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# Potential Temperature and Salinity Anomalies in the 1970s Along the Flemish Cap Section

by

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## ABSTRACT

The departures from the mean of potential temperature and salinity along the Flemish Cap Section in the decade of the 1970's is presented. The analysis suggests that the early part of the decade shows colder, fresher water than the mean dominating the water column. In the latter part of the decade warmer, saltier water prevails. The change over from cold, fresh to warm, salty conditions seems to have occurred sometime in 1976 or 1977.

## Introduction

At the June 1980 meeting of the Northwest Atlantic Fisheries Organization (NAFO) it was recommended "that a special session to review environmental conditions in the 1970-79 decade be held". (Anon 1980). This report has been prepared partly in response to that recommendation.

As a first step, it is necessary to consolidate as much of the data as possible. At present, no one organization can claim to have access to all of the physical oceanographic data collected by members of NAFO. However, a significant portion is held by the Marine Environmental Data Service (MEDS) in Ottawa, Canada. The analysis presented here, uses these data to focus on a specific area of the Northwest Atlantic Ocean.

The NAFO area of interest is large and data collections are not frequent in any one location. Because of this, it was decided to treat only an area where physical oceanographic data are relatively plentiful. The most obvious choice is to consider analysis of the data collected along the standard NAFO sections (Anon, 1978) shown in figure 1. Gagnon (1977) analysed the data holdings of MEDS along these sections. An examination of this report showed that data were most plentiful along the Flemish Cap section (figure 2). It is the physical oceanographic data analysis from this section which are presented in this report.

The Analysis of Mean Conditions

In order to calculate anomalies of any variable it is first necessary to have an estimate of the mean conditions. These have already been calculated by Keeley (1981 a). The data used in calculating the mean consisted of all bottle observations taken between 46.75° to 47.25° N and 41.5° to 52.5° W. In total, this set was composed of about 3000 stations, the earliest in 1910 and the latest in 1980. Only the potential temperature, θ, and the salinity, S, were treated since these were the only ones for which sufficient observations existed. Rough range checks were made on the data and those lying outside the ranges were deleted. For θ, the range was -2° to 30°, and for S, 10 to 40°/oo.

The first requirement was to decide on the intervals over which mean conditions were to be calculated. The choice was constrained by the sampling in space and time. For the Flemish Cap section, there are 25 standard stations (Anon. 1978). In the vertical, observations were made at standard depths. In order to have enough observations to calculate mean conditions, it was necessary to use all the data in a month. Mean conditions were computed for each standard station at each standard depth every month.

The simplest way to compute mean conditions is to add up all the observations and divide by the total number. Implicit in this computation are assumptions about the data. One of these is that there is no significant trend in the data over time. Since averages are calculated by the month, this also assumes that the variations in observations in any month are smaller than the variations from one year to the next.

Even if there is an insufficient amount to determine trends there may be enough data to address the variability aspect. Since mean conditions were computed for each month the assumption about the variability in the data translates to assuming that the variations in observations within any month in one year is larger than the variations in observations in any month but different years. There were enough data to allow the testing of this assumption.

The analysis of these data showed that year to year variations in both θ and S were larger than variations found in a single month in any one year. The consequence of this is that many years of observations are required before the major portion of the variability can be described.

There were a total of 43 years in which stations had been sampled along this section. The earliest was 1910 and the record is continuous from 1948 to 1980. The data are most scarce from the winter months and from stations east of 44° W. The largest number of observations proved to have been made in the Flemish Pass region (stations 7 to 16). The mean conditions calculated in the region where the data are most plentiful are based on about 20 to 25 years of measurements. For the times or locations where the data are scarce there are sometimes only 1 year in which observations were made.

The Calculation of Anomalies

The data available to the calculation of the anomalies for the 1970s is shown in figure 3. The analysis of such irregular observations along a section causes some difficulties as will be seen. The anomaly was calculated to be the difference between the θ or S observation at a particular time and the mean conditions. Hence, positive anomalies indicate conditions above the mean and negative values are conditions below the mean.

It was not necessary to present the results of all the sections for which data are available. The anomalies and their characteristics accross the section can be more compactly presented by looking at only six stations along the section. These six have been chosen because they sample the oceanographic regime most effectively. The anomalies for θ and S for these stations are presented in figures 4 - 9 and 10 to 15 respectively.

All of the figures have been contoured using a routine called CONMAP, described by Taylor (1976, 1977). There is only one notable change from the procedures described in the references. This is, that the ability to allow flexible grid spacing in the horizontal direction has been added. This has been done so as to accommodate the pecularities of oceanographic observation programs. That is, stations are rarely equally spaced along a section, or observations taken at regular intervals of time.

In order to contour the data, it must first be interpolated to some regular grid. If an equispaced grid is used, this often implies interpolations which can easily generate false features in the contoured data. The solution was to pretend the observations were all uniformly distributed horizontally and then after interpolations were done, the contours are stretched out so that the station spacing was representative of the physical or temporal separations.

There was some consideration given to using the technique of optimum interpolation (Bretherton, Davis and Fandry, 1976) to assist in contouring the data. The central point to this technique is to determine a correlation function for the data in both the horizontal and vertical directions of the grid. The θ anomaly data from station 10 from 1947 to 1979 were analysed in the time axis only (as in figure 6) but the results were inconclusive. The time scale of the correlation function (the time necessary before the correlation function drops to zero) was very short for data in the upper 50 m. This implies that the data are dominated by variations with time scales shorter than a few months. Results from 75 to 125 m. depth, showed a gradual decrease in the variance until below 150 m., the time scale was on the order of 3 years.

The amount of data available to the analysis was not great so that the results cannot be considered to be well established. It is intriguing, however, to find such long time scales for the anomalies. This aspect was pursued no further since there was no obvious remedy to the paucity of data.

Results

The presented contours of θ and S in time and depth are difficult to absorb because of the great deal of complexity. Some of this may be an artifact generated by the procedures used in calculating the mean conditions reflecting the amount of data available. With these considerations in mind, the figures can be examined in more detail.

The most obvious aspect of both the θ and S figures is the long time over which anomalies persist. This was already infered by the optimum interpolation analysis. Because of the frequency of sampling, few statements can be made about variations on time scales shorter than a few months. For the occasions on which data are more frequently available, the anomalies do appear to persist and in particular maintain their positive or negative signs.

Before examining the stations individually it is of some value to attempt to correlate the anomalies of θ and S. An examination of figures 4 to 15 appears to show that like signed anomalies are correlated. That is, colder than normal water is associated with relatively fresher water and warmer temperatures are correlated with saltier conditions. This correlation is seen at stations 10, 13, 16 and 20. In particular, the anomalies at station 10 show good correspondance in virtually all of the larger features. It appears, then, that for the stations in and east of the Flemish Pass, that colder water can be associated with fresher conditions and warmer water with saltier conditions.

Looking at stations 1 and 7, both on the Grand Banks, the situation is more clouded. At station 1 it is difficult to assess if a correlation of any kind exists. The largest feature in the salinity anomalies can be associated with colder water. For other features, it is too confused. A simple test of the correlation between θ and S anomalies at this station, showed a statistically non significant positive correlation between cold and salty conditions. Most importantly, there was not a strong correlation. The anomalies at station 7 are even more confused. Overall, it appears that stations 1 and 7 exhibit the same characteristics.

The next step was to examine the correlation of anomalies across the six stations. To begin, however, it is worthwhile to discuss the oceanographic regime sampled by each station. Water circulation through and around the Flemish Cap section is most strongly influenced by the Labrador Current. This current appears to be comprised of an inshore and offshore branch (Buzdalin and Elizarov, 1960, Hachey, 1961 among others). The inshore branch can be found up on the shelf in less than 200 m. of water and consists of water typically colder than $0^{\circ}$ C. When this branch encounters the Grand Banks it appears to divide with some portion flowing south through the Avalon Channel and some flowing over and around the Grand Banks. Both stations 1 and 7 sample this water. The offshore branch of the current flows in deeper water along the shelf break but is typically confined above 1000 m. depth. This branch flows around the Grand Banks and through the Flemish Pass on the western side. Station 10 samples this water.

At this point there is some discussion as to the details of the flow (Worthington, 1962, Mann, 1967) but in any case the Labrador Current water mixes with Gulf Stream water south of the section and a northerly flow of water with these mixed characteristics occurs on the eastern flank of the Flemish Pass (station 13). There is apparently a weak anticyclonic flow around the Flemish Cap (Ross, 1980) and it is part of this flow which is sampled by stations 13 and 20. Station 16 is situated in the most shallow water on the Flemish Cap.

The decade begins with a saltier than normal inshore branch of the Labrador Current seen at stations 1 and 7. The offshore branch sampled at station 10 appears to be warmer and saltier in particular in waters below 200 m. The northward flowing water in Flemish Pass shows the same conditions again in particular below about 150 m. Both on the Cap and to the east, conditions especially below 100 m. are warm and salty to start the decade.

Sometime in late 1970 to late 1971 conditions change. The inshore branch begins to show cold anomalies with extremes recorded below 30 m. and particularily at station 7. The salinity in the corresponding period appears to be fresher than usual. The offshore branch seen at station 10 shows cold, fresh conditions persisting into 1973 but only in the upper 250 m.. Below this, the water is still both warm and salty compared to the mean. On the east side of Flemish Pass cold conditions begin in late 1970 but persist into 1975. Extremes of 2$^{\circ}$ C below normal are in evidence in 1972, 1973 and 1974, at about 50 m.. Salinities in this time are fresher than normal and this is seen over the whole water column. Conditions on the Flemish Cap follow these events but the cold period extends well into 1977 with extremes occuring in the upper 50 m. The salinities are freshest near the surface in 1971 and 1973 but show a fairly abrupt return to conditions closer to normal in 1974. East of Flemish Cap both temperatures and salinities fall over the whole water column so that by mid 1972 cold, fresh conditions prevail. It is interesting that the only significant time of water fresher than normal occurs in 1971 and can be associated with cold water at 50 m..

These cold, fresh conditions prevail over the mid part of the decade except for the odd warm, salty event. The most notable ones are a brief period of warm, salty conditions over the whole water column in 1973 at station 10, and another event in the upper few hundred metres. The event in 1973 shows no correspondance with events at the other stations except perhaps at station 1. If anything, conditions in mid 1973 at the other stations show colder and fresher conditions. The warm event in 1975 at station 10 does appear to be reflected at station 13 although to a lesser extent.

A shift in the characteristics appears to begin in 1976 or 1977 at all of the stations of the section. The water in the upper 300 - 400 m. becomes warmer and saltier than the mean. These conditions persist into 1979 with extremes in late 1978.

## Discussion

It is possible to make a comparison of these results to those of others. Burmakin (1980) presents an analysis of the heat content of the upper 200 m. along a number of standard sections, one of which is the Flemish Cap. Quantitative comparisons are difficult because of the different ways the analysis are presented but qualitative comparisons are in basic agreement. Burmakin's general statement, that the first 5 years are characterized by colder waters and the second 5 years by warmer waters can be further qualified to be colder and fresher, and warmer and saltier respectively. In particular, there is agreement that a change to warmer conditions occurred in about 1976 or 1977.

It is also possible to compare the presentation for station 1 here with the results of the analysis of the data from station 27 (situated just off St. John's, Newfoundland) presented by Keeley (1981 b). Unfortunately, that analysis cannot present the anomalies beyond the end of 1977 because of the techniques used in their calculation. However, in the early part of the decade, comparisons can be made at certain depths. The consideration of comparisons must be tempered by the differing ways in which means are calculated. In the report for station 27 the long data record was filtered and the low pass portion was used as the mean.

The comparison of the analysis here is best made to the figures in Appendix E of the station 27 report. In particular cold anomalies are seen in 1972 and 1973 at all depths but most pronounced at depth.

## REFERENCES


1. Anon, List of ICNAF Standard Oceanographic Sections and Stations, ICNAF Papers #3, p.109-117, 1978.

2. Anon, Provisional Report of the Scientific Council, Dartmouth, Canada 3-13 June 1980, NAFO SCS DOC 80/V1/25, 1980.

3. Bretherton, F.P., R.E. Davis, B. Fandry, A technique for objective analysis and design of oceanographic experiments applied to MODE -73, Deep Sea Research, Vol. 23, p.559-582, 1976.

4. Burmakin, V.V., Review of hydrological observations in Northwest Atlantic in 1970 - 1979. NAFO SCS DOC 80/IX/136, 1980.

5. Buzdalin, Yu. I., A.A. Elizarov, Hydrological conditions in the Newfoundland Banks and Labrador areas in 1960, Soviet Fisheries Investigations in the Northwest Atlantic, translated by the Israel Program for Scientific Translations for the U.S. Department of the Interior, p.152-168, 1960.

6. Gagnon, J., Time series of oceanographic bottle stations along ICNAF standard sections, MEDS Technical report 159 pp April 1977.

7. Hachey, H.B., Oceanography and Canadian Atlantic Waters. Fisheries Research Board of Canada, Bulletin # 134, 1961.

8. Keeley, J.R., Mean conditions of potential temperatures and salinity along the Flemish Cap section, MEDS Technical Report #9, 149 pp., 1981 a.

9. Keeley, J.R., Temperature, salinity and sigma-t at Station 27, analysis of historical data, MEDS Technical Report #8, 56 pp, January 1981 b.

10. Mann, C.R., The termination of the Gulf Stream and the beginning of the North Atlantic Current, Deep Sea Research, Vol. 14, 337-359, 1967.

11. Ross, C.K., Moored current meter data from Flemish Cap January - July, 1979, NAFO SCR DOC 80/IX/128, 1980.

12. Taylor, J., CONMAP: A computer program for contouring oceanographic data, MEDS Technical Note #12, 41 pp, 1976.

13. Taylor, J. , Changes in program CONMAP from January, 1976 to November, 1977, MEDS. Technical Note #27, 22 pp., 1977.

14. Worthington, L.V., Evidence for a two gyre circulation system in the North Atlantic, Deep Sea Research, 9, p51-67, 1962.

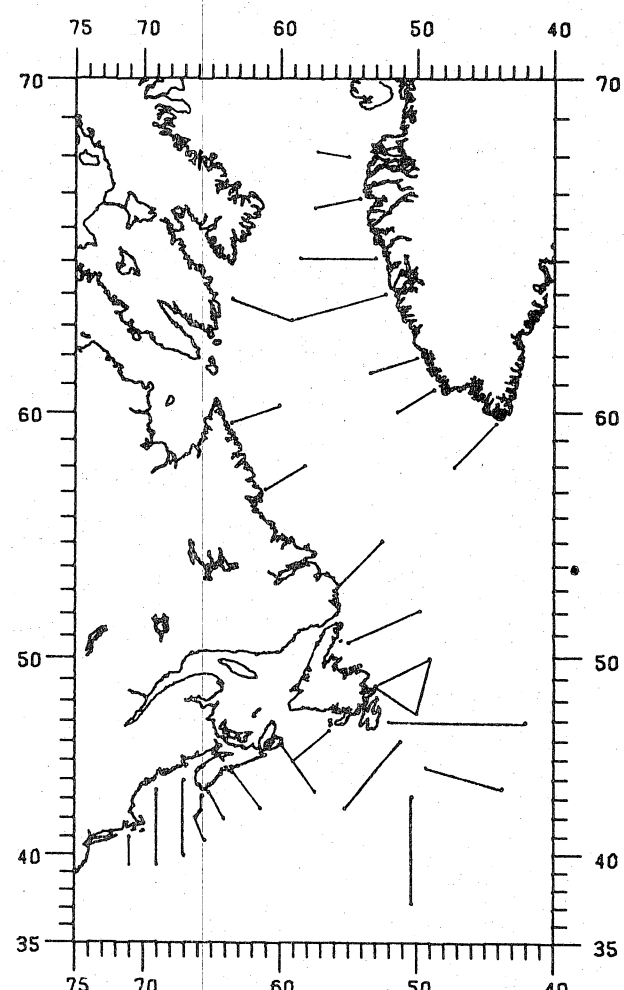



Figure 1

NAFO standard sections.

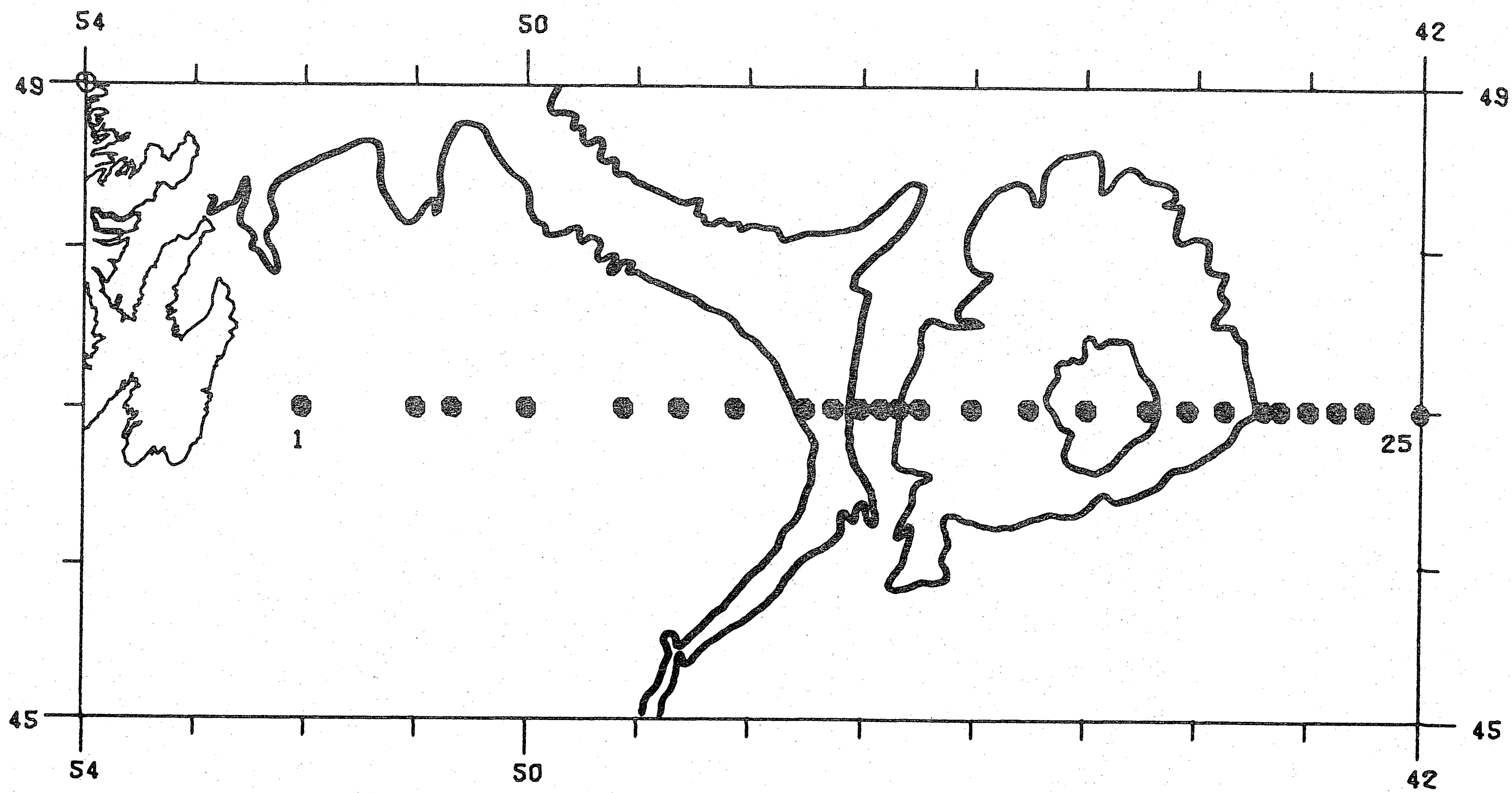



Figure 2

Flemish Cap section.

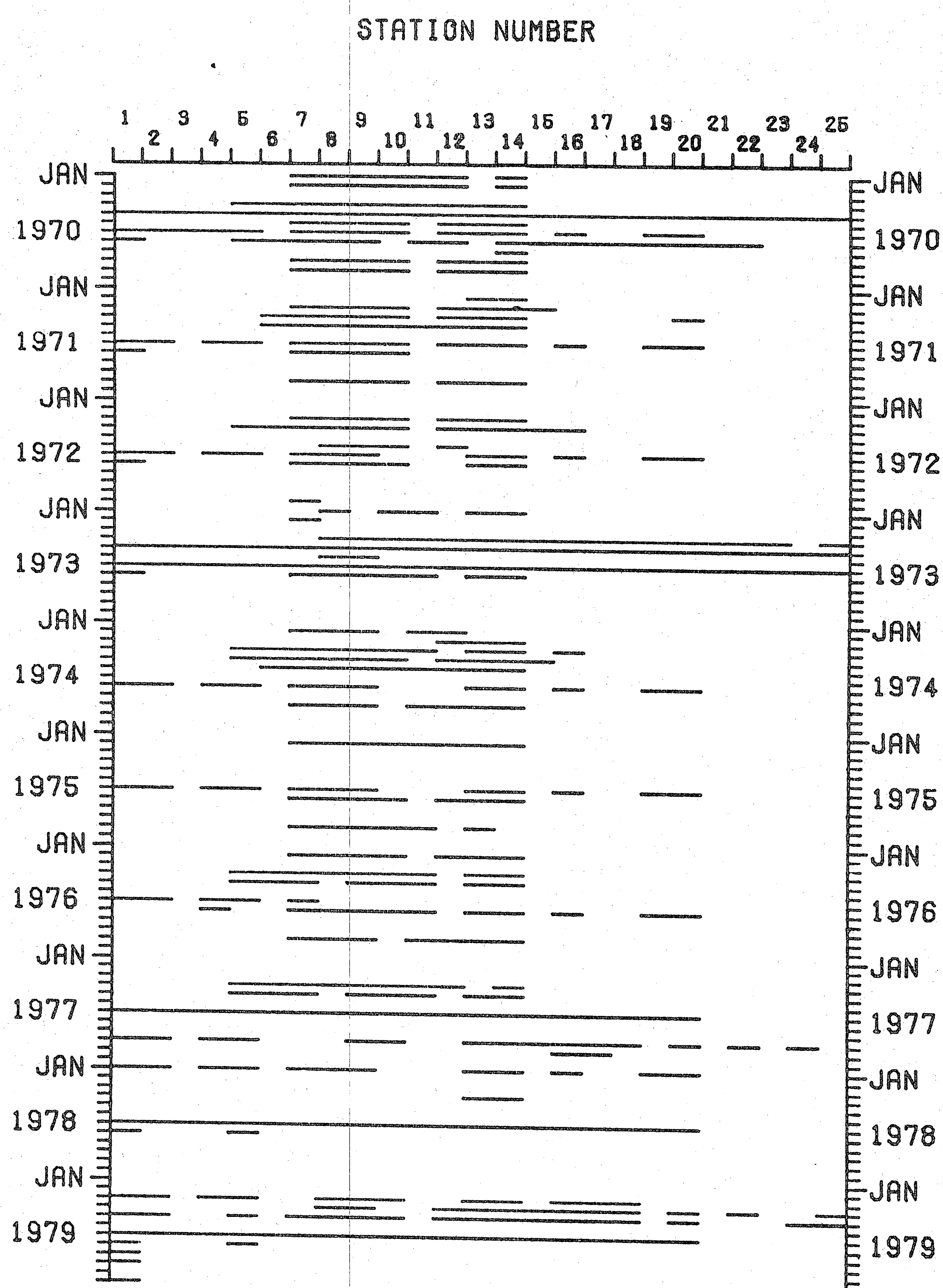

STATION NUMBER
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
JAN
1970
JAN
1971
JAN
1972
JAN
1973
JAN
1974
JAN
1975
JAN
1976
JAN
1977
JAN
1978
JAN
1979

Fig. 3

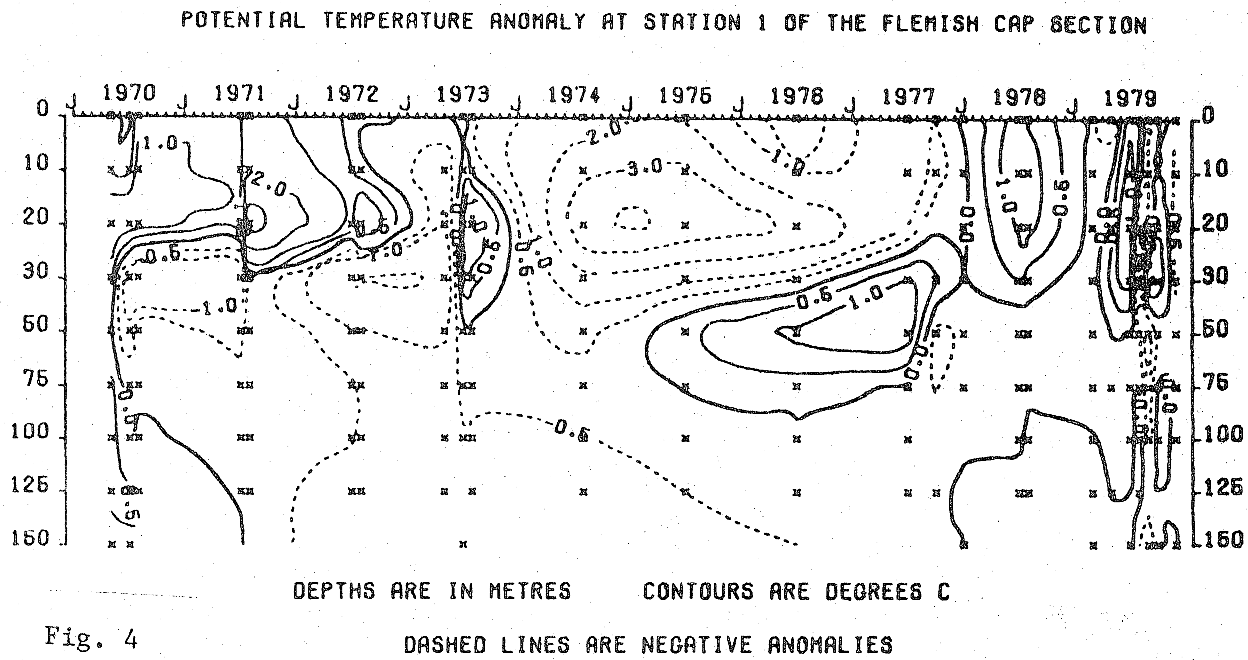

POTENTIAL TEMPERATURE ANOMALY AT STATION 1 OF THE FLEMISH CAP SECTION
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
0
10
20
30
50
75
100
125
150
DEPTHS ARE IN METRES
CONTOURS ARE DEGREES C
DASHED LINES ARE NEGATIVE ANOMALIES

Fig. 4

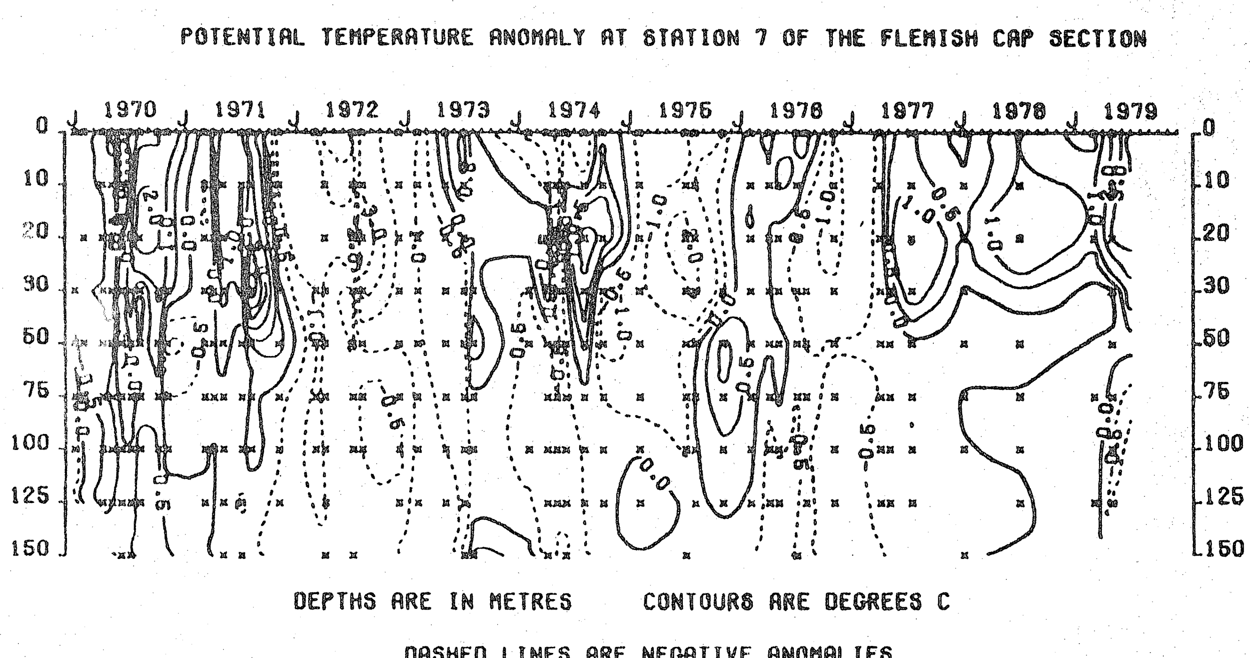
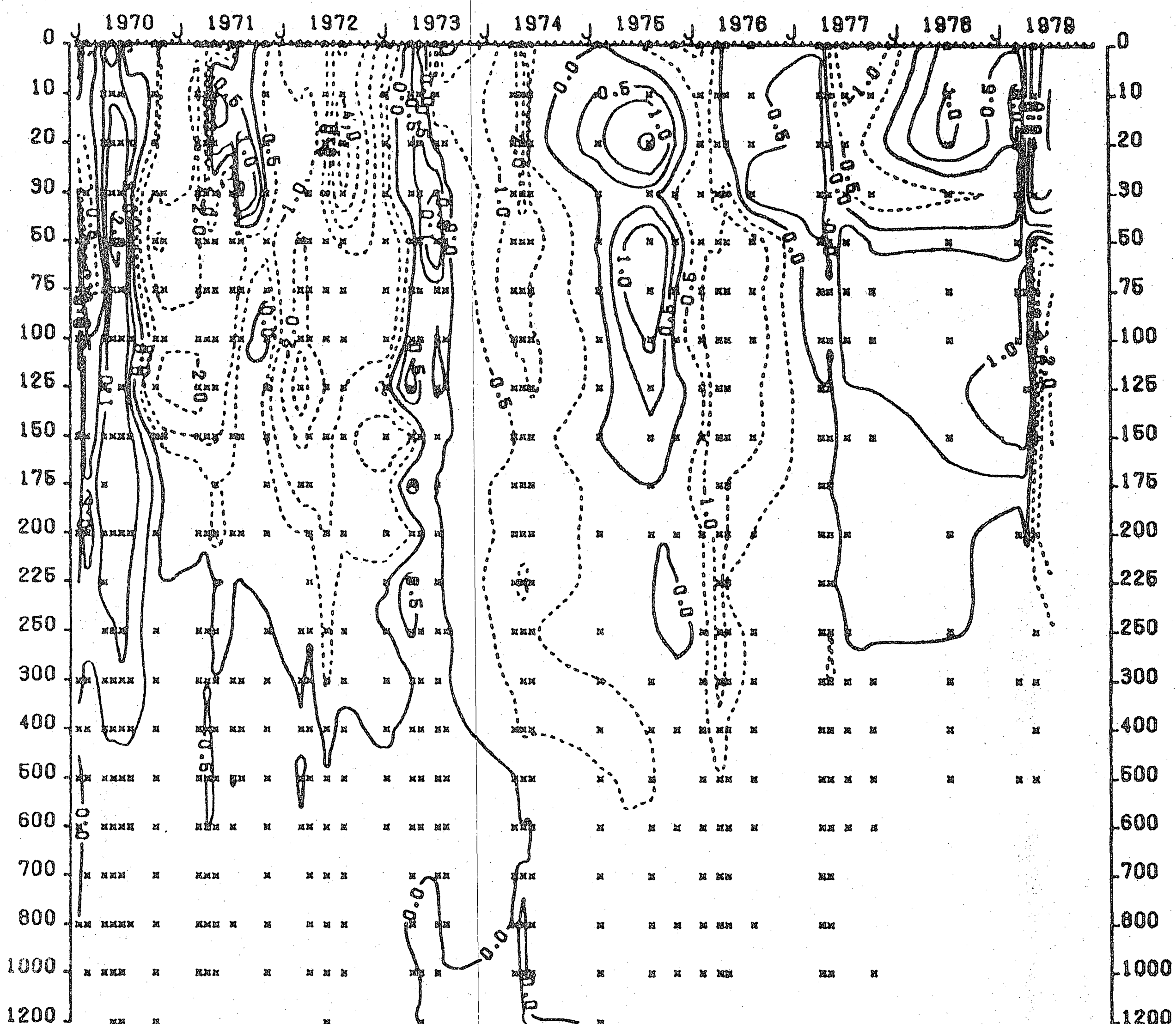

POTENTIAL TEMPERATURE ANOMALY AT STATION 7 OF THE FLEMISH CAP SECTION
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
0
10
20
30
50
75
100
125
150
DEPTHS ARE IN METRES
CONTOURS ARE DEGREES C
DASHED LINES ARE NEGATIVE ANOMALIES

Fig. 5

POTENTIAL TEMPERATURE ANOMALY AT STATION 10 OF THE FLEMISH CAP SECTION




DEPTHS ARE IN METRES     CONTOURS ARE DEGREES C

DASHED LINES ARE NEGATIVE ANOMALIES

Fig. 6

POTENTIAL TEMPERATURE ANOMALY AT STATION 13 OF THE FLEMISH CAP SECTION

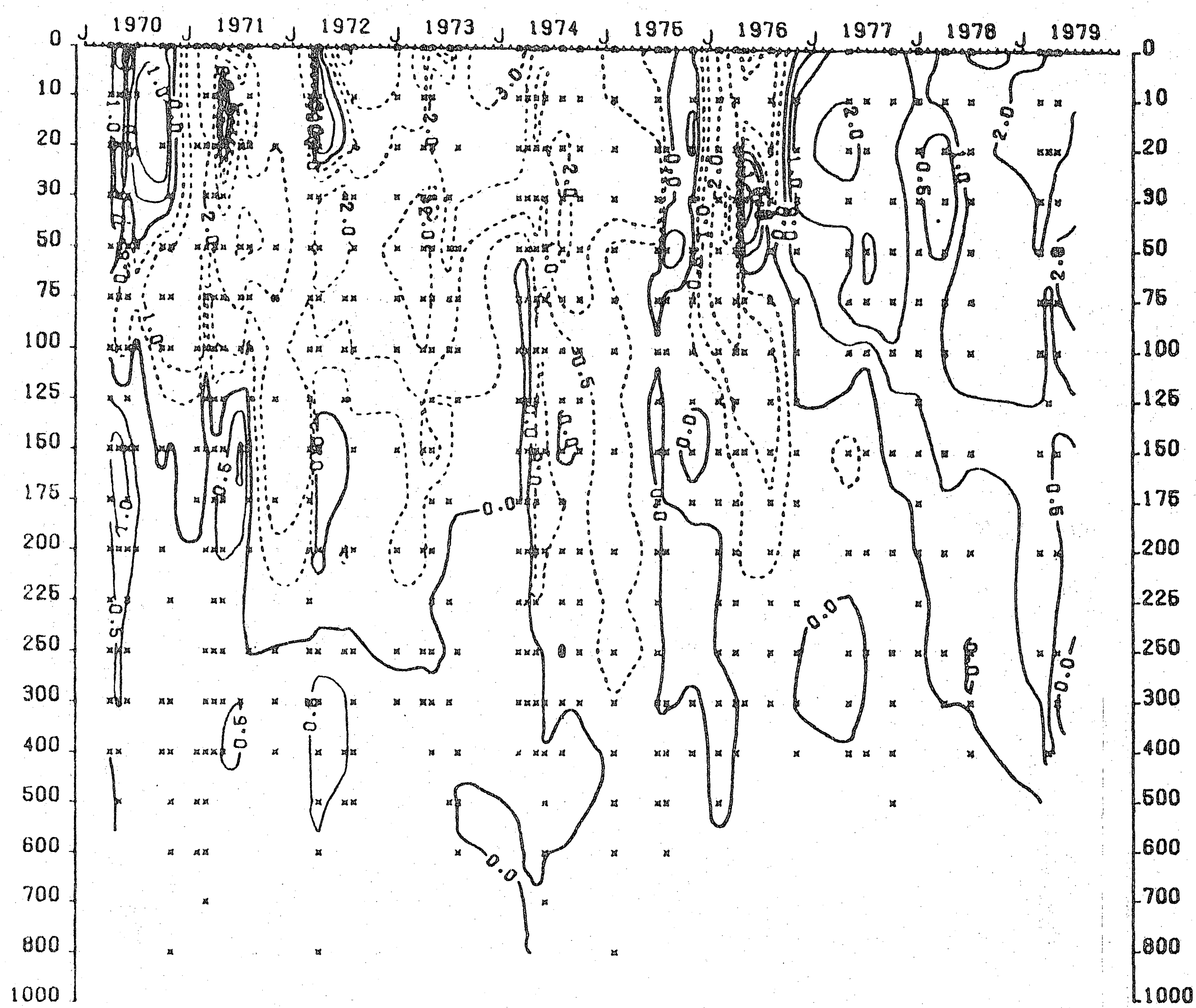
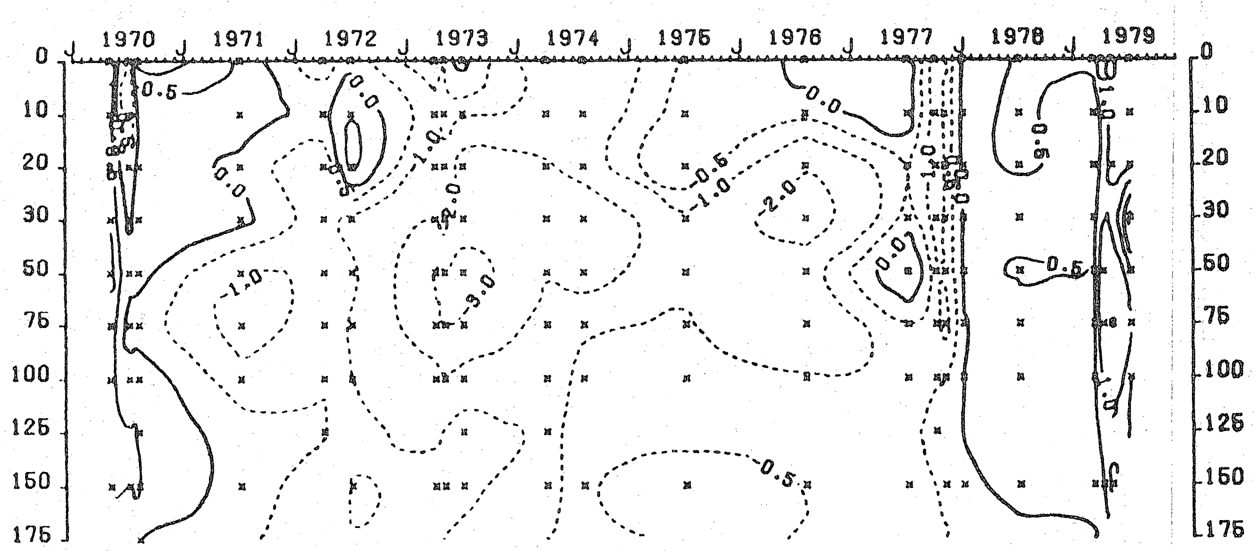



Fig. 7

DEPTHS ARE IN METRES CONTOURS ARE DEGREES C

DASHED LINES ARE NEGATIVE ANOMALIES

POTENTIAL TEMPERATURE ANOMALY AT STATION 16 OF THE FLEMISH CAP SECTION

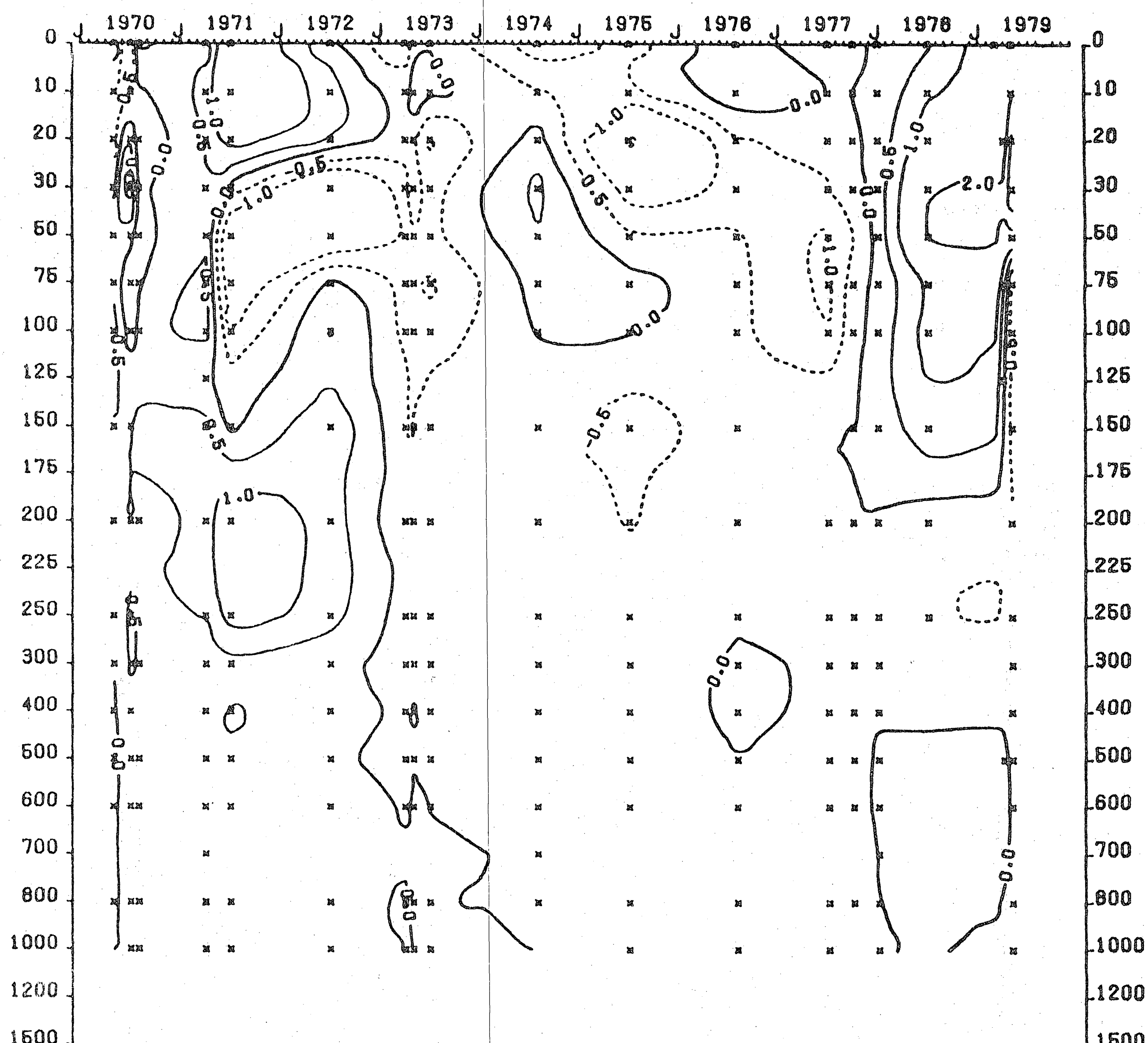



DEPTHS ARE IN METRES CONTOURS ARE DEGREES C

Fig. 8

DASHED LINES ARE NEGATIVE ANOMALIES

POTENTIAL TEMPERATURE ANOMALY AT STATION 20 OF THE FLEMISH CAP SECTION




DEPTHS ARE IN METRES CONTOURS ARE DEGREES C

DASHED LINES ARE NEGATIVE ANOMALIES

Fig. 9

SALINITY ANOMALY AT STATION 1 OF THE FLEMISH CAP SECTION

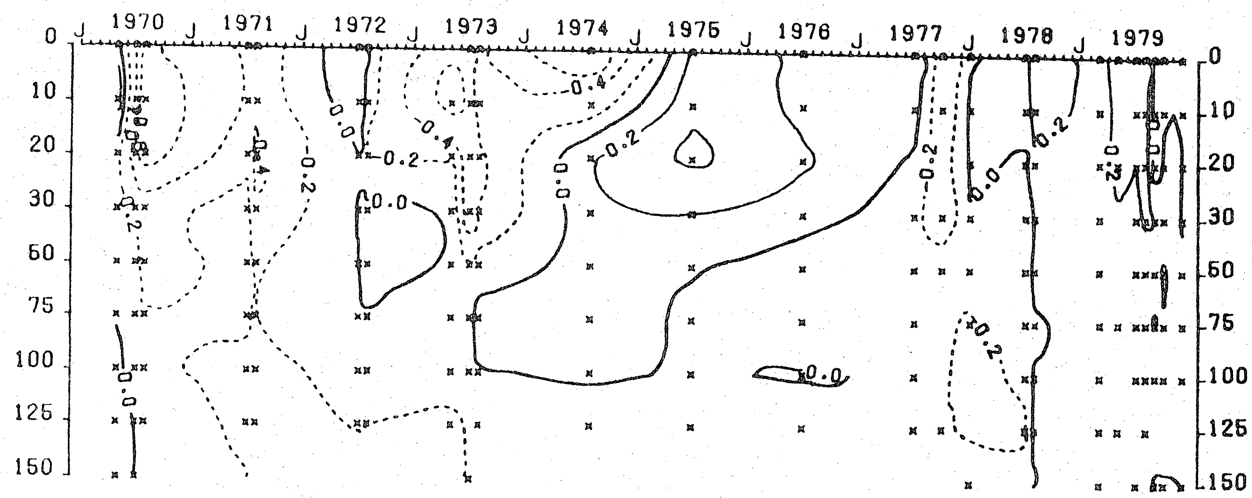



Fig. 10

DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 7 OF THE FLEMISH CAP SECTION

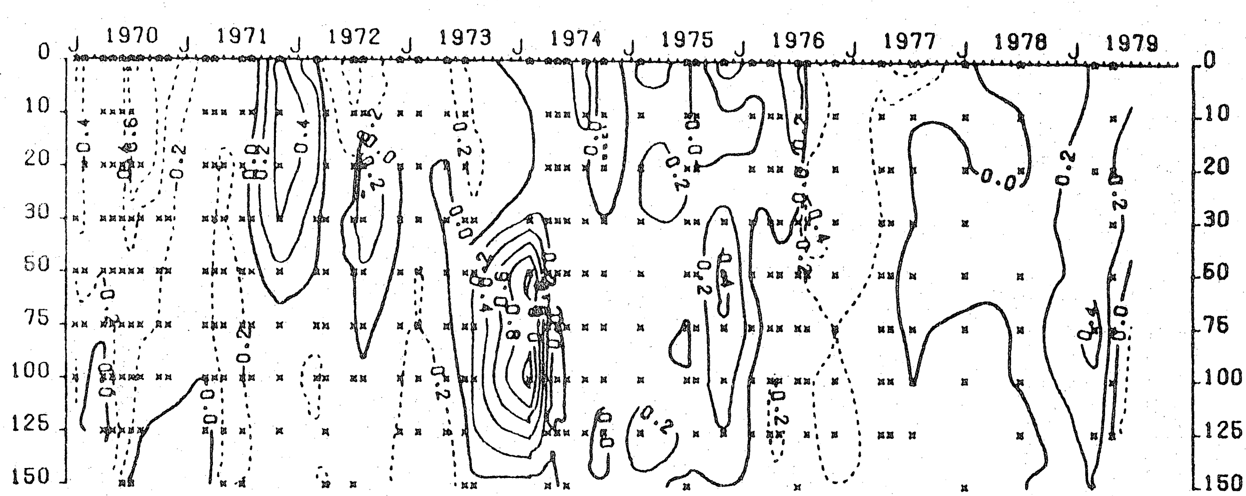
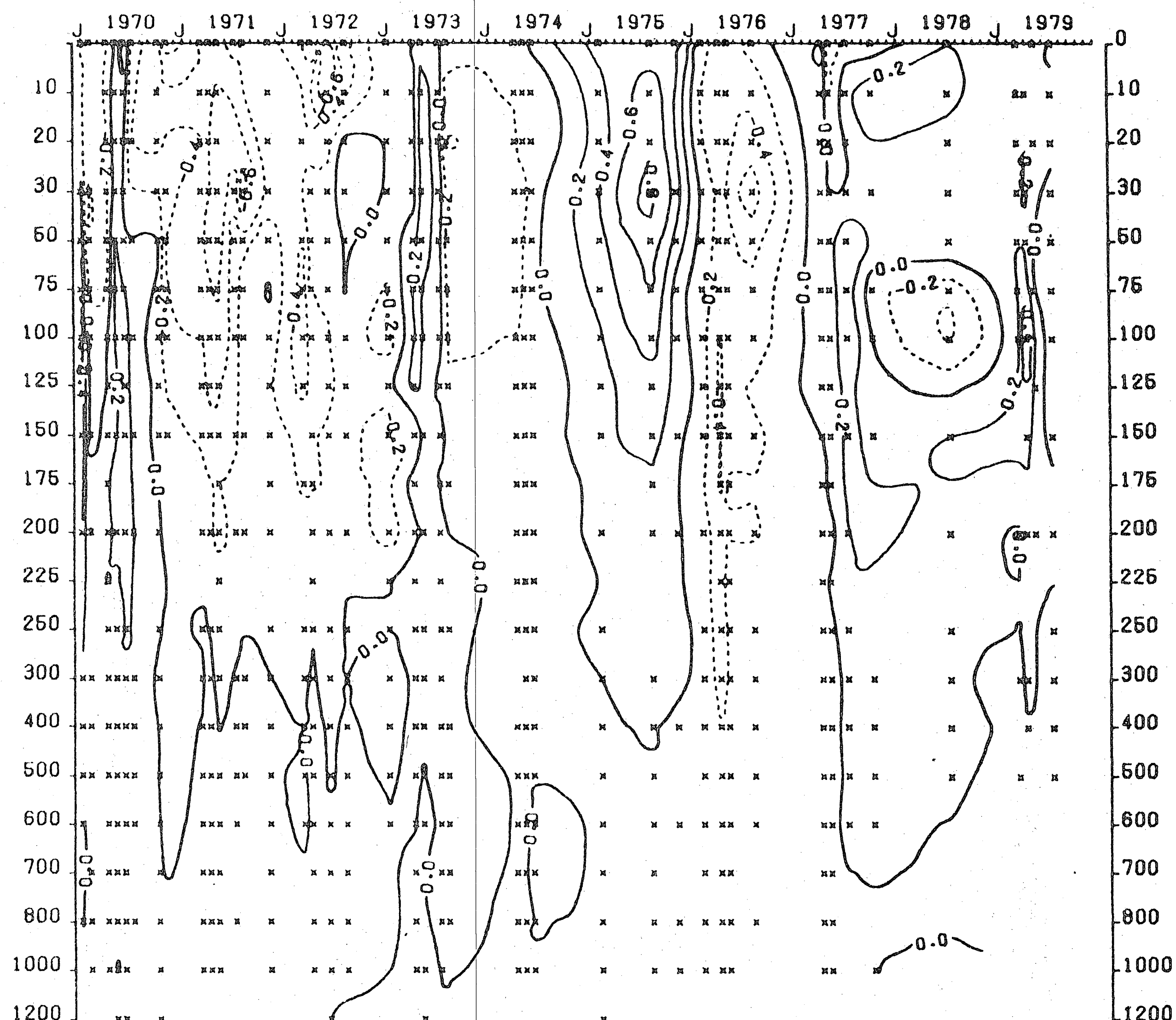



Fig. 11

DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 10 OF THE FLEMISH CAP SECTION




DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

Fig. 12

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 13 OF THE FLEMISH CAP SECTION

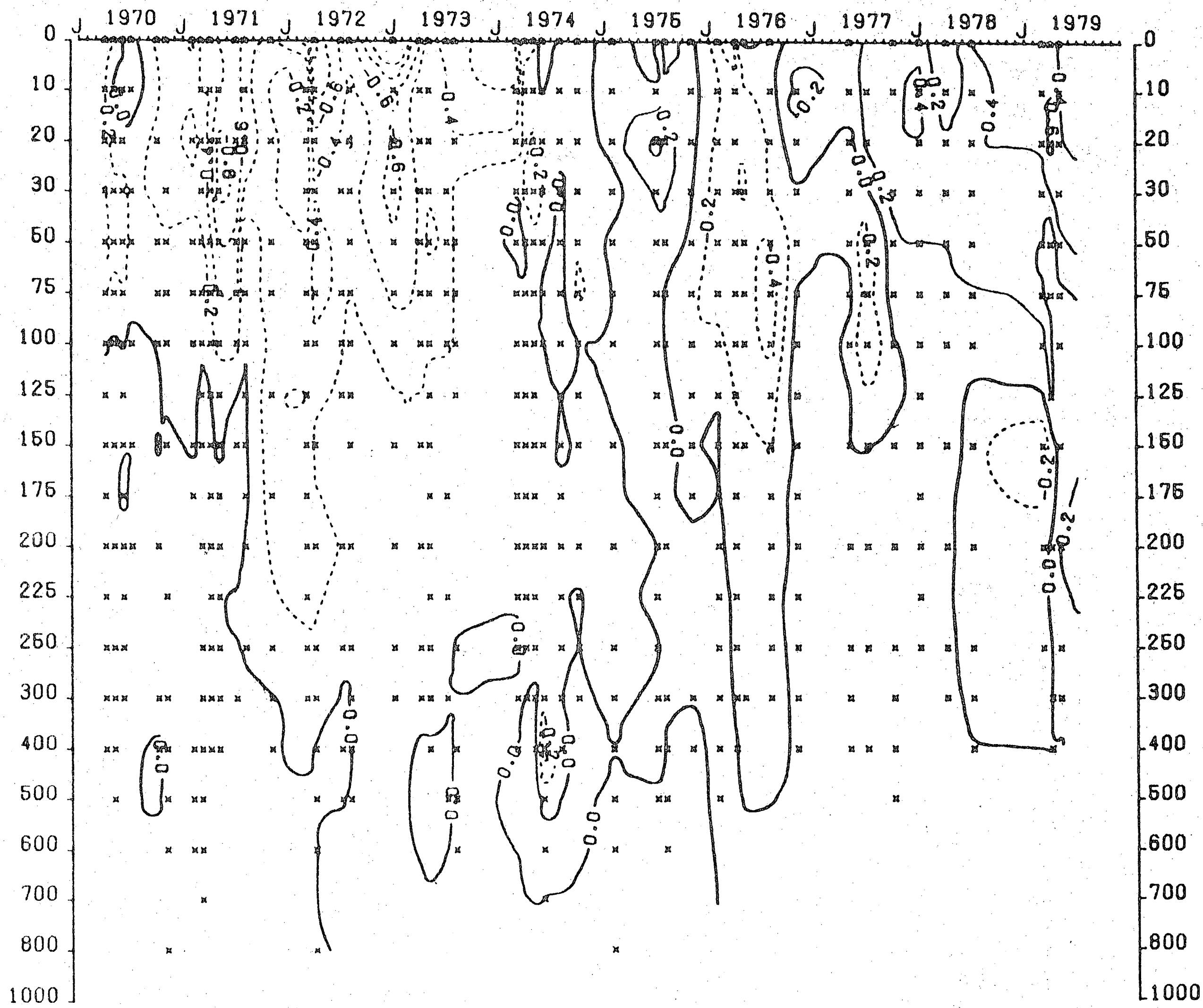



Fig. 13 DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 16 OF THE FLEMISH CAP SECTION

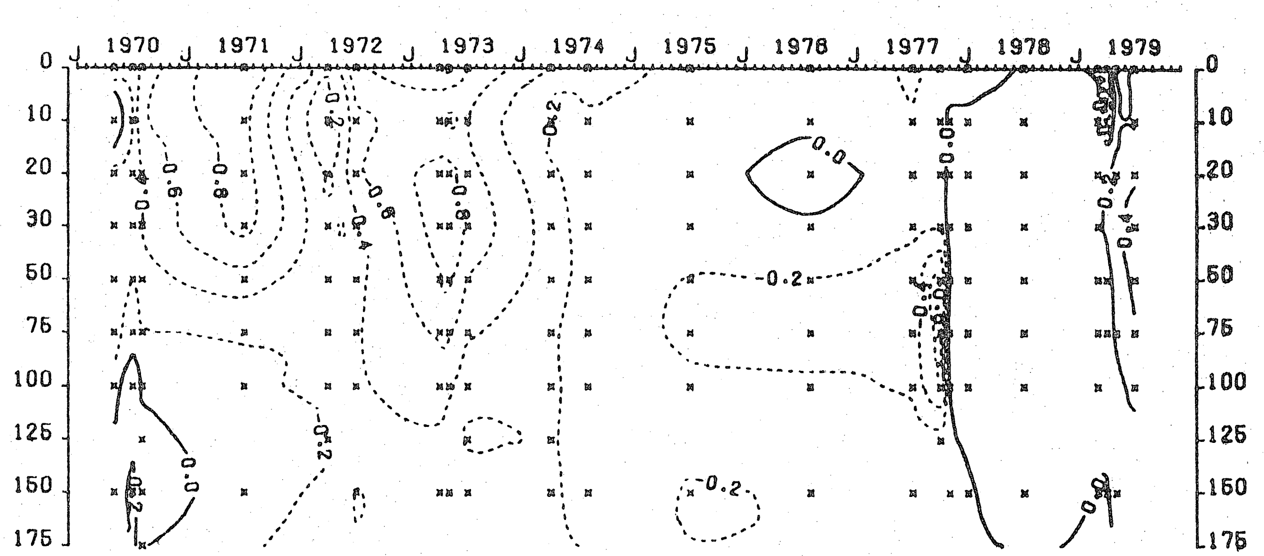
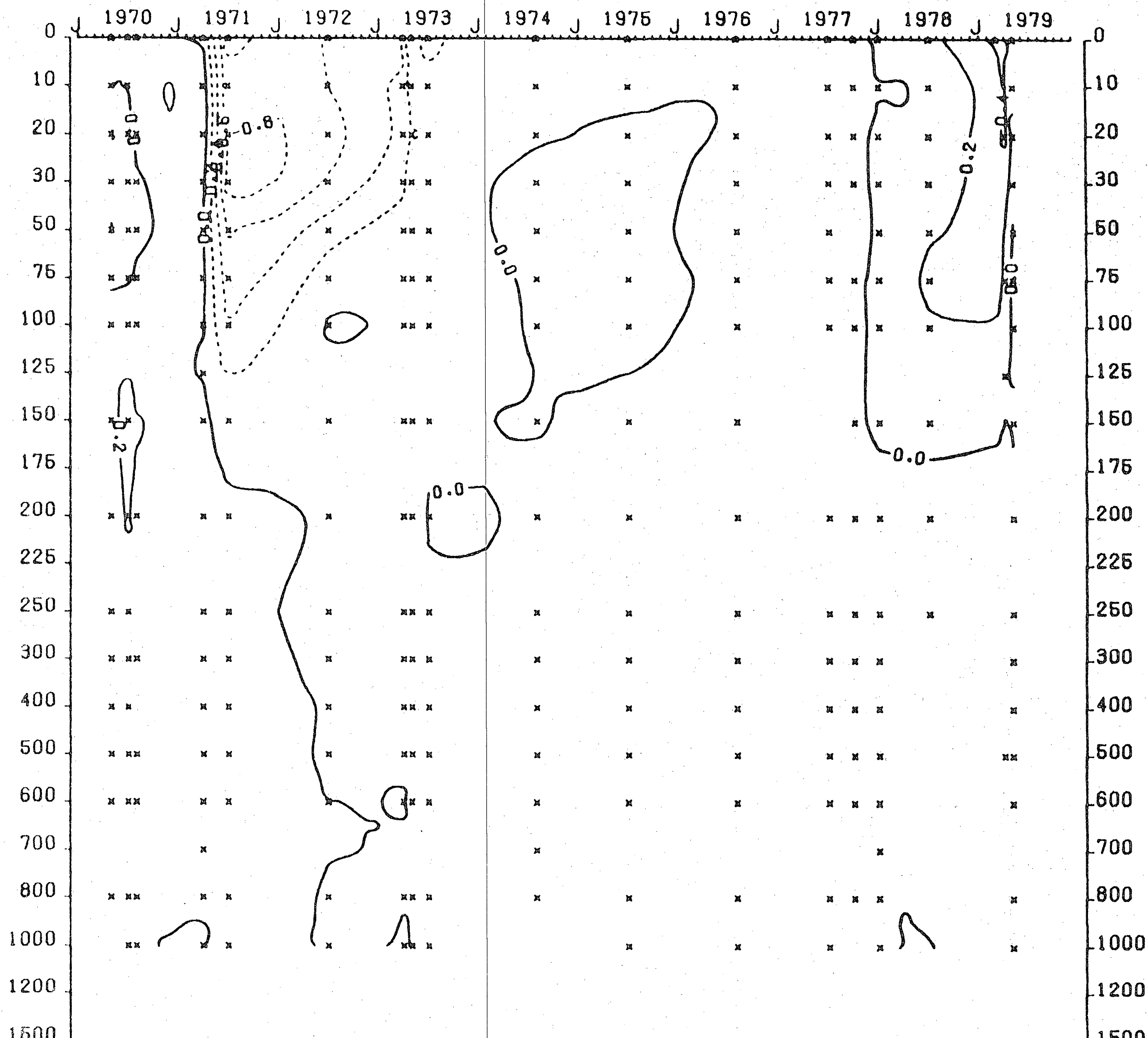



Fig. 14 DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 20 OF THE FLEMISH CAP SECTION




DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

Fig. 15