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## Oceanographic Observations in the Bay of Fundy since 1952

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ATLANTIC OCEANOGRAPHIC GROUP

# OCEANOGRAPHIC OBSERVATIONS IN THE BAY OF FUNDY SINCE 1952

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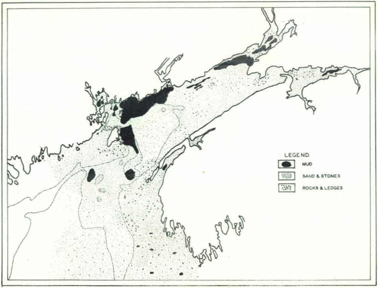

Chart of the Bay of Fundy showing the distribution of bottom types.

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## INTRODUCTION

### General Observations

Since the summer of 1950, the Fisheries Research Board of Canada, Atlantic Oceanographic Group, has made oceanographic observations quarterly at five stations in a section across the Bay of Fundy. This section, which is part of a network of observations designed to monitor oceanographic conditions along the Atlantic Coast, has been occupied on nineteen occasions up to the end of 1955. The observations taken up to the end of 1952 have been reported by Bailey (1953).

Surveys of the Bay were carried out in April 1953 and in February 1954 to give coverage of conditions in the early spring and in the late winter, and to augment the results of previous surveys.

### Some Features of the Waters of the Bay of Fundy

It has been generally agreed by previous investigators that the circulation in the main portion of the Bay of Fundy is in an anticlockwise direction, and that inflowing waters from the open ocean hold close to the Nova Scotia coast, while outflowing waters hold to the Grand Manan side of the Bay. In Grand Manan Channel, Mavor (1922) found northward residual currents whereas the calculations of MacGregor and McLellan (1952) indicated the residual currents to be southwards. Both Watson (1936) and McLellan (1951) suggest that residual currents are determined chiefly by the winds. On the basis of the varying nature of the residual flow in Grand Manan Channel, it would appear that outflowing waters from the Bay of Fundy keep generally to the eastern rather than to the western side of Grand Manan.

In the Gulf of Maine, Bigelow (1927) has described the circulation as westward along the coast of Maine, west and north through the Fundian Channel towards the Bay of Fundy on the northern side of the channel and east and south out of the Gulf on the Georges Bank or southern side of the channel. In addition a superficial movement takes waters from the eastern central part of the Gulf towards the Bay of Fundy. These concepts of the circulation of the waters are in general agreement with the data herein reported.

As the waters are carried into the Bay, a progressive mixing takes place with the result that the waters at the head of the Bay are found to be thoroughly mixed. Mixing on a considerable scale takes place in an area to the southwest of Grand Manan, and also over an extensive area along the northwestern coast of Nova Scotia.

The principle drainage basin supplying fresh water to the Bay of Fundy is that of the Saint John River, and the resultant outflow from the Bay of Fundy is influenced to a considerable extent by these waters, which can readily be traced, at times of freshets, as far as Grand Manan (Watson, 1936; Hachey and Bailey, 1952).

Large tides are features of the area with a maximum amplitude at springs exceeding 53 feet at the head of the Bay (Tide Tables, 1956). Tidal action together with the physical features of the Bay are responsible for intense mixing of the waters (Bailey, MacGregor and Hachey, 1954).

Detailed description of the Bay of Fundy region have been given by Mavor (1923), Watson (1936), and Hachey and Bailey (1952). A chart of this region is provided in the Frontispiece showing the bottom sediments.

## WINTER OCEANOGRAPHIC CONDITIONS IN THE BAY OF FUNDY AND THE NORTHERN PART OF THE GULF OF MAINE IN 1954

Oceanographic data from the Bay of Fundy during the winter months are meagre. One survey was made in the winter of 1932 but most of the data were destroyed by fire. The remainder, which have been presented by Hachey (1934a), are comprised of seven stations in a longitudinal section showing temperature conditions. Other data are provided through the monthly observations at Station P5, a single series of observations from 1916-1918 from a station in the central part of the Bay occupied by Mavor (1923) and from winter crossings made by the Atlantic Oceanographic Group since 1950.

### Data Used

The temperature and salinity data collected from the C.N.A.V. "Sackville" during the period of March 4-8, 1954, are presented in section in Figures 2-9 and on charts showing the horizontal distributions at surface, 20, 50 and 100 metres in Figures 10-13. The locations of oceanographic stations occupied at this time are shown in Figure 1.

## Circulation as indicated by the Vertical Distribution of Temperature and Salinity

The vertical distribution of temperature and salinity in eight sections across the Bay of Fundy, Gulf of Maine and the southwestern end of the Scotian Shelf are given in Figures 2-9.

At stations 65-73 and 74-77 (Figs. 9 and 8), two distinct bodies of water are shown. The first, found over the Scotian Shelf in depths less than 100 metres, is representative of the coastal waters at the southwestern end of the Scotian Shelf at this time of the year. This water has characteristic temperatures ranging from less than 1.5°C. to greater than 4.0°C., with corresponding salinities ranging from 30.8‰ to 33.0‰. The second body of water, found along the edge of the continental shelf, has temperatures greater than 11.0°C. and salinities greater than 35.0‰. McLellan, Lauzier and Bailey (1953) identified waters with these characteristics (11.6°C., 35.2‰) as intermediate slope water.

These two water masses were moving westward and undergoing lateral mixing as they moved along. On reaching the southern end of Nova Scotia, the coastal waters curved around it while the deeper waters on meeting the Fundian Channel flowed into it. This indraft did not contain the slope water as defined above, but a mixture of the coastal and slope waters. Taking the salinity of coastal waters as 30.8‰ and that of a slope water as 35.2‰, the percentage of either water type in a given water mass may be calculated. The proportion of slope water to coastal water increased with depth. The maximum was about 84% slope water which was found in this proportion as far west as stations 84-88.

In passing around the southern tip of Nova Scotia, the coastal waters were being subjected to increased vertical mixing due to stronger tidal action and the shoaling waters with the result that temperatures and salinities were increased. At the mouth of the Bay of Fundy (stations 88-94, Fig. 4), the most saline water contained only 44% slope water and the major portion of the section contained waters with temperatures between 4.0°C. and 5.0°C. and with corresponding salinities between 32.0‰ and 32.5‰.

In the outer sections discussed above, the water columns were stratified and the general tendency was for the two water masses to be superimposed. At the mouth of the Bay of Fundy, the situation was being radically changed. The remnants of the coastal water were confined inside station 89 and strong vertical mixing was in evidence at stations 90 and 92. An additional feature was the body of water between stations 90 and 91 with low salinities to a depth of 50 metres. A similar feature was shown by Hachey and Bailey (1952, Fig. 4) for late summer observations, but was not shown in spring observations. This feature would appear to be due to the irregular bottom configuration in the vicinity of station 90 as indicated by the bottom contours in Figure 2.

Section 95-99 (Fig. 3) in the central part of the Bay of

Fundy had about 34% slope water near the bottom at station 97 where strong vertical mixing was in evidence. On the Nova Scotia side of the Bay, in this area, no coastal waters from inshore were found, only those from near the edge of the Shelf. This is more clearly shown by the horizontal distribution (Fig. 10).

As the waters progressed further into the Bay, vertical mixing became more intense and the waters were further cooled through chilling along the shore and by mixing with land drainage. At the head of the Bay, the water had temperature and salinity characteristics very similar to the inshore waters on the southern parts of the Scotian Shelf.

The mixed waters from the mouth of the Bay of Fundy that had reached the head of the Bay and which had been diluted and chilled there, flowed westward along the north side of the Bay as illustrated in Figures 2 and 3. As these waters proceeded along the coast of New Brunswick, they underwent further mixing with waters from the mouth of the Bay so that by the time they completed the circuit of the Bay of Fundy (station 93), they had temperature and salinity characteristics very similar to the waters at station 88.

During the winter months, the waters in the Bay of Fundy and in the shallower areas adjacent to it have their maximum temperatures and salinities near the bottom. Vertical mixing is much greater during this season due to decreased stability brought about by the relatively small river discharges and the increased densities at the surface due to winter chilling. Strong vertical mixing in the Bay is maintained by the higher surface temperatures than would otherwise exist if the mixing were weak.

## Circulation as indicated by the Horizontal Distribution of Temperature and Salinity

The horizontal distribution of temperature and salinity at 0, 20, 50 and 100 metres are shown in Figures 10-13, respectively.

The horizontal distribution patterns of temperature and salinity is similar at all depths discussed. At the surface, the principle features are the cold water from the Scotian Shelf with temperatures between 1.7 and 3.0°C. and with salinities less than 31.5‰, which blow around the southern tip of Nova Scotia, and the cold waters flowing out of the Bay of Fundy with temperatures less than 3.0°C. The waters entering the Bay were from near the edge of the Scotian Shelf and had temperatures between 3.0 and 4.0°C. This water had a salinity between 31.5‰ and 32.0‰. A special features is the tongue of warmer water at the eastern part of the area where warmer temperatures (greater than 2.0°C.) were located in the cold shelf water. From the data available, several interpretations are possible. The tongue-like distribution appears to be associated with an indraft of water to the gullies located on the Scotian Shelf.

At depths of 50 and 100 metres, the influence of the bottom tópography is very apparent on the circulation of the deeper waters.

The cold coastal water from the Scotian Shelf is modified through lateral mixing with the offshore waters as it rounds the southern tip of Nova Scotia so that it has completely lost its characteristic low temperature and salinity before it passes the islands off western Nova Scotia. The warmer offshore waters enter the Gulf of Maine through the Fundian Channel and are diluted through progressive mixing with inshore water towards the head of the Bay of Fundy.

It would appear that the shoal waters at the southern tip of Nova Scotia tend to deflect the westward flowing waters from the Scotian Shelf towards the south to cause a considerable decrease in its volume due to mixing with the westward flowing waters along the edge of the shelf.

The deeper waters which entered the Gulf of Maine through the Fundian Channel and flowed towards the Bay of Fundy were deflected westwards by a shoaling of the bottom at the mouth of the Bay with the result that high salinity water did not enter directly into the circulation of the Bay of Fundy at this time of the year.

From the above discussion of the distribution of temperature and salinity in the Bay of Fundy and adjoining areas, it is apparent that the general circulation during the winter months is essentially the same as that for summer and autumn as described by previous authors (Mavor, 1923; Watson, 1936; Hachey and Bailey, 1952).

Temperature-Salinity Relationship

Figure 14 shows the general T-S curve for all data taken during the period March 4-8, 1954. The mean curve has been drawn as a solid line and the dashed lines represent the limits of deviations from it.

The low end of the curve represents the T-S relationships at the head of the Bay of Fundy while a little further along the curve represents the relations of the waters close inshore along the coast of Nova Scotia. The small bulge in the limiting dashed line was caused by stations at the southern end of the Scotian Shelf where mixing with high salinity water had evidently taken place. The peak of the T-S curve represents the intermediate slope water as found at the edge of the continental shelf while the end of the curve represents the deep slope water as found in the offshore stations.

## EARLY SPRING OCEANOGRAPHIC CONDITIONS IN 1953

Spring surveys of the Bay of Fundy have been made by Hachey in 1930 (Hachey and Bailey, 1952) and by Watson in 1932 (Watson, 1936). Additional data have been provided by three seasonal sections by the Atlantic Oceanographic Group in 1952-54.

### Data Used

An oceanographic survey of the Bay of Fundy was carried out over the network of stations shown in Figure 15, from C.N.A.V. "Sackville" during the period March 29-April 3, 1953. The vertical distribution of temperature and salinity are presented in Figures 16-18 and the horizontal distribution of temperature and salinity in Figures 19-22.

### Vertical Distribution of Temperature and Salinity

At the time of the 1953 survey, the waters in the Bay of Fundy were just beginning to warm up after the chilling of the previous winter, and had not come under the full influence of the spring freshet. Tidal stirring during the winter and early spring months is very effective due to reduced stability brought about by winter chilling combined with low river discharges. With the exception of stations 11-15, all sections indicate a high degree of stirring as indicated by the vertical or nearly vertical positions of the isotherms and isohalines. A cold water layer was located at station 13 (Fig. 17). It extended from near the surface to a depth of 75 metres. Temperatures in the cold water layer were less than 5.0°C. with the minimum of 4.88°C. occurring at 25 metres. The lowered salinities and marked stratification at station 11 indicates vernal freshening due to the spring runoff of the Saint John River.

The most pronounced temperature and salinity gradients were for the most part horizontal rather than vertical. The colder and lower salinity waters were contained on the New Brunswick side of the Bay. This is more clearly demonstrated by the horizontal distribution of temperature and salinity (Fig. 19).

## Horizontal Distribution of Temperature and Salinity

The horizontal distributions of temperature and of salinity have the same patterns, and are relatively consistent at all depths. The principal features illustrated by the horizontal distributions are: the inflow of warm waters from the offshore regions south of Nova Scotia, the introduction of cold fresh waters or cooling or both at the head of the Bay and in the Saint

John area, and its subsequent movement after mixing with the warmer waters, out along the coast of New Brunswick.

At the surface inflowing waters had temperatures between 4°C and 5°C., while the outflowing temperatures were less than 5.0°C. and as low as 2.0°C. Salinities in the inflowing waters were greater than 31.6‰ and as high as 32.4‰, while the for the outflowing water was generally less than 31.5‰.

At greater depths the temperature ranges were similar to those found at the surface, but salinity ranges were much reduced below 25 metres. At 50 metres most of the waters had salinities greater than 32.0‰. A low of 31.8‰ was recorded at station 4 and a high of 32.8‰ at station 18.

## Temperature-Salinity Relationships

The general temperature-salinity relationships of the waters of the Bay of Fundy in the early spring are shown in Figure 20. Two features are outstanding in this diagram. First, there are two types of water in the Bay which do not appear to be directly related to each other. Second, there is a single station which has characteristics intermediate between the two principal types.

The waters with T-S characteristics indicated by the lower group of T-S curves were found at stations 1-7 inclusive. As shown in Figure 15, these stations were located in the inner reaches of the Bay. The upper group of T-S curves indicates the type of water found at the other stations with the exception of station 11. Station 11 makes up the spur from the upper group of T-S curves. Observations were made at station 11 on several occasions during the survey and the details of these are shown in Figure 21.

From the two groups of T-S curves shown in Figure 20, it would appear that warmer waters (upper group) had been introduced into the Bay while the colder waters (lower group) appear to be remnants of the mid-winter regime. The lack of any evidence of mixing between the two types of water seems to indicate that an exchange of waters between the Bay and the Gulf of Maine had taken place in a short period of time. This may be associated with a very large excess of northeast winds in March 1953, as shown in Figure 33. Some indication of an influx of more saline water from offshore is given by the changes in the percentages of coastal and slope waters at station P5 in Figures 31 and 32. It would seem that the colder winter water in the Bay had been blown out of the Bay by the wind and had been replaced by warmer waters from offshore.

A comparison of the T-S diagrams for winter and for spring (Figs. 14 and 20), indicates that there were no large scale changes in the T-S characteristics of the water masses which mix to form Bay of Fundy waters. The changes which took place were of a local nature.

The changes in the T-S characteristics of the waters at station 11 are indicated by the T-S curves shown in Figure 21. It is noteworthy that as the salinity of the surface waters decreased, the salinity of the deeper waters increased. These changes suggest that the process of "draw-in" as a result of mixing of stratified water was in action. A check of the surface salinities with the state of the tide indicates that the rate of decrease is nearly uniform and that no tidal influence is in evidence. The decreased salinities appear to be due to the increasing discharge of the Saint John River at the time of the spring freshet.

The T-S curves for station 11 indicate that the waters there were principally composed of a mixture of (a) central Bay of Fundy waters, and (b) low salinity water, probably originating near the mouth of the Saint John River. The inflection in the T-S curves indicates that a third water mass was present. The third water mass appears to be a dilute mixture of waters from the head of the Bay with river discharge water. The presence of this water at station 11 indicates that waters from the head of the Bay flow out of the Bay along the New Brunswick coast and have lost most of their identity by the time they reach the vicinity of Grand Manan.

## SEASONAL VARIATIONS IN TEMPERATURE AND SALINITY

The seasonal variations of temperature and salinity between 1916 and 1952 were discussed by Bailey (1953). The important features evolving from this study are that seasonal variations of temperature and salinity show the influence of tidal mixing, vernal warming spring runoff, autumnal cooling and winter chilling. Year to year changes were not great over the period discussed, but temperature-salinity relationships showed that the waters at all depths were about 2.0°C. warmer in 1952 than in 1917, while at 175 metres the increase was about 3.2°C.

The network of stations over which observations were taken is shown in Figure 22.

## Seasonal Variations of the Vertical Temperature and Salinity Distribution in 1954

In early March (Fig. 3), the time at which extreme winter conditions are generally found in the Bay of Fundy, the waters in the central part of the Bay had temperatures over 4.0°C. and as high as 4.8°C. At the sides of the Bay, temperatures were somewhat less, being as low as 1.80°C. at station 11. The inshore waters on the Nova Scotian side were warmer and more saline than those on the New Brunswick side. The salinity range in the section was small (31.2-32.2‰). A comparison of salinities taken at 90 metres at station P5 shows that at this level the lowest salinity since 1932 was recorded in March, 1954, and that the minimum salinity for the year occurred at this time rather than in April or May at the usual time of freshet conditions. A general description of oceanographic conditions in the Bay of Fundy at this time has been given on Page 3.

Figure 23 shows the spring conditions. For the most part temperatures and salinities had increased from those observed in March. A notable exception was the small body of water located between stations 1 and 3 which had salinities less than 30.5‰ and as low as 28.08‰. Temperatures throughout the section were higher than 4.9°C. with a maximum of 7.8°C. at station 2 in the low salinity water. The warm low salinity water represents the discharge of the Saint John River as it reached the Grand Manan area.

During the summer months (Fig. 24), the waters had become more stratified which tended to reduce vertical mixing. At station 3 temperatures ranged from 13.7°C. at the surface to 7.7°C. at 170 metres. Salinities had increased from the spring values throughout the section and reached a maximum of 33.7‰ at 170 metres at station 3.

Autumn conditions as represented by the October section (Fig. 25) show that the waters in the upper 30 metres had commenced to cool from the high summer temperatures while below this level, the water had continued to warm. The greatest change was in the salinities which had continued to rise so that the greater percentage of water had salinities greater than 33.0‰ with a maximum of 34.07‰ near the bottom at station 4.

Table I. Changes in temperature and salinity from season to season for selected depths at station 3 in the Bay of Fundy in 1954.

| Depth | Autumn-Winter | | Winter-Spring | | Spring-Summer | | Summer-Autumn | |
|---|---|---|---|---|---|---|---|---|
| M | T°C. | S‰ | T°C. | S‰ | T°C. | S‰ | T°C | S‰ |
| 0 | -5.5 | -0.4 | +2.7 | -1.4 | +7.1 | +0.8 | -2.9 | +1.2 |
| 20 | -5.2 | -0.3 | +1.6 | -0.6 | +6.5 | +0.2 | -1.5 | +0.9 |
| 50 | -5.8 | -0.6 | +1.1 | -0.2 | +3.6 | +0.7 | -1.7 | +0.3 |
| 100 | -5.4 | -0.8 | +0.7 | +0.2 | +2.5 | +0.7 | +2.1 | +0.3 |
| 150 | -5.4 | -1.2 | +0.9 | +0.6 | +2.0 | +0.7 | +2.3 | +0.4 |

The variations of temperature and salinity at various depths in the central part of the Bay of Fundy are summarized in

Table I. The cooling from autumn to winter was about uniform from top to bottom, but the change in salinity was greatest near the bottom due to a large decrease in the inflow of more saline waters from offshore along the bottom and to increased vertical mixing brought about by decreased stability. The changes from winter to spring show warming throughout the column, being greater at the surface than elsewhere. The changes in salinities however, reflected the greater inflow of fresh water at the surface and an increased "draw-in" of more saline waters near the bottom. After the spring freshet had subsided, surface temperatures and salinities increased from spring to summer. The changes from summer to autumn indicate that while the surface waters were cooled the deeper waters continued to warm, and the salinities reflect the increased mixing that is brought about by the decreased stability. The changes in temperature and salinity from one season to the next may vary from year to year but those values given in Table I may be taken as representative ones.

The vertical temperature and salinity structures for the sections representative of the Bay of Fundy for April, October and November, 1953, are given in Figures 17, 26 and 27. Those for June, August and November, 1955, are illustrated in Figures 28-30.

## The Relationships between Coastal Water and Slope Water in the Bay of Fundy

As indicated in the preceeding diagrams, the waters in the Bay of Fundy are composed, in varying proportions, of a mixture of coastal and slope waters. The diagrams also indicate that the coastal waters have salinities which are generally greater than 30.8‰. Intermediate slope water has a salinity of 35.2‰ (McLellan, Lauzier and Bailey, 1953). By taking these salinities as representative of coastal and slope waters, the percentage of each may be calculated for a given salinity observation.

Figure 30 shows the percentage of coastal water near the bottom at station 3 (175 m.) and at station P5 (90 m.) for the period August 1950 to December 1955. The program of observations at station 3 was not as frequent as at station P5, thus there are many gaps in the curve. The dashed lines in the station 3 curve were put in to indicate the probable percentages where observations were missing. The placing of the dashed lines was based on the assumption that the maxima and minima are about the same from year to year.

Figure 31 shows the relationship between the percentage of slope water in the Bay of Fundy (3) with that in the northern part of the Gulf of Maine (79) and at the edge of the Scotian Shelf (71), during the period August 1950 to February 1956. The locations of these stations are shown in Figures 1 and 15.

Figure 32A gives the excess of components of southwest and northeast wind mileages calculated from observations taken at Saint John Airport from June 1950 to December 1955. The components of the SW and NW winds were determined from observations at eight points of the compass taken by the Canadian Department of Transport, Meteorological Service, as supplied through the Monthly Record of Meteorological Observations. The discharge of the Saint John River at Pokiok, N.B. is shown in Figure 32B. These values represent about 60 percent of the total discharge of river water into the Bay of Fundy. These data were supplied by the Canadian Department of Northern Affairs and National Resources, Water Resources papers, numbers 112 and 116.

The three diagrams showing percentage of slope and coastal waters, river discharges and excess of wind mileages all show certain seasonal variations. The peak river discharges usually occurred in April with a small peak discharge in December. The winds have a predominant NE component during the early spring and the peak SW component usually occurred in July or about the same time as the minimum river discharge. The percentage of coastal water is usually at a maximum in the early spring prior to the peak river discharge. These relationships indicate that all these parameters are related either through a common influencing factor or by their actions on one another or both.

From the curves in Figure 31, it can be seen that in the Bay of Fundy, the percentage of slope water near the bottom varies between 34 and 76%. In the Fundian Channel it varied between 84 and 106% (where a salinity of 35.2‰ was taken as the basic salinity of the slope water). On the edge of the Scotian Shelf it varied between 95 and 116%. Data are not sufficient to support any detailed comparisons, but in general, there seems to be some direct relationship between the percentage of slope water in the Fundian Channel and in the Bay of Fundy, particularly between 1953 and 1956. There appears to be no relationship between the slope water off the Scotian Shelf with that in the Fundian Channel.

These facts indicate that the percentage of slope water in the Bay of Fundy is due primarily to the extent of the local processes that combine to determine the oceanographic conditions in the Bay, and to a lesser extent to the availability of slope water from the Gulf of Maine. Incursions of slope water on the Scotian Shelf apparently are of little or no consequence to conditions in the Bay of Fundy.

During the period 1950-55, the minimum values of percentage of slope water at station P5 show a definite increase from 7% in 1950 to 17% in 1955.

A comparison of Figures 30 and 32 indicate that the percentage of coastal water at the 90-metre level at station P5 varies in a manner similar to the discharges of the Saint John River. In many instances even minor changes in the river discharges are reflected by the waters at station P5. However, major changes in the river discharges are not reflected by correspondingly large scale changes in the percentage of coastal waters. For instance, the peak river discharge of 1953 was significantly greater than that for 1952, but the percentage of coastal water at station P5 was less in 1953 than it was in 1952. In addition, the low volumes of river discharges that occur during the winter months are not reflected at station P5. The percentage of coastal water <u>increases</u> between November and January reaching a maximum in April or May prior to the peak river discharge. This apparent anomaly can be explained by the fact that the increased vertical mixing due to autumnal cooling considerably reduces the salinity of the deep water. The relatively rapid decrease in the amount of coastal waters, in the deeper levels during and after the spring freshets, suggest that a large "draw-in" of water from the Gulf of Maine takes place at this time. The addition of large quantities of fresh water plus vernal warming may sufficiently increase the stability of the water column so that mixing is not sufficiently vigorous to further dilute the deep waters.

The occurrence of water with salinities greater than 34.0‰, had previously been considered to be a rare event, and was attributed by Bailey (1953) to be due to incursions of slope water on the Scotian Shelf near the Fundian Channel. It was believed that the high salinities in the Bay of Fundy resulted from the coincidence of an incursion of slope water with the period of maximum salinities due to reduced river discharges. The relationships between coastal and slope waters indicate that this idea is not correct.

Salinities greater than 34.0‰ were observed near the bottom (175 m.) in the Bay of Fundy on 21 November, 1952, 17 October, 1953, and 8 October, 1954. The wide variation in the time of the inflow of the saline waters may be due to the holding action of SW winds. This may have been the case in 1952. Figure 30 indicates an abnormal amount of coastal water in the Bay in the early autumn. Figure 32, showing the difference between NE and SW component winds mileages at Saint John Airport, indicates that from June until October, 1952, there was a continued excess of SW winds, which was followed by an excess of NE winds in November. The effect of the SW winds on the water would be to hold the surface waters in the Bay until early autumn. Vertical mixing through tidal action would increase the percentage of coastal waters at all levels. The abrupt change in the winds from SW to NE would then blow the waters out of the Bay. The lighter waters would then be replaced by more saline waters from the Gulf of Maine.

From the foregoing and from the amount of slope water at the mouth of the Bay of Fundy (84%, P.5), it appears that the amount of slope water available for mixing with Bay of Funday is more or less constant. The factors controlling the time, duration and amount of slope water entering the mixing mechanism of the Bay are: (a) the volume of river discharge, and (b) the prevailing wind system.

## Influence of Wind on Water Movement

Hachey (1934a) investigated replacements of the water by taking maximum and minimum temperatures of each year at several levels using data for station P5 for 1924 to 1930. The annual temperature range and the temperature gradient between three levels were determined. The relative magnitude of the two gradients were used to indicate the relative amount of replacement that took place in a given year. These were then correlated with the "adverse excess" of SW winds at Eastport, Me., and the discharge of the Saint John River at Pokiok, N.B. Good agreements with theoretical consideration were found in both cases.

Following the same procedure but using wind mileage data from Saint John, N.B., calculations were made for the period 1924-1952. Preliminary results indicate that agreement with theory were obtained 67% of the time for the wind data and 52% of the time for the discharge data. Combined agreement was obtained only 50% of the time. Further, neither abnormal values of river discharges nor large excess of SW winds are reflected by abnormal replacement values. These percentages indicate that the replacements are complex and that a thorough and intensive study is required to determine just how the replacements are influenced by the wind and river discharges.

## FLUSHING TIMES OF THE BAY OF FUNDY WATERS

### The Flushing Time

The average length of time required to remove one day's contribution of river water is equal to the ratio of the quantity of river water accumulated within the estuary to the quantity introduced daily by the rivers. This has been called the "Flushing Time" (Ketchum and Keen, 1953).

The flushing time may be determined by two methods. The first method requires a detailed knowledge of both the vertical and horizontal distribution of salinity from which the amount of fresh water held within the estuary may be determined. The second method described by Ketchum (1951) requires that the estuary be subdivided into segments which are horizontally defined by the width of the estuary and the average excursion of a particle of water on the flooding tide. This latter method is called the Tidal Exchange method.

Ketchum and Keen (1953) have calculated the exchange of fresh and salt water in the Bay of Fundy by the two methods described above, and found that they gave very close agreement. In the first method, they used salinity results from 385 hydrographic stations available from the published literature and divided the Bay into sections located 11.5 miles apart.

Since the analyses gave average values of the exchanges of fresh and salt water, it seemed to the author that it might be of interest to make the same calculations using the data from a synoptic survey. Salinity data collected during the period March 4-8, 1954, were used.

At each station average salinities were computed for depth ranges of 0 to 25, 25 to 50, 50 to 100, and greater than 100 metres. The results were then plotted on a chart for each layer and the isohalines drawn in. From these charts the average salinity in each segment 11.5 miles apart were calculated. The segments selected were similarly located as those used by Ketchum and Keen to allow the use of their volume determinations. The figures of the Saint John River discharge into the Bay of Fundy were supplied by the Canadian Department of Northern Affairs and National Resources, Water Resources Division. Mean discharges of the rivers into the Bay of Fundy provided by Watson (1936) indicate that the discharge of the Saint John River at Pokiok supplied about 60 percent of the total. Using the average daily discharge of the Saint John River for the months of December, January and February, 1953-54, the data were corrected to give the average daily efflux into the Bay during this period. The average discharge of river water into the Bay of Fundy during this period was $3.9 \times 10^9 ft^3$/day, the salinity of the ocean water was taken at 32.6‰. The results of calculation are given in Table II.

Table II. The mean salinities, volumes of river water and flushing times for the various segments in the Bay of Fundy for March, 1954.

| Segment | Depth | Total Volume $10^9 ft^3$ | Mean Salinity ‰ | River Water % | River Water $10^9 ft^3$ | Mean Flushing Time |
|---|---|---|---|---|---|---|
| A | 0-25 | 860 | 31.00 | 4.90 | 42.1 | 10.8 |
| B | 0-25 | 873 | 31.50 | 3.38 | 29.5) | 11.8 |
| | 25-50 | 759 | 31.90 | 2.14 | 16.3) | |
| C | 0-25 | 949 | 31.70 | 2.76 | 26.2) | 12.6 |
| | 25-50 | 851 | 31.90 | 2.14 | 18.2) | |
| | 50-100 | 373 | 32.17 | 1.32 | 4.9) | |
| D | 0-25 | 1069 | 31.80 | 2.45 | 26.2) | 14.7 |
| | 25-50 | 982 | 31.95 | 1.99 | 19.5) | |
| | 50-100 | 900 | 32.17 | 1.32 | 11.9) | |
| E | 0-25 | 1225 | 31.80 | 2.45 | 30.0) | 18.7 |
| | 25-50 | 1132 | 31.95 | 1.99 | 22.5) | |
| | 50-100 | 1540 | 32.17 | 1.32 | 20.3) | |
| F | 0-25 | 1398 | 31.65 | 2.92 | 40.7) | 25.2 |
| | 25-50 | 1265 | 31.95 | 1.99 | 25.2) | |
| | 50-100 | 2044 | 32.17 | 1.32 | 27.1) | |
| | 100 | 689 | 32.35 | 0.77 | 5.3) | |
| G | 0-25 | 1540 | 31.60 | 3.06 | 47.1) | 29.9 |
| | 25-50 | 1382 | 31.95 | 1.99 | 27.4) | |
| | 50-100 | 2446 | 32.17 | 1.32 | 32.3) | |
| | 100 | 2084 | 32.45 | 0.41 | 9.6) | |
| H | 0-25 | 1486 | 31.70 | 2.76 | 40.9) | 25.6 |
| | 25-50 | 1238 | 31.70 | 2.76 | 34.2) | |
| | 50-100 | 1762 | 32.17 | 1.32 | 23.2) | |
| | 100 | 1474 | 32.56 | 0.12 | 1.8) | |
| | | | | | 582.4 | 149.3 days |

A total flushing time of 149 days for the winter period is much longer than the 76 days determined by Ketchum and Keen (1953). This would appear to be due to the low river discharge during this period.

In the same manner flushing times were calculated from data collected from March 29 to April 3, 1953, using a base salinity of 32.8‰ and an average river discharge of $3.02 \times 10^9 ft^3/day$. The results of calculations are shown in Table III.

The flushing time for the spring conditions was slightly longer than for the winter due to a reduced river discharge during that time of the year. A considerable difference in the flushing time results when the river discharge was averaged for varying intervals. The average for January-March was $3.02 \times 10^9 ft^3/day$ while that for March alone was $4.9 \times 10^9 ft^3/day$. These figures gave flushing times of 183 and 113 days, respectively. It is questionable which figure is more representative of actual conditions at the time of the survey.

Table III. The mean salinities, volumes of river water and flushing times for the various segments in the Bay of Fundy for March 1953.

| Segment | Depth | Total Volume $10^9 ft^3$ | Mean Salinity ‰ | River Water % | River Water $10^9 ft^3$ | Mean Flushing Time Days |
|---|---|---|---|---|---|---|
| A | 0-25 | 860 | 31.40 | 4.26 | 36.6 | 12.1 |
| B | 0-25 | 873 | 31.40 | 4.26 | 37.2 | 20.4 |
| | 25-50 | 759 | 31.75 | 3.20 | 24.3 | |
| C | 0-25 | 949 | 31.72 | 3.29 | 31.2 | 18.2 |
| | 25-50 | 851 | 32.10 | 2.13 | 18.1 | |
| | 50-100 | 373 | 32.30 | 1.53 | 5.7 | |
| D | 0-25 | 1069 | 31.50 | 3.96 | 42.3 | 24.6 |
| | 25-50 | 982 | 32.10 | 2.13 | 20.9 | |
| | 50-100 | 900 | 32.40 | 1.22 | 11.0 | |
| E | 0-25 | 1225 | 31.95 | 2.59 | 31.8 | 23.5 |
| | 25-50 | 1130 | 32.20 | 1.83 | 20.4 | |
| | 50-100 | 1540 | 32.40 | 1.22 | 18.8 | |
| F | 0-25 | 1398 | 32.02 | 2.38 | 33.3 | 24.1 |
| | 25-50 | 1265 | 32.18 | 1.59 | 20.1 | |
| | 50-100 | 2044 | 32.52 | 0.85 | 17.4 | |
| | 100 | 689 | 32.70 | 0.30 | 2.1 | |
| G | 0-25 | 1540 | 32.00 | 2.44 | 37.6 | 35.8 |
| | 25-50 | 1382 | 32.00 | 2.44 | 33.7 | |
| | 50-100 | 2446 | 32.39 | 1.25 | 30.6 | |
| | 100 | 2084 | 32.70 | 0.30 | 6.2 | |
| H | 0-25 | 1486 | 32.10 | 2.13 | 31.6 | 24.5 |
| | 25-50 | 1238 | 32.00 | 2.13 | 26.4 | |
| | 50-100 | 1762 | 32.50 | 0.91 | 16.0 | |
| | 100 | 1474 | 32.80 | 0.00 | 00.0 | |
| | | | | | 553.3 | 183.2 days |

The large variations in the flushing times as calculated here and those given by Ketchum and Keen indicate that further investigations into the subject might prove worthwhile. The data of Ketchum and Keen were reworked using different values for the river discharge, and the 1953 and 1954 data were reworked using several base salinities and appropriate river discharges. The results of these calculations are given in Table IV.

Table IV. Total flushing times for the Bay of Fundy as determined from various sets of data.

| | Base Salinity ‰ | Accumulated River Water ($10^9 ft^3$) | Total Flushing Time Days | Average River Discharge $10^9 ft^3$/day | Intervals for Average Discharges |
|---|---|---|---|---|---|
| I | 33.0 | 600 | 76 | 7.90 | April-July |
| | 33.0 | 585 | 74 | 7.90 | April-July |
| II | 33.0 | 600 | 101 | 5.96 | April-Sept. |
| | 33.0 | 600 | 210 | 2.86 | June-Sept. |
| | 33.0 | 600 | 125 | 4.79 | Year |
| III | 33.0 | 585 | 98 | 5.96 | April-Sept. |
| | 33.0 | 585 | 204 | 2.86 | June-Sept. |
| | 33.0 | 585 | 122 | 4.79 | Year |
| IV | 33.0 | 661 | 84 | 7.90 | April-July |
| | 33.0 | 661 | 111 | 5.96 | April-Sept. |
| | 33.0 | 661 | 231 | 2.86 | June-Sept. |
| | 33.0 | 661 | 139 | 4.79 | Year |
| V | 32.6 | 582.4 | 149 | 3.90 | Dec.1953-Feb.1954 |
| | 32.6 | 582.4 | 157 | 3.14 | Nov.1953-Feb.1954 |
| | 32.6 | 582.4 | 87 | 6.60 | Year |
| VI | 32.5 | 477.6 | 122 | 3.90 | Dec.1953-Feb.1954 |
| | 32.5 | 477.6 | 131 | 3.64 | Nov.1953-Feb.1954 |
| | 32.5 | 477.6 | 72 | 6.60 | Year |
| VII | 32.8 | 553.3 | 183 | 3.02 | Jan.-Mar. 1953 |
| | 32.8 | 553.3 | 57 | 9.70 | Jan.-Apr. 1953 |
| | 32.8 | 553.3 | 113 | 4.9 | March 1953 |

Group I in Table IV shows the results of calculations as given by Ketchum and Keen (1953) as determined from the salinity distribution and from the tidal exchange calculations.

The results shown in Group II were obtained by varying the amount of river water used in the calculation by taking it over a different period of the year. The base salinity and accumulated river water were determined from the salinity distribution. The river water data used were those presented by Watson (1936).

In Group III the same procedure was followed, but the accumulated river water was determined from Ketchum and Keen's tidal exchange calculations. In these calculations the accumulated river water below 100 metres was not taken into account.

Group IV results differ from those in Group III, in that, the accumulated river water below 100 metres was included in the calculations.

Groups V and VI show the effect on the flushing times by taking the river discharges over different portions of the year and by changing the base salinity for the 1954 survey data.

Group VII shows the results obtained by varying the period over which river discharges were taken for the 1953 data.

It is not suggested that all of these results are applicable to their respective cases as reasonable flushing times, but are supplied merely for the sake of comparison.

Several noteworthy facts are illustrated by the results in Table IV. These are:

1. The flushing times calculated from discharges including that for the month of April are generally less than 100 days. The average is 86 days.

2. The flushing times calculated from discharges excluding

that for April are frequently greater than 200 days. The average is 173 days.

3. A variation of 0.10 parts per mille makes a difference in the flushing times of 26 days.

4. The average discharge is inadequate to use with similarly averaged salinity observations. Unless great care is taken in determining the effective river discharge, possible calculations of the flushing time could vary almost threefold. This is shown by the determinations in Groups I, II and VII.

From the above, it appears that in the Bay of Fundy there are two periods of the year which have widely differing flushing times. The first period is the spring-summer one in which the heavy spring freshets play a leading role. Flushing times during this period appear to vary between 75 and 105 days with an average of about 86 days. The second period takes in the remainder of the year, and has a much wider range of flushing times which average about 173 days. The results of these calculations serve well to illustrate Pritchard's (1952) remarks that this method provides only a gross picture of the flushing.

Two types of water movements occasioned by the mixing of stratified waters have been demonstrated by Hachey (1934b). The mixing of stratified waters causes an inflow of surface and bottom waters to, and an outflow of mixed waters from the mixing zone, provided that the addition of fresh water is small. With the addition of large quantities of fresh water, the system breaks down to two movements, away at the surface and towards at the bottom. The inflow of bottom waters has been termed "draw-in".

From the flushing times given in Table IV, and from the T-S curves for Station 11 (Fig. 21), it appears that in the Bay of Fundy tidal mixing causes the three-current system to operate for the greater portion of the year. There is, however, a period during spring freshets when a rapid change over to the two-current system takes place. Judging from the Station 11 data, this appears to be abrupt and critical

## TIDAL INFLUENCE ON OCEANOGRAPHIC CONDITIONS IN THE BAY OF FUNDY

"The enormous tides of the Bay of Fundy have made these waters well known the world over. The conditions produced by these tides make the region one of utmost interest and importance to the oceanographer. However, the rapid changes in the hydrographic conditions caused by the ebb and flood of large masses of water over such an extensive area, presents a problem that allows present sampling methods to give only a picture of the general hydrographic conditions in this area." (Hachey and Bailey, 1952).

The problems occasioned by large tidal movements was discussed by Watson (1936) who utilized two vessels to overcome the influence of tidal variations on his observations. There have been no apparent attempts to analyse data to determine the tidal influence on the oceanographic conditions in the Bay of Fundy. A preliminary scrutiny of the seasonal sections across the Bay of Fundy (Bailey, 1953) suggests that, on the basis of the general distribution of temperature and salinity from time to time, the tides have only a small influence on the hydrographic conditions. Since the section (Fig. 22) was occupied at random with respect to the state of the tide, some tidal influence should have been discernable if it were of some consequence.

## Procedure

In an effort to gain knowledge of the High Water and Low Water conditions, the section was occupied on six successive occasions during the survey of March-April, 1953. Each run was staged at a specific phase of the tide so that a particular station would be occupied at H.W. and at L.W. as given in the Tide Tables for Saint John, N.B. By staggering the runs, the three central stations were occupied very near to the time of H.W. and of L.W., while the two end stations were occupied within one hour of these times. This procedure allows composite diagrams of conditions near High and Low Water, as well as six ordinary sections to be drawn. Table V gives the time that the station was occupied relative to H.W. or L.W. The times of H.W. and L.W. at St. John, N.B. are also given for convenience.

Table V

| Station | 11 | 12 | 13 | 14 | 15 | Time |
|---|---|---|---|---|---|---|
| Crossing | | | H. W. | | | |
| A | 1:02a | 0:07b | 1:22b | 2:28b | - | 12:56 1st April |
| C | 2:38a | 1:27a | 0:17b | 1:09b | 2:21b | 01:08 2nd |
| E | - | 2:32a | 1:04a | 0:02b | 1:10b | 13:25 2nd |
| | | | L.W. | | | |
| B | - | 2:04b | 0:53b | 0:15a | 1:21a | 19:04 1st |
| D | - | 0:57b | 0:17a | 1:34a | - | 07:23 2nd |
| F | 1:04b | 0:12b | 0:49a | 2:04a | 3:23a | 19:38 2nd |

Observations

The object of the survey was to obtain data for two sections illustrating temperature and salinity conditions at High Water and Low Water. From these, it was hoped to learn how these parameters vary with the state of the tide. The experiment was only partially successful because of the rapidly changing conditions occasioned by seasonal variations.

From the six crossings, two composite diagrams were produced showing the vertical distributions of temperature and salinity at High Water and Low Water (Figs. 34 and 35).

In viewing the two sections, it is readily apparent that the general hydrographic picture is little changed from High Water to Low Water. However, at Station 11, there was a considerable reduction in salinity from H.W. to L.W., the salinity changing as much as 2.4‰ while the temperatures vary by approximately 0.5 Centigrade degrees, from one stage of the tide to the next. This large change in salinity cannot be wholly attributed to tidal influence, but must, for the most part, be explained as the result of the increasing influence of the spring freshet reaching into the Outer Quoddy region.

Figure 36 shows temperature and salinity changes between (a) H.W. and L.W. (crossings C and D), (b) L.W. and H.W. (crossings D and E), and (c) successive H.W.'s (crossings C and E).

From High Water to Low Water, temperatures and salinities increased as much as 0.40 Centigrade degrees and 0.33 parts per mille for the Nova Scotia half of the section and decreased up to 0.12 Centigrade degrees and 0.18 parts per mille on the New Brunswick half.

The changes from Low Water to High Water, that is after a full run of the flooding tide, are shown in Figure 36B. Temperatures showed a general increase at station 14 and a general decrease at station 13, the remainder of the section was for the most part unchanged. Salinities decreased over most of the section except near the bottom and between 50 and 75 metres at stations 12 and 13. It should be noted that these two areas had decreased during the ebbing tide. The maximum subsurface change was 0.19 Centigrade degrees at station 13, and the maximum salinity change was 0.14 parts per mille.

Between successive High Waters (Fig. 36C), subsurface temperatures increased by as much as 0.16 Centigrade degrees on the Nova Scotia side and decreased by a like amount on the New Brunswick side. The largest changes took place in the central portion of the Bay. Salinities decreased in the central and western part of the section with no significant changes in the eastern part, except for a small area between 50 and 100 metres at station 14 where salinities increased by amounts as much as 0.13 parts per mille.

The changes in temperature and salinity that took place between various stages of the tide were discussed above. There is no clear indication as to the principal causes of these changes. For the most part, the changes seem to be due to two causes, namely, the tidal excursion of waters and to seasonal changes.

The ebb and flood of the tides is in a general SW-NE direction, while the distribution of properties seems to be at an angle to the tidal movement line so that changes in these parameters may be entirely different from the expected decrease on an ebb tide and increase on a flood tide. In all, however, it seems that the purely tidal changes are small.

One feature of the changes is the persistent increase on the Nova Scotia side of the Bay and the persistent decrease on the New Brunswick side. These changes may be linked with the theory of mixing of stratified waters in which there is a "draw-in" of salt water to replace those consumed in mixing with fresher waters. It is clearly evident from Figures 33 and 34 that the effects of the spring freshets were having an increasing influence on the oceanographic conditions in the vicinity of stations 11 and 12. Since there was a greater amount of fresh water introduced into the Bay, it is reasonable to assume that there would be an increased "draw-in" at this time.

## SUMMARY

1. The distribution of temperature and salinity in the Bay of Fundy and the northern part of the Gulf of Maine in the late winter indicated a westward movement of cold water over the banks at the southern tip of Nova Scotia. In the Fundian Channel, the waters are warmer and more saline. These waters enter into a general cyclonic circulation in the Bay of Fundy.

2. Slope water entered the Fundian Channel in strength as far as a line southwest of Yarmouth, N.S. In the Bay of Fundy, it was diluted to less than half its salinity value.

3. On the Nova Scotia side of the Bay no coastal waters from inshore areas of Nova Scotia were found.

4. Winter chilling along the shore at the head of the Bay appeared to play an important role in determining oceanographic conditions in this area.

5. The distributions of temperature and of salinity in the spring of 1953 indicate an inflow of warm waters from the offshore regions south of Nova Scotia, the introduction of cold waters or cooling or both at the head of the Bay, and their subsequent movements after mixing with warmer waters, out along the coast of New Brunswick.

6. Seasonal variation of temperature and salinity in the Bay of Fundy indicated that the occurrence of high salinity water is not unusual in recent years. The "draw-in" of the high

salinity water is associated with the increased vertical mixing brought about by autumnal cooling.

7. Relationships between coastal water and slope water found in the Bay of Fundy indicate that river discharges play a very important part in controlling oceanographic conditions in the Bay of Fundy. This, coupled with large tidal stirring, vernal warming, autumnal cooling and wind circulation, causes remarkable changes in the oceanographic conditions over relatively short periods. The percentage of slope water in the Bay of Fundy near the bottom varies between 34% and 76%, if the salinities of coastal waters and slope waters be taken at 30.8‰ and 35.2‰, respectively.

8. Calculations of flushing times for the Bay of Fundy from several sets of data indicate that in the spring and early summer the times are less than 100 days while during the remainder of the year, they are frequently greater than 200 days.

9. Investigations into the tidal influence on oceanographic conditions in the Bay of Fundy indicate that changes in temperatures and salinities were generally small. A change of 0-10 units in either parameter being considered within the limit of error. Causes of these changes appeared to be due primarily to seasonal changes and to tidal excursions.

## ACKNOWLEDGMENT

The assistance of all members of the Fisheries Research Board of Canada, Atlantic Oceanographic Group, in collecting and processing these data is gratefully acknowledged.

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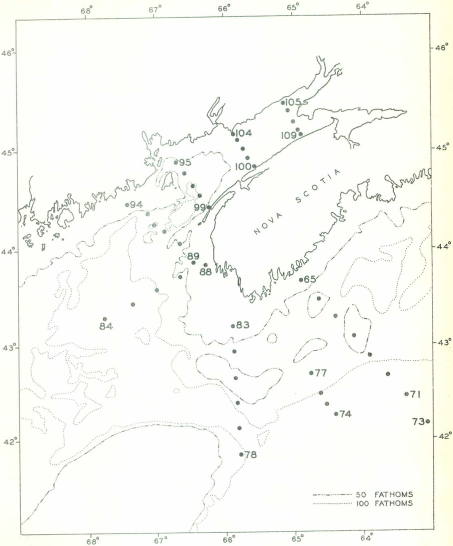

Figure 1. Chart of Bay of Fundy and southwestern coast of Nova Scotia showing the locations of oceanographic stations occupied during Cruise S-17, 4th to 8th March, 1954.

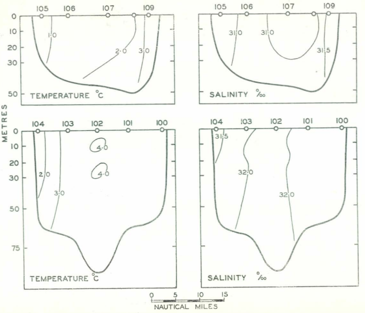

**Figure 2.** Temperature and salinity distributions between stations 105 and 109, and between stations 104 and 100.

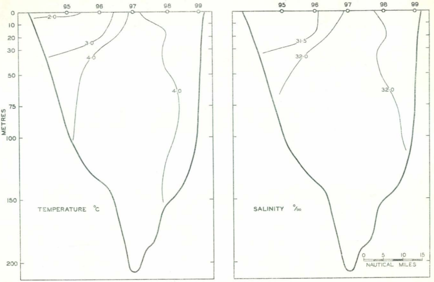

Figure 3. Temperature and salinity distributions between stations 95 and 99.

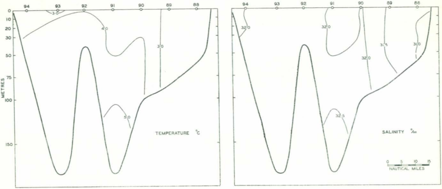

Figure 4. Temperature and salinity distributions between stations 94 and 88.

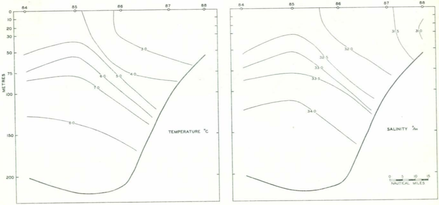

Figure 5. Temperature and salinity distributions between stations 84 and 88.

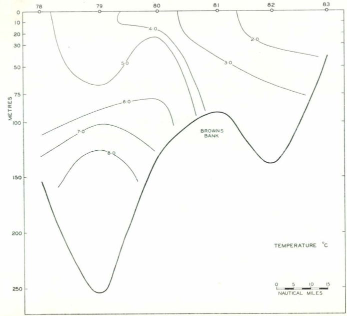

Figure 6. Temperature distribution between stations 78 and 83.

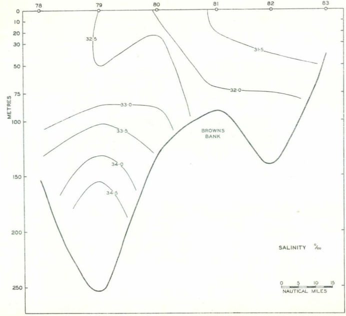

Figure 7. Salinity distribution between stations 78 and 83.

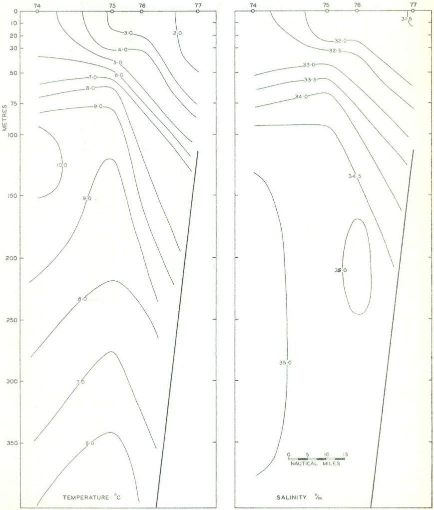

Figure 8. Temperature and salinity distributions between stations 74 and 77.

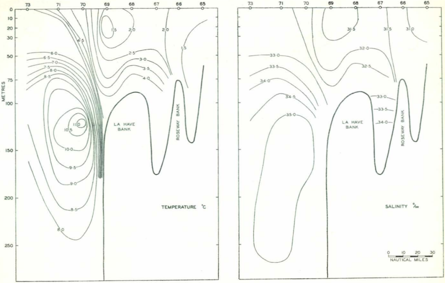

Figure 9. Temperature and salinity distributions between stations 73 and 65.

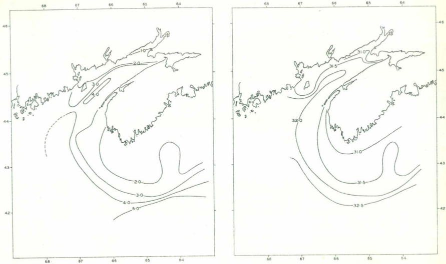

Figure 10. Horizontal distribution of temperature and salinity at the surface, 4th to 8th March, 1954.

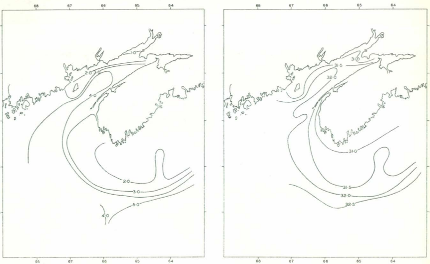

Figure 11. Horizontal distribution of temperature and salinity at 20 metres, 4th to 8th March, 1954.

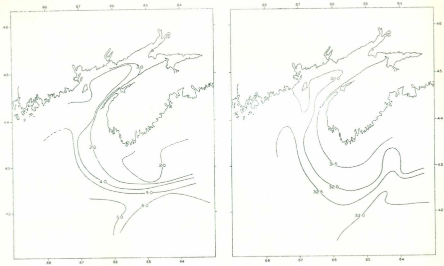

Figure 12. Horizontal distribution of temperature and salinity at 50 metres, 4th to 8th March, 1954.

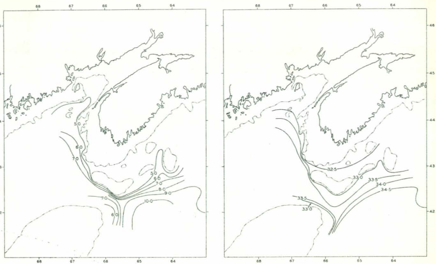

Figure 13. Horizontal distribution of temperature and salinity at 100 metres, 4th to 8th March, 1954.

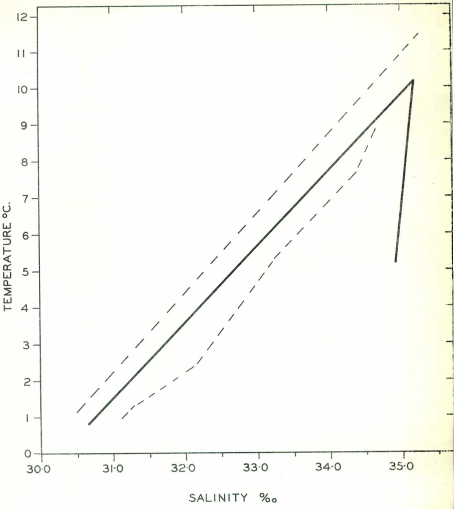

Figure 14. Temperature-Salinity correlation curve for waters found in the Bay of Fundy and off the southwestern coast of Nova Scotia from 4th to 8th March, 1954.

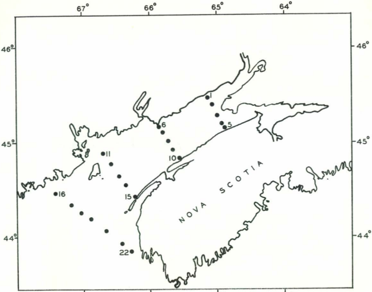

Figure 15. Chart of the Bay of Fundy showing the locations of stations occupied during cruise S-13, March 29 to April 3, 1953.

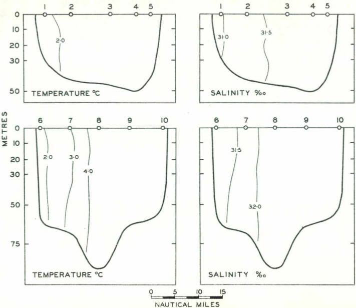

Figure 16. Vertical distributions of temperature and salinity between stations 1 and 5, and between stations **6** and **10**.

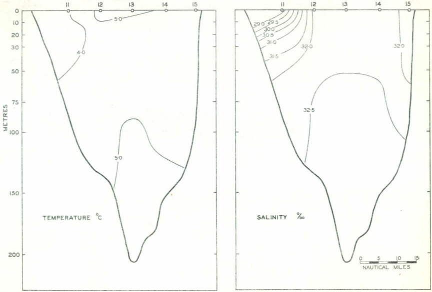

Figure 17. Vertical distributions of temperature and salinity between stations 11 and 15 .

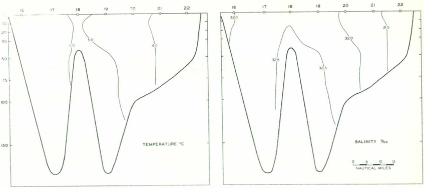

Figure 18. Vertical distributions of temperature and salinity between stations 16 and 22.

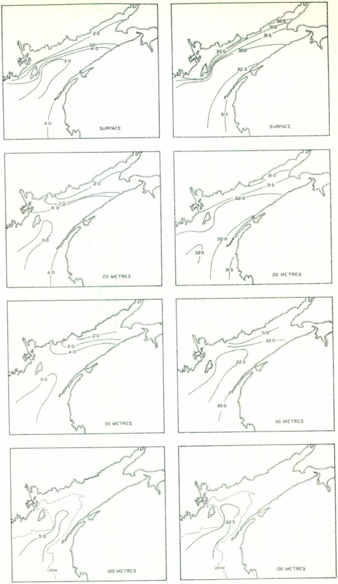

Figure 19. Horizontal distributions of temperature and salinity at depths of 0, 20, 50 and 100 metres. March 29 to April 3, 1953.

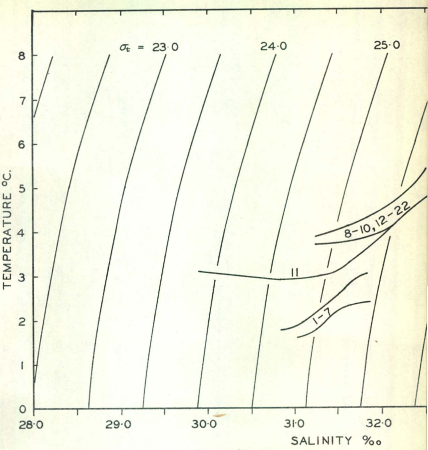

Figure 20. Temperature-salinity correlati
for waters found in the Bay of Fundy fr
to April 3, 1953.

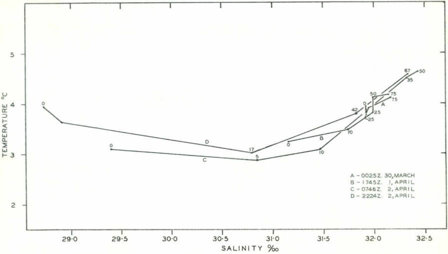

Figure 21. Temperature-salinity correlation curves for station 11, March 30 to April 2, 1953.

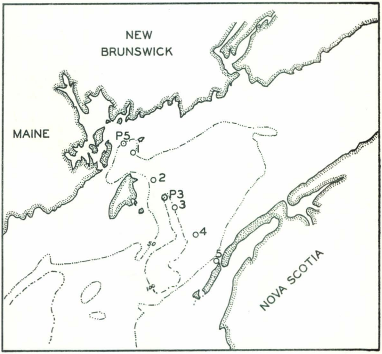

Figure 22. Map of Bay of Fundy showing locations of Hydrographic stations.

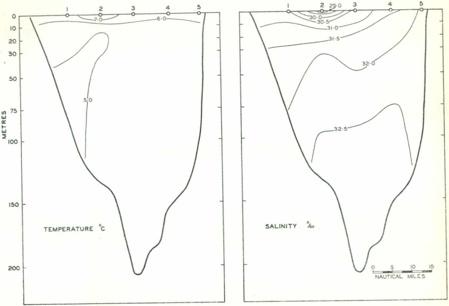

**Figure 23** Temperature and salinity distributions between stations 1 and 5 in the Bay of Fundy Cruise S-19, 20th May, 1954.

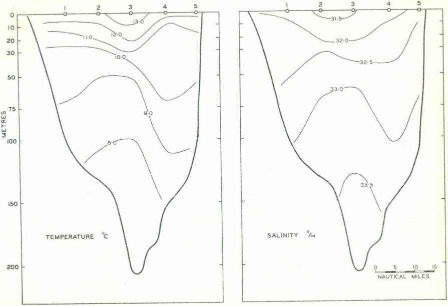

**Figure 24.** Temperature and salinity distributions between stations 1 and 5 in the Bay of Fundy Cruise S-23, 18th August, 1954.

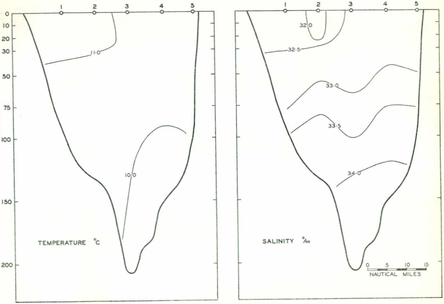

**Figure 25** Temperature and salinity distributions between stations 1 and 5 in the Bay of Fundy Cruise S-25, 8th October, 1954.

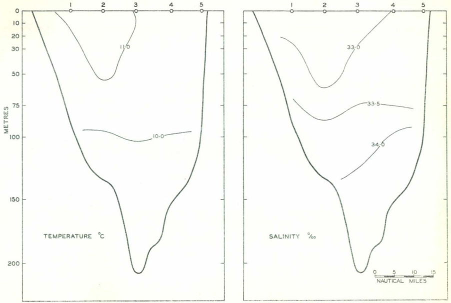

**Figure 26** Temperature and salinity distributions between stations 1 and 5 in the Bay of Fundy Cruise S-15, 17th October, 1953.

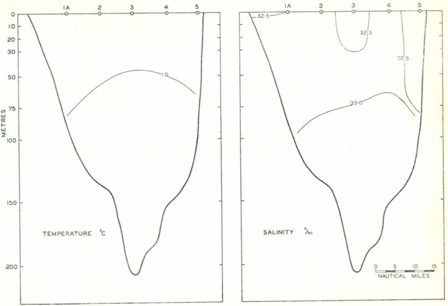

Figure 27 Temperature and salinity distributions between stations 1 and 5 in the Bay of Fundy Cruise S-16, 16th November, 1953.

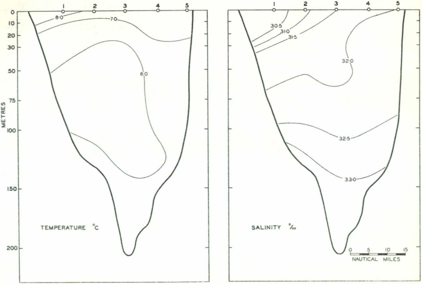

Figure 28. Vertical distributions of temperature and salinity between stations 1 and 5 in the Bay of **Fundy. Cruise S-26, June 12, 1955.**

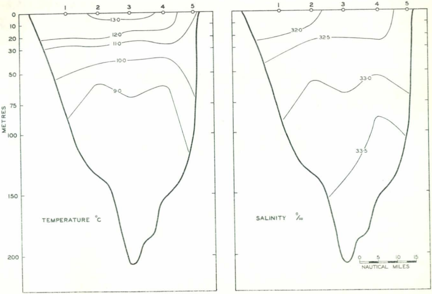

Figure 29. Vertical distributions of temperature and salinity between stations 1 and 5 in the Bay of Fundy. Cruise S-27, September 4, 1955

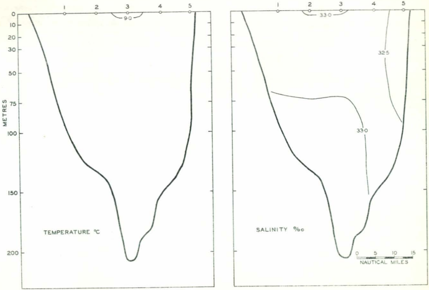

Figure 30. Vertical distributions of temperature and salinity between stations 1 and 5 in the Bay of Fundy. Cruise **S.29, November 15, 1955.**

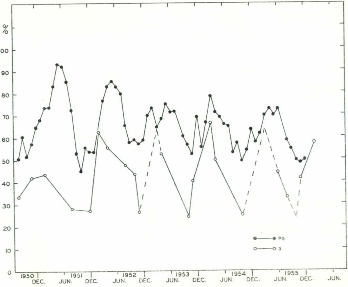

Figure 31. Percentage of coastal water in the Bay of Fundy at station 3 and P5 at 175 and 90 metres, respectively, from August 1950 to August 1955.

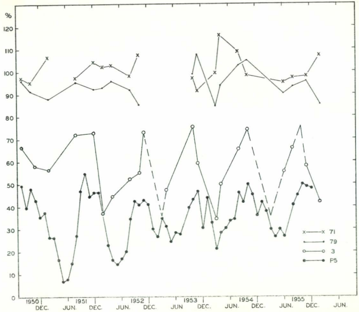

Figure 32. Percentage of "slope water" at stations in the Bay of Fundy (3,P5), Fundian Channel (79), and at the edge of the Scotian Shelf (71).

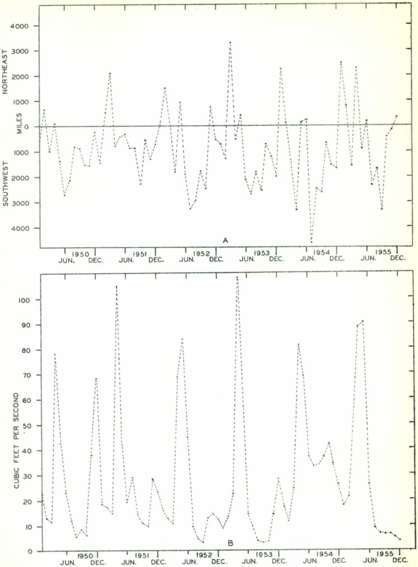

Figure 33. (A) Differences in the components of southwest and northeast wind mileages at Saint John, N.B. from January 1950 to December 1955. (B) Discharges of the Saint John River at Pokiok, N.B. from January 1950 to December 1955.

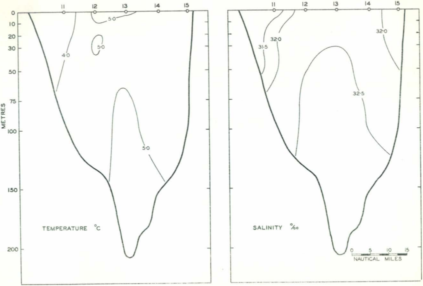

Figure 34. Composite diagrams of the vertical distributions of temperature and salinity at High Water, April 1953.

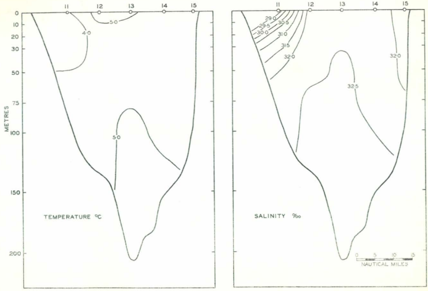

Figure 35. Composite diagrams of the vertical distributions of temperature and salinity at Low Water, April 1953.

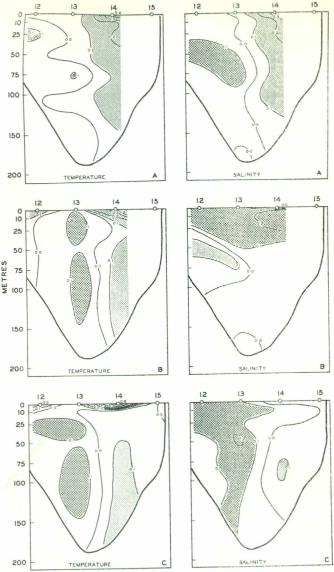

Figure 36. Changes in temperatures and salinities between various states of the tide. (a) From High to Low Water, (b) From Low to High Water, and (c) Between successive High Waters. The dotted sections show significant decreases while the cross-hatched section show significant increases.