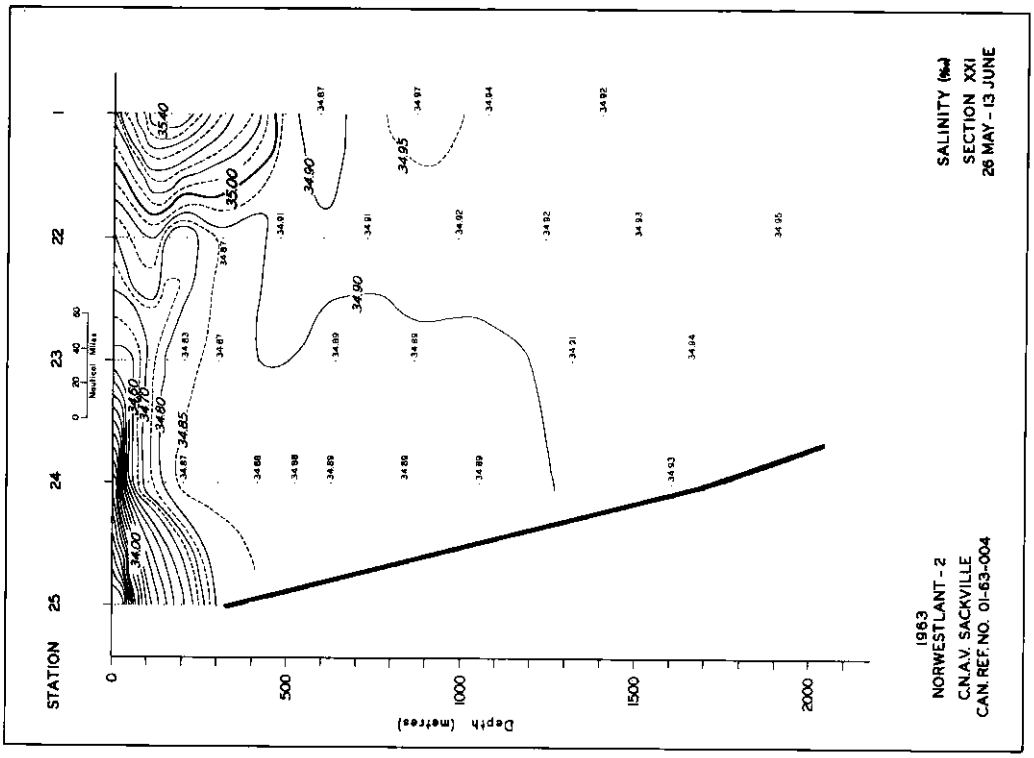

Figure 19

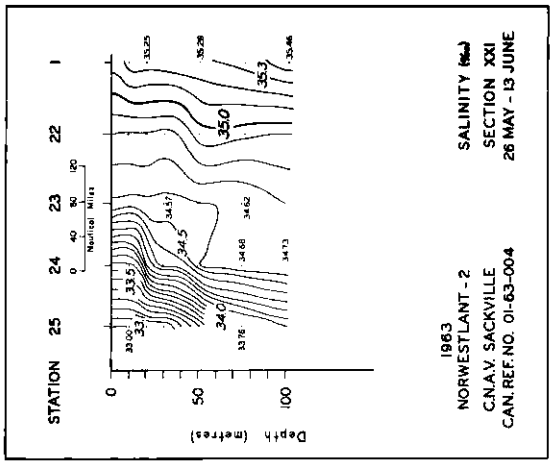

Figure 18

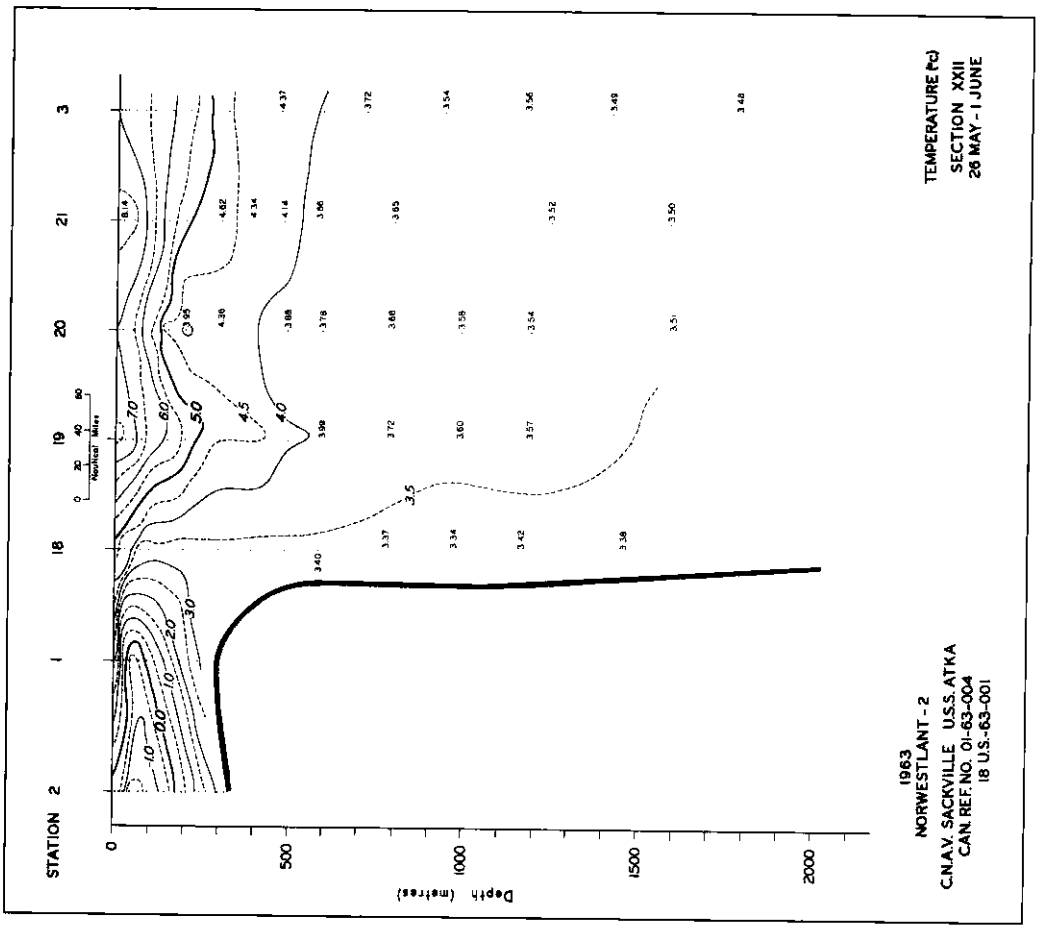

Figure 21

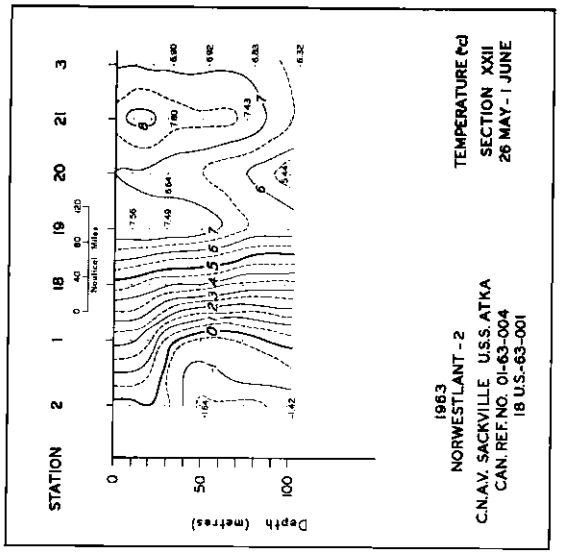

Figure 20

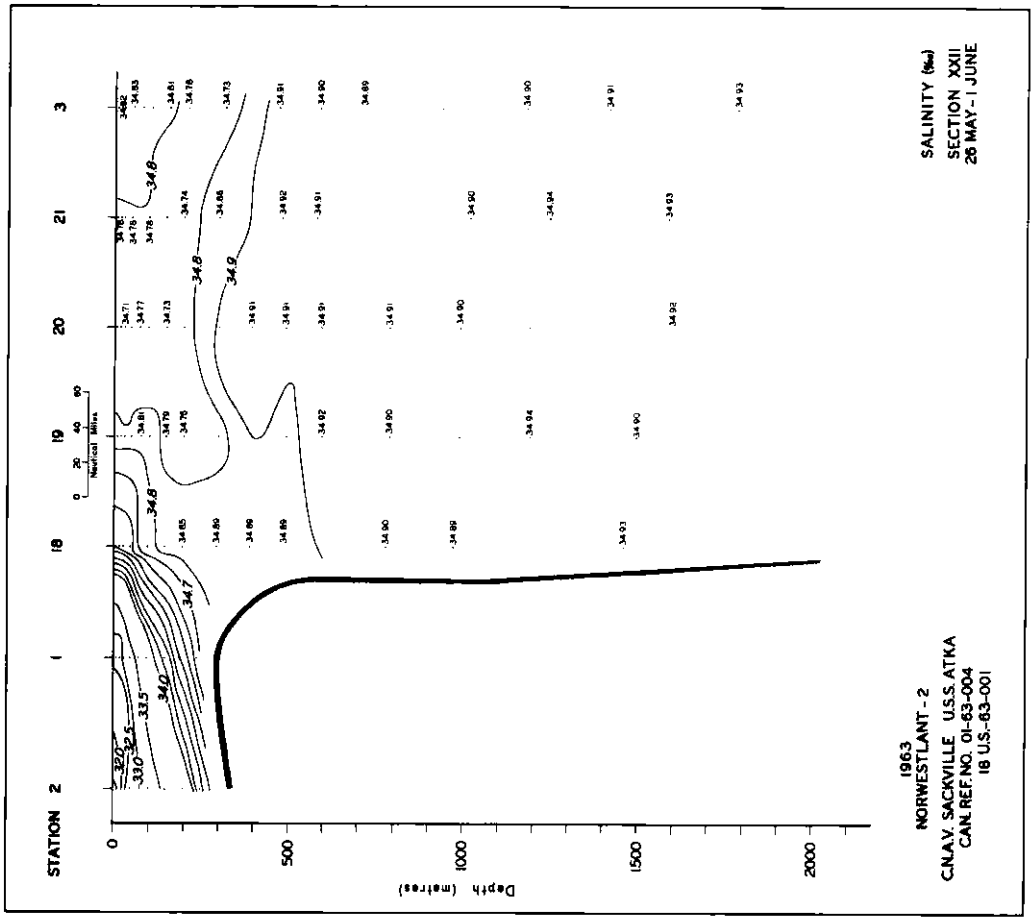

Figure 23

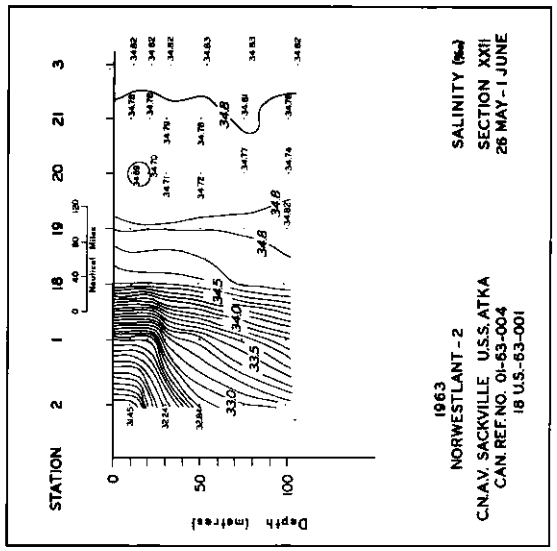

Figure 22

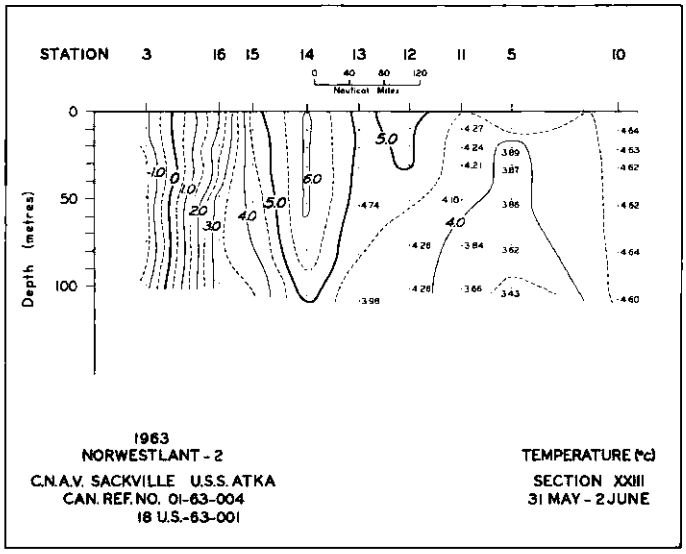

Figure 24

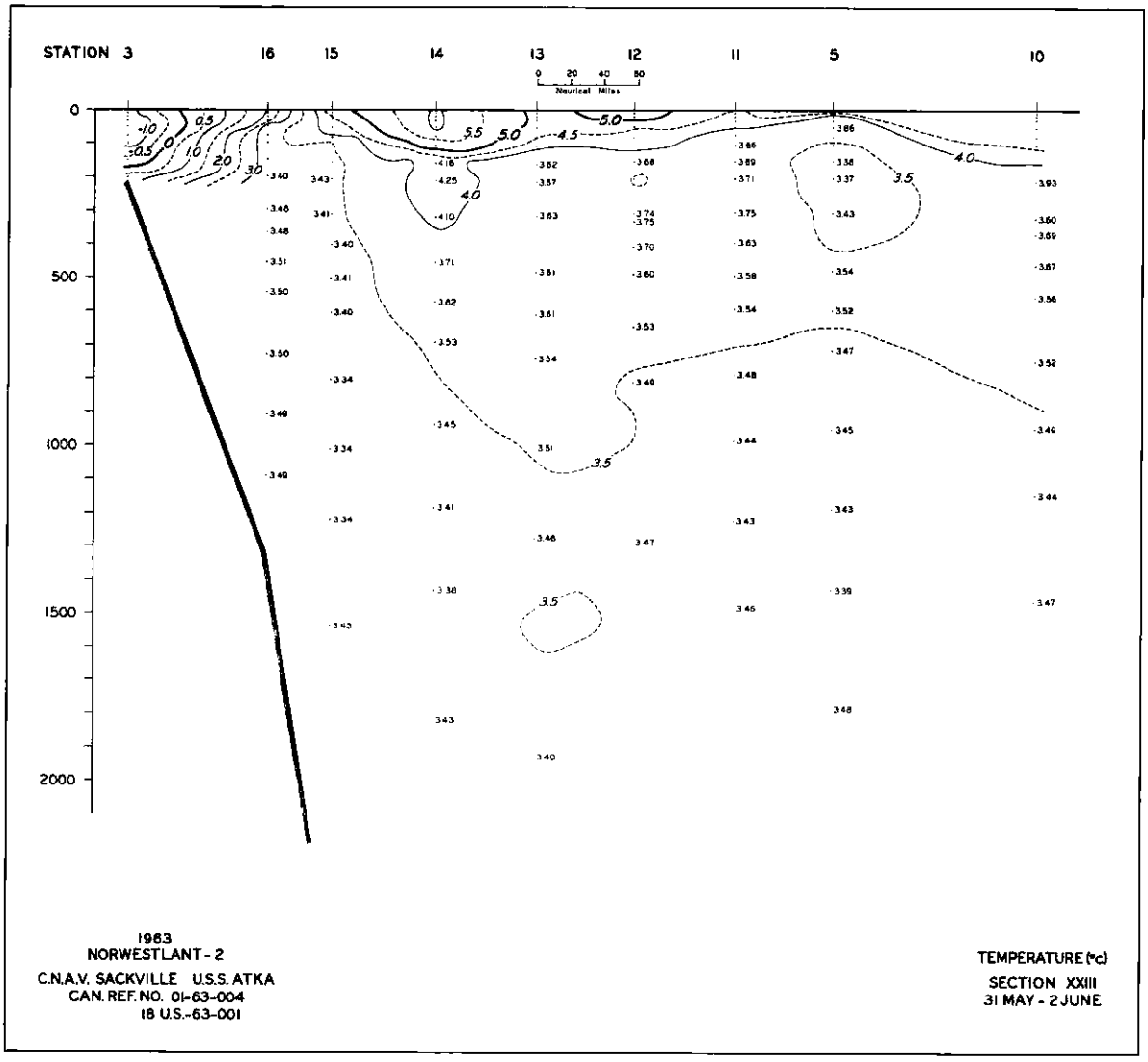

Figure 25

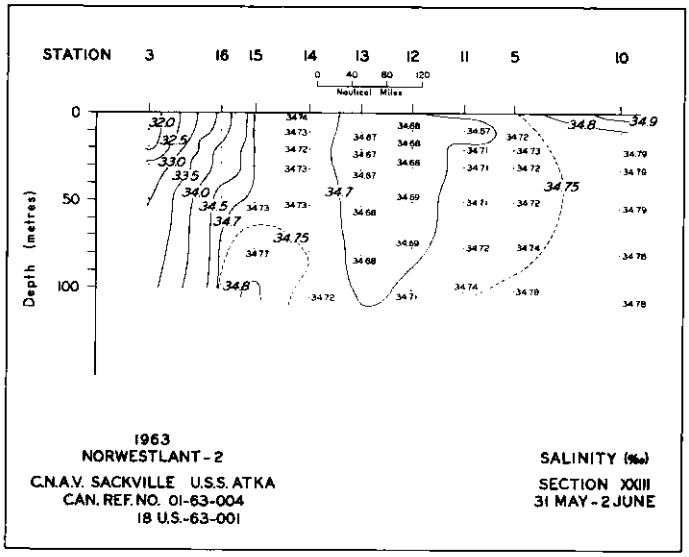

Figure 26

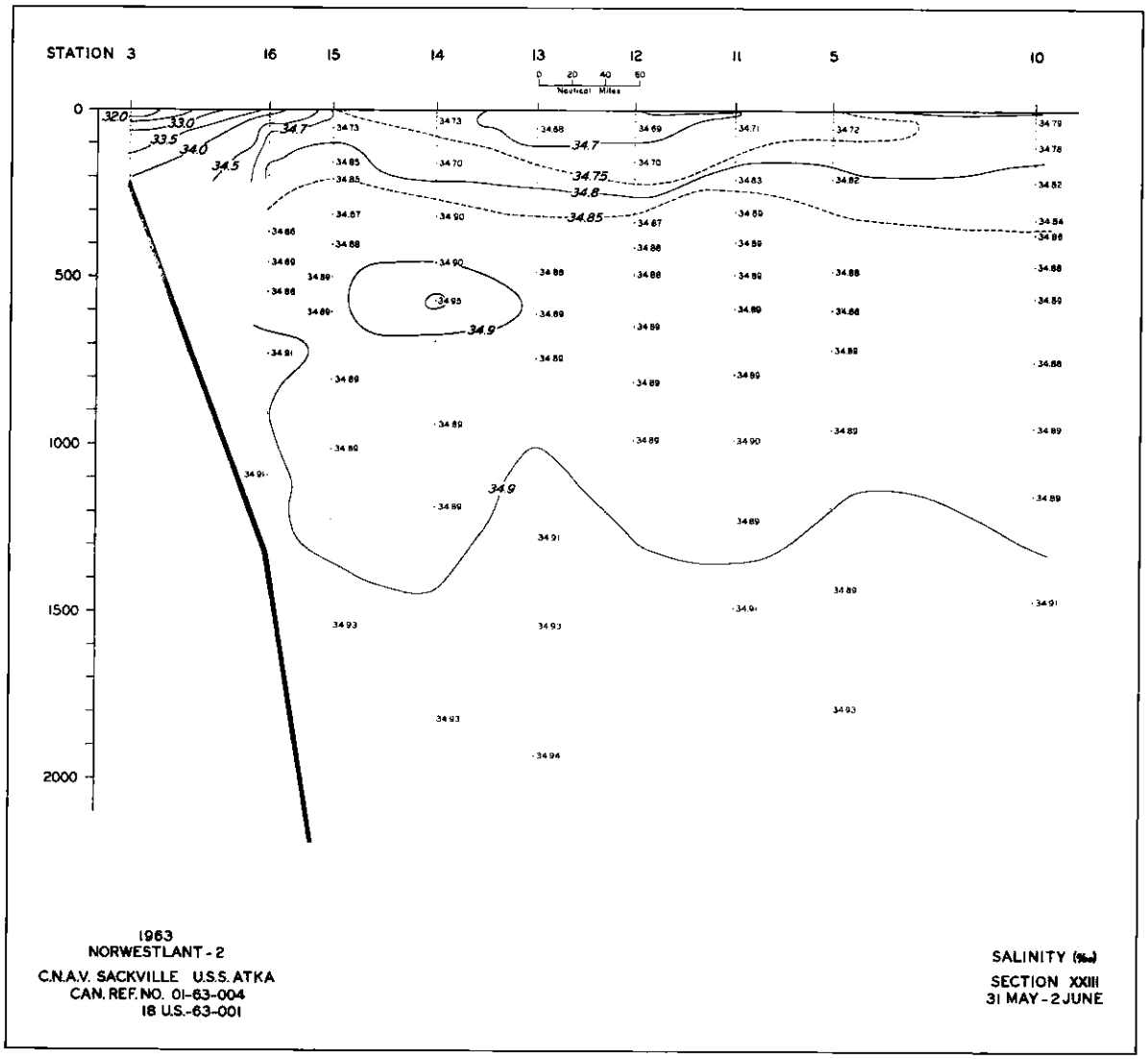

Figure 27

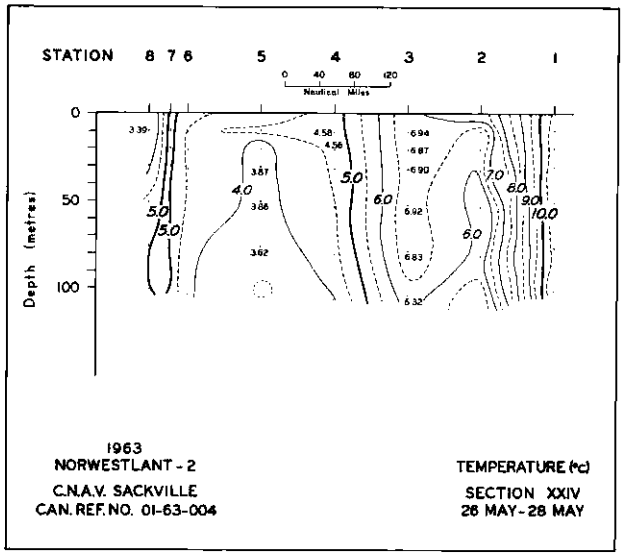

Figure 28

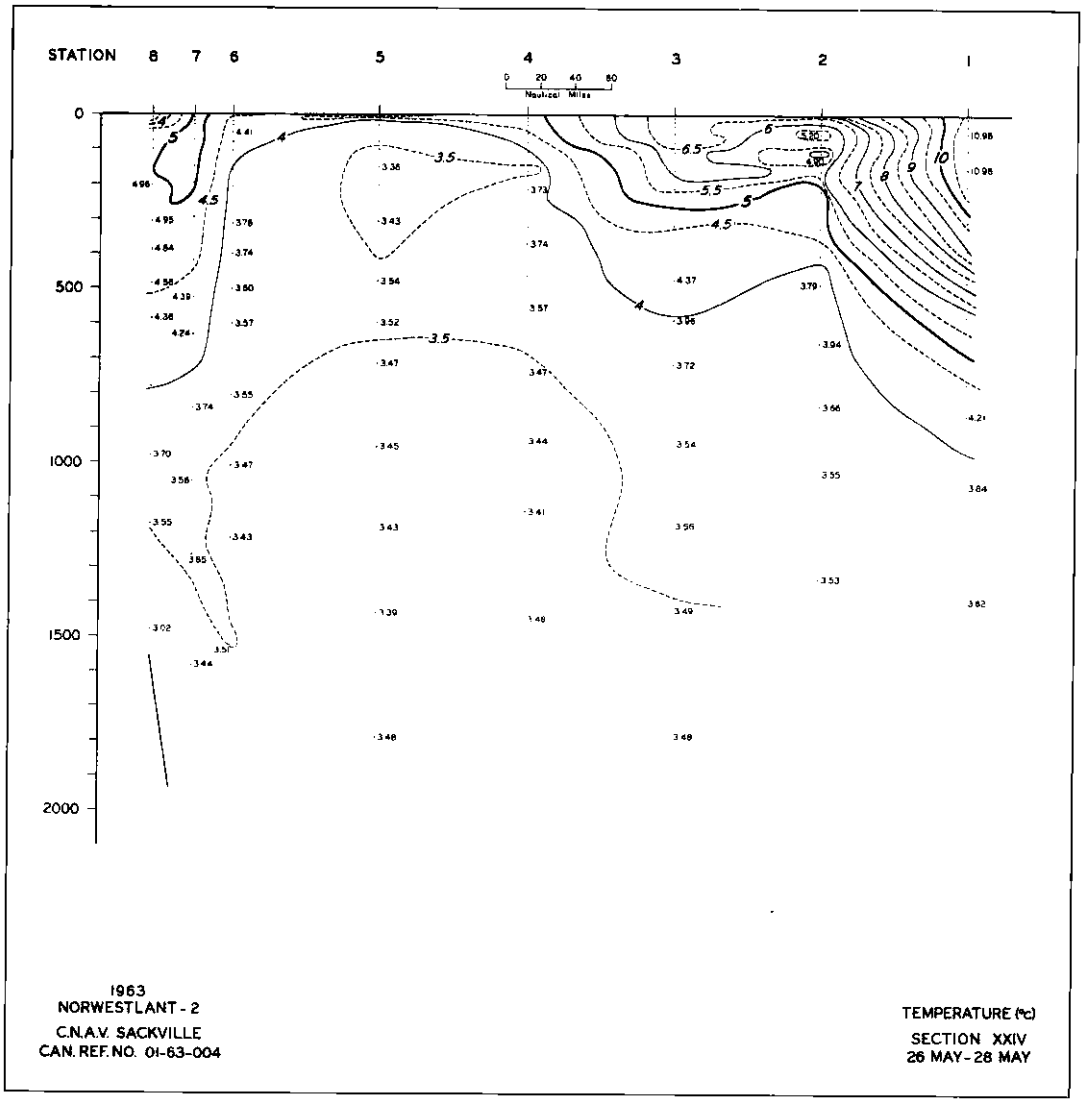

Figure 29

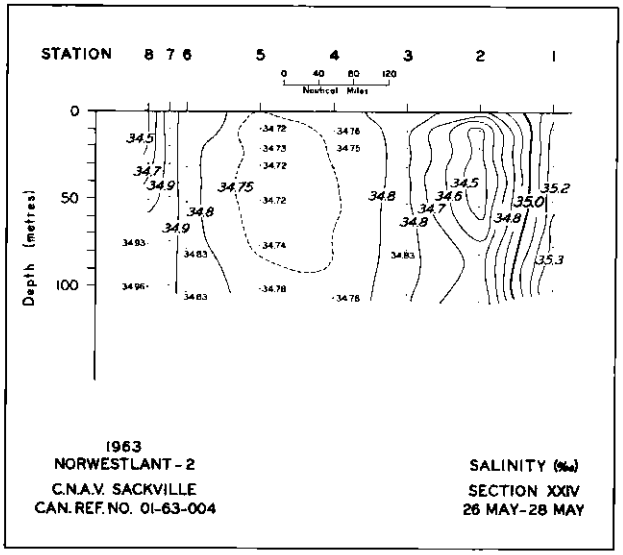

Figure 30

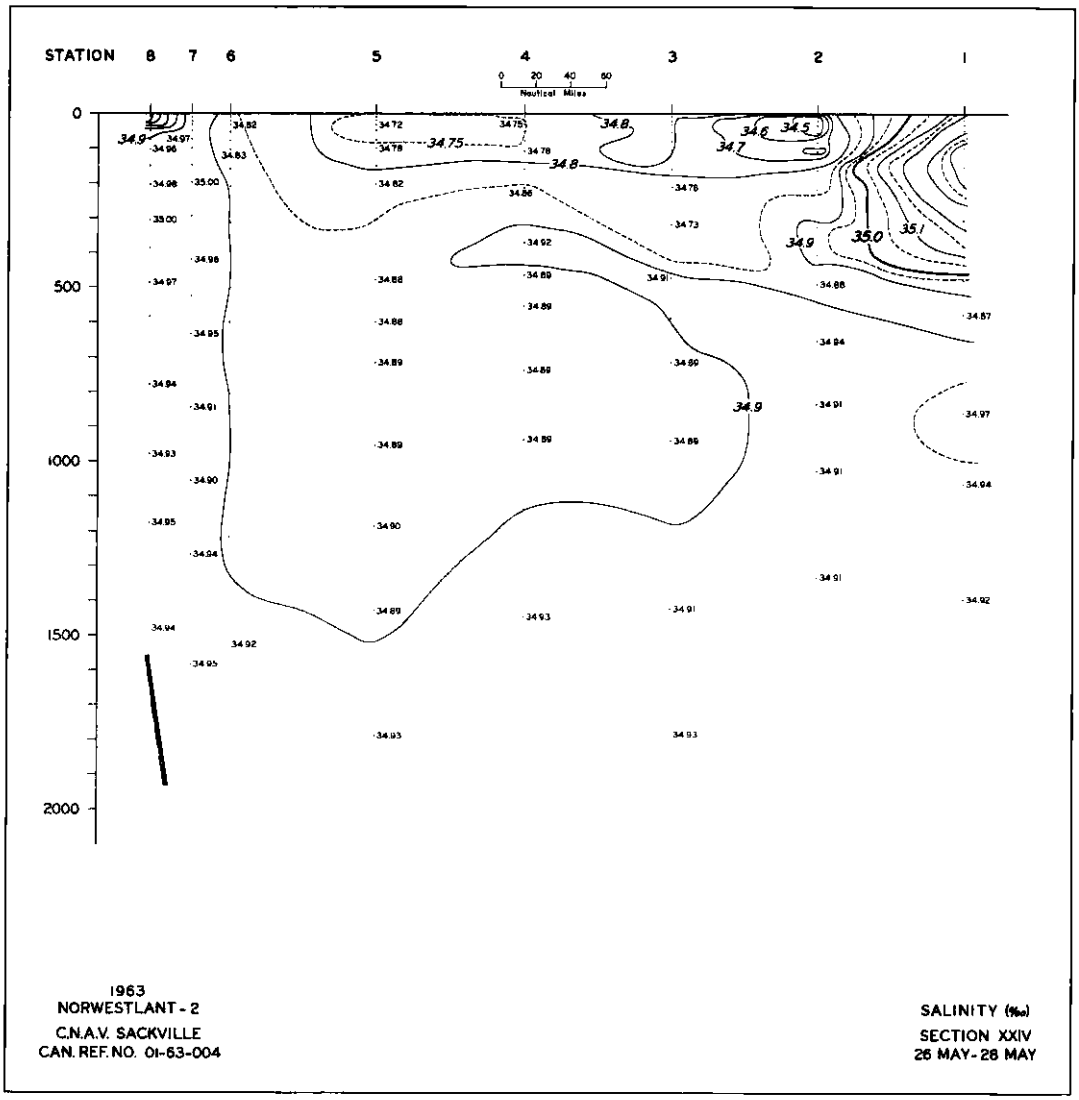

Figure 31

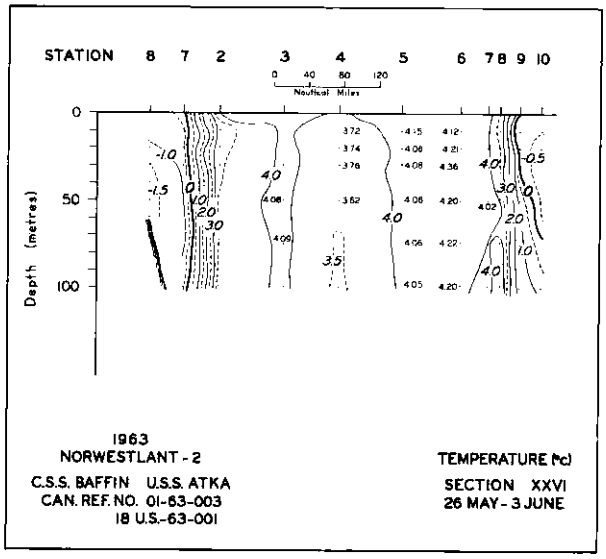

Figure 32

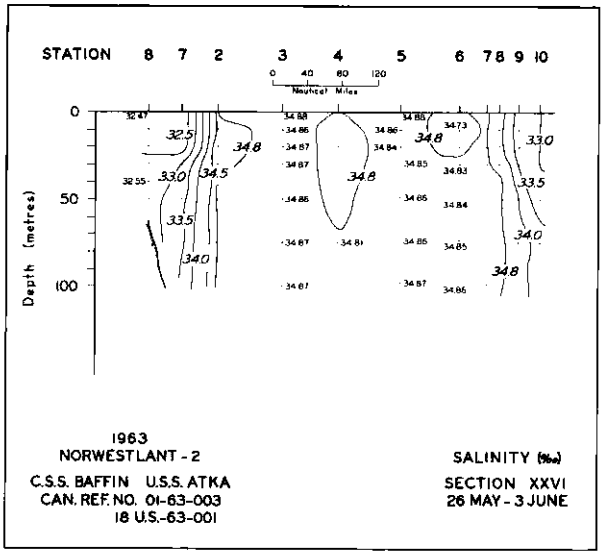

Figure 33

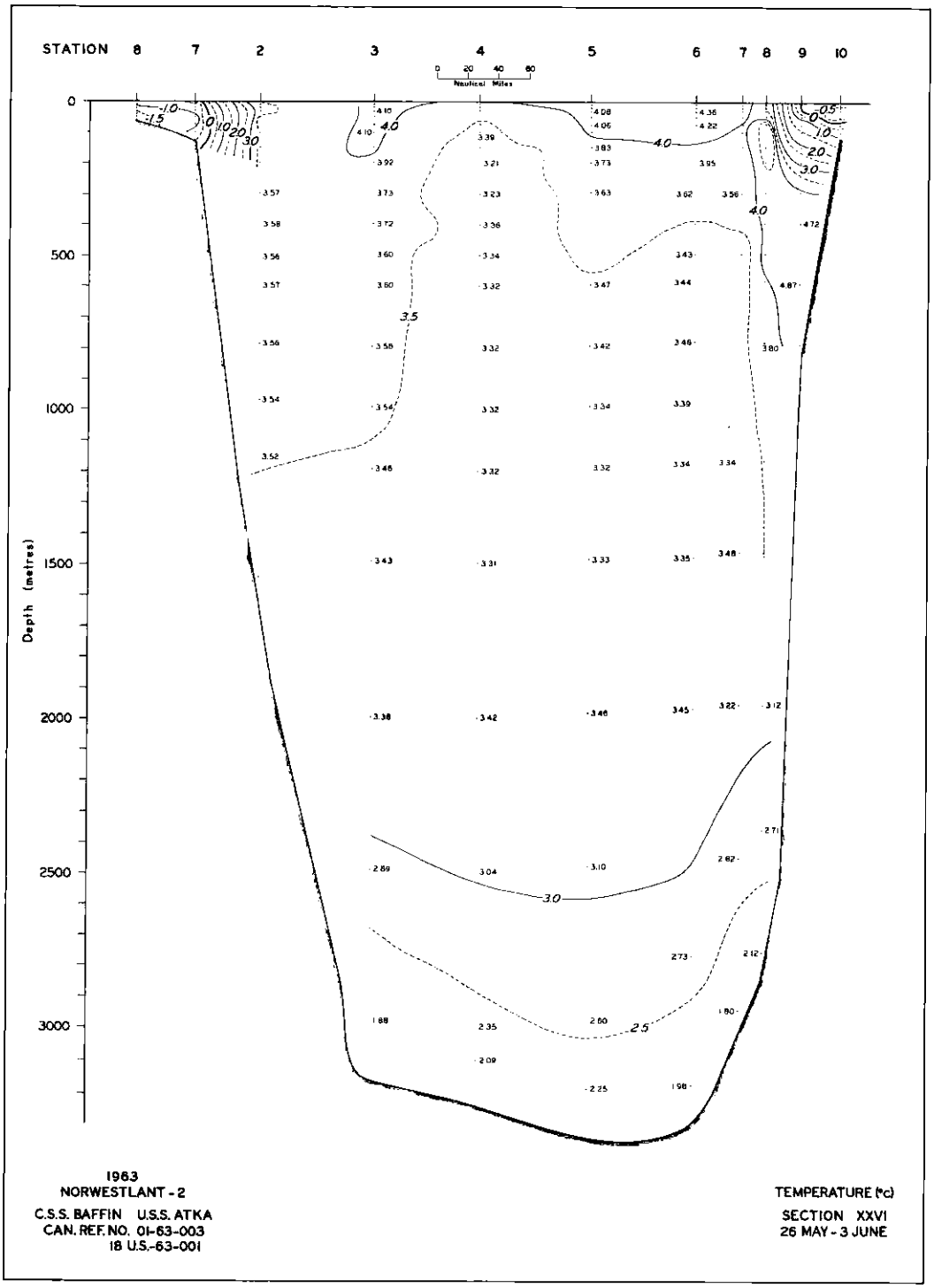
STATION 8 7 2 3 4 5 6 7 8 9 10
0 20 40 60
Nautical Miles
Depth (metres)
0
500
1000
1500
2000
2500
3000
1963
NORWESTLANT - 2
C.S.S. BAFFIN U.S.S. ATKA
CAN. REF. NO. 01-63-003
18 U.S.-63-001
TEMPERATURE (°c)
SECTION XXVI
25 MAY - 3 JUNE

Figure 34

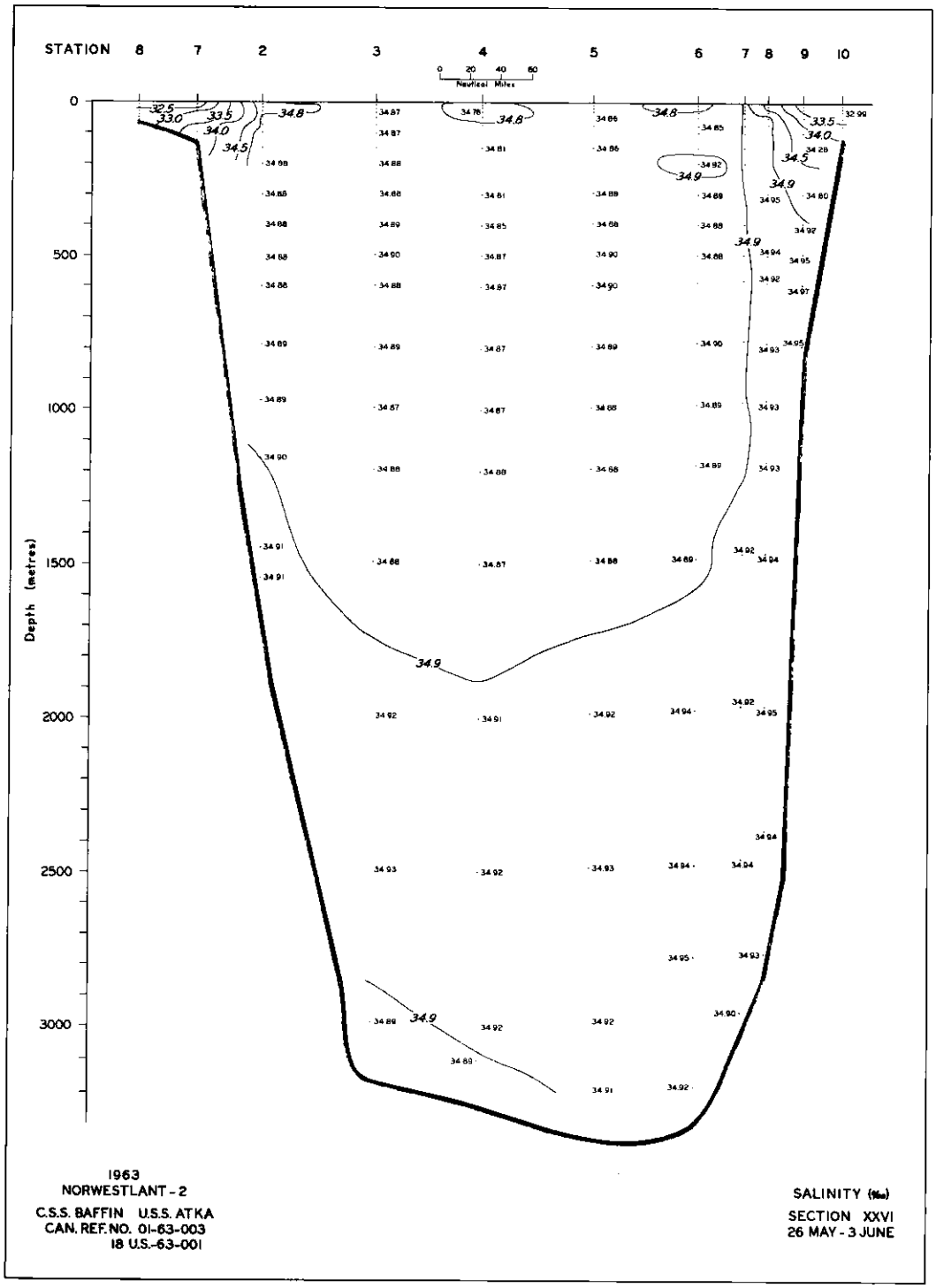
STATION 8 7 2 3 4 5 6 7 8 9 10
0 20 40 60
Nautical Miles
Depth (metres)
0
500
1000
1500
2000
2500
3000
1963
NORWESTLANT - 2
C.S.S. BAFFIN U.S.S. ATKA
CAN. REF. NO. 01-63-003
18 U.S.-63-001
SALINITY (‰)
SECTION XXVI
26 MAY - 3 JUNE

Figure 35

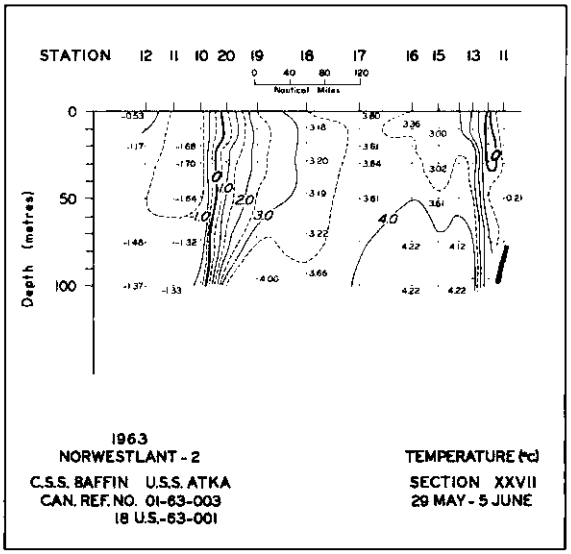

Figure 36

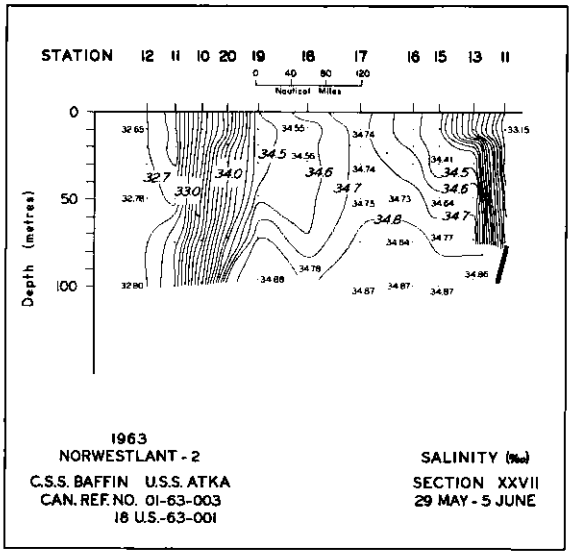

Figure 37

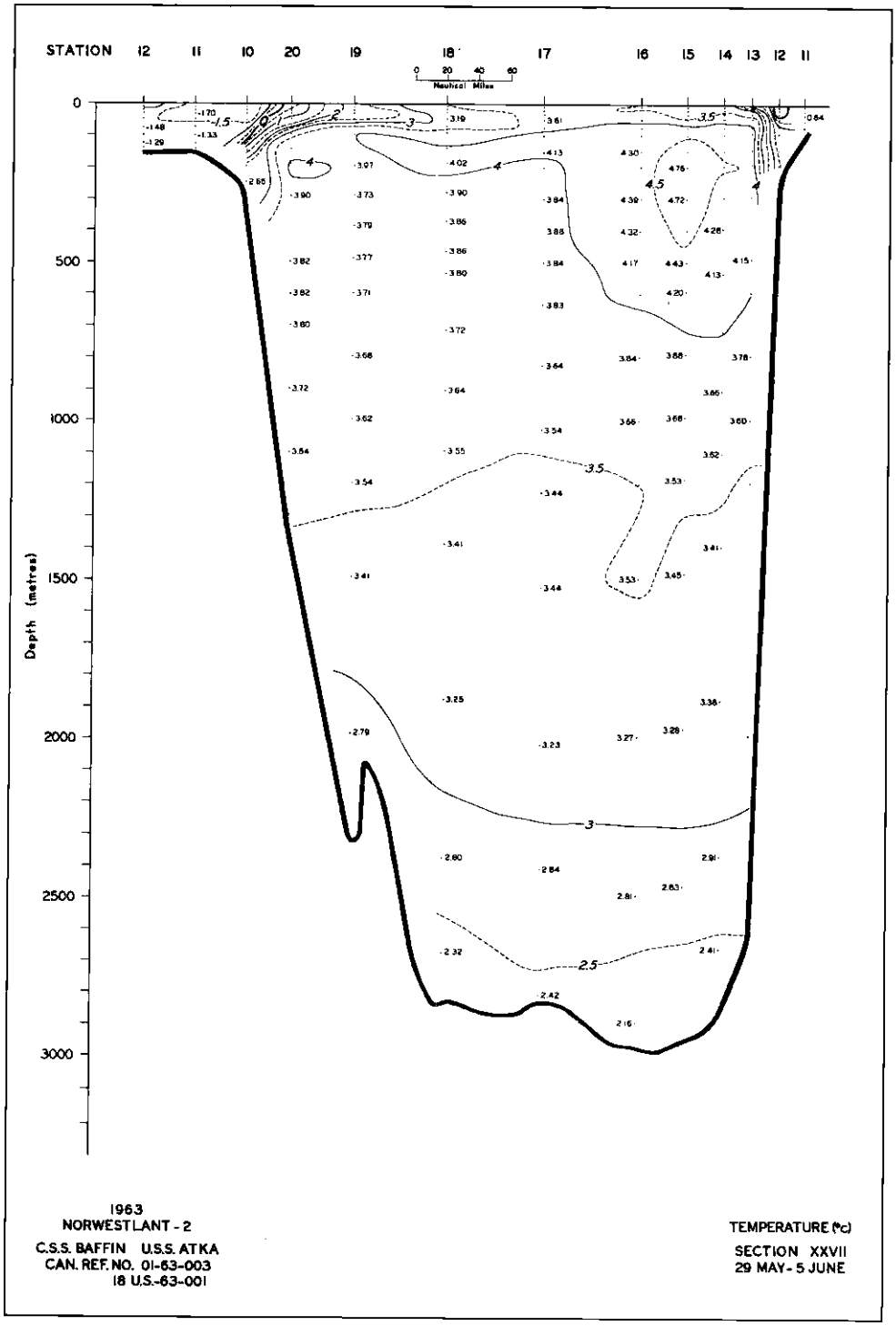
STATION 12 11 10 20 19 18 17 16 15 14 13 12 11
0 20 40 60
Nautical Miles
Depth (metres)
0
500
1000
1500
2000
2500
3000
1963
NORWESTLANT - 2
C.S.S. BAFFIN U.S.S. ATKA
CAN. REF. NO. 01-63-003
18 U.S.-63-001
TEMPERATURE (°C)
SECTION XXVII
29 MAY - 5 JUNE

Figure 38

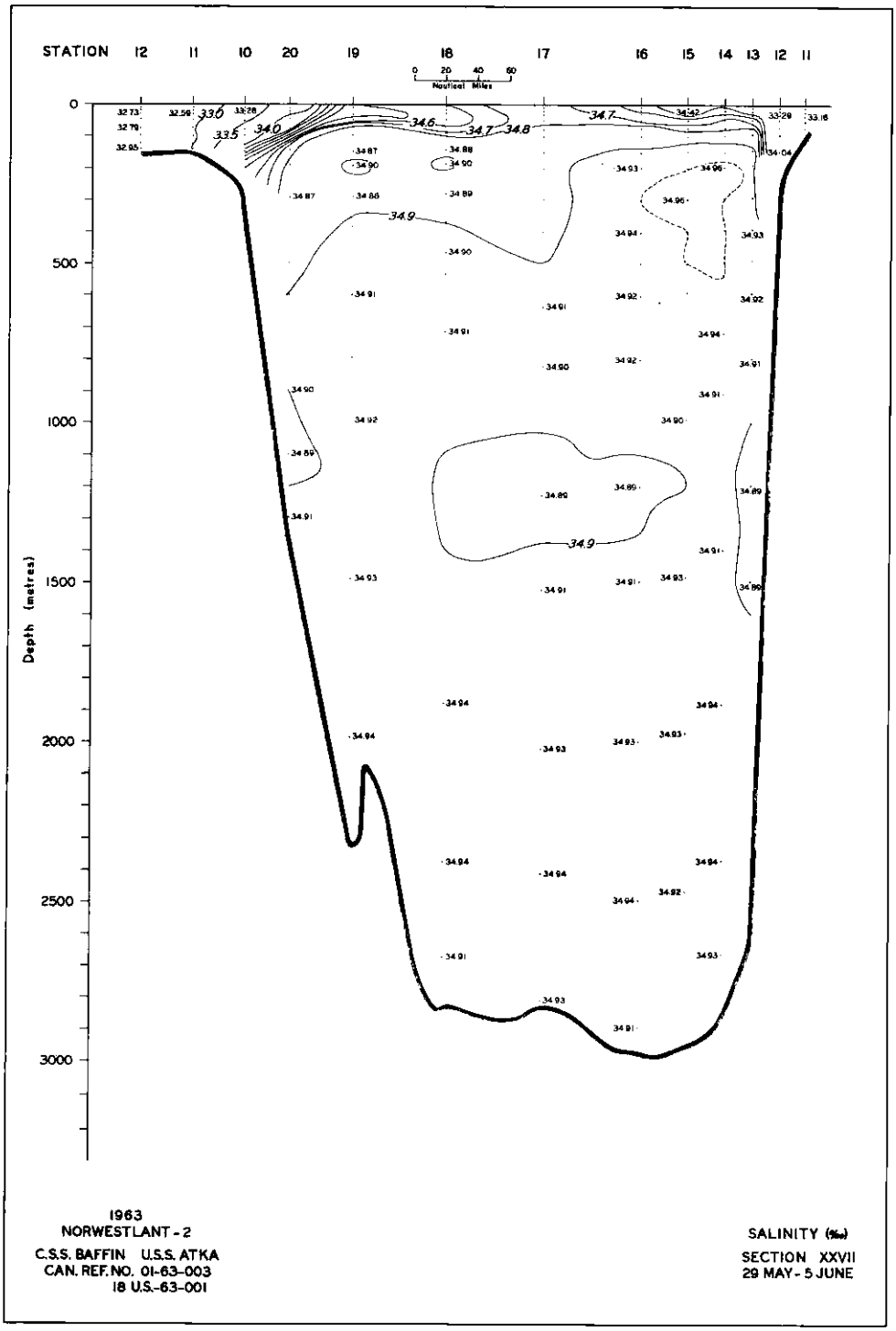
STATION 12 11 10 20 19 18 17 16 15 14 13 12 11
0 20 40 60
Nautical Miles
Depth (metres)
0
500
1000
1500
2000
2500
3000
1963
NORWESTLANT - 2
C.S.S. BAFFIN U.S.S. ATKA
CAN. REF. NO. 01-63-003
18 U.S.-63-001
SALINITY (‰)
SECTION XXVII
29 MAY - 5 JUNE

Figure 39

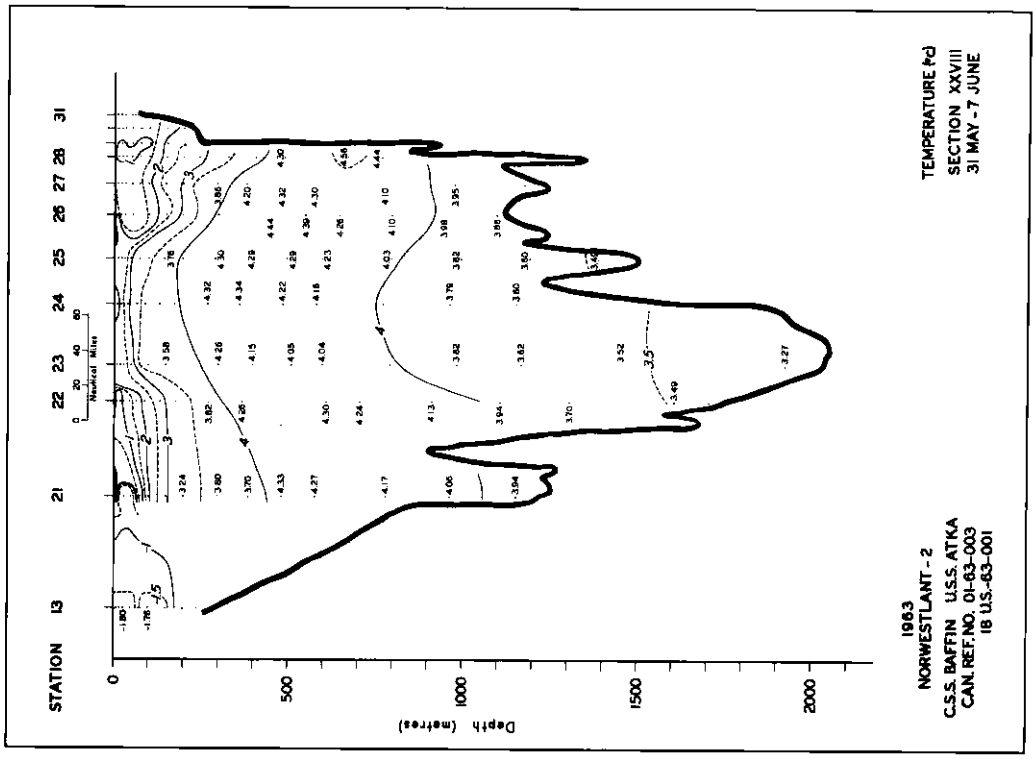

Figure 41

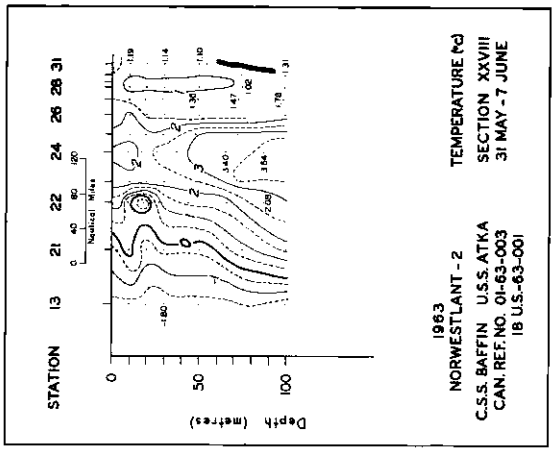

Figure 40

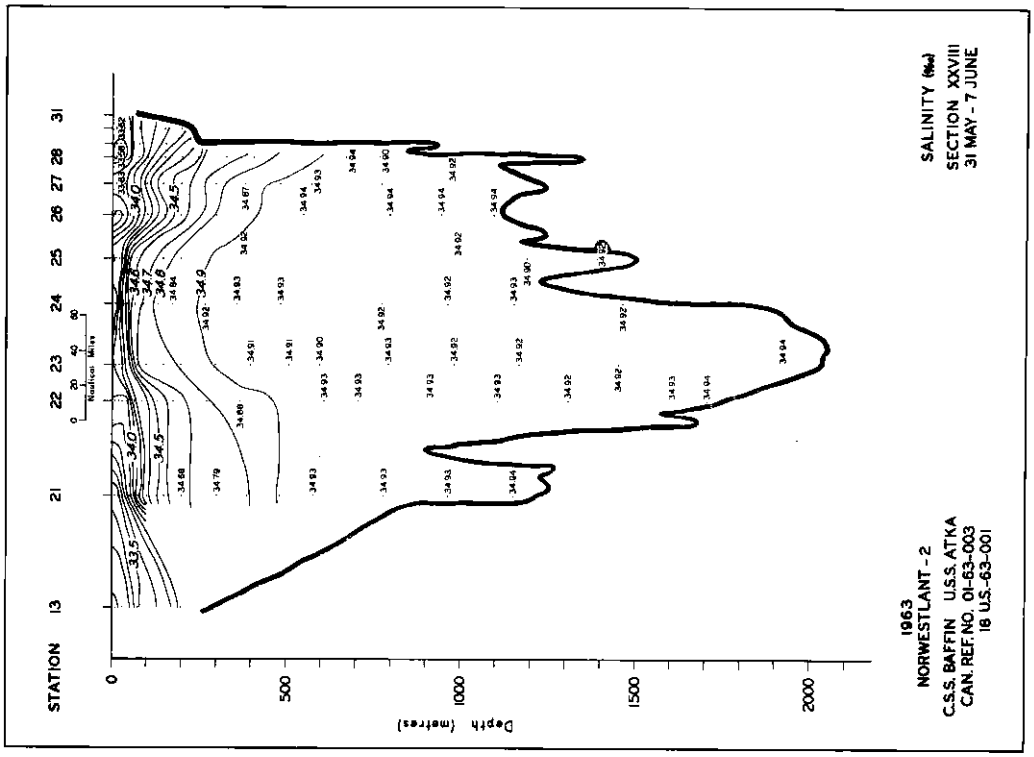

Figure 43

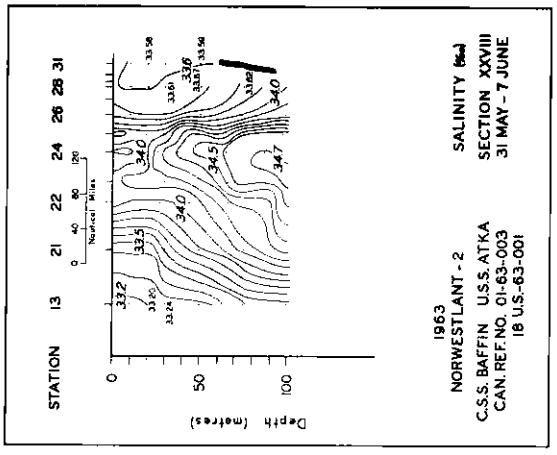

Figure 42

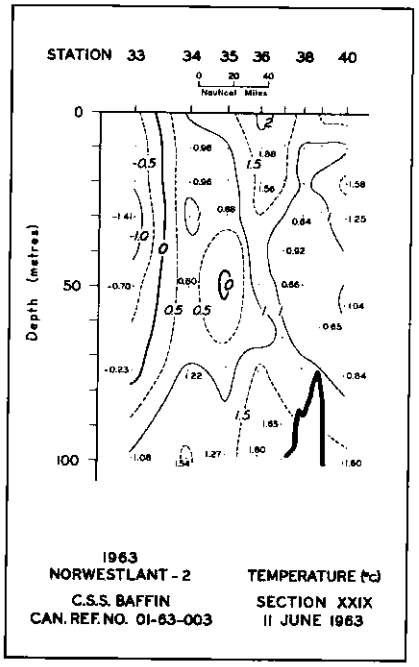

Figure 44

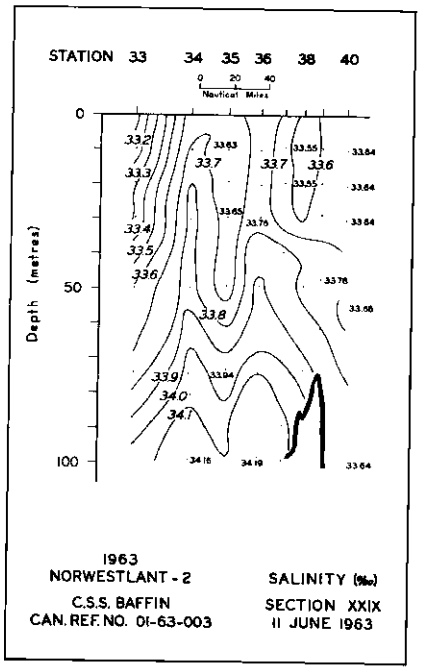

Figure 45

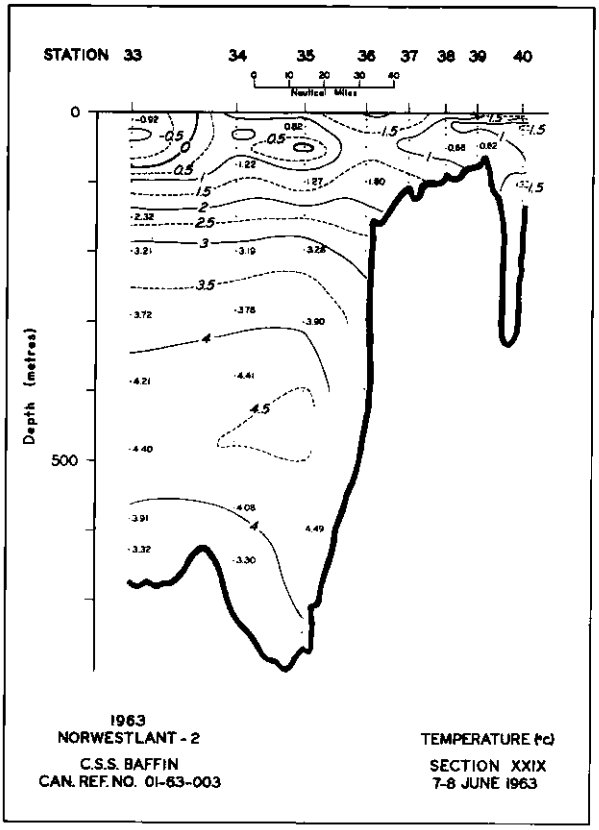

Figure 46

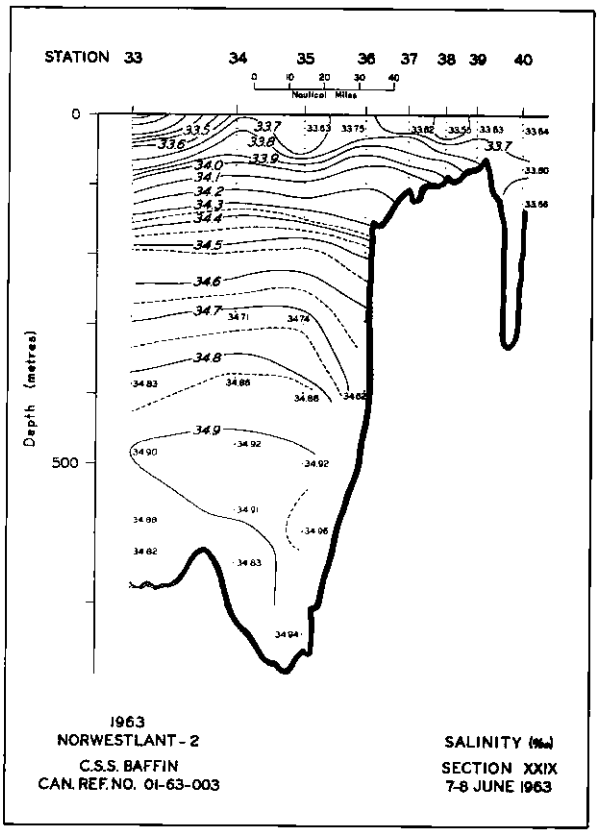

Figure 47

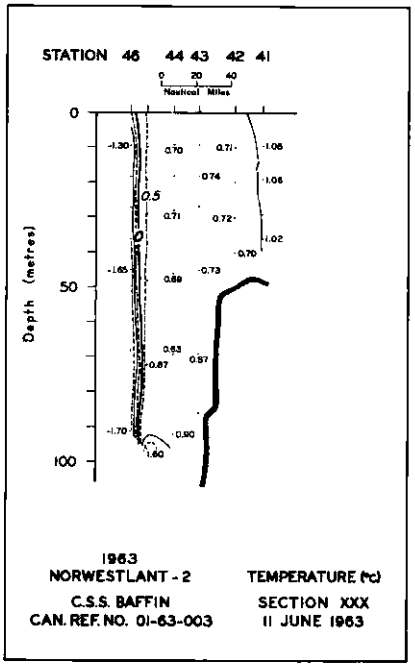

Figure 48

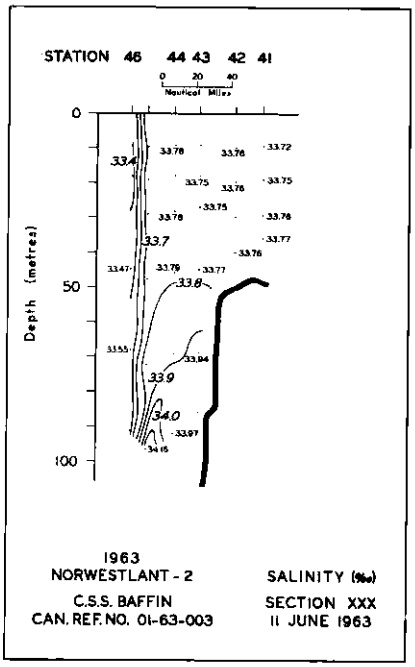

Figure 49

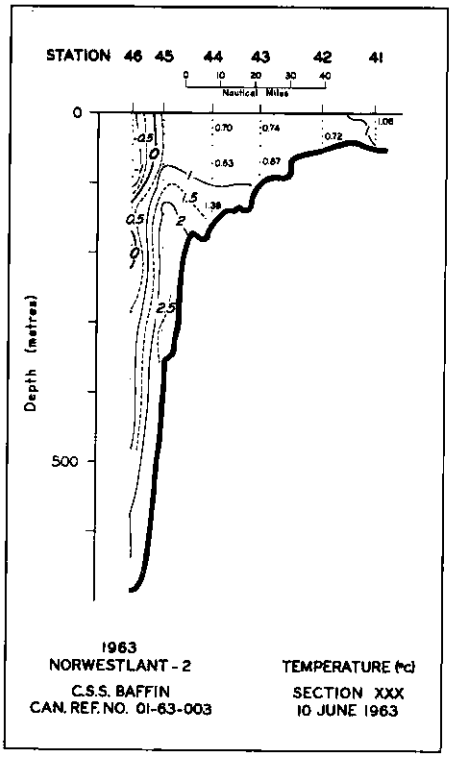

Figure 50

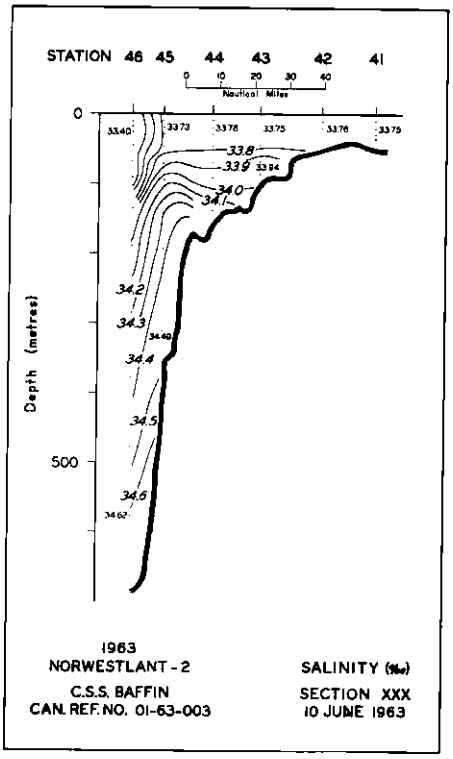

Figure 51

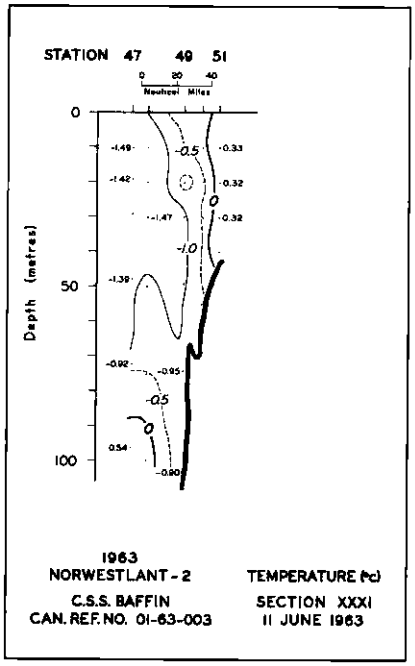

Figure 52

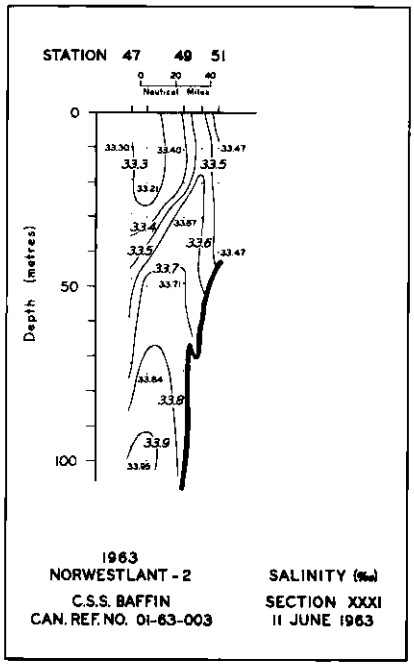

Figure 53

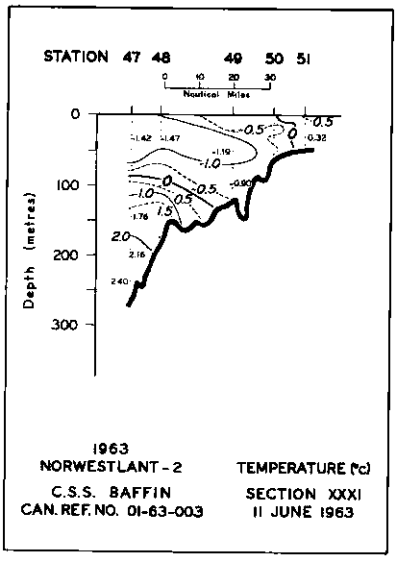

Figure 54

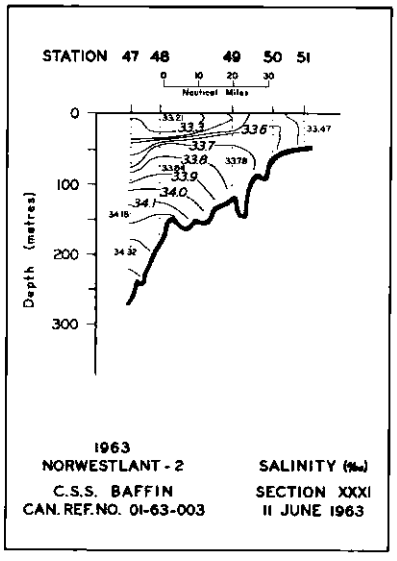

Figure 55