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INTRODUCTION

The Gulf of St. Lawrence bordering on the shores of five Canadian provinces is featured by, a deep channel extending from a point near the mouth of the Saguenay River to the edge of the continental shelf, a distance of some 750 miles (1400 km.). This channel, the Laurentian Channel, has a tributary, the Esquiman Channel, extending towards the Strait of Belle Isle (figure 1), and it has a branch on the north side of Anticosti Island. In the Laurentian Channel depths range from 100 to 300 fathoms (180-540 metres), thus allowing waters of oceanic origin to proceed a distance of approximately 500 miles inland (920 km.). The origin of the Laurentian Channel or submarine valley has been described (Shepard 1951) as primarily due to glaciation and perhaps it pre-existed the ice age (Wisconsin glacier) as a river valley.

In a previous work (Lauzier and others, 1951) the features of the waters in the surface layers in the Gulf of St. Lawrence have been described. The present work sets forth the intermediate and lower water layers in the Laurentian Channel and attempts to show how they vary both seasonally and from year to year. Several writers have attempted to explain the origin of the intermediate or cold-water layer in the Gulf and on the Scotian Shelf (Bjerkan, 1919; Huntsman, 1930; Hachey, 1938; Tremblay and Lauzier, 1940) however, little more than passing mention has been made of the lower warmer layers of the waters in the Gulf of St. Lawrence.

The data used as the basis for this paper were collected during the period 1946-1948 by observers of the Atlantic Herring Investigation Committee and members of the Atlantic Oceanographic Group. Since the hydrographic observations have been relatively continuous and along the same observations pattern, an opportunity to discuss the variations from season to season and from year to year is afforded.

The data collected in the Laurentian Channel are used to describe the prevailing conditions in Spring, Summer, early Autumn and late Autumn, the Summer and late Autumn cruises being in 1947, the Spring and early Autumn ones in 1948.

Sections across the Laurentian Channel are plotted to show the vertical distribution of temperature and salinity, and to delineate the intermediate and lower water layers. T-S diagrams are used to complete the study of water masses found in the channel, as well as the different types of water that form the intermediate and lower water layers.

The intermediate or cold-water layer is that layer of cold water lying between the surface layer and the lower layer of warmer waters. For our purposes here we have defined the intermediate water layer as being bounded by the 0.0° C. isotherms, and thus having temperatures less than 0.0° C.

Below the intermediate water layer, the lower water layer is found in which temperatures are as high as 5.6° C. and salinities as high as 34.7 °/oo. In this region positive temperature gradients exist, whereas in the intermediate water layer both positive and negative temperature gradients are found.

VERTICAL DISTRIBUTION OF TEMPERATURE AND SALINITY

The sections of temperatures and salinities are described in succession from Cabot Strait to the St. Lawrence River Estuary for Spring, Summer, early Autumn, and late Autumn, respectively. The hydrographic stations used in this paper are contained in the following sections:

Section I	Stations 33 - 39
" II	" 69 - 100
" III	" 78 - 83
" III(A)	" 78E - 89
" IV	" 90 - 94
" V	" 46 - 52
" VI	" 65 - 67

Distribution in Spring 1948 (May and June)

In Section I (figure 2) a layer of cold water, as defined by the 0.0° C. isotherms, is seen to extend across the entire section with an average thickness of sixty-five metres. The most notable feature of this cold-water layer is that the two bounding surfaces are equidistant across the section. The mean depth of the cold-water layer varies from 50 metres at station 35 to 115 metres at station 37W, and then rises to 90 metres at station 39. The mean salinity in the core of this layer is approximately 32.10 °/oo. The warmer water, underlying the cold water and confined to depths greater than 100 metres, has an upper boundary whose mean depth is somewhat greater than 140 metres. A feature worth noting is the association between the 1.0° C. isotherm and the 33.0 °/oo isohaline. This feature will be even more predominant in other sections than in this one. The main temperature gradient in this water is between the 190 and 280 metre levels where the temperature changes from 1 to 5 °C. Below 300 metres to the bottom (500 metres) the temperature gradient is slightly negative as compared to higher levels, with a maximum salinity of 34.70 °/oo.

The cold-water layer in Section II (figure 3) reaches across the entire section as in Section I. Commencing at station 69 where the layer is only eight metres thick at the 75 metre level, the thickness changes rapidly to seventy-five metres in the middle of the section and then it tapers to a thickness of twenty-five metres at station 100. The salinity in this minimum-temperature layer varies between 32.4 and 32.6 °/oo. The deep waters found on the average below the 150 metre level show a rapid change in temperature between 150 and 200 metres. Below 200 metres the changes are more gradual, with temperatures slightly greater than 5.0 °C. at 300 metres, and with a salinity less than 34.9 °/oo.

In Section III (figure 4) the cold-water layer extends from its point of greatest thickness at station 82 to midway between station 78 and 79 where it is pinched out by the surface layer. The upper boundary is seen to vary from 30 metres at stations 80 and 81, to 40 metres at station 83, and to 75 metres between stations 78 and 79. The lower boundary varies in a similar manner as the upper boundary, and ranges from 115 metres at station 79 to 85 and 125 metres at stations 80 and 82 respectively. The salinities, at the minimum-temperature levels, vary between 32.0 to 32.4 °/oo from station 79 to 82. The lower water layers, found below the 120 metre level exhibit gradual changes in temperature and salinity with depth, reaching a maximum temperature of 4.8 °C. and a corresponding salinity of 34.4 °/oo, at the 300 metre level.

Figure 5 shows the cold-water layer in Section IV extending across the entire section as a broad band of approximately forty-five metres thickness. Salinities in the core of this cold-water layer generally range between 31.8 and 32.3 °/oo, while a minimum temperature of -0.8° C. is found at station 91. In this section the lower waters, with temperature greater than 1.0° C. and salinities generally greater than 33.0 °/oo have an upper boundary varying in depth from 100 metres at station 90 to 125 metres at stations 92N and 94. The same general stratification is in evidence, as was shown throughout the previous sections, with temperatures and salinities near the bottom as high as 4.6° C. and 34.5 °/oo respectively.

In the Esquiman Channel (Section V)(figure 6) the cold-water layer was on the average one hundred metres in thickness. About 40% of this water was of the temperature of less than -1.0° C., and the average salinity in the core of this layer was of the order of 32.40 °/oo. In the deep trench along the Newfoundland Coast maximum salinities of 34.60 °/oo were associated with a temperature of 5.1° C. The 1.0° C. isotherm and 33.0 °/oo isohaline were closely related as in the Laurentian Channel.

In the Jacques-Cartier Passage (figure 7A) a minimum temperature -0.9° C. was recorded at 75 metres and the maximum temperature at depth was 4.4° C.

Distribution in Summer 1947

In Section I (figure 8) the intermediate water layer extends from a point between stations 35 and 37W to a point between stations 38 and 39. Between these two points the bounding surfaces are practically level, the distance between them being approximately sixty metres. In this body of cold water the observed temperatures range from -0.10° C. at station 38 to -0.36° C. at 37W, while the corresponding salinities range from 32.1 to 32.5 °/oo. This cold-water layer, which is confined to the deeper portion of the section and the Newfoundland shore, lies between the 65 and 125 metre levels. In the lower water layers the distribution of temperature and salinity is similar to that observed in the Spring. There is a close association between the 4.0° C. isotherm and the 34.0 °/oo isohaline which may be observed in other sections. An observed maximum temperature of 5.2° C. and a corresponding salinity of 34.5 °/oo are found at the 300 metre level. While no observations were made below this level, on the basis of previous observations, it is expected that there is little change in temperature and salinity from this level to the bottom (485 metres).

A large body of intermediate water is in evidence, in Section II (figure 9), with a maximum thickness of approximately one hundred and twenty metres at station 99. The cold water is replaced by the warmer water flowing over and around American Bank (station 69) on one side, and tapers to a thickness of sixty metres at station 100 on the other side. In addition, a small core of water with temperatures less than -1.0° C. is found at the 75 metre level at station 99. The warmer waters in the lower layers have been depressed to some extent by the large volume of cold water at station 99, so that the upper boundary (1.0° C. isotherm) extends from 135 metres at station 98 to 175 metres at station 99, and rises to 165 metres at station 100. No observations were made below 250 metres, where at station 99, in the deeper portion of the section, a temperature of 3.9° C.

and a salinity of 33.8 °/oo were observed.

Figure 10 shows the cold-water layer in Section III to be about fifty metres thick, and to extend diagonally across the section to a point midway between stations 78 and 79. At station 79 the thickness increases to seventy metres. The lower layers of warmer water in this section all slope to the left and conform generally to the slopes of the isotherms and isohalines throughout the entire section. The vertical distribution at any particular station is similar to that described earlier. The close association between the 1.0° C. isotherm and the 33.0 °/oo isohaline, and the 4.0° C. isotherm and the 34.0 °/oo isohaline, is again noted for this section.

The cold-water layer in Section IV (figure 11) in the Summer of 1947, is continuous across the entire section, and appears to be fairly uniform in depth and thickness throughout. The temperature minima throughout the cold-water layer are approximately -0.5° C., while the salinity, increasing with depth, varies from slightly less than 32.0 °/oo at the upper 0.0° C. isotherm, to approximately 32.5 °/oo at the lower one. In the lower water layers the salinity and temperature distribution are similar to previous sections, with the greatest temperature changes being observed in the upper 100 metres.

In the Jacques-Cartier Passage (figure 7B) the minimum temperature observed in the cold-water layer was -0.7° C. Near the bottom, the temperature had decreased since Spring from 4.4° C. to 3.5° C., the salinity from 34.4 to 33.7 °/oo.

Distribution in the early Autumn 1948

In early Autumn, the cold-water layer in Section I (figure 12) is confined to two small areas at opposite ends of the section. One, at station 35 lying between the 80 and 110 metre levels, extends from the eastern slopes of the Magdalen Shallows toward station 37W. The other, of moderate size, is found at station 38 between the 90 and 125 metre levels. In the lower layer, temperatures and salinities greater than 1.0° C. and 33.0 °/oo respectively, were observed below 120 metres. As in other cases the 1.0° C. isotherm and the 33.0 °/oo isohaline are very closely associated with each other. The 5.0° C. isotherm, at the 250 metre level, is significantly nearer the surface than in the previous sections. This seasonal variation in the depths of isotherms in the lower layers would seem to be associated with the varying volume of cold water in the intermediate layer. A temperature of 5.2° C. at 300 metres indicates that there is little temperature gradient in the deeper waters.

In figure 13 the intermediate layer extends across the whole of Section II, and the upper boundary varies in depth from 80 to 40 metres at stations 69 and 100 respectively. The lowest temperatures were found at station 100 where temperatures as low as -0.6° C. were observed at the 75 and 100 metre levels. The average salinity in the core of the intermediate layer was 32.4 °/oo. The lower boundary of the cold-water layer varies between 90, 75 and 115 metres at stations 98, 99 and 100 respectively. The upper boundary of the lower water layers is indicated by the 1.0° C. isotherm and is generally associated with the 33.0 °/oo isohaline. This boundary is shallowest at station 99 where it is found at 115 metres; at stations 98 and 100 it drops to 130 and 150 metres respectively. Observations extended only to 250 metres where a temperature of 4.5° C. and a salinity of 34.33 °/oo were observed.

Section IIIA, as shown in figure 14, has the cold-water layer divided into two bodies with temperatures less than 0.0° C. One, extending from between stations 78E and 80 to south of station 85, is found occupying the levels between 40 and 80 metres, and having temperatures as low as 0.4° C. The other, extending from north of station 85 to Banc Rouge, is found between the 65 and 100 metre levels, with temperatures as low as -0.1° C. The average salinity of the core of these two bodies is approximately $32.3^{\circ}/oo$, in each case. The warmer water in the lower layers has its upper boundary, as indicated by the 1.0° C. isotherm, extending from the 100 metre level near station 78E to 125 metres at station 87.

The cold-water layer in Section IV (figure 15) is seen to be confined to a tongue of water with temperatures as low as -0.4° C. with salinity of $32.5^{\circ}/oo$, extending from depths of 30 metres down to 75 metres. This tongue was observed, in the main, to the southern portion of the Laurentian Channel passing through this section. The lower water layer in this section, with temperatures and salinities respectively greater than 1.0° C. and $33.0^{\circ}/oo$, is found below the 100 metre level and follows the usual distribution pattern with observed maximum of temperature and salinity of 4.3° C. and $34.3^{\circ}/oo$ respectively.

Section V for Esquiman Channel (figure 16) shows the cold-water layer as being located chiefly on the Newfoundland side. The minimum temperature water has an average salinity of $32.6^{\circ}/oo$. However, in the northern channel, station 52, the observed minimum temperature was 0.4° C. with a salinity of $32.7^{\circ}/oo$. The maximum salinity of the deep water in the channel was recorded as $34.4^{\circ}/oo$ which had a maximum temperature of 5.0° C. In the Jacques-Cartier Passage (figure 7C) the cold-water layer had almost disappeared and the maximum bottom temperature had increased to 4.2° C., approaching the spring level of temperature. The bottom salinity was 33.7°/oo.

Distribution in late Autumn 1947

Figure 17, depicting Section I, in November shows that the cold-water layer, as defined, is absent in this section. The minimum temperature in this section is greater than 0.2° C. In the space usually occupied by temperatures of less than 0.0° C., there is a water mass with salinities similar to these of the cold-water layer, 32.4°/oo on the average, but with temperatures all above 0.0° C. It is of interest to note that this body of water appears to extend from the Magdalen Shallows area, rather than from the Newfoundland Coast as did the water with temperatures less than 0° C. in earlier seasons. The upper boundary of the lower water layers is found as shallow as 118 metres at station 37W, but deepens to 136 and 143 metres at station 35 and 38 respectively. This raising of the warmer water boundary is in good agreement with the theory expressed earlier in viewing the distribution in the early Autumn in this section. This decrease in depth of the isotherms is also shown in the change in the depth of the 5.0° C. isotherm, which is found at the 220 metre level at station 37W. The observed maximum temperature on the bottom was 5.6° C. with a salinity of 34.7°/oo.

In Section II (figure 18) the intermediate water is confined in two small bodies. One, at station 97 between the 45 and 65 metre levels, has a minimum temperature of -0.13° C. The other is tongue-shaped with its base at station 100 between the 85 and 115 metre levels, and, extending to the 75 metre level just north of station 99. A minimum temperature of -0.97° C. was found at the 100 metre level at station 100. The average salinity of that layer was 32.4 °/oo. The upper boundary of the lower water layers is practically level between stations 98 and 99 at 120 metres, but drops to 140 metres at station 100.

In Section IIIA (figure 19) the cold-water layer, with temperatures as low as -0.4° C., is confined to a small body centred between stations 80 and 85 with a mean depth of 100 metres and average salinity of 32.4 °/oo. The upper boundary of the lower water layers varies from 170 metres at station 78E to 115 metres at station 80, and then drops to 145 metres at station 82. The most marked temperature and salinity gradients in these waters occur between the 100 and 250 metre levels with only slight changes below 250 metres. At 300 metres the temperature and salinity were respectively 4.4° C. and 34.2 °/oo.

SEASONAL VARIATIONS IN THE VOLUME OF THE COLD-WATER LAYER

From the foregoing description of the vertical distributions of temperature and salinity it is evident that there are considerable variations in the extent and thickness of the cold-water layer from one season to another.

By averaging the respective depths of the upper and lower boundaries for each section and taking the differences, we arrive at the average thickness of the cold-water layer. These figures are entered in Table I. The measured width of each body of cold water was multiplied by the thickness to give the area occupied by the cold-water layer in each section.

In Table II, the total areas of the sections are given, and the portions of the respective sections occupied by the intermediate layer are indicated.

TABLE I

Features of the intermediate cold-water layer.

Season	Particulars	Stations					
		90-94	78-83	69-100	33-39	52-46	65-67
Spring	Upper 0°C. Depth (m)	35	41	66	70	30	60
	Lower 0°C. Depth (m)	96	106	114	110	136	112
	Thickness (metres)	61	59	48	40	106	52
	Width (kilometres)	87	55	87	120	81	28
	Area (square km.)	5.3	3.3	4.1	4.8	8.3	1.4
Summer	Upper 0°C.	31	68	42	67		67
	Lower 0°C.	70	114	127	113	no	111
	Thickness	39	46	86	46		44
	Width	83	59	78	83	data	18
	Area	3.2	2.9	6.7	3.8		0.8
Early Autumn	Upper 0°C.	30	43	40	73	55	70
	Lower 0°C.	75	80	95	118	115	80
	Thickness	45	37	55	45	60	10
	Width	31	65	74	74	55	6
	Area	1.4	2.4	4.1	3.4	3.2	0.1
Late Autumn	Upper 0°C.	no	85	65	---		
	Lower 0°C.		115	92	---	no	no
	Thickness	Data	30	27	---		
	Width		33	46	---	data	data
	Area		1.0	1.3	0		

The geographical variations in the depth and volume of the intermediate layer, in any one season, are not very consistent, but the following observations might be recorded:

(a) The upper isotherm of 0.0°C. has a tendency to be deeper from Anticosti Island to Cabot Strait than in the northwest and northeast sectors of the Gulf,

(b) the thickness of the intermediate layer seems to be greatest in the Esquiman Channel, and,

(c) in the Spring, the intermediate layer occupies more space in Esquiman Channel than anywhere else.

TABLE II

Areas of sections and portions occupied by the intermediate layer.

Particulars	Stations					
	90-94	78-83	69-100	33-39	52-46	65-67
Total Area (square km.)	26.6	17.2	18.7	43.5	16.3	4.7
Portion of intermediate layer in:						
Spring	20%	19%	22%	11%	51%	31%
Summer	12	17	36	8.7	no data	17
Early Autumn	5.3	14	22	7.7	20	1.3
Late Autumn	no data	5.9	6.7	0.0	no data	no data

The seasonal variations are quite prominent. The upper isotherm of 0.0° C. tends to deepen with the season, and the lower isotherm of 0.0° C. to shallow. As a result of both movements the thickness decreases from Spring to Autumn. During the same period the intermediate layer also contracts. There is thus an obvious change in the volume of the cold-water layer in any particular section from season to season, a decrease from a maximum in Spring to a minimum in the Autumn. These changes are indicated in Table III where the volume (per unit length) of cold water in Spring has been taken emperically as 100% and the relative percentages of the cold-water layer remaining at different seasons calculated.

With the exception of stations 69-100 in the Summer months, the sections show a decrease in the volume of cold water from Spring to Autumn. The greatest decrease in the volume of cold water (less than 0.0° C.) takes place between the months of September and November, as much as 70% at the stations 33-39. Unfortunately no data are available in the winter months to allow a fuller estimation of the minimum and maximum amount of cold water in any given year.

TABLE III

Relative percentage of intermediate layer at different seasons as compared to the Spring distribution.

Seasons	Stations					
	90-94	78-83	69-100	33-39	52-46	65-67
Spring	100%	100%	100%	100%	100%	100%
Summer	60	87	161	78	no data	57
Early Autumn	27	72	100	70	39	4
Late Autumn	no data	31	31	0	no data	no data

The cold-water layer, up to this point has been described as an intermediate layer. However, the layer is also present over the Magdalen Shallows (the southwestern Gulf) where the depths are less than 100 metres, and hence the lower water layer is absent. The data collected in 1948 and listed in Table IV show the regression of the cold-water layer in the Magdalen Shallows, its disappearance from certain sections and its thinning in other sections. The average depth of the 0.0° C. isotherm and the recorded minimum temperature were the criteria used in this case.

TABLE IV

Seasonal Variations in the cold-water layer in the southwestern Gulf of St. Lawrence.

Area	Season	Average Depth of 0.0° C. isotherms	Recorded Minimum Temperatures
Off Cape Breton S.E. of Magdalen Island	Spring (May)	32 metres	-1.0° C.
	Early Summer (July)	47	-0.6
	Late Summer (August)	--	0.2
	Early Autumn (October)	--	0.2
Around Bradelle Bank - W. of Magdalen Is.	Spring	40	-0.9
	Early Summer	43	-0.5
	Late Summer	47	-0.4
	Early Autumn	50	-0.15

SEASONAL VARIATIONS IN THE VOLUME OF WARM DEEP LAYER

The body of water underlying the cold-water layer has been described as a warm water layer having temperatures as high as 5.6° C. and salinities greater than 34.0 °/oo. The 4° C. isotherm was observed in all sections throughout the year, but the 5° C. isotherm occurred only in a few. Thus in calculating the volume of the deep layer the upper boundary was taken as the 4° C. isotherm and the lower boundary as the bottom. Table V, shows the calculated unit volumes or areas, for each section throughout the various seasons.

TABLE V

Area of the deep warm layer.
(in square km.)

Season	Stations					
	90-94	78-83	69-100	33-39	52-46	65-67
Spring	3.5	3.3	4.2	16.5	1.2	0.2
Summer	6.3	2.1	3.4	16.0	no data	0.0
Early Autumn	5.6	2.7	4.9	18.5	2.0	0.2
Late Autumn	no data	4.0	4.6	19.0	no data	no data

It may be seen from Table V that the volume of the warm deep layer increases from Spring to Autumn, and that the actual volume is large near Cabot Strait and comparatively small in Esquiman Channel. The seasonal variations show that, on the average, the volume of the deep layer had increased by approximately 20% over all the Gulf. However, the geographical variations are largely masked by the variations in depth and the bottom configuration of each section, since the bottom is the lower limit of this body of water. The variation in the depth of the 4° C. isotherm shows that the deep layer is somewhat wedged into the Laurentian Channel, being at greater depths toward the Estuary than towards the open ocean. These depths are shown in Table VI.

The data from Table VI show that the 1° C. isotherm as did the 0° C. isotherm (see Table I), had a tendency to shallow from the Cabot Strait area to the northwest end of the Channel. From the geographical variations of the two isotherms it may be seen that the temperature gradient between 1° and 4° C. decreases with the distance from the ocean. This indicates that mixing is more intense in the northwest sector of the Channel than in Cabot Strait.

TABLE VI

Average depth of the 1.0° C. and 4.0° C. isotherms and 34.0 °/oo isohaline.

Season	Particulars	Stations					
		90-94	78-83	69-100	33-39	52-46	65-67
Spring	1° C.	120 m.	130	145	145	165	140
	4°	270	250	240	210	225	190
	34.0 °/oo	270	220	205	210	240	185
Summer	1°	95	150	155	115	no data	130
	4°	225	280	260	240		---
	34.0 °/oo	210	280	260	240		---
Early Autumn	1°	115	115	130	140	130	110
	4°	240	255	220	200	190	185
	34.0 °/oo	230	210	200	190	190	---
Late Autumn	1°	no data	140	125	135	no data	no data
	4°		230	225	185		
	34.0 °/oo		215	200	200		

The seasonal variations of the depth of 1° C. isotherm are not as consistent as those for the 4° C. isotherm, but they show a tendency of decreasing depths from Spring to Autumn. Nevertheless they follow the variations of the lower 0° C. isotherm. On the average, the 34.0 °/oo isohaline falls within 15 metres of the 4° C. isotherm.

As previously mentioned, a decrease in the volume of the cold-water layer is accompanied by an increase in the volume of the warm deep layer, with a subsequent raising of the depth of some of the isotherms in this water. Since the temperature and salinity are also increased in the cold-water layer, with the progress of the seasons, this suggests that the lower layer water from the ocean is maintained, and that the cold water is being consumed by vertical mixing between the cold-water layer and the two bounding water bodies.

TEMPERATURE-SALINITY RELATIONSHIP

The relationship between the two variables, temperature and salinity, were described earlier in this paper in referring to associations such as those of the 1.0° C. isotherm and the 33.0 °/oo isohaline. The salinity associated with minimum temperatures was given for most sections.

The temperature-salinity (T-S) characteristics as shown on a T-S diagram are used to define water masses and to study the various mixture of water types. The temperature-salinity characteristics of the waters of the St. Lawrence Estuary in Summer were investigated earlier in relation of origin of the cold-water layer (Tremblay and Lauzier, 1940).

T-S diagrams have been plotted for all stations at different seasons and a few of them are presented herewith to show the geographical variations during two seasons and also the typical seasonal variations at a representative station.

T-S diagrams for the Spring

The V-shape of the T-S curves shown in figure 20 is typical for all stations in the Gulf of St. Lawrence. The T-S diagrams indicate the wide variations in the composition of the surface layer, and its influence in the mixture between the surface layer, and the intermediate layer. At the apex of the "V", the intermediate cold layer itself shows some geographical variations in its T-S characteristics. For the stations located in the Esquiman Channel, along the North Shore, and in the central part of the Gulf (stations 48N, 60 and 65), the intermediate layer has a somewhat higher salinity and a lower temperature, and also a wider range of salinity at the minimum temperature, than the waters in the western sector of the Gulf and even in the southern part of the Laurentian Channel (stations 92N, 80 and 35). The deeper layer, and its mixture with the intermediate layer, are fairly uniform and stable all over the Gulf. Some variations seemed to occur only in the sub-layer immediately adjacent to the intermediate layer.

T-S diagram for the early Autumn

The T-S diagram for the early Autumn (figure 21) indicate that, since Spring, both the surface and the intermediate layers have been modified but that the deep layer has retained its characteristics. The surface layer has reached a higher salinity for a given temperature. Consequently, the salinity gradient between the surface and the intermediate layers is less in the Autumn than in the Spring. The characteristics of the intermediate layer have changed since the Spring, but they still show the same geographical variations as in the Spring. The geographical variations were, however, more pronounced in the

Spring than in the early Autumn. As a whole, the changes consist in a warming of the intermediate layer and a slight increase of its average salinity. The deep layer did not change appreciably, but the range or variability of temperature and salinity seemed to be less in the early Autumn than in the Spring.

Seasonal Variations in T-S Relationship

It can be readily seen from figures 20 and 21 that the waters of the Gulf of St. Lawrence, at least in the Laurentian Channel and Esquiman Channel where depths are greater than 100 fathoms, are the results of mixtures of three types of water:

A - water of relatively low salinity and of relatively high and variable temperature.

B - water of salinity less than 33.0 °/oo, usually in the vicinity of 32.0 and 32.5 °/oo, and of temperature less than -1.0 °C. in the Spring.

C - water of salinity 34.5 °/oo and of temperature 5.0 °C.

The seasonal variations of A-water are very wide, and have been given attention in an earlier paper on the features of the surface layer (Lauzier and others, 1951). B-water undergoes some variations which are well shown in figure 22, the T-S diagrams of station 80. In the Spring B-water of the intermediate layer has a salinity of 32.1 °/oo and a temperature of -1.3 °C. In the Autumn, the same water had apparently been modified to 32.4 °/oo and -0.5 °C., which point is on the straight line joining the original B-water and C-water. This would suggest that B-water is dissipated through vertical mixing, diffusion, etc., and is not replenished at a comparative rate. C-water, on the other hand, kept its identity from May to November.

Station 80 has been cited as being typical. It is also one of the stations for which the most data have been collected. The B-water at other stations, such as in the northeast sector of the Gulf or in the southern part of the Laurentian Channel, would differ somewhat from B-water at station 80, but the seasonal variations at most of them follow the same trend.

Figure 23 shows T-S relationships at typical stations in the southwestern Gulf. The seasonal variations of the characteristics of this water mass seems to be larger than in the Laurentian Channel. Moreover, as a whole, the characteristics differ considerably from those in the Laurentian Channel, the salinity in the minimum temperature layer being 31.5 °/oo in the southwestern Gulf as compared to 32.0 - 32.5 °/oo in the Channel. Becuase of the shallowness of the area, the minimum temperature layer disappears from most of the stations in the Magdalen Shallows by the month of October.

Distribution of Salinity at the Upper 0.0 °C. isotherm

The intermediate cold-water layer in the Gulf of St. Lawrence has been defined as a minimum temperature layer being bounded by the 0.0 °C. isotherms. It has been shown that its upper and lower boundaries vary in depth, both geographically and seasonally. An analysis of the distribution of salinity at the upper 0.0 °C. isotherm will simplify the T-S relationship, and may possibly elucidate the formation of the cold-water layer.

Figures 24, 25, and 26 show the distribution of salinity at the level of the upper 0.0 °C. isotherm for the Spring, Summer and early Autumn respectively. The main feature of the distributions is the location of low salinity, less than 32.0 °/oo, in the west and southwest sectors of the Gulf, and of the maximum salinity in the centre of the Gulf and in the northern sector. The boundary between low and high salinity, taken as the 32.0 °/oo isohaline, varies somewhat from Spring to early Autumn, but it is generally located in the Laurentian Channel. It may be seen from the distribution of salinity that, while the 0.0° C. water is decreasing in amount from Spring to early Autumn, the remaining body of water has higher average salinity in the Autumn than in the Spring.

The distribution of salinity at the level of the upper 0.0° C. isotherm in the early Spring indicates the relative distribution of surface salinity as remaining from the Winter. The very few late Winter observations in the Gulf indicate that isothermal and isohaline conditions exist down to at least 50 metres. It could be assumed that, by mid-winter, all over the Gulf, because of intense vertical mixing, the isothermal and isohaline conditions exist down to a depth below which temperature and salinity increase. At this time there is no intermediate layer, since a uniform layer extends from the surface down to the deep layer. It may be reasoned also that because of vernal warming and the melting of ice, vertical mixing will have decreased considerably, by the month of May, due to increase in stability. It is generally assumed also that increase of temperature precedes a decrease of salinity. As vernal warming proceeds, the intermediate layer becomes delineated as a body of water of temperatures less than 0.0° C. The distribution of salinity at its upper boundary, the upper 0.0° C. isotherm, therefore reflects at this time the relative distribution of surface salinity in winter irrespective of the melting of ice in the Spring. However, the average salinity at the upper 0.0° C. surface in a given area, as well as the average depth of the upper

0.0° C. isotherm would vary from year to year depending on the ice cover in the winter.

DISCUSSION

Origin of the Cold-Water Layer

If the cold water layer had its origin outside the Gulf of St. Lawrence, its salinity, by Spring should be almost uniform, and at least higher than 32.0 °/oo and tending towards 33.0 °/oo. From the distribution of salinity at the upper 0.0° C. isotherm in Spring, one may see that between one-third to one-half of the Gulf is covered with water of salinity less than 32.0 °/oo and as low as 31.0 °/oo. It may be concluded therefore that at least one-third of the cold-water layer found in the Gulf of St. Lawrence in the Spring was formed "in situ". The other two-thirds, at the most, seem to have an outside origin. If there was communication between the cold-water layers inside the Gulf and outside, it would be expected that the layer would be replenished. The data have shown that the layer in the Gulf had decreased in volume, with progress of the seasons, and that its temperature and salinity had increased. In other words, the cold intermediate water had been expended either by mixing, diffusion and/or movement, faster than replenished from May to November. It therefore follows that if water from an outside source contributes to the cold-water layer of the Gulf of St. Lawrence that this water enters the Gulf through Cabot and Belle Isle Straits, probably during the winter months as a surface layer, and is modified by horizontal mixing to yield a salinity lower than its original source, namely the Labrador Current.

Origin of the Warm Deep Layer

Comparison of T-S curves of the deep waters of the Gulf of St. Lawrence with those of the deep waters off the southeast corner of the Scotian Shelf (McLellan and others, 1952) shows that the same type of water is being observed in both places (34.0 - 34.5 ‰). These waters are formed apparently by the mixing of the cold-water layer outside the Gulf of St. Lawrence (-1.3°C., 32.95 ‰) with the water system found in the very deep Central Atlantic waters which upwells against the continental slopes. However, the deep waters in the Gulf of St. Lawrence, formed in the continuation of the Laurentian Channel to the south, and penetrating through Cabot Strait, are somewhat colder than the waters outside for a given salinity. For instance, water of 34.0 ‰ has an average temperature of 5.0°C. off the Scotian Shelf, and 4.0°C. in the Laurentian Channel within the Gulf of St. Lawrence. This indicates that, in the process of mixing, the cold-water layer has a greater influence on the mixture that penetrates into the Gulf than on the water of the continental slopes.

The deep warm layer in the Gulf of St. Lawrence, with an increasing volume from Spring to Autumn, does not show any appreciable variation of its properties with the progress of the seasons, its temperature-salinity relationship remaining fairly constant.

SUMMARY

1 - The distribution of temperature and salinity in sections of the deep channels of the Gulf of St. Lawrence have been described for different seasons. Spring, Summer, early Autumn and late Autumn.

2 - The intermediate cold-water layer in the Gulf of St. Lawrence has been defined as a body of water of temperature less than 0.0° C. The deep warmer layer has a temperature greater than 0.0° C. and as high as 5.6° C.

3 - The volume of the intermediate cold-water layer undergoes seasonal variations from a maximum in the Spring to a minimum in the Autumn. The layer decreases in thickness and extent. Its volume decreases to at least $30\,^{o}/o$ of its original spring value, disappearing entirely in the Cabot Strait area.

4 - The thickness of the intermediate layer is greatest in the Esquiman Channel.

5 - There is a seasonal influx of the warm deep layer (temperature greater than 4.0° C.) with a maximum in the Autumn. The average increase from Spring to Autumn was observed as being approximately $20\,^{o}/o$.

6 - The warm deep layer is somewhat like a wedge on the bottom of the Laurentian Channel. The 4° C. isotherm deepens as the distance from Cabot Strait increases.

7 - The vertical gradient of temperature between 1° and 4°, decreases from the Cabot Strait area to the estuary of the St. Lawrence showing more vertical mixing in the latter.

8 - In general, the 1° and 4° C. isotherms are associated with the 33.0 and $34.0\,^{o}/oo$ isohalines.

9 - T-S relationships show that the waters of the Gulf of St. Lawrence, where depths are greater than 100 fathoms, are the results of the mixing in different proportions, of three types of water.

10 - From Spring to Autumn the intermediate cold-water layer warms, with a slight increase of salinity, while the warm deep layer retains its characteristics.

11 - The distribution of salinity within the intermediate cold-water layer, as well as its geographical and seasonal variations, lead to the conclusion that at least one-third of the intermediate layer is formed <u>in situ</u> and that the remainder might have its origin outside of the Gulf.

12 - The intermediate layer is not replenished to any great extent if at all, during the summer and autumn months.

13 - The warm deep layer is formed outside the Gulf of St. Lawrence, in like manner to the deep layer on the Scotian Shelf and along the continental slopes, but in the Gulf, for a given salinity, the temperature is somewhat lower.

ACKNOWLEDGMENT

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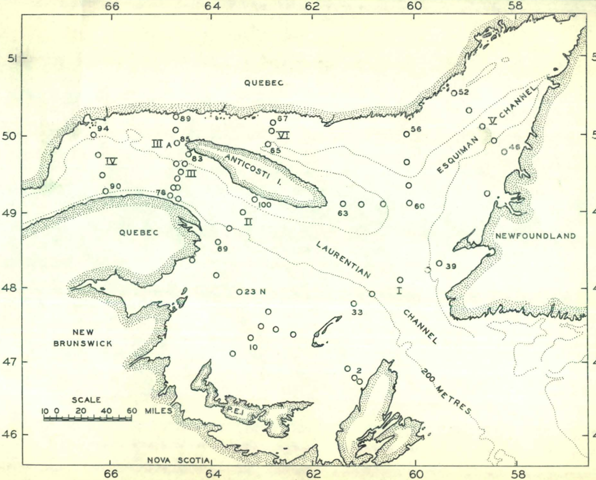

Figure 1. Location of hydrographic stations and sections in the Gulf of Saint Lawrence.

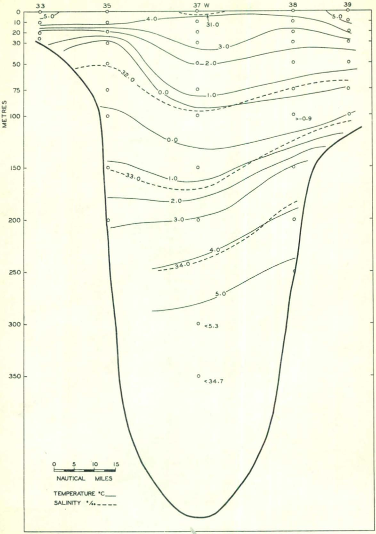

Figure 2. Vertical distribution of temperature and salinity in Section I for Spring, 1948.

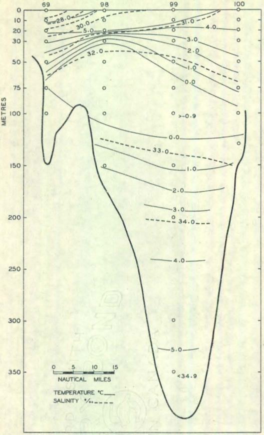

Figure 3. Vertical distribution of temperature and salinity in section II for the Spring 1948.

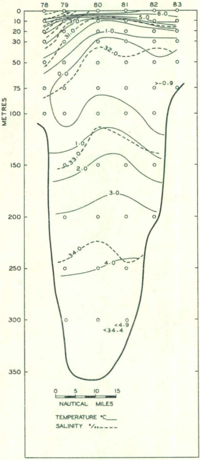

Figure 4. Vertical distribution of temperature and salinity in section III for the Spring 1948.

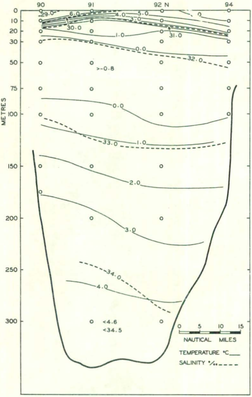

Figure 5. Vertical distribution of temperature and salinity in section 1V for the Spring 1948.

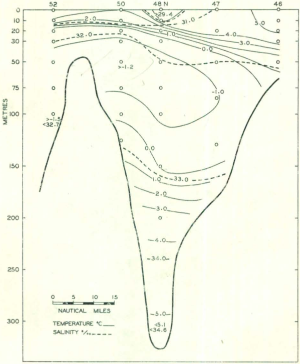

Figure 6. Vertical distribution of temperature and salinity in section V for the Spring 1948.

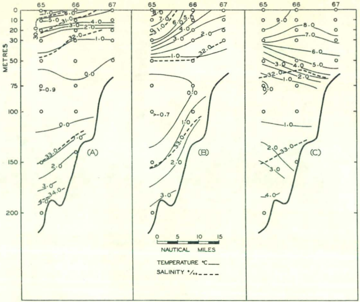

Figure 7. Vertical distrubution of temperature and salinity in section Vl:

A. Spring 1948
B. Summer 1947
C. Early Autumn 1948.

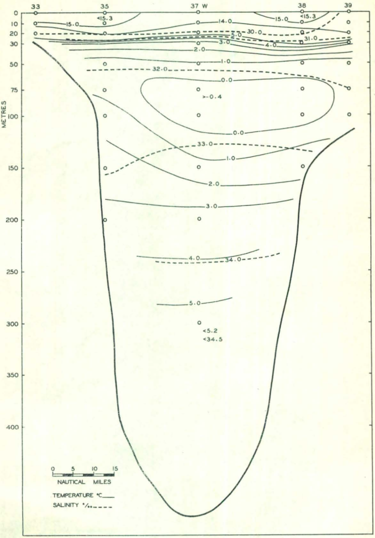

Figure 8. Vertical distribution of temperature and salinity in section I for the Summer 1947.

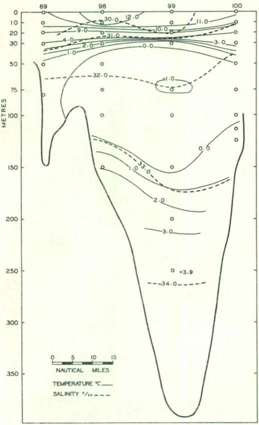

Figure 9. Vertical distribution of temperature and salinity in section II for the Summer 1947.

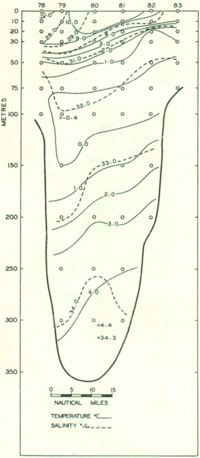

Figure 10. Vertical distribution of temperature and salinity in section III for the Summer 1947.

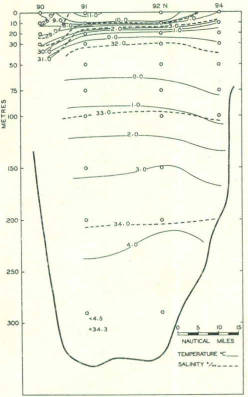

Figure 11. Vertical distribution of temperature and salinity in section lV for the Summer 1947.

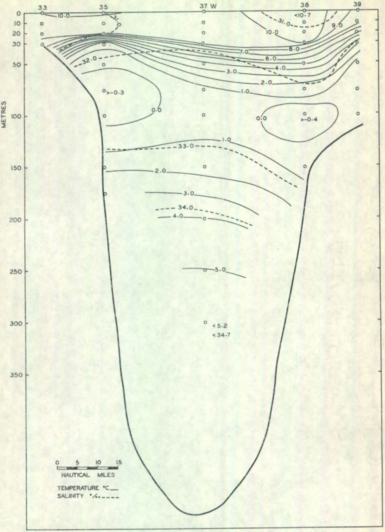

Figure 12. Vertical distribution of temperature and salinity in section I for the early Autumn 1948.

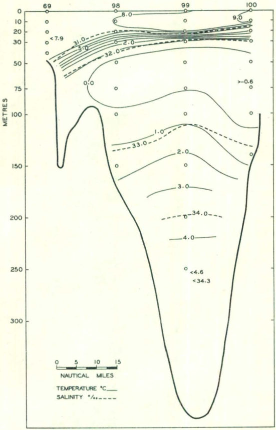

Figure 13. Vertical distribution of temperature and salinity in section II for the early Autumn 1948.

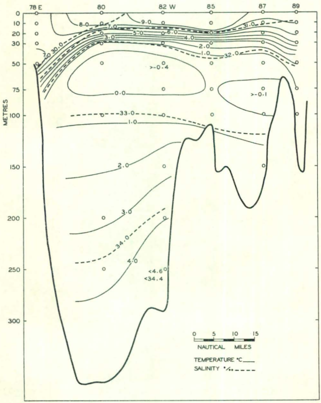

Figure 14. Vertical distribution of temperature and salinity in section IIIA for early Autumn 1948.

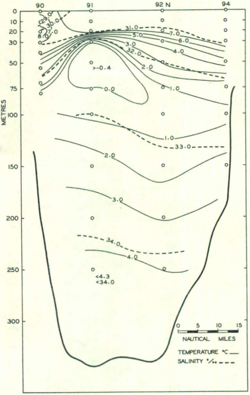

Figure 15. Vertical distribution of temperature and salinity in section lV for early Autumn 1948.

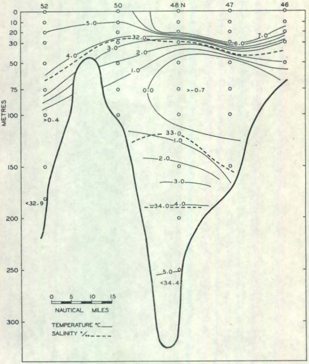

Figure 16. Vertical distribution of temperature and salinity in section V for the early Autumn 1948.

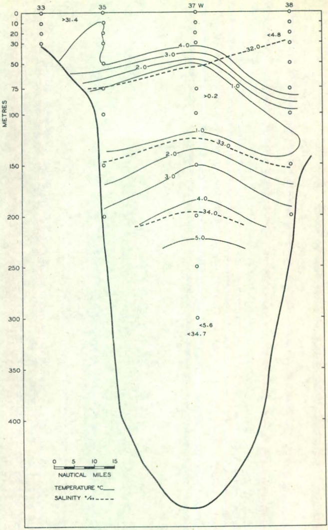

Figure 17. Vertical distribution of temperature and salinity in section I for the late Autumn 1947.

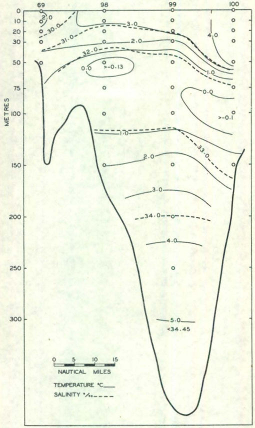

Figure 18. Vertical distribution of temperature and salinity in section II for the late Autumn 1947.

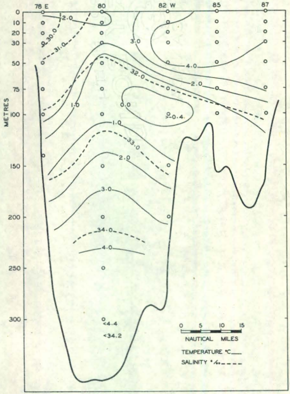

Figure 19. Vertical distribution of temperature and salinity in section IIIA for the late Autumn 1947.

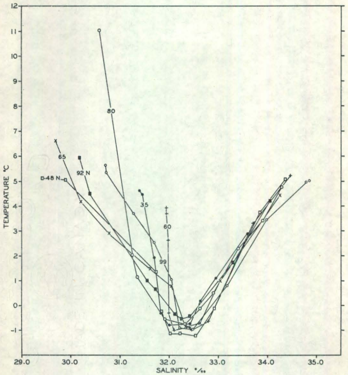

Figure 20. Temperature-Salinity relationships for representative deep stations of the Gulf of Saint Lawrence for the Spring 1948 (surface data included).

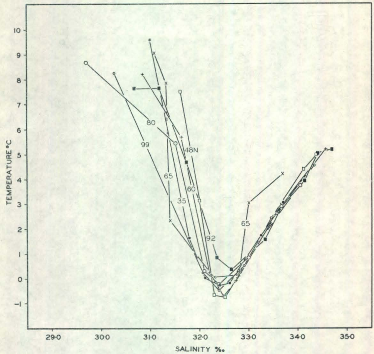

Figure 21. Temperature-Salinity relationships for representative deep stations of the Gulf of Saint Lawrence for the early Autumn 1948 (surface data included).

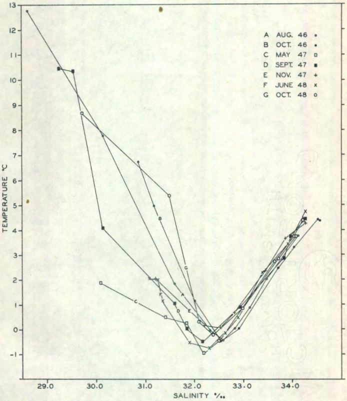

Figure 22. Temperature-Salinity relationships for the waters of Station 80 (Section III) for the different seasons (surface data excluded).

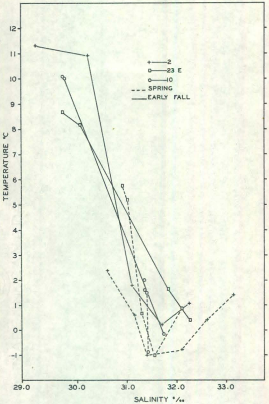

Figure 23. Temperature-Salinity relationships for representative shallow stations of the southwestern sector of the Gulf of Saint Lawrence (surface data included).

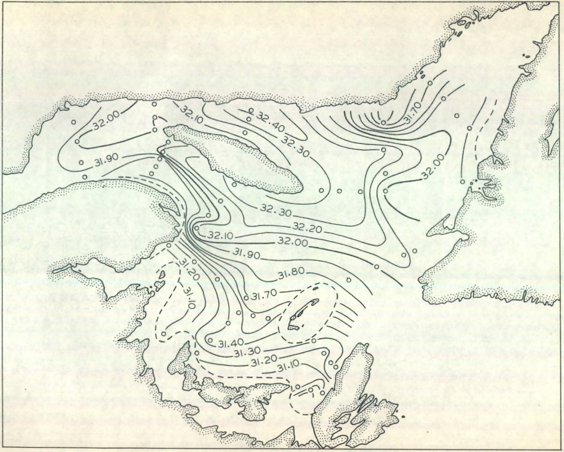

Figure 24. Isohalines at the upper $0^{\circ}C.$ surface for the Spring 1948.

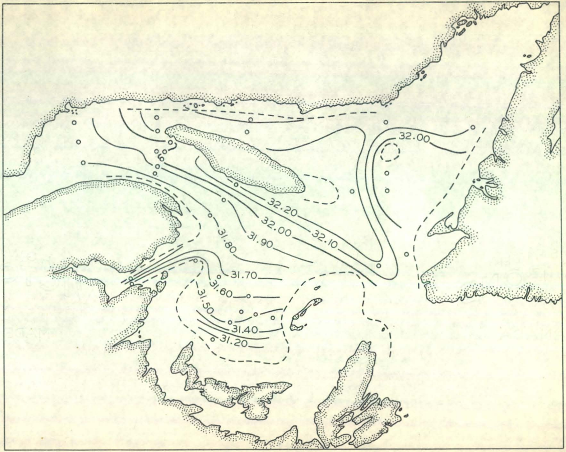

Figure 25. Isohalines at the upper 0°C. surface for the Summer 1947.

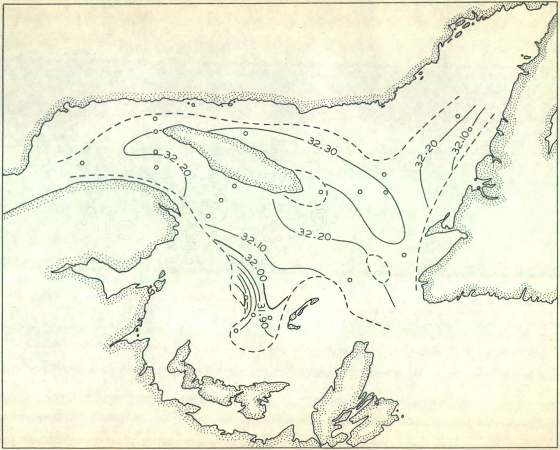

Figure 26. Isohalines at the upper 0°C. surface for the early Autumn 1948.