No. 8

THE CIRCULATION OF THE WATER IN THE BAY OF FUNDY

PART I

INTRODUCTION AND DRIFT BOTTLE EXPERIMENTS

BY

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CONTENTS

1. INTRODUCTION

The object of the present series of investigations has been to determine what, if any, general movement of the water other than the tides occurs in the Bay of Fundy. The movement of sea-water made evident in the tides is always of the nature of an oscillation, whether it be the rise and fall seen on all shores, or the flow to and fro seen in tidal streams. Such an oscillatory movement does not produce a constant flow in one direction and does not lead to any continuous translation of the water. It may often be in fact that the flow and ebb of the tidal streams in a given region obscure a slower but continuous movement of the water in one direction not due to the tidal force. The importance of such continuous movements in any consideration of the life history of marine organisms is obvious; eggs, larvae or post-larval stages may be transported far from the place of breeding to waters either suited or unsuited to their survival.

2. PHYSICAL FEATURES OF THE BAY OF FUNDY

The Bay of Fundy extends in a north-easterly direction from the northern side of the Gulf of Maine and forms with the southern coast of Nova Scotia the northern boundary of the Gulf. The western boundary of the Gulf is formed by the coast of the United States from Canada to Cape Cod and the southern and eastern boundaries by Nantucket shoals, Georges Bank and Brown Bank, which reach to from 20 to 30 fathoms (36 to 55 meters) of the surface. The 50 fathom (91 meter) contour line enters the Gulf of Maine south of Nova Scotia, following the coast line at a distance of 20 to 30 miles. Entering the Bay of Fundy only 5 miles from the coast, and enclosing a large basin forming most of the lower half of the Bay, it leaves to the southeast of Grand Manan (see bathymetric chart, Plate I). From the Bay of Fundy this contour line follows at a distance seldom over 10 miles the coast of the United States and the outlines of the banks, leaving

the Gulf some 60 miles to the south of where it entered. Between the 50 fathom contour line, as it enters and as it leaves the Gulf, is the Eastern Channel, the only deep passage between the Gulf and the Atlantic. The entrance to the Bay of Fundy is funnel-shaped, the narrow part of the funnel being placed between Grand Manan and Brier Island. All of the upper part of the Bay, that is the part above a line joining St. John and Digby, is under 50 fathoms in depth.

Opening into the lower part of the Bay of Fundy on its north-western side is Passamaquoddy Bay, a large enclosed bay averaging 15 to 20 fathoms (27 to 36 meters) in depth and communicating with the Bay of Fundy by two narrow and irregular channels, Head Harbour Passage and Letite Passage. On the south-eastern side of the mouth of the Bay of Fundy is St. Mary Bay, a long and narrow bay, widest where it opens into the Gulf of Maine and connected with the Bay of Fundy only by two narrow passages, Grand Passage and Petite Passage. The depth of St. Mary Bay gradually decreases from about 20 fathoms (36 meters) at its mouth to the shallow upper end. Passing farther up the Bay of Fundy on the north-western shore we find St. John Harbour, and across the Bay at about the same level Annapolis Basin with its narrow outlet, Digby Gut. At its upper end the Bay of Fundy divides into two arms. To the north-east is Chignecto Channel, a long bay extending to the north-east with a depth of about 20 fathoms, decreasing to 8 or 10 fathoms (15 to 18 meters) at its upper end. To the east is Minas Channel, connected by a narrow passage with Minas Basin. The depth of Minas Channel is 20 to 30 fathoms (36 to 55 meters), that of the Basin 10 to 5 fathoms (18 to 9 meters).

The north-western shore of the Bay of Fundy is somewhat shallower than the south-eastern. The shore line from St. John to Maine is strikingly irregular, as is also the corresponding shore of Grand Manan, a condition for which the prevailing south-west winds may be largely responsible.

The bottom of the Bay is covered with mud and sand, with rocks and gravel appearing in places (see chart, figure 1). Mud alone is found in the Chignecto

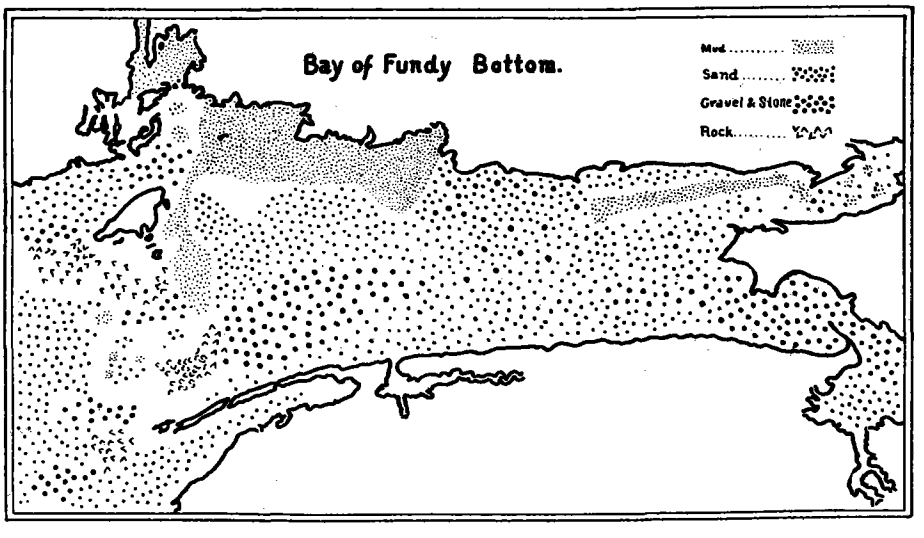


Fig. 1. Bottom deposits in the Bay of Fundy.

Channel, and on the north-west shore to Quaco Head, about half way to St. John and from St. John to near Passamaquoddy Bay and north and east of Grand Manan. The latter area of mud is of importance in the discussion of the flow of fresh water from the River St. John into the Bay.

Fresh water enters the Bay of Fundy from five important rivers: the St. Croix draining into Passamaquoddy Bay, the St. John opening directly on the north-west shore of the Bay, the Petitcodiac leading into Chignecto Channel, the Shubenacadie opening into the Basin of Minas, and the Annapolis draining into Annapolis Basin. The area drained is approximately 26,000 square miles. Considerably more than half of this area is drained by the St. John River (see chart of drainage areas, figure 2).

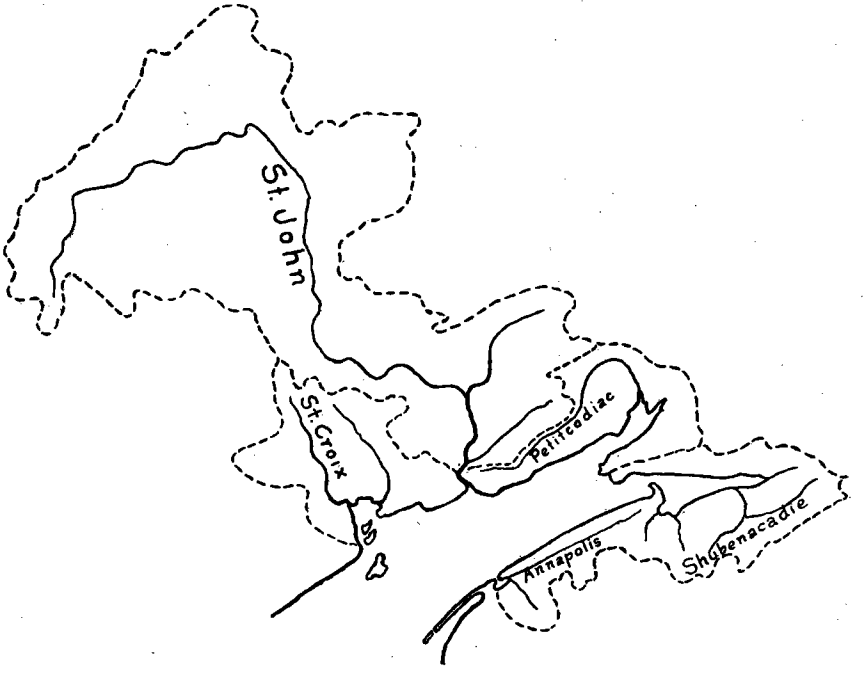


Fig. 2. River basins draining into the Bay of Fundy.

With these physical features in mind we are prepared to approach the problem of the movement of the water in the Bay.

3. METHODS OF INVESTIGATING CURRENTS

The problem of the general movement of any large body of sea-water may be approached by three quite different physical methods. The most direct method is to measure the actual movement of the water with a current meter. The observations must extend over at least one complete tidal period. The determinations are then treated so as to separate the general movement of the water from the tidal oscillation. Such measurements with current meters require the service of a large vessel anchored for days at a time; it is, therefore, rarely that simultaneous, or even approximately simultaneous, measurements can be made at different places. A second method is to record the drift of

objects floating in the water. By comparing numerous records of this kind where the drift has occurred between different places and under different conditions of wind and tide a picture of the movement of the surface water can be obtained. The third method may be called the hydrodynamic method since it involves the calculation of the movement of the water from a determination of the position and contour of the surfaces of equal buoyancy in it, or, in other words, from the hydrodynamic forces which such surfaces can be shown to express. Since observations of temperature and salinity can be made with considerable rapidity, it being possible with the proper equipment to take a whole series from the surface to a depth of 100 fathoms (182 meters) in less than an hour, it is possible for a single vessel to make observations over a large area which are practically simultaneous, so far as the comparatively slow changes in the sea are concerned. All three of these methods have been applied to the Bay of Fundy, and there is a striking agreement with regard to the general movement of the water as determined by the three different methods.

4. MEASUREMENTS WITH CURRENT METERS

During the summers of 1904 and 1907 W. Bell Dawson made an extensive series of accurate observations on the tidal currents in the Bay of Fundy, using the surveying steamer *Gulnare* and anchoring at 19 different stations in the Bay and its approaches. Current meters working at a depth of 3 fathoms, or slightly under 5 meters, were used and records of the direction and velocity of the current were taken half hourly throughout the period spent at each station, which varied from two days to one week. The results of these observations are published in "Tables of Hourly Direction and Velocity of Currents and Time of Slack Water in the Bay of Fundy and its Approaches." The actual velocities found at the different stations are reduced in the tables to mean velocities for each hour, the mean being the average for the lunar period calculated from the recorded observations by comparing the range of tide at each station with the range of tide at St. John, N.B. Observations with the current meter were made also at greater depths since Dr. Dawson states: "Almost everywhere the current is as strong down to a depth of 30 fathoms as it is at the surface, and at most places it turns in direction on the surface and below at practically the same time. This has an important bearing on wind disturbance, as it shows that the current will soon regain its normal direction and strength after a storm moderates." From a consideration of the direction and velocity of the water determined at the different stations, Dawson concludes: "There is no general movement of the water in any one direction in this region which is at all well marked, nor did the temperature of the water give any definite indication of this."

As it is planned to submit Dawson's tables to a simple dynamic treatment one of these tables is here reproduced.

Let us imagine a drop of water moving with the current at the depth, velocity and direction stated in this table, and construct a diagram of the path which it would take. Such a diagram is shown in figure 3 on a scale of $\frac{1}{2}$ inch to the nautical mile. Starting just after high water at the point *a* in the diagram, we find from the table the average velocity of 0.60 nautical miles per hour in a

TABLE I

Station A from Dawson's Tables.

Station A. 13½ miles S 26°W from Cape Spencer Light. Depth, 55 fathoms.

No. of line in figure representing Velocities[1]	Tide at St. John N.B.	Direction and Velocity of Current	No. of line in figure representing velocities[1]	Tide at St. John N.B.	Direction and Velocity of Current
..	At H.W.	NE bN 0.76	..	.....	.....
1	1 h. after	N b W 0.60	7	5 h. before	N b E 0.64
2	2 h. "	W b N 0.97	8	4 h. "	E N E 1.39
3	3 h. "	W 1.42	9	3 h. "	E N E 1.69
4	4 h. "	W 1.60	10	2 h. "	E N E 1.61
5	5 h. "	W 1.05	11	1 h. "	NE b N 1.29
6	6 h. "	W 1.10			

Time.—The state of the current is here referred to the time of High Water at St. John, N.B., to be found in the Tide Tables published by the Survey.

Direction and Velocity.—The directions indicate the point towards which the current sets. They are magnetic throughout, the average variation in these regions being 18°W. The velocities are in knots, tenths and hundredths. They correspond with the average range of 21 feet at St. John, and will be stronger or weaker as the range varies from springs to neaps.

direction north by west. The line marked *1* will represent in magnitude and direction this velocity. Since the velocities and directions given in the table are the averages of half hourly determinations made during a number of different tidal periods, we may assume that to a first approximation the drop of water moves with a uniform velocity equal to that of the table and in the direction given. At the end of the first hour it will then have arrived at the end of the line marked *1*, and will have approximately followed the course of that line. In the same way we draw the line marked *2* to represent the course which the drop takes during the second hour. Similarly for the lines *3* to *11* and *H. W.* In this way we have traced the movement of the drop to the point *b*. Only twelve hours have been represented, the extra 25 minutes in the tidal interval would be represented by a very short line between west and north when the current is turning 6 hours after high water. It is thus seen that the drop of water, instead of returning to the point *a* which it would have done if it moved only in the equal oscillations of the tidal stream, has been moved to the point *b*. The result of this movement is the same as if the drop had moved in the direction of the straight line *ab* for a distance equal to *ab*. The line *ab* may, therefore, be said to represent in magnitude and direction a resultant velocity which, in this case, is 5.10 nautical miles per tidal period of approximately 12½ hours. This is the same as a velocity of 0.41 knots and is in the direction N ½ W. In this discussion we have started with the drop of water at the end of high water, and followed it till the next high water, but it is easily seen that the same resultant velocity in the same direction would have been obtained had we started with the drop at any other time and followed it through a complete tidal period since a line joining, for example, the ends of the lines marked *3* in the diagram would be equal in length and parallel to the line *ab*. This method of treating the

[1]These two columns are inserted by the writer and refer to his figure 3.

velocities and directions given for Station A in Bell Dawson's "Tables of hourly direction and velocity of the currents and time of slack water in the Bay of Fundy and its approaches" has, therefore, shown that there is a general movement of the water in the Bay at this point in a direction toward one half point West of North at a rate of 0.4 knots.

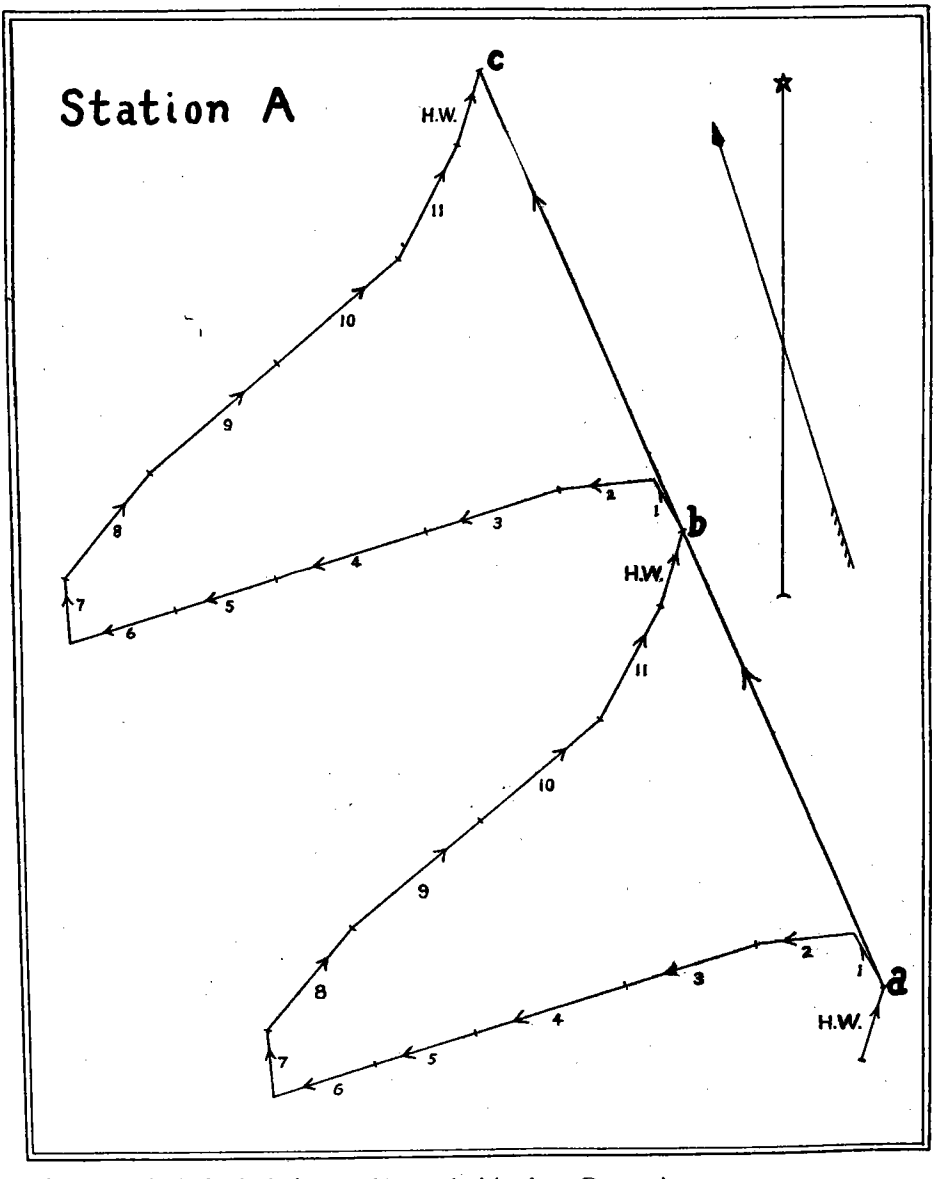


Fig. 3. Method of calculating resultant velocities from Dawson's current measurements.

When this method is applied to the figures for the other stations in the tables similar resultant velocities are obtained for these stations. The graphical constructions for the other stations in Dawson's tables are shown on a reduced

scale in Plates II and III, and the positions of the stations are on the chart in Plate IV. At stations *A* and *B*, which are well within the Bay, the general movement is across that of the tidal stream. Here, as might be expected, the direction as recorded by the current meter at the time of the turn of the tidal stream (Station *A*, *H.W.*, *1* and *7*; Station *B*, *H.W.*, *1* and *11*) is not far from that of the general movement. In Table II are given the directions and velocities of the resultant movement of the water for stations *A* to *M*. The velocities and directions given in this table are shown graphically in the chart (Plate IV) where the arrows at the different stations show the direction of the resultant or general velocity and are drawn of such a length that they represent to the scale of the chart the distance which the general movement of the water carries it in two tidal periods, or approximately one day.

TABLE II

Resultant Velocities determined by the method of graphic summation from Bell Dawson's "Table of hourly direction and velocity of the currents and time of slack water in the Bay of Fundy and its approaches."

Station (see Chart, Plate IV)	Velocity in nautical miles per tidal period	Velocity in knots	Direction referred to Magnetic North
A	5.10	0.41	N ½ W
B	3.88	0.31	N b E
C	2.34	0.19	E b S
D	3.35	0.27	N E
E	6.53	0.52	W S W
F	4.72	0.38	N E b N
G	1.04	0.08	N
H	1.62	0.13	N N E
J	1.98	0.16	E S E
K	4.46	0.36	E N E
L	3.75	0.30	N N W
M	3.77	0.30	E N E

Although not made in the Bay of Fundy but at the entrance to the Gulf of Maine certain measurements made by Bigelow ('17, p. 203) on July 27 to 28 in 1914 are of interest for comparison with Bell Dawson's. He worked at the same depth (3 fathoms), but used an Ekman current-meter, while Dawson used an electric current meter. Bigelow's station is not far from Dawson's station *T*. He found that "the general movement of water for the whole tide was about four miles toward the south-west." A direct comparison of this with Dawson's figures for station *T* is not possible, as he found the direction too variable to record, but Bigelow's determination agrees in direction and rate with the general movement as determined at Dawson's other stations.

The conclusion to be drawn from these observations and calculations is that there is a general movement of the water in the Bay of Fundy which may be described as follows: Water from the North Atlantic enters the Gulf of Maine

on the north, passes round the southern end of Nova Scotia and into the Bay on its eastern side. The water then moves along the Nova Scotia coast, crosses the Bay from the Nova Scotia to the New Brunswick side and flows out of the Bay to the east of Grand Manan. In the Grand Manan Channel there is a movement inward.

5. DRIFT-BOTTLES

A. Bottles picked up in the Bay of Fundy.

During the summer of 1919 three hundred and ninety-six drift-bottles were set out by the staff of the Atlantic Biological Station of the Biological Board of Canada in the Bay of Fundy. These bottles were put out in sets and spaced on lines crossing the Bay. Two types of drift-bottle were used; one kind consisted of simply a bottle with either a rubber or a paraffined cork stopper; the other, designed to be less affected by the wind and the wind-driven water at the surface, had attached to it to hang usually at a depth of 3 fathoms (5.5 meters), a drag made from a square of galvanized iron 5 inches on a side cut into at the middle of two opposite sides, and bent so as to oppose about a half of its surface to any lateral movement. These drags were hung by 3 pound cod line (about 1.5 mm. in diameter) and the line was tied to the bottles so that they floated with the neck out of the water.

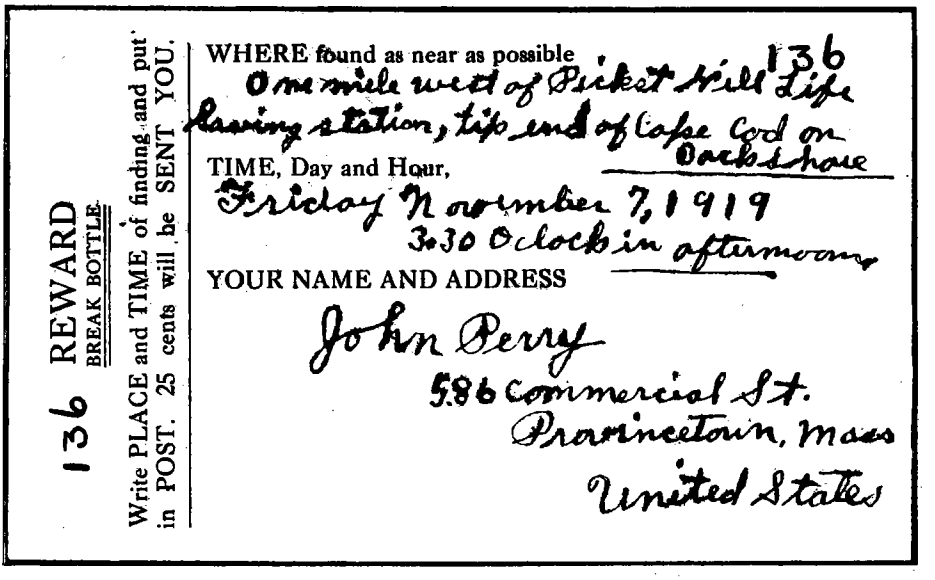


Fig. 4. Post card from drift bottle number 136.

Each of these bottles contained rolled up inside of it an ordinary post card (Figure 4) on which was printed on one side the address of the Biological Station and on the other side the offer of a small reward (twenty-five cents) which would be sent to the finder who wrote in the spaces provided on the card, the answers to the three questions: "Where found? When found? By whom found?" and returned it.

The station cruiser, *Prince*, crossed the lower part of the Bay of Fundy during the summer and the bottles were thrown overboard from her, being spaced in some cases a mile and in other cases half a mile apart. When the experiment was started it was thought that very few of the post cards would ever be seen again. As a matter of fact seventy-three out of the three hundred and ninety-six cards set out had been found and returned through the post by December 1, 1919. The post mark gives a very convenient way of verifying the statements on the cards regarding the time and place of finding, for in all cases the cards seem to have been posted near where they are said to have been found. Almost all the bottles were found on the sea shore where they had been left by the tide, although some were picked up at sea. The finders were mostly fisher folk, lighthouse keepers, coast guardsmen and others, whose callings make them keen observers of the sea and the sea shore. The accuracy with which these people have answered the questions is quite noticeable. Many of them have asked about the experiment and where the bottle was sent adrift. One card found during a north-east storm on Cape Cod has this note attached: "Never mind the 25 cents, but send details of your experiment which has to do, I judge, with ocean currents."

The first set consisted of ten 8 oz. bottles with rubber corks and having attached to them by a cod line a galvanized iron drag to hang at a depth of 3 fathoms. They were spaced in a line between Flag Cove, Grand Manan and Petite Passage, Nova Scotia, on June 18. Two of these cards have been returned.[1]

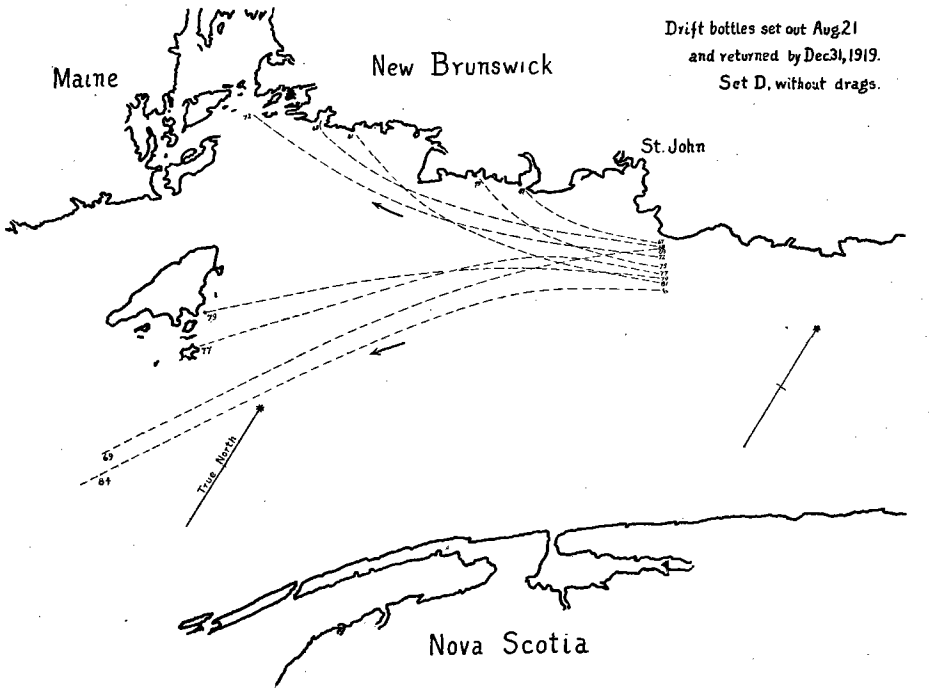


Fig. 5. Drift bottles of set D. Chart showing where bottles set out on the northwestern side of the Bay of Fundy were found.

[1] The present description refers only to drift bottles post cards from which were received by December 31, 1919.

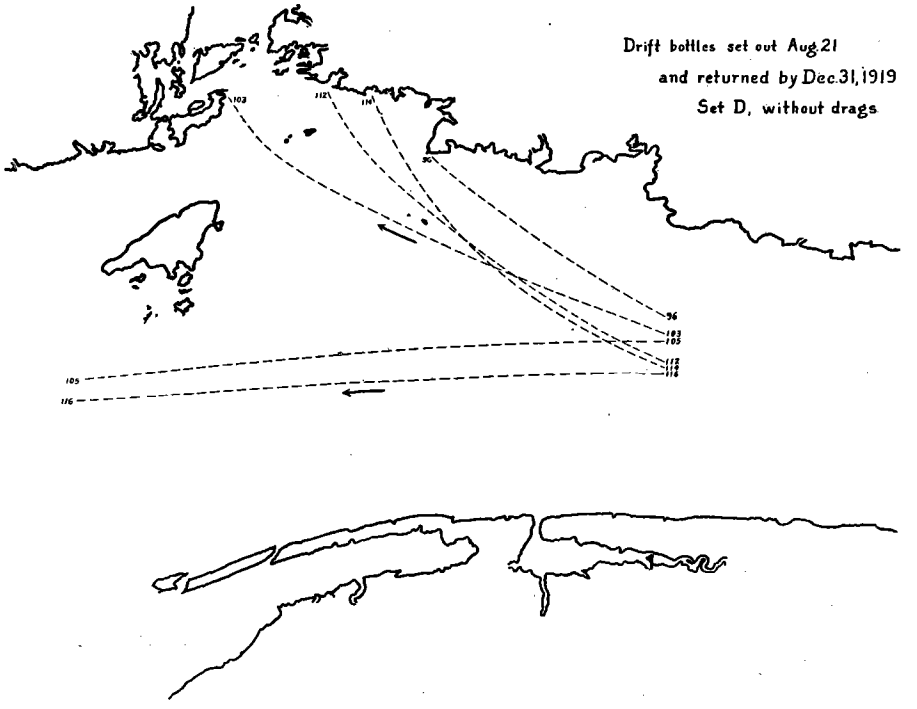


Fig. 6. Drift bottles of set D. Chart showing where bottles set out in the middle of the Bay of Fundy were found.

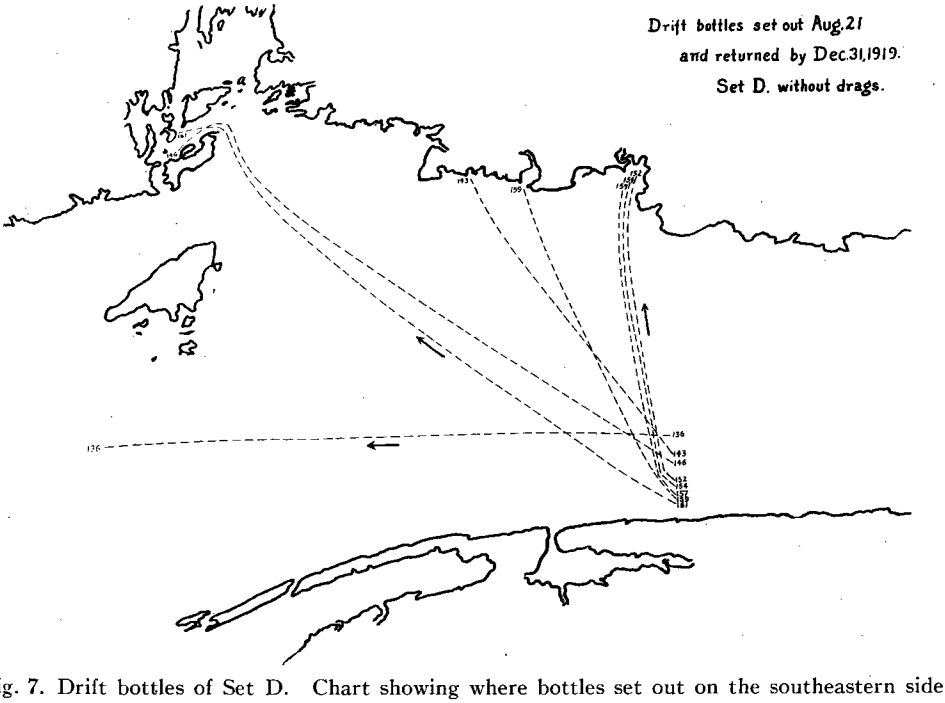


Fig. 7. Drift bottles of Set D. Chart showing where bottles set out on the southeastern side of the Bay of Fundy were found.

Both were found on the coast of Maine (Figure 14). The next set from which returns were received, Set D, consisted of 100 2 oz bottles with paraffined cork stoppers and without drags. They were spaced evenly between Cape Spencer and Parker's Cove on August 21. Of these twenty were found within the Bay, all on the coast of New Brunswick west of Cape Spencer, those set out on the Nova Scotia side tending to come across the Bay. Figures 5, 6 and 7 show the positions where these bottles were set out and found. The interrupted lines in the figures are drawn merely to join the place of finding with that of setting out, and are not intended to show a course which the bottle may have taken. Five out of the eight bottles represented were returned by September 4 or within two weeks. The prevailing and strongest winds during the latter part of August as determined by the Meteorological Station at Pt. Lepreaux were south to south-east; the maximum velocity was 33 miles per hour and occurred before the bottles were put out. Thus the wind could not have been responsible for the drift of the bottles westward. Three of these bottles were found so soon after they were set out that their rate of travel is significant as establishing a minimum rate for the current in which they were carried. Bottle 67, which was set out near Cape Spencer on August 21, was found three days later in Musquash Harbour, a distance of about 15 nautical miles per day. Bottle 75, which was set out at about the same time and further from shore, was found four days and six hours later at a distance of about 20 nautical miles, giving a rate of a little less than 5 nautical miles per day. Bottle 96, set out also on the same day about a third of the way across from Cape Spencer to Parker's Cove, was found six days later at Little Lepreaux, near Point Lepreaux, a distance of about 30 nautical miles, giving again a rate of about 5 nautical miles per day. Bottle 72, put out on the same day near Bottle 75, was found eleven days later in Letite Passage, a distance of about 46 nautical miles, giving a rate of about 4 nautical miles per day. The finding of these bottles, therefore, indicates the presence of a current running along the New Brunswick shore from east to west at a rate of at least 5 nautical miles per day. The places of finding of the rest of the bottles of set D are shown in the two charts, figures 6 and 7. Bottles set out on the Nova Scotia side of the Bay have all come across. Three from near Nova Scotia, Numbers 152, 154 and 157, were found in St. John Harbour on the same day by different people. They were found 8 days after being set out. The distance in a straight line from the place of setting out to that of finding is about 30 nautical miles. This gives about four nautical miles per day as a minimum rate for crossing the Bay. The south to south-east wind may have helped these bottles to cross the Bay.

Another set, H, of 50 bottles similar to those of the set just considered, were put out on September 13 by Dr. Philip Cox from the passenger steamer plying from St. John to Digby. Twelve post cards from these bottles were received by December 31, 1919, nine from the New Brunswick coast west of St. John, one a few miles to the east, and two from the Nova Scotia coast (Figures 8 and 9). The drift of these bottles has, then, in the main repeated that of the previous set put out on a line slightly to the east of them.

Another set, G, consisting of 100 bottles of the same kind, 2 oz bottles without drags, were set out to the west of these on a line from Point Lepreaux, N.B.,

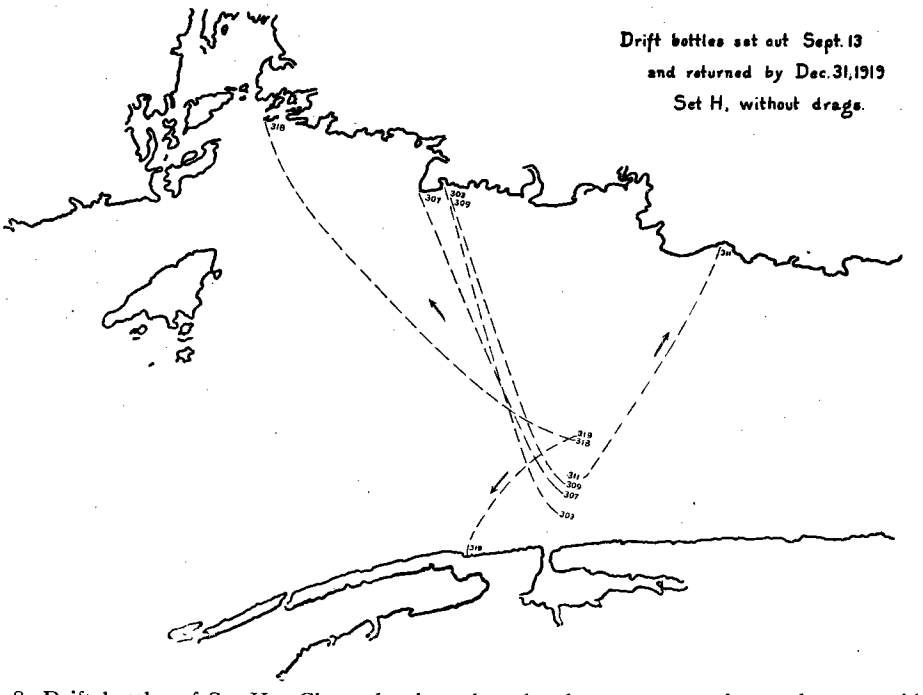


Fig. 8. Drift bottles of Set H. Chart showing where bottles set out on the southeastern side of the Bay of Fundy were found.

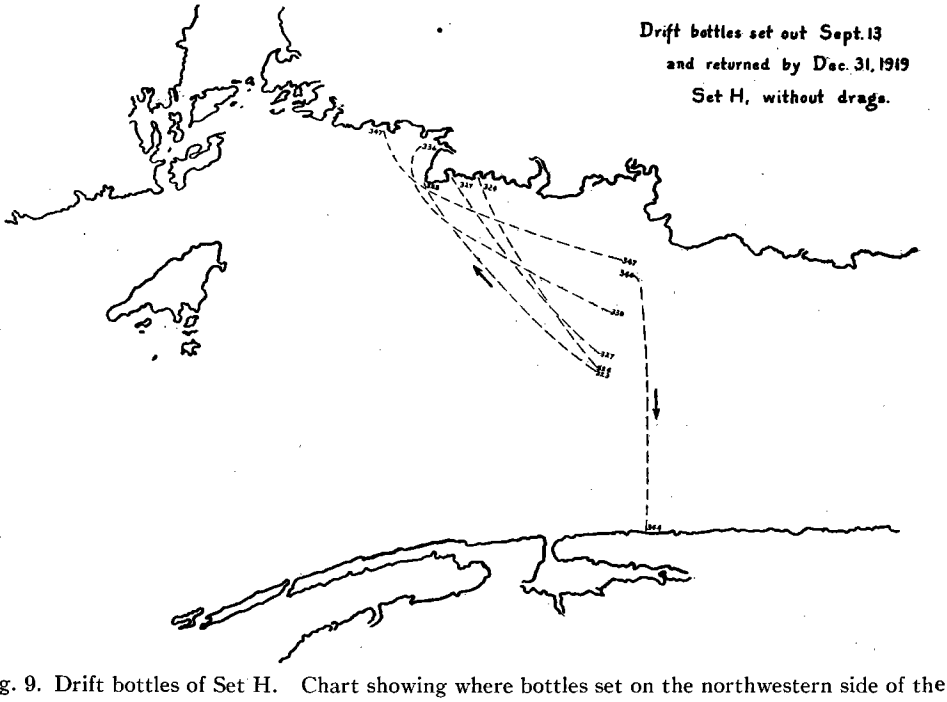


Fig. 9. Drift bottles of Set H. Chart showing where bottles set on the northwestern side of the Bay of Fundy were found.

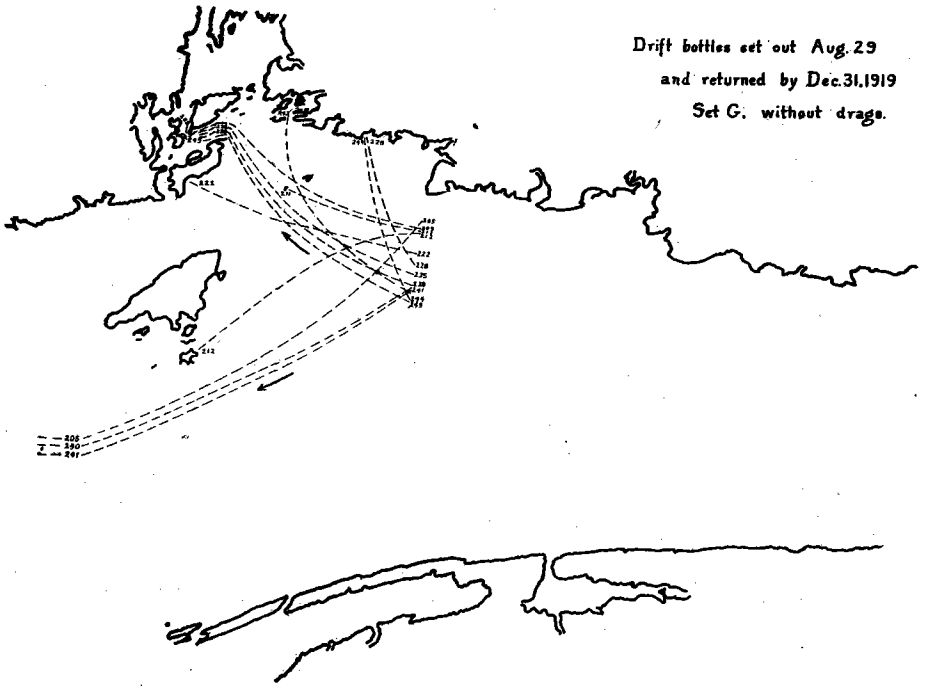


Fig. 10. Drift bottles of Set G. Chart showing where bottles set out on the northwestern side of the Bay of Fundy were found.

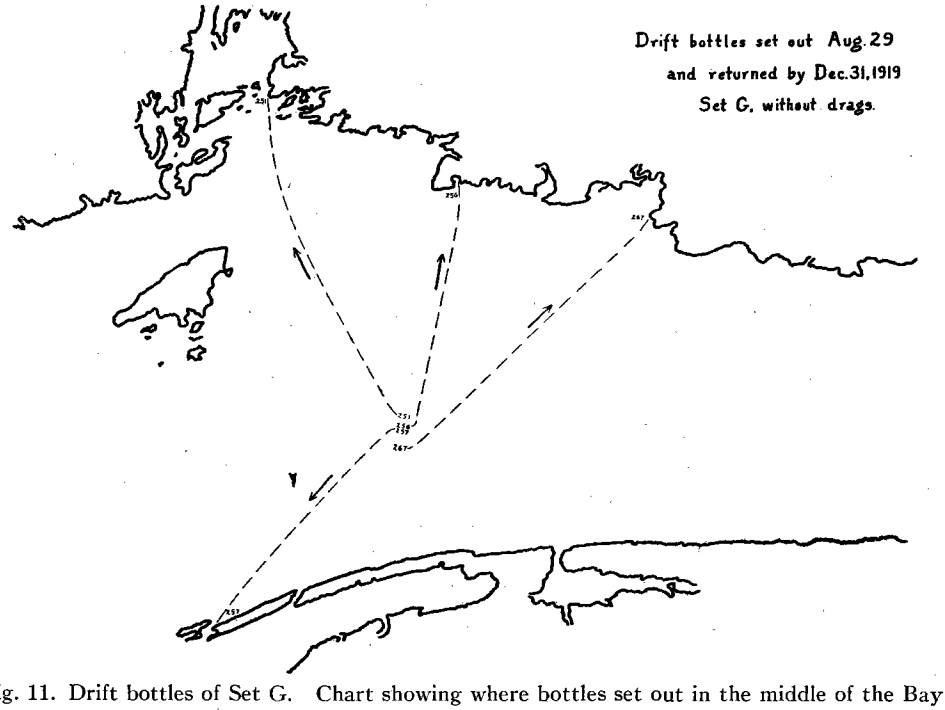


Fig. 11. Drift bottles of Set G. Chart showing where bottles set out in the middle of the Bay of Fundy were found.

to Petite Passage, N.S., on August 27. By the end of the year 27 post cards had been received from these. The drift of the bottles of this set (Figures 10, 11 and 12) also confirms the presence of a current westward along the New Brunswick shore, and indicates a current across the Bay. Four of the bottles, Numbers 251, 256, 257 and 267, shown in Figure 11, were set out close together about two-thirds of the way across from the New Brunswick to the Nova Scotia coast. They were picked up at widely separated points on both sides of the Bay, a considerable time after they were set out. This would seem to indicate that they were put out near the boundary between currents running in different directions. It is also noticeable that some of the bottles set out on the Nova Scotia side, Numbers 267, 281 and 293, were picked up to the north-east of Point Lepreaux, indicating that they may have drifted up the Bay on the Nova Scotia side before crossing. The fact that the bottles set out on the Nova Scotia side were found in the Bay on the average after a much longer time (25 to 93 days) indicates also that they may have taken a longer route going up on the Nova Scotia side and down on the New Brunswick side.

Set E consisted of bottles similar to those of set A with iron drags attached. They were set out on the same day and spaced evenly along the same line as set D. None of these have been reported from the Bay, but four were found in the Gulf of Maine (Figure 14), indicating that being less affected by the wind than the bottles without drags, they were carried out of the Bay by the westward current on the New Brunswick side.

Turning now to another series of 50 bottles, 25 small without drags, set J, and 25 large with drags, set I, which were set out on a line N.W. by N. from North Point, Brier Island, N.S., extending for 10 nautical miles, we find that five of these (Figure 13) had been reported from before the end of the year, and that they were all found on the Nova Scotia coast in the Bay of Fundy to the east of Brier Island, three of them reaching as far as Port George near the head of the Bay, a distance of 70 nautical miles. One of the bottles, 387, was found at Port George, only 17 days after it was set out, giving a minimum rate for the drift along the Nova Scotia shore of over 4 nautical miles per day.

From the drift of these bottles it seems clear that during the summer of 1919 there was a general movement of the water in the Bay of Fundy of the same general nature as that shown to be the case in 1904 and 1907 from Bell Dawson's tables. This movement is into the Bay along the Nova Scotia coast across the Bay, along the New Brunswick shore and out (Figure 15). The times of finding of certain of the drift-bottles show that the rate of this movement is probably not less than five nautical miles per day. This rate is not quite as great as that deduced from the current measurements, but is of the same order of magnitude.

B. Drift-Bottles Picked up in the Gulf of Maine.

All the drift-bottles which have been recorded from outside the Bay of Fundy were picked up in the Gulf of Maine.[1] Table III shows the number of bottles found outside of the Bay. Figure 14 shows the places of setting out and finding of the bottles of set A of June 18, and sets D and E of August 21. There seems no doubt that during the times these bottles were at sea there was a general drift of the water in the north-west part of the Gulf of

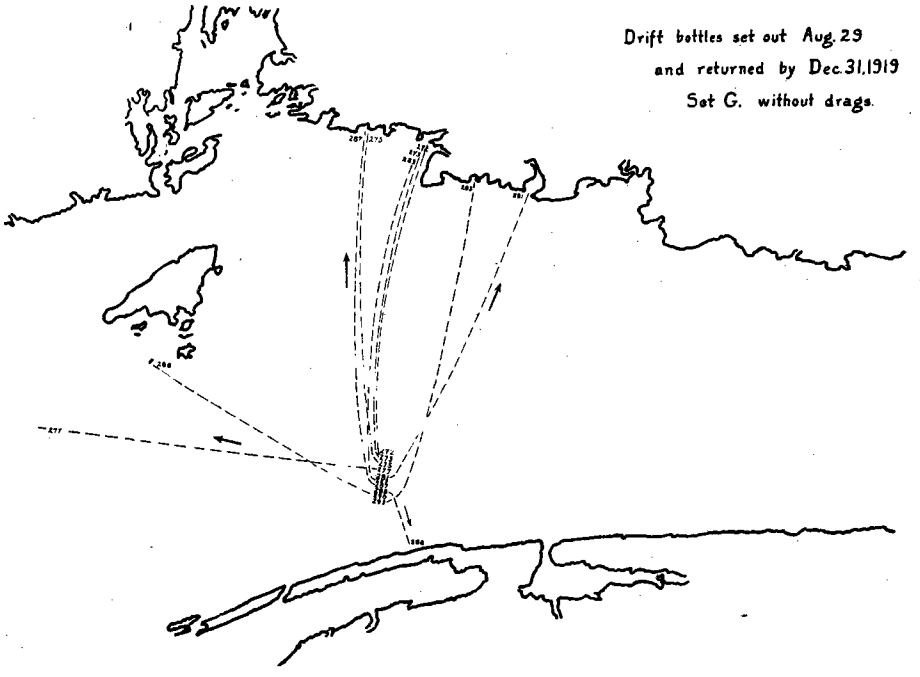


Fig. 12. Drift bottles of Set G. Chart showing where bottles set out on the southeastern side of the Bay of Fundy were found.

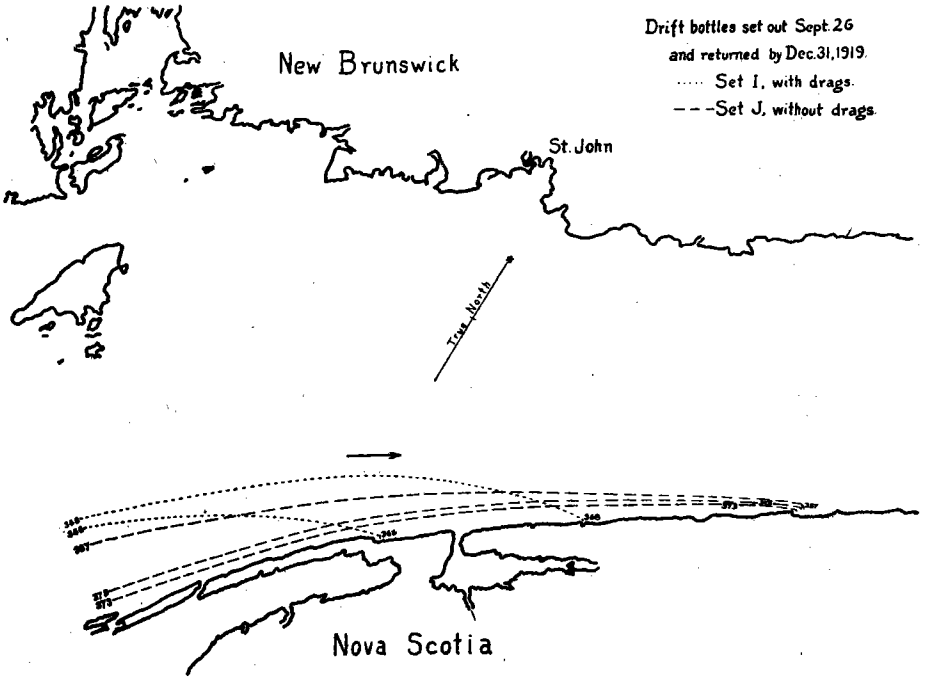


Fig. 13. Drift bottles of Sets I and J.

Maine in a south-westerly direction toward Cape Cod. A chart showing the distribution of the bottles of set G of August 29, which were found in the Gulf of Maine, would show the same general drift. Of the bottles with drags three were picked up on the Cape Cod peninsula, the other three on the coast of Maine. Of the bottles without drags eight were picked up on the Cape Cod peninsula and two on the coast of Maine. Here again the times of finding are significant. Seven out of the eleven bottles which went to Cape Cod or its vicinity were found between 70 and 80 days after being put out, the shortest time being 73 days. The distance in a straight line from the Bay of Fundy is about 300 nautical miles. The rate of the drift was, therefore, about four nautical miles per day.

The drift of these bottles, set out at various times during the summer indicates a surface movement of the water from the Bay of Fundy, through the north-western part of the Gulf of Maine and striking Cape Cod, the rate of this drift being about four nautical miles per day.

TABLE III

Drift bottles found and reported by Dec. 31, 1919, complete records.

Set No.		Date set out	No. set out	Found in Bay		Found outside Bay		Total found	
				No.	%	No.	%	No.	%
With drags	A	June 18	10	0	0	2	20	2	20
	E	Aug. 21	20	0	0	4	20	4	20
	I	Sept. 26	25	2	8	0	0	2	8
Without drags	D	Aug. 21	100	19	19	5	5	23	23
	G	Aug. 24	100	23	23	4	4	27	27
	H	Sept. 13	50	12	24	0	0	12	24
	J	Sept. 26	25	3	12	0	0	3	12
All sets[1]		.....	330	59	18	15	5	73	22

TABLE IV

Drift bottles set out during 1919 and returned by the end of that year.

SET A. DRIFT BOTTLES NOS. 1-10

Put overboard on a line between *Flag Cove*, Grand Manan, and *Boar's Head*, Petite Passage, N.S., on June 18, 1919, by the *Prince*.

Eight oz. medicine bottles with rubber stoppers and zinc drags made by bending a galvanized iron square 5″ on a side and attaching it with 3 lb. cod line to hang at a depth of 3 fathoms. Bottles contained Canadian Post Cards with usual legend stamped with rubber stamp. Probably legend bleached out after one or two months in sunlight.

2 returned by Dec. 31, 1919.

Number on card	Distance from Flag Cove	Set out Aug. 21, 1919	Time found	No. of days out	Where found
3	14 mi.	8.53 a.m.	July 23, 7.30 a.m.	35	*Bailey's Mistake*, Me.
5	18 mi.	9.27 a.m.	Sept. 2, 2.00 p.m.	76	Penobscot Bay, ½ mi. S. of Heron Neck Light.

[1] Sets B, C and F from which no returns were received are omitted from this table.

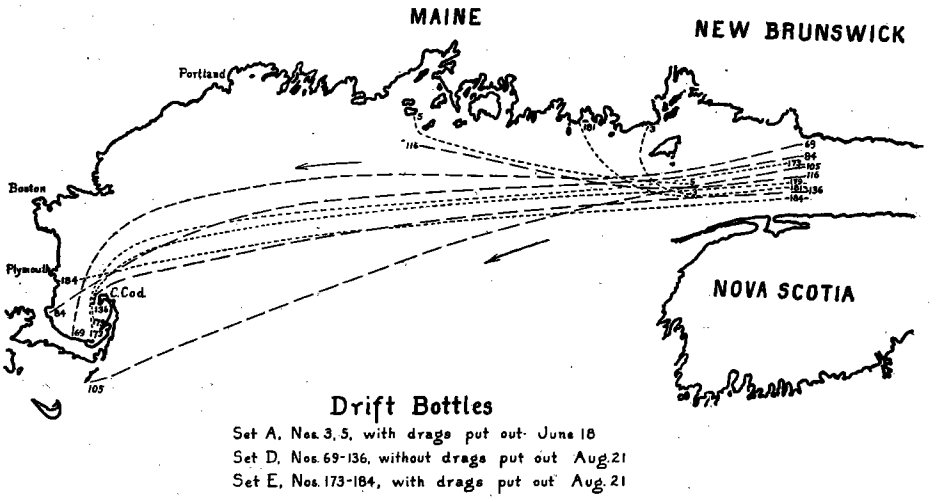


Fig. 14. Drift bottles. Chart showing where those found outside of the Bay of Fundy were found.

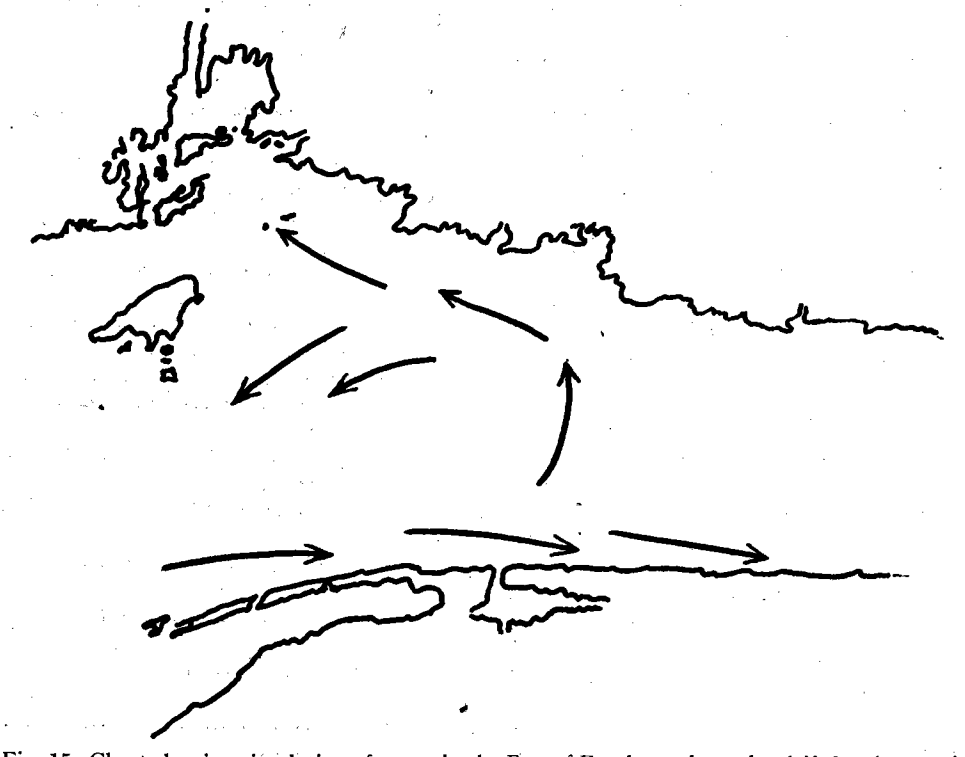


Fig. 15. Chart showing circulation of water in the Bay of Fundy as shown by drift bottle experiments.

SET D. DRIFT BOTTLES NOS. 66-165

Set out on a line between *Cape Spencer* and *Parker's Cove* on Aug. 21, 1919, by the *Prince*. Eight oz. flat-sided medicine bottles without drag, with rubber stoppers, containing Canadian Post Cards with usual legend printed.

23 returned by Dec. 31, 1919.

Number on card	Distance from Cape Spencer naut. mi.	Set out Aug. 21, 1919	Time found	No. of days out	Where found
67	1.3	9.38 a.m.	Aug. 24, 12.05 a.m.	3	*Musquash Harbour*, Near Narrows.
68	1.7	9.40½ a.m.	Sept. 9, 9.00 a.m.	19	*Beaver Harbour*, Eastern Wolfpool Cove.
69	2.	9.42½ a.m.	Dec. 6, 1.00 p.m.	107	*Scorton Beach*, East Sandwich, *Cape Cod*, Mass.
72	2.7	9.49 a.m.	Sept. 1, 2.30 p.m.	11	*Letite Passage*, 300 yds. below Green's Point.
75	3.5	9.55½ a.m.	Aug. 25, 3.45 p.m.	4	*Chance Harbour*, 100 yds. S. of Light house.
77	4.	10.00 a.m.	Oct. 5, 12.00 N.	45	*Grand Manan*, Gull Cove, White Head.
79	4.5	10.04 a.m.	Sept. 9, 4. 30 p.m.	19	*Grand Manan*, Nantucket I.
81	5.	10.08½ a.m.	Sept. 2, 9.00 a.m.	12	*Seeley's Head*, 2 mi. S. (at sea?)
34	5.7	10.15 a.m.	Nov. 8, 7.00 a.m.	79	*Cape Cod*, Mass., Sagamore Beach.
96	9.	11.03 a.m.	Aug. 28, 9.45 a.m.	7	*Little Lepreaux.*
103	10.7	11.18 a.m.	Sept. 11, 2.00 p.m.	21	*Campobello Island*, Head Harbour, "landed."
105	11.2	11.22½ a.m.	Nov. 2, 2.30 p.m.	73	*Chatham*, Mass. (on C. Cod), Monomoy Point.
112	12.7	11.37½ a.m.	Oct. 11, 2.00 p.m.	51	*Mace Bay*, Pocologan, Char. Co.
114	13.2	11.42 a.m.	Sept. 14, 4.00 p.m.	24	*Seeley's Basin*, on Beach.
116	13.7	12.09 p.m.	Oct. 10, 5.00 p.m.	50	*Penobscot Bay*, Wooden Ball Isl. Knox Co., Maine.
136	19.	12.53 p.m.	Nov. 7, 3.30 p.m.	78	*Cape Cod.* "Back shore," 1 mi. W. of Picket Hill Life-Saving Station.
143	20.7	1.31 p.m.	Sept. 11, 4.00 p.m.	21	*Chance Harbour*, Little Dipper Harbour.
146	21.6	1.37½ p.m.	Sept. 4, 12.45 p.m.	14	*Campobello Isl.*, Wilson's Beach.
152	23.2	1.50½ p.m.	Aug. 29, 8.30 a.m.	8	*St. John*, Red Head Beach.
154	23.7	1.56 p.m.	Aug. 29, 7.30 p.m.	8	*St. John*, Red Head Bank.
157	24.5	2.08 p.m.	Aug. 29, 11.00 a.m.	8	*St. John*, Red Head.
159	25.	2.16 p.m.	Aug. 29, 6.00 p.m.	8	*Musquash Harbour*, Frenchman's Creek.
161	25.6	2.24 p.m.	Sept. 12	22	Eastport, Me., Gondy's Point, in weir.

SET E. DRIFT BOTTLES NOS. 166-185

Set out on a line between *Cape Spencer* and *Parker's Cove* on Aug. 21, 1919, by the *Prince*.

Eight oz. medicine bottles with galvanized iron drag made by bending piece 5 inches square tied with 3 lb. cod line to hang 3 fathoms below bottle. Bottles contained Canadian Post Card with usual legend printed.

4 returned by Dec. 31, 1919.

Number on card	Distance from Cape Spencer	Set out Aug. 21, 1919	Time found	No. of days out	Where found
173	11 mi.	11.21 a.m.	Nov. 9, 3.30 p.m.	80	*Cape Cod.* South Wellfleet, Marconi Wireless Sta. on beach.
179	17 mi.	12.37 p.m.	Nov. 5, 2.05 p.m.	76	*Cape Cod.* Pamet River, Truro, Mass. 500 ft. N. of Watch House Station 37, U.S. Coast Guards.
181	19 mi.	12.54 p.m.	Sept. 22, 7.15 a.m.	32	*Jonesport*, Me. 300 yds. S.W. from Norton's Island, 100 yds. N. from Bush Ledge, West End.
184	22 mi.	1.40 p.m.	Nov. 9, 8.00 a.m.	80	*Plymouth*, Mass. White Horse Beach, after heavy storm.

SET G. DRIFT BOTTLES NOS. 198-297

Set out between *Point Lepreaux* and *Gulliver Hole* on Aug. 29, 1919, by the *Prince*.

Two oz. plankton bottles with paraffined corks, no drags, and containing Canadian Post Cards with usual legend printed.

28 returned by Dec. 31, 1919.

Number on card	Distance from Pt. Lepreaux, naut. mi.	Set out Aug. 29, 1919	Time found	No. of days out	Where found
205	2.4	11.10½ a.m.	Dec. 22, 9.30 a.m.	115	*Cape Cod*, Sagamore Highlands, Mass.
209	3.2	11.16½ a.m.	Sept. 14, 9.30 a.m.	16	*Deer Island*, Cumming's Cove Wharf.
211	3.6	11.19½ a.m.	Sept. 10,	12	*South Wolf Island.*
212	3.8	11.21 a.m.	Nov. 6? 2.00 p.m.	69	*Grand Manan*, North Pond Beach.
222	5.8	11.36 a.m.	Sept. 13, 3.00 p.m.	15	*Campobello Island*, Southern Head Herring Cove.
228	7.	11.45 a.m.	Sept. 28, 3.00 p.m.	30	Below *Seeley's Head.*
235	8.4	11.55½ a.m.	Sept. 20, 11.00 a.m.	22	Near *Deer Island*, Indian Cove, Indian Island.
238	9	12.00 N.	Sept. 5, 10.30 a.m.	7	Near *Deer Island*, Indian Island.
240	9.4	12.03 p.m.	Dec. 10, 9.30 a.m.	103	*Schoodic*, Maine.
241	9.6	12.04½ p.m.	Nov. 18, 2.00 p.m.	81	7½ mi. from *Provincetown Harbour* Beach at N. Truro.
242	9.8	12.06 p.m.	Oct. 20, 11.00 p.m.	52	*Letang River*, Char. Co.

SET G. DRIFT BOTTLES Nos. 198-297—*Cont.*

Number on card	Distance from Pt. Lepreaux naut. mi.	Set out Aug. 29, 1919	Time found	No. of days out	Where found
244	10.2	12.09 p.m.	Sept. 4, 4.00 p.m.	6	*Seeley's Basin*; Beach.
245	10.4	12.10½ p.m.	Sept. 10, 6.00 a.m.	12	*Eastport, Me.*, on beach below Dog Island Light.
251	22.6	1.54½ p.m.	Oct. 8, 9.00 a.m.	40	*Muscabin Point*, Letite Passage.
256	23.6	2.02 p.m.	Nov. 8, 10.30 a.m.	71	*Mace Bay*, 2 mi. N. by W. from Point Lepreaux.
257	23.8	2.03½ p.m.	Nov. 4, 3.00 p.m.	67	*Freeport*, Digby Co., N.S. Beautiful Cove.
267	25.8	2.18½ p.m.	Oct. 5, 11.00 a.m.	37	*Mispec*, 2 mi. north of Cape Spencer.
272	26.8	2.26 p.m.	Nov. 30, 11.00 a.m.	93	*Lepreaux Harbour.*
273	27	2.27½ p.m.	Oct. 8, 10.00 a.m.	40	*Lepreaux Harbour.*
275	27.4	2.30½ p.m.	Sept. 26, 10.00 a.m.	28	*Seeley's Cove.*
277	27.8	2.33½ p.m.	Dec. 2, 9.00 a.m.	95	*Cape Cod*, between Wood End Light and Race Point Light.
281	28.6	2.39½ p.m.	Sept. 23, 11.45 a.m.	25	*Little Musquash*, Maguire's Beach.
283	29	2.42½ p.m.	Dec. 10, 4.00 p.m.	103	*Lepreaux Harbour.*
287	29.8	2.48½ p.m.	Sept. 25, 6.00 p.m.	27	*Seeley's Cove.*
288	30	2.50 p.m.	Nov. 7, 11.00 a.m.	70	1 mi. N.E. of *Centreville*, Digby Co.
290	30.4	2.53 p.m.	Oct. 16, 10.00 a.m.	48	*Grand Manan*, Lower Green Island.
293	31	2.57½ p.m.	Sept. 29, 4.00 p.m.	31	*Dipper Harbour.*

SET H. DRIFT BOTTLES NOS. 298-347

Set out between *Digby* and *St. John* on Sept. 13, 1919, by Dr. Philip Cox on the passenger steamer running from Digby to St. John.

Two oz. plankton bottles with paraffined corks, and without drags, containing Canadian Post Cards with usual legend printed.

12 returned by Dec. 31, 1919.

Number on card	Distance from Whistle Buoy off Digby Gut, naut. mi.	Set out Sept. 13, 1919	Time found	No. of days out	Where found
303	2.4	3.08 p.m.	Oct. 11, 9.00 a.m.	28	*Dipper Harbour* East.
307	4.2	3.16 p.m.	Sept. 28, 9.00 a.m.	15	*Point Lepreaux*, Mace Bay, 2 mi. below Pt. Lepreaux, low water; shore.
309	5.2	3.20 p.m.	Sept. 22, 11.00 a.m.	9	*Dipper Harbour.*
311	6.1	3.24 p.m.	Oct. 5?, 3.00 p.m.	22	On *Black River* Beach, St. John Co.
318	9.4	3.38 p.m.	Oct. 10, 11.00 a.m.	27	*Bliss Harbour*, near Howard Island.
319	9.9	3.40 p.m.	Oct. 30, 1.00 a.m.	47	*Gulliver's Cove.*
323	15.7	4.05 p.m.	Sept. 22, 8.00 a.m.	9	*Pt. Lepreaux* Beach, 25 yds west of whistle house.
324	16.2	4.07 p.m.	Sept. 22, 9.00 a.m.	9	*Little Dipper Harbour*, Ledges.
327	17.6	4.13 p.m.	Oct. 8, 7.00 a.m.	25	*Dipper Harbour.*
336	21.8	4.31 p.m.	Sept. 28, 10.45 a.m.	15	*Little Lepreaux.*
344	25.6	4.47 p.m.	Oct. 31, 11.00 a.m.	48	*Litchfield Cove.*
347	27.1	4.53 p.m.	Sept. 27, 4.00 p.m.	14	*Red Head Cove*, Char. Co. (near Seely's Cove, N.W. Pt. Lepreaux).

Set I. Drift Bottles 347A-371

Set out on a line running N.W. by N. from *North Point of Brier Island* on Sept. 26, 1919, by the *Prince*.

Eight oz medicine bottles with galvanized iron drags made from strips 7" x 3½" and attached with cotton twine so as to hang at a depth of 5 meters.

2 returned by Dec. 31, 1919.

Number on card	Distance from Brier Island naut. mi.	Set out Sept. 26, 1919	Time found	No. of days out	Where found
366	8.8	5.58½ p.m.	Nov. 10, 5.00 p.m.	45	*Gulliver's Cove*, Digby Neck.
368	9.6	6.04½ p.m.	Oct. 18, 10.30 a.m.	22	*12 miles below Digby* on the Bay of Fundy shore.

Set J. Drift Bottles Nos. 372-396

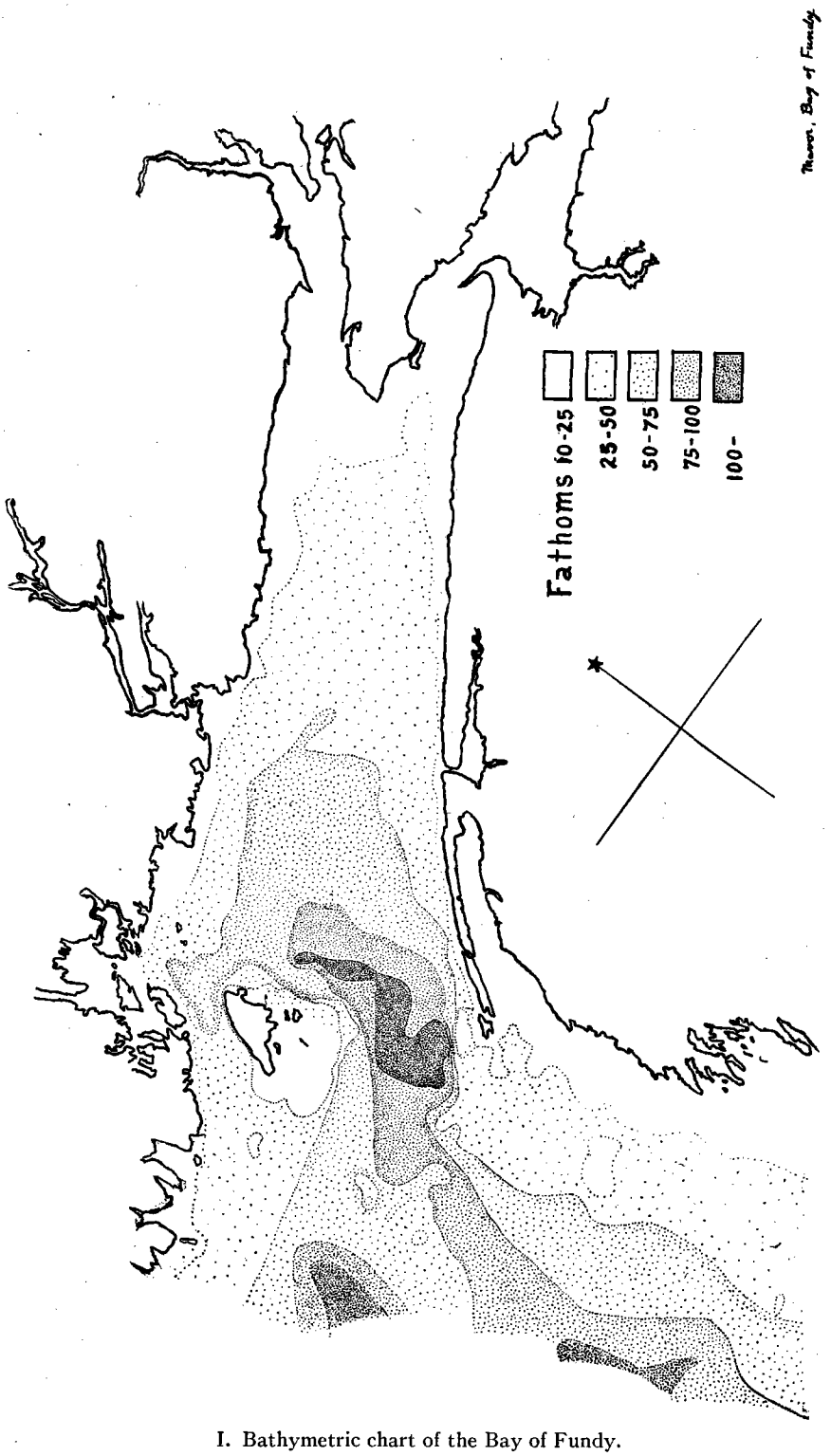
Set out on a line running N.W. by N. from *North Point of Brier Island* on Sept. 26, 1919, by the *Prince*.

Two oz. plankton bottles without drags with corks paraffined, containing Canadian Post Cards with usual legend printed.

3 returned by Dec. 31, 1919.

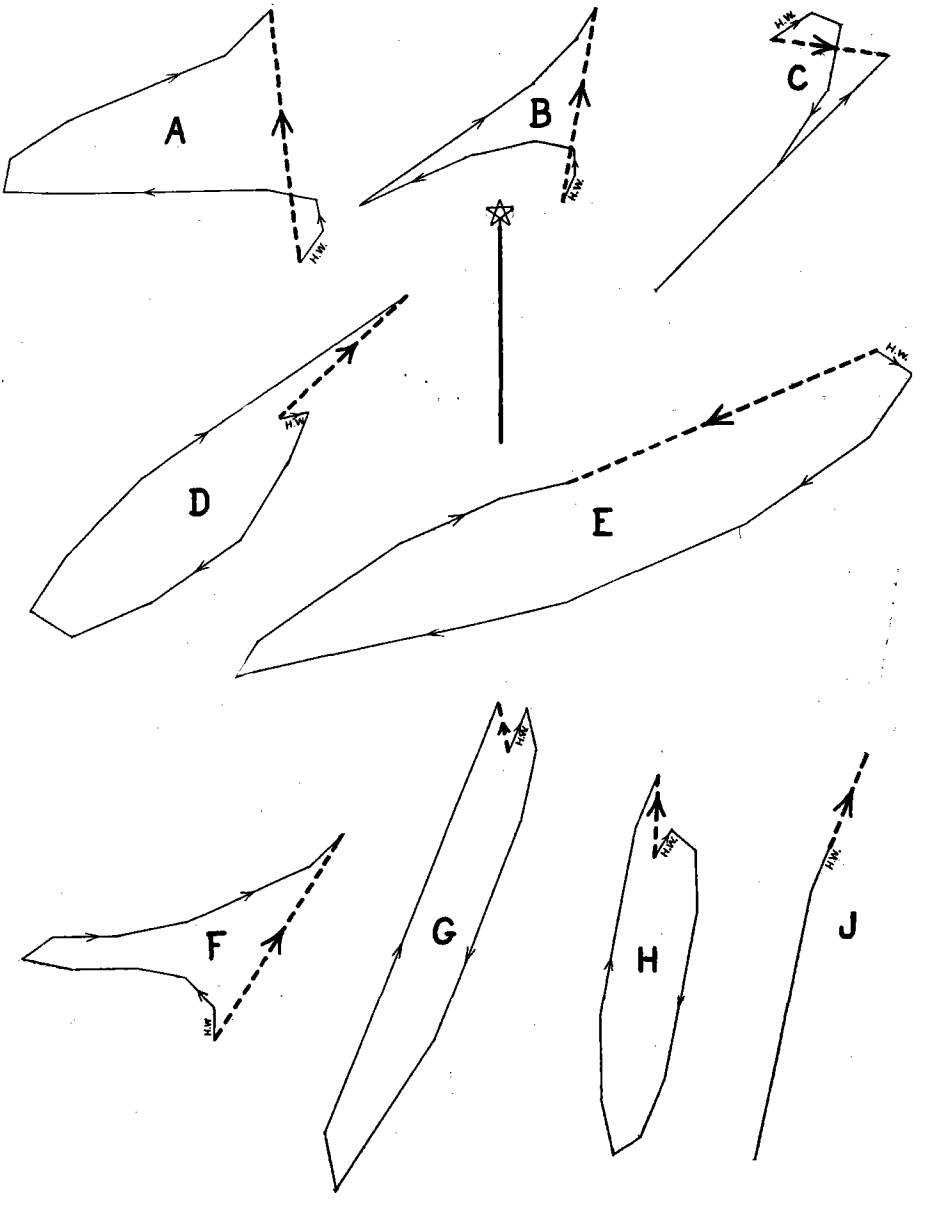
Number on card	Distance from north. point of Brier Isl. naut. mi.	Set out Sept. 26, 1919	Time found	No. of days out	Where found
373	1	5.03 p.m.	Nov. 3, 10.00 a.m.	38	*Port George*, 35 mi. East of Digby Gut, Annapolis Co., N.S.
375	2	5.09 p.m.	Oct. 19, 5.00 p.m.	23	*Port George.*
387	7	5.45 p.m.	Oct. 13, 7.00 a.m.	17	*Port George.*

A bibliography will be published in the concluding part of this paper.



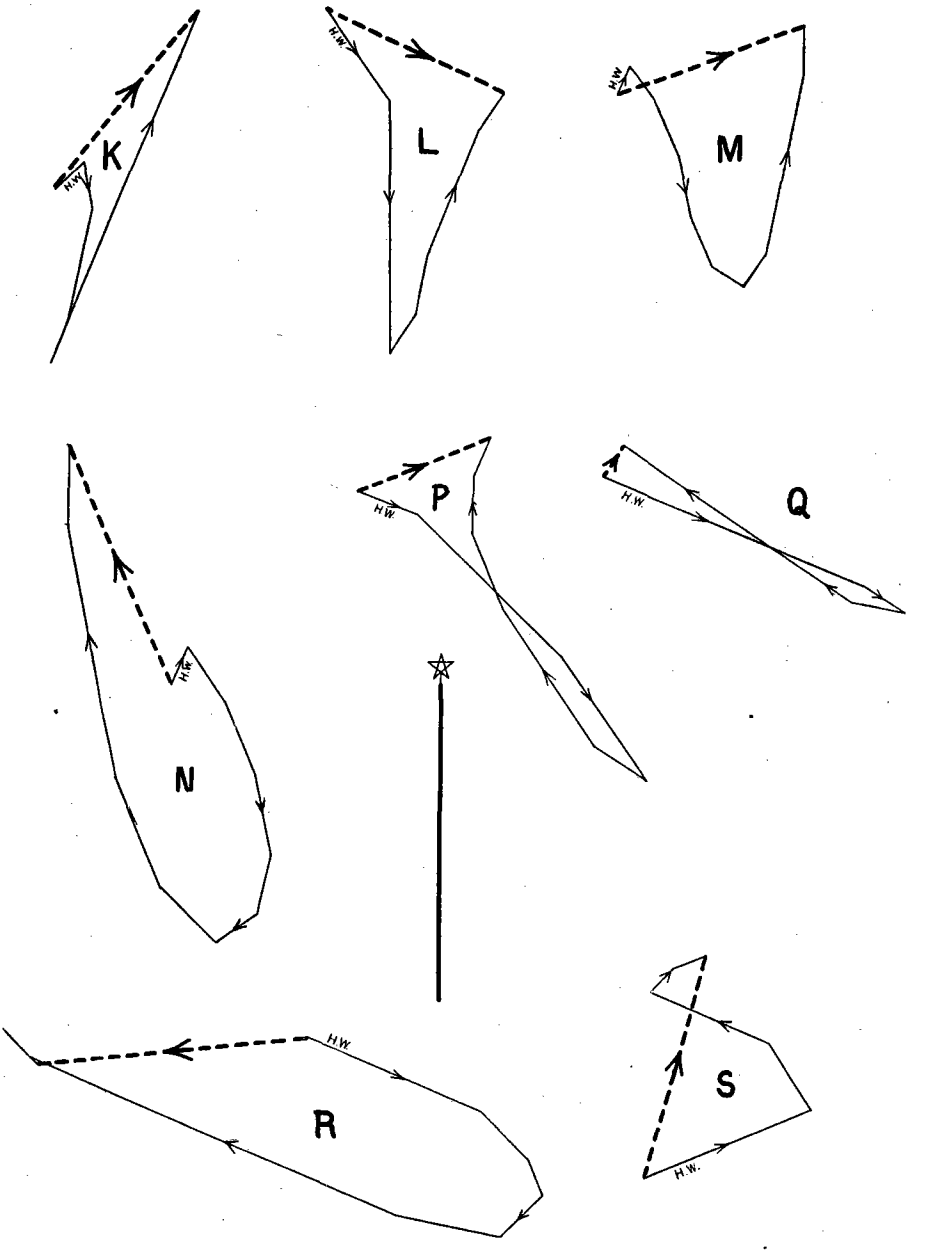
I. Bathymetric chart of the Bay of Fundy.

PLATE II.



Velocity diagrams for Dawson's stations A-J.

PLATE III.



Velocity diagrams for Dawson's stations K-S.

In making Plates II and III the average velocity at high water (*H.W.*) was plotted first and then the average velocity for each hour after that until the next high water. The resultant, general velocity, of the water is shown by the heavy dotted line. For the method of finding this see text-figure 3. All the diagrams are drawn to the same scale and oriented alike. The direction of true north is indicated on each plate.

PLATE IV.

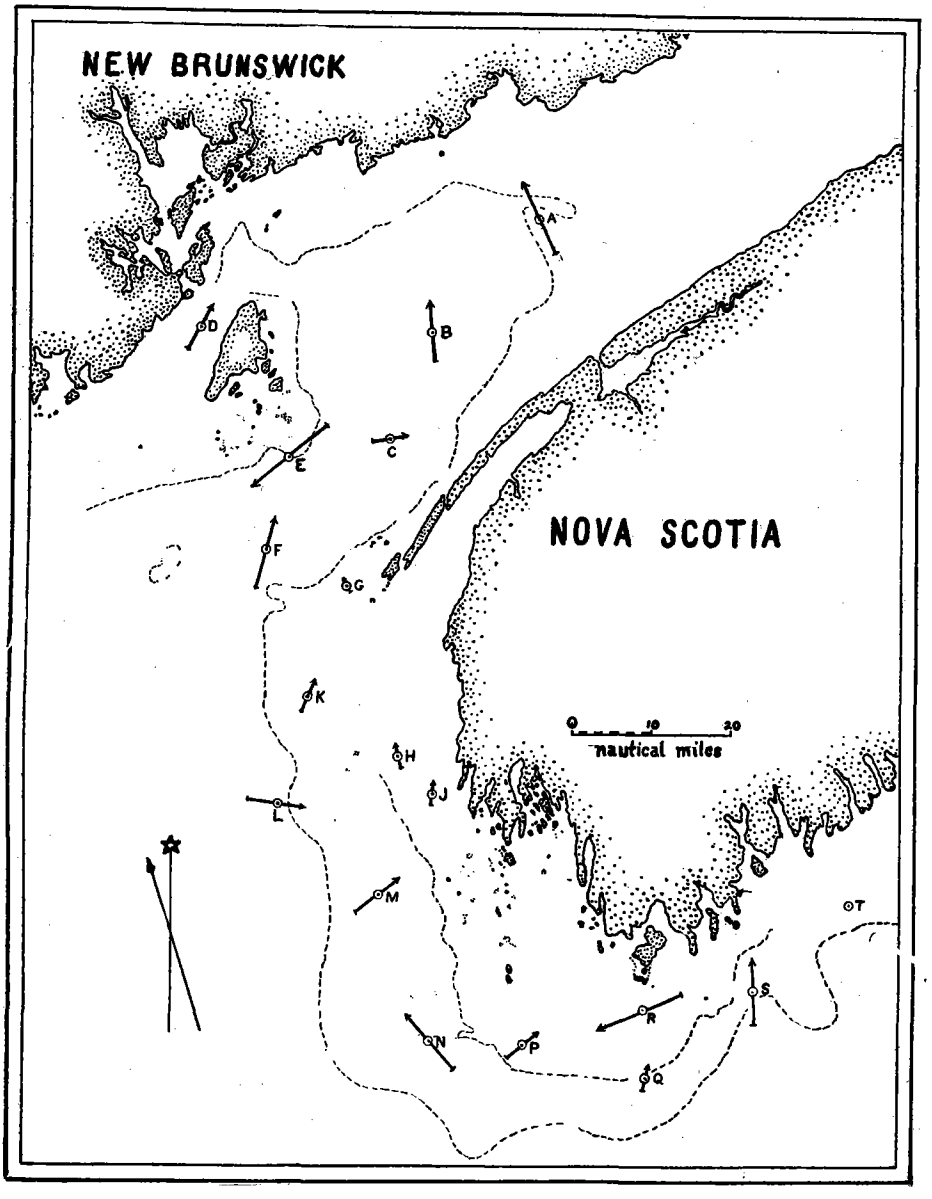


Chart showing resultant velocities at stations A-S as calculated from Dawson's tables.